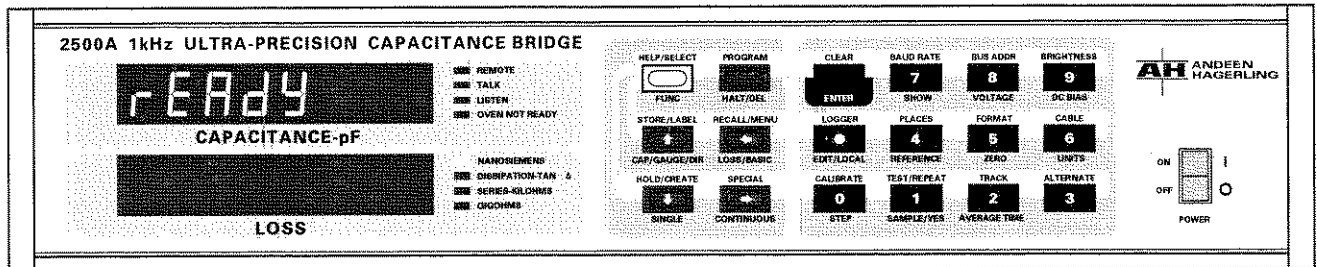# AH 2500A
1 kHz Ultra-Precision
Capacitance Bridge

Operation and Maintenance Manual

AH **ANDEEN-HAGERLING**

AH 2500A

1 kHz Ultra-Precision Capacitance Bridge

NSN 7Z 6625-01-327-1163

Patent No. 4,772,844

Serial Number _____

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This manual applies to
Serial Numbers 00050+

Revised
June, 1995

WARRANTY

Andeen-Hagerling Incorporated warrants the AH 2500A to be free from defects in materials and workmanship and to operate within applicable published specifications for a period of three (3) years from the date of shipment, provided that it is properly used. This warranty does not apply to sealed devices which have been opened or to any item which has been repaired or altered without our authorization.

During the warranty period, we will repair, or at our option, replace any instrument which fails to meet its published specifications.

There will be no charge for parts, labor, or forward and return shipment during the first three months of this warranty.

There will be no charge for parts and labor during the fourth through thirty-sixth months of this warranty. Forward and return shipping and insurance will be charged during this period.

LIMITATION OF WARRANTY

THE FOREGOING WARRANTY OF ANDEEN-HAGER-LING INCORPORATED IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESS OR IMPLIED. ANDEEN-HAGERLING INCORPORATED SPECIFICALLY DIS-CLAIMS ANY IMPLIED WARRANTIES OR MER-CHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE.

In no event shall we be liable for special or consequential damages (including loss of profits). If we are unable, within a reasonable period of time, to repair or replace any product to a condition as warranted, Buyer shall be entitled to a refund of the purchase price upon return of the product, shipping charges pre-paid, to us.

EXCLUSIVE REMEDIES

THE REMEDIES PROVIDED HEREIN ARE THE BUY-ERS SOLE AND EXCLUSIVE REMEDIES. ANDEEN-HAGERLING INCORPORATED SHALL NOT BE LIA-BLE FOR ANY DIRECT, INDIRECT, SPECIAL, INCI-DENTAL, OR CONSEQUENTIAL DAMAGES, WHETHER BASED ON CONTRACT, TORT OR ANY OTHER LEGAL THEORY.

DESIGN OF THIS MANUAL

This manual was writtten and formatted using FrameMaker publishing software running on a network of Macintosh computers. The schematics and block diagrams were drawn using FlexiCAD software. Parts layout drawings and the exploded view were created using Adobe Illustrator. The remaining three-dimensional illustrations were done using Vellum. A number of drawings combined results from several of these software packages. The graphical specifications were computed using a custom written contour plotting program running under MatLab software.

The style chosen for this manual contrasts significantly with what is commonly found today. Many of today's manuals put very little content on each page and leave large open spaces for notes or whatever. Unfortunately, many more pages are then required to publish a given amount of material. Much more turning of pages is also required to find anything.

In contrast, the AH 2500A manual style avoids wasting space and pages. A two column format ensures that readability is not lost. As a result, the entire manual fits in only one binder instead of the three binder set that would be required otherwise. We are especially interested in feedback about this style issue.

FEEDBACK

We are always eager to receive praise and/or criticism about this manual and product. It is your comments and suggestions that have helped guide the content of this manual and the design of the AH 2500A. We expect that this process will continue with new products.

We are also very interested in hearing about new ways that you have found to put the AH 2500A to use.

Please feel free to contact us by phone, FAX, or letter with your suggestions, comments, criticisms and questions.

SAFETY PRECAUTIONS

The following safety precautions must be observed while operating and servicing the AH 2500A:

- This instrument is intended for use by qualified personnel who understand electrical shock and other hazards associated with electronic instrumentation. Failure to observe these precautions and other cautions and warnings in this manual may violate design safety standards and intended use of the instrument and may cause injury. Andeen-Hagerling Inc. assumes no liability for the customer's failure to comply with these precautions.

- Do not operate a damaged instrument. If there is any reason to suspect the instrument is physically damaged, unplug the instrument and do not use it until safe operation can be verified by service-trained personnel.

- Do not substitute parts or modify the instrument. Doing so could violate built-in safety features.

- Operating the instrument with externally applied DC Bias voltages can cause hazardous voltages to be present at the input connections of the instrument. Be certain that any external bias voltages are switched off and discharged if necessary before touching, connecting or disconnecting the input connectors.

- For operator safety, the instrument cabinet should be grounded. The 3-wire power line cord shipped with the instrument provides this protection when plugged into a properly grounded power receptacle. Do not attempt to defeat the power cord grounding.

- Operating personnel must not remove the instrument covers. Service and internal maintenance adjustments are to be made by qualified maintenance personnel.

Throughout this manual you will see certain safety related messages. Their meanings are described below:

WARNING !

WARNINGS call attention to procedures or conditions that could cause bodily injury or death.

CAUTION

CAUTIONS call attention to procedures or conditions where damage to the instrument or irrecoverable loss of data could occur.

NOTE

NOTES call attention to important procedural details that deserve special attention by the reader.

AH 2500A Capacitance Bridge

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Chapter 1   Description and Installation

This chapter introduces the major capabilities of the AH 2500A capacitance bridge and summarizes its specifications. It also discusses basic installation and the GPIB and serial interface options that are possible.

GENERAL DESCRIPTION

The AH 2500A Ultra-Precision Capacitance Bridge is an extremely accurate and stable instrument used for precise measurement of capacitance and loss[1]. The unparalleled accuracy and stability is derived from the use of a carefully designed ratio transformer coupled with an extremely stable fused-silica standard capacitor that is contained in an internal temperature-controlled oven.

Measurements are made automatically, eliminating the cumbersome manual balancing previously associated with precision capacitance measurements. The bridge can be operated as a stand-alone instrument from the front panel controls. It can also be operated remotely from either of the built-in RS-232 or GPIB remote device ports.

The AH 2500A is also available in an Option-E version which offers higher precision and significantly enhanced calibration and verification features.

APPLICATIONS OF THE BRIDGE

The AH 2500A Ultra-Precision Capacitance Bridge is designed to meet the critical requirements of the calibration and research laboratory, as well as those of manufacturing and incoming inspection where measurement precision is important. Some common applications are:

- Calibration work including use as a transfer standard in primary and secondary laboratories.

- Fuel gauge calibration.

- Measurements at cryogenic temperatures.

- Thermal expansion measurements for any type of matter, particularly metals, but also non-metals.

- Liquid and vapor level measurements.

- AC resistance measurements to 1000 teraohms.

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1. The term "loss" is used to refer to the component of the impedance which is 90° out of phase with respect to the capacitive component. The AH 2500A can report loss in units of conductance, dissipation factor, or series or parallel resistance.

- Displacement and strain measurements. Very small changes in dimensions are measurable, approaching the diameter of an atomic nucleus. (This is less than a millionth of the wavelength of visible light.)

- Quality and characteristics of any insulating medium (solid, liquid or gas). The presence of contaminating water is particularly easy to detect. See ASTM D150 and D924.

- Research, development and production testing of capacitance or loss based sensors.

- Measurement of pressures ranging from high vacuum to high pressure.

There are many other applications to which the AH 2500A has been applied and to which it could be applied.

FEATURES OF THE BRIDGE

The most important features of the AH 2500A are summarized in the sections below.

Performance Characteristics

A summary of the AH 2500A specifications is given here. Detailed specifications are given in Appendix C, "Performance Specifications".

- **Accuracy** of 5 ppm (or 3 ppm with Option-E)

- **Stability** better than 1 ppm/year (or 0.5 ppm/year with Option-E)

- **True Resolution** of 0.5 attofarad (0.000 0005 pF) and 0.15 ppm (or 0.5 aF and 0.07 ppm with Option-E)

- **Reportable Resolution** of 0.1 attofarad (10^{-7} pF)

- **Temperature coefficient** of 0.03 ppm /°C (0.01 ppm/°C with Option-E)

- **Measures extremely low loss** down to a dissipation factor of 1.5×10^{-8} tan δ, a conductance of 3×10^{-7} nanosiemens or a resistance up to 1.7×10^{6} gigohms

- **Operating frequency** is 1.0000 ±0.005% kHz

- **Less than 0.5 second** required for full precision measurements.

- **About 40 milliseconds** required for repeated measurements on the same sample

- **Negative capacitance and loss ranges** measure negative values to allow for unusual samples or three terminal networks

- **No significant zero offset**

- **Less than 15 minutes warm-up** required after power-on for full precision

- **Quiet operation** is the result of careful thermal design which requires no cooling fan.

Measurement Features

- **Fully self-contained** — no external standard or other apparatus required for three-terminal measurements

- **Three-terminal BNC connections** minimize connector costs and number of cables

- **Two-terminal measurements** of any ungrounded device

- **Commutation** (test signal reversal) to minimize external power line or other periodic signal pickup

- **Autoranging** — one button or command takes all measurements

- **Selectable measurement time** to optimize speed vs. noise trade-off

- **Test voltage** is settable to an upper limit

- **Deviation measurements** of capacitance, loss, or both, expressed in absolute numbers or as percentages

- **Zero correction** of test fixture capacitance and loss

- **DC bias** may be externally applied up to ±100 volts

- **Tracking mode** can be entered automatically for unknown impedances that start changing rapidly

- **Units of loss** are reportable as conductance, dissipation factor, or series or parallel resistance

Interface and Control Features

- **IEEE-488 interface** included; external device can serve as controller or logger

- **RS-232 interface** included; external device can serve as controller or logger

- **Non-volatile memory**, not DIP switches, used to store interface set-up data

- **Flexible reporting formats** for data to external devices

- **Programmable commands** can eliminate the need for an external controller

- **Full or abbreviated commands** and error messages in English

- **Large displays** of capacitance and loss having variable brightness and eight digits each

- **External trigger** capability

- **Parameter sets** allow measurement settings to be stored and recalled in groups

- **Sample switch port** provides for automated switching of unknown sample impedances

Calibration and Test Features

- **Automated internal calibration/verification**

- **Simple calibration/verification** against an external, traceable capacitor

- **Automated ratio-transformer calibration/verification** with Option-E

- **Full report** of all calibration points with Option-E

- **Passcode hierarchy** for calibration control

- **Self-test diagnostics** of processor on power-on

- **Non-volatile memory** used to store virtually all calibration data; eliminates reliability problems associated with trimmers

- **Comprehensive, operator initiated, diagnostic tests** of measurement circuitry

- **Cable length compensation** is available in the few cases where this is desirable

- **Oven not ready indicator** shows when oven is not warmed-up or ambient temperature is too hot or cold

PATENT INFORMATION

The AH 2500A is protected by U.S. Patent No. 4,772,844. Foreign patents are pending.

REQUIREMENTS

Operating Environmental Requirements

Operating Temperature Range

0° to 45°C

Operating Humidity Range

0 to 85% relative humidity, non-condensing

General

Operation should occur in a non-corrosive environment while adhering to the operating conditions above.

Storage Environmental Requirements

Storage Temperature Range

-40° to +75°C

Storage Humidity Range

0 to 60% relative humidity, non-condensing

General

Storage in a clean, non-corrosive environment while adhering to the storage conditions above is sufficient for short or long periods of time.
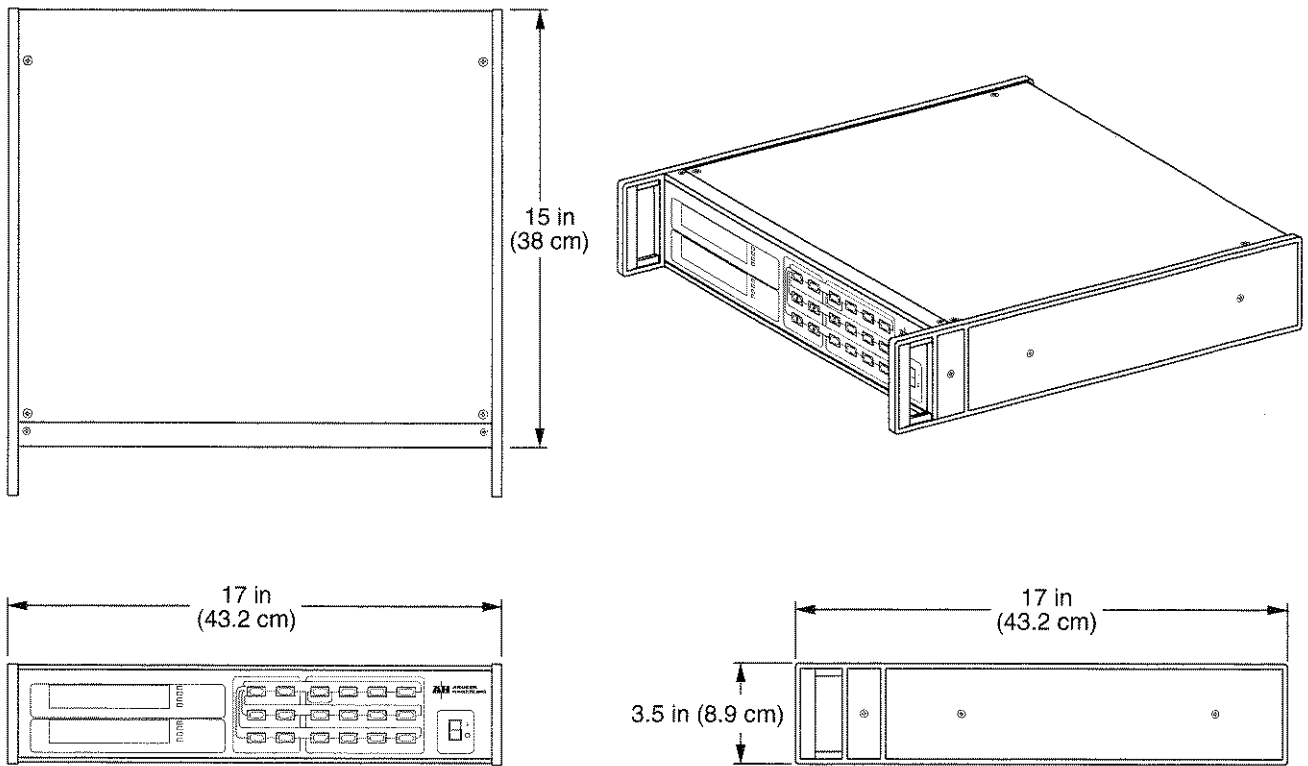
Figure 1-1 AH 2500A external dimensions

Power Requirements

Line Voltage

100, 120, 220 or 240 volts AC ±10%

Line Frequency

48 to 440 Hz

Power Consumption

25 watts

PHYSICAL DESCRIPTION

Dimensions and Weight

Height

3.5 inches (8.9 cm)

Width

17 inches (43.2 cm) when bench mounted

19 inches (48.3 cm) when rack mounted

Depth

15 inches (38 cm) deep behind the front panel

17 inches (43.2 cm) overall

Weight

18 pounds (8.2 kg).

Mounting

Hardware for rack mounting and a bail and feet for bench top use are provided.

Safety

Designed in accordance with UL1244, IEC348 and BS4743. See the safety messages sheet at the front of this manual.

Radiated Emissions

Designed and tested to meet FCC and VDE class A requirements.

ITEMS USED WITH AH 2500A

Items Furnished with the AH 2500A

The AH 2500A is shipped with the following items:

1. AH 2500A Automatic Capacitance Bridge.

2. Power line cord.

3. Rack mounting kit.

4. Certificate of calibration.

5. Passcode sheet.

6. Operation and Maintenance manual.

Items Required for Operation and Maintenance

The required items are listed in three groups. The verification equipment list and the disassembly tools list stand by themselves. The maintenance and diagnostics list requires the items in the first two lists also.

Equipment and Accessories Required for Verification or Calibration

The following test equipment and accessories are required to verify or calibrate the AH 2500A:

1. 0.5 to 1600 pF three-terminal capacitance standard having a traceable accuracy of 1 ppm. For Option-E bridges, 0.5 ppm is recommended. Andeen-Hagerling AH 1100/11A is recommended. See "Obtaining the Capacitance Verification Data." on page 9-9 for a discussion of what is appropriate.

2. Andeen-Hagerling DCOAX-1-BNC (or equivalent) coaxial cable pair to connect to the device under test.

3. 1 pF to 1 µF, three-terminal, precision decade capacitor (Option-E only).

4. AC resistance standard having a value of 10 kΩ with an accuracy at 1.0 kHz of 0.005% (0.0025% for Option-E). See "Finding a Suitable AC Resistor Standard" on page 9-16 for a discussion of what is appropriate.

5. Digital frequency meter with an accuracy of 0.001% at one kilohertz

6. Digital multimeter with an AC voltage accuracy of 1% and an input impedance of at least 10 megohms.

Tools Required for Disassembly and Reassembly

The following tools are required to disassemble and reassemble the AH 2500A:

1. #2 Phillips head screwdriver.

2. Torque screwdriver set to 18 in-lb (200 N-cm) with #2 Phillips head adapter - Utica TS-30 (or equivalent).

3. Right-angle torque wrench set to 18 in-lbs (200 N-cm) with a #2 Phillips bit.

4. Right-angle torque wrench set to 75 in-lbs (800 N-cm) with a deep 5/8 inch (16 mm) hex socket.

5. Integrated circuit insertion/extraction tool for 24 & 28-pin IC for replacing firmware.

6. Small diagonal cutter.

7. Soldering equipment.

Equipment and Accessories Required for Maintenance and Diagnostic Testing

1. A 5/64 inch or 2 mm hex key wrench for changing the power line voltage selector setting.

2. Three-terminal, 1000 pF capacitor. If Option-E, use the 1 pF to 1 µF, three-terminal, precision decade capacitor that is required for calibration.

3. Metered and current limited lab DC power supply variable from 0-250 V.

4. BNC to dual male banana-plug cable to connect power supply to a female BNC jack.

5. Triggered DC-50 MHz oscilloscope and probe

6. 2 each BNC "T" Female/Male/Female connectors - Pomona 3285 (or equivalent).

7. Male BNC to dual binding-post adapter - Pomona 1296 (or equivalent).

8. 50Ω BNC resistor terminator - Pomona 3840-50 (or equivalent)

9. One 2 kΩ and one 10 kΩ 5% carbon resistor

UNPACKING AND INSPECTION

Your AH 2500A was carefully examined and tested before it left the factory. If the shipping carton arrives in good apparent condition externally, the bridge and accessories should all be present, undamaged and in good working order. Examine the shipping carton for signs of visible damage. If the carton shows signs of damage, ask that the shipper's representative be present as the carton is unpacked.

NOTE

We highly recommend that you save the original packaging for re-shipment of the bridge should that ever become necessary. A substantial percentage of bridges shipped in packaging other than the original are improperly packed. Many of these are damaged as a result.

Unpack the bridge and check for damage such as scratches, dents and especially cracked or broken front panel handles. Verify that the items listed in "Items Furnished with the AH

2500A" on page 1-4 are all present. Additional items such as a DCOAX-1-BNC coaxial cable may have been ordered. Check the packing list that is in the pocket on the outside of the shipping box to see if such additional items should be present.

Damaged Shipment Instructions

If the bridge is damaged, notify both the carrier and Andeen-Hagerling. Andeen-Hagerling will arrange for repair or replacement of the bridge while a damage claim is being processed. Save the shipping carton and packing materials for inspection by the carrier or to return the bridge if necessary.

WARNING !

If damage of any kind is visible or suspected, do not attempt to operate the bridge until its safety can be verified by a qualified technician.

INSTALLING THE BRIDGE

The AH 2500A is ready for benchtop use as shipped. It has a bail on the bottom that can be swung down to raise the front of the bridge to a more convenient operating angle.

The bridge can be converted for mounting in a standard nineteen inch equipment rack using the rack mounting hardware kit supplied with the bridge.

Rack Mounting

To convert the bridge for rack-mounted operation, perform the following:

1. Refer to Figure 1-2.
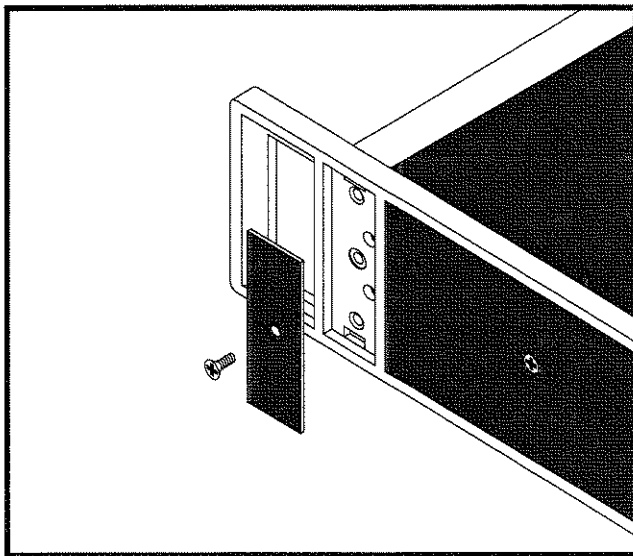
Figure 1-2 Cover plate removal
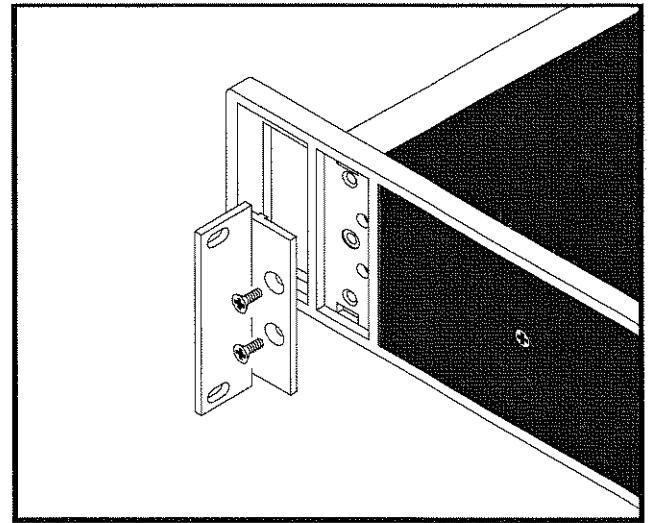
Figure 1-3 Rack mount adapter installation

2. Remove the screws holding each of the two small cover plates and remove these plates.

3. Refer to Figure 1-3.

4. Attach each of the two rack mounting brackets using two screws each from the hardware kit.

5. Remove the bottom feet and the tilt bail. Save the parts in case you want to convert back to bench operation.

6. Install the bridge in the intended rack and secure with four screws from the rack mount hardware kit.

Power Line Cord

The bridge is shipped with a power line cord appropriate for its destination country. Since some countries do not have uniform power line connector standards, this line cord may not always be correct. If not, replace it with one that is appropriate for your location.

CAUTION

It is extremely important that the chassis grounds of all equipment being interconnected be properly grounded through the power cord of each piece of equipment. Ground pins on power cords must never be cut off or otherwise defeated. Failure to observe this will frequently cause RS-232 and GPIB ports to be damaged if these ports are disconnected while the equipment is plugged in. Damage can occur even if the bridge is not powered on. The failure results from the ability of power line RFI filter capacitors to cause an ungrounded equipment chassis to float to a voltage midway between the voltages on the two input power lines. This can put the chassis voltage at 50 to 120 volts above ground (for line voltages of 100 to 240 volts) with enough current capacity to be a shock hazard and to cause damage to interface ports. (The AH 2500A does not use such filter capacitors, but many other pieces of equipment do.)

WARNING !

For operator safety, the bridge cabinet should be grounded. The 3-wire power line cord shipped with the bridge provides this protection when plugged into a properly grounded power receptacle. Do not attempt to defeat the power cord grounding.

Choosing the Proper Fuse

There are two fuse current ratings suitable for use in your bridge. The correct fuse rating depends on the power line voltage that is to be used. The table below relates the power line voltage to the correct fuse rating.

Table 1-1 Power line fuse ratings

Line voltage	Fuse rating
100 or 120 VAC	0.5 A slo-blo (Littelfuse 313.500 or equivalent)
220 or 240 VAC	0.25 A slo-blo (Littelfuse 313.250 or equivalent)

CAUTION

The AH 2500A is shipped with a power line fuse that is probably correct for its destination country. Since some countries do not have uniform power standards, this fuse may not always be correct. The fuse should be checked for the proper rating in the table above before applying power.

WARNING !

Do not ever substitute a fuse having a larger current rating than is indicated in the table. A significant fire hazard exists if this warning is not heeded.

Changing the Fuse and Voltage Values

The AH 2500A incorporates a power line voltage selector to quickly configure it for local line voltages. This is located in the center of the rear panel as shown in Figure 1-8 on page 1-10. This voltage selector is set at the factory for the probable power line voltage for its destination country. Since some countries do not have uniform power standards, this line voltage setting may not always be correct.

CAUTION

The voltage selector setting should be checked prior to applying power to the bridge for the first time.

To change the fuse or voltage selector, proceed as follows:

1. Unplug the power line cord from its receptacle on the back of the bridge. Slide the plastic fuse cover to the right to expose the fuse and voltage selector circuit board.

2. Rotate the black plastic fuse-pull toward you to remove the fuse. This will expose a voltage value (100, 120, 220, or 240) on the selector circuit board. If the value is your desired operating voltage, then the voltage is set properly. If you don't need to change the operating voltage, skip to step five.

3. Remove the voltage selector circuit board with a 5/64 inch or 2 mm hex key wrench. This is done by putting the end of the key into the hole in the circuit board and using the bottom edge of the selector module to pry the board loose.

4. Select the desired voltage by orienting the circuit board so that the desired voltage value is facing up and is on the left side of the circuit board. Push the circuit board firmly back into the fuse block. The desired operating voltage value will be visible directly below the fuse.

5. Rotate the fuse-pull away from you, back into its normal position. Check the current rating of the fuse you removed against the rating given in the table in the previous section. If the rating is correct, then re-install the fuse by pressing it back in. If it is not correct, then install a fuse having the correct rating. Slide the fuse cover back over the fuse and plug the power line cord into its receptacle. The bridge is ready to power on.

Checking/Replacing the Fuse

To check or change the fuse, proceed as follows:

1. Unplug the power line cord from its receptacle on the back of the bridge. Slide the plastic fuse cover to the right to expose the fuse.

2. Rotate the black plastic fuse-pull toward you to remove the fuse. Rotate the fuse-pull away from you, back into its normal position.

3. Check the current rating of the fuse you removed against the rating given in the table in the previous section. If the rating is correct, then use an ohmmeter to check the continuity of the fuse. If it is continuous, then re-install the fuse. If the fuse rating is not correct or if the fuse is open, then install a new fuse having the correct rating. Note that the fuse must be a slo-blo type or you will have trouble with periodic fuse failures. Slide the fuse cover back over the fuse and plug the power line cord into its receptacle. The bridge is ready to power on.

REPAIR SERVICE

Andeen-Hagerling offers full repair and calibration services for the AH 2500A. If you are uncertain as to whether your bridge needs repair or not, refer to Chapter 9, "Verification/Calibration" where you will find instructions about how to verify your bridge's performance. If you are sure there is a problem, but uncertain as to whether it might be repairable in your own facility, refer to Chapter 11, "Diagnosis and Repair".

If you conclude that you need to return the AH 2500A to the factory for repair or calibration, we ask that you follow the simple procedure below:

1. Call or fax the factory to obtain a Return Authorization number. You will be asked what needs to be done to the bridge and whom to contact if further information is needed by the factory. You will also be asked for the five digit serial number of the bridge. This is found on its back panel. The phone number to call is 216-349-0370. The fax number is 216-349-0359.

2. Attach a tag or label to the bridge containing the Return Authorization number, the name and address of your person to contact for additional information, a phone number and the work to be done.

3. Package the bridge as described in "Packaging for Shipment" below.

4. Make two shipping labels. Put one on the outside of the carton and one on the inside. Ship the carton to the following address:

   > Andeen-Hagerling Inc.
   > 31200 Bainbridge Road
   > Cleveland, OH, 44139-2231 U.S.A.

5. It is suggested that you insure the bridge against shipping loss or damage. Shipping problems are not covered under the warranty.

Packaging for Shipment

If you need to ship the AH 2500A, it is extremely important that there be at least three inches (8 cm) of a compliant cushioning material on all sides of the bridge. The handles which are part of the side castings are especially vulnerable if proper packing is not used.

To meet these requirements, a shipping carton that is *much* larger than the bridge itself is required. Using a strong shipping container such as a wood crate *will not compensate* for a lack of adequate cushioning material on all sides. If you do not have an adequate shipping container and compliant cushioning material, you can obtain these things from Andeen-Hagerling.

NOTE

We highly recommend that you use either the original packaging or new packaging from Andeen-Hagerling for any shipping of the bridge. A substantial percentage of bridges shipped in packaging other than the original are improperly packed. Many of these are damaged in shipping as a result.
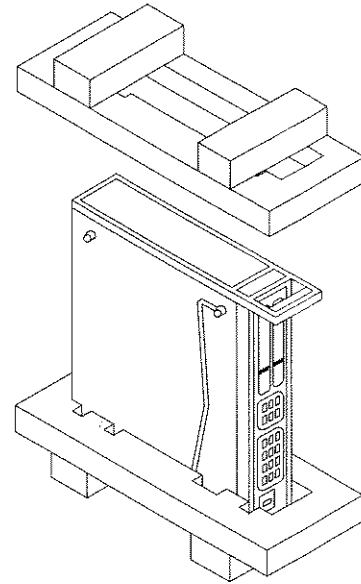
Figure 1-4 AH 2500A foam inserts

If you use Andeen-Hagerling packaging, carefully press the foam inserts onto each side of the bridge exactly as shown in Figure 1-4. These may be a very tight fit. The bridge with foam inserts then goes into the carton as shown in Figure 1-5. The bridge can optionally first be sealed in a polyethylene bag for protection against moisture.
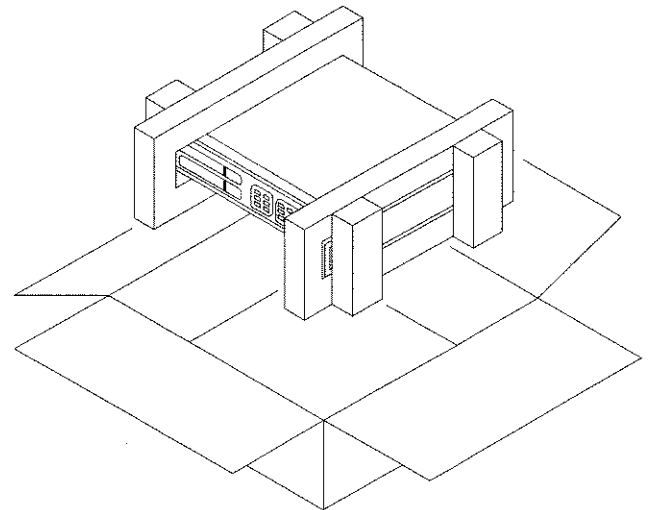
Figure 1-5 AH 2500A packaging
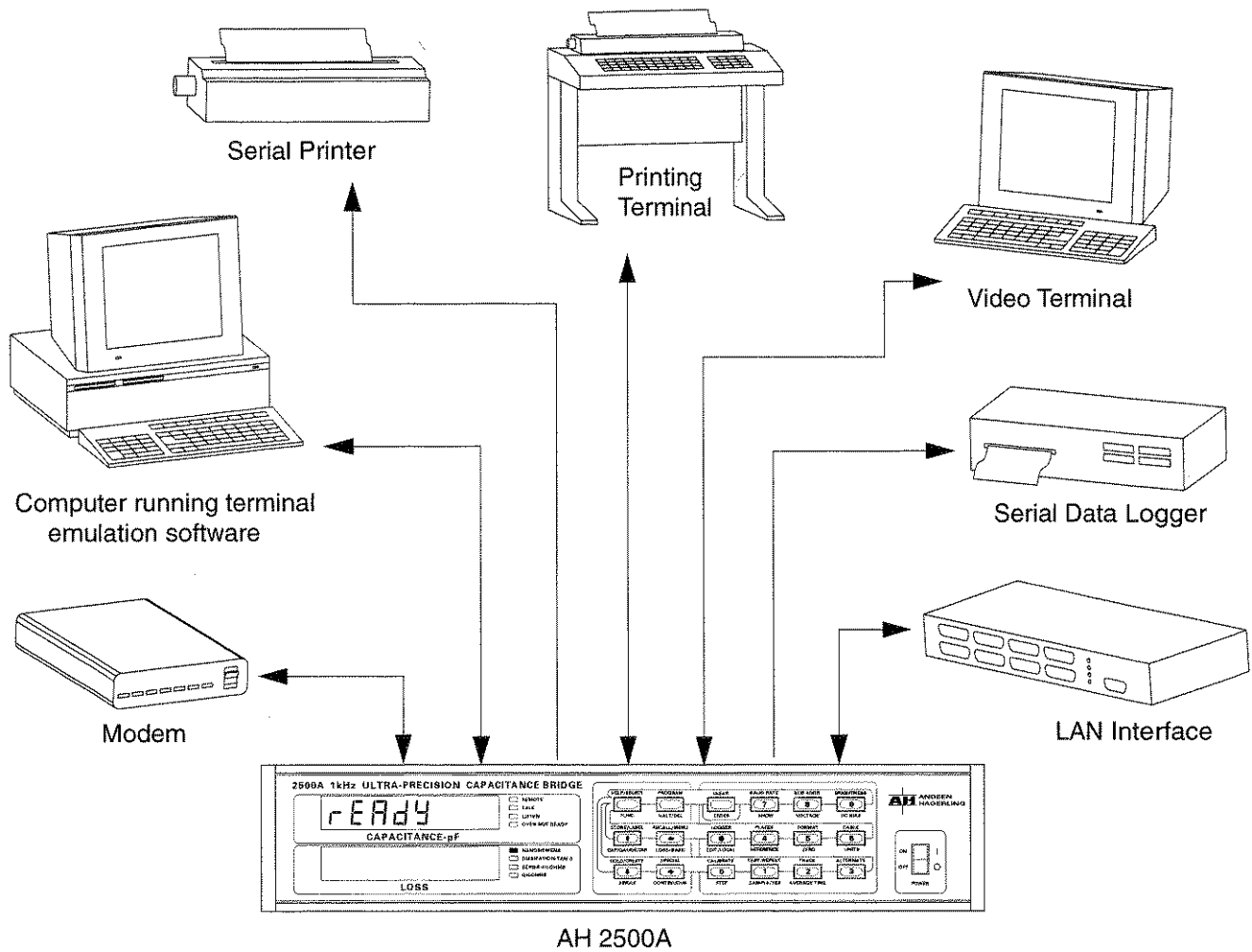
Figure 1-6 AH 2500A connections to RS-232 devices

CHOOSING REMOTE DEVICE COMMUNICATION OPTIONS

In addition to operation from the bridge's front panel the AH 2500A can be operated from a variety of other remote devices ranging from simple dumb terminals to mainframe computers. Connection to these remote devices can be through direct connection to the device or can be indirect using a modem and data communications lines. Connection to the bridge is made through either the serial (RS-232 or current loop) or GPIB (IEEE-488) parallel ports.

Serial Communication Options

The serial port allows many possible ways of communicating with remote devices. These options are shown schematically in Figure 1-6. The arrows in the figure indicate that two of the options will only *collect* data from the AH 2500A (using its logging capability). The remaining five options allow remote control *and* data collection from the bridge. The options shown are:

1. **A dumb video terminal.** This is probably one of the simplest devices to connect. It provides a very friendly alternative to operation from the bridge's front panel, but does not offer any storage capability.

2. **A computer running terminal emulation software.** This method of operation is very similar to using a video terminal except that the software will probably allow you to save all communication between the computer and the bridge. If you have used your computer to access any dial-up computer services, the same software should be able to access your AH 2500A. The situation is the same whether you are using a personal computer or a large mainframe. Naturally, custom written software will work also, but terminal emulation software will work without modification.

3. **A printing terminal with a serial interface.** A printing terminal is useful in much the same way as a video terminal except that a printed record of all results is produced. Since a printer may be much slower than a video terminal, it is a good choice only when a printed record is really desired.
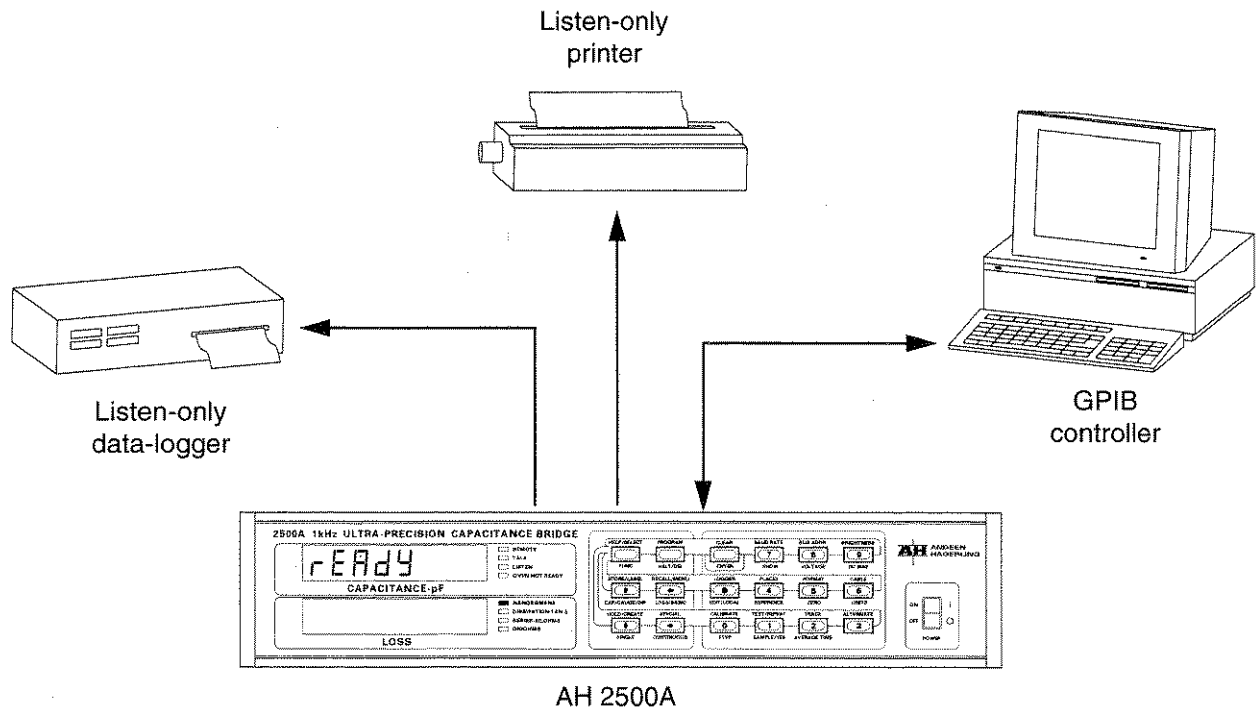
Figure 1-7 AH 2500A connections to GPIB devices

4. **A serial printer.** Any serial printer should work and will allow producing a printed record of all front panel operations. The AH 2500A's flexible logging options are useful here.

5. **A serial data logger.** This is a less commonly available device, but is specifically designed to record data in printed or magnetic form. Large amounts of data may be recorded in magnetic form. Again, the AH 2500A's flexible logging options are useful here.

6. **An asynchronous modem up to 9600 baud.** Connection to a modem allows operation with any of the previously mentioned devices over telephone lines.

7. **A LAN interface.** Serial port interfaces are now available for all common local area network standards. This is another way to connect over larger distances to any of the devices listed above.

The specifics of connecting and operating a remote serial device with the AH 2500A are discussed in Chapter 7, "Serial/RS-232 Remote Operation". Some serial ports can be a challenge to make connection to due to a lack of standardization. However, once connected, most serial links require no programming to operate. The bridge is even easier to operate this way than from the front panel.

GPIB Communication Options

If you wish to use the GPIB interface, you will find it is more capable, more complex, and more difficult to learn to use than the RS-232 interface. It is not within the scope of this manual to present a tutorial on the GPIB interface. Many discussions of the GPIB bus have been published. GPIB controllers will often have good descriptions of the bus in their manuals. See the very beginning of Chapter 6, "GPIB/IEEE-488 Operation" for specific references.

The possible options available for operation of the AH 2500A with the GPIB are shown in Figure 1-7. The arrows in the figure indicate that two of the options will only *collect* data from the AH 2500A (using its talker-only and logging capabilities). The remaining option allows remote control and data collection from the bridge. The options shown are:

1. **A GPIB controller** or a computer having a GPIB interface. This is the most common way to operate instruments with the GPIB bus.

2. **A listen-only printer.** Some printers (HP Thinkjet for example) are available with GPIB interfaces. These are very easy to connect to the AH 2500A. The AH 2500A's flexible logging options are useful here.

3. **A GPIB data logger.** This is a less commonly available device, but is specifically designed to record data in printed or magnetic form. Large amounts of data may be recorded in magnetic form. Again, the AH 2500A's flexible logging options are useful here.

The specifics of connecting and operating a remote GPIB device with the AH 2500A are discussed in Chapter 6, "GPIB/IEEE-488 Operation".
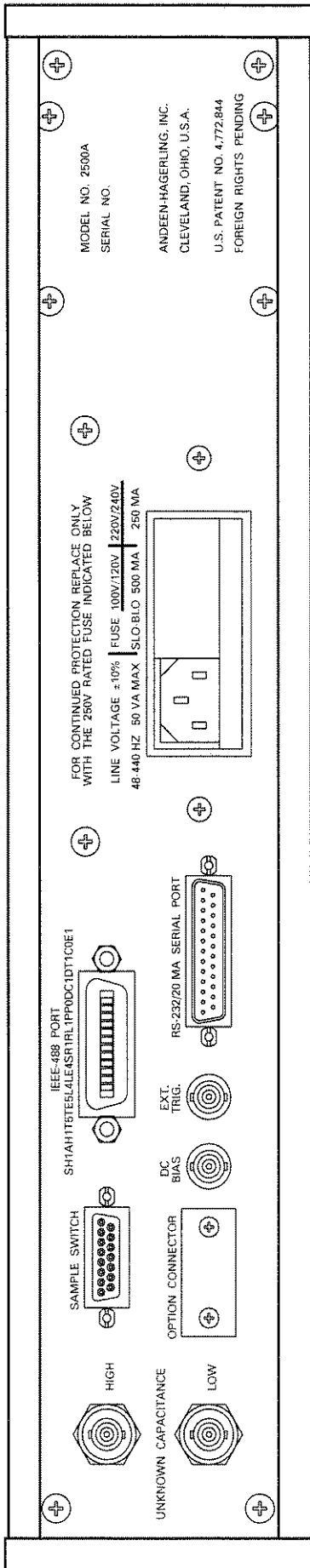
Figure 1-8 AH 2500A rear panel

Table 1-2 Identification of rear panel connectors

Rear Panel Connector	Used For
Power line module	Connection to power line
HIGH terminal output	Low impedance drive to DUT (Device Under Test) (HIGH power and voltage)
LOW terminal input	High impedance input from DUT (LOW power and voltage)
SAMPLE SWITCH	Connection to external sample switching system to select one of multiple inputs
DC BIAS	Connection to external power supply of up to ±100 VDC to bias the Device Under Test
EXT. TRG.	Connection to grounding switch or to a negative pulse to initiate a measurement or program
IEEE-488 PORT	Connects instrument to other GPIB devices
SERIAL PORT	Connects instrument to other serial devices
OPTION CONNECTOR	Blank position for future optional connector

C04

This chapter is intended to be helpful if you are using the AH 2500A for the first-time. It covers familiarization and simple single and continuous measurements using the front panel keypad and default parameter sets. It then describes some experiments to perform to help develop an intuitive grasp of the basic measurement concepts of the bridge. If you are already acquainted with the basic operation of the AH 2500A, you can skip this chapter.

SOME TERMINOLOGY

There are many terms that have been used to describe the impedance to be measured that is connected to the AH 2500A. Some of the more common of these are: "unknown", "sample", "unknown sample", "unknown capacitance", "unknown loss", "unknown impedance", and "DUT" (Device Under Test). You will find these terms used interchangeably in this manual.

BEFORE APPLYING POWER

If the bridge is being installed for the first time, be sure that it is correctly configured for the proper line voltage and has the correct fuse installed. See the sections beginning with "Choosing the Proper Fuse" on page 1-6 of Chapter 1, "Description and Installation" to check for proper configuration.

CAUTION

It is extremely important that the chassis grounds of all equipment being interconnected be properly grounded through the power cord of each piece of equipment. Ground pins on power cords must never be cut off or otherwise defeated. Failure to observe this will frequently cause RS-232 and GPIB ports to be damaged if these ports are disconnected while the equipment is plugged in. Damage can occur even if the bridge is not powered on. The failure results from the ability of power line RFI filter capacitors to cause an ungrounded equipment chassis to float to a voltage midway between the voltages on the two input power lines. This can put the chassis voltage at 50 to 120 volts above ground (for line voltages of 100 to 240 volts) with enough current capacity to be a shock hazard and to cause damage to interface ports. (The AH 2500A does not use such filter capacitors, but many other pieces of equipment do.)

APPLYING POWER

Turn the power switch on the front panel to the ON position and wait a few seconds for the words

```
[   CPU  tESt   ]
[   PASSEd      ]
```

to appear on the displays. During start-up, the bridge is performing internal self-tests of its processor circuitry. The test passed message appears when these tests are successful.

To make accurate measurements, you must ordinarily wait until the OVEN NOT READY indicator stops blinking, but for the following experiments, you may begin immediately.

KEYPAD AND DISPLAYS

Refer to the actual bridge front panel or to the front panel in Figure 2-1 on page 2-3 in the discussion below.

Front Panel Display

The AH 2500A uses two eight-digit, seven-segment, LED displays to show measurement results and other information. Front panel display results are often shown as seven segment letters as in the words CPU tESt PASSEd. Notice that "CPU tESt PASSEd" has a mixture of upper and lower case characters. This is necessary to be able to show letters using displays with only seven segments and has no other significance.

Capacitance and Loss Displays

Most of the time, the upper seven-segment display shows the measured capacitance result, usually in picofarads, with a floating decimal point. The lower display shows the measured loss result in one of five units that you can select. These are selectable with the UNITS command, an example of whose use occurs later in this chapter in the section titled "Measuring Loss" on page 2-9. See Appendix A, "Command Reference" for further details on how to use the UNITS command and any other command.

Both seven-segment displays are also used to show other information and error messages. Most information that can be sent to a remote device is also reportable on these displays. This is true even though a line sent to a remote device may have as many as 80 characters. Such longer lines are reported on the front panel displays by dividing the information on the line into smaller portions. These portions can then

be shown one at a time on the front panel displays. Reporting the contents of a line in this manner is like looking through a window at the line.

For this reason, the term "window" is used in this manual to describe the portion of a line currently being shown in the displays. The term "line" is used to describe any information shown on the front panel that is sent as a single line to remote devices. Some lines are displayable on the front panel in a single window, but others require as many as six windows.

Status and Units Indicators

To the right of the seven-segment displays are two groups of four LED indicators. The upper group usually shows GPIB interface status and internal oven status. The lower group usually shows the current loss units.

The oven status indicator blinks on and off if the oven temperature goes out of range. Blinking is normal for about 15 minutes after the bridge is first powered on, but can also occur if the bridge is in an environment that is too hot or too cold. Measurements can be made when this indicator is on, but the calibration will not be accurate during such times.

Front Panel Brightness

The brightness of the seven-segment displays and of the two indicator groups to the right of the seven-segment displays is controlled using the BRIGHTNESS command. Individual brightness parameters for each display ranging from 0 (off) to 9 (brightest) are entered to control the display brightness. Examples of how to set the brightness of the front panel displays are given later in this chapter in the sections titled "Qualifier Key Labels" on page 2-4 and in "Setting Display Brightness – An Example" on page 2-4. See Appendix A, "Command Reference" for a complete description of this command.

Front Panel Keypad

The AH 2500A may be operated entirely from the front panel using the keypad on the right side.

In this manual, front panel keys are indicated by enclosing the key label name, such as BRIGHTNESS or ENTER within a box. A given key can have as many as six different labels printed on the front panel, but only one will be shown in the box. Which label is recognized by the AH 2500A is determined by the context in which the label is used and that is the label that will appear in the box.

The functions of the key labels can be organized into six different groups. These groups are described in the next six sections below.

Special Key Labels

The special key labels are FUNC, ENTER, CLEAR, DEL, ↑, →, ↓ and ←. Each of these keys performs a special and unique function as described below.

The FUNC key (similar to a shift key) allows all other keys to have at least one additional label. Labels printed on the yellow background above a key require that the FUNC key be pressed prior to pressing the desired key. Note that the FUNC key is to be pressed and *released* before pressing the key having the desired label. The FUNC key is different from a shift key in this respect.

The ENTER key is used to terminate almost all commands. It functions very similarly to the return key on a computer keyboard in this respect.

The CLEAR key label is above the ENTER key and is thus activated by the key sequence FUNC CLEAR. The clear function simply aborts the current command entry sequence. If you made an entry error, this allows you to start entering another command sequence without completing the previous one. An example is given in the section titled "Correcting Erroneous Input – Examples" on page 2-4.

The CLEAR key is also used to perform the DEVICE CLEAR function by pressing FUNC CLEAR FUNC CLEAR. The DEVICE CLEAR function immediately aborts any currently executing command, command line or program. It is explained in more detail in Appendix A, "Command Reference".

The DEL key is used to delete the most recently entered digit of a number. Each time it is pressed, it will delete the rightmost digit of any number being entered and shown on the display. In a different context, this key also starts the DELETE command. The two functions are unrelated.

The ↑, →, ↓ and ← arrow keys are used to view different parts of what can be displayed on the front panel. The front panel can display a list consisting of one or more lines of data. Each line in the list consists of one or more windows. The ↑ and ↓ keys are used to move up and down through the lines of the list. The ← and → keys are used to move left and right through the windows on a given line. If there is only one window, then these keys will have no effect. The ← key will have no effect while the left-most window is being shown. Similarly, the → key will have no effect while the right-most window is being shown. Pressing ENTER or FUNC CLEAR will initialize the display and inactivate the arrow keys.

Some kinds of result lines "remember" the last window that was being shown so that if that kind of result line is shown again, the window last associated with that line will also be shown. This is true of measurement, calibration and test result lines. It is also true of the windows of a program that is being shown. This feature allows you to select a window of interest on a result line. That window will then be shown every time that kind of result line is shown.
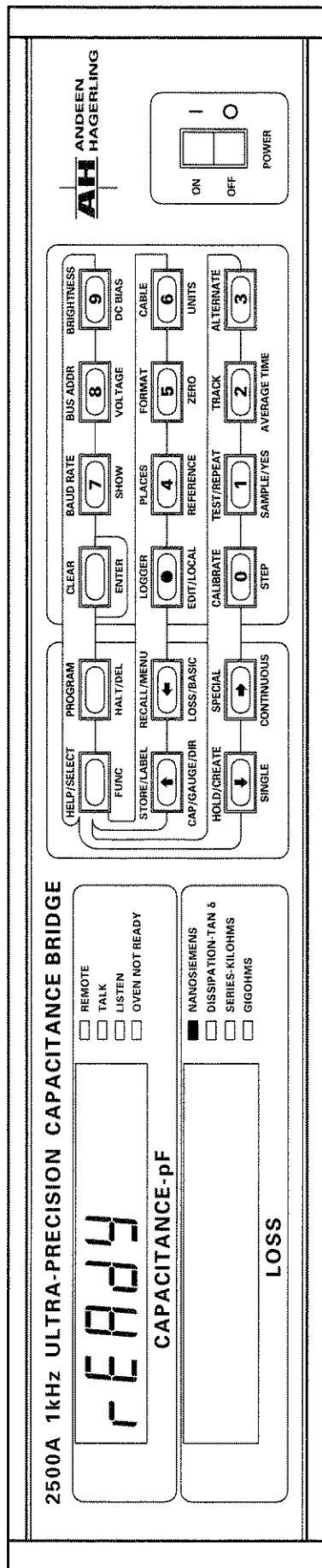
Figure 2-1 AH 2500A front panel

Command Key Labels

The following labels are used as the first word of nearly all front panel commands that the AH 2500A can execute:

[ALTERNATE]	[LOGGER]
[AVERAGE TIME]	[PLACES]
[BAUD RATE]	[PROGRAM]
[DC BIAS]	[RECALL]
[BRIGHTNESS]	[REFERENCE]
[BUS ADDR]	[SAMPLE]
[CABLE]	[SHOW]
[CALIBRATE]	[SPECIAL]
[CLEAR]	[STORE]
[CONTINUOUS]	[TEST]
[DEL]	[TRACK]
[DIRECTORY]	[UNITS]
[FORMAT]	[VOLTAGE]
[HOLD]	[ZERO]

Most of these command labels can be followed by numeric parameters and/or qualifying label words. All of these command labels require that the [ENTER] key be pressed to complete the entry of the command key sequence.

Numeric Key Labels

These key labels are: [0], [1], [2], [3], [4], [5], [6], [7], [8], [9], [.]. These labels are all on the black keys on the right side of the keypad. These are used to enter numbers and numeric parameters.

Qualifier Key Labels

The qualifier key labels are [CAP], [LOSS], [CREATE], [EDIT], [GAUGE], [BASIC], [REPEAT], [SINGLE], [UNITS] and [HALT]. All of these labels are used to follow certain command key labels for the purpose of qualifying the command. For example, in the key sequence [BRIGHTNESS] [CAP] [8] [ENTER], the [CAP] qualifier causes the brightness setting to apply only to the capacitance display rather than to both displays.

Some of these same qualifier labels are also used to start commands. Likewise, some command key labels are also used as qualifiers.

Immediate-Action Command Key Labels
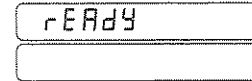
The immediate-action command labels are [LOCAL], [SINGLE] and [STEP]. These are commands that execute as soon as their key is pressed. These commands accept no qualifiers or parameters and are not terminated with the [ENTER] key.

Reserved Key Labels

The labels [HELP], [LABEL], [MENU], and [SELECT] are reserved for future options.

ISSUING COMMANDS

The bridge will always accept commands that are issued to it when the display reads:

```
┌─────────────────┐
│  r E A d Y      │
├─────────────────┤
│                 │
└─────────────────┘
```
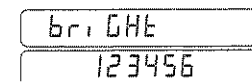
Most bridge commands are issued from the front panel by pressing a command key (sometimes preceded by the [FUNC] key) followed by a numeric parameter and terminated by pressing the [ENTER] key. Notice that most of the front panel keys have command names printed both above and below the keys. To issue a command printed below a key, simply press the key, enter a parameter (if any), and press the [ENTER] key. To issue a command printed above a key, the [FUNC] key must be pressed first. Then press the desired command key, enter the parameter (if any) and press the [ENTER] key.

Setting Display Brightness – An Example

When using the BRIGHTNESS command, a number corresponding to the desired brightness of the display needs to be entered. To set the display for the minimum visible amount of brightness, press [FUNC] [BRIGHTNESS] [1] [ENTER]. The word r E A d Y will be dimly lit, indicating that the command was properly carried out. To show the maximum brightness, press [FUNC] [BRIGHTNESS] [9] [ENTER]. The word r E A d Y will now appear very bright.

Correcting Erroneous Input – Examples

The [DEL] key is used to correct errors while entering parameters. Numbers that are entered from the keypad appear on the lower display, introduced from the right-most digit position. Enter the command [FUNC] [BRIGHTNESS] [1] [2] [3] [4] [5] [6]. (We are picking arbitrary numbers to partly fill the display.) Do not press [ENTER]. You should see:

```
┌─────────────────┐
│  b r i G H t     │
├─────────────────┤
│    1 2 3 4 5 6   │
└─────────────────┘
```

Now press [DEL] six times and you will notice that the numbers are deleted one by one from right to left. Now press [DEL] one more time and notice that nothing happens. The [DEL] key cannot delete the word b r i G H t in the upper display.

Suppose you would like to issue a command other than BRIGHTNESS. Press [FUNC] [CLEAR] and notice that b r i G H t is replaced by r E A d Y in the upper display. The BRIGHTNESS command was not executed and the bridge is now ready to accept a new command.

Try entering FUNC BRIGHTNESS 1 0 ENTER. The display will read:

```
┌─────────────────────┐
│   bAd PAr           │
├─────────────────────┤
│                     │
└─────────────────────┘
```

meaning that the number 10 was not an allowable parameter. Another command can be entered at this time or the ENTER key can be pressed to make the display show rEAdY.

Try entering FUNC SPECIAL 5 5 ENTER. The display will read:

```
┌─────────────────────┐
│   SYntACS           │
├─────────────────────┤
│   Error             │
└─────────────────────┘
```

There is no special command numbered 55 so a syntax error is reported. Another command can be entered at this time or the ENTER key can be pressed to make the display read rEAdY.

There are not many ways to cause a syntax error on the front panel because pressing an unallowed command key usually causes it to be ignored. For example, press AVERAGE TIME followed by any or all non-numeric keys other than FUNC or ENTER. Notice that none have any effect. Now press 4 ENTER and notice that the AVERAGE TIME 4 ENTER command is accepted just as if no incorrect keys were ever pressed.

Using Qualifying Labels – An Example

Suppose you would like to dim the lower display relative to the upper one. The CAP and LOSS qualifier labels will select the display to which the BRIGHTNESS command is to apply. Issue the command BRIGHTNESS LOSS 5 ENTER. Notice that the lower display is now dimmer and that the upper display is unchanged. Issue the command BRIGHTNESS CAP 5 ENTER to make them equal again.

Exploring a List with the SHOW command

The SHOW command can be used to display the values of virtually all parameters that can be entered with the various commands. In this example you will explore a list that contains the measurement related parameter lines. This list is called the Gauge parameter set. The meaning of most of the parameters that you will see is not important at the moment and will be explained in later chapters. Issue the command SHOW GAUGE ENTER. The display will show:

```
┌─────────────────────┐
│   ALtrnAtE          │
├─────────────────────┤
│   0                 │
└─────────────────────┘
```

meaning that the Alternate parameter is set to 0. Now press the → key to see if there are any more windows to be dis-

played for this line. Notice that nothing happens, meaning that there is only one window to be displayed.

Now press the ↓ key. The display will show:

```
┌─────────────────────┐
│   AUErAGE           │
├─────────────────────┤
│   4                 │
└─────────────────────┘
```

meaning that the Average parameter is set to 4. Press the → key again to see if there are any more windows to be displayed for this line. Notice that again nothing happens.

Use the ↓ key to continue through the list. Press the → key after each step to see if the display will show more than one window. After a few more steps, you will reach a parameter line that shows the two windows below in the displays:

```
┌─────────────────────┐   ┌─────────────────────┐
│   0.0000000         │   │   rEF               │
├─────────────────────┤   ├─────────────────────┤
│   0.0000000         │   │   0.0000000         │
└─────────────────────┘   └─────────────────────┘
```

This display first showed two numbers like those at the left. Pressing the → key displays rEF like that at the right indicating that the numbers are reference values. Pressing the → key again has no effect, but pressing the ← key causes the left window to appear again. You can go back and forth between these two windows in this manner.

Continue using the ↓ key, pressing the → key after each step to see if the display will show more than one window. After a few more steps, you will reach a parameter line that shows the window below:

```
┌─────────────────────┐
│   ZErO on           │
├─────────────────────┤
│   0                 │
└─────────────────────┘
```

If you continue pressing the ↓ key at this point, nothing happens because you are at the end of the list, indicating that you have explored the entire Gauge parameter set. If you press the ENTER key, the rEAdY prompt will appear in the upper display and you are now able to enter another command. You can also get back to the rEAdY prompt at any other time without stepping through an entire list just by pressing the ENTER key.

Alternatively, if you don't press the ENTER key you can continue to explore the list by pressing the ↑ key which will cause the display windows to move backward through the list.

The SHOW command is much easier to use on a remote device. There, issuing the command is all that is needed to show the entire list.

Showing a Single Parameter Line

It is not necessary to step through a parameter list to find a particular parameter line. Suppose the value of the Track parameter is desired. Press $\boxed{\text{SHOW}}$ $\boxed{\text{FUNC}}$ $\boxed{\text{TRACK}}$ $\boxed{\text{ENTER}}$ and see on the display:

```
┌──────────────┐
│  ЬгЯс        │
├──────────────┤
│  0           │
└──────────────┘
```

The $\boxed{\rightarrow}$ key can also be pressed here to see if there are any more windows in this line to display. All parameters that have labels on the front panel keypad can be shown on the front panel displays in this way.
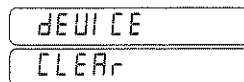
Aborting Commands

Sometimes there is a need to immediately abort a command that will take a long time to execute rather than to wait for it to finish. The way in which this can be done will depend upon whether the command to be aborted is a query command or not.

A query command is any command that produces a result that can be sent to a remote device. All commands that take measurements or that show parameter values are query commands. Commands that only change parameter values are not query commands.

Any query command may be aborted simply by issuing another command. This is called a "query interrupt". Any remaining results from the interrupted command are lost and the interrupting command begins executing immediately. If another command is issued while a non-query command is executing, the interrupting command will not be executed until after the non-query command is finished.

To abort a non-query command, a DEVICE CLEAR command must be issued. (This will also abort query commands.) On the front panel, this is done with the key sequence $\boxed{\text{FUNC}}$ $\boxed{\text{CLEAR}}$ $\boxed{\text{FUNC}}$ $\boxed{\text{CLEAR}}$. This sequence may be entered at any time, even in the middle of entering another command. When this is done, the front panel will display:

```
┌──────────────┐
│  dEUI CE     │
├──────────────┤
│  CLEЯг       │
└──────────────┘
```
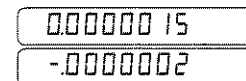
You can try this by issuing a time delay. Enter $\boxed{\text{FUNC}}$ $\boxed{\text{HOLD}}$ $\boxed{3}$ $\boxed{0}$ $\boxed{0}$ $\boxed{\text{ENTER}}$ and observe a countdown timer on the front panel display starting with 300 seconds. Pressing random keys on the front panel will not interrupt the timer. Now if you enter $\boxed{\text{FUNC}}$ $\boxed{\text{CLEAR}}$ $\boxed{\text{FUNC}}$ $\boxed{\text{CLEAR}}$, the timer will stop immediately. For more about this command see "DEVICE CLEAR" on page A-15.

MAKING SINGLE MEASUREMENTS

The AH 2500A has two measurement modes, the single measurement mode and the continuous measurement mode. When power is applied to a new AH 2500A, the bridge is in the single measurement mode. Single measurements can be initiated from the front panel, from a remote device or (indirectly) from an externally supplied trigger pulse. In the single measurement mode a new measurement is started from the front panel each time the $\boxed{\text{SINGLE}}$ key is pressed.

Without attaching any capacitance or measurement cables to the bridge, press the $\boxed{\text{SINGLE}}$ key. A ЬU5У message appears briefly, followed by the measurement result being displayed. For example:

```
┌──────────────┐
│  0.000000 I5 │
├──────────────┤
│  -.0000002   │
└──────────────┘
```

Press the $\boxed{\text{SINGLE}}$ key again and see that the previous result remains on the display until the new result is displayed. The bridge displays ЬU5У whenever a new measurement is started and more than ten seconds have elapsed since the last measurement.

In reality, each measurement produces a result having two windows such as:

```
┌──────────────┐    ┌──────────────┐
│  0.000000 I5 │    │  5: I        │
├──────────────┤    ├──────────────┤
│  -.0000002   │    │  U: I5.0     │
└──────────────┘    └──────────────┘
```

The $\boxed{\leftarrow}$ and $\boxed{\rightarrow}$ keys are used to move between the two windows. The upper right window displays the sample number in case a sample switch is connected. The lower right window displays the AC test signal voltage that was actually used to make the measurement.

With no measurement cables connected to the bridge, the capacitance between the uncapped HIGH and LOW connectors on the rear panel is being measured. This capacitance is shown in the left upper display and should be in the range of +0.0000000 to +0.000003 pF. The left lower display shows the loss which should be in the range of -0.000006 to +0.000006 nS. When the AH 2500A is new, it will show loss using units of nanosiemens after power-on. An example of how to change the loss units is given in "Measuring Loss" on page 2-9.

You may want to take several single measurements to see the change in the capacitance and loss. The variation in the readings is caused mostly by externally generated noise entering the uncapped LOW input terminal of the bridge. The source of this noise is usually from nearby power lines and digital instruments and cables.

MAKING CONTINUOUS MEASUREMENTS

The AH 2500A can be set to perform continuous measurements almost as easily as single measurements. When in continuous measurement mode, the bridge takes measurements continually with a period that you specify until it is manually halted. To initiate continuous measurements, press CONTINUOUS ENTER. Notice that the displays show a new pair of numbers about twice per second. If the LOW input terminal was not deliberately left exposed (uncapped), there might not be enough noise to cause the displays to change with each measurement. The CONTINUOUS command makes it easy to quickly observe many readings and thus get a feeling for the amount of noise being picked up.

The bridge remains in continuous measurement mode until a key is pressed on the front panel. Pressing a key causes the measurement in progress to be immediately aborted. After a key has been pressed, the bridge waits for the rest of a command to be entered and then executes it. If the SINGLE key is pressed, the bridge will go back to single measurement mode and take one reading. If any other command is issued, continuous measurements will restart immediately following execution of the command. This allows issuing commands without having to exit and re-enter continuous measurement mode.

MEASUREMENT EXPERIMENTS

This section describes some simple experiments that show how to make actual measurements of capacitance and loss. The high sensitivity of the AH 2500A and the meaning of various error messages is demonstrated.

Equipment Needed for Experiments

To perform the experiments that are described next, you will need a few commonly available items listed below.

- Obtain or make two coaxial cables about one meter long. They should have BNC connectors on one end and alligator clips on the other end. Identify the cables by labeling them with an "H" on one of the cables and an "L" on the other. The following manufacturer's part numbers should work: Pomona Models 4531-C-36, 4532-C-36 or 5187-C-36 or E-Z-Hook Part Numbers 1020XR-36, 1021XR-36, 1020XH-36, 1021XH-36, 1029-36 or 1029M-36.

- An ordinary capacitor with a value between 100 and 10,000 pF. A more stable type such as a mica is preferable to most ceramic capacitors.

- A resistor in the range of 10 kΩ to 1 MΩ.
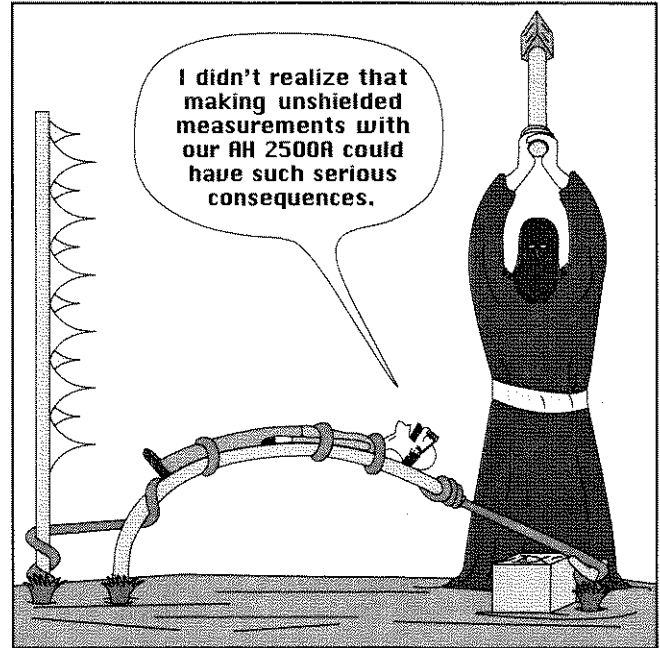
Figure 2-2 Possible effects of using unshielded apparatus for precision measurements

Connecting the Test Cables

Connect the BNC plugs on the ends of your coaxial cables to the connectors marked HIGH and LOW on the rear panel of the bridge. Connect the cable labeled "H" to the HIGH connector and the cable labeled "L" to the LOW connector. The HIGH connector is an output that supplies a 1 kHz sinusoidal test signal. The LOW connector is a sensitive input. Use a table or a flat work surface to lay the cables on.

WARNING !
The AH 2500A normally drives the high terminal with an AC signal. While the voltage level of this signal is not high enough to cause serious harm, (15.0 volts RMS maximum), it is enough to cause a mild shock, especially if one's hands are damp or wet.

Demonstrating Noise Sensitivity

You can easily demonstrate that the LOW terminal is the terminal most sensitive to noise and interference.

Start a continuous measurement as described earlier. Note the capacitance reading resulting from the stray capacitance between the HIGH and LOW center conductor clips. Now touch the bare center conductor clip of the HIGH cable. Notice that the capacitance measurement increases, but no error message appears. Touching the bare clip makes your body part of the HIGH side of the stray capacitor thereby making the capacitor dimensions much larger and the capacitance somewhat larger.

Now touch only the center conductor clip of the LOW cable. You should see on your display the error message:

```
┌─────────────────────────┐
│   AC  on  L             │
├─────────────────────────┤
│    I nPut               │
└─────────────────────────┘
```

or the message:

```
┌─────────────────────────┐
│   ECCESS                │
├─────────────────────────┤
│    nOI SE               │
└─────────────────────────┘
```

These error messages indicate that too much noise is being picked up and it is interfering with the measurements. Your body is acting as an antenna. You have observed a very important difference between the HIGH and LOW connections to the bridge. Awareness of this difference can be very useful when designing, debugging or repairing capacitor fixtures.

If you now hold the bare coaxial cable shield clip of either cable while touching the LOW center conductor clip, the error message will probably go away. If it does not, you are in a fairly noisy environment. Connected in this manner, your body acts as a poor conductor which shunts most (but perhaps not enough) of its picked-up signal to the shield clip. You may want to verify that touching any screw on the case of the bridge has the same effect as touching the shield clip. (The same, that is, unless your hand or body is also moving closer to or further from a significant, nearby source of noise.) You have demonstrated one way in which an ungrounded connection can introduce noise into your measurements.

Low Frequency Noise

The error message AC on L $InPut$ indicates that low-frequency noise is being picked up. This is a condition you might see if you are working in an area where there are power lines close by.

High Frequency Noise

The conditions that generated the AC on L $InPut$ error message, may also generate an $ECCESS$ $nOISE$ error message. The $ECCESS$ $nOISE$ message indicates that high-frequency noise is being picked up. This situation might occur if you are working in an area where computer equipment is being operated.

Reducing the Effect of Noise – Averaging Time

Put the cables in a stable position on your work surface. Watch the capacitance and loss displays as measurements are being displayed and note the most positive and the most negative value shown in each display over a period of several minutes. Since a new AH 2500A has a default average time of 4, these measurements were probably taken with that value. To verify this, press [SHOW] [AVERAGE TIME] [ENTER]. You should see $AUErAGE$ 4 on the displays.

Now change the averaging time parameter to 8 by pressing [AVERAGE TIME] [8] [ENTER]. This will cause each measurement to take sixteen times longer than at averaging time 4. Since noise is proportional to the inverse of the square root of the measurement time, you will expect to see a factor of four less noise in your measurements at averaging time 8.

Now again, watch the capacitance and loss displays as measurements are being displayed and note the most positive and the most negative value shown in each display over a period of several minutes. The most positive value minus the magnitude of the most negative value should now be about one fourth what it was previously for both capacitance and loss results. You have demonstrated how the use of a longer averaging time can reduce the uncertainty of your measurements due to noise.

Demonstrating Measurement Sensitivity

Now, you will measure the capacitance between the two clips. Leaving the cables connected to the bridge, take the HIGH and LOW center conductor clips of each cable and lay them an inch apart on your work surface. Observe the measurement results. (If you did the previous experiment, you will want to restore the averaging time back to 4.)

Now move the clips slightly closer together and observe that the capacitance increases. The closer together you move the clips, the higher the capacitance value reads.

Now move the clips further apart. As you move the clips further apart, the capacitance value decreases.

If you bridge the HIGH and LOW clips with your hand without actually touching either clip or any other conductor, your hand will serve as an intermediate conductor that will increase the capacitance.

If you touch a ground or shield with one hand and put your other hand between the HIGH and LOW clips, your hand
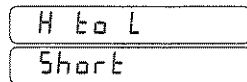
will act as a shield. This will cause the capacitance to decrease.

These crude experiments demonstrate basic issues that are used to design precision capacitance measuring fixtures. These experiments are easily extended to more sophisticated configurations by constructing electrodes and shields from whatever materials happen to be readily available in your laboratory (or even in your kitchen).

Hard Measurement Errors

High to Low Shorts

While still making continuous measurements, connect the clips of the center conductor HIGH and LOW cables together. An error message showing:
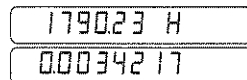
```
┌──────────────────────┐
│  H  to  L            │
├──────────────────────┤
│  Short               │
└──────────────────────┘
```

should appear, indicating that the HIGH terminal is shorted to the LOW terminal.

High to Ground Short

Now connect the capacitor that you collected earlier between the HIGH and LOW clips. Its capacitance and loss will be displayed on the front panel. Now connect the clip of either ground to the clip of the HIGH center conductor cable. An H error message should appear in the extreme right-hand position of the upper display as in the example below:

```
┌──────────────────────┐
│  1790.23  H          │
├──────────────────────┤
│  0.003421 17         │
└──────────────────────┘
```

The dead short that you have created will cause the capacitance value to be seriously in error.
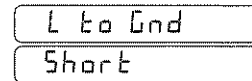
The H error message differs from most other error messages, in that it is one of the few that are displayed beside a measurement value. Rather than replacing the measurement, it appears with it. The H error message indicates that the impedance between the high center conductor and ground is too low. The measurement value may have some significance, but is usually not to be trusted.

Low to Ground Short

With the capacitor used in the previous experiment still connected, connect the LOW center conductor clip to one of the shields. You must do this without touching the LOW center conductor with any other conductor (or your fingers) that might introduce noise. You should observe that the measurement result does *not* change, nor is any error message reported. If you keep the LOW center conductor shorted to ground, you can even remove the capacitor entirely without changing the results reported by the bridge. The bridge is

unable to distinguish the situation where its LOW terminal input is shorted to ground from the situation where the bridge is perfectly balanced. In both cases, the bridge sees no signal on its input. This is the most significant kind of external error that can occur which the bridge is not always able to detect.

Now change the averaging time parameter to 7 by pressing [AVERAGE TIME] [7] [ENTER] and repeat this experiment. You will find that every time you short the LOW center conductor to ground, the result of the *next* measurement will be the error message:

```
┌──────────────────────┐
│  L  to  Gnd          │
├──────────────────────┤
│  Short               │
└──────────────────────┘
```

indicating that the LOW terminal is shorted to ground. For averaging times of seven or higher, a test is performed at the beginning of every measurement that will detect a low-to-ground short.

Measuring R, C and combined R and C

Measuring Capacitance

Connect the center conductor clips of the HIGH and LOW coaxial cables to your capacitor of about 1000 pF. With the bridge still in continuous mode, record the measured capacitance value.

Measuring Loss

Now remove the capacitor and connect the center conductor clips of the HIGH and LOW cables to a resistor of approximately 100 kΩ.

Since loss is currently being displayed in nanosiemens, and the resistor value is in ohms, we want to change the loss units to display in gigohms for comparison purposes. Use the UNITS command to change loss units by pressing [UNITS] [4] [ENTER]. (The loss units parameters are numbered in the same order that the loss units indicators on the front panel are arranged.) Notice that the nanosiemens unit indicator turns off and the gigohms unit indicator turns on, meaning that the bridge is now displaying loss in gigohms. If your resistor is 100 kΩ, the lower display will show approximately 0.000100 GΩ. Record the measured loss value.

Measuring Parallel Capacitance and Loss

Now connect the center conductor clips of the HIGH and LOW coaxial cables to both the resistor and the capacitor connected in parallel. The displays should now read values that are close to the values recorded when the parts were measured individually. If this procedure were performed more carefully and if the bridge was perfect, there would be no difference in the individual versus combined readings. To the extent that the procedure is carefully performed, it is a demanding test of the bridge's capabilities.

To perform the experiment more carefully requires that *both* the capacitance *and* loss be recorded when each part is measured individually. The capacitances are added to get the expected capacitance value for the combined parts. The reciprocals of the resistances are added giving the reciprocal of the resistance value for the combined parts. (This is where the use of conductance units for loss measurements is preferable since nanosiemens can simply be added just the way the capacitance values are.)

Can you perform a similar experiment by combining the parts in series rather than in parallel? (This is a less precise experiment since there is a stray capacitance from the center node that cannot be eliminated.)

Two- Vs. Three-Terminal Connections

All of the experiments described so far have been of the two-terminal variety. The third terminal of a three-terminal device is used to ground an enclosure around that device. The enclosure contains the fields of the device and shields the device from external fields. None of the components measured so far have incorporated a three-terminal shield. As a result, you observed that all of these experimental configurations were very susceptible to externally generated noise and to changes in position, orientation, and proximity to other objects. A properly constructed three-terminal device will eliminate all of these effects. For a more detailed discussion of three-terminal measurements, see "THREE-TERMINAL MEASUREMENTS" on page 4-2.

The AH 2500A can make floating two-terminal measurements at least as well as any other instrument, but it is difficult to take advantage of the AH 2500A's exceptional precision unless measurements are made on three-terminal devices. If a three-terminal fixed or decade capacitor and cabling is available, another experiment can be performed to show the enormous improvement that three-terminal devices offer.

Connect your three-terminal capacitor to the HIGH and LOW connectors on the back of the AH 2500A using a DCOAX-1-BNC or equivalent cable. With the bridge in continuous mode, observe the readings. Any respectable three-terminal capacitor will produce readings with very little randomness. The least significant digit may hardly change at all.

Now try to induce changes into the reading. Move your hands in the vicinity of the cable and the capacitor. Touch the cable and the capacitor. You should see no effect. Move the cable to other positions. This should have no effect. If it does, the cable is probably defective. Try moving the capacitor to different positions. This should not cause a change in the readings if the capacitor is not bumped so as to change its value slightly. Try moving the capacitor to different orientations. All but the highest quality standards will change slightly as a result of orientation changes, especially capacitors having a gas dielectric. However, the changes will be fairly repeatable if the capacitor is handled gently. The noise

level in the readings for all of these experiments should be consistently low.

The experiments you have performed were intended to improve your intuitive grasp of the sensitivity of the AH 2500A and of the importance of making three-terminal rather than two-terminal measurements. Chapter 4, "Measurement Essentials" discusses these and other measurement issues in more detail.

Chapter 3   Parameter and Program Files

Many of the AH 2500A's commands accept groups of various numeric parameters. These parameters control the operation of the bridge. For convenience, these groups of parameters are collected into "parameter sets" to make it easy to change the bridge quickly to a new configuration, especially after power-on. Many of the parameter sets can be stored in permanent files within the bridge for later recall and use. This chapter describes the various sets and files and the commands necessary to change, show, store and recall them. To use the AH 2500A with maximum efficiency, an understanding of parameter sets and files is essential. However, the bridge is easily used to make measurements with little understanding of sets and files. Thus if you are a first-time user, you may initially want to skip this chapter, but if you are a serious user, you will eventually want to read it.

This is the first chapter having command examples and command syntax definitions for remote devices. Since remote command entry is slightly different from GPIB versus serial devices, it is described in those chapters. For more information, see "REMOTE COMMAND ENTRY" on page 6-3 for GPIB usage, "REMOTE COMMAND ENTRY" on page 7-8 for serial usage and the beginning of Appendix A, "Command Reference" for the command description syntax.

FILES AND MEMORY

The concept of files as used in the AH 2500A is very similar to that used by a computer. The main difference is that the AH 2500A uses internal, non-volatile, writable memories (EEPROM) rather than disks in which to store its files. Programs and all but one parameter set type can be stored in these files. The working, writable memory of the bridge is RAM, the contents of which are lost when power is lost. The firmware that operates the bridge is located in permanent, read-only memory (ROM or EPROM). Figure 3-1 helps to visualize these memory types. The EEPROM files, ROM files and current RAM contents are labeled in the figure.

PARAMETER SET TYPES

Listed below are the five types of parameter sets used in the AH 2500A. You can change the parameters in the first four directly. The first four can also be saved as a file; the last one cannot be.

The **Basic Parameter Set** contains general information about how the bridge is configured and how results are reported.

The **Gauge Parameter Set** contains information about how capacitance and loss measurements are to be taken and how results are represented.

The **Baud Parameter Set** contains information such as the baud rate that is used to configure the RS-232 port.

The **Bus Parameter Set** contains information such as the bus address that is used to configure the GPIB port.

The **Special Parameter Set** contains some information that identifies the bridge and its current condition and status. The special parameter set contains either fixed information or information which is maintained by the bridge. You cannot directly change this information.

Current Parameter Sets

There is one current parameter set of each type (Basic, Gauge, Baud and Bus) located in the bridge's RAM memory. These sets are shown in Figure 3-1. Their contents are also indicated in this figure. When a command is issued that changes a parameter, it is a parameter in one of the four current parameter sets that gets changed. You issue commands to set and modify the parameters contained in the current Basic, Gauge, Baud and Bus parameter sets to meet your needs. Bridge operations are directly controlled by the values of the parameters in the current parameter sets. Since the current parameter sets are stored in RAM, the contents are lost when power to the bridge is removed.

Stored Parameter Files

The AH 2500A allows you to create multiple versions of the Basic, Gauge, Baud and Bus parameter sets which are stored as files. Storage in EEPROM memory prevents loss of the contents of the parameter files when the power is removed. Collections of parameters can be created and edited in the current parameter sets, stored in a file and recalled back to the same current parameter set. Stored parameter files must be recalled before they will control the operation of the bridge. Figure 3-1 shows examples of stored parameter files and a store and recall operation. These operations are discussed in more detail later under "WORKING WITH FILE CONTENTS" on page 3-9.

Power-on Parameter Files

When the bridge is first powered up, files of default parameters are used to make measurements. The parameters can be the factory-supplied default parameters or they can be parameter files of your creation. If you are always satisfied with the values in the default power-on parameter files, you may not need to learn more about parameter files. Figure 3-1 shows an example of what data is moved during power-on. See "Using Power-on Parameter Files" on page 3-10 for more information.
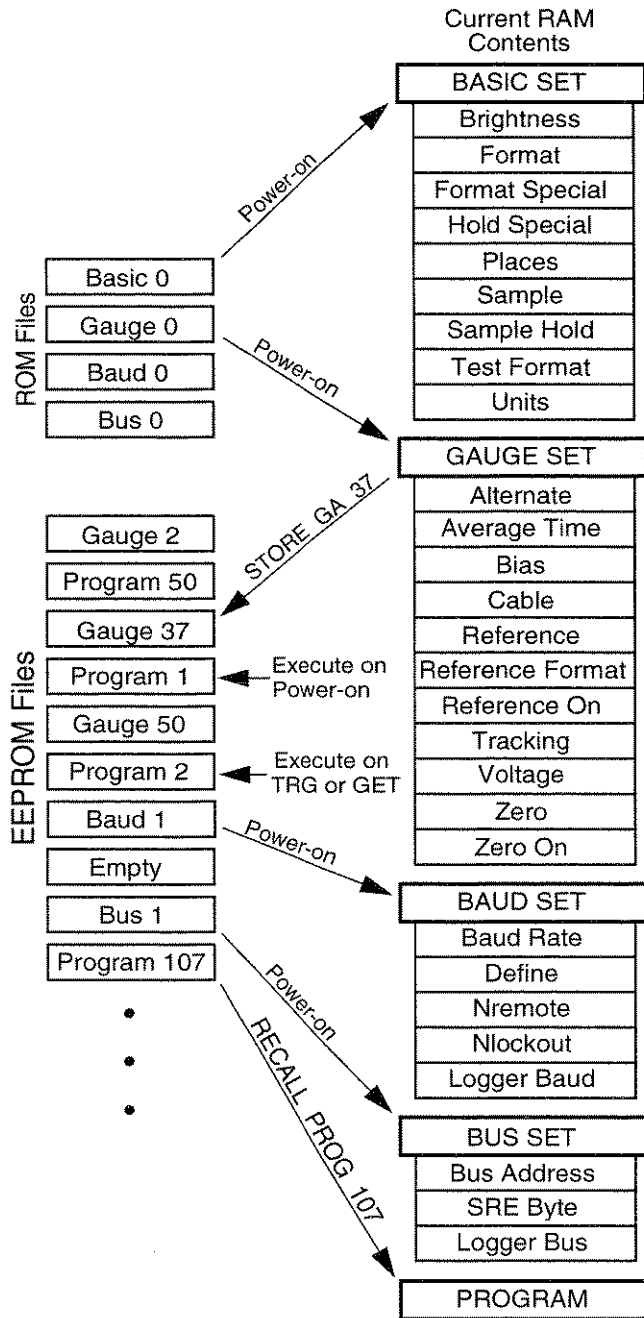
Figure 3-1 Pictorial conception of AH 2500A stored files, structure of current parameter sets and typical operations

PARAMETER SET CONTENTS

The contents of all parameter sets are listed below. The order of the parameters shown below is the same as the order displayed by the SHOW command. The order is mostly alphabetical, but parameter groups having similar functions are grouped together. See "Exploring a List with the SHOW command" on page 2-5 for some examples of how to use this command.

The sections below give a brief description of each parameter or group of parameters. The description is followed by examples of the images of the parameters as the SHOW command displays them on the front panel and on remote devices. The examples use the parameter values in the default files stored in the AH 2500A's permanent memory.

Some parameter groups have more than one window that can be displayed on the front panel. The ◄ and ► keys are used to move right and left through these windows. The lists show all the available windows side-by-side.

If a parameter group is modifiable, the command needed to do so is given. This command can be looked up in Appendix A, "Command Reference" where more information on the parameters in the group will be found.

Basic Parameter Set

The Basic parameter set contains the following parameters:

Brightness

The Brightness parameters control the brightness of the front panel displays. The brightness of the capacitance and loss displays can be controlled individually. The parameters are modified using the BRIGHTNESS command. On the front panel, SHOW FUNC BRIGHTNESS ENTER gives:

```
br i GHt
C5  L5
```

On remote devices, SH BR gives:

```
BRIGHTNESS   C=5  L=5
```

Format

The Format parameters contain information about which of the various measurement-related types of information get sent to a remote terminal or logging device. Changing the format parameters does not affect the front panel displays. The parameters are modified using the FORMAT command. On the front panel, SHOW FUNC FORMAT ENTER gives:

```
For nAt                SCLULL PF
0. 1. 1. 1. 1. 10. 1    0. 1. 1. 1. 1. 10. 1
```

where the ◄ and ► buttons are used to move between the
ForΠAt display window on the left and the one on the
right which associates a single letter label with each format
bit on the lower line. On remote devices, SH FO gives:

```
FORMAT  SMP=0 CAP=1 LOS=1 ULT=1
               MSG=1 LBL=1 PUN=0 FFD=1
```

For more information, see "REMOTE DEVICE FORMATS"
on page 5-5.

Format Special

The Format Special parameter controls the numeric notation
of measurement results that are sent to remote devices. This
parameter is modified using the FORMAT SPECIAL com-
mand. On the front panel, [SHOW] [FUNC] [FORMAT] [FUNC]
[SPECIAL] [ENTER] gives:

```
ForΠAt
SPEC    0
```

On remote devices, SH FO SP gives:

```
FRMT SPEC    N=0
```

For more information, see "Numeric Notation" on page 5-8.

Hold Special

The Hold Special parameter controls the handling of external
trigger pulses that arrive when no HOLD 0 command has
been executed to receive them. This parameter is modified
using the HOLD SPECIAL command. On the front panel,
[SHOW] [FUNC] [HOLD] [FUNC] [SPECIAL] [ENTER] gives:

```
HOLd buF
            1
```

On remote devices, SH HO SP gives:

```
HOLD SPEC    TRIGBUF=1
```

For more information, see "Handling Unexpected Trigger
Pulses" on page 3-14.

Places

The Places parameters control the number of significant dig-
its of measurement results that are displayed on the front
panel and which are sent to remote devices. These parameters
are modified using the PLACES command. On the front
panel, [SHOW] [FUNC] [PLACES] [ENTER] gives:

```
PLACES
C9 L9
```

On remote devices, SH PL gives:

```
PLACES   C=9 L=9
```

For more information, see "Setting a Limit on the Significant
Digits" on page 5-1.

Sample

The Sample parameter indicates which sample number is
being measured when using a sample switch. The SAMPLE
command is used to select the sample number. On the front
panel, [SHOW] [SAMPLE] [ENTER] gives:

```
SAMPLE
1
```

On remote devices, SH SA gives:

```
SAMPLE   NUMBER= 1
```

For more information, see Appendix D, "Sample Switch
Port".

Sample Hold

The Sample Hold parameter is a delay time that occurs fol-
lowing each change of position of a sample switch by the
SAMPLE command. The SAMPLE HOLD command is
used to set this time. On the front panel, [SHOW] [SAMPLE]
[FUNC] [HOLD] [ENTER] gives:

```
SAMP HLd
0.00
```

On remote devices, SH SA HO gives:

```
SAMPLE HLD DELAY=0.00       SEC
```

For more information, see Appendix D, "Sample Switch
Port".

Test Format

The Test Format parameters determine what conditions cause
the diagnostic self-tests to stop. They also determine which
test results are reported. They are modified with the TEST
FORMAT command. On the front panel, [SHOW] [FUNC]
[TEST] [FUNC] [FORMAT] [ENTER] gives:

```
tSt FrΠt         hOC  rPr
hO   r2          hO   r2
```

On remote devices, SH TE FO gives:

```
TEST FRMT   HOC=0 RPR=2
```

For more information, see "Selection of Options: the TEST
FORMAT command" on page 11-7.

Units

The Units parameter contains a value that specifies the units in which measured loss values are displayed. It allows you to choose one of five different measurement units in which to display loss values. The UNITS command is used to change the units. On the front panel, [SHOW] [UNITS] [ENTER] gives:

```
┌─────────────────────┐
│   Uni t5            │
├─────────────────────┤
│   L I               │
└─────────────────────┘
```

On remote devices, SH UN gives:

                UNITS   L=1

For more information, see "DECIDING WHICH UNITS TO USE" on page 4-10.

Gauge Parameter Set

The bridge measures capacitance and loss using the parameter values in the current Gauge set. These parameters determine what settings and features are used when each measurement is made. Most of these parameters are discussed in Chapter 4, "Measurement Essentials"

Alternate

The Alternate parameter contains a value that indicates whether the applied 1 kHz test signal alternation (commutation) is in effect and, if so, what alternation interval is being used. You can specify alternation intervals in steps ranging from one quarter second to sixteen seconds. The parameter is modified using the ALTERNATE command. On the front panel, [SHOW] [FUNC] [ALTERNATE] [ENTER] gives:

```
┌─────────────────────┐
│   ALtrnAtE          │
├─────────────────────┤
│   0                 │
└─────────────────────┘
```

On remote devices, SH AL gives:

         ALTERNATE   ALTEXP=0

For more information, see "REJECTING INTERFERING SIGNALS" on page 4-8.

Average Time

The Average Time parameter contains a value that determines how many measurements are averaged to calculate the final capacitance or loss measurement result that is displayed. It is modified using the AVERAGE command. On the front panel, [SHOW] [AVERAGE TIME] [ENTER] gives:

```
┌─────────────────────┐
│   AUErAGE           │
├─────────────────────┤
│   4                 │
└─────────────────────┘
```

On remote devices, SH AU gives:

         AVERAGE   AVEREXP=4

For more information, see "MEASUREMENT SPEED VS. MEASUREMENT FLUCTUATION" on page 4-5.

Bias

The Bias parameter contains a value that controls whether a user-supplied external DC Bias voltage is connected through the bridge to the device under test. If such a voltage is connected, this parameter further specifies whether a 1 MΩ or a 100 MΩ internal series resistor is used to make the connection. This parameter is modified using the BIAS command. On the front panel, [SHOW] [DC BIAS] [ENTER] gives:

```
┌─────────────────────┐
│   dc bIAS           │
├─────────────────────┤
│   0                 │
└─────────────────────┘
```

On remote devices, SH BI gives:

         DC BIAS   ENABLE=0

For more information, see "UNKNOWNS WITH DC VOLTAGE" on page 4-13.

Cable

The Cable parameters contain four values that correspond to the cable length, cable resistance, cable inductance and cable capacitance of the test cable that is used to connect to the device under test. All four parameters are used internally by the bridge to provide automatic cable compensation in the measured result. These parameters are modified using the CABLE command. On the front panel, [SHOW] [FUNC] [CABLE] [ENTER] gives:

```
┌─────────────────────┐
│   CAb LEn           │
├─────────────────────┤
│   I.00              │
└─────────────────────┘
```

Pressing the [↓] button gives:

```
┌─────────────────────┐
│   CAb rES           │
├─────────────────────┤
│   40.               │
└─────────────────────┘
```

Pressing the [↓] button again gives:

```
┌─────────────────────┐
│   CAb Ind           │
├─────────────────────┤
│   I.10              │
└─────────────────────┘
```

Pressing the [↓] button again gives:

```
┌─────────────────────┐
│   CAb CAP           │
├─────────────────────┤
│   70.0              │
└─────────────────────┘
```

On remote devices, SH CAB gives:

```
CABLE     LENGTH= 1.00   M
CABLE     RESISTANCE/M= 40.0   MO
CABLE     INDUCTANCE/M= 1.10   UH
CABLE     CAPACITANCE/M= 70.0   PF
```

For more information, see "SOURCES OF ERROR" on page 8-4.

Reference / Ref Format / Ref On

Two of the Reference parameters are the values of capacitance and loss that are subtracted from the measurements when reference result mode is enabled. A Reference Format parameter determines whether the results are to be displayed as an absolute deviation from the reference or whether the results are expressed as a percentage deviation from the reference. There is also an indicator as to whether reference mode is enabled or disabled. The Reference parameters are modified using several forms of the REFERENCE command. On the front panel, [SHOW] [REFERENCE] [ENTER] gives the two reference values as:

```
0.00000000        rEF
0.00000000        0.00000000
```

Pressing the [↓] key then shows that reference percent mode is disabled:

```
rEF  FrNt
CO  LO
```

Pressing the [↓] key again shows that reference mode is disabled:

```
rEF  on
CO  LO
```

On remote devices, SH REF gives:

```
REFERENCE   C=0.00000000 PF L=0.00000000 NS
REF  FRMT   C=0  L=0
REF   ON    C=0  L=0
```

For more information, see "RESULT MODES" on page 5-2.

Tracking

The bridge can be set to follow otherwise stable unknowns that occasionally change at a rate much faster than normal. The Tracking parameter contains a threshold value that is the maximum rate of change allowed in the value of the unknown sample before tracking mode takes over. This results in occasional faster measurements at reduced accuracy. The tracking threshold is modified using the TRACK

command. On the front panel, [SHOW] [FUNC] [TRACK] [ENTER] gives:

```
trAc
0
```

On remote devices, SH TR gives:

```
TRACKING   THRESHOLD=0
```

For more information, see "Auto Switching to High Speed" on page 4-7.

Voltage

The Voltage parameter allows you to specify a maximum signal level to be applied. The bridge will measure the sample at a voltage equal to or less than this maximum. The bridge will report the actual voltage at which the measurement is taken. The parameter is modified using the VOLTAGE command. On the front panel, [SHOW] [VOLTAGE] [ENTER] gives:

```
UOLtAGE
15.0
```

On remote devices, SH U gives:

```
VOLTAGE  HIGHEST= 15.0   U
```

For more information, see "VOLTAGE OF THE TEST SIGNAL" on page 4-12.

Zero / Zero On

The Zero parameters contain capacitance and loss values that may be used to compensate for stray impedance in a test fixture. There is also an indicator as to whether zero mode is enabled or disabled. The parameters are modified using several firms of the ZERO command. On the front panel, [SHOW] [ZERO] [ENTER] gives:

```
0.00000000        2Er0
0.00000000        0.00000000
```

Pressing the [↓] key then shows that zero mode is disabled:

```
2Er0  on
0
```

On remote devices, SH Z gives:

```
ZERO       C=0.00000000 PF L=0.00000000 NS
ZERO ON    C&L=0
```

For more information, see "COMPENSATING FOR STRAY FIXTURE IMPEDANCE" on page 4-12.

Baud Parameter Set

The Baud parameter set contains all the parameter definitions related to operation via the serial port. All the serial parameters are discussed in Chapter 7, "Serial/RS-232 Remote Operation".

Baud Rate

The Baud Rate parameters contain fundamental communications settings such as the baud rate that are used in conjunction with the serial port. The parameters are modified using the BAUD command. On the front panel, $\boxed{\text{SHOW}}$ $\boxed{\text{FUNC}}$ $\boxed{\text{BAUD}}$ $\boxed{\text{ENTER}}$ gives:

```
┌─────────────────────┐   ┌─────────────────────┐
│  bAUd               │   │  r E.E.P.L.S.F.E     │
├─────────────────────┤   ├─────────────────────┤
│  96. 1.0.8. 1.0. 1  │   │  96. 1.0.8. 1.0. 1  │
└─────────────────────┘   └─────────────────────┘
```

On remote devices, SH BAU gives the entire Baud parameter set of which the first line is:

```
BAUD   RATE=96 DTE=1 PAR=0 LEN=8
                    STP=1 FIL=0 ECH=1
```

Only the first two digits of the rate are shown. For more information, see "SERIAL COMMUNICATION PARAMETERS" on page 7-6.

Define

The Define parameter specifies which ASCII control characters are used for interactive editing via the serial port. The choice of characters is modified using the DEFINE command. On remote devices, SH DEF gives:

```
DEFINE   ERASE=^U DEL=DEL BACKSP=^H
                    DCL= ^E TERM=PRINTER
```

For more information, see "Correcting Typing Errors" on page 7-10.

Nremote

When set, the Nremote parameter *largely* disables front panel (local) control of the bridge. The NREMOTE and LOCAL commands may be issued from the serial port to change this parameter. The $\boxed{\text{LOCAL}}$ button will reset this parameter. On remote devices, SH NREM gives:

```
NREMOTE   STATE=0
```

For more information, see "LIMITING FRONT PANEL ACCESS" on page 7-11.

Nlockout

When set, the Nlockout parameter *totally* disables front panel (local) control of the bridge when the Nremote parameter is *also* set. The NLOCKOUT command may be issued only from the serial port to change this parameter.

On the front panel, $\boxed{\text{SHOW}}$ $\boxed{\text{FUNC}}$ $\boxed{\text{BAUD}}$ $\boxed{\text{ENTER}}$ followed by $\boxed{\downarrow}$ gives:

```
┌─────────────────────┐
│  nLocout            │
├─────────────────────┤
│  StAtE 0            │
└─────────────────────┘
```

On remote devices, SH NLOCK gives:

```
NLOCKOUT   STATE=0
```

For more information, see "Selecting the Serial Control States" on page 7-12.

Logger Baud

The Logger Baud parameter determines whether results created in response to front panel commands are sent to the serial port. It also provides some control over what kind of results are sent. The Logger Baud parameter is modified with the LOGGER BAUD command. On the front panel, $\boxed{\text{SHOW}}$ $\boxed{\text{FUNC}}$ $\boxed{\text{LOGGER}}$ $\boxed{\text{ENTER}}$ gives:

```
┌─────────────────────┐
│  LOG bAUd           │
├─────────────────────┤
│  Contnt 0           │
└─────────────────────┘
```

On remote devices, SH LOG gives two lines, the first of which is:

```
LOG BAUD CONTENT=0
```

For more information, see "SERIAL DATA LOGGING" on page 7-13.

Bus Parameter Set

The Bus parameter set contains all the parameter definitions related to operation via the GPIB port. All the GPIB parameters are discussed in Chapter 6, "GPIB/IEEE-488 Operation".

Bus Address

The Bus Address parameters contain fundamental communications settings that are used in conjunction with the GPIB port. The parameters are modified using the BUS command. On the front panel, $\boxed{\text{SHOW}}$ $\boxed{\text{FUNC}}$ $\boxed{\text{BUS}}$ $\boxed{\text{ENTER}}$ gives:

```
┌─────────────────────┐   ┌─────────────────────┐
│  bUS  Addr          │   │  Pri.SC.t.C.P       │
├─────────────────────┤   ├─────────────────────┤
│  28.    .0.0.0      │   │  28.    .0.0.0      │
└─────────────────────┘   └─────────────────────┘
```

On remote devices, SH BU gives the entire Bus parameter set of which the first line is:

```
BUS ADRS    PRI=28 SEC=
                    TON=0 CPT=0 PRP=0
```

For more information, see "BUS CONFIGURATION PARAMETERS" on page 6-1.

SRE Byte

The SRE parameter byte contains the GPIB service request enable mask. This mask determines which of the bits that are set in the GPIB device status register can cause a service request to occur. You can modify the GPIB service request enable mask using the SRE command, and thereby determine which bridge conditions or events can cause GPIB service requests to occur. On the front panel, [SHOW] [BUS] [ENTER] followed by [↓] gives:

```
 5r E            |   |    n. Er.PU.E.0
 0. 0.0.0.0.0    |   |    0. 0.0.0.0.0
```

On remote devices, SHOW SRE gives:

```
SRE    MAU=0 EXE=0 RDY=0 PON=0
                   URQ=0 CME=0 ONR=0
```

For more information, see "Service Requests" on page 6-7.

Logger Bus

The Logger Bus parameter determines whether results created in response to front panel commands are sent to the GPIB port. It also provides some control over what kind of results are sent. The Logger Bus parameter is modified with the LOGGER BUS command. On the front panel, [SHOW] [FUNC] [LOGGER] [ENTER] followed by [↓] gives:

```
 L OG bUS
 Eontnt  l
```

On remote devices, SH LOG gives two lines, the second of which is:

```
LOG BUS   CONTENT=1
```

For more information, see "GPIB DATA LOGGING" on page 6-15.

Special Parameter Set

The Special parameter set contains information that is specific to the bridge. It is different from the other parameter sets since the bridge *automatically* updates all of the parameters in this set. You can see but not change its contents using the SHOW SPECIAL command. It cannot exist as a file. The parameters it contains are listed below.

Status

Status shows the settings of the bits in the status byte sent to the GPIB interface. On the front panel, [SHOW] [FUNC] [SPECIAL] [ENTER] gives:

```
 5tAtU5           |   |    n.n.E.r.P.U.E.0
 0.0.0.0. l.0.0.0 |   |    0.0.0.0. l.0.0.0
```

For more information, see "STATUS REPORTING" on page 6-5.

Elapsed Time

The Elapsed Time contains approximately the total number of hours the bridge has been on since it was manufactured. On the front panel, [SHOW] [FUNC] [SPECIAL] [ENTER] followed by [↓] gives:

```
 ELAPSEd
 Hr   1234
```

Serial Number

The Serial Number contains the serial number that is stamped into the rear panel of the bridge. On the front panel, [SHOW] [FUNC] [SPECIAL] [ENTER] followed by [↓] [↓] gives:

```
 SEr  nUn
 54321
```

ROM Version

The ROM Version contains the revision level of the bridge's firmware. On the front panel, [SHOW] [FUNC] [SPECIAL] [ENTER] followed by [↓] [↓] [↓] gives:

```
 rOn UErS
 AA 123
```

Options

The Options contains a string showing optional internal hardware or firmware installed in the bridge. On the front panel, [SHOW] [FUNC] [SPECIAL] [ENTER] followed by [↓] [↓] [↓] [↓] gives:

```
 OPti onS
 E - - - - - - -
```

Showing the Special Set on Remote Devices

On remote devices, SH SP gives:

```
STATUS       MAU=0 MSS=0 EXE=0 RDY=0
                   PON=1 URQ=0 CME=0 ONR=0
ELAPSED      TIME=1234 HRS
SERIAL       NUMBER=654321
ROM          VERSION=AA123
OPTIONS      TYPE=E
```

WORKING WITH FILES

This section describes file naming conventions, how to list files currently stored in the bridge and how to add and delete them.

File Names

In order to distinguish one file from another, each file must have an identifier. The AH 2500A does this with an identifier containing a file type followed by a file name. For parameter sets, the file type is the same as the parameter set type. The allowable file types are Basic, Gauge, Baud, Bus and Program.

The file name uses only numerals and has from one to eight digits. The file name is stored as a string which means that "3" is not the same file name as "003". Examples of allowable file identifiers are: BASIC 0, GAUGE 34, BAUD 1, BUS 12345678 and PROGRAM 250. A file name of "0" is special and means that the file is permanently stored in ROM. For files in EEPROM, the file name can be anything other than "0".

Listing the File Names

Since one can not be certain what file names have been stored, it is essential to be able to get a list of those files that are currently in the bridge's EEPROM memory. The DIRECTORY command does this. On the front panel, press [DIR] [ENTER] and see:

```
   GAUGE
     I
```

press [↓] and see:

```
   bASIC
     I
```

press [↓] and see:

```
   bAUd
     I
```

press [↓] and see:

```
   bUS
     I
```

press [↓] and see no change, then press [ENTER] and see:

```
   rEAdY
```

You have displayed the four parameter files in the EEPROM memory that were shipped with the bridge. There is one of each type of file. As discussed in "Using Power-on Parameter Files" on page 3-10, these happen to be the four files that will be read following power-on. (Remember that files may have been changed or added to since you received the bridge. This could make the directory listing totally different from what is shown above.)

If you have a lot of files, you may want to limit the types that the DIRECTORY command reports. You can do this by adding the desired file type following the DIRECTORY command. For example, the DIRECTORY GAUGE command will list only the Gauge parameter types.

If there are no files of the type you specify, then the message below appears:

```
   FILE not
   Found
```

The Permanent Files

The DIRECTORY command only shows the files stored in the EEPROM memory; not any stored in the RAM or permanent memory. There are four permanently stored files with the names: GAUGE 0, BASIC 0, BAUD 0 and BUS 0. When the bridge is first purchased, these files have exactly the same contents as those displayed with the DIRECTORY command above. See "Power-on Parameter Files" on page 3-2 for an explanation of how these two collections of files are used by the bridge.

Adding Files

Files are created with the STORE command. To create a new file, the desired parameters must first exist in one of the current parameter sets. The current parameter sets always contain usable parameters that can serve as a starting point. To try an example, issue the command [FUNC] [ALTERNATE] [3] [ENTER]. This will change the alternate parameter in the current Gauge set from 0 to 3. Now issue the command [FUNC] [STORE] [GAUGE] [3] [7] [ENTER]. You have created a new file with the name GAUGE 37. Figure 3-1 on page 3-2 shows this pictorially. If you issue a DIRECTORY command and then step through the names, you will find a new entry:

```
   GAUGE
    37
```

The contents of this file are identical to those in the current Gauge set since that is where they were copied from.

A Program file is added in the same way. A current program must exist before the STORE command is issued.

Deleting Files

Suppose you want to delete the file you just created above. Issue the command DEL GAUGE 3 7 ENTER. If you again issue a DIRECTORY command and then step through the names, you will find that your new entry has vanished from the list.

If you want to delete all files of a given type, you can do this by adding the desired file type following the DELETE command. For example, the DELETE BUS command will delete all the Bus parameter files in the EEPROM. Whenever you try to delete more than one file, you will get an "Are you sure?" prompt. On the front panel this looks like:

```
┌─────────────────────┐
│   ArE  YOU          │
├─────────────────────┤
│   SUrE              │
└─────────────────────┘
```

If you want to continue with the operation, you must answer "yes" by pressing the YES key on the front panel. Pressing any other key is interpreted as "no".

WORKING WITH FILE CONTENTS

Showing the Contents of a File

In "Exploring a List with the SHOW command" on page 2-5, you learned how to use the SHOW command to examine parameters both individually and in a current parameter set. The form of the SHOW command that you used there examined parameters only in the current parameter sets. This section shows how to examine parameters in any file.

The form of the SHOW command that will display parameter files or programs stored in files is:

SHOW [BASIC, GAUGE, BAUD, BUS
                    or PROGRAM [*filename*]]

If the *filename* is omitted, this command reduces to that used to show the current parameter sets.

Issue the command SHOW GAUGE 1 ENTER. Use the ↓ key to see the entries in this GAUGE 1 parameter file. Notice that one of the parameter entries is:

```
┌─────────────────────┐
│   Al trnAtE         │
├─────────────────────┤
│   0                 │
└─────────────────────┘
```

Now issue the command SHOW GAUGE ENTER. Use the ↓ key again to look at the entries in this current Gauge parameter set. Notice that one of the parameters is:

```
┌─────────────────────┐
│   Al trnAtE         │
├─────────────────────┤
│   3                 │
└─────────────────────┘
```

This is the parameter that you entered in the earlier section, "Adding Files". The differing display windows demonstrate that you really are looking at different parameter sets.

Changing the Contents of a Parameter File

A parameter file's contents can only be changed by copying them to a current parameter set, making the changes in the current set, and copying the contents back to the original file. The RECALL command will copy a file having a given file type to its corresponding current location. After making changes in the current set, the results are copied back using the STORE command. The STORE command will automatically overwrite an existing file having the same name.

For example, suppose you want to change the brightness to 9 in the BASIC 1 file. Issue the command FUNC RECALL BASIC 1 ENTER to copy the BASIC 1 file into the current Basic parameter set. Issue the command FUNC BRIGHTNESS 9 ENTER to change the brightness in the current Basic parameter set. Notice that the brightness of the display increases. Now issue the command FUNC STORE BASIC 1 ENTER to replace the original contents of the BASIC 1 file with the contents having the modified brightness. The next section will demonstrate that you have actually made this change.

Using the Contents of a Parameter File

The bridge can only act on the contents of a parameter file when the contents are copied to the corresponding current parameter set. To use the contents of the BASIC 0 file, issue the command FUNC RECALL BASIC 0 ENTER. This will cause the contents of this permanently stored file to overwrite the contents of the current Basic parameter set. Notice that the brightness of the displays decreased immediately. By issuing the RECALL command, you have overwritten the brightness of 9 that you had left in the current Basic parameter set with a brightness of 5 that was in the BASIC 0 file. The brightness change occurred immediately because the bridge is continually monitoring the values of the parameters in the current parameter sets.

Now issue the command FUNC RECALL BASIC 1 ENTER. The brightness of the displays will have increased again because you recalled the higher brightness that you stored in "Changing the Contents of a Parameter File" above.

PARAMETER SET INITIALIZATION

Using Power-on Parameter Files

When power is first applied, the bridge looks to see if there are any parameter files having a file name of "1" in the EEPROM memory. If so, the bridge will copy the contents of these files into the current locations of the same file type in RAM memory. For any parameter file types that are not found with a file name of "1", the bridge will read the permanent ROM memory where a file of each file type having a file name of "0" always exists. The bridge will copy the contents of these remaining files into the current locations of the same file type. Thus all current locations are loaded at power-on with data from files named "1" if they exist, and files named "0" otherwise.

Specifically, the BASIC 1, GAUGE 1, BAUD 1 and BUS 1 files stored in EEPROM memory will be loaded into the current parameter sets in RAM if the files exist. For any that do not exist, the corresponding BASIC 0, GAUGE 0, BAUD 0 and BUS 0 files are loaded into the current parameter sets instead.

This allows you to define your own power-on bridge characteristics simply by storing the desired power-on files with the file name "1" for each desired file type.

Figure 3-1 on page 3-2 shows a power-on example where a BAUD 1 and a BUS 1 file exists in EEPROM and are loaded into RAM. No BASIC 1 and GAUGE 1 files exist so the BASIC 0 and GAUGE 0 files are loaded from ROM into RAM instead.

The RST Command

Another way to initialize some parameter sets is with the RST command. This command initializes a number of things in the bridge and in particular it resets the current Basic and Gauge parameter sets to their power-on contents. The current Baud and Bus parameter sets are not affected.

This command is identical to the SPECIAL HALT command which can be entered from the front panel with the key sequence [FUNC] [SPECIAL] [HALT] [ENTER]. See page 33 of Appendix A, "Command Reference" for more information.

WORKING WITH PROGRAMS

The AH 2500A has the ability to create, store and execute simple programs. These are sometimes called "macros". You can create programs consisting of collections of most of the available AH 2500A commands. The bridge has no conditional instructions and therefore, any programs that are created do not have this capability either.

Purpose

The ability to create programs can help to automate simple, repetitive tasks. These programs, when used in conjunction with a logger or printing terminal, may be sufficient to eliminate the need for more complex hardware such as a personal computer or GPIB controller.

Programs are useful for automatically performing a number of sequential measurements where bridge settings are slightly different for each measurement. For example, one may want to measure each of many samples at six different voltage settings.

Another example is when multiple samples are to be measured with a sample switch. Programs allow the bridge to sequentially measure each sample position and, if necessary, to change bridge settings for each sample position. For example, each position might have a different zero error for which to compensate.

Programs are also very useful when executed as part of the power-on procedure or via an external trigger pulse or the GPIB bus GET command. These special capabilities are described later.

A more subtle but very important use of programs is to guarantee that desired results logged to remote GPIB devices are not lost. See "Receiving Every Response Message" on page 6-4.

Creating Programs

Programs are easily created by entering the command:

<u>P</u>ROGRAM <u>C</u>REATE

The bridge will respond with a special "#" prompt when the command is entered from remote devices. When entered from the front keypad the display will show:

```
┌─────────────────────┐
│  r E A d Y  P r      │
├─────────────────────┤
│                     │
└─────────────────────┘
```
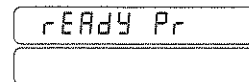
At this point, the sequence of commands that is to form the program can be entered in the normal manner. The bridge will continue to accept commands in this mode until it receives a blank line. This occurs as an [ENTER] from the front keypad, a CR from the serial port, or an EOL from the GPIB port.

If you enter an incorrect line, the only way to fix it is to start over. There is no way to edit these programs. For this reason, each individual program should be kept short. Since programs can call programs, it is preferable to create several short programs rather than one long one.

Commands Not Allowed Within Programs

Not all AH 2500A commands can be included in a program. The commands below are not allowed and will produce a syntax error as soon as they are entered.

        DELETE
        DELETE PROGRAM
        PROGRAM CREATE
        RECALL PROGRAM
        STORE PROGRAM

In addition, no STORE commands are allowed in any program that is executed with the REPEAT or CONTINUOUS qualifiers. These qualifiers are discussed later. The STORE commands are also not allowed in any subprogram that is *called* by a program that is executed with the REPEAT or CONTINUOUS qualifiers. The ⌐ nd no⌐ OPEr AbLE error message will be reported if a STORE command is detected in any program that repeats.

Nesting Considerations

Programs can contain any of the commands that execute other (sub)programs. Programs can thus be nested one within another. This can occur to a nesting depth of eight. If this depth is exceeded, a Pr G nE5⌐ Error will be reported.

Prompts Generated within Programs

Some AH 2500A commands generate prompts. Outside programs, these prompts always cause execution to stop and must be answered before the command will continue. Inside programs, most of these prompts can be answered by the program itself or they can prompt you for a response.

1. The DELETE and TEST 1.*x* commands will check the next command in the program to see if it is a YES. If so, the command will be executed. If not, you will be prompted with ARE YOU SURE?.

2. All other TEST commands that generate prompts will check the next command in the program to see if it is a STEP or SAMPLE command. If so, the STEP or SAMPLE command will be executed and the TEST will continue. If not, you will be prompted with a message corresponding to the test being executed.

3. A number of calibration related commands require the entry of passcodes. You can include a passcode in a program so that the program will run without prompting if the passcode is correct. Even though a passcode can be stored in a program, there is no way to read it even with the SHOW PROGRAM command.

    If you want a program to prompt for a passcode, you must follow the prompting command in the program with the EDIT command word. Each occurrence of the EDIT command word will cause you to be prompted for one passcode.

4. The CALIBRATE 3 command will never take a response from a program; it will always prompt you.

Saving Programs

After your program has been entered, it becomes the current program and is located in RAM. It can be executed in this location, but it will be lost if the power is lost.

The current program can be stored as a file in EEPROM memory using the command:

<p style="text-align:center">STORE PROGRAM filename</p>

where *filename* is any digit string as described in "File Names" on page 3-8. If a program file with the same *filename* already exists in EEPROM memory, it will be overwritten by the new program.

Recalling Programs

A program can be recalled from EEPROM memory into the current program location and will overwrite the current program. The value of this operation is in changing the *filename* of a program since the current program can now be stored under a different name.

A program can be recalled from EEPROM memory using the command:

<p style="text-align:center">RECALL PROGRAM filename</p>

Figure 3-1 on page 3-2 shows an example where PROGRAM 107 is recalled.

If you are unsure of what program files have been stored, the DIRECTORY PROGRAM command can be used to list them.

Showing the Contents of Program Files

The following command will report the contents of any program file:

<p style="text-align:center">SHOW PROGRAM [filename]</p>

The current program will be shown if no *filename* is entered.

On Remote Devices

The contents of a program file as reported to remote devices has a format that is virtually identical to that which was used to enter the commands from a remote device. The main difference is that only the three leading characters of each command word will be reported even though many more may have been entered. The other difference is that a space is printed in the first column of each result line where the "#" prompt was located when the commands were entered.

On the Front Panel Display

On the front panel display, the contents of each line of a program file are shown in a group of up to three windows. An additional one at the right is used to display a line number for the command. As usual, each window of a line can be shown one-by-one by pressing the ◄ and ► keys. As with remote devices, only the three leading characters of each command word will be shown. Pressing the ENTER key will abort the SHOW command at any time on the front panel.

Executing Programs

There are two fundamentally different ways of executing a program. One is to let it run unattended at its maximum rate (unless limited by the CONTINUOUS qualifier discussed below). The other is to let it run until a result is generated at which time it stops and waits for you to cause it to continue. The choice will usually be determined by whether the results are to be recorded by a remote device or read from the front panel display.

Non-Stop Mode

The following command will execute any program file:

PROGRAM [filename]

The program will execute at its maximum rate until it is finished. The current program will be executed if no filename is entered.

Single-Step Mode

The following command will execute any program file in single-step mode:

PROGRAM [filename] SINGLE

The program will stop every time it reports a query result. When it stops, pressing the STEP key on the front panel keypad will cause it to continue.

On remote devices, a "/" prompt will be printed following the query result. Entering the STEP or X command will cause the program to continue.

The current program will be executed if no filename is entered.

Repetitive Mode

Any program can be executed repetitively in single-step or non-stop modes. The number of times it is to execute can be selected. The command used is:

PROGRAM [filename] REPEAT [count]

If the REPEAT qualifier with no count is entered, execution of the program will be repeated indefinitely. If the REPEAT qualifier with a count is entered, the program will be executed the number of times specified by the count.

Continuous Mode

The time interval used to execute (sub)program commands and all query commands within a program can be specified. The command is:

PROGRAM [filename] CONTINUOUS interval

The time interval is entered in seconds to the nearest tenth. This interval is measured from the start of execution of any contained query or (sub)program command to the start of execution of the next contained query or (sub)program command.

The CONTINUOUS command qualifier is useful in two ways. First it can set the rate at which programs execute. This is helpful when too much data might otherwise be generated. Second, this qualifier can help extend the display time of results shown on the front panel. (See "PROGRAM EXAMPLE" on page 3-14 for another way to control the display time.)

Full Program Execution Command

The general form of the program execution command is given below. This includes all the options described above.

PROGRAM [filename] [SINGLE]
[CONTINUOUS interval] [REPEAT [count]]

The optional qualifiers and parameters in this command may be combined in any way.

Execution of Subprograms

The execution mode, the time interval value and the repeat count are applied only to the program whose filename was entered with these values. These values are not applied to any subprograms that this program may call. Such subprograms will use the values that were entered with the command that called the subprogram. This means that a program containing subprograms can execute with different settings of the execution mode, time interval value and repeat count for each subprogram.

Information Available During Execution

An executing program is indicated by a flashing units indicator. The LED that flashes is the one that would normally be lit to indicate the current loss units. The flash rate is about two per second.

The number of windows shown in the front panel display is dependent upon the results produced by the command that a program is executing at the moment. For example, a measurement will have two windows available and a test command will have six available. As with other results, these can be displayed one-by-one by using the ◄ and ► keys.

Aborting Programs Prematurely

The DEVICE CLEAR command can be used to abort any program prematurely. This command is described in more detail in Appendix A. "Command Reference".

Programs in the process of execution, may or may not behave like query commands. If the root program or any of the sub-programs that it calls contain a query command then the root program will be query interruptible. If no query command is contained, then the program will not be query interruptible. Thus, some programs can be aborted simply by entering another command while the program is running.

SPECIAL PROGRAMS

Two special program filenames exist in the AH 2500A. These are PROGRAM 1 and PROGRAM 2. Any program stored as PROGRAM 1 will be executed immediately after power-on. Any program stored as PROGRAM 2 will be executed whenever the GPIB GET bus command or TRG commands are received. These programs are seen in Figure 3-1 on page 3-2.

Power-On Programs

Normally the AH 2500A performs some tests of its digital circuitry immediately after power-on. This takes only a matter of seconds to complete. The bridge is then ready to execute commands. About fifteen minutes is required for the oven to warm up and stabilize before full precision measurements can be taken. These are the only events that occur if no PROGRAM 1 file exists.

If a PROGRAM 1 file does exist, it will be executed following completion of the digital circuitry tests. Since the AH 2500A program features are very flexible, there are a variety of possibilities here, some of which are:

- Use the HOLD command to delay 15 minutes until the oven has stabilized, configure the bridge to log its measurements to a remote device and then take measurements continuously.

- Perform some verifications and/or tests while the bridge is warming up. An internal calibration might be created and saved after warm-up so that the bridge is functioning optimally in its power-on environment.

- Recall parameter sets other than the default sets and then make further adjustments to the current parameter settings.

- Use the SHOW command to log current device settings for routine documentation purposes while waiting for the bridge to warm up. This is an easy way to ensure that relevant bridge settings are recorded with each day's data run.

- Zero compensation values could be measured and stored as corrections for each setting of a sample switch.

The emphasis with all possibilities such as these is that they can occur fully automatically with no operator intervention.

The TRG/GET Program

The GPIB implements a special bus command called Group Execute Trigger or GET. When a GPIB controller sends this command over the GPIB, all instruments that are addressed to listen will begin performing an operation. Thus the GET command is a convenient way of initiating simultaneous actions among a group of instruments.

An ordinary AH 2500A command also exists which performs exactly the same function as the GPIB GET command. This is the "trigger" command which has the syntax:

$$\underline{TRG}$$

Typically, in response to a GET or TRG command any instrument performs the basic function for which it is designed. In the case of the AH 2500A, this is the SINGLE command. *This is the command that will be executed if no PROGRAM 2 file exists.*

If a PROGRAM 2 file *does* exist, then its contents will be executed when a GET or TRG command is received. Thus, the existence of a PROGRAM 2 file allows the GET and TRG commands to initiate much more complex operations than would otherwise be possible.

There is no special relationship between the GET or TRG commands and the external trigger input.

TIMING IN PROGRAMS

In addition to being able to specify the time interval between the start of one execution of a program to the start of the next execution, it is also possible to introduce delays at any point within a program. These delay times can be specified by values contained within the program or they can be specified to last until an external trigger pulse is received.

Specifying a Fixed Delay Time

Execution of the following command causes the bridge to execute no further commands until the specified period of time has elapsed.

$$\underline{HO}LD \quad delay$$

The *delay* parameter is the delay time until the bridge is to execute the next command. The maximum delay time is 99,999,999 seconds. Once this command is executed, it can only complete by timing out or it can be aborted with a DEVICE CLEAR command. Additional commands may be entered following the HOLD command, but they will not be executed until the HOLD command finishes.

Since this command is capable of hanging the bridge for a long time, its execution is indicated on the lower front panel display by a decrementing timer that shows the time remaining before the command completes. For example:

```
┌─────────────────────┐
│  HOLd               │
└─────────────────────┘
┌─────────────────────┐
│              59.9   │
└─────────────────────┘
```
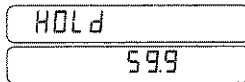
Specifying the Display Time of a Result

You can set the amount of time that a result is displayed on the front panel by a program using the HOLD command. This is done by simply putting a HOLD command *immediately* following the command whose displayed result time is to be set. Instead of showing the countdown timer on the front panel display, the bridge will show the result of the previous command instead.

Synchronizing to an External Trigger Pulse

Another version of the HOLD command described above can cause the bridge to stop executing commands until an external trigger pulse is received. This will occur if the *delay* parameter is set to zero when the HOLD command is entered. The bridge will wait indefinitely until an external trigger pulse is received. This is the *only* command that is affected by external trigger pulses.

The external trigger input is a BNC connector located on the back of the bridge. Any TTL compatible negative edge-triggered signal applied to this input will be interpreted by the bridge as a trigger signal. This input is normally at +5 volts when nothing is connected to it. It can be shorted to ground with a switch to generate a trigger signal. If triggering is done with logic devices, they must be capable of sinking at least 2 milliamperes of current at 0.4 volts or less in the low state and sourcing 100 microamperes at 2 volts or more in the high state.

Perhaps the most common application for an external trigger input is to take a single measurement for each trigger signal that is received. See "Initiating with an External Trigger Signal" on page 4-4 for an example. This is a simple but useful application of the HOLD 0 command. It can also be used within programs to trigger much more complicated command sequences.

─────────────────────────────────────

CAUTION

Voltages outside the range of -25 to +25 volts may damage the external trigger input.

─────────────────────────────────────

Handling Unexpected Trigger Pulses

You have a choice of what happens to external trigger pulses that arrive when no HOLD 0 command has been executed to receive them. The choice is to allow such pulses to be buffered or to report an error.

If the pulses are buffered, as many as 255 of them can be accumulated. Any trigger pulses that occur which would cause this number to overflow are ignored. Every time the HOLD 0 command is executed with a non-zero buffer count, the buffer count will be decremented and the HOLD 0 command will finish immediately.

Alternatively, if you choose to report an error, then each trigger pulse that is received with no waiting HOLD 0 command will cause an "E" error. This is a soft error that will be added to the next measurement result. It will be shown as an "E" in the upper right corner of the front panel display.

You choose which way the trigger pulses are handled by executing the following command:

$$\underline{\text{HO}}\text{LD} \quad \underline{\text{SP}}\text{ECIAL} \quad trigbuf$$

This causes external trigger pulses to be buffered as they come in if *trigbuf* is set to a one. If *trigbuf* is set to a zero, then no buffering occurs. The default value stored in the BASIC 0 parameter file is one.

Execution of this command clears the trigger buffer. As a result, this command should be placed at the beginning of any program that will use buffered trigger pulses. This will ensure that the program does not immediately "choke" on leftover trigger pulses.

PROGRAM EXAMPLE

There is an easy way to control the display time of results in programs of any complexity. First, create a program like:

```
SINGLE
PROGRAM
```

Store this program as PROGRAM 10. This program takes one measurement and then executes the current program once. Now use PROGRAM 10 as a subprogram in your main program in every place where you want to take a measurement. If you create a *current* program that just has the HOLD 1 command, then your main program will pause for one second after every measurement. Since it is easy to change the current program, it is also easy to change the display time even if the measurement occurs in many places and in many subprograms.

This chapter discusses the fundamental technical aspects of making precision capacitance and loss measurements. It is intended for anyone who needs to know not only how to operate the AH 2500A but also how to set it up to make precision measurements.

It is easy for an unskilled operator to make accurate capacitance and loss measurements with the AH 2500A by simply connecting an unknown impedance or manufactured transducer between its HIGH and LOW terminals. However, for anyone who wishes to design or repair transducers, or who simply wants to increase his or her level of knowledge or confidence when making precision measurements, the basic principles of operation that the AH 2500A uses to make measurements are important.

BASIC BRIDGE CIRCUITS

Unlike most other automatic capacitance meters produced today, the AH 2500A incorporates a true *bridge* in the conventional sense of the word. For general information about bridge circuits see chapters 3 and 4 of Reference 14 in the Bibliography.

Construction of the Basic Bridge

The use of specially-wound ratio transformers and a temperature-controlled fused-silica capacitor in the basic bridge circuit are major contributors to the extremely high accuracy and precision that the AH 2500A offers. The basic bridge circuit is shown in Figure 4-1.

A 1 kHz sine wave generator excites the ratio transformer which forms legs 1 and 2 of the basic bridge. Both of these legs have many transformer taps to allow selection of precisely defined voltages to drive legs 3 and 4 of the bridge. Leg 3 consists of one of several fused-silica capacitors plus other circuitry that simulates a very stable resistor. Leg 4 contains the unknown impedance. The microprocessor in the AH 2500A performs the task of selecting (or balancing) Taps 1 and 2 of the transformer and of selecting C_0 and R_0 so that the voltage present at the detector is minimized. The detector is capable of detecting both in-phase and quadrature voltages with respect to the generator voltage. This allows both resistive and capacitive components of the unknown impedance to be independently balanced. If the microprocessor is able to obtain this null (minimum voltage) condition, the unknown capacitance can then be determined since the ratio of the unknown capacitance (C_x) to C_0 is equal to the ratio of the voltage on Tap 1 to the voltage on Tap 2. Similarly, the
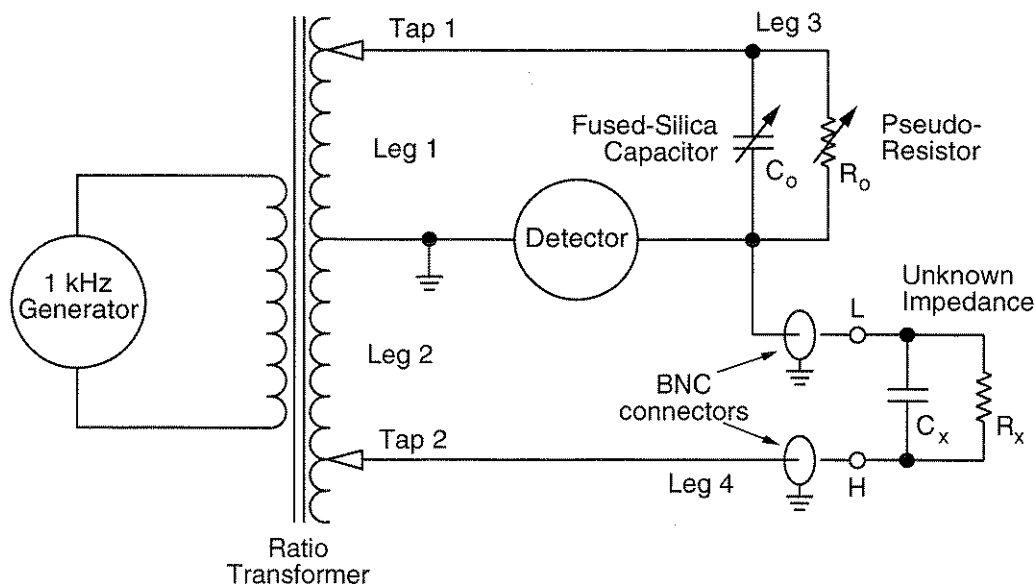
Figure 4-1 Basic bridge circuit

unknown resistance can be determined since the ratio of the unknown resistance (R_x) to R_0 is equal to the ratio of the voltage on Tap 2 to the voltage on Tap 1. The microprocessor performs these calculations and displays the capacitance and loss results. For a more detailed description of the circuitry in the AH 2500A, refer to Chapter 10, "Circuit Descriptions".

Bridge Connection Issues

The connections to the unknown capacitance marked H (HIGH) and L (LOW) in the diagram correspond to the center conductors of the BNC connectors on the rear panel of the AH 2500A. The grounds (shields) of the BNC connectors are connected to the junction of legs 1 and 2 and to the detector. Examining Figure 4-1 shows that the HIGH and LOW terminals are very different from each other. The HIGH terminal is switched directly to the ratio transformer and is a low impedance source of voltage which can range from 0.0005 to 15 volts RMS. In contrast, the LOW terminal is a very high impedance input.

The voltage present on the LOW terminal can vary greatly when the bridge is not balanced. When the bridge is balanced, the signal on the LOW terminal is a few microvolts, but broadband noise at the LOW terminal is far greater in amplitude. The greater the capacitance of the LOW cable and the lower the unknown impedance, the more this noise will tend to be shunted to ground. If one were to connect an oscilloscope to the LOW terminal with the bridge balanced, a small, noisy signal would be displayed. The HIGH terminal would display a pure one kilohertz sine wave (but this is hard to measure cleanly in practice if the voltage is small).

Because of the small signal levels present on the LOW terminal, all connections to this terminal must be very well shielded against external electrical noise. Care must also be taken to minimize mechanically generated triboelectric voltages in the LOW cable. This is done by using low-noise cable and subjecting it to as little mechanical shock and vibration as possible. The HIGH cable requires no special treatment in this respect.

THREE-TERMINAL MEASUREMENTS

In the section "Two- Vs. Three-Terminal Connections" on page 2-10, the limitations of making two-terminal measurements were explored. Since the highest-precision capacitance measurements can only be made using three terminals, the discussion of the operation of the AH 2500A will be concentrated on this method.

How the Bridge Makes Three-Terminal Measurements

The unknown impedance is measured between the center conductors of the BNC coaxial connectors on the rear panel of the bridge. The impedances between these center conductors and ground (bridge chassis) do not contribute to the measurement result. The reason for this is understood by referring to Figure 4-1.

If an impedance is added between the HIGH terminal and ground the only effect it has is to load the ratio transformer. Loading the ratio transformer is normally caused by the capacitance of the coaxial cable connected to the HIGH terminal. The ratio transformer has a sufficiently low impedance that this loading will cause a noticeable error only for long cable lengths.

If an impedance is added between the LOW terminal and ground, the effect is to shunt the detector. For normal cable capacitance, this will reduce noise at the detector. If a resistor shunts the LOW terminal, its thermal noise will add to the noise that the detector sees.

Measurements other than Three-Terminal

Two-terminal measurements can be made by simply making no connection to the three-terminal ground; the unknown is placed between the HIGH and LOW terminals. This works only for unknown impedances where both terminals are free to float with respect to ground. If either terminal needs to be grounded or related to ground through a low impedance, the measurement cannot be made.

Some capacitance bridges use four- and five-terminal measurement techniques to sense and correct for voltage drops that occur in the cables that connect the unknown to the bridge. The voltage drops are the result of measuring low impedance unknowns and/or operating at high frequencies which causes relatively large currents to flow. The AH 2500A uses only three terminals because the medium and high impedance ranges that it covers do not require four- or five-terminal techniques to obtain the required level of precision. Three-terminal measurements are much easier to make than four- or five-terminal measurements because of the reduced number of connections that are needed.

Three-Terminal Advantage over Two

To better understand the advantages of three-terminal measurements, we can represent a physical capacitor connected to the AH 2500A as three separate capacitors as shown in Figure 4-2.

The direct capacitance C_{HL}, which appears between the HIGH and LOW terminals is the desired unknown three-terminal capacitance combined with whatever undesired stray capacitance may exist. The capacitors C_{HG} and C_{LG} represent the capacitance of the unknown capacitor plates to surrounding objects (such as the capacitor case and ground), of the coaxial cable center conductor to its shield, and of the

C04
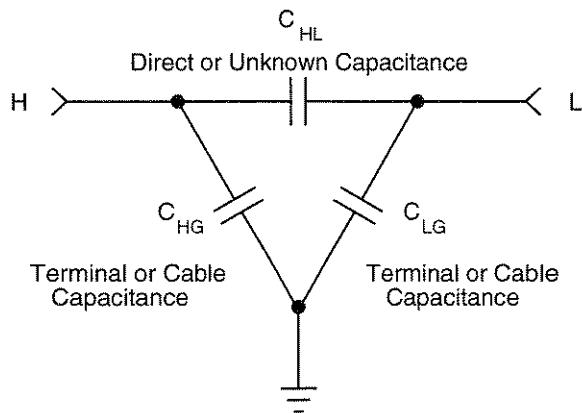
Figure 4-2 Simple three-terminal capacitor model

center of the coaxial connector to ground. As we saw earlier, the stray capacitance does not affect the measured value of C_{HL} when three-terminal measurements are made.

Now consider what happens when the three-terminal measurement configuration is converted to a two-terminal measurement configuration by connecting the LOW terminal to ground. This eliminates C_{LG} and puts C_{HL} and C_{HG} in parallel so that two-terminal measurements cannot separate the two capacitances. C_{HG} contains stray capacitance caused by surrounding objects and also capacitance contributions from the coaxial cable that are proportional to the cable length. Therefore, C_{HL} cannot be measured accurately, unless it is much larger than C_{HG}. This is a very serious limitation to precise measurement.

NOTE

*One of the most important consequences of this need to minimize C_{HG} is the choice and use of connecting cables. **Precision** three-terminal measurements are never, never, never, made with cables or structures that provide anything other than 100% shielding. This means, for example, that such measurements must never use clip leads or unshielded banana terminals even if only at the end of a coaxial cable. This also means that the quality of the shielding on any cable used should be explicitly determined by measuring the peek-through capacitance with your AH 2500A. The result should be zero.*

Three-Terminal Construction Considerations

Figure 4-3 shows an ordinary two-terminal capacitor. Figure 4-4 shows a shield that was added to the two-terminal capacitor to make it three-terminal. The second figure illustrates that the shield completely surrounds the connections to the HIGH and LOW terminals of the bridge from the three-terminal capacitor. Although it is important to shield the LOW terminal connection from electrical noise, the primary purpose of the shielding is to isolate the HIGH and LOW

connections from each other. Any breaks in the shield that are sufficient to allow conductors connected to the LOW terminal to see conductors connected to the HIGH terminal (other than across the plates of the unknown capacitor itself) will create an undesired capacitance that adds to the measured value of the unknown capacitor, causing the measured value to be greater than the actual value. Changes in the physical geometry of the measurement system that affect the values of C_{HG} and C_{LG} (for example different cable lengths) will, ideally, have no effect on the measured value of the unknown capacitor. Changes in the internal geometry of the measurement system that affect the direct capacitance will be measured.
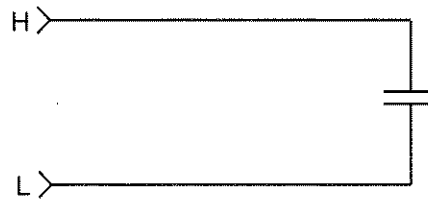
Figure 4-3 Common two-terminal capacitor
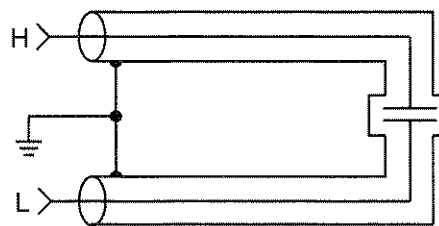
Figure 4-4 Ideal three-terminal capacitor

These internal changes can occur not only in the area and/or separation of the capacitor plates, but also in the shield geometry in a way that changes the direct electric field. They can also occur in the chemical nature or the physical geometry of the dielectric in which the direct electric field exists. The shield can even be configured to come between the capacitor plates so that only a small aperture remains in the shield. This would allow the direct capacitance to be made arbitrarily small.

Similar considerations also allow the loss associated with the direct capacitance to be limited to the loss that is actually part of the unknown capacitance. This is important when measurements of dielectric properties are being made. The insulating materials which are necessarily a part of the measurement setup (for example the polyethylene in the coaxial cable) must not contribute to the measured value for the direct loss. Conceptually, this is simply a matter of keeping undesirable dielectrics out of the field of the direct capacitor, but practically, it places constraints on the design of three-terminal capacitors and transducers. Figure 8-6 on page 8-3 shows an example of such an undesired dielectric.

INITIATING MEASUREMENTS

The rest of this chapter assumes that you are familiar with Chapter 2, "Basic and Initial Operation".

Taking Measurements One at a Time

The command that initiates a single measurement from the front panel or a remote device is:

SINGLE or Q

This command accepts no parameters. The operation of the SINGLE command from the front panel is discussed in "MAKING SINGLE MEASUREMENTS" on page 2-6. In addition to the SINGLE command, pressing only the letter Q (for Question) without the return key will start a measurement on an RS-232 device. This is more convenient for making repeated measurements.

Initiating with an External Trigger Signal

The simplest way to remotely trigger a new reading from the AH 2500A is by using the external trigger input. The bridge does not default to this mode of operation but it is easily set up so that an external trigger signal causes a reading to be taken. To do this requires that a very simple program be written and executed. The example below shows how:

```
>PROGRAM CREATE
#HOLD 0
#SINGLE
#
>STORE PROGRAM 10
>PROGRAM 10 REPEAT
 C=843.318 PF L=0.03721 NS
 C=843.320 PF L=0.03719 NS
 C=843.323 PF L=0.03721 NS
```

After the program was created, it was saved as a PROGRAM 10 file. The program was then executed repetitively. The HOLD 0 command waits indefinitely for an external trigger pulse to occur. A measurement result will be reported by this program for each pulse that is received. This is a simple application of the HOLD 0 command. It can also be used within programs to trigger much more complicated command sequences. See "WORKING WITH PROGRAMS" on page 3-10 and especially "Synchronizing to an External Trigger Pulse" on page 3-14 for a more detailed description of the external trigger input and of the HOLD 0 command.

Initiating with a TRG/GET Program

A new measurement can also be initiated with a TRG command or a Group Execute Trigger (GET) from the GPIB. One way to do this requires that no PROGRAM 2 file exists. If this is the case, then one measurement will be taken every time a GET from the GPIB or a TRG command is issued.

The other way to use the TRG/GET commands requires that a very simple program be written and executed. The example below shows how:

```
>PROGRAM CREATE
#SINGLE
#
>STORE PROGRAM 2
>TRG
 C=347.312 PF L=0.01021 NS
>
```

After this one-line program was created, it was saved as a PROGRAM 2 file. That special file is executed every time a TRG command or a GET from the GPIB is issued. The advantage of this more complicated method is that you can write the program to do many other things. See "WORKING WITH PROGRAMS" on page 3-10 and especially "The TRG/GET Program" on page 3-13 for more information.

Taking Measurements Continuously

In the continuous reading mode, the bridge takes measurements repetitively until temporarily interrupted with a command input or permanently stopped. The discussion below assumes that you are familiar with "MAKING CONTINUOUS MEASUREMENTS" on page 2-7. To put the bridge into continuous mode, enter the command:

CONTINUOUS [*interval*]

where the optional *interval* parameter can be entered as seconds or as seconds and tenths of seconds. If *interval* is zero, readings are taken at the maximum rate. This maximum rate is determined primarily by the setting of the averaging time which is discussed in "Averaging Time" on page 4-6.

The *interval* parameter represents the time from the beginning of one measurement to the beginning of the next measurement. As a result, this time must be chosen to be long enough so that it exceeds the time that the bridge requires to take a reading. If this is not the case, then readings will be taken at the maximum possible rate just as if no *interval* parameter had been entered. The maximum *interval* that can be entered is 99,999,999 seconds.

The action of the CONTINUOUS command is stopped with the command:

SINGLE or Q

In other words, the CONTINUOUS command enables continuous measurements and the SINGLE or Q command disables them. If continuous reading mode is active, issuing the SINGLE or Q command will cause a reading to be taken and will abort continuous measurements.

MEASUREMENT SPEED VS. MEASUREMENT FLUCTUATION

In most applications it is desirable not to spend any more time than necessary to make a measurement. In some applications, it is critically important to make measurements as fast as possible. The AH 2500A has been optimized to make the fastest measurements possible within several fundamental constraints.

First, the operating frequency of the AH 2500A is 1 kHz. To make a very fast measurement still requires a minimum number of complete cycles of the 1 kHz test signal. Under ideal conditions, the bridge can report measurements so fast that it takes only 40 cycles of the test signal. This is assuming that the ratio-transformer taps have already been set-up correctly.

If the ratio-transformers need to be balanced, then a number of relay settling times are involved so that several tenths of seconds are required. The first measurement of an unknown will require a minimum of about 0.3 to 0.5 seconds, most of which is used to balance the bridge.

Beyond these issues, there is a fundamental trade-off between the amount of fluctuation in the measurement results and the time taken per measurement. To reduce the effects of unavoidable input-amplifier noise and thereby to get the highest-quality measurements requires averaging (internally or externally) as many measurements as is practical over a period of time.

Understanding what the Bridge may do During a Measurement

Bridge Balancing Algorithms

The simple diagram of the basic bridge shown in Figure 4-1 suggests that the process of balancing the bridge is a simple one, but this is not the case. Bridge firmware does not control a straight-forward dual slope detector, it controls many decades of transformer taps of a true ratio-transformer bridge. Complex algorithms are required to balance the resistive and reactive components of the unknown over greater than twelve orders of magnitude. This is especially difficult when the unknown may be changing, may contain high noise levels or may exhibit negative resistive and/or reactive components. The balancing algorithm must always respond with a meaningful, precise measurement result or it must identify why a precise measurement is not possible and reply with an error message. Instead of meaningless results, the AH 2500A has been designed to report either valid measurements or relevant error messages when the unknown differs from what the bridge expects to measure. All the while, measurements must occur as quickly as possible.

The many possible outcomes of an attempt to make a measurement cause the amount of time required to make a measurement to vary. The time variation can range from under 40 milliseconds to about 1000 seconds. Two factors account for

most of the variation. One factor is the averaging time and the other is the use of cold-starts versus warm-starts.

Cold-Start

The terms "warm-start" and "cold-start" refer to the degree to which the bridge has previously been balanced. A cold-start means that the bridge is so far out of balance that the balancing algorithms must be started from the beginning. This can add as much as 0.4 seconds to the time needed to make a measurement.

Warm-Start

A warm-start means that the bridge is very close to being in balance so that the preliminary work done during a cold-start is complete. A warm-start requires from zero to 0.2 seconds to perform. At the beginning of every measurement, the AH 2500A attempts a warm-start. If a warm-start does not succeed, it reverts to performing a cold-start. The total measurement time consists approximately of the sum of the cold or warm-start times plus the averaging time.

Measurement Times

For time-critical applications, it is important to realize that the balancing algorithms of the AH 2500A can take varying amounts of time to execute depending on the behavior of the unknown. If a problem occurs while a measurement is in progress such that the unknown prevents the bridge from balancing, the measurement attempt is aborted and a second attempt is made using a cold-start. If the second attempt fails, an error message is displayed and the time spent on the two attempts is typically on the order of a second. If the second attempt succeeds, a measurement is displayed and the incident will be transparent to you except that the measurement time can be at least twice as long as the selected averaging time.

For well-behaved unknowns, the measurements will be performed in the normal time period nearly 100 percent of the time. If the unknown is slowly changing, a different transformer tap will occasionally need to be selected. Selecting a different transformer tap may cause the current measurement to be aborted, causing a cold-start followed by a normal measurement. When this occurs, the normal measurement time is increased by the time taken for the cold-start and the partially completed measurement. This occurs infrequently, but is apparent, particularly for short averaging times and is considered normal behavior.

When measuring noisy or poorly behaved unknowns, an occasional abnormally long measurement time may occur more frequently. Noise can introduce a spike or burst that causes the bridge to briefly appear unbalanced thereby requiring a cold-start. In summary, changing or noisy unknowns may require more or less than a normal measurement time to display a result and you should consider this to be normal bridge operation.

Averaging Time

Averaging time is a measurement parameter that reduces the effects of random noise by internally averaging the noise over a period of time. Any high gain amplifier (like the detector connected to the LOW terminal of the AH 2500A) generates random noise at its input. Amplifier noise is unavoidable and is the main reason for providing control over the averaging time. *Externally* generated noise can also be reduced by averaging if it is random.

Because of noise, measurements taken with a short averaging time will fluctuate more than those taken with longer averaging times. If the noise is truly random, the amount of variation in the measurements is inversely proportional to the square root of the time over which the results are averaged. Therefore, a four second averaging time gives a result that has half the variation from measurement to measurement as one taken with a one second time. Unknowns whose actual value changes slightly during the measurement time will show a measured value that is the average of the actual value during this time. This is true only for small changes in the unknown's value; changes which are large enough to require selecting a different ratio transformer tap may cause the measurement to be re-started or aborted.

You may ask why you should use the averaging abilities of the AH 2500A rather than those of the computer that you may be using to capture data from the bridge. Indeed, for longer measurement times, using your computer may be useful. However, for shorter averaging times, the AH 2500A spends proportionately less time internally in the process of sampling and averaging the noise that it sees on the LOW terminal. Proportionately more time is spent preparing to take a measurement and in reporting the results. Thus the best results will always be obtained when the bridge is set to a longer averaging time so that it spends proportionately more of its time sampling its input. Due to this effect, the variation in the measurement results improves more rapidly than the inverse square root of the measurement time for short times.

Changing the Averaging Time

The length of time during which data is being measured before being displayed may be selected with the following syntax:

AVERAGE *averexp*

Where the possible values of *averexp* (average time exponent) are listed in Table 4-1. The AVERAGE command is so named because the bridge takes multiple internal sampling readings during this time and averages them to reduce the effects of noise before printing or displaying the result. The number of samples taken and the time per sample depend on *averexp* as shown in the table. The averaging time is the product of the number of samples and the sample time. (The

Table 4-1 Measurement times

Aver-exp	Number of Samples	Sample Time	Approximate Warm-start Measurement Time
0	1	0.01 sec.	0.04 sec.
1	1	0.05	0.08
2	1	0.10	0.14
3	2	0.10	0.25
4	4	0.10	0.5
5	8	0.10	1
6	16	0.10	2
7	32	0.10	4
8	64	0.10	8
9	128	0.10	15
10	256	0.10	30
11	512	0.10	60
12	1024	0.10	120
13	2048	0.10	250
14	4096	0.10	500
15	8192	0.10	1000

term "sample" as used here is totally different from that associated with the "sample switch".)

Except for short averaging times, the warm-start measurement time is about 25% greater than the averaging time. This is true when repeated measurements are made on fairly stable unknowns with tracking mode (discussed below) disabled. Table 4-1 shows the approximate warm-start measurement times in seconds which result from the various averaging time exponents.

For the first measurement on an unknown, and for changing unknowns, the minimum time between measurements is longer than the warm-start time by as much as 0.4 seconds. This is a result of having to perform a cold-start as discussed in "Cold-Start" on page 4-5. Thus the *expected* total measurement time can be as much as 0.4 seconds longer than the warm-start time. Unusual unknowns may cause the bridge to do additional error checking. This could make the *actual* total measurement time exceed the *expected* time.

Notice that increasing *averexp* by 1 approximately doubles the measurement time. Increasing *averexp* by 2 approximately quadruples the measurement time and therefore reduces the fluctuation in the measurement results by a factor of two.

The default value of *averexp* stored in the GAUGE 0 parameter file is four which gives a warm-start time of 0.5 second.

Forcing a Cold-Start to get Highest Reliability

Since a cold-start requires a significant amount of time to perform, the bridge avoids doing it for the shorter averaging time settings. If the bridge senses that a well-behaved unknown impedance is connected and the averaging time is low, a cold start is done only on the very first measurement. Another cold-start will never be performed as long as the unknown appears to be well-behaved. In practice this works fine, but in theory, rare problems could occur.

The worst possibility is when a LOW to ground short occurs sometime following a cold-start and with an otherwise well-behaved unknown. The bridge still appears to be balanced since the input voltage has remained near zero. This will be true even if the unknown changes or is removed provided that the short is not interrupted. The bridge is "fooled" into reporting the same readings as before the short occurred even though the capacitor may have been removed.

This problem can be avoided by forcing the bridge to perform a cold-start for every measurement. Setting *averexp* to be greater than or equal to 7 will force a cold-start to be performed for every measurement.

Unfortunately, this solution has more than just a time penalty. Performing a cold-start requires that relays be opened and closed for every cold-start. Being mechanical components, relays have a lifetime that is inversely-proportional (statistically) to the number of contact closures. It is therefore not desirable to arbitrarily perform *very large* numbers of cold-starts without some justification. In practice, you will not often find that justification.

Auto Switching to High Speed

The AVERAGE TIME command allows you to set the AH 2500A either to a long measurement time to get a high quality reading or to a short measurement time to allow taking fast readings. You have to decide what setting will give the most information about your unknown. If your unknown is sometimes fairly stable and sometimes changes much more rapidly, it will not be possible to choose an averaging time that works well in both situations. If the average time is long, you will lose most or all data from the unknown while it rapidly changes. If the averaging time is short, you will be deluged with a lot of readings, all of which are lower resolution. As discussed in "Averaging Time" on page 4-6, using a computer to average these readings has disadvantages. What you need is a way to automatically shorten the averaging time if your unknown starts changing rapidly.

Using Tracking Mode

Tracking mode is an AH 2500A feature that allows measurement of fairly rapidly changing or drifting unknowns. When rapid change occurs, long averaging times that are normally used to cancel noise and provide better accuracy in the measured result are not desirable. Enabling tracking mode causes the bridge to monitor the rate of change of the unknown. If the rate exceeds a preset amount, the bridge will override the current averaging time setting and begin taking measurements at a rate of about 25 measurements per second to track the changing unknown at a lower resolution. The bridge will continue this override as long as the unknown continues to change more rapidly than the preset amount. As soon as the unknown stops its rapid change, measurements will again use the current average time setting. Tracking mode can be entered no matter what the averaging time has been set to. The bridge tries to automatically provide the best of both worlds.

The syntax for the command to enable tracking mode is:

$$\text{TRACK } threshold$$

where the *threshold* is an integer ranging from 0 to 5. A zero value disables the feature. The *threshold* is a measure of the maximum rate at which the capacitance can change before high speed tracking takes over. The smaller the *threshold*, the more likely the tracking algorithm will be to take over and the less likely it will be to revert back to the current averaging time setting. The *threshold* equals

$$2\log\frac{dC}{dt} + k$$

where dC/dt is the maximum allowable rate of change of the capacitance and k is a constant for a given measurement configuration. Thus, incrementing the *threshold* by one increases the rate at which the capacitance may change without tracking occurring by a factor of approximately 3. Increasing the *threshold* by two increases this rate by a factor of 10. The *threshold* covers a range of 100.

It would be nice to define a value for k so that the *threshold* could be related to specific numeric values of dC/dt. Unfortunately, k depends in a complicated way on the impedance value being measured, on the capacitance to ground of the LOW terminal, and other things. The *threshold* is therefore only a relative parameter.

Track mode is disabled with either of the following commands:

$$\text{TRACK } \underline{\text{HALT}} \quad \text{or} \quad \text{TRACK } 0$$

The track mode works in either single or continuous modes. If you are reading the front panel and the data is not being written down, then the continuous mode is likely to be the best choice. If there is no computer available to rapidly trigger single readings then the continuous mode is the only way to generate the high data rate that the track mode can provide. On the other hand, if a computer has control then it may be

very desirable to program it to trigger each reading individually. Otherwise, in continuous mode it could be overloaded with an unexpected burst of data if the unknown begins to change too rapidly.

Track mode will follow a rapidly changing unknown at the bridge's highest rate unless the unknown either stops changing rapidly or it changes by a large ratio relative to the value at which the tracking started. If the rapid change stops, the bridge will take subsequent readings using the selected averaging time. If the unknown changes by a large capacitance or loss ratio, the bridge will take one measurement with a cold-start to make some internal adjustments and will then continue taking readings at the highest rate. This event will interrupt the high speed tracking by adding about 0.5 second to one of the readings.

When the bridge switches to making measurements at a high rate, this is indicated with a "ь" in the upper right corner of the front panel display and with a "T" message to remote devices.

The default *threshold* in the GAUGE 0 parameter file is zero.

REJECTING INTERFERING SIGNALS

Usually noise problems are due to input amplifier noise or apparently random noise from external sources. However, the most insidious source of noise is that from an externally generated interfering signal whose frequency is very close to the 1 kHz sine wave that the AH 2500A uses. If the interference is close but not identical in frequency to that of the bridge, beating effects can occur that cause measurement results to vary in a regular, periodic manner. If the interference is so close in frequency to that of the bridge that the phase difference between the two signals does not change significantly while a sequence of measurements is being taken, then a constant error may exist in every measurement in the sequence. This is the worst case because there is no clue in the measurement results that there is a problem.

You might think that it is improbable that an interfering signal could have a frequency that is nearly identical to that of the AH 2500A, but that is not the case.

Interference from Other Instrumentation

One kilohertz is a very popular test frequency. Many other impedance measuring instruments offer this frequency. If it is a modern instrument, the signal is likely to be derived from a quartz-crystal oscillator (as is the AH 2500A's) and will therefore be very accurate. This high accuracy means that such an interfering signal will be very close in frequency to that of the AH 2500A.

Just because there is another nearby signal with nearly the same frequency does not automatically pose a problem—there must still be a way of coupling it into the AH 2500A. There are many ways this can happen. One interesting example occurs with some formerly popular ratio-transformer

based capacitance bridges. These have fairly large ratio-transformers that are not well shielded. These transformers will radiate significant levels of magnetic EMI at their test frequency. Magnetic interference at 1 kHz is harder to shield against since it easily passes through non-ferrous metals. Such interference can be picked up by loops in any circuit even if they are formed of coaxial cable.
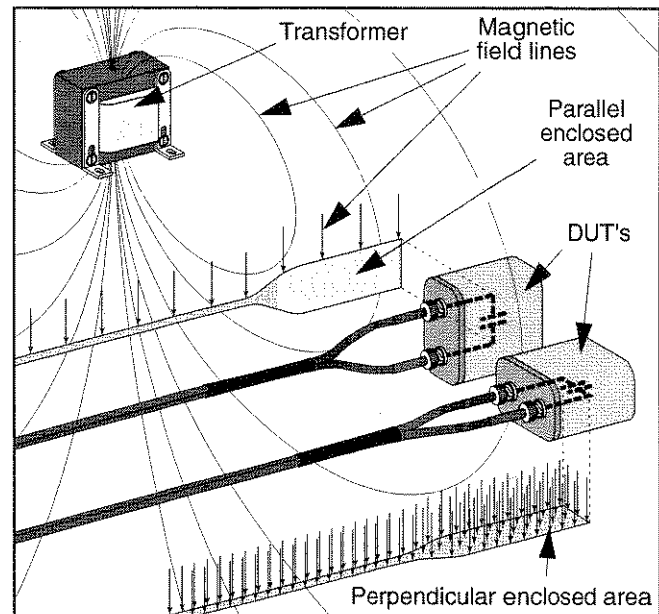
Figure 4-5 Magnetically-induced pickup into enclosed areas that are parallel and perpendicular to the field.

Interference from Power Lines

Most power line interference is obviously worst at 50 or 60 Hz. This is so far from 1 kHz that it is not a problem in any reasonably well shielded configuration. However, because so much power is involved, even higher harmonics of the fundamental power frequencies can be a problem. The 20th harmonic of 50 Hz is exactly 1.000 kHz. The 17th harmonic of 60 Hz is exactly 1.020 kHz. Since the frequency of national power grids is very precisely controlled, a 1.000 kHz harmonic from 50 Hz power lines is an especially serious potential source of interference. Since power lines are everywhere in a laboratory, the possible prospects for coupling an interfering harmonic into a bridge are many.

Minimizing the Coupling of Interference

The best way to avoid interference problems is not to couple the interference into the bridge in the first place. The ways of accomplishing this are:

1. Turn off the interference source.

2. Put a significant distance between the interference source and the bridge.

3. Reduce the coupling by shielding. Three-terminal construction should virtually eliminate any electrostatic

coupling to an interference source. Shielding of magnetic interference is more difficult at one kilohertz. It requires carefully designed shielding using high-permeability ferro-magnetic alloys.

4. If the coupling is magnetic, reduce the enclosed area of the measurement circuit and orient the enclosed area so it is parallel to the field. Figure 4-5 shows a power transformer and some typical magnetic field lines that radiate from it. Two DUT's are located within this field at a point where the field lines are vertical. The field lines will penetrate the DUT's and the shielded coaxial cables.

The measurement circuit of the DUT on the right forms a loop whose enclosed area is oriented roughly perpendicular (normal) to the direction of the field lines. This area is shown in an extracted form below this DUT with a *large* number of field lines passing through it.

The measurement circuit of the DUT on the left forms a loop whose enclosed area is oriented roughly parallel to the direction of the field lines. This area is shown in an extracted form to the left of this DUT with a *small* number of field lines passing through it.

The interference voltage induced in these measurement circuits is proportional to the number of field lines passing through their enclosed areas. The measurement circuit of the DUT on the right therefore picks up much more magnetic interference from the transformer than the DUT on the left. The figure demonstrates that the induced interference voltage can be reduced by *constructing* the measurement circuit so as to minimize the enclosed area and by *orienting* the circuit so that it intercepts as few field lines as possible.

5. If the above steps are not sufficient, then use the Alternate feature of the AH 2500A explained below.

Changing the Alternate Period

The AH 2500A has a feature which allows it to reject signals from external sources generated at the same or similar frequency and phase as the one kilohertz sine wave test signal that the bridge uses. The AH 2500A does this by periodically alternating (or reversing or commutating) the applied test signal to make it distinguishable from the synchronous interference signal. This ability to reject synchronous signals is enabled with the following command:

<u>AL</u>TERNATE *altexp*

The possible values of *altexp* range from zero to seven with zero being used to disable this feature. The time periods that may be selected to perform a complete reversal cycle are listed in Table 4-2.

The Alternate time period is the shortest when *altexp* is set to one and increases by factors of two as *altexp* is incremented. The selectable range of times for a complete Alternate cycle is from 0.25 to 16 seconds. However, the Alternate time can not exceed the averaging time and thus will automatically be reduced by the bridge to the current value of the averaging time if you try to set it otherwise. The Alternate feature is not available for *averexp* values of 0, 1, or 2. If an *averexp* value of 3 is chosen, an *altexp* value of 0.25 seconds will automatically be used no matter what non-zero value you have selected *altexp* to be. These dependencies of the Alternate time period on *averexp* will not appear in the value of *altexp* reported by the SHOW command, the only effect is on the Alternate time period actually used during measurements.

Table 4-2 Alternate time periods

Altexp	Alternate time period
0	Alternating Disabled
1	0.25 Seconds
2	0.50
3	1.00
4	2.00
5	4.00
6	8.00
7	16.00

To get the best rejection of interfering signals, the Alternate time period should be chosen to be short in comparison with significant changes in phase of the interfering signal relative to the AH 2500A's test signal. The Alternate feature is only effective when the interfering frequency is so close to the AH 2500A's frequency that the period of any beat effects is comparable to or longer than the averaging time. This means that the 1020 Hz harmonic of a 60 Hz power line is just outside the range of frequencies that can be rejected by the Alternate feature even for the shortest possible setting of the Alternate time period. However, all measurements use an 0.1 second basic sampling period which rejects 20 Hz beat frequencies. This also causes rejection of the 950 and 1050 Hz odd harmonics from 50 Hz power sources.

Although the Alternate feature has no known detrimental effects on the quality of the measurements, choosing a longer Alternate time will reduce whatever effect might possibly be observed.

The default *altexp* in the GAUGE 0 parameter file is zero.

DECIDING WHICH UNITS TO USE

You have some ability to select the units in which the measurement results are presented, especially in the case of the loss units. Capacitance is always displayed in units of picofarads unless Reference result mode is enabled in which case units of percent are available also. This mode is discussed in "Reference Result Mode" on page 5-2.

Five different loss units are normally available. When Reference result mode is enabled, units of percent deviation are also available. Understanding how the five units of loss are related to one another will help you to choose the most appropriate units for a given application.

Before getting into descriptions of each of the available units, it is important to understand that *all* capacitance and loss units on the AH 2500A fall into one of the two major categories discussed below.

Series Versus Parallel Circuit Models

Real capacitors are not perfect. Real capacitors contain loss mechanisms that cause the parallel resistive component of their impedance to be less than the infinite value expected of an ideal capacitor. The leads and plates of capacitors (superconductors excluded) always contain some resistance that appears in series with the actual capacitance. The dielectric material in which the field between the capacitor plates exists also contains one or more loss mechanisms that appear in parallel with the actual capacitor. A model of a real capacitor might appear as shown in Figure 4-6 which contains both the series and parallel resistances.
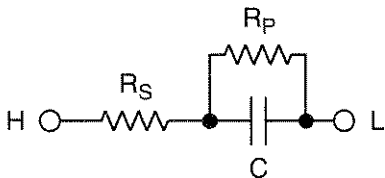
Figure 4-6 Capacitor model with both series and parallel resistances.

However, a single-frequency bridge has no way of separately measuring these two resistances with a single measurement. A bridge must report either a series resistance or a parallel resistance but not both. Fortunately, it is possible to treat both of these resistances as if they were a single series resistance or as a single parallel resistance. These equivalent circuits are shown in Figure 4-7 and Figure 4-8.

The hardware of the bridge makes its measurements in the form of parallel capacitance and loss. If you request that the results be reported in the series form, the bridge converts from parallel capacitance (C_P) and resistance (R_P) to series
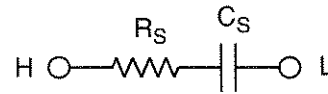
Figure 4-7 Capacitor model with loss represented by a single series resistor.
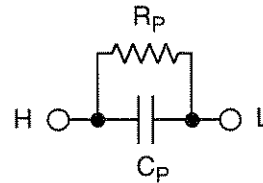
Figure 4-8 Capacitor model with loss represented by a single parallel resistor.

capacitance (C_S) and resistance (R_S) using the following equations:

$$C_S = (1 + D^2) C_P \qquad \text{Eq. 4-1}$$

$$R_S = \frac{D^2 R_P}{1 + D^2} \qquad \text{Eq. 4-2}$$

where the dissipation factor (D) is given by:

$$D = \frac{1}{\omega C_P R_P} \qquad \text{Eq. 4-3}$$

and ω is 2π times the frequency (1000 Hz). D has the same value for series or parallel configurations. Since the bridge does these conversions, you should not need to use these equations yourself. However, it is instructive to realize that the conversion is somewhat messy and non-linear.

Deciding on the Circuit Model

It is important to understand that your choice of loss units also implicitly selects either the series or the parallel circuit model. Only a choice of series resistance units will cause the bridge to report its result in series units. All other units choices will cause parallel results to be reported. It is also important to understand that choosing units of series resistance affects not only the loss units and value, but also the value of the capacitance result. The capacitance units (usually picofarads) will not change, but the value will be a series value, not a parallel value. If the loss is zero (D = 0), the series and parallel capacitance values are the same. If the loss is significantly different from zero, the series and parallel capacitance values may deviate significantly from each other.

C04

Usually, in a real capacitor, either the series or the parallel resistance dominates. Series resistance usually dominates for large capacitances and parallel resistance usually dominates for small capacitances. Thus the measurement of such a capacitor should, ideally, be chosen to give results in the form of series or parallel resistance to correspond to the nature of the actual capacitor. Measurements on capacitance standards are *always* reported using the parallel model.

Available Loss Units

The five loss units which you may select are described below. They are described in the same order as the units indicators appear on the front panel.

Conductance

Conductance (G) is a natural way to measure the loss of a capacitor because conductance is directly proportional to the amount of loss in the capacitor. The AH 2500A uses units of nanosiemens to measure conductance. The conductance is a parallel loss parameter and is the inverse of R_P. Units of nanosiemens are also the exact inverse of units of gigohms which are used to report R_P. Therefore one nanosiemen is the conductance produced by one gigohm. (The term Siemens replaces the older term Mhos).

Dissipation Factor

Dissipation factor is related to parallel capacitance and resistance by Eq. 4-3. Unlike the other parallel methods of expressing loss, dissipation factor is dependent on the capacitance value. A useful way to think of dissipation factor is as the ratio of the conductance to the capacitive susceptance (B):

$$D = -G/B \quad \text{where} \quad B = -\omega C_P \qquad \text{Eq. 4-4}$$

Dissipation factor may be thought of as the ratio of the loss to the capacitance. If the capacitance and loss are the components of a vector having an angle δ, then D is tan δ.

Dissipation factor tends to describe a property of the unknown impedance that is essentially independent of the value of the capacitance. For a given kind of capacitor construction, doubling the value of the capacitor usually doubles the conductance also. This means that the dissipation factor will tend to be constant for a given type of capacitor while the capacitance and conductance will tend to change in proportion to the size of the capacitor. This makes dissipation factor useful for describing a given *type* of capacitor and also for characterizing dielectric materials. Conductance and resistance, in contrast, are better to use when measuring a *specific* capacitor.

Like all the other loss units, the dissipation factor can have either a positive or a negative sign. If the capacitance and loss are both negative then D will be positive. D is the inverse of the quality factor Q, (Q = 1/D).

Series Resistance

As explained above in "Deciding on the Circuit Model" , selecting series resistance units gives results that differ from all the other loss unit choices in important ways. Series resistance is reported in units of kilohms.

The obvious utility of having series resistance units is in being able to measure devices whose series resistance is believed to comprise most of the total loss. In this case, it may be possible to accurately measure resistances that are not physically accessible by any other means.

Parallel Resistance

For those familiar with electronic circuitry where impedances are usually expressed as resistance measured in ohms, the most easily understood way to measure loss will probably be as parallel resistance (R_P). R_P is the inverse of the conductance ($R_P = 1/G$). The AH 2500A displays resistance in units of gigohms (1 gigohm = 1 billion ohms). Notice that units of nanosiemens are the inverse of gigohms. See the discussion in "Conductance" above for the relationship between conductance and parallel resistance.

It is important to understand that R_P as measured by the AH 2500A will not usually have the same value as that obtained from a DC resistance measurement. In fact, the value measured by the AH 2500A is likely to be much smaller, even by orders of magnitude. The reason is that the AH 2500A measures the DC leakage resistance *combined* with the loss of the capacitor. However, R_P does serve to put a lower bound on the value of the DC resistance.

Loss Vector – an Alternative to Conductance

If you desire to report your capacitance and loss results as orthogonal vectors, the AH 2500A provides units of G/ω jpF for this purpose. These units cause the measurement results to be reported as the two components of a complex admittance vector. The capacitance (or susceptance component) is still given in picofarads. Two components of the same vector should have the same units so that the loss (or conductance component) is also reported in picofarads. The phase angle between the conductance and the capacitance is 90 degrees. This is represented by "j" in complex terminology so the loss vector units are labeled as jpF rather than just pF. The magnitude of the loss vector is simply equal to G/ω.

This set of units is not labeled on the front panel. It is indicated by having both the dissipation-tanδ and series-kilohms LED indicators illuminated.

Changing the Loss Units

The units of loss are selected with the following command syntax:

UNITS *lossunit*

where *lossunit* is a number in the range from 1 to 5. The list below gives the corresponding units for the respective *lossunit* numbers. The unit abbreviations are given in the column to the right.

1 - Nanosiemens   (nS)

2 - Dissipation factor (tan δ)   (dimensionless)

3 - Series resistance in kilohms   (kΩ)

4 - Parallel resistance in gigohms   (GΩ)

5 - G/ω in j picofarads   (jpF)

To make the *lossunit* numbers easy to remember, numbers one through four are in the same order as they appear on the front panel unit indicator labels.

The UNITS command does not initiate a new measurement, but its execution will cause the previous measurement result to be *re-calculated* and reported using the new units selected. This provides a simple way to compare the results of different units settings on the same measurement. If you are not familiar with some of the available units settings, some experimentation with this command as applied to a given measurement may be helpful.

The default loss units in the BASIC 0 parameter file are nanosiemens.

COMPENSATING FOR STRAY FIXTURE IMPEDANCE

Some applications may require measuring the capacitance or loss of a device which is not directly connectable to the AH 2500A. Such a device is often called the "Device Under Test" or DUT. Often, the DUT may only have contacts rather than cables or leads with which to make connections. Even if something better than contacts exists, it will usually not be three-terminal. In such a case, a fixture is used to hold the DUT, to make connection to it and to provide the proper cabling to carry three-terminal measurement signals to the bridge. In most cases, this fixture will have a capacitance and loss (impedance) of its own. Usually, some part of this fixture impedance will contribute to any measurements taken with the DUT mounted in the fixture.

The AH 2500A offers a means of correcting the measurement result so that a constant fixture impedance is mathematically removed. This is called the "Zero compensation result mode" and is controlled by various forms of the ZERO command. This compensation mode allows you to directly *measure* the parallel fixture impedance and then to optionally remove that impedance from the measurement result. Alternatively, an impedance value for the fixture can be *entered* into the bridge rather than measured. Since the ZERO command is very similar to the REFERENCE command, both are described together in "RESULT MODES" on page 5-2 of Chapter 5, "Data Presentation".

VOLTAGE OF THE TEST SIGNAL

The AC RMS voltage applied to the unknown is largely automatically determined by the AH 2500A. The voltage used to make a measurement is reported with that measurement's results both on the front panel and on remote devices. The section "MAKING SINGLE MEASUREMENTS" on page 2-6 explains how to show this voltage on the front panel. Chapter 5, "Data Presentation" discusses the ways that the applied voltage is reported to remote devices.

Due to the nature of the technology that the AH 2500A uses, it is not possible to specify the amplitude of the 1 kHz sinusoidal voltage that is applied to the unknown in the process of making a measurement, but it *is* possible to *limit* that voltage to a maximum value.

For capacitance values below about 80 pF and unless otherwise limited, the AH 2500A will apply its maximum test signal of 15 volts to the unknown to make measurements. For capacitances larger than about 80 pF, the bridge must reduce the applied voltage in order to balance the bridge. The larger the capacitance, the smaller the applied voltage must be in order to balance the bridge. Unless otherwise limited, the bridge will always choose the largest possible voltage that will balance the bridge.

The range of capacitance that can be measured with a given voltage is listed in Table 4-3. These values are very approximate and vary significantly from one serial number to another. For some bridges, these values will be 25% higher than the table shows. The table shows ranges covering negative values because the bridge can measure negative values of capacitance and loss. These ranges cover all values between the listed limits no matter how small.

The same issues apply to loss measurements as for capacitance. The loss ranges are also shown in the table.

Limiting the Test Voltage

You can set the voltage of the 1 kHz test signal applied to your unknown to a maximum value. This does not mean that the actual applied voltage will necessarily come close to the maximum value that you specify — it could be far lower. To use an extreme example, a voltage of 15 volts might be specified, but if the unknown capacitance is near the top of the AH 2500A's range, only 0.001 volts may actually be used to measure the unknown. The command used to specify the limiting voltage is:

VOLTAGE *highest*

The *highest* parameter is the maximum AC voltage in volts RMS that the bridge will apply to the unknown. Any voltage may be entered, but the bridge will limit the maximum measurement voltage to a value equal to or below the amount specified. Table 4-3 lists the actual RMS voltages that the AH 2500A uses.

Table 4-3 Capacitance and loss ranges for the available limiting voltages.

Limit (volts)	Capacitance Range (pF)		Loss Range (nS)	
	From	To	From	To
*15.00	-8	+80	-0.4	+4
*7.50	-16	+160	-0.8	+8
3.75	-16	+160	-0.8	+8
*3.00	-40	+400	-2	+20
*1.50	-80	+800	-4	+40
*0.750	-160	+1600	-8	+80
0.375	-160	+1600	-8	+80
*0.250	-480	+4800	-24	+240
0.125	-480	+4800	-24	+240
*0.100	-1200	+12 000	-60	+600
0.050	-1200	+12 000	-60	+600
*0.030	-4000	+40 000	-200	+2000
0.015	-4000	+40 000	-200	+2000
*0.010	-12 000	+120 000	-600	+6000
0.0050	-12 000	+120 000	-600	+6000
*0.0030	-40 000	+400 000	-2000	+20 000
0.0015	-40 000	+400 000	-2000	+20 000
*0.0010	-120 000	+1 200 000	-6000	+60 000
0.0005	-120 000	+1 200 000	+6000	+60 000

The asterisks mark preferred voltages which will give slightly better accuracy. The basic bridge circuit inside the instrument is driven by its maximum voltage when these marked voltages are selected. The bridge circuit is driven by half its maximum when the other voltages are selected.

The capacitance values listed are the largest that can be measured at the associated voltage. The maximum voltage specified does not represent the maximum voltage ever applied to the unknown; it represents the maximum voltage that is used to get the final measurement result. Transient voltages as high as 0.1 volts can occur no matter what the maximum voltage is set to. The default value of *highest* in the GAUGE 0 parameter file is fifteen volts.

UNKNOWNS WITH DC VOLTAGE

The AH 2500A allows DC voltages to be applied to or be bled from unknowns or to be left unaffected.

DC Bias Disabled

With the DC bias feature disabled, the bridge actively drives any residual DC voltage across the unknown to zero. The internal driving source can supply up to 10 microamperes. If the DC current supplied by the unknown capacitance exceeds 10 microamperes, the error message dC on L InPut will appear on the display. An external resistor to shunt the LOW terminal to ground might also work in this case, but would increase the amount of noise that the bridge sees.

Applying a DC Bias Voltage

The AH 2500A allows a DC bias voltage of up to ±100 volts to be applied to the unknown. This voltage is supplied externally between the center conductor of the DC bias connector on the back of the bridge and ground. In addition to making this external connection, it is also necessary to execute a command which closes an internal relay. When closed, this relay connects the external bias voltage through an internal series resistor to the LOW input of the bridge. Thus the LOW input may then have the same DC voltage as is applied to the external DC bias connector. The HIGH terminal of the bridge is always a low impedance DC ground.

WARNING !

The voltage that you apply to the DC bias input will be passed to the LOW input terminal. From there it will go to whatever unknown impedance and fixture you have connected. Be sure that your fixture and cable are constructed in a manner that will prevent personal contact with any applied, high DC voltages. The frame of the fixture and the shield of the cable should be grounded.

CAUTION

The voltage connected to the DC bias input appears directly across the internal fused-silica capacitance standard. Application of voltages significantly in excess of 100 volts may damage or destroy the standard.

The command used to enable DC bias measurements and to select the value of the internal series resistor is:

<u>BIAS</u> *enable*

where the *enable* choices are:

0   Disabled (no series resistor connected)

1   100 megohm series resistor connected

2   1 megohm series resistor connected

The *enable* choices are numbered in order of ability to feed increased levels of current into the unknown.

The default *enable* value in the GAUGE 0 parameter file is zero.

Optimizing the Series Resistance

The value chosen for the internal series resistor involves a compromise. The *larger* this value is, the smaller the noise will be in the resulting measurements. Thus for measurements which do not require a DC bias, the internal series resistor is not connected and the noise is thus held to a minimum. On the other hand, if there is any DC leakage in the unknown being measured, then a voltage divider is created which causes the voltage across the unknown to be less than the voltage applied to the external DC bias connector. To minimize *this* effect, the internal series resistor should be as *small* as possible. To allow you to optimize this trade-off, the value of the internal series resistor may be selected with the BIAS command to have a value of either 1 megohm or 100 megohms.

Another reason for wanting the series resistor to be smaller is the *time* required to charge the unknown capacitor to a bias voltage that is within an acceptable tolerance of the desired voltage. You can avoid this trade-off by using an *enable* value of two to rapidly charge your unknown, then switching to an *enable* value of one to take a low-noise reading.

To allow you to further optimize these trade-offs, the internal series resistors which are R643 and R644, respectively, on the preamp board can be shunted with resistors that you supply using the terminals provided for this purpose. Resistor values as low as 10 kilohms are practical. Since a current is flowing, to minimize noise, these should not be carbon composition, but rather carbon film or, better yet, metal film. Be aware that 100 volts across 10 kilohms dissipates one watt. Changing the value of the series resistors on the preamp board is something that should be done only by a person qualified to work on electronic circuits. See "DC BIAS Resistor Tests" on page 11-16 to learn how to measure and/or change these resistors. For safety and performance reasons, it is extremely important to observe the warning and caution messages given there.

Measuring the Actual Applied DC Voltage

For unknowns that have some DC leakage, it is desirable to measure the actual DC voltage that is applied to the unknown. This is done by measuring the DC voltage between the LOW terminal and ground while the unknown is connected. Several considerations are important while doing this. A typical internal series resistor may have a resistance that is comparable to or larger than the input resistance of a typical voltmeter. Thus either the internal series resistor must be made small or the meter must be chosen to have an exceptionally high input impedance or both. If this is not possible, then the DC bias voltage across the unknown will change depending on whether the voltmeter is connected or not. The voltmeter can remain connected to the LOW terminal while the bridge takes readings if the voltmeter is shielded from external noise and from the HIGH terminal and if the voltmeter itself does not introduce an unacceptable amount of noise. If the internal resistance of the voltmeter is the only source of noise, then the higher this resistance is the better.

Charged Unknowns

Some unusual unknowns (like piezoelectrics) have the ability to generate a DC current which may be greater than what the input of the AH 2500A can zero out under normal operation (i. e., with DC bias disabled). In this case, the solution is to enable the DC bias with the BIAS command. This allows at least 100 volts to exist across the unknown without affecting the measurement and thus preventing the DC ON LOW INPUT error message from appearing. The external bias connector can be left open or shunted to ground. The latter configuration would allow the internal series resistor to bleed off any excess charge that tended to build up on the unknown.

Input Protection

A number of protection devices are incorporated in the AH 2500A to prevent charged capacitors or excessive external bias voltages from causing damage to the capacitance standard or the preamp which are both connected to the LOW input. If voltages much in excess of 100 volts are applied, a gas discharge device which is connected between the LOW input and ground will suddenly begin conducting to hold the voltage at the preamp input within range. This will not change a voltage applied to the DC bias connector but will very suddenly remove charge from any external capacitor having an excessive voltage.

CAUTION

Charged capacitors or low impedance power sources must not be connected between the HIGH terminal of the bridge and ground. Connection of such sources will cause them to discharge into the contacts of the attenuator relays which will damage these contacts.

This chapter explains the various ways that you can present capacitance and loss measurement data using the AH 2500A.

The first part of this chapter explains variations in the ways in which measurement data can be presented that apply to both the front panel displays and to remote devices. How to control the number of significant figures that are reported is discussed. Methods of subtracting constant amounts from measurement results are also introduced.

The second major part of this chapter explains additional ways in which data can be presented on remote devices only. Topics discussed include the ways to control the number of columns and fields that are printed, the ways in which the data is labeled and punctuated and the numeric notation that is used.

SIGNIFICANT DIGITS

"Significant digits" refers to those digits in the measured result that are meaningful. The "most-significant digits" are at the beginning of a number and are always the most meaningful. The "least-significant digits" are at the end or right side of a number and are always the least meaningful. Often there are one or more digits at the right side of a measurement result that represent a level of performance that is beyond an instrument's capabilities. In this manual, the term "significant digits" will be used to refer to all the digits in a measurement result except those that are beyond an instrument's capabilities. This is a subjective concept since there is no accepted, rigorous method by which to separate one kind of digit from the other.

Automatic Limitations

When making measurements, the AH 2500A monitors the amount of noise coming from the unknown impedance. It also monitors its internal systematic error contributions. Using these two error sources, it computes the maximum number of meaningful digits and rounds (rather than truncates) the results so that meaningless or misleading digits are not reported. If the meaningless digits are to the right of the decimal point they are replaced by a space. If they are to the left of the decimal point they are replaced with zeroes.

The AH 2500A can report as many as ten digits in a measurement result. For many measurements, not all of these digits will be significant. The bridge's ability to eliminate meaningless digits reduces the clutter in the results. More importantly, by eliminating meaningless or misleading digits, the bridge ensures that your time is not unintentionally wasted attempt-

ing to interpret such digits. Unfortunately, it is common practice by many other manufacturers to report many more digits than are meaningful or useful.

Reporting that Last Digit

It will sometimes happen that the bridge will not report as many digits as you would like for your measurements. This is most frustrating when the least-significant digit that you would like to get is sometimes reported and sometimes not. The obvious thing to try in this situation is to reduce the noise that the bridge sees by using one or more of the techniques discussed under "MEASUREMENT SPEED VS. MEASUREMENT FLUCTUATION" on page 4-5 and "REJECTING INTERFERING SIGNALS" on page 4-8. If you have applied the features described in those sections; if you are confident that your unknown sample is as noise-free as you can make it; if your application restricts you from increasing the averaging time any further; and if you would still like another digit to be reported, then you will need to consider the approach below.

It is important to understand that the AH 2500A does not eliminate digits that contain useful information. The bridge is careful to always choose the number of digits that are reported such that at least one of the least-significant digits is noisy if there is noise in the measurement. This is extremely important because it allows you to *externally* average a number of measurement results to get a number having a higher resolution than the ones reported by the bridge. Such averaging would not be productive if the bridge did not leave some noise in its measurement results. One application of this is to obtain data of higher resolution by averaging the results of relatively fast, synchronously triggered measurements of an unknown sample that is being slowly modulated by some external influence.

Setting a Limit on the Significant Digits

The AH 2500A normally reports all significant digits that it has available. Sometimes it is desirable to round off the measurement result to one with fewer significant digits. The PLACES command can be used to specify the number of significant digits (from one to nine) for the capacitance and loss values that are displayed on the front panel and sent to the remote devices. When you limit the number of significant digits in this way, the bridge will automatically round off the result to the number of digits you specify. This feature does not override the automatic limitations described above, it can only further limit the number of digits reported.

The number of significant digits to be reported is selected by changing the *digits* parameters with the PLACES command. The syntax of the PLACES command is:

PLACES [CAP or LOSS] *digits*

The *digits* parameters can have any value from one to nine. When counting significant digits, don't include the decimal point, signs, or the exponential part of numbers expressed in scientific or engineering notation. The default numbers of significant digits for both capacitance and loss are stored in the BASIC 0 parameter file. Both default numbers are nine which is the maximum possible.

The capacitance and loss values can have different numbers of significant digits if needed by explicitly specifying the CAP or LOSS qualifiers. If neither CAP nor LOSS qualifiers are explicitly specified, both cap and loss are affected simultaneously. If only one of the values is explicitly changed, the other will remain at the previous setting.

Examples

To show some examples of the effects of the PLACES command, consider a printout using the default places parameters of nine.

C= 987.654321   PF L= 0.0012345   NS

If the command PLACES C 2 is executed, the printout would appear as:

C= 990.0   PF L= 0.0012345   NS

Notice that 987 was rounded to 990 and that the digits that were eliminated were replaced with spaces rather than being deleted. For fixed field width settings (see "Fixed/Variable Field Widths" on page 5-8), this example demonstrates that the PLACES command does not change the starting column numbers of the printed fields. Suppose that the command PL L 2 is entered next. The printout will be:

C= 990.0   PF L= 0.0012   NS

As another example, if the bridge measured a capacitance of 47834.891 PF and you change the number of significant digits to two, (PLACES2) the bridge will report the result as 48000. The same measurement following a PLACES 6 command would report 47834.9.

RESULT MODES

The AH 2500A can be placed into a "Reference result mode" where it reports deviations of capacitance and/or loss from a reference value that you entered *or* measured. These deviations can be presented in an absolute format or as a percentage of the reference values.

The bridge can also be placed into a "Zero result mode" in which compensation is made for stray capacitance and loss that exists in a test fixture used to measure the unknown impedance.

The Reference result mode and the Zero result mode can be active simultaneously.

The default mode of operation has all of the above features disabled. This mode is called the "Absolute result mode". The default mode is contained in the Reference and Zero parameters in the GAUGE 0 parameter file.

Absolute Result Mode

Operation of the AH 2500A is most commonly done in Absolute result mode. The measurements taken in Absolute result mode are the actual values of capacitance and loss as seen by the bridge. The values have not been corrected for stray fixture impedances or modified to adjust for other differences or offsets that may exist at the far end of the measurement cables.

Absolute result mode is active when Reference and Zero result modes are both disabled. As explained below, executing the commands REFERENCE HALT and ZERO HALT will cause Absolute mode to be active.

Reference Result Mode

When the AH 2500A is operated in Reference result mode, measurement results are reported as a deviation from a reference value that you define.

There are two ways to enter the reference values. You can either enter them manually or the bridge can use the last measured capacitance and/or loss values as the new reference values. In addition, you can choose to report the measurement result as either the absolute deviation from the reference or as a percentage deviation from the reference.

Entering reference values does not necessarily mean that the values are being used to produce deviation results. Enabling Reference mode is a separate operation from entering the values. Entering the values only makes them available for future use. Reference result mode must be enabled to begin using the values to produce deviation results.

Entering Reference Values Manually

To manually enter the reference values, the command

REFERENCE [CAP or LOSS] *refvalue*

is used, where *refvalue* is the desired reference value for capacitance or loss. The command must be issued twice if reference values for both capacitance and loss are needed. The maximum length of the reference values that can be entered is nine digits.

When this command is entered from the front panel, the upper display will show either CAP or $LOSS$ and the lower display will show the value being entered.

When reference values are entered from a remote device, the values can be negative and may be entered in any of three numeric notations discussed later in "Numeric Notation" on page 5-8. The bridge will automatically detect which format is used.

The current Units parameter settings are assumed when entering reference values. You can see what the current units are by using the **SHOW UNITS** command. If you change the units *after* entering reference values, these values will be converted to the new units. This is useful if you know the desired reference value(s) in one set of units but wish to make measurements in a different set of units.

The default reference values stored in the GAUGE 0 parameter file for capacitance is zero picofarads and for loss is zero nanosiemens.

Entering Reference Values Automatically

The version of the **REFERENCE** command shown below causes the *last* measured capacitance and/or loss values to become the reference values.

REFERENCE [CAP or LOSS] SINGLE

If both CAP and LOSS qualifiers are omitted from the command, then both of the last measured capacitance and loss values are used as the new reference values.

Enabling Reference Result Mode

To enable reporting deviations one must enter a command with the syntax:

REFERENCE [CAP or LOSS]

If an optional CAP or LOSS qualifier is not entered, then both results will be reported in Reference result mode.

This command does not initiate measurements, but its execution will cause the previous measurement result to be *re-calculated* and reported with Reference result mode enabled. If the bridge is not in continuous mode when the command is issued, a SINGLE or CONTINUOUS command must be entered to make the bridge report a *new* deviation measurement. All subsequent measurements will be reported in Reference mode until Reference mode is disabled.

The Reference-result-mode-enabled condition is stored as a part of each Gauge parameter set. The default value in the GAUGE 0 parameter file is the disabled condition.

Disabling Reference Result Mode

To disable Reference result mode, the command syntax is:

REFERENCE HALT

Execution of this command will cause the previous measurement result to be re-calculated and reported with Reference result mode disabled.

Selecting Reference Percent Format

The following command is used to enable and disable Reference percent format:

REFERENCE FORMAT [CAP or LOSS] *percent*

If the *percent* parameter is entered as a one, Reference percent format is enabled. This format will have no effect on any reported results unless Reference result mode is also enabled with the **REFERENCE** command. This will cause the previous measurement result to be re-calculated and reported.

Percent format causes the reference value to be subtracted from each measurement. The difference is then divided by the reference value and multiplied by 100. The calculation always starts with the current units, but the final result is dimensionless, of course.

If the *percent* parameter is entered as a zero, Reference percent format is disabled.

If an optional CAP or LOSS qualifier is not entered, then both results will be reported in Reference percent format.

Indication of Reference Result Mode

To indicate to a remote device that Reference mode is enabled for capacitance results, the capacitance units indicator PF changes to RPF. When the Reference result mode for loss is enabled, the loss units indicator (NS for example) becomes RNS. When Reference percent format is enabled, the respective units identifiers are $\%PF$ and $\%NS$.

To indicate on the front panel that Reference mode is active, the word rEF is shown on the appropriate upper and/or lower displays whenever the $bUSY$ message appears:
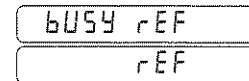
$bUSY$ rEF
rEF

When Reference percent format is active then Prc is displayed with the $bUSY$ message on the appropriate upper and/or lower displays:
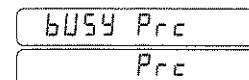
$bUSY$ Prc
Prc

These can also occur in mixed combinations such as:

```
 bUSY Prc
      rEF
```

A second front panel indication appears as a "P" (for Percent) or as an "r" (for reference) in the right-hand window of the measurement result:

```
 0.00000 15         5= 1      P
 -.0000002          U= 15.0   r
```

A third way to see which mode and format is active is to use the **SHOW** command. See "REFERENCE value" on page A-32 for more information about showing the Reference parameters.

Zero Compensation Result Mode

Zero compensation result mode (or simply, Zero result mode) causes the AH 2500A to compensate for residual capacitance and *parallel* loss effects that are usually inherent in test fixtures. For a discussion of where this mode might be useful see "COMPENSATING FOR STRAY FIXTURE IMPEDANCE" on page 4-12.

Zero result mode is identical to Reference result mode in many ways, but the mathematical compensation performed in Zero result mode is much more than just a simple subtraction. The compensation calculation performed is dependent upon the units currently in use and can be complicated. The calculations require *both* capacitance and loss Zero values. Thus, the Zero result mode differs from the Reference result mode by not allowing you to enter a capacitance value without a corresponding loss value or vice-versa.

Zero result mode can be used in combination with either Absolute result mode or Reference result mode. There are two ways to enter the Zero compensation values. You can enter the values manually or the bridge can use the last measured capacitance and loss values as the new Zero compensation values.

As in Reference result mode, it is important to understand that just entering Zero compensation values does not necessarily mean that the values are being used to produce Zero compensated results. Enabling Zero result mode is a separate operation from entering the Zero compensation values. Entering the Zero values only makes them available for future use. Zero result mode must be enabled to begin using the values to produce Zero compensated results.

Entering Zero Values Manually

To manually enter the Zero values the command

ZERO CAP *capvalue* LOSS *lossvalue*

is used, where *capvalue* is the desired value of capacitance and *lossvalue* is the desired value of loss. Both *capvalue* and *lossvalue must* be entered. The maximum length of these Zero values is nine digits.

When *capvalue* and *lossvalue* are entered from a remote device, the values can be negative and may be entered in any of three numeric notations discussed later in "Numeric Notation" on page 5-8. The bridge will automatically detect which format is used.

The current Units parameter settings are assumed when entering *lossvalue*. You can see what the current units are by using the **SHOW UNITS** command. If you change the units *after* entering the Zero values, these values will be converted to the new units. This is useful if you know the desired Zero value(s) in one set of units but wish to make measurements in a different set of units.

The default Zero values stored in the GAUGE 0 parameter file for *capvalue* is zero picofarads and for *lossvalue* is zero nanosiemens.

Entering Zero Values Automatically

The version of the ZERO command shown below causes the last measured capacitance and loss values to become the Zero values.

ZERO SINGLE

This command causes both the *last* measured capacitance and loss to be used as the new Zero values. This command is useful for measuring the stray impedance of a fixture when the fixture contains no DUT or a dummy DUT.

Enabling Zero Result Mode

To enable the reporting of Zero compensated results, you must enter the command:

ZERO

This command does not initiate measurements, but its execution will cause the previous measurement result to be *re-calculated* and reported with Zero result mode enabled. If the bridge is not in continuous mode when the command is issued, a **SINGLE** or **CONTINUOUS** command must be entered to make the bridge report a *new* Zero-compensated measurement. All subsequent measurements will be reported in Zero result mode until Zero result mode is disabled.

The Zero result mode enabled condition is stored as a part of each Gauge parameter set. The default value in the GAUGE 0 parameter file is the disabled condition.

Disabling Zero Result Mode

To disable Zero result mode use the following command:
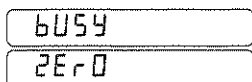
$$\underline{Z}ERO\ \underline{HA}LT$$

Execution of this command will cause the previous measurement result to be *re-calculated* and reported with Zero result mode disabled.

Indication of Zero Result Mode

To indicate to a remote device that Zero result mode is enabled, the PF capacitance units indicator changes to ZPF and the loss units indicator (NS for example) becomes ZNS.

To indicate on the front panel that Zero result mode is enabled, the word ZErO is shown on the lower display whenever the bUSY message appears:

```
┌─────────────────┐
│   bUSY          │
├─────────────────┤
│   ZErO          │
└─────────────────┘
```

The Zero indicator will be combined with Reference mode indicators if Reference result mode is also enabled:

```
┌─────────────────┐
│   bUSY  rEF     │
├─────────────────┤
│   ZErO  rEF     │
└─────────────────┘
```

A second front panel indication appears as a "Z" (for Zero) in the right-hand window of the measurement result:

```
┌─────────────────┐   ┌─────────────────┐
│  0.00000015     │   │   S: 1      Z    │
├─────────────────┤   ├─────────────────┤
│  -.0000002      │   │   U: 15.0        │
└─────────────────┘   └─────────────────┘
```

A third way to see which mode and format is active is to use the SHOW command. See "ZERO value" on page A-59 for more information about showing the Zero parameters.

FRONT PANEL FORMAT

Measurement results are displayed on the front panel in the formats described above. Unlike the remote device formats, you have no other control over the front panel formats. In almost all cases, the number formats used on the front panel are conventional. An exception to this is explained below.

Displaying Large Numbers with Large Uncertainties

As discussed in "Automatic Limitations" on page 5-1, the bridge always tries to display only digits which are meaningful and not excessively noisy. The display of meaningful resistance values presents a unique challenge in the case of parallel resistance because very small changes in conductance values translate into large changes in very large resistance values. This is due to the division that is required. In situations where the only possible resistance values that could be reported would be wildly varying, the AH 2500A

reports, instead, only the minimum resistance that the unknown impedance could have. To indicate this minimum resistance, a "greater than" symbol "ⴺ" on the front panel is displayed to the left of the resistance value R_P. This symbol is also used with results for tan δ, C_S, and R_S. See "Field Labels" on page 5-7 for the equivalent discussion for remote device formats.

REMOTE DEVICE FORMATS

Capturing measurement results on remote devices rather than on the front panel gives you greater flexibility in choosing what is reported and how it is formatted. The following sections describes the measurement result formats that are sent to remote devices and how you can customize these formats to meet your needs.

Result Line Format Options

Measurement results that are sent to remote devices can have up to nine significant digits reported versus the eight digits displayed on the front panel.

Measurement results that are sent to remote devices can contain up to five separate fields. A "field" is one number or string value including its associated labeling and punctuation.

The five fields that can be reported in the result line are the:

- Sample number.
- Measured capacitance value.
- Measured loss value.
- Actual test voltage used.
- Error code or error message.

You can further control what is sent in the result line by selecting the:

- Presence or absence of field and units labels.
- Punctuation style.
- Fixed vs. variable field widths.
- Numeric notation.

Full Measurement Result Format

A measurement result with all five fields enabled is sent as a single line to a remote device and looks like the following:

S=*ss* C=±*d.dddddddd* PF L=±*d.dddddddd* NS
U=*d.dddd* U [*error message*]

where:

- *ss* is a 2-digit sample number. This identifies the position of a sample switch if one is connected. See Appendix D, "Sample Switch Port" for more information.

- the *d's* are the measured values of capacitance, loss and the applied test voltage respectively.

- "S=", "C=", "L=" and "U=" are labels to identify the sample number, capacitance, loss and voltage values respectively.

- "PF", "NS" and "U" are units identifiers (picofarads, nanosiemens and volts) for capacitance, loss and voltage values respectively. The "NS" label depends on the units selected and can alternately appear as "DS", "KO", "GO", or "GU".

- If there is an error, an *error message* is sent as the rightmost field. If there is no error, no *error message* is sent.

The default measurement result format stored mostly by parameters in the BASIC 0 parameter file is identical to the full format described above except that the sample field is omitted.

When the serial port is used and echoing is enabled, a result line being sent to the serial port will begin with a single space character. This serves as a place holder for the prompt character (>) and improves the readability of fixed field width, mixed single and continuous measurements by keeping the data columns aligned.

Selecting which Fields to Send

The FORMAT command allows you to select which of four fields in the result line are sent to the remote device. The bits in the format parameter byte allow you to selectively send or not send the sample number, capacitance, loss and/or voltage fields. An error field will always be sent if an error occurs, but you can select whether it is sent as an English message or as a decimal code. The syntax of the FORMAT command which allows you to set and clear the Format bits is:

FORMAT *smp.cap.los.vlt.msg.lbl.pun.ffd*

where each of the parameters in parentheses are binary digits having the following effects:

smp	enables sending the sample field when set.
cap	enables sending the capacitance field when set.
los	enables sending the loss field when set.
vlt	enables sending the voltage field when set.
msg	enables an *error message* to be sent when set, or an *error code* to be sent when clear.
lbl	enables labels to be sent.
pun	enables IEEE-488.2 compatible punctuation when set.
ffd	fixes field widths when set.

This command uses positional parameter entry so you only need to enter the values for the bits that you wish to change. For example, to turn off the *smp* and *vlt* fields you issue the FO 0...0 command. The other bits will not be changed.

Positional parameters are explained in "Positional Parameters" on page A-1.

Field Selection Example

As an example, recall the default format parameters from the BASIC 0 parameter file and show them by executing the command REC BAS 0;SH FO. You will get the result:

```
FORMAT    SMP=0 CAP=1 LOS=1 ULT=1
                    MSG=1 LBL=1 PUN=0 FFD=1
```

Notice that all the bits are set to one except for the sample and punctuation bits. This means that the capacitance, loss, and voltage fields will all be sent to a remote device when a measurement is taken. The exact format for this is shown in "Full Measurement Result Format" above.

Now suppose that you do not want to print the voltage field. Enter the command FO ...0 to disable sending the voltage field without affecting any other settings. If you take a measurement, your result will now have the format:

C=±*d.dddddddddd* PF L=±*d.dddddddddd* NS

[*error message*]

Notice that the voltage field is gone. In the same manner, you can clear other bits in the Format parameter byte to inhibit sending the capacitance, loss, and/or sample fields.

Error Messages vs. Error Codes

The measurement result formats above included an *error message* in both cases. This *error message* will always appear to the right of any other information that is sent. If there is no error, no message is printed.

If the nature of the error is such that a meaningful measurement cannot be made (hard error), only the *error message* will appear on the line. If the error is one that does not prevent a measurement from being taken (soft error), the *error message* and the measurement result will both be sent.

If your results are to be analyzed by a computer, you might rather have an *error code* sent using the following format:

ee S=*ss* C=±*d.dddddddddd* PF L=±*d.dddddddddd* NS

U=*d.dddd* U

where *ee* is a 2-digit, decimal *error code*. An *error code* *always* appears at the beginning of the line. The *error code* is sent as "00" if there is no error.

The *msg* bit in the Format parameter byte described above allows you to select whether an *error message* or an *error code* is sent to remote devices. If *msg* is set then an *error message* will be sent if one exists. If *msg* is zero then an *error code* will be *always* be sent. The command FO ....0 is used to change the default to a format such as the one above.

As you can see, measurement result lines have either error *codes printed first* or error *messages printed last* depending on the setting of the Format parameter bits. This option arises from the differences between computer and human readability. When a *computer* is analyzing the data, an error indication should be the first data sent in the result string so that checking for an error condition before accepting the measurement result is easily done. In this case, an *error code* is typically used rather than an *error message*. When a *person* is visually reading the results instead of a computer, error messages are preferable. Since the messages are of variable length, they are reported last to allow orderly column alignment of the measurement results. A list of the error messages and their meaning is in Appendix B, "Error Messages".

Field Labels

Each numeric value sent may have one or two labels next to it. A field identification label is sent preceding a value and a unit label may be sent following a value. The field labels sent preceding the corresponding values are "S=" to identify the sample number, "C=" for the capacitance value, "L=" for the loss value, and "U=" for the voltage value. The unit labels are sent following the capacitance, loss and voltage values. The unit labels will be "PF" for capacitance, one of five different units specified by the Units parameter for loss, and "U" for the voltage value.

The FORMAT command can be used to enable or disable the sending of all of these labels. When the *lbl* parameter bit is set to a one, field labels and unit identifiers will be sent. When this bit is zero they will not be sent. For example, the command FO . . . . . 0 will change the full format to:

ss ±d.ddddddddd ±d.ddddddddd d.dddd [error message]

where all the labeling has been removed from the result line. This option is useful when a computer is analyzing the measurement results. A computer doesn't need labels to help it to identify fields; it may need to be programmed to avoid processing such fields. The *lbl* parameter also controls the results from other commands such as SHOW, CALIBRATE and TEST.

Both the field identification labels and the units labels have alternate forms that are used to convey additional information. The "=" symbol in the capacitance and loss field labels will be replaced with a ">" symbol in certain situations where the reported values are known to be larger than a certain amount but where it is not known by how much. This can occur when measuring series capacitance and when using loss units of dissipation factor, series kilohms and parallel gigohms. For more information, see "Displaying Large Numbers with Large Uncertainties" on page 5-5 and "Punctuation" below.

The units labels for the capacitance and loss fields can both be immediately preceded by the "R", "Z", and "%" characters. The combinations that can appear are Z, R, RZ, %, and %Z.

These characters are used to indicate that the Reference and/or Zero result modes are active. See "Indication of Reference Result Mode" on page 5-3 and "Indication of Zero Result Mode" on page 5-5 for more information.

Punctuation

The IEEE-488.2 standard defines how data is to be sent over the GPIB. Part of this definition specifies what will be described here as the "punctuation" of the data. Specifically, this standard specifies that fields are to be separated by commas rather than spaces and that strings are to be enclosed in quotation marks. If you desire your results to have this kind of punctuation, then you can set the *pun* bit in the Format parameter byte. For example, the command FO . . . . . . 1 will change the full format to:

S=*ss*,"C=",±d.ddddddddd PF,"L=",
    ±d.ddddddddd NS,U=d.dddd U,["*error message*"]

Notice that the space separators have become commas and the error message is enclosed in quotes. The "C=" and "L=" strings contain variable information since the "=" can sometimes be a ">" symbol. For this reason, these labels but no others are enclosed in quotes. The *pun* parameter bit also controls the punctuation of results from other commands.

Label and Punctuation Examples

The example in Figure 5-2 is a printout demonstrating the effects of the *lbl* and *pun* parameters. First, the command FO 0 . . . . . 1 . 0 . 0 turns off the sample number field and clears the *ffd* parameter. The FORMAT command then is used to set up all combinations of the *lbl* and *pun* parameters to create the four example results shown in the figure.

```
lbl=1, pun=0:
FO 0 . . . . . 1 . 0 . 0
C=-0.4271 PF L>40000.0 GO U=15.0 U OUEN


lbl=1, pun=1:
FO . . . . . 1 . 1
"C=",-0.4271 PF,"L>",40000.0 GO,
                        U=15.0 U,"OUEN"
lbl=0, pun=1:
FO . . . . . 0 . 1
" ",-0.4271,">",40000.0,15.0,"OUEN"


lbl=0, pun=0:
FO . . . . . 0 . 0
 -0.4271 >40000.0 15.0 OUEN
```

Figure 5-1 Examples of label and punctuation effects.

The first example with *lbl*=1 and *pun*=0 is optimized for human readability. It provides the maximum number of labels and the minimum punctuation clutter. The third example with *lbl*=0 and *pun*=1 is optimized for machine readabil-

ity and IEEE-488.2 compatibility. It provides no labels and all the punctuation required by the IEEE-488.2 standard. The remaining second and fourth examples show other variations that might be useful.

No matter which combination of *lbl* and *pun* parameters is selected, the ">" symbol will always be sent if it is generated. On the other hand, the units labels with their possible "R", "Z", and "%" characters are only sent if labeling is enabled.

Fixed/Variable Field Widths

The AH 2500A allows you to determine whether fields sent to remote devices have a fixed or variable width.

When set to a fixed value, the field widths can be thought of as the number of *columns* available (but not necessarily used) to print the numbers in the fields. These field widths are independent of the number of significant places discussed in "SIGNIFICANT DIGITS" on page 5-1. The field width settings are only applicable to data sent to remote devices.

The AH 2500A has as many as nine significant digits available for each measurement result for both capacitance and loss. This results in a total of ten digit columns being sent when the field width is fixed.

The main advantage of fixing the field widths is that this also fixes the starting column numbers of each field. This can greatly enhance the readability of columns of results.

The fields can also be set to send exactly the number of significant digits that are available. Since the number of significant digits can vary with each measurement, so can the width of such fields. The advantage of variable fields is that only significant characters are sent, not fill characters. This optimizes speed and memory usage. It also makes the results IEEE-488.2 compatible since no fill spaces are sent. The disadvantage is that the fields will not align into straight columns and will thus be harder to read when printed or displayed.

Field Width Examples

The example in Figure 5-2 is a printout demonstrating the effects of the *ffd* parameter. First, the PLACES 9 command sets the number of significant digits to the maximum (See"-Setting a Limit on the Significant Digits" on page 5-1). The FORMAT command then enables punctuation, labeling and fixed field widths.

In the first two measurement result lines, all nine significant digits are shown implying that a high quality measurement was made because all the possible significant digits were sent. In the next two result lines, fewer digits were sent even though no parameter changes were made. This implies that a measurement of lower quality was made which caused a loss of significant digits. Since the *ffd* parameter was set, the number of *columns* sent remained *fixed*, even though the number of *digits* sent *changed*.

Next, the command FO ....0 was executed to clear the *ffd* parameter causing *all fields* to become variable width. Notice that all fields in the three lines following this command have no extraneous spaces whereas most fields in the four preceding lines do. (The space preceding the units' labels goes away if labeling is turned off.) Notice also that the columns in the three lines following the command are no longer straight.

```
PL 9
FO 0,1,1,0,1,1,1,1
C=140,427134   PF,L= 0,000121    NS
C=140,427245   PF,L= 0,000105    NS
C=140,42741    PF,L=-0,0001      NS
C=140,42748    PF,L=-0,00003     NS
FO .......0
C=140,42749 PF,L=-0,000022 NS
C=140,4275 PF,L=0,000009 NS
C=140,4275 PF,L=-0,000011 NS
```

Figure 5-2 Examples of field width effects.

Numeric Notation

The AH 2500A is capable of both *accepting* input and *formatting* measurement results sent to remote devices in three different numeric notations. These notations are floating-point, scientific, and engineering.

The front panel always displays floating-point notation only. For results sent to remote devices, one of three kinds of numeric notation can be selected for use with capacitance, loss, resistance, inductance, voltage, length and time fields. These fields will all use whichever notation has been selected; the notation cannot be individually specified for different result fields.

Numbers received from remote devices will be accepted no matter which of the three notation types is used. The bridge will automatically sense which type is being sent.

Floating-Point Notation

Floating-point notation has been used in all of the examples given thus far in this chapter. It can be described as a string of characters beginning with an optional sign character. This is followed by one or more digits, followed by a decimal point and ending with one or more digits.

A specific example of a floating-point notation result is:

```
C=113,876543 PF L=0,0076543 NS U=15,0 U
```

Scientific Notation

Scientific notation can be described as a string of characters beginning with an optional sign character followed by exactly one digit and then a decimal point. A least one digit follows the decimal point, the number depending on the number of significant digits to be reported. The portion of the notation described thus far is called the mantissa. The mantissa is immediately followed with a capital "E", then a sign character and finally two digits. The two digits are a base-ten exponent that indicates the factors of ten by which the mantissa is to be multiplied. If the sign following the E is negative then the mantissa is divided by factors of ten.

A specific example of a scientific notation result using the same numbers as in the last example is:

```
C=1.13876543E+02 PF  L=7.6543E-03 NS
                       V=1.50E+01  V
```

Engineering Notation

Engineering notation is identical to scientific notation except that the mantissas will have from one to three digits to the left of the decimal point and the exponent will appear only in increments of three (i.e. -06, -03, +00, +03,+06, etc.). These exponents are useful because they correspond to engineering unit prefixes of micro, milli, kilo, mega, etc.

A specific example of an engineering notation result using the same numbers as in the last example is:

```
C=113.876543E+00 PF  L=7.6543E-03 NS
                       V=15.0E+00  V
```

Selecting the Numeric Notation

The desired numeric notation to be sent to remote devices is selected by changing the *notation* parameter with the FORMAT SPECIAL command. The syntax of this command is:

FORMAT SPECIAL *notation*

The *notation* parameter can be set to 0, 1 or 2. The corresponding notations are:

0 Floating-point notation

1 Scientific notation

2 Engineering notation

The default notation stored in the BASIC 0 parameter file is zero.

IEEE-488.2 Compatible Results

The various formatting options discussed in this chapter provide a wide range of ways to format your results. How you format results will be based largely upon whether they are to be read by a person or by a computer. If the results will be read by a person, then the formatting choices will probably be largely subjective, being based upon what you feel most comfortable reading.

If the results will be read by a computer, then there may be existing programs available to help analyze your data. Newer programs are likely to be able to accept data more easily if it is formatted in a standard way. If you are using the GPIB, the newer IEEE-488.2 standard defines the data formats, codes, and protocols that should be used.

If you decide that formatting your data to be IEEE-488.2 compatible is desirable, the AH 2500A offers several possible formats. To do this you must disable labeling and enable compatible punctuation. You do this by clearing the *lbl* bit and setting the *pun* bit in the Format parameter byte. See the paragraphs about "Field Labels" and "Punctuation" above. The IEEE-488.2 standard also requires that there be no extraneous spaces in number fields. This is done by setting the *ffd* parameter to zero. See the paragraph about "Label and Punctuation Examples" above. Issuing the command FOR .....0.1.0 will correctly change all three of these format bits.

Having executed this command, you now have a choice of any of the three available numeric notation formats. All three will now be IEEE-488.2 compatible. See the section about "Numeric Notation" above.

Chapter 6   GPIB/IEEE-488 Operation

This chapter discusses operation of the AH 2500A from the GPIB/IEEE-488 port. This chapter and this manual assume that you are familiar with operating instruments using a GPIB controller. The concentration here will be on those aspects of GPIB operation that are specific to the AH 2500A. The major options that GPIB operation can give you are discussed in "GPIB Communication Options" on page 1-9 of Chapter 1.

If you are not familiar with GPIB operation, you will probably want to refer to other publications. If there is a GPIB controller in your lab, the GPIB controller manuals will often have good descriptions of the bus and how to use it. Many different languages are used with many different kinds of controllers to operate GPIB instruments. As a result, your GPIB controller manual should be your most important reference. It should explain not only general GPIB operation, but it will also explain the specifics of the controller and the interface language that it uses. The IEEE-488.1 standard specifies the lower-level operation of the GPIB bus operation. This standard is so widely accepted that, with a friendly controller, you should be able to avoid learning much about the hardware details of the GPIB bus.

If you do not yet have a GPIB controller, then you may want to refer to some general references. Many good tutorials and explanations of the GPIB bus have been published. We recommend numbers 1, 5 and 6 in the bibliography. Numbers 5 and 6 contain definitions of the GPIB (IEEE-488) bus standards. These are difficult reading (but very complete) and intended for use by instrument designers. Reference number 1 is quite readable.

The major topics discussed in this chapter are how to:

- Set the GPIB bus address using the BUS command.
- Save the bus configuration parameters introduced in this chapter using the STORE command.
- Use the bridge's abbreviated command syntax.
- Read response messages.
- Configure the bridge to operate in a friendly, interactive mode over the bus.
- Change the end-of-line separator, if desired.
- Initiate a GPIB service request.
- Interpret the bits in the GPIB status byte.
- Initialize the bridge over the bus.
- Connect to your GPIB port to log results from your bridge rather than to control your bridge. The LOGGER command controls this method of operation.

CONNECTING GPIB CABLING

The AH 2500A has as standard equipment a GPIB interface whose connector is on the rear panel. Any GPIB controller may be connected to it. Devices with listen-only capability can also be connected to serve as loggers. Electrical connection is made with any standard GPIB cable having black metric screws. The IEEE-488.1 standard specifies that no more than 15 devices should be connected to the bus and that the total length of cable should not exceed two meters per device or 20 meters total, whichever is less.

CAUTION

It is extremely important that the chassis grounds of all interconnected equipment be properly grounded through the power cord of each piece of equipment. Ground pins on power cords must never be cut off or otherwise defeated. Failure to observe this will frequently cause the GPIB port to be damaged if the port is disconnected while the equipment is plugged in (but not necessarily powered on). The failure results from the ability of power line RFI filter capacitors to cause an ungrounded equipment chassis to float to a voltage midway between the voltages on the two input power lines. This can put the chassis voltage at 50 to 120 volts above ground (for line voltages of 100 to 240 volts) with enough current capacity to be a shock hazard and to cause damage to interface ports. (The AH 2500A does not use such filter capacitors, but many other pieces of equipment do.)

BUS CONFIGURATION PARAMETERS

Several GPIB variables must be set before you can operate the AH 2500A via the GPIB bus. Fundamental variables which directly affect the ability of the bus to communicate are called bus configuration parameters. This section introduces the configuration parameters and explains how to set and permanently save each one. The two address parameters are explained in detail here, while the other parameters are explained as they are encountered throughout the chapter. Each explanation gives the default value of the parameter as stored in the BUS 0 parameter file.

Setting the Configuration Parameters

The BUS command is used to set the bus configuration parameters. The BUS command can be entered from the front panel or from a remote device using the following full syntax:

BUS *priaddr. secaddr. ton. compat. prompts*

The full BUS command accepts five parameters which are described in different sections of this chapter. Each time the BUS command is entered, it can be followed by any combination of its parameters provided that the place-holder periods are entered and that the order is preserved. As an example, the entry BUS 12..1 specifies a primary address of 12, the *ton* bit set, and the other two parameters left unchanged.

The bus configuration parameters can be changed from the GPIB controller, but the changes take effect immediately so you must be able to change the controller's expectations at the same time if communication between the controller and the bridge is not to be interrupted.

Once the bus configuration parameters have been correctly set, sending an addressed SINGLE command to the AH 2500A from the GPIB controller should cause the bridge to take a measurement whose result will appear on the front panel of the bridge. The same measurement result should also be readable via the bus by the GPIB controller.

Primary Bus Address

If a GPIB controller is used to communicate with the bridge, a unique bus address must be specified for the bridge. This can be selected using the following partial syntax:

BUS *priaddr*

The primary bus address can have any value from 0 to 30 that is not used by another device on the bus. Primary bus addressing *only* is used unless a secondary address is entered. The default primary bus address is 28.

Optional Secondary Bus Address

In some cases, it may be desirable to specify a secondary address in addition to the primary address. If a secondary address is specified, the primary/secondary address combination must be unique on the bus. The secondary address can be selected by itself using the following partial syntax:

BUS *. secaddr*

The optional *secaddr* (secondary address) can have any value from 0 to 30. Primary bus addressing *only* is used unless a secondary address is entered. Secondary addressing is disabled by entering the command and the first dot followed by no secondary address. For example, the commands "BUS ." and "BUS 28 ." would both disable secondary addressing if it was previously enabled.

Permanently Saving Your Settings

All the parameters discussed in this chapter are stored in the Bus parameter set. This set contains all the parameters that are used in conjunction with the GPIB port. An overview of this parameter set is given in Chapter 3, "Parameter and Program Files" in the section "Bus Parameter Set" on page 3-6.

To permanently save all of the parameters related to operating via the GPIB bus in a way that will automatically restore them after power-on of your bridge, simply issue the command [FUNC] [STORE] [FUNC] [BUS] [1] [ENTER] from the front panel.

To better understand the ways in which you can save your serial device parameters, refer to "WORKING WITH FILE CONTENTS" on page 3-9 and especially "Power-on Parameter Files" on page 3-2 and "Using Power-on Parameter Files" on page 3-10.

STATES AND INDICATORS

The local, local-with-lockout, remote and remote-with-lockout IEEE-488.1 standard states are discussed in the sections below.

The TALK and LISTEN indicators on the front panel will illuminate whenever the bridge is placed in the talker-active (TACS) or listener-active (LACS) states, respectively, by the GPIB controller.

Local States

In the local state all of the keypad functions on the front panel can be used and the bridge will also respond to the GPIB controller. The bridge powers on in this state. The local state is indicated by the REMOTE LED on the front panel being off.

The local-with-lockout state functions identically to the local state. The only difference is that this state *remembers* the lockout condition so that if the controller returns the instrument to the remote states, the remote-with-lockout state will be entered automatically. The local-with-lockout state is entered from the local state only when the GPIB controller executes the LLO bus command. The local-with-lockout and remote-with-lockout states are exited only when the controller clears the REN bus line.

Remote States

The GPIB controller can cause the bridge to enter the remote state from the local state by setting the REN bus line and addressing the bridge. The bridge will indicate the remote state by illuminating the REMOTE LED on the front panel and will accept commands *only* from the GPIB controller.

In the remote state, all front panel keys with the exception of the [LOCAL] key are disabled. The front panel keys can be enabled by pressing the [LOCAL] key to cause the bridge to

enter the local state. This will occur unless the remote-with-lockout state is active. The GPIB controller can cause the bridge to exit the remote state and enter the local state by executing the GTL bus command. It can also do this by clearing the REN bus line.

The remote-with-lockout state is entered from the remote state when the controller executes the LLO bus command. The remote-with-lockout state is entered from the local-with-lockout state when the controller addresses the bridge.

When in the remote-with-lockout state, the [LOCAL] key is disabled as well as all the other front panel keys, preventing *any* front panel activity from interfering with remote operation. If you press the [LOCAL] key while the bridge is in the remote-with-lockout state, the front panel will display the message:
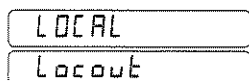
```
 LOCAL
 Locout
```

The GPIB controller can cause the bridge to exit the remote-with-lockout state and enter the local-with-lockout state by executing the GTL bus command. The controller can also cause the bridge to exit the remote-with-lockout state and enter the local state by clearing the REN bus line.

REMOTE COMMAND ENTRY

The entry of commands from a GPIB controller is identical to that from a remote serial device except that immediate-action keys described in the RS-232 chapter are not as useful with the GPIB.

Basic Syntax

The command line entry style used by the AH 2500A will be familiar if you are a user of small computers or terminals. The syntax and command words used also closely parallel those used by the bridge's front panel. The AH 2500A command *definition* syntax is described in "CONVENTIONS USED" on page A-1.

Command lines consist of a leading command word followed by optional command qualifier words followed by optional parameters which are usually numeric. Each command line is terminated with an end-of-line character or character sequence.

Command Word Entry

Since remote commands are named and spelled as they appear on the front panel, any commands described in this manual using key labels also describe the remote commands. When the front panel key label consists of two words, only the first word is used as the remote command word with the exception of the BIAS command. The [FUNC] key has no equivalent on remote devices, of course.

Although commands are English words, it is rarely necessary to use the entire word. You need to use only the first few letters of the command. The minimum number of letters needed depends on the particular command and ranges from one to three letters. The minimum letters needed are underlined where each command is introduced in the text and in Appendix A, "Command Reference". If you do not type in enough letters, the bridge responds with the message AMBIGUOUS WORD :, followed by the offending characters that were entered. If more letters than the required minimum are entered, they must spell the command word correctly or the error message ILLEGAL WORD : will appear, followed by the illegal word that was entered.

Command words are separated from each other and from their associated parameters by spaces. Parameters are separated from each other by periods.

Examples

To illustrate the ideas above, consider the BRIGHTNESS command whose syntax is:

$$\underline{BR}IGHTNESS \; [\underline{C}AP \; or \; \underline{L}OSS] \; level$$

Several examples of valid command lines that might be sent from a GPIB controller are:

```
BRIGHT CAP 5
```

```
BR C 5
```

```
BRIG L 5
```

```
BR 5
```

All are terminated by an end-of-line character.

The entry B 5 will return the error message:

```
AMBIGUOUS WORD: B
```

The entry BRIHGT 5 will return the error message:

```
ILLEGAL WORD: BRIHGT
```

Additional Features

Query Commands

All AH 2500A commands can be classified as query or non-query commands. A query command is one that generates a response message such as a measurement result. The most common examples of these on the AH 2500A are the SINGLE, CONTINUOUS and SHOW commands. If a query command is interrupted by a new command, the query command is immediately aborted, any unread results are cleared from the bridge's output buffer and the new command begins to execute.

A non-query command will finish executing even if it is interrupted by a new command. The new command will be executed after execution of the non-query command is complete.

The concept of query commands is defined by the IEEE-488.2 standard and serves to ensure synchronization between the controller's commands and the responses from the controlled device. In other words, this scheme ensures that any response message received by a controller was generated by the most recently entered command and not by some earlier command. See "Aborting Commands" on page 2-6.

Entering Multiple Commands

Several commands can be entered on the same line separated by semicolons (;). As with individual commands, lines having multiple commands are not executed until an end-of-line character or character sequence is received. An immediate-action command such as Q or X can be entered anywhere on a multi-command line except as the first character and will not be executed until the whole line is received.

Each command line is either a query line or a non-query line. If a multi-command line contains any query commands, the whole command line is considered to be a query line. It will not be possible to predict which commands were executed and which were not if a query command line is interrupted by a new command.

Multi-command lines can be useful with commands that respond with a prompt. For example, every version of the STORE CALIBRATE command prompts for a passcode. The passcode can be entered after the command on the same line if the two are separated by a semicolon. Except for passcodes, any command that requires a response to a prompt will first check the next command on the line. If the next command is an acceptable response to the prompt then it will be used. If not, the next command will not be executed yet. Instead, the prompt will be produced and the bridge will wait for input. If you want to guarantee that a prompt is generated, insert the EDIT command word where the answer to the prompt would go on the command line.

Multi-command lines can also be used to guarantee that a command produces a result. The TEST command can be configured to produce no result unless a failure is detected. However, the command line TEST ; SHOW TEST will always produce a result.

Input Buffer

All command messages including GET messages are stored in the bridge in an input buffer that can hold eighty characters. This means that the bridge will not buffer more than eighty characters ahead of what it is able to process. In addition, it will not accept a command line whose total length exceeds eighty characters. If the latter occurs, the error message LINE TOO LONG will be reported.

RESPONSE MESSAGES

All multi-character data is sent over the GPIB in the form of "messages". Data which is sent *from* the bridge to a controller or logger is sent in the form of "response messages". These messages consist of at least one ASCII character. The END of the message is indicated by simultaneously asserting the GPIB EOI bus wire during the transmission of the last character of the message which is a LF character (ASCII $0A_H$).

A response message consists of one or more lines. Each line is terminated with a semicolon ";" or with CR and LF characters (ASCII $0D_H$ and $0A_H$). The choice of line terminators used is selectable as described in "COMPATIBILITY MODE" on page 6-14.

Almost all query commands generate a single response message. If several commands are entered on a single line separated by semicolons, that command line produces only one response message for the line, not one for each command on the line.

The AH 2500A has three commands that can generate multiple response messages. These are the CONTINUOUS command and the TEST and PROGRAM commands when used with the REPEAT qualifier. The CONTINUOUS command generates response messages continuously until stopped by the SINGLE command. The TEST and PROGRAM commands can also do that or they can generate a pre-determined number of response messages.

Receiving Every Response Message

Some response messages can be lost if the controller or logger is not fast enough or if the controller is not programmed appropriately. However, you have control over what, if anything, is lost by the way in which you operate the bridge and the controller.

Once the controller or logger begins to read a response message, the bridge will wait indefinitely for the rest of the message to be read. This makes it impossible to lose *part* of a message due to a slow response from the controller or logger. On the other hand, if the bridge has a new response message to send before *any* of the previous message has been read, then the previous message will be overwritten by the new message. Thus controllers and loggers are guaranteed to receive *all* or *none* of a response message.

There are two ways in which you can lose a response message:

1. If the controller issues a new command to the bridge while the bridge is waiting for it to read (or finish reading) the last response message, the remainder of that message will be lost. This occurs when a query command is interrupted as described in "Query Commands" on page 6-3. The way that you program and operate your controller determines whether this situation ever occurs.

2. If the bridge is generating multiple response messages from a CONTINUOUS, TEST or PROGRAM command, some messages can be lost if the controller or logger is not fast enough to keep up with the results generated by the bridge.

    If it is important that every response message be received by a controller, then these three commands should not be used. The SINGLE command should be used instead of the CONTINUOUS command and the TEST and PROGRAM commands should be used without the REPEAT qualifier.

    If it is important that every response message be received by a logger, then the HOLD command should be used within a program to add some delay time between each response message. This can slow the bridge down to the speed of the logger. Using the CONTINUOUS qualifier when executing a program will produce similar results.

You *may not* want to capture every result. You may, for example, want to put the bridge into continuous mode so that new measurements are constantly reported to the front panel display while reading only a small fraction of these measurements with the controller.

Using a Multi-command Line to Create a Single Response

The most important difference between commands entered on a single line and commands entered each on their own line is in the response messages that they produce. Each command line produces, at most, one response message except for entry of a CONTINUOUS command or a TEST or PROGRAM command when used with the REPEAT qualifier. It does not matter how many commands are on a line.

All commands entered on a single line will produce a single response message containing all the results generated by the commands on that line. No matter how slow your controller is, it will be sent all of this message if it reads any of it.

Using a Program to Create One Response Message

Placing your commands into an AH 2500A program is another way to guarantee that *all* results from a group of commands are received by a controller or logger. All programs produce a single response message. If a program contains subprograms, the results from all subprograms are also contained in the single message produced by the main program. See "WORKING WITH PROGRAMS" on page 3-10.

As an example, a program containing the command TEST 50 REPEAT will cause every result to be logged no matter how slow the logger is. The command by itself will lose results if the logger is not as fast as the bridge.

Output Buffer

The GPIB output buffer can hold response messages up to 680 characters in length. This is long enough to hold any individual measurement result, but it is not long enough to hold some SHOW, TEST and PROGRAM response messages. In the case where the length of the response message exceeds the size of the output buffer, the controller or logger *must* begin reading the message *before* the buffer overflows. Otherwise, the entire message will be lost. Once the first character of the result is read, the AH 2500A will not generate more results to put in the buffer until the space becomes available as a result of the controller's reading what is there. If the controller starts to read the message but stops or pauses before finishing, the message

```
GPI b  Out
buF  FuI I
```

will appear in the front panel display after about ten seconds. This message will go away as soon as the controller or logger continues reading the message.

STATUS REPORTING

A common feature in GPIB instrumentation is the availability of a status byte that can be read by the GPIB controller at any time without disturbing other operations. Associated with this status byte is a service request enable mask byte which controls the ability to generate service requests that will asynchronously request attention from the controller. The most common use of serial polls and service requests is discussed in "Determining When to Read Results" on page 6-9 and in the subsections on "Serial Polling" and "Service Requests".

Contents of the GPIB Status Byte

The AH 2500A supports the serial poll features of the GPIB bus by assigning all of the available seven bits in its status byte (SB) register to indicate various events and conditions. To identify the meaning of each of these bits, assume that they are numbered with the least significant bit being zero and the most significant bit being seven. The meanings and functions are given in Table 6-1.

This table gives the full name and the abbreviated label used in this manual for each bit. The column labeled "Set when" describes the condition(s) required to set the corresponding bit. Similarly, the column labeled "Cleared when" describes the condition(s) required to clear the corresponding bit.

In general, service requests may be generated when one of these bits makes a transition from zero to one, from one to zero or both. The column labeled "Generates SRQ when" describes the transition required of the bit to cause a service request. This is discussed further in "The Service Request Enable Mask Byte" on page 6-7.

Table 6-1 Status byte register bit definitions and functions

Bit	Label	Name	Set when	Cleared when	Generates SRQ when
0	ONR	Oven Not Ready	Oven temperature is abnormal	Oven temperature returns to normal	set or cleared
1	CME	CoMmand Error	An error in the entry of a command occurred. See Appendix B, "Error Messages" for a list.	SHOW STATUS or RST is executed	set
2	URQ	User ReQuest	The USER command is executed	SHOW STATUS or RST is executed	set
3	PON	Power-ON	Bridge power comes on	SHOW STATUS or RST is executed	set
4	RDY	ReaDY for command	A command line finishes its execution; see "INTERACTIVE OPERATION" on page 6-12	A new command line is received	set
5	EXE	EXecution Error	An error occurred executing a command. See Appendix B, "Error Messages" for a list.	SHOW STATUS or RST is executed	set
6	RQS	ReQuest for Service	Service from controller is requested	Controller performs a serial poll	see text
6	MSS	Master Summary Status	Inclusive OR of the bit-wise combination of bits 1-7 of the SB and SRE registers is true or when the ONR status bit changes while the corresponding ONR bit in SRE register is set.	Inclusive OR of SB and SRE is false	see text
7	MAV	Message AVailable	A message is available in the GPIB output buffer	No message is in the GPIB output buffer.	set

The meaning of bit six of the status byte depends upon whether it is read with a command or it is read by a serial poll. This is explained in the sections below.

The possible applications of the ONR, CME, PON, and EXE bits are self-evident. See Appendix B, "Error Messages", for a complete list of all the error conditions that can set the CME and EXE bits. The MAV bit is the single most useful status bit. Its utility is discussed in "Determining When to Read Results" on page 6-9. Examples follow the discussion. The RDY bit is probably the second most useful bit. Its utility is discussed in "INTERACTIVE OPERATION" on page 6-12. The use of the URQ bit is discussed next.

A User Settable Status Bit

There is one bit in the AH 2500A status byte that you can *directly* cause to be set by issuing a command. This is the User ReQuest (URQ) bit (bit 2). The URQ bit is set by executing the command:

USER

Once set, this bit will stay set until a SHOW STATUS or RST command is executed.

This command allows you to indicate to the GPIB controller when certain conditions of your choosing occur. The USER command gives you the ability to indicate the initiation or completion of commands in command lines having more than one command or in AH 2500A programs.

As an example, suppose an external trigger is to cause a measurement to occur. If the command line or program executed is "HOLD 0; USER; SINGLE", then the GPIB controller will be informed via the setting of the URQ bit in the status register (or via an equivalent service request) that an external trigger has just initiated a new measurement.

Reading the Status with a Command

The status byte can be read with a command whose syntax is:

SHOW STATUS

The result will be reported as individual binary bits unless compatibility mode is enabled. Compatibility mode will cause the value to be reported as a binary-weighted-decimal integer. To change the setting of compatibility mode see "COMPATIBILITY MODE" on page 6-14.

This command also clears the four event status bits (CME, URQ, PON and EXE) in the status byte and the ONR *event* bit. These bits indicate the occurrence of *events* whereas the ONR, RDY and MAV status bits represent *states or conditions*.

While not apparent by reading the table, there is both an ONR *status* bit and an ONR *event* bit. The ONR status bit always indicates the current condition of the oven. The ONR event bit is set when the ONR status bit changes. There is no way to read the ONR event bit.

The SHOW STATUS command reads the event bits in the status byte *immediately before they are cleared* so that no information can be lost between the time they are read and the time they are cleared. The SHOW STATUS command is not available from the front panel of the AH 2500A. However, the status can be read from the front panel as the first line in the SHOW SPECIAL list.

The SHOW STATUS command will always return the most recent status byte value in the GPIB output buffer. The meanings of the status byte bits are independent of how the byte is read except for bit six. When this command is used, bit six of the status byte is read as the Master Summary Status (MSS). This bit provides a summary of all the other status bits that have been enabled to cause service requests. The MSS bit does not necessarily indicate that a service request is pending. It only indicates that one was initiated and may or may not have been serviced. This is discussed in more detail in "Selecting What Can Make Requests"below.

Reading the Status with a Serial Poll

A serial poll is an operation performed by the GPIB controller to read the status byte(s) of a device or group of devices. More specifically, a serial poll is most often used to determine which devices are ready for service and what the nature of that service should be. The advantage of a serial poll is that it does not disturb the operations of the instrument that is being polled. The controller can either periodically perform a serial poll of all devices to determine their current status or the controller may do so only when interrupted by a service request from one of the remote devices.

The status information obtained with a serial poll will be identical to that obtained with the SHOW STATUS command except for the value of bit six. When read using a serial poll, bit six is always the ReQuest for Service (RQS) bit, not the MSS bit. Bit six will be set if the bridge initiated a service request, and clear if it did not. Performing a serial poll clears the RQS bit but has no effect on any other bits in the status register including the MSS bit.

Reviewing the technical details required to perform a typical serial poll, the controller first sends an SPE bus command to the remote devices. This places the remote devices in serial poll mode. The controller then addresses each device one-by-one to talk. Each device returns its own status byte to the controller when its turn to talk comes. The controller can act on this status information immediately or save it for later analysis. When all the devices have been polled, the controller sends the SPD bus command followed by the UNT bus command.

Most controllers provide simple ways of performing serial polls. For examples, see "Controller Initiated / Serial Poll" on page 6-10 and "Non-Controller Initiated / Serial Poll" on page 6-11.

Service Requests

If the other devices in the system have the GPIB service request function in addition to the serial poll function, then the use of service requests in conjunction with the serial poll function is probably preferable to doing serial polls by themselves. To use service requests, your controller must first enable this function in each of the desired individual instruments using the commands defined by the manufacturers of these instruments. The controller is then free to ignore the bus and perform other lower priority tasks. When one or more of the instruments on the bus requires service, it will assert the SRQ bus line which in turn will interrupt the controller. The controller then performs a serial poll in the manner described earlier. When the controller reads the status byte of the device that asserted the SRQ line, the device will release this line. If that device was the only requesting device, the line will become unasserted. If the controller is checking the SRQ line, it can terminate the poll at this time. The bits in the status byte read from the requesting device should indicate the nature of the service that the requesting device requires.

If more than one device on the bus had requested service, then the SRQ line will not become unasserted when the status byte of the first requesting device is read. For this reason, it is essential when there is more than one remote device on the bus with service requests enabled, for the controller to test the RQS bit (bit six) of the status byte that is received from each device. The requesting device(s) will always have this bit set and thus the controller can determine which devices need service even if there is more than one. The bus controller must service each request before another request can occur.

The next two sections explain how to enable service requests in the AH 2500A. Examples of their use are given in "Controller Initiated / Service Request" on page 6-10, "Non-Controller Initiated / Service Request" on page 6-11 and "Two Interactive Program Examples" on page 6-13

The Service Request Enable Mask Byte

To control which status changes can cause service requests to occur, the AH 2500A contains a second register called the "Service Request Enable mask byte" abbreviated SRE. The bits in this register mirror those in the status byte except for bit six which is not used in the SRE byte.

The SRE byte is used to determine which bit changes in the status byte are allowed to send a service request to the GPIB controller. Any bits which are set in the SRE byte will allow certain changes in the corresponding bits in the status byte to cause a service request. Which status changes (set or clear) that are actually allowed to cause a service request are listed for each bit in the column labeled "Generates SRQ when" in Table 6-1.

Selecting What Can Make Requests

To specify which of the bits in the AH 2500A status byte are allowed to initiate a service request, the following command can be issued only from a remote device to set bits in the SRE byte:

$$SRE \quad mav . exe . rdy . pon . urq . cme . onr$$

where each label that is entered is a one if transitions in that status condition are to cause a service request and zero if not. The first period is mandatory when the mask is entered in this binary format. This command uses positional parameters as described in "Positional Parameters" on page A-1.

The example SRE .1...0.1 will enable the *exe* and *cme* error event bits to cause service requests. The *urq* event status bit will be disabled and all other SRE bits will be left as they were.

The binary parameter accepted by the SRE command shown above is easier to use and more flexible than the conventional binary weighted decimal that is standard. If you prefer to use the standard, enter the command:

$$SRE \quad bwdmask$$

The *bwdmask* (binary-weighted-decimal mask) value can have any value from 0 to 255. When this value is translated to binary, the bit positions that are ones will cause the corresponding service requests to be allowed. The only exception is bit position six which is ignored. The default value of the service request enable mask stored in the BUS 0 parameter file is zero.

Note that under certain conditions it is possible for the AH 2500A to cause extraneous service requests. This is not a problem provided that the controller always performs a serial poll after each service request to verify that a new reason for service has actually occurred. Note also that all status bits must be treated like *states*, not *events*, since *multiple* service requests might occur for the same status bit.

Reading the Service Request Enable Byte

The current value of the service request enable mask can be read using the command:

$$SHOW \quad SRE$$

The value will be reported as individual binary bits unless compatibility mode is enabled. Compatibility mode will cause the value to be reported as a binary weighted decimal integer. To change the setting of this mode see "COMPATI-BILITY MODE" on page 6-14.

The SHOW SRE command is not available from the front panel of the AH 2500A, but can be shown there as one of the windows in the SHOW BUS list. The SRE commands can be executed *indirectly* from the front panel if they are placed in an AH 2500A program.

MAKING GPIB MEASUREMENTS

This section discusses the various ways that a GPIB controller can be programmed to initiate measurements and read results from the AH 2500A. There is not much that is unique to the AH 2500A presented in this section. With the exception of the exact command syntax, everything discussed here is typical of other GPIB measuring instruments. This section should be helpful if you are not very familiar with GPIB operation and are looking for some examples to get started with.

Initiation of Measurements

There are two fundamentally different ways of initiating measurements in a GPIB environment. Either the GPIB controller can initiate them or something else can initiate them.

Controller Initiated Measurements

A GPIB controller has two ways of initiating measurements.

1. One way is to use the SINGLE or TRG commands to start a measurement. These AH 2500A commands are each capable of initiating a single measurement. They are described in more detail in "Taking Measurements One at a Time" on page 4-4.

2. A measurement can also be initiated from the controller with a GET (Group Execute Trigger) bus command if the bridge is addressed to listen. The GET command will be executed by the bridge in the remote or in the local states. This command has the ability to simultaneously trigger a number of devices that are connected to the GPIB bus. This can be useful for fast bus devices, but offers little advantage with the AH 2500A.

The common characteristic of the SINGLE, TRG and GET commands is that the controller initiated these commands and therefore, the controller "knows" when the corresponding results are expected to be available.

Non-Controller Initiated Measurements

There are several ways that measurements can be initiated without the GPIB controller being involved. These are:

1. The bridge can be programmed so that a signal on the external trigger input of the AH 2500A can initiate a measurement.

2. The SINGLE key on the front panel of the bridge can initiate a measurement.

3. The CONTINUOUS command will cause the AH 2500A to initiate readings on its own at a rate specified when the command is entered. Although the GPIB controller could issue this command, the resulting readings cannot be considered to be controller initiated. The controller would "know" the *rate* at which measurements would be taken, but it would not "know" *when* the results would be available.

4. Program files in the AH 2500A can initiate more complex measurement sequences. The TRG and GET commands also have this ability.

The common characteristic of the external trigger, front panel SINGLE key and CONTINUOUS commands and possibly of the programmed command sequences, is that the controller did not initiate these commands. Therefore, the controller "does not know" when the corresponding results are expected to be available without its getting more information.

Synchronization

Perhaps the most important reason for distinguishing between controller and non-controller initiated measurements is the effect upon synchronization. It is frequently critical to know that a given measurement result was caused by a particular initiation event and not by the initiation event preceding or following the desired event. Synchronization occurs when the result read by the GPIB controller is always caused by the desired initiation event.

When the controller initiates each individual measurement, synchronization is automatically obtained if the controller does not initiate another measurement until the result from the current measurement has been read. (To guarantee synchronization, it is essential that a measuring instrument automatically abort query commands which are interrupted by other commands.)

When the controller does not initiate each individual measurement, it will have no way to maintain synchronization unless other information or signals can be used.

Determining When to Read Results

Once a measurement has been initiated, the AH 2500A will then spend anywhere from about 40 milliseconds to 1000 seconds making the requested measurement. The GPIB controller then has three methods available to read the result from the bridge. These are discussed in the three sections below in increasing order of performance.

Hanging the Bus

The simplest way for a GPIB controller to get results from an bridge is to initiate a data transfer from the bridge anytime a measurement result is expected to be forthcoming. This will cause the GPIB bus to be hung until a result becomes available from the bridge. There is little disadvantage to this approach *if* no other devices on the bus need to be serviced during this time and *if* the controller does not need the processing time for another task.

Serial Polling

The GPIB controller can be programmed to periodically perform a serial poll of the status bytes of all the active devices on the bus. Such polling could read the status byte of the AH 2500A to see if a result is available. If the MAV bit in the status byte is set, then the measurement has been completed and it (or an error message) can be read by the controller.

When there are a number of devices on the GPIB bus, a disadvantage to this approach is that controller programs may have to be carefully written to ensure that the status byte is checked often. Otherwise, if measurements are not controller-initiated, data may be lost since the most recent measurement result will overwrite any unread previous result.

Service Requests

The highest performance method is to use the service request interrupt capability of the GPIB bus. With the MAV bit of the AH 2500A service request enable mask set, the GPIB controller will be interrupted every time a measurement result becomes available. This allows the controller to start a measurement and then perform other tasks until a service request occurs. The controller then does a serial poll to find out which device caused the interrupt. If it finds that the RQS bit (bit six) in the AH 2500A status byte was set then it knows that the AH 2500A generated a service request to the controller. The controller should then check the other bits in the status byte to see if the expected measurement result is available or if some kind of error has occurred instead or in addition. If it finds the MAV bit set and no error bits set, then the measurement result can be read from the bridge and assumed to be valid.

Using service requests almost always minimizes the amount of GPIB controller processing time used. The amount of time spent doing GPIB bus operations is also almost always minimized.

Six Examples

Each section below gives one example of a program having the characteristics given in its section title. The programs show several different examples of both controller and non-controller initiated measurements. All programs are written in TransEra HTBASIC which emulates an HP9000 series 200/300 workstation. The AH 2500A default parameters are assumed.

None of the example programs in this chapter test the status byte for errors because all errors generate a result, even for commands that are not ordinarily query commands. Thus it is only necessary to report any results that become available in order to catch any error messages that might occur. For examples using a serial poll, it is only necessary to test the MAV bit to detect a possible error message. The EXE and CME error bits need not be checked if MAV is checked and if the corresponding result is reported.

Controller Initiated / Bus Wait

The first example, shown in Figure 6-1, is the very simplest. This program contains a short loop which issues a SINGLE command to the AH 2500A, then immediately sets up a data transfer from the bridge. The controller then waits as long as necessary for the measurement result to be returned. When it is, the controller reports the result and starts the loop again.

```
100 DIM A$[80]
110 OUTPUT 728; "SINGLE"
120 ENTER 728; A$
130 PRINT A$
140 GOTO 110
150 END
```

Figure 6-1 A simple controller-initiated program.

Pros and cons:

*   Simplest to implement.

*   No readings are ever lost.

*   Maximum measurement rate if controller initiates readings before bridge finishes measurements.

*   Wastes controller execution time if controller initiates readings before bridge finishes measurements.

*   Wastes bus operation time if controller initiates a reading before bridge finishes a measurement.

Controller Initiated / Serial Poll

The second example, shown in Figure 6-2, uses the GPIB GET command to initiate a measurement. A GET program producing a *single* measurement result is assumed to exist. An example is given in "Initiating with a TRG/GET Program" on page 4-4. After measurement initiation, the controller stays in the serial poll program loop until the MAV bit (bit seven) in the AH 2500A status byte is set. When this occurs, the result is reported and the main program loop is started again.

```
100 DIM A$[80]
110 OUTPUT 728; "BUS ...1.0"
120 TRIGGER 728          !ISSUE A "GET"
130 S=SPOLL(728)
140 IF NOT BIT(S,7) THEN GOTO 130
150 ENTER 728; A$
160 PRINT A$
170 GOTO 120
180 END
```

Figure 6-2 A GET-initiated, serial poll program.

Pros and cons:

*   No readings are ever lost.

*   High measurement rate.

*   Wastes controller execution time.

Controller Initiated / Service Request

The third example, shown in Figure 6-3, uses the TRG command to initiate each measurement. As in the previous example, an appropriate GET program such as that in "Initiating with a TRG/GET Program" on page 4-4 is assumed to exist. After service requests are enabled and the initial TRG command is issued, the controller program is free to execute any other code that might be useful.

When the bridge has a result, it will generate a service request which will cause the controller to begin executing the program's interrupt code. This code will poll the instruments on the bus to see which have the RQS bit (bit six) set. When the code finds this bit set in the AH 2500A's status byte, it will check the MAV bit (bit seven) to see if the measurement completed. If so, the result is reported, a TRG command is issued again to start another measurement, and the controller returns to the code that was executing at the time of the service request interrupt.

```
100 DIM A$[80]
110 ON INTR 7 GOSUB 170
120 OUTPUT 728; "BUS ...1.0"
130 OUTPUT 728; "SRE 1.;TRG"
140 ENABLE INTR 7;2
150 GOTO 150                    !IDLE LOOP
170 STATUS 7,1; S !CLEAR CONTROLR STATUS
180 S=SPOLL(728)
190 IF NOT (BIT(S,6) AND BIT(S,7))
      THEN GOTO 230
200 ENTER 728; A$
210 PRINT A$
220 OUTPUT 728; "TRG"
230 ENABLE INTR 7;2
240 RETURN
250 END
```

Figure 6-3 A controller-initiated program using service requests.

Pros and cons:

*   Minimizes controller execution time.

*   No readings are ever lost.

*   High measurement rate.

*   Minimizes effects on operation of other bus devices.

Non-Controller Initiated / Bus Wait

The fourth example, shown in Figure 6-4, is similar to the first except that measurements are started with the CONTINUOUS command. This command is issued once at the top of the program. Since the default time parameter for the CONTINUOUS command is zero, the bridge will take measurements at a rate determined by the AVERAGE command.

The program contains a short loop which immediately sets up a data transfer from the bridge. The controller then waits as long as necessary for the measurement result to be returned. When it is, the controller reports the result and starts the loop again. If the time used by the controller to read and report the result is less than the time used by the bridge to make a measurement, then no measurement results will be missed.

```
100 DIM A$[80]
110 OUTPUT 728; "CONTINUOUS"
120 ENTER 728; A$
130 PRINT A$
140 GOTO 120
150 END
```

Figure 6-4 A simple non-controller-initiated program.

Pros and cons:

- Simple to implement.

- Front panel display always shows the latest measurement independent of the controller's actions.

- No readings are ever lost only if the controller consistently begins reading the bridge before the bridge finishes the next measurement.

- Maximum measurement rate if controller initiates readings before bridge finishes measurements.

- Wastes controller execution time if controller initiates readings before bridge finishes measurements.

- Wastes bus operation time if controller initiates a reading before bridge finishes a measurement.

Non-Controller Initiated / Serial Poll

The example in Figure 6-5 is similar to that in Figure 6-2 except that the measurements are assumed to be initiated by signals entering the external trigger input of the AH 2500A. This example creates an external trigger program and stores it in PROGRAM 10. This program file causes a single measurement to occur for each external trigger pulse or contact closure. As in the previous example, if the time used by the controller to read and report the result is less than the time used by the bridge to make a measurement, then no measurement results will be missed. However, trigger pulses can be lost (ignored) if they occur too rapidly. See "Handling Unexpected Trigger Pulses" on page 3-14 for more information.

```
100 DIM A$[80]
110 OUTPUT 728; "PROGRAM CREATE"
120 OUTPUT 728; "HOLD 0"
130 OUTPUT 728; "SINGLE"
135 WAIT .1 !NEED AFTER QUERY IN PROGRAM
140 OUTPUT 728; ""
150 OUTPUT 728; "STORE PROGRAM 10"
160 OUTPUT 728; "PROG 10"
170 S=SPOLL(728)
180 IF NOT BIT(S,7) THEN GOTO 170
190 ENTER 728; A$
200 PRINT A$
210 GOTO 160
220 END
```

Figure 6-5 A non-controller-initiated program using serial polls.

Pros and cons:

- Front panel display always shows the latest measurement independent of the controller's actions.

- No readings are ever lost due to a slow controller since the HOLD 0 command synchronizes the controller to the external trigger buffer.

- High measurement rate.

- Wastes controller execution time.

Non-Controller Initiated / Service Request

The example in Figure 6-6 is similar to that in Figure 6-3 except that the measurements are assumed to be initiated by a person that has executed a command from the front panel of the bridge. This can be any command or AH 2500A program that generates measurement results.

```
100 DIM A$[80]
110 ON INTR 7 GOSUB 180
120 OUTPUT 728; "BUS ...1.0;SRE 1."
130 OUTPUT 728; "LOG BUS 1"
140 LOCAL 728
150 ENABLE INTR 7;2
160 GOTO 160                    !IDLE LOOP
170 !
180 STATUS 7,1; S !CLEAR CONTROLR STATUS
190 S=SPOLL(728)
200 IF NOT (BIT(S,6) AND BIT(S,7))
        THEN GOTO 230
210 ENTER 728; A$
220 PRINT A$
230 ENABLE INTR 7;2
240 RETURN
250 END
```

Figure 6-6 A non-controller-initiated program using service requests.

The controller program enables service requests and then causes a GPIB GTL bus command to be executed. This puts the bridge in the local state so that commands entered on the front panel will be accepted. The program could have unasserted the GPIB REN line instead of causing a GPIB GTL bus command to be executed.

This program changes the Logger Bus parameter to its default value of one in case it has been changed to zero. Otherwise, the controller will not receive any results.

Pros and cons:

- Minimizes controller execution time.

- Front panel display always shows the latest measurement independent of the controller's actions.

- No readings are ever lost only if the controller consistently begins reading the bridge before the bridge finishes the next measurement.

- High measurement rate.

- Minimizes effects on operation of other bus devices.

INTERACTIVE OPERATION

It is possible to program your GPIB controller so that you can converse interactively with your AH 2500A just as you would from the front panel of the bridge or via the RS-232 port. Such programming can communicate even while other bus and controller operations are going on.

Benefits

Interactive communication can be very useful in the following situations:

1. You are just learning how to use the bridge and want to explore its commands.

2. You know how to use the bridge and its commands, but want to experiment with bridge parameters to determine what is best for your application.

3. You have written a program, but it doesn't work. You can use an interactive program (like the example given later) to test the ideas in the program you wrote.

4. Your use of the bridge is not sufficiently structured or your applications are too varied to justify writing programs for your controller. Nevertheless, you want the advantages of seeing your commands and results on your GPIB controller screen and you want the option of saving them to a file or printer.

5. You want *one* program that can access virtually all of the bridge's features.

6. You want to fully calibrate the bridge via the GPIB. This *requires* interactive operations.

If any of the above situations apply, you will benefit from running an interactive program on your GPIB controller.

Establishing Interactive Operation

An interactive program operates by accepting a command line that you type into your GPIB controller. When you press the RETURN key on your keyboard, the interactive program sends your command line to the AH 2500A. The bridge executes the command line and may or may not produce a result for you to read. If a result is available, an interactive program will read it and display it on your GPIB controller screen. Whether or not a result was available, a prompt is shown on your screen to indicate that the bridge is ready for you to enter another command line. This loop can continue indefinitely.

A second feature is required of an interactive program to handle the case where you might want to interrupt a CONTINUOUS command or other command. Your controller may require that its interactive program execute a command such as INPUT to be able to read its keyboard. While a CONTINUOUS command is executing, an interactive program will not put a prompt on your GPIB controller screen or attempt to read its keyboard. Without this, you are unable to enter a

new command line to interrupt the bridge. As a result, an interactive program must have the ability to recognize a special key or key sequence from your keyboard. When this key sequence is pressed, the program will put a new command line prompt on your GPIB controller screen and request input from the keyboard. The bridge will be interrupted after a complete command is entered in response to this prompt.

The key to communicating interactively is in having a way for the GPIB controller to determine that the bridge is ready for another command. The AH 2500A provides two ways to do this:

1. The Status Byte Register contains a RDY bit that is set when the bridge is waiting to receive another command.

2. An optional prompt string can be sent to the GPIB when the bridge is ready to receive another command.

The GPIB controller can be programmed to use either or both of these detection methods to communicate interactively. In either case, it is necessary to monitor the MAV status bit. The use of these two methods is discussed below.

Using the RDY and MAV Status Bits

A program running on a GPIB controller can communicate interactively by using the MAV and RDY bits. The MAV bit tells the controller when to read and display a result from the AH 2500A. The RDY bit tells the controller when to show a prompt on its screen to indicate that another command line can be entered. On some controllers the RDY bit may also be essential for telling the program when to request input from its keyboard. The RDY bit provides a simple way to determine when the bridge is ready to receive a command, but it does not pass any other information. The RDY and MAV bits can be monitored with a serial poll or with service requests.

Enabling the GPIB Prompts Feature

You can configure your bridge to send all the same prompt strings to the GPIB port as are sent to the RS-232. This is useful because many of these prompts contain information that suggests what to do next. With Option-E bridges, execution of a CALIBRATE 3 command *requires* the ability to read these prompts.

GPIB prompts are enabled and disabled with the command:

$$\underline{BUS} \; \ldots . \, prompts$$

The prompts feature is enabled when the *prompts* parameter bit is set to a one. The default value of the *prompts* parameter stored in the BUS 0 parameter file is zero.

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When the *prompts* parameter is set, each prompt generated by the bridge is appended as the last line of any query result. If there is no associated query result, then a message is sent that contains only the prompt. These prompts provide much more information than the RDY bit, but add complexity to any results sent from the bridge. For this reason, they are best suited for human readability whereas the RDY bit by itself is more optimum for machine readability.

Two Interactive Program Examples

The examples in Figure 6-7 and Figure 6-8 will allow interactive communication with the AH 2500A via a GPIB controller. The first program uses only serial polls; the second uses service requests. Like the previous examples, these programs are also written in HTBASIC.

```
10   ! A PROGRAM TO COMMUNICATE
20   ! INTERACTIVELY WITH THE 2500A
30   ! USING ONLY SERIAL POLLING.
40   !
100  DIM A$[3000]
110  DIM B$[100]
120  ! F11 KEY FORCES COMMAND MODE
130  CONFIGURE KEY 133 TO NUM("1")
140  ON KEY 1 GOTO 910
150  ! ENABLE PROMPTS TO BE SENT:
160  OUTPUT 728; "BUS ...1.1"
170  !
300  ! BEGIN MAIN LOOP
310  S=SPOLL(728)
320  ! TEST MAV STATUS BIT:
330  IF BIT(S,7) THEN GOTO 510
340  ! TEST RDY STATUS BIT:
350  IF BIT(S,4) THEN GOTO 920
360  GOTO 310
370  !
500  ! PROCESS RESULT FROM 2500A
510  ENTER 728 ; A$
520  I=POS(A$,";")
530  IF I=0 THEN 600
540  B$=A$[1,I-1]
550  PRINT B$     !SHOW A LINE AT A TIME
560  A$=A$[I+1,LEN(A$)]
570  GOTO 520
600  PRINT A$;    !SHOW LAST LINE OF RESULT
610  IF BIT(S,4) THEN GOTO 920
620  PRINT        !FORCE NEW LINE IF NO PROMPT
630  GOTO 310
640  !
900  ! DCL AND COMMAND INTERRUPT
910  PRINT "CMD>";
920  S=SPOLL(728)  !TURN OFF 2500 TALK LED
930  B$=""         !ELIMINATE PREVIOUS INPUT
940  INPUT B$
950  ! CONTROL E RESETS AH2500A:
960  IF B$[1]<>CHR$(5) THEN GOTO 990
970  CLEAR 728
980  GOTO 920
990  OUTPUT 728; B$
1000 PRINT B$
1010 GOTO 310
1020 END
```

Figure 6-7 A program that allows interactive operation with the AH 2500A using only serial polling.

Both programs first configure the AH 2500A so that it is in GPIB compatibility mode and so that prompt messages will be sent. Near the top of each program, the ON KEY 1 instruction was executed to make the "F11" key special. Pressing the F11 key on the GPIB controller's keyboard causes a COMMAND INTERRUPT routine to be executed. This routine first displays a "CMD>" prompt on the controller's screen. After a command line is entered in response, the program sends the line to the AH 2500A where it is executed. If a ^E is entered instead, a Device Clear is sent to the bridge and the controller will continue to wait for a command line to be input.

When the AH 2500A is done executing the command line, it sets its MAV bit and possibly its RDY bit also. If the OUTPUT 728; "SRE 1..1" instruction was executed as in the program of Figure 6-8, then a service request will also occur. The controller then reads the bridge's status byte with a serial poll. The controller tests the MAV bit in the status byte. If it is set, the controller reads the result from the bridge and displays it on the controller's screen. If the RDY bit is also set, then the controller prompts for another command input. Otherwise, the controller returns to wait for the MAV or RDY bit to become set again.

In these programs, the message result processing routine looks for any semi-colon (;) characters that might be in the message sent by the bridge. These are used to delineate each line of characters of the message that is shown on the GPIB controller's screen. If the bridge is not run in compatibility mode, then this code must search for line feed characters (LF or 10) rather than semicolons. Many controllers are more sophisticated and would not require this translation.

These programs are "hung" in a loop until a command line is entered, but a more sophisticated rewrite of this program might allow the controller to do other things while it is waiting for a command line to be entered.

Both programs will work as they stand without enabling prompt messages to be sent. They will simply be less friendly to use since less information will be shown on the controller screen.

Sometimes the RDY and MAV bits are both set together in the status byte. Other times they are set separately so that two readings of the status byte are required to detect them. Depending on exactly how the interactive program works, this difference can leave the TALK LED on the bridge's front panel on in one case and off in the other. Since it is more meaningful to have the TALK LED off when no talking is actually occurring, line 910 in both programs is used only to ensure that the AH 2500A is untalked when prompts are displayed.

```
10   ! A PROGRAM TO COMMUNICATE
20   ! INTERACTIVELY WITH THE 2500A
30   ! USING SERVICE REQUESTS.
40   !
100  DIM A$[3000]
110  DIM B$[100]
120  CONFIGURE KEY 133 TO NUM("1")  ! F11
130  ON KEY 1 GOSUB 820
140  ON INTR 7 GOSUB 310
150  ! ENABLE PROMPTS TO BE SENT:
160  OUTPUT 728; "BUS ...1.1"
170  ! SET MAV AND RDY SRE BITS:
180  OUTPUT 728; "SRE 1..1"
190  ENABLE INTR 7;2
200  !
210  GOTO 210                    ! IDLE LOOP
220  !
300  ! PROCESS SERVICE REQUESTS
310  STATUS 7,1; S !CLEAR CONTROLR STATUS
320  S=SPOLL(728)
330  ! TEST RQS STATUS BIT:
340  IF BIT(S,6) THEN GOSUB 510
350  ON KEY 1 GOSUB 820          !GOSUB
360  ENABLE INTR 7;2
370  RETURN
380  !
500  ! REPORT ANY RESULT FROM 2500A
510  ON KEY 1 GOTO 820           !GOTO
520  ! TEST MAV STATUS BIT:
530  IF BIT(S,7) THEN GOTO 610
540  ! TEST RDY STATUS BIT:
550  IF BIT(S,4) THEN GOTO 910
560  RETURN
570  !
600  !PROCESS RESULT FROM 2500A
610  ENTER 728 ; A$
620  I=POS(A$,";")
630  IF I=0 THEN 700
640  B$=A$[1,I-1]
650  PRINT B$          !SHOW A LINE AT A TIME
660  A$=A$[I+1,LEN(A$)]
670  GOTO 620
680  !
700  PRINT A$;     !SHOW LAST LINE OF RESULT
710  IF BIT(S,4) THEN GOTO 910
720  PRINT      !FORCE NEW LINE IF NO PROMPT
730  RETURN
740  !
800  ! DCL AND COMMAND INTERRUPT
810  OFF INTR 7
820  PRINT "CMD>";
830  GOSUB 910
840  ON INTR 7 GOSUB 310
850  RETURN
860  !
900  ! TEST INPUT FOR ^E DEVICE CLEAR
910  S=SPOLL(728) !TURN OFF 2500 TALK LED
920  B$=""        !ELIMINATE PREVIOUS INPUT
930  INPUT B$
940  IF B$[1]<>CHR$(5) THEN GOTO 970
950  CLEAR 728
960  GOTO 920
970  OUTPUT 728; B$
980  PRINT B$
990  RETURN
999  END
```

Figure 6-8 A program that allows interactive operation with the AH 2500A using service requests.

COMPATIBILITY MODE

The IEEE-488.2 standard requires at least two unfortunate data formats that are still used only to maintain compatibility with past practice. These are:

1. The values of status and mask bytes are represented as binary weighted decimal numbers. A modern representation would use binary, octal or hexadecimal. Any of the latter formats allows the value of individual bits to be much more easily determined and changed.

2. Result lines are separated with semicolons (;) rather than LF characters (ASCII $0A_H$). For message results having multiple lines totaling more than about 80 characters the use of semicolons as separators makes such a result harder to display and print. Most other conventions require LF as a line terminator.

Using an abbreviated form of the command introduced in "Setting the Configuration Parameters" on page 6-2, the AH 2500A allows you to choose between compatibility and convenience. This command

$$\underline{BUS} \ldots compat$$

selects compatibility mode when *compat* is set to one. In compatibility mode, all status byte values are reported in binary weighted decimal and all result lines are separated with semicolons. With compatibility mode off, all status byte values are reported in binary and all result lines are separated with LF characters. All messages are terminated with LF^END no matter how compatibility mode is set. (A message consists of one or more result lines.)

The default compatibility parameter value stored in the BUS 0 parameter file is zero.

INITIALIZING THE BRIDGE

There are three different initialization functions that can be issued to the AH 2500A from the GPIB bus. These are the Interface Clear bus command (IFC), the DCL and SDC Device Clear bus commands and the RST bridge command. The DCL and SDC commands have the same effect on the bridge.

These three initialization commands form a hierarchy in the sense that it may be necessary (due to some malfunction) to issue a lower command before the next will be accepted. The RST command might not be accepted before an SDC or DCL command is issued. The SDC or DCL commands might not be accepted before an IFC command is issued.

Interface Clear

The interface clear (IFC) command is communicated from the GPIB controller via a dedicated line on the GPIB bus. This command will clear parts of the AH 2500A GPIB interface to the extent required to be able to (at least) accept a DCL or SDC command.

Device Clear Commands

The execution of a general DCL (Device CLear) command from the GPIB controller will cause all remote devices on the bus with this capability including the AH 2500A to reset their internal command processing related functions. The controller may also address an instrument to be a listener and then issue an SDC (Selective Device Clear) bus command to reset the same functions in that instrument only. The GPIB device clear commands have exactly the same effect as a ^E character from the serial port and the FUNC CLEAR FUNC CLEAR front panel key sequence.

The items reset include:

- The GPIB input buffer
- The GPIB output buffer
- Command processing functions
- Result formatting functions

The RST Command

The effect of this AH 2500A command is to put all higher control sections of the bridge except for the bus control circuitry into the same state as at power-on. The PON status bit is *not* set when this command is executed. In fact, it is cleared.

Bridge parameters in the Basic and Gauge parameter sets are set to their power-on values as contained in the parameter sets numbered zero or one. Parameters in the Bus and Baud parameter sets are *not* initialized. See "PARAMETER SET INITIALIZATION" on page 3-10 for a more detailed explanation of power-on parameters.

GPIB DATA LOGGING

The AH 2500A can send all commands that are entered and all measurement data that is initiated from the front panel to the GPIB port. This allows you to keep a log of some or all bridge activity without necessarily having a GPIB controller. You can, instead, connect a GPIB printer or other GPIB logging device (logger) to the GPIB port.

The logger should be able to read fast enough to handle the maximum data rate that the bridge is expected to produce. If it is not fast enough, all result lines will still be complete, but some lines will be lost. See "Receiving Every Response Message" on page 6-4 for more information.

Enabling/Disabling GPIB Logging

Logging to the GPIB port is enabled and disabled with the following command:

$$\underline{\text{LOGGER}} \ \underline{\text{BUS}} \ \textit{content}$$

The *content* parameter controls what, if anything, is logged to the GPIB port. The allowable values of the *content* parameter and the corresponding messages sent are listed in Table 6-2. This table is identical to the corresponding serial port Table 7-2 on page 7-13.

Table 6-2 Content parameter values

Content	Messages Sent to Logger
0	None (logging is disabled)
1	Measurement results only
2	All results (measurement and show)
3	All commands and all results

The default *content* parameter value stored in the BUS 0 parameter file is one. This enables logging to a remote GPIB device. This is a different default value from the RS-232 case. The reason is discussed in the next section.

Logging to a Controller

Logging to a GPIB controller is simple. Once logging has been enabled with the LOGGER BUS command from the front panel, all the controller has to do is to read the results. To create some results to read, use the CONTINUOUS command, also from the front panel. The program that does the reading can have any of the three basic non-controller initiated forms given earlier in "Six Examples" on page 6-9.

The AH 2500A defaults to logging only measurement results to the GPIB port, no matter what is there to take them. This makes working with the GPIB port a little friendlier since if any measurements have been taken, there will always be a measurement result there for the controller to read whether the controller "asked" for it or not. The LOGGER BUS command can be used to change this default so that either no results are sent unless asked for by the controller or so that more kinds of results are sent without the controller asking for them.

Logging to a Non-Controller

Although the default logging setting sends measurement results to the GPIB port, a GPIB controller is normally required to be able to read these results. However, if data logging is the only function that is desired (no commands issued by a controller), it is possible to log results without a GPIB controller by putting the bridge into talk-only mode. This is useful if you have a printer or other logging device that has a GPIB port that can be set to listen-only.

Talk-Only Mode

If a listen only logging device such as a printer, is used instead of a bus controller, then the AH 2500A *ton* (talk-only) bit must be set to a one to put the AH 2500A in talk-only mode. This mode causes the bridge's GPIB port to send results without having to first be addressed. As a consequence, there can be no other talkers on the bus at the same time. The command to set and clear talk-only mode is

$$\underline{BUS} \ .. \ ton$$

Talk-only mode will be set when *ton* is entered as a one. The mode will be disabled when *ton* is entered as a zero. The default ton parameter value stored in the BUS 0 parameter file is zero. Bus addresses are ignored in this mode.

Chapter 7   Serial/RS-232 Remote Operation

Operating the AH 2500A via the serial RS-232/current-loop port is often the simplest, friendliest and least expensive method of obtaining a remote control link. A serial link will also run much greater distances than a GPIB link. Because the RS-232 standard is so widely used, there are a wide variety of possible computing devices to which the bridge may be connected. See "Serial Communication Options" on page 1-8 of Chapter 1, "Description and Installation" for a more detailed discussion of the advantages of using the serial port and of the many possible configurations.

The serial port is usually used as an RS-232 port, but it can also be connected as a 20 mA current-loop port.

This chapter discusses how to setup and operate your AH 2500A via the serial port. Specifically, the major topics discussed are how to:

- Specify a cable to connect between a remote serial device and your AH 2500A.

- Set the communication parameters using the BAUD command.

- Save the serial configuration parameters introduced in this chapter by using the STORE BAUD command.

- Optimize keyboard usage on your serial device using the DEFINE command.

- Limit front panel access to your AH 2500A using the LOCAL, NREMOTE, and NLOCKOUT commands.

- Use your serial device to log results from your bridge rather than to control your bridge. The LOGGER BAUD command controls this method of operation.

CABLE CONNECTION ISSUES

Finding or building the right cable to connect two serial devices to each other is, on the average, 90% of the effort required to establish a serial link. First, a cable must be found that will mechanically fit between the AH 2500A and the remote device. Unfortunately, this, by itself, is not usually sufficient to make a serial link operate. Making RS-232 connections is fairly easy, but two issues often trip the inexperienced user. One issue is that the DTE/DCE identity of the serial devices to be linked must be known so that transmit lines are connected to receive lines and vice-versa. The other issue is that unconnected handshake lines can prevent operation even if they are not intended to be used. Neither of these issues is difficult to handle if you read enough of this section.

For an *excellent and concise* discussion of RS-232 interfacing, see pages 720-726 of Reference 4 in the bibliography. For a thorough discussion of this topic, see Reference 11.

Specifying an RS-232 Cable

Finding or building the right cable involves selecting the right length, the right connectors, and the correct configuration of conductors inside.

Cable Length

The RS-232 standard specifies the maximum length of an RS-232 cable to be 50 feet (15 meters). In practice, a length of 250 feet (75 meters) will work at 9600 baud. Much longer lengths are possible at reduced baud rates. Note that ribbon cable with insulation displacement connectors will not work over such large distances. (Using ribbon cable requires that signal conductors not run side-by-side in the cable; they must be spaced with a ground conductor to work reliably over even short distances. No serial connector pinout in common use supports such an alternating signal/ground arrangement.) See Appendix A of Reference 10 which has some graphs and a good discussion of cable lengths for several serial transmission methods.

Type of Connectors

Once upon a time, there was only one kind of RS-232 connector in common use. This was the 25 pin D connector. Now, the IBM PC AT and some of its clones use a nine pin D. The RJ-11, RJ-45 and other telephone connectors have come into common use. DIN connectors are used on Macintosh and other computers where space is at a premium. Other than the original 25 pin D connector, there are only de facto standards, if that, to define RS-232 pinouts for these connectors.

The AH 2500A has on its rear panel a serial port using an RS-232 standard 25 pin male DB-25 connector. You therefore will need a female mate to this connector, plus a mate to whatever connector is on your remote device.

Connector Pinouts

Table 7-1 lists connector pinouts for a cable to link one of a number of the most common remote serial device ports to your bridge. The first or left-most column in the table lists the pinout of the male DB-25 connector on the rear panel of the AH 2500A. (Since mating connectors always have the same pin numbering, this pinout is also that of the female DB-25 needed at the bridge end of the cable.) The next two columns in this table list the names and functions of the signals found

Table 7-1 Cable pinouts from the AH 2500A to other common serial ports

AH 2500A DB-25	Signal Name	Signal Function	Standard DCE DB-25	Standard DTE DB-25	IBM PC AT DTE DE-9	Apple Macintosh Mini-DIN-8	DEC MicroVAX 3100
2	TD	Transmitted data*	2	3	2	5	5
3	RD	Received data	3	2	3	3	2
4	RTS	Request to send*	4	5	8		
5	CTS	Clear to send	5	4	7		
6	DSR	Data set ready	6	20	4		
7	SG	Signal ground	7	7	5	4	3
8	CD	Carrier detect	8	20	4		
20	DTR	Data terminal ready*	20	6 & 8	1 & 6		
22	RI	Ring indicator	22				

on these pins. The remaining columns list the corresponding pinouts of connectors that will mate with the remote devices or ports which are indicated at the head of each column. These columns contain the pinouts for standard DCE and DTE 25 pin D ports, the IBM PC AT and some clones 9 pin D connector, the Macintosh mini-DIN-8 port, and the MicroVAX 3100 MMJ port.

If your remote serial device has one of these ports, then this table shows how to make a corresponding cable. All that is required is that each pin of your female DB-25 connector in the left-most column be connected to the corresponding pin of the column at the right whose port you will link to. Your bridge must also use the default *DTE* parameter bit setting as explained in "Swapping Transmit and Receive Data Lines" below. With this setting, the bridge will drive (or transmit on) the lines identified with asterisks (*) in the signal function column in the table.

If your remote device has a DB-25 connector and is DCE, then the table shows a simple one-to-one correspondence of pins between the bridge and the remote device connectors. This allows using an ordinary straight-through cable having at least the conductors listed in the table. The connections for such a cable are shown in Figure 7-1. If you can't determine if your remote port is DCE or if you don't understand this term, read "Identifying Your Remote Serial Port" below.

If your remote device has a DB-25 connector and is DTE, then the table shows that the connections inside the cable are more irregular. Notice that pin 20 of the connector going to the bridge connects to both pins six and eight of the connector that plugs into the remote device. The reverse is also true; pin 20 of the connector to the remote device connects to both pins six and eight of the connector that plugs into the bridge. Making cables of this nature is time-consuming. Fortunately, a product called a "null modem" performs exactly this function and can easily be purchased.

Female DB-25 connector to AH 2500A
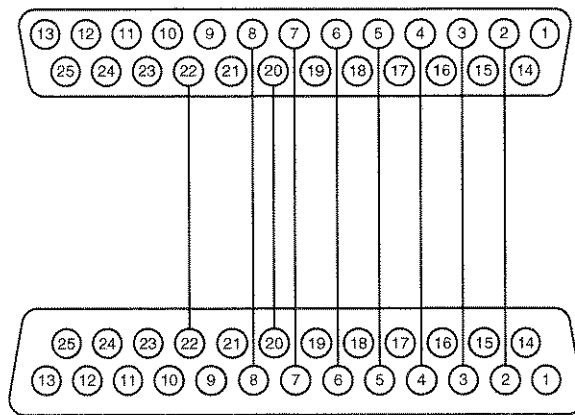
Male DB-25 connector to remote DCE device

Figure 7-1 Straight-through DTE-to-DCE cable

A null modem can be either a cable or a short adapter. It is intended to connect two DTE devices together. (It will also connect two DCE devices together.) When inserted in place of or in series with a straight-through RS-232 cable, a null modem will ensure that all of the input pins are driven by corresponding output pins. The pinouts in Table 7-1 show one way to wire a null modem. There are actually many available variations in the pinouts. Fortunately, all of the commercially available null modem variations that we have seen are compatible with the AH 2500A. This is true because the bridge does not use these lines for data flow control. A schematic for the null modem whose connections are given in Table 7-1 is shown in Figure 7-2.

The sixth column in the table gives the pinout needed to specify a cable to link to an IBM PC AT or similar clone. The pinout is for a cable that connects to such a computer and *not* to another device that could connect to that same computer.

Female DB-25 connector to AH 2500A

Mini-DIN-8 connector to
Macintosh computer

Female DB-25 connector to remote DTE device
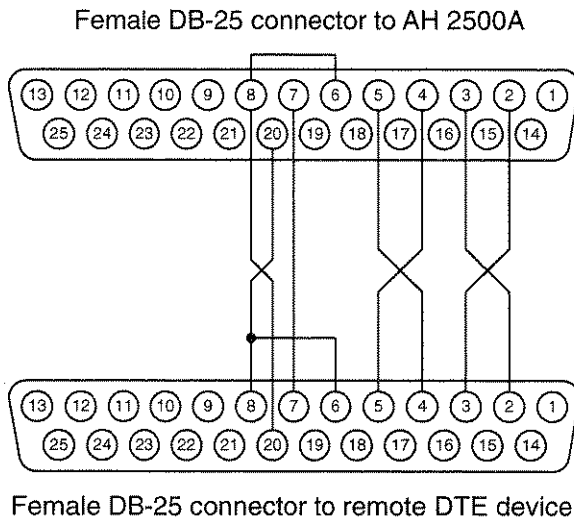
Figure 7-2 A typical null modem

The interface on such a computer has DTE signals. The schematic for this IBM cable is shown in Figure 7-3.

Female DB-25 connector to AH 2500A

Female DE-9 connector to
IBM PC style computer
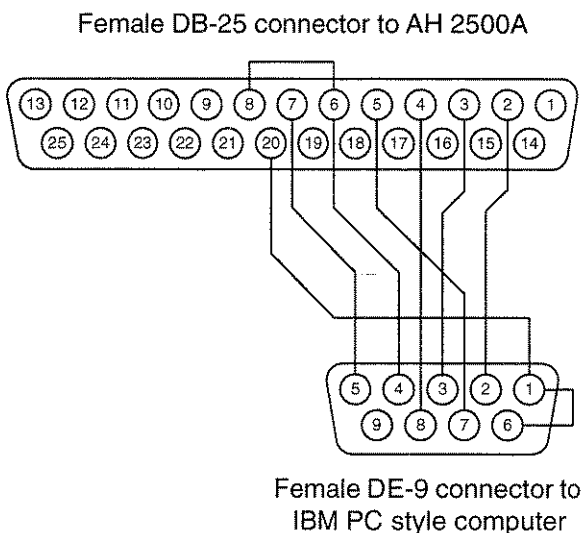
Figure 7-3 Serial cable to IBM personal computer

Macintosh computers implement the newer RS-422 standard which specifies differential drivers and receivers. RS-422 is not really RS-232 compatible, but will communicate if connected as shown in the table and if the distance is not too long and the environment is not too noisy. It is desirable to connect pin 4 to pin 8 on the mini-DIN-8 connector. This shorts the positive, differential, data receive input to ground so it doesn't pick up noise. The schematic for this Macintosh cable is shown in Figure 7-4.

The DEC MicroVAX 3100 uses a special connector called an MMJ. This connector looks like an RJ style telephone connector, but the latch is offset so that the two are not compati-

Female DB-25 connector to AH 2500A
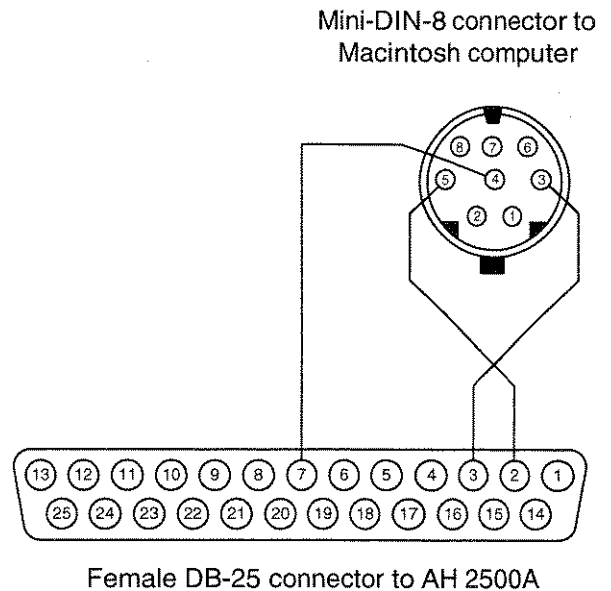
Figure 7-4 Serial cable to Macintosh computer

ble. These connectors are readily available from third-party sources. MicroVAX 3100's use the RS-423 standard which is single ended and uses lower voltages than RS-232 but not as low as RS-422. The schematic for this DEC cable is shown in Figure 7-5.

MMJ connector to DEC MicroVAX 3100 computer

Female DB-25 connector to AH 2500A
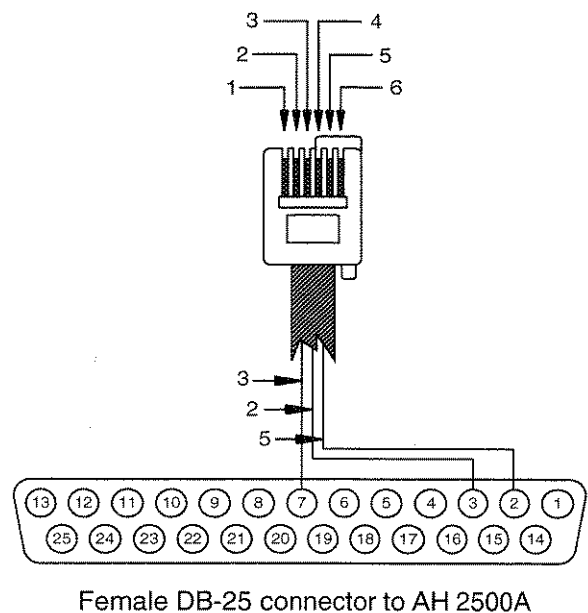
Figure 7-5 Serial cable to DEC MicroVAX 3100

One commonly used pin is not listed in Table 7-1. On the DB-25 connector this is pin one and is called the frame ground. Common usage just connects the frame ground on

one connector to the frame ground on the other. However, the recent RS-232D standard specifies that the frame ground line is only to be connected to an equipment frame at *one* end of the cable, *not* the other. Therefore, we will make no recommendation as to how this should be connected. It is, however, extremely important that the signal grounds SG always be connected to each other.

CAUTION

It is extremely important that the chassis grounds of all equipment being interconnected be properly grounded through the power cord of each piece of equipment. Ground pins on power cords must never be cut off or otherwise defeated. Failure to observe this will frequently cause RS-232 ports to be damaged if the serial link is disconnected while the equipment is plugged in (but not necessarily powered on). The failure results from the ability of power line RFI filter capacitors to cause an ungrounded equipment chassis to float to a voltage midway between the voltages on the two input power lines. This can put the chassis voltage at 50 to 120 volts above ground (for line voltages of 100 to 240 volts) with enough current capacity to be a shock hazard and to cause damage to interface ports. (The AH 2500A does not use such filter capacitors, but many other pieces of equipment do.)

You may not find the information in Table 7-1 to be sufficient to specify a cable because your remote device is not listed or because you are not sure if it is listed. The next section explains how to identify the most important characteristics of a serial port.

Identifying Your Remote Serial Port

If your remote device has a serial port using a DB-25 connector, you may be uncertain as to whether it is DCE or DTE. If you aren't sure which you have, you won't know which column in Table 7-1 to use to specify your cable. This problem tends not to arise with the other ports shown in the table, although it might be an issue with an IBM-like port. The discussion below will refer only to a DB-25, but the same principles apply to ports of all kinds.

DTE and DCE

There are two basic kinds of RS-232 devices. One is called Data Terminal Equipment or DTE. Examples are video terminals and printing terminals. The other is calledData Communication Equipment or DCE, of which modems are examples. The intent of the RS-232 standard originally was that a DTE always be connected to a DCE. Today, all possible connections are commonly used.

A DTE should have a connector with male pins and a DCE should have a connector with female pins. Unfortunately, this is usually but not always true and therefore can not be used to determine the DCE/DTE nature of a connector.

Although the gender of your remote serial port will suggest which kind of data equipment it is, if you have a DC voltmeter, you can reliably determine its kind. (An RS-232 breakout box is even better than a voltmeter.) The trick is to measure the voltage (with respect to pin seven) on pins two and three of the DB-25 connector to determine which is the transmit pin. The transmit pin will have a negative level larger than four volts. The other pin will be the receive pin and it will have a voltage near zero. Referring to the table, if pin two is the transmit pin, then the port is DTE. If pin three is the transmit pin then the port is DCE.

Having made this identification, you should be able use the table to specify the pinout of a cable that will work. However, having made this identification, you may want to make some additional measurements which may allow you to apply some shortcuts described in the "Shortcuts" section below.

Handshake Lines

If your remote serial port does not implement handshake lines, you will be able to take some shortcuts described in the sections below. The handshake lines are listed in the table as RTS, CTS, DSR, CD, and DTR. RI is also a handshake line, but is of lesser importance here.

The best way to determine how your remote port implements handshake lines is to read the documentation that you have about that port. This is important because some ports may allow you to disable these lines. If there is a way to disable them with a switch setting or with software, you should do so.

If you can't find information which specifies the implementation of your remote port's handshake lines, then you can find the information yourself using a DC voltmeter as was done in the last section. In this case, a voltmeter can be used to determine whether some handshake lines on your remote port are actually *driven* or whether they are not connected.

Measure the voltage with respect to pin seven on the six handshake pins on your remote port connector. If your port is DTE, then, if handshaking is implemented, one or both of the handshake pins marked with an asterisk (*) in the table will be driven to a positive or negative voltage level larger than four volts. If your port is DCE, then some of the handshake pins *not* marked with an asterisk will be driven if handshaking is implemented.

If *any* pins are driven, then to be safe, you must conclude that some handshake lines are implemented. (Looking for input pins on a port by measuring their voltage is less useful. The expected lower voltages make the results harder to interpret.) If no handshake pins are driven, then you can be fairly confident that your remote serial port does not implement any handshaking signals. If this is the case, then the shortcuts described below are available to you.

C04

Shortcuts

If you are sure that your remote serial device does not implement any handshake lines or if you can disable them, then you have two shortcuts available that will make your serial link easier to complete. One is to reduce the number of conductors in your cable to only three. The other is to use a feature of the AH 2500A which eliminates any need for a null modem.

Eliminating Handshake Lines

As discussed in "Controlling Data Flow" on page 7-5, handshaking is an essential function in most serial data links. However, the use of hardware lines (as opposed to flow control characters) to perform handshaking is unnecessary and undesirable in most modern RS-232 ports, including that of the AH 2500A. The reason is that an RS-232 serial link, using flow control characters, will work just as well without handshake lines. Eliminating the use of unnecessary handshake lines also removes the unnecessary complexity associated with them.

The shortcut that you can take here is to simply not make any connections to any of the handshake pins on either end of your cable. This is true even for the cable connections shown in Table 7-1. You *only* need to connect lines to pins two, three and seven on the bridge even though more lines may be listed in the table. This allows you to use a cable having only three conductors rather than eight.

Alternatively, you also have the choice of using a cable that may have many more conductors than the three that you need without being concerned about how the unused conductors are connected. If pins two and three are properly handled as described in the next section below, this will allow using a straight-through 25 conductor cable. General purpose cables and especially ribbon cables often have all 25 pins connected.

Be aware that it is important not to attempt the above shortcuts unless you are certain that the handshake lines on your remote serial device are not implemented. Using a cut-and-try approach here could be *very* troublesome because active handshake lines that are not properly connected can produce very intermittent symptoms. This is especially true of undriven lines that are connected to handshake inputs. Such lines will pick up noise that is then fed to the inputs.

Swapping Transmit and Receive Data Lines

If the handshake lines are not implemented on your remote device port, you can use *any* cable intended for RS-232 use between your AH 2500A and your remote serial device. The cable need only have mating connectors of the correct gender. It doesn't matter whether the cable you choose is a straight-through or null modem type. This can be very handy if your serial link consists of a chain of several cables of uncertain identity or limited accessibility. The trick is that the AH 2500A has the ability to internally swap the transmit and receive data lines.

When originally purchased, the bridge has the transmit and receive data lines configured as DTE. This default setting is stored as a one in the *DTE* bit in the BAUD 0 parameter file. The partial syntax of the BAUD command shown below can be used to change the *DTE* parameter bit:

BAUD . *DTE*

When the *DTE* parameter bit is zero, the bridge's RS-232 data lines will be configured as DCE (pin three transmits). When *DTE* is a one, the data lines will be configured as DTE (pin two transmits). The SHOW BAUD command will identify the current setting of the *DTE* parameter bit.

If you know whether your remote device is DTE or DCE and you know the configuration of the two data lines in each of the cables in whatever chain of cables connects the remote device to your bridge, then you have all the information needed to determine how to set the *DTE* parameter bit. If any of this information is missing, then you can again use a voltmeter to determine what the correct setting is for the *DTE* parameter bit.

To do this, fully connect whatever cabling you intend to run between your bridge and your remote device but leave the female DB-25 cable end disconnected from your bridge. With your remote device powered on but not sending data, measure the voltage on pin two with respect to pin seven on this disconnected female connector. If the voltage is more negative than minus four volts, then the female connector is DTE so the *DTE* parameter bit must be set to a zero to make your bridge DCE-like. If pin two is instead near zero volts, then check that pin three relative to pin seven is more negative than minus four volts. If so, then the *DTE* parameter bit must be set to a one to make your bridge DTE-like.

If handshake lines were never an issue, the shortcut method of establishing a serial link described above would be nearly all you ever need.

Be aware that if the AH 2500A is to be connected to a remote device with active handshake lines, *all* RS-232 lines on the serial port of the bridge must be configured as DTE. This means that the *DTE* parameter bit *must* be left set to its default state of one when active handshake lines are present in the remote port.

Controlling Data Flow

Some kind of handshaking scheme is required to control the flow of data between two serial devices. The AH 2500A uses the Control-S and Control-Q, ASCII characters for regulating the flow of data between it and a remote device. The bridge sends a Control-S when it wants the flow of data being sent to it to stop and sends a Control-Q when the data is to resume. Similarly, the bridge will stop sending data when it receives a Control-S and will continue only after receiving a Control-Q. This is the most common method.

The AH 2500A, as purchased, is configured to ignore handshake line signals. Specifically, it is not affected by signals on

the clear to send (CTS), data set ready (DSR), carrier detect (CD), and ring indicator (RI) lines. The bridge does, however, drive the request to send (RTS) and data terminal ready (DTR) lines so as to keep them constantly enabled. This approach should minimize trouble from remote device ports that implement handshake lines but don't use them for data flow control.

Some remote devices may try to use the handshake lines (probably RTS/CTS) to control the flow of data. All of the discussion in all the sections above assumes that *no* RS-232 handshake lines are used for data flow control. The connections described above will *not* function this way because the bridge will not monitor these handshake signals. Any remote device connected to the AH 2500A *must* use the Control-S and Control-Q characters for data flow control. Otherwise, the baud rate will have to be set very low.

If a remote device requires that handshake lines be used for data flow control, then the AH 2500A has internal jumper options that may solve such handshake line problems. Consult the factory if you need a handshake line feature not available with the standard jumper configuration.

20 mA Current-Loop Operation

Current-loop operation is sometimes used in preference to RS-232 for use in noisy environments such as factories. The receiving circuit in the AH 2500A is optically-isolated and thus has very high noise immunity. If the receiver on the remote device is also opto-isolated, then the overall circuit should have excellent noise immunity.

Current-loop operation functions identically to a three-wire RS-232 configuration except for the voltage/current levels employed and the connector pinout on the AH 2500A. See Chapter 3 of Reference 10 for a good discussion of 20 mA current loops.

Pinout

Current-loop operation requires a pair of conductors to transmit a signal and another pair to receive a signal. These two pairs should be connected to pins on the RS-232/20 mA SERIAL PORT on the back of the bridge as shown below:

> Pin 9   Positive Receive Line
>
> Pin 11   Negative Receive Line
>
> Pin 18   Positive Transmit Line
>
> Pin 25   Negative Transmit Line

In this case, "positive" is used to mean that the voltage on the positive line is *more* positive than the voltage on the other line of this pair labeled "negative". It is likely that both voltages on both pairs of conductors are positive with respect to the bridge's ground.

Powered/Unpowered Receiver Selection

Some current-loop interfaces use the transmitting end to provide current to the interface loop; others use the receiving end. The AH 2500A always supplies current to the interface loop through its transmitting circuit. When originally purchased, the bridge is configured to provide no current to the loop through its receiver. A change of jumpers can configure the receiver to provide current to the loop, but this will defeat the isolation provided by the opto-isolator.

If you need to reconfigure the jumpers, you must remove the top cover of the bridge to gain access to the processor PC board. This is described in "Removal and Installation of Covers" on page 12-3. With the help of the assembly drawing Figure F-8 on page F-24, locate JP311 in the lower right corner. This is a six pin header which should always have three jumpers on it. As originally purchased, there are jumpers bridging pins two and three and pins four and five. Pin six holds a jumper as a storage location. Since the location of these jumpers is symmetric, the pin numbering of JP311 can be counted from either end of the header. To change these jumpers so that the receiver will provide current to the loop, move the jumpers so that they bridge pins one and two, three and four, and five and six.

SERIAL COMMUNICATION PARAMETERS

A number of variables such as baud rate, parity, number of stop bits and others, must be set to conform to the settings of the corresponding variables in your remote device. Fundamental variables such as these which directly affect the ability of the serial link to communicate are called communication parameters. This section explains the function of each communication parameter, states the default value of each parameter as stored in the BAUD 0 parameter file, and explains how to set and permanently save each one.

Setting the Serial Parameters

The BAUD command is used to set all the serial communication parameters. The BAUD command can be entered from the front panel or from a remote device using the following full syntax:

> BAUD *rate* . *DTE* . *parity* . *length* . *stop* . *fill* . *echo*

The full BAUD command uses seven parameters which are described in the sections below. Each time the BAUD command is entered, it can be followed by any combination of its parameters provided that place-holder periods are entered and that the order is preserved. As an example, the entry BAUD ..1.8..4 specifies odd parity, an 8 bit character, and 4 fill characters with the other four parameters left unchanged. See "Positional Parameters" on page A-1 for more information about this method of parameter entry.

The communication parameters can be changed from the serial port, but the changes take effect immediately so you must be able to change the communication parameters of the remote device at the same time if the communication link is not to be interrupted.

Once the serial link has been correctly established, sending a carriage return character from the remote device should cause the bridge to send the character sequence "CR, LF, >", which should cause a ">" prompt to appear on the remote device.

Baud Rate

The *rate* is the rate in bits per second at which the data is sent and received. This can be selected using the following partial syntax:

BAUD *rate*

The *rate* can have one of the following values: 50, 75, 110, 135, 150, 300, 600, 1200, 1800, 2400, 3600, 4800, 7200 or 9600 with 9600 being the default. All digits of the desired value must be entered even though only the first two digits are reported by the SHOW command.

DTE

The *DTE* parameter bit is explained in detail in "Swapping Transmit and Receive Data Lines" on page 7-5. The partial syntax of the BAUD command shown below can be used to change the *DTE* parameter bit:

BAUD . *DTE*

When the *DTE* parameter bit is zero, the bridge's RS-232 data lines will be configured as DCE (pin three transmits). When *DTE* is a one, the data lines will be configured as DTE (pin two transmits).

Parity

The *parity* parameter bit controls whether a parity bit is *sent* as part of the serial data byte or not. Parity is *not* tested when characters are received no matter how the *parity* parameter bit is set. The *parity* parameter bit can be changed with the command syntax:

BAUD .. *parity*

The *parity* parameter bit can be set to no parity, odd parity or even parity using the digits 0, 1 or 2, respectively. The default is zero for no parity.

Character Length

The *length* parameter determines the number of bits in each serial data byte. This can be selected using the following partial command syntax:

BAUD ... *length*

The *length* parameter can be 7 or 8 bits with the default being 8.

Stop Bits

The *stop* parameter is the number of serial bits sent at the end of each serial byte. This can be selected using the following partial command syntax:

BAUD .... *stop*

The *stop* parameter can be 1, or 2. A one always indicates 1 stop bit. A two indicates 1 stop bit if the word length is 8 with parity selected, and 2 stop bits in all other configurations.

The default is 1.

Fill Characters

Some older, unbuffered printers need extra time at the end of each line for the carriage to return. Sending empty characters at the end of each line can provide this extra time. The *fill* parameter determines the number of fill characters (nulls) sent following each CR, LF character combination. The number of fill characters can be selected using the following partial command syntax:

BAUD ..... *fill*

The *fill* parameter can range from 0 to 9 with the default being 0.

Command Echoing

You may choose whether or not to have commands echoed to remote serial devices. The *echo* parameter determines whether characters entered on a serial device are echoed by the AH 2500A back to that device.

If data acquisition is being controlled by a computer, command echoing is normally disabled since a computer typically has little use for the echoed characters. If you are working interactively with the bridge, it is important to be able to see the commands that have been typed in. Since lack of echoing effectively disables all interactive communication, it should always be enabled for human interactions, but it makes computer data acquisition easier if it is disabled.

When the remote device is a half-duplex serial device, the device itself will probably echo the commands. For half-duplex devices, echoing should be disabled, otherwise double characters may occur.

If the remote device is a full-duplex terminal then echoing should be enabled.

If command echoing is unknowingly disabled, it may give you the impression that the bridge or the remote device is not working. To test for this, you can type a return character on the remote keyboard. If command echoing is not disabled, a prompt ">" will be printed at the beginning of the line indicating that the remote device is receiving characters and the bridge is ready to receive a command. If nothing is printed, the SHOW command should be entered at the remote keyboard followed by a carriage return even though the characters you enter are not echoed and therefore you do not see them. The SHOW command will be accepted when echoing is disabled even though no direct evidence in the form of a response on the screen or printer will appear. If the serial link is working, then several lines will be printed since the SHOW command always prints something.

The partial syntax of the BAUD command shown below can be used to change the *echo* parameter bit:

$$BAUD \ldots \ldots echo$$

When the *echo* parameter bit is set to one, command echoing is enabled. When *echo* is set to zero, echoing is disabled. The *echo* parameter is set to one as the default so that echoing is enabled.

First-Time Serial Link Operation

If you have connected a cable between your AH 2500A and your remote serial device, and have set all the communication parameters with the BAUD command, you are now ready to try to operate the bridge from your remote serial device. If your serial device is a dumb video terminal or printing terminal, you can simply press the RETURN key and expect to see a prompt (>) printed at the beginning of a line on the terminal. Once you see the prompt, you can enter any of the AH 2500A commands that you are familiar with and expect to see the corresponding results.

If your serial device is actually a computer, then you have additional things to set. Usually, in addition to setting the communication parameters of your computer's serial port, you will also have to run a program that makes your computer "look" like a dumb terminal. There are many commercially available programs that will perform this function for you. If you connect your computer to a modem to access a remote service, the program that makes that connection work will probably also make your computer "talk" to your AH 2500A. In fact, the bridge could be run at the far end of a modem link using your computer in exactly the same configuration as used to access a remote service.

Permanently Saving Your Settings

All the parameters discussed in this chapter are stored in the Baud parameter set type. This set type contains all the parameters that are used in conjunction with the serial remote device port. An overview of this parameter set type is given in Chapter 3, "Parameter and Program Files" in the section titled "Baud Parameter Set" on page 3-6.

To permanently save all of the parameters related to operating the remote serial device in a way that will automatically restore them after power-on of your bridge, simply issue the command [FUNC] [STORE] [FUNC] [BAUD] [1] [ENTER] from the front panel.

To better understand the ways in which you can save your serial device parameters, refer to "WORKING WITH FILE CONTENTS" on page 3-9 and especially "PARAMETER SET INITIALIZATION" on page 3-10.

REMOTE COMMAND ENTRY

The entry of commands from a remote serial device is identical to that on a GPIB controller except that most of the immediate-action keys described later in this section are not directly executable from a GPIB controller's keyboard without special programming of the controller. GPIB controllers also have their own methods of correcting typing errors.

All of the discussion in this section applies if your remote serial device is a dumb terminal or some other device that behaves like a dumb terminal. Computers may be configurable to be "dumb" or "smart". If you are using a computer that is configured to be smart, it may have its own methods for editing keyboard input and may only be able to send serial results in the form of whole lines. If so, this will put you in the same position as if you were operating a GPIB controller. The immediate-action keys described below will not be readily executable and the section about "Correcting Typing Errors" will not be useful.

A dumb terminal configuration is preferable unless the alternative has obvious and significant advantages.

Basic Syntax

The command line entry style used by the AH 2500A will be familiar if you have used small computers or terminals. The syntax and command words used also closely parallel those used by the bridge's front panel. The AH 2500A command *definition* syntax is described in "CONVENTIONS USED" on page A-1.

Commands consist of a leading command word followed by optional command qualifier words followed by optional parameters which are usually numeric and ended with a carriage return character. Only two special commands described below require no termination character. The carriage return character (CR) is entered by pressing the RETURN or ENTER key on the keyboard of the remote serial device.

The bridge does not act on command lines until it receives a carriage return. This allows you to edit commands before terminating the command line. This editing is described in detail in "Correcting Typing Errors" below.

Command Word Entry

Since remote commands are named and spelled as they appear on the front panel, any commands described in this manual using key labels also describe the remote commands. When the front panel key label consists of two words, only the first word is used as the remote command word with the exception of the BIAS command. The FUNC key has no equivalent on remote devices, of course.

Although commands are English words, it is rarely necessary to type the entire word. You need to type only the first few letters of the command. The minimum number of letters needed depends on the particular command and ranges from one to three letters. The minimum letters needed are underlined where each command is introduced in the text and in Appendix A, "Command Reference". If you do not type in enough letters, the bridge responds with the message AMBIGUOUS WORD:, followed by the offending characters that were entered. If more letters than the required minimum are entered, they must spell the command word correctly or the error message ILLEGAL WORD: will appear, followed by the illegal word that was entered.

Command words are separated from each other and from their associated parameters by spaces. Parameters are separated from each other by periods.

Immediate-Action Keys

A RETURN must terminate all command lines from the serial port with only two exceptions. The front panel has several immediate-action keys. The immediate-action function of two of these is duplicated on remote serial devices. These front panel keys are the SINGLE and STEP keys. These same command words can be entered from a remote device, but they will require termination with the RETURN key. This multiple-key sequence defeats the desired immediate-action effect. As a result, two single character commands are available on remote serial devices. These are Q and X which perform the same function in a single keystroke as the SINGLE and STEP commands, respectively.

Examples

To illustrate the ideas above, consider the BRIGHTNESS command whose syntax is:

$$\underline{BRI}GHTNESS \ [\underline{C}AP \ or \ \underline{L}OSS] \ level$$

Several examples of valid command lines that might be entered from a remote terminal are:

BRIGHT CAP 5

BR C 5

BRIG L 5

BR 5

All are terminated by a RETURN.

The entry B 5 will return the error message:

AMBIGUOUS WORD: B

The entry BRIHGT 5 will return the error message:

ILLEGAL WORD: BRIHGT

Additional Features

Entering Multiple Commands

Several commands can be entered on the same line separated by semicolons (;). As with individual commands, lines having multiple commands are not executed until a RETURN is received. An immediate-action command such as Q or X can be entered anywhere on a multi-command line except as the first character and will not be executed until the whole line is received.

Multi-command lines can be useful with commands that respond with a prompt. For example, every version of the STORE CALIBRATE command prompts for a passcode. The passcode can be entered after the command on the same line if the two are separated by a semicolon. Except for passcodes, any command that requires a response to a prompt will first check the next command on the line. If the next command is an acceptable response to the prompt then it will be used. If not, the next command will not be executed yet. Instead, the prompt will be produced and the bridge will wait for input. If you want to guarantee that a prompt is generated, insert the EDIT command word where the answer to the prompt would go on the command line.

Multi-command lines can also be used to guarantee that a command produces a result. The TEST command can be configured to produce no result unless a failure is detected. However, the command line TEST; SHOW TEST will always produce a result.

Inserting Comments

When commands are being printed or recorded, it may be desirable to insert comments between the command lines. This is done by starting a line with a percent (%) character. Text or other non-control characters following the percent character are ignored until a RETURN is entered.

Query Commands

All AH 2500A commands can be classified as query or non-query commands. A query command is one that generates a response message such as a measurement result. The most common examples of these on the AH 2500A are the SIN-GLE, CONTINUOUS and SHOW commands. If a query command is interrupted by a new command, the query command is immediately aborted and the new command begins to execute. See "Aborting Commands" on page 2-6.

A non-query command will finish executing even if it is interrupted by a new command. The new command will be executed after execution of the non-query command is complete.

Each command line is either a query line or a non-query line. If a multi-command line contains any query commands, the whole command line is considered to be a query line. It will not be possible to predict which commands were executed and which were not if a query command line is interrupted by new command.

Input Buffer

All command messages are stored in the bridge in an input buffer that can hold eighty characters. This means that the bridge will not buffer more than eighty characters ahead of what it is able to process. In addition, it will not accept a command line whose total length exceeds eighty characters. If the latter occurs, the error message LINE TOO LONG will be reported.

Correcting Typing Errors

The AH 2500A offers several of the most common ways of correcting typing errors during keyboard entry. You have the option of selecting the ways that work best with your remote device. The options given below assume that your remote serial device behaves like a dumb terminal.

Customizing the Editing Keys

To accommodate the wide variety of serial remote devices that might be used with the AH 2500A, the bridge allows you to define which keys or control characters are used to perform editing. This is done from the remote device using the DEFINE command after your serial link is properly functioning.

Any characters may be used for these functions except for Control-A (^A), CR, LF, Control-Q (^Q), Control-S (^S) and the current erase and delete keys.

The characters that can be changed with the DEFINE command can be shown with the SHOW DEFINE command. This command is not available from the front panel and the defined characters will not appear in the list of Baud parameters when the list is shown on the front panel.

Defining a Key to Delete Characters

The delete key deletes the last character typed and can be used as many times as needed to delete all the way back to the beginning of the line that you are entering.

The default key (stored in the BAUD 0 parameter file) which one must press to delete the character just entered is the DELETE (or RUBOUT) key. This is the key which produces a character with the ASCII hexadecimal code 7F. If your keyboard cannot generate this code, then you can choose some other code with the command:

<div align="center">DEFINE DELETE delchar</div>

The *delchar* parameter may be entered in one of three ways. It may be entered directly by simply pressing the desired delete key. If it is to be a control key, it may be entered as the corresponding letter preceded by an up arrow (^). Finally, it may be entered as the word DELETE if it is to be the ASCII delete character.

For example, DEF DEL Y would define Y as the delete key. The command DEF D ^Y would define Control-Y as the delete key, where "^" and "Y" were entered explicitly. To restore the DELETE (or RUBOUT) key to its original default function the actual delete character may be typed in or entered as the word DELETE. You could type D E F D E L DEL to do this.

Selecting Delete Key Behavior

The default handling of the DELETE key will work on a printer *or* video terminal. When the DELETE key is pressed, a backslash (\) is printed followed by the character that was deleted. If the DELETE key is pressed again, only the deleted character is printed. This continues until the next character to be entered is typed which causes a second backslash to be printed. Thus the deleted characters appear in reverse order within the backslashes. For example: CORRECSHUN\NUH-S\TION. After the N was typed the DELETE key was pressed four times followed by TION. Obviously, this scheme does not take advantage of a video screen's ability to overwrite a character and thus there are better techniques if you use a video screen.

To change the DELETE handling between use with a video terminal and use with a printer, enter the command:

<p style="text-align:center">DEFINE TERMINAL termtype</p>

The termtype parameter is entered as either VIDEO or PRINTER depending on which kind of device is connected to the serial port. The default is PRINTER.

If VIDEO is selected, it may be necessary to redefine the backspace character using the command:

<p style="text-align:center">DEFINE BACKSPACE backspchar</p>

where the backspchar parameter is the code that causes the cursor on your video terminal to be backspaced by one character position. The default backspchar stored in the BAUD 0 parameter file is Control-H (^H).

The backspchar parameter may be entered in one of three ways. It may be entered directly by simply pressing the key which produces the desired backspace code. If it is to be a control key, it may be entered as the corresponding letter preceded by an up arrow (^). Finally, it may be entered as the word DELETE if it is to be the ASCII delete character.

The character that you enter must cause the cursor to move left by one place. When the bridge receives a DELETE key code, it will send the sequence backspace-space-backspace which backs the cursor over the character to be deleted, writes a space over it, and finally positions the cursor under the space that was written.

Erasing Lines

Pressing the ERASE key causes the contents of the entire current line except for the prompt character to be deleted. The default character used to delete the current command line is Control-U (^U). If this is not acceptable then you can redefine the erase character with the command:

<p style="text-align:center">DEFINE ERASE erasechar</p>

The erasechar parameter may be entered in one of three ways. It may be entered directly by simply pressing the desired erase key. If it is to be a control key, it may be entered as the corresponding letter preceded by an up arrow (^). Finally, it may be entered as the word DELETE if it is to be the ASCII delete character.

Aborting Command Execution

The execution of any command or program may be aborted from the serial port with the DEVICE CLEAR command. The default character (stored in the BAUD 0 parameter file) that is used to issue the DEVICE CLEAR command is Control-E (^E). If this is not acceptable then you can redefine this character with the command:

<p style="text-align:center">DEFINE DCL devclrchar</p>

The devclrchar parameter may be entered in one of three ways. It may be entered directly by simply pressing the desired key. If it is to be a control key, it may be entered as the corresponding letter preceded by an up arrow (^). Finally, it may be entered as the word DELETE if it is to be the ASCII delete character.

The DEVICE CLEAR command is not needed to abort query commands since entry of any command will abort a query command. However, the DEVICE CLEAR command is the only way to prematurely abort non-query commands such as HOLD or CALIBRATE from the serial port. The serial port ^E command has exactly the same effect as the FUNC CLEAR FUNC CLEAR front panel key sequence and the GPIB DCL command.

LIMITING FRONT PANEL ACCESS

The AH 2500A can be set to limit the ability to enter commands from the bridge's front panel keypad. This can be important if your remote serial device is taking data and you want to prevent anyone from disturbing your measurements by pressing keys on the bridge's keypad.

Serial Control States

The bridge operates in one of four serial control states which determine the degree of front panel access. These states discussed below are applicable only to serial operation. The GPIB interface has fully analogous capabilities in the form of its own set of REMOTE/LOCAL and LOCKOUT features.

Serial Local State

In the Serial Local State, the bridge will accept all commands that are entered from either the front panel keypad or from a remote serial device. In this state, the front panel keypad and the remote serial device can be thought of as both having simultaneous control over the bridge. The Serial Local State (without lockout) is stored as the default in the BAUD 0 parameter file.

Serial Remote State

In the Serial Remote State, the bridge will accept all commands that are entered from a remote serial device but will ignore all attempted command entries from the front panel keypad except for one. That one is the LOCAL key. The front panel display will continue to be updated with whatever the bridge is measuring.

The REMOTE indicator on the front panel is illuminated while the bridge is in the Serial Remote State.

Serial Remote State with Lockout

In the Serial Remote with Lockout State, the bridge will accept all commands that are entered from a remote serial device but will ignore *all* attempted command entries from the front panel keypad with no exceptions. Even the $\boxed{\text{LOCAL}}$ key is ignored. If the $\boxed{\text{LOCAL}}$ key is pressed, the front panel display will show:

```
┌──────────────────┐
│  L O C A L        │
├──────────────────┤
│    L o c o u t    │
└──────────────────┘
```

indicating that there is currently no way to establish operation of the bridge from the front panel.

Serial Local State with Lockout

The Serial Local State with Lockout is operationally identical to the Serial Local State in all respects. The *only* distinction between the two states is that the serial lockout parameter is *enabled* in the Serial Local State with Lockout and is *disabled* in the Serial Local State. There is no observable effect from these differences until one of the serial remote states is entered.

Selecting the Serial Control States

The commands introduced in the four sections below are used to select the Remote/Local and the Lockout states.

Selecting the Serial Remote States

The Serial Remote State and the Serial Remote State with Lockout are selected using the command:

NREMOTE

This command (NetworkREMOTE) can be entered from the remote serial device, but not from the front panel. If the NREMOTE command is issued when the bridge is in the Serial Local State, the Serial Remote State will be entered. If the NREMOTE command is issued when the bridge is in the Serial Local State with Lockout, the Serial Remote State with Lockout will be entered. Notice that the effect of this latter situation is that the bridge will go from totally unrestricted local behavior to being fully locked out from the front panel; the Serial Remote State is bypassed.

Selecting the Serial Local States

The Serial Local State and the Serial Local State with Lockout are selected using the command:

LOCAL

If the bridge is in the Serial Remote State, this command can be entered from the remote serial device *and* from the front panel. When entered from the front panel, the $\boxed{\text{LOCAL}}$ key has an immediate effect; the $\boxed{\text{ENTER}}$ key does not need to be pressed. If the LOCAL command is issued when the bridge is

in the Serial Remote State, the Serial Local State will be entered.

If the bridge is in the Serial Remote State with Lockout, this command can be entered *only* from the remote serial device because front panel entry of all commands is locked out in this state. If the LOCAL command is issued when the bridge is in the Serial Remote State with Lockout, the Serial Local State with Lockout will be entered.

Setting the Serial Lockout States

The Serial Remote State with Lockout and the Serial Local State with Lockout are selected using the command:

NLOCKOUT

This command (NetworkLOCKOUT) can be entered from the remote serial device, but not from the front panel. If the NLOCKOUT command is issued when the bridge is in the Serial Remote State, the Serial Remote State with Lockout will be entered. If the NLOCKOUT command is issued when the bridge is in the Serial Local State, the Serial Local State with Lockout will be entered.

Clearing the Serial Lockout States

The Serial Remote State and the Serial Local State are selected using the command:

NLOCKOUT HALT

This command can be entered from the remote serial device, but not from the front panel. If the NLOCKOUT HALT command is issued when the bridge is in the Serial Remote State with Lockout, the Serial Remote State will be entered. If the NLOCKOUT HALT command is issued when the bridge is in the Serial Local State with Lockout, the Serial Local State will be entered.

Saving and Showing the Serial States

The serial control states are saved as part of the Baud parameter sets. The Remote and Lockout state parameters can be determined using the SHOW NREMOTE and SHOW NLOCKOUT commands. The remote state parameter is a 1 when the bridge is in the Serial Remote State or the Serial Remote State with Lockout. Similarly, the lockout state parameter is a 1 when the bridge is in the Serial Remote State with Lockout or the Serial Local State with Lockout.

Because these states can be permanently stored, they can also be automatically recalled during power-on. This makes it possible to set the BAUD 1 parameter file so that the front panel is always disabled after power-on. Be aware that the only way to restore front panel access is through a remote device or via a special maintenance procedure described in Table 11-2 on page 11-3.

Power-on lockout can be useful even when the bridge is not connected to *any* remote device. The bridge can be configured to automatically run a dedicated program continuously after power-on with the front panel locked out. A remote device would be required for setup, but not for operation.

SERIAL DATA LOGGING

The AH 2500A can send all commands that are entered and all measurement data that is initiated from the front panel to the serial port. This allows you to keep a log of some or all bridge activity by connecting a serial printer or other serial logging device (logger) to the serial port.

The capture speed of the logger must be high enough to receive all the data at the baud rate at which it is sent. Otherwise, the baud rate must be reduced or the logger must use the Control-S and Control-Q handshaking characters to synchronize the data flow between the bridge and the logger. Low data transmission rates to the logger may cause the front panel display rate to be slower also. The effect can be very noticeable at low baud rates. Extraneous Control-S characters coming into the serial port when logging is enabled can cause the bridge to hang indefinitely until it receives a Control-Q character.

Enabling/Disabling Serial Logging

Logging to the serial port is enabled and disabled with the following command:

LOGGER BAUD *content*

The *content* parameter controls what, if anything, is logged to the serial port. The allowable values of the *content* parameter and the corresponding messages sent are listed in Table 7-2.

Table 7-2 Content parameter values

Content	Messages Sent to Logger
0	None (logging is disabled)
1	Measurement results only
2	All results (measurement and show)
3	All commands and all results

This table is identical to the corresponding GPIB Table 6-2 on page 6-15. The default *content* parameter stored in the BAUD 0 parameter file is zero so that logging to a remote serial device is disabled.

C04

This chapter introduces concepts which will help you interpret the meaning of your three-terminal measurements. Several additional commands are introduced here in case you need the ultimate in accurate measurements. The discussions here assume you are familiar with the AH 2500A.

The equations used in this chapter assume that you are familiar with how to apply complex algebra to network calculations. This turns out to be much easier than it might look at first. If you need help, there are literally hundreds of books that discuss basic theory. Reference 8 in the bibliography has some good theoretical discussions including wye-delta transformations on p. 195. Chapter 9 of this reference also has an interesting discussion of capacitors and capacitance.

INTERPRETING MEASUREMENT RESULTS

Sometimes it is desirable to convert raw measurement results from the AH 2500A to another form. A different form may better model the unknown sample (as in the case of series versus parallel configurations), or it may simply make a physical process more comprehensible (as in the case of negative capacitances and conductances).

Trusting the Results

Obviously, there is no point performing complicated calculations on measurement results unless they are meaningful. In particular, some users are surprised when they discover that the AH 2500A capacitance result *really* reads capacitance and the loss result *really* reads loss. There seems to be a tendency to not expect the bridge to be capable of *truly* separating the capacitance result from the loss result. In fact, it does this very well to the limit of its specifications. The bridge can almost be thought of as two distinct instruments, one that measures capacitance and one that measures loss.

The practical effect of this is that the bridge is very good at isolating the capacitive contributions of an unknown impedance from the loss contributions. Obviously, this is essential for understanding complicated unknown impedances, but it can also be a big help with diagnosing transducer and cable problems. You may only be interested in measuring the capacitance, for example, but if you are having a problem, it may be the *loss* reading that holds the answer! Even if your interest is only in the capacitance, monitoring the loss for any unexplained changes will give you increased confidence in your capacitance results.

In most cases, a change in your capacitance reading is a result of a change in the capacitance or inductance of your unknown impedance or of its connecting cables. A problem with stray capacitance is a common possibility.

In most cases, a change in your loss reading is a result of a change in the dielectric loss or resistance of your unknown impedance or of its connecting cables. A problem with bad connections is a common possibility.

There are ways in which a change in dielectric loss or resistance can cause a change in the *capacitance* reading. There are also ways in which a change in capacitance or inductance can cause a change in the *loss* reading. The existence of such interactions implies a complicated unknown impedance or possibly a connecting cable problem. Understanding the theoretical basis of these interactions is the subject of the next section.

WYE-DELTA TRANSFORMATIONS

The three-terminal measurement method used by the AH 2500A allows one to use wye-delta transformations to gain a better understanding of certain impedance configurations.

Suppose that the circuit of Figure 4-2 on page 4-3 is generalized so that the three capacitors are replaced with admittances as shown in Figure 8-1. It is possible to convert between this delta network and the one shown in Figure 8-2 which is a wye network using the equations below:

$$Y_{HL} = \frac{Y_H Y_L}{Y_H + Y_L + Y_G} \qquad \text{Eq. 8-1}$$

$$Y_{HG} = \frac{Y_H Y_G}{Y_H + Y_L + Y_G} \qquad \text{Eq. 8-2}$$

$$Y_{LG} = \frac{Y_L Y_G}{Y_H + Y_L + Y_G} \qquad \text{Eq. 8-3}$$

$$Y_H = \frac{Y_{HL} Y_{HG} + Y_{HL} Y_{LG} + Y_{HG} Y_{LG}}{Y_{LG}} \qquad \text{Eq. 8-4}$$

$$Y_L = \frac{Y_{HL} Y_{HG} + Y_{HL} Y_{LG} + Y_{HG} Y_{LG}}{Y_{HG}} \qquad \text{Eq. 8-5}$$

$$Y_G = \frac{Y_{HL} Y_{HG} + Y_{HL} Y_{LG} + Y_{HG} Y_{LG}}{Y_{HL}} \qquad \text{Eq. 8-6}$$
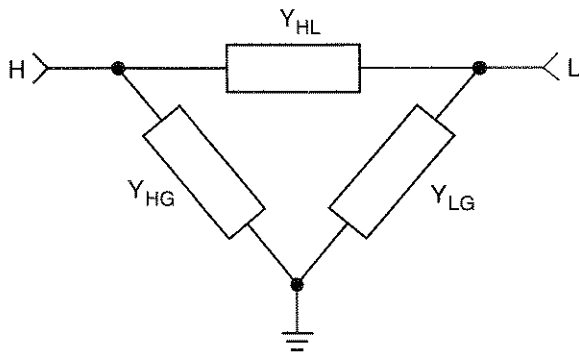
Figure 8-1 Delta network
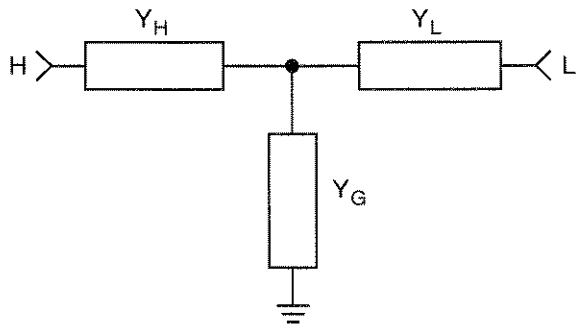
Figure 8-2 Wye network

This transformation is very powerful because three-terminal measurements are fundamentally of the delta variety whereas real unknown samples are sometimes of the wye variety. The AH 2500A measures Y_{HL} only, while excluding Y_{HG} and Y_{LG}. In contrast, some samples behave like they are connected in a wye network and can only be understood that way.

As an example, suppose that a wye network consists only of resistors so that:

$$Y_G = \frac{1}{R_G} \text{ and } Y_H = Y_L = \frac{1}{R} \qquad \text{Eq. 8-7}$$

By applying Eq. 8-1:

$$Y_{HL} = \frac{R_G}{R\,(2R_G + R)} \qquad \text{Eq. 8-8}$$

Suppose further that R = 1 megohm and that R_G = 1 ohm. This gives $Y_{HL} = 10^{12}$ ohms (1 teraohm). This demonstrates that by starting with some readily available resistor values, one can construct a wye network which, when measured by the AH 2500A, will appear to be a resistor far larger than is commonly available. Since the AH 2500A can measure extremely large resistances, one use of wye networks could

be in making performance and calibration checks of the bridge.

Interpretation of Negative Capacitance

The AH 2500A is capable of displaying negative capacitance and loss for values up to 10% of the corresponding full scale positive values. Negative values, particularly negative loss values, are not expected to be seen with most impedance measurements. However, negative values may be encountered more often than you might expect. They are as meaningful as positive values and can be useful if you understand them.

Negative capacitance values can be interpreted in two ways. The common interpretation is simply that a negative capacitance is an inductance. This assumes that the capacitive reactance and the inductive reactance are equal, that is:

$$j\omega L = \frac{1}{j\omega C} \qquad \text{Eq. 8-9}$$

where L is the inductance, j is the square root of -1 and ω is 2π times the frequency. This reduces to:

$$L = \frac{-1}{\omega^2 C} \qquad \text{Eq. 8-10}$$

and shows that the more negative the capacitance, the smaller the inductance will be. Since the largest negative capacitance the AH 2500A can measure is -0.12 µF, the smallest inductance that could be measured is 0.21 henries. While inductances of this size are commonly made, they are near the upper limit of manufacturability. They are far beyond anything that could be considered to be a stray circuit inductance. This means that any negative capacitances that are measured by the AH 2500A should not be interpreted as inductances unless a large inductance has been explicitly included in the unknown sample. See "INDUCTANCE MEASUREMENTS" on page 8-8 for a discussion about measuring real inductors.

The second interpretation of negative capacitance (and of negative loss) requires the use of wye-delta transformations. Consider the circuit in Figure 8-3.
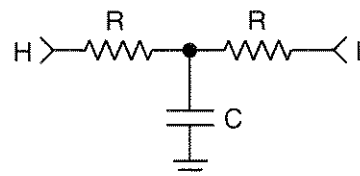
Figure 8-3 RCR wye network

Two resistors R which are in series have their center point tied to ground through a capacitor C. Eq. 8-1 may be used to calculate the admittance that this network would present to the H and L terminals of the bridge. The result is:

$$Y_{HL} = \frac{\frac{2}{R} - j\omega C}{4 + \omega^2 C^2 R^2} \qquad \text{Eq. 8-11}$$

The real (conductance) term is positive in this result while the imaginary (capacitive susceptance) term is negative. For normal resistors and capacitors the conductance and susceptance are both positive. For this to be true, R must be positive and C must be negative. Since R and C are what the bridge measures, we have found a simple network which produces negative capacitance readings for all positive values of R and C!

Actual Situations

Although this network has been analyzed as a lumped circuit, it is representative of any resistor which has a distributed capacitance to ground. Since most resistors have some capacitance to ground, this effect would seem to be quite common. However, the calculation did not allow for any shunt capacitance between the H and L terminals or for any capacitance shunting the resistors. Such shunting capacitances will have a positive contribution and will often overwhelm the negative effect in a real resistor. Therefore, details in the stray capacitances of the unknown sample will ultimately determine whether the measured capacitance is positive or negative. An example of a configuration which will produce a negative capacitance is that of an ordinary resistor whose body passes through a closely fitting hole in a grounded plane such as that shown in Figure 8-4. The stray capacitance across the resistor can be made nearly zero by choosing the correct hole diameter.
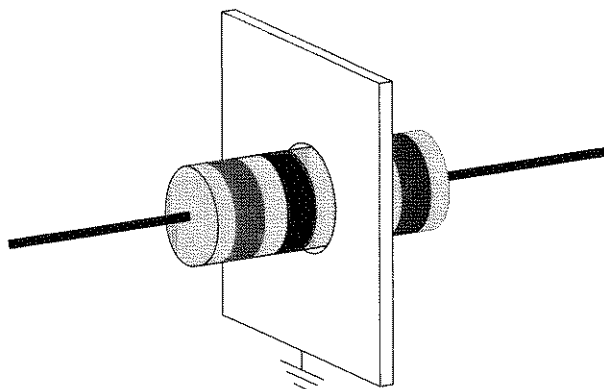
Figure 8-4 Resistor through a grounded plane

Interpretation of Negative Loss

Now consider a second case using the circuit in Figure 8-5. Two capacitors C which are in series have their center point
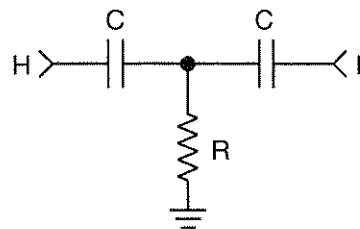
Figure 8-5 CRC wye network

tied to ground through a resistor R. Eq. 8-1 can again be used to calculate the admittance that this network would present to the H and L terminals of the bridge. The result is:

$$Y_{HL} = \frac{-\omega^2 C^2 R + 2jR^2\omega^3 C^3}{1 + 4R^2\omega^2 C^2} \qquad \text{Eq. 8-12}$$

The real (conductance) term is negative in this result while the imaginary (capacitive susceptance) term is positive. For normal resistors and capacitors, the conductance and susceptance are both positive. This leads to the conclusion that R must be negative and C must be positive in this equation. Since R and C are what the bridge actually measures, we have found a simple network which produces negative loss readings for all positive values of R and C.
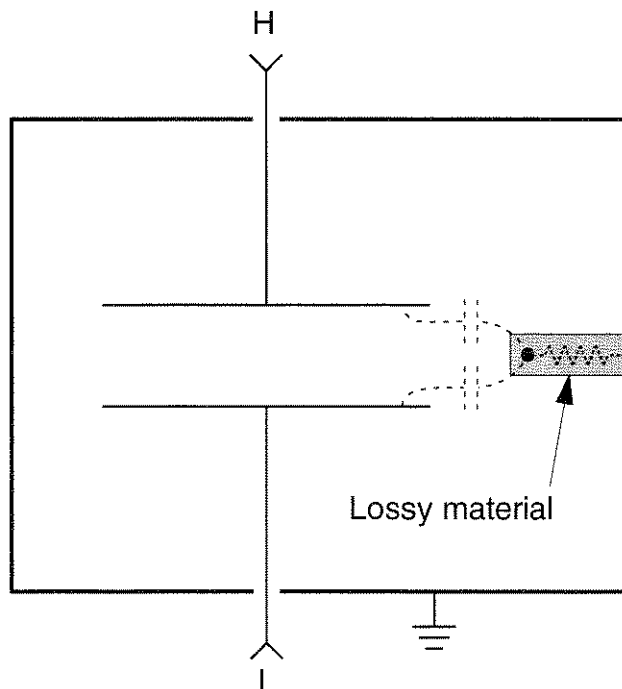
Figure 8-6 Shielded capacitor showing CRC network formed by stray capacitances to nearby lossy material
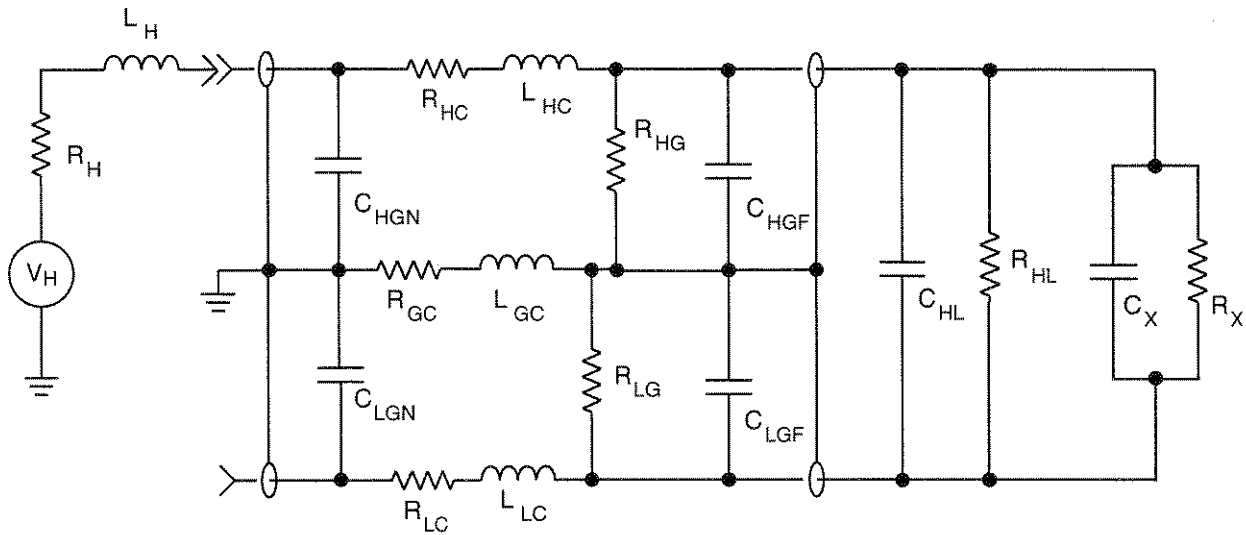
Figure 8-7 Advanced 3-terminal equivalent circuit

Actual Situations

At least two physical situations can be represented by this network. First, any loss to ground within the unknown sample measurement area which is coupled capacitively to the H and L terminals could behave like this network. A loss mechanism like this can be physically *outside* the actual sample specimen yet still within the field between the H and L terminals. See Figure 8-6. Examples include a piece of wood, an insect, a hand or, more likely, an insulating support. A second situation occurs when the sample itself has a distributed loss to ground within its own dielectric. This could be a meaningful effect in the sample.

This calculation assumed no series loss between the H and L terminals. If a loss exists, it will make a positive contribution to the measured reading. If the contribution is large enough, it can overwhelm the negative contribution so that no net negative loss is observed. Whether or not this occurs will depend largely on the particular sample. There are many materials with sufficiently low loss to easily allow the negative contribution to dominate and consequently, negative losses are not uncommon.

SOURCES OF ERROR

To better understand what kinds of errors can occur when connecting three-terminal impedances to the AH 2500A, Figure 8-7 shows a circuit model of such a connection. The schematic diagram shows all of the major circuit elements that have already been discussed in "THREE-TERMINAL MEASUREMENTS" on page 4-2 and also some new ones that usually have more subtle effects. The unknown impedance to be measured is represented by C_X and R_X. Undesirable stray capacitance or leakage resistance that contributes to the unknown is represented by C_{HL} and R_{HL}. The extent of coverage of the shielding braid in coaxial cables is not always 100%. To minimize C_{HL}, coaxial cables having a high shield coverage must be chosen to carry the H and L terminal signals.

The leakage resistances in the cable dielectric are indicated by R_{HG}, and R_{LG}. These resistances should be very high in most test configurations and therefore, should not have any significant effect.

The cable capacitances occur from the center conductors to the shields and are proportional to the length of the cable. These capacitances are modeled by placing half at the *near* end as C_{HGN} and C_{LGN} and half at the *far* end as C_{HGF} and C_{LGF}.

The series resistances of the center conductors of the coaxial cables are represented by R_{HC} and R_{LC}. The series resistance of the shielding braid is indicated by R_{GC}. Assuming the connectors on the ends of the cables are in good condition, all three of these resistances will be proportional to the length of the cable.

The inductances of the center conductors of the cables are represented by L_{HC} and L_{LC}. The inductance of the shielding braid is indicated by L_{GC}.

The voltage at the H terminal is supplied by the source V_H driven through an effective resistance R_H and inductance L_H. All of the series resistances in this drawing and the inductance combine with the cable capacitances to cause small errors in the measured results which increase with the length of the cables and with C_X.

Table 8-1 Approximate uncorrected cable error in capacitance (in ppm) and loss (in 10^{-6} tan δ) vs. length and unknown capacitance

Length	1 pF	10 pF	100 pF	1000 pF	10000 pF	100000 pF	1000000 pF
1 m	0.04* (C in ppm)	0.01	0.01	0.04	0.40	4.0	40
	0.30* (10^{-6} tan δ)	0.04	0.09	0.50	5.0	50	500
2 m	0.15*	0.02	0.02	0.09	0.8	8.0	80
	1.3*	0.15	0.20	1.1	10	100	1000
3 m	0.40*	0.05	0.03	0.15	1.3	12	120
	3.0*	0.35	0.35	1.5	15	150	1500
5 m	1.3*	0.18*	0.08	0.25	2.0	20	200
	11*	1.1*	0.80	3.0	25	250	2500
10 m	8.0*	0.8*	0.25	0.60	4.0	40	400
	70*	7.0*	2.0	7.0	50	500	5000
20 m	60*	6.0*	1.3	1.5	9	80	800
	500*	50*	5.0	16	100	1000	10000
30 m	200*	20*	2.0	2.5	14	120	1200
	1500*	150*	10	30	160	1500	15000
50 m	800*	80*	8.0	6.0	25	200	–
	7000*	700*	50	70	280	2500	–
100 m	6500*	650*	55*	20	60	400	–
	60000*	6000*	400*	220	650	5000	–

Effects of Error Sources

Cable Length

For errors caused by L_{HC}, L_{LC}, R_{HC} and R_{LC} the amount of error is proportional to the cable length if the unknown capacitance C_X is much larger than the cable capacitances C_{HGF} or C_{LGF}. If the unknown capacitance C_X is much smaller than the cable capacitances, the error is proportional to the square of the cable length.

Cable Resistance

The presence of $R_H + R_{HC} + R_{LC}$ causes the measured loss to be larger than it should be by an amount that is proportional to the unknown capacitance C_X plus the cable capacitances C_{HGF} or C_{LGF}.

Cable Inductance

The presence of $L_H + L_{HC} + L_{LC}$ causes the measured capacitance to be larger than it should be by an amount that is proportional to $(L_{HC} + L_{LC})(C_X + C_{HGF})$. Unlike all the other model parameters, L_{HC}, L_{LC} and L_{GC} can change in response to changes *outside* of the cables. The reason is that at 1 kHz, the skin-depth is much greater than the thickness of the coaxial shield. Therefore, the shield does not contain the *magnetic* field generated by the center conductor of the cable. Because the field penetrates the shield, the proximity of other conduc-

tors and especially steel can affect the value of L_{HC}, L_{LC} and L_{GC}. In addition, there will also be some sensitivity to interference from externally generated magnetic fields.

These effects will be minimized by minimizing the area enclosed by the coaxial cables. The use of Andeen-Hagerling DCOAX dual coaxial cable will minimize and standardize these effects.

Cable Shield Impedance

The presence of R_{GC} and L_{GC} causes the measured loss to be more negative than it should be by an absolute amount. It causes the capacitance to be larger than it should be due to the predominantly capacitive cable load. This error is independent of C_X and R_X and varies approximately as the cube of the cable length. Fortunately, it is fairly stable and can be subtracted out as a zero correction.

Importance of Cable Errors

While all of the above sources of error may seem intimidating, it is important to keep in mind that for short cables (1-2 meters), the errors will have little, if any, effect on your measurements. Longer cables and capacitance measurements at the top of the AH 2500A's range will have some effect and may require cable compensation with the CABLE command to achieve highest accuracy.

If you suspect that the error sources mentioned above are affecting the measurement results, simple tests such as changing the length of the cables can quickly demonstrate whether a cable-related problem exists. For another kind of definitive test, read "Testing Parameter Importance" on page 8-7.

It is very important to understand that the cable errors only affect the *accuracy* of the bridge, not the *precision*. For high accuracy calibration work, getting the most *accurate* measurements is important; for all other measurements, the high *precision* of the AH 2500A is likely to be all that is needed.

You can get a more quantitative grasp of the effect of cable errors by referring to Table 8-1. This gives the approximate *uncorrected* error in the capacitance and loss results as a function of cable length and unknown capacitance. The numbers assume that Andeen-Hagerling DCOAX cable is used. Other cables will show similar trends, but the magnitudes may differ substantially.

Table entries whose biggest error contribution is correctable by using the ZERO SINGLE command are marked with an asterisk (*). These are absolute errors in the sense that they do not depend upon the unknown capacitance. That causes them to appear to increase for smaller unknown capacitances since the error is expressed in ppm rather than in pF.

Connectors: Type 874 vs. BNC

The AH 2500A uses BNC connectors rather than type 874 for two reasons. First, type 874 connectors today are literally as much as 100 times more expensive than BNC connectors. Second, BNC connectors are much smaller and therefore more compatible with modern electronic instruments.

Traditionally, type 874 connectors have been commonly used for high precision capacitance measurements. While the hermaphroditic design of these connectors makes them friendly to use, they offer no performance advantage over BNC's at 1 kHz and for the impedance range measured by the AH 2500A. (At high frequencies they have some advantages.)

Both types of connectors have failure mechanisms that can cause subtle problems. The type 874 center pin is attached with a nut that compresses against a piece of insulating plastic. This plastic yields over time so that the nut becomes loose and makes the electrical connection of the center pin unreliable.

BNC plugs have a splined cylinder just inside the outer bayonet. These splines are the contacts that mate the shield between the plug and a jack. Unfortunately, the metallurgy of these splines often leaves something to be desired. They frequently yield and thereby lose enough contact pressure to affect the ground connection. Fortunately, there are six of these splines in each plug and in the case of the AH 2500A, there are two BNC connectors having a parallel ground path. Since it is rare for all twelve splines to make poor contact, properly assembled BNC connectors have proven to be quite reliable when used with the bridge.

Connectors fail because the resistance in the connector or between connectors becomes too large. Since loss is a measure of resistance, a failing connector will be revealed by AH 2500A measurements as an increase in the loss. A failing connector will not affect the capacitance measurement until the effect on the loss component is large.

CABLE ERROR CORRECTIONS

The AH 2500A can automatically correct for errors caused by the connecting coaxial cables. For the bridge to be able to perform these corrections, you must enter four parameters which describe the cable used to connect the bridge to the device under test. These are cable length, resistance, inductance and capacitance per meter of length. In addition, you must use the ZERO SINGLE and ZERO commands to correct the cable zero offset.

It is important to understand that all of these corrections are small for short cables and for small to medium capacitances. Unless your cables are much longer than one meter or you need the very highest accuracy, you can ignore the CABLE commands and hence this section entirely. It will be difficult to detect any effect from these commands for capacitance values below about 1000 pF and cable lengths below about three meters. For values near 1 µF or for long cables, the effects will be easier to detect. You should read "SOURCES OF ERROR" on page 8-4 and especially "Importance of Cable Errors" if you have not done so.

Setting up the Corrections

The cable resistance, capacitance, and inductance parameters are called the "cable electrical parameters". Changing these parameters and the cable length is described below.

Extent of Correction

The extent to which the errors shown in Table 8-1 can be corrected is variable. The major contributor to this variation is the accuracy of the numbers used for the cable electrical parameters. Typical accuracies will correct the cable errors by an order of magnitude. If extra efforts are made to ensure that each number is accurate, it is possible to correct the cable errors by two orders of magnitude. The cable correction model used by the bridge cannot go beyond this level.

Changing the Cable Length

The length of cable between the bridge and the unknown sample determines the amount of cable resistance, capacitance and inductance that must be corrected for. Consequently, the length in meters of one of the cables can be entered from a remote device using the syntax:

CABLE LENGTH *length*

or from the front panel:

FUNC CABLE 1 FUNC CABLE *length*

Cable *length* can be entered to the nearest hundredth of a meter up to a maximum of 999.99 meters. The default cable *length* in the GAUGE 0 parameter file is one meter.

Changing the Cable Resistance

Cable resistance is the resistance (in milliohms) of the center conductor of one meter of the cable that is used to connect the AH 2500A to the unknown capacitance. Cable resistance is changed using the command:

CABLE RESISTANCE *resistance*

or from the front panel:

FUNC CABLE 2 FUNC CABLE *resistance*

The value of *resistance* (resistance/meter) can range from 0 to 9999.0 milliohms per meter. The default resistance in the GAUGE 0 parameter file is 40 milliohms per meter.

Changing the Cable Inductance

Cable inductance is the inductance of the center conductor in microhenries per meter of cable that is used to connect the AH 2500A to the unknown capacitance. Cable inductance is changed using the command:

CABLE INDUCTANCE *inductance*

or from the front panel:

FUNC CABLE 3 FUNC CABLE *inductance*

The value of *inductance* (inductance/meter) can range from 0.00 to 99.99 microhenries per meter. The default value in the GAUGE 0 parameter file is 1.10 microhenries per meter.

Changing the Cable Capacitance

Cable capacitance is the capacitance in picofarads per meter of cable that is used to connect the AH 2500A to the unknown capacitance. Cable capacitance is changed using the command:

CABLE CAPACITANCE *capacitance*

or from the front panel:

FUNC CABLE 4 FUNC CABLE *capacitance*

The value of *capacitance* (capacitance/meter) can range from 0.0 to 999.9 picofarads per meter. The default value in the GAUGE 0 parameter file is 70.0 picofarads per meter.

Measuring the Zero Offset Error

The zero error of the cable is measured by using the ZERO SINGLE command in the standard manner described in "Zero Compensation Result Mode" on page 5-4. As described there, (and unlike the other cable correction commands) this mode must be explicitly activated with the ZERO command before it will affect the measurement results. The ZERO commands will, of course, also allow you to correct for whatever residual impedance exists in any fixture at the far end of your cable. (The ZERO command can not (and need not) correct for the cable capacitance *itself*. It corrects for a much smaller and more complicated effect that *depends* on that capacitance.)

Physical Configuration

It is important that the cable-pair shields are connected together at the *far* end of the cable. The cable correction calculations made by the bridge will only be correct if this is the case.

Another important consideration is that the cable *must* be routed to its final position before any testing or measurements are performed with it. The routing of the cable influences especially the capacitive error which is due to C_{HG}, C_{LG} and L_{GC}. This routing sensitivity occurs because L_{GC} is affected by the proximity of the cable to metal and other wiring.

Testing Parameter Importance

If you have read how to change the cable parameters above, you will be able to confidently determine the individual importance of any of the cable parameters for your particular application. You need to connect your AH 2500A using your cables to one of your typical unknown samples. Make a series of measurements while varying the values of the cable parameters. See if you can detect in your measurements the effect of changing the cable parameter values.

In particular, try changing any parameters that you think might be important for your particular configuration. The effects of the electrical cable parameters should be tried with the *length* parameter being set to the length of your cable. You should compare the effect of a default cable parameter value to the effect of that same parameter being set to zero. Since the cable corrections are small, your sample will have to be more stable than the magnitude of the cable corrections or you will not be able to detect their effect. If you either can't detect the cable effects in your measurements or they are too small to be of concern, then you can use the default values in the GAUGE 0 parameter file and not be concerned any further with cable corrections.

Determining the Parameters of your Cable

If you have decided that cable corrections are necessary in your application, then you will want to read this section.

If you are using a standard one meter Andeen-Hagerling DCOAX-1-BNC cable then the default parameters from the GAUGE 0 parameter file will be correct for this cable. In other words, if you have not created a GAUGE 1 parameter file, then when the bridge is turned on, it will automatically have chosen the correct cable parameters. See Chapter 3 titled "Parameter and Program Files" if you want to learn how to make your bridge power-on with the correct parameter settings.

If you are using an Andeen-Hagerling DCOAX cable of a length other than one meter and you want to set the cable parameters correctly, then you will have to use the CABLE LENGTH command to change the *length* parameter. The cable electrical parameters will still be correct without making any changes.

If you are using any other type of cable and you want to set the cable parameters correctly, you will have to determine the parameters for your cable. If your cable is RG-58 or similar, the three default electrical parameters will be very close to those for your cable. If that is the case, you may want to just set the *length* parameter and forget about adjusting the electrical parameters.

Determining the *length* is trivial provided that you understand that the *length* is that of the *pair* and *not of the sum* of two single coaxial cables. The capacitance/meter and the resistance/meter are usually available for any commercially made cables. They are not hard to measure if published specifications cannot be found. In either case you must understand that these parameters are for a *single* piece of coaxial cable and *not for the sum* of two single coaxial cables. The resistance/meter can vary significantly since some cables such as RG-59 and RG-62 have only a copper-coated *steel* center conductor rather than solid *copper* such as RG-58.

Determining the inductance/meter is *not* easy because the correct specification will *not* be published. You may find an inductance specification but it will *not* be what you are looking for. The problem, as was discussed in "Cable Inductance" on page 8-5, is that the inductance at 1 kHz is dependent on more factors than just the construction of the cable. *Calculating* the inductance would be difficult even for the simplest configurations. *Measuring* it is more practical *if* the measurement can be made at one kilohertz.

To make the measurement, tie the unknown sample ends of the cable together so that the center conductors are connected to each other. At the other end, measure the inductance between the open H and L cable ends as shown in Figure 8-8. The cable shields can be connected in parallel with the center conductors, but this will not have a significant effect. This measurement will be very difficult for short cables such as one meter since the inductive component of the impedance will be small in an absolute sense *and* will be small relative

to the resistance of the cable. Few instruments will be capable of making this measurement for short cables at 1 kHz. Having measured the inductance and the length of the cable, it is then simple to calculate a number for the inductance/meter parameter.
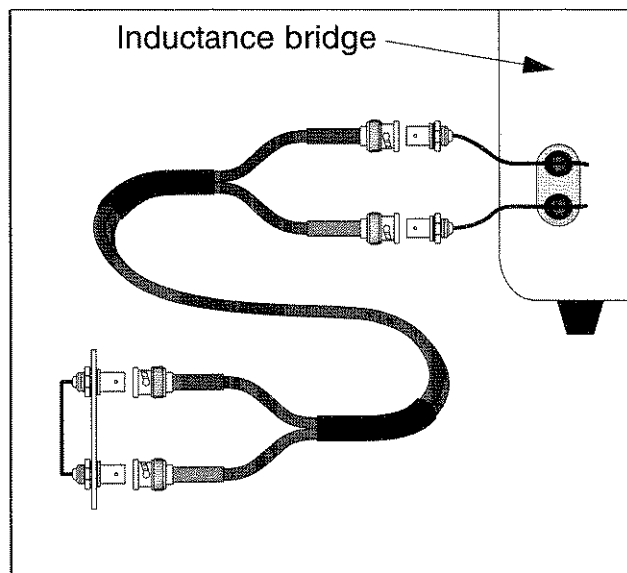
Figure 8-8 Measurement of cable inductance

CALIBRATION AT OTHER FREQUENCIES

The AH 2500A operates only at 1 kHz. However, because it can make capacitance measurements more accurately than any other current product *at any frequency*, there is a desire to be able to use it as the basis for calibration of capacitors at frequencies other than 1 kHz. This can in fact be done with four-terminal capacitance standards and is used by one of the world's largest electronic instrument manufacturers to perform NIST traceable calibrations.

This method requires the use of a network analyzer that covers the frequency range of interest. The method is described in reference 7 in the bibliography. This is a brief and highly technical discussion for the advanced user who wants to pursue this topic further.

INDUCTANCE MEASUREMENTS

As discussed in "Interpretation of Negative Capacitance" on page 8-2, a negative capacitance may be interpreted as an inductance. You can, in fact, use your AH 2500A to make accurate measurements of large inductors at 1 kHz.

Unlike capacitors, an important contributor to the loss of inductors is the resistance of the wire used to make the inductor. For air-core inductors with a low stray capacitance, this is the primary loss mechanism. The most accurate circuit model is then a resistor in series with an inductor. You should, there-

fore, measure inductors with your AH 2500A set to units of series-kilohms. This will allow you to directly read the series resistance of an inductor connected between the HIGH and LOW terminals of the bridge. For air-core inductors such as a Leeds & Northrup 1520-C Brooks Inductometer (no longer made), this value will be in close agreement with DC measurements.

Calculating the Inductance

The inductance can be determined by inserting the measured negative capacitance value into Eq. 8-2 and calculating the result. This leads to dividing the magnitude of your measured negative capacitance in picofarads into 25330.3 to give an inductance in henries. Table 8-2 shows the conversions for popular values.

Table 8-2 Negative capacitance to inductance conversion table

Capacitance	Inductance
-120000 pF	0.21109 H
-100000 pF	0.25330 H
-50661 pF	0.50000 H
-50000 pF	0.50661 H
-25330 pF	1.0000 H
-20000 pF	1.2665 H
-12665 pF	2.0000 H
-10000 pF	2.5330 H
-5066.1 pF	5.0000 H
-5000.0 pF	5.0661 H
-2533.0 pF	10.000 H
-2000.0 pF	12.665 H
-1266.5 pF	20.000 H
-1000.0 pF	25.330 H
-506.61 pF	50.000 H
-500.00 pF	50.661 H
-253.30 pF	100.00 H
-200.00 pF	126.65 H
-126.65 pF	200.00 H
-100.00 pF	253.30 H
-50.661 pF	500.00 H
-50.000 pF	506.61 H
-25.330 pF	1000.0 H
-20.000 pF	1266.5 H
-12.665 pF	2000.0 H
-10.000 pF	2533.0 H

Measurement of Large Inductances

Although the AH 2500A has the necessary range to measure extremely large inductances, the accuracy of the measurement decreases as the inductance increases and eventually becomes useless for obtaining an inductance value. The problem occurs when the capacitive reactance of the DUT becomes significant relative to its inductive reactance. Because these have opposite signs, they tend to cancel one another so that the instrument sees a reactance that is bigger than the inductive component. (The measured capacitance is smaller than it would otherwise be.)

If the reactances are equal at 1 kHz, then self-resonance occurs and the DUT is effectively a resistor. When this occurs, the measured capacitance value tells nothing about the actual capacitance or inductance of the DUT; it simply is an indication of resonance. A lower measurement frequency would be required to avoid the resonance point.

Table 8-2 goes down to -10 pF, but this should be well past the resonance point for real devices. The stray capacitance for large inductors increases rapidly with inductance because of the large number of turns that are required. As a result, most inductors will not read accurately above about 10 H using this method.

Loss and Q-factor

On the other hand, the measured series resistance *is* a meaningful value for the DUT at 1 kHz. In fact, the series resistance should be a meaningful 1 kHz measurement whenever the bridge is able to report a reading above or below resonance. The series resistance in this case will *not* likely be in good agreement with the DC value because the large stray capacitance implies a substantial loss in the insulation that covers the wire of the inductor.

The bridge can also be used to measure the Q-factor of a large inductor above or below resonance. This is done by setting the bridge to units of dissipation factor (D). The Q-factor is just the reciprocal of the dissipation factor ($Q = 1/D$). This measurement should be valid for any result reported by the bridge, but as with the series resistance setting, the capacitance reading will only be meaningful for smaller inductance values.

Chapter 9   Verification/Calibration

This chapter describes how to verify that your AH 2500A is properly calibrated and how to re-calibrate it if a verification shows that recalibration is needed. Several issues regarding "when to calibrate" and "what standards to use" for calibration are discussed. The bridge's ability to use either its original capacitance and transformer calibrations or the most recent versions of these is described. Finally, the passcode structure used to protect the calibrations is presented.

GENERAL ISSUES

Recommended Equipment and Accessories

The following list gives the tools and equipment required to verify/calibrate the AH 2500A.

1. 0.5 to 1600 pF three-terminal capacitance standard having a traceable accuracy of 1 ppm. For Option-E bridges, 0.5 ppm is recommended. See "Obtaining the Capacitance Verification Data." on page 9-9 for a discussion of what is appropriate.

2. Dual, low noise, low inductance, one meter, coaxial cables with male BNC ends. Andeen-Hagerling DCOAX-1-BNC is recommended.

3. For Option-E bridges, a 1 pF to 1 μF three-terminal, six-decade capacitor box. An accuracy of ±0.5 pF from 0 to 600 pF and to ±0.5% from 600 pF to 1 μF is desirable, but *traceability is not needed.*

4. AC resistance standard having a value of 10 kΩ with an accuracy at 1.0 kHz of 0.005% (0.0025% for Option-E). See "Finding a Suitable AC Resistor Standard" on page 9-16 for a discussion of what is appropriate.

5. Digital multimeter with an AC voltage accuracy of 1%.

6. Digital frequency meter with an accuracy of 0.001% at one kilohertz

7. For Option-E bridges, connection to a GPIB or RS-232 device capable of recording the verification results is desirable.

Types of Calibrations/Verifications

There are a number of procedures required to verify adequate calibration of an AH 2500A. These can be grouped into the various types listed below.

1. Internal - verifies numerous internal calibration points, especially related to the DAC (or RTMDAC). See "ANALOG CIRCUITS BLOCK DIAGRAMS" on page 10-2 for an introduction to the DAC circuitry.

2. Capacitance - verifies that the internal reference standards are calibrated relative to a traceable standard.

3. Transformer - verifies that the transformer voltage ratios are correct. (Option-E only)

4. Loss - verifies that the internal phase shifters are accurately producing a 90 degree phase shift.

5. Frequency - verifies that the frequency of the test signal is within tolerance.

6. Output voltage - verifies that the voltage of the test signal is within tolerance.

The internal, capacitance and transformer calibrations are all maintained by values stored in an EEPROM (re-writable, non-volatile memory). The loss calibration is derived from the capacitance and internal calibrations using a patented phase-shifting technique. The test signal frequency is determined by a quartz oscillator and a digital divider. The output voltage is set by an internal trimpot.

Calibration versus Verification

Definitions
A complete calibration of the AH 2500A accomplishes two major functions:

- Makes all measurements taken with a given AH 2500A consistent with each other.

- Makes all measurements taken consistent with and traceable to national and international standards.

The internal and transformer calibrations accomplish the first function. The capacitance and output voltage calibrations accomplish the second function. A calibration accomplishes these things by making permanent adjustments to a bridge.

A verification is a test of whether a bridge is sufficiently well calibrated and fully functional. A verification does not adjust a bridge, but its results may show cause to perform a calibration or repair. The loss and frequency checks are only verifications because they are not adjustable.

```
DEV FROM LAST INT:    CAL AGE =     345 HRS    TEMP = -5.1C
DEV FROM ORIG CAP:    CAL AGE = 12345 HRS    TEMP = -4.6C
DEV FROM ORIG TRF:    CAL AGE = 12346 HRS    TEMP = -4.2C  (Option-E only)
```

Figure 9-1 Example of results of SHOW CAL command sent to remote devices

```
┌──────────────┐   ┌──────────────┐   ┌──────────────┐
│  dEu   Fro   │   │  CAL  AGE    │   │  tEMP        │
├──────────────┤   ├──────────────┤   ├──────────────┤
│  LASt I nt   │   │     345 H    │   │    -5.1 C    │
└──────────────┘   └──────────────┘   └──────────────┘

┌──────────────┐   ┌──────────────┐   ┌──────────────┐
│  dEu   Fro   │   │  CAL  AGE    │   │  tEMP        │
├──────────────┤   ├──────────────┤   ├──────────────┤
│  Or i G CAP  │   │    12345 H   │   │    -4.6 C    │
└──────────────┘   └──────────────┘   └──────────────┘
```

Figure 9-2 Example of results of SHOW CAL command displayable on non-Option-E bridges

Availability of the Verification Option

Conventionally, a calibration has typically involved making some kind of measurement of a calibratable quantity (called a calibration point here) within an instrument, the result of which is compared against the desired value for that measurement. If the measured and desired values are close enough, no actual adjustment of the instrument being calibrated is needed. In this case, a *verification* has been performed. If the measured and desired values are different, then an adjustment of the instrument is made. In this case, a *calibration* has been performed. When a calibration/verification involves physically adjusting a variable control, the choice of verifying *or* calibrating is always available.

Using firmware, today's instruments can calibrate dozens and even hundreds of internal instrument settings automatically. This can make it impractical to provide the option of calibrating *or* verifying each calibration point.

The AH 2500A has only one physically adjustable calibration control (the output voltage). All other adjustable calibration points are controlled by firmware.

Firmware Calibration/Verification

The AH 2500A uses three-step procedures to perform the firmware calibrations. These steps are:

1. Make calibration point measurements to obtain data that is suitable for calibrating the bridge. This data is referred to here as "verification" data until it is permanently stored.

2. Allow examination of this data to determine if a calibration is needed or if a verification is sufficient.

3. If the decision of the previous step is to calibrate, then permanently store the new verification data (into the EEPROM) by overwriting the current calibration data.

These steps are executed using versions of the CALIBRATE, SHOW CALIBRATE and STORE CALIBRATE commands, respectively. These commands are all introduced in this chapter. All versions of the STORE CALIBRATE command require passcodes since these are the commands that actually change the calibration of a bridge. Since the other calibration commands require no passcodes, anyone can *verify* the calibration of the bridge at any time.

In other words, after using the CALIBRATE commands to obtain the internal, capacitance and possibly transformer verification data, you can use the SHOW CALIBRATE commands to create a report that summarizes this verification data relative to previously stored calibration data. If the newly obtained data does not deviate significantly from the stored calibration data, then the calibration state of the bridge may be considered to be verified. If the newly obtained data *does* deviate significantly from the currently stored calibration data, then you will probably want to use the STORE CALIBRATE commands to replace the currently stored calibration data with the newly obtained data. As explained in "Selecting Update vs. Original Capacitance Calibration Data" on page 9-11, you may alternately or additionally change your bridge's selection of Original versus Update capacitance calibration data. If your bridge is an Option-E, then you have an additional, equivalent choice with transformer calibration data.

Reasons for Verifying Only

In some applications, it is important that a bridge's measurements not change suddenly from one day to the next, even by tiny amounts. In other words, the day-to-day *stability* may be more important than the long-term stability or the accuracy. In cases such as this, the ability to verify without calibrating can be essential. A verification can prove that a bridge has not suffered an unexpected shift in its measurements, yet a verification will not change the bridge's measurements in any way. It might be more helpful for a verification to follow and document a small drift in a bridge rather than to try to periodically correct it. Each such correction would cause a tiny offset in the bridge's measurements that might be undesirable. The bottom line is that the decision between calibration and verification is dependent on the application.

In general, the above comments apply mostly to the capacitance calibration rather than the internal calibration. The latter corrects for changes over time and for differences in ambient temperature. The errors which are corrected by the internal calibration occur mostly in the linearity of the AH 2500A. An inadequate internal calibration will affect the linearity by causing small offsets, steps, or staircase effects in the measurements as a function of the actual capacitance or loss value. Since such errors are too complex to predict or externally correct, it is desirable to perform frequent internal calibrations to minimize them.

Your experience may lead you to believe that internal calibrations are not important, because the effects are not easily observed. However, if you make a series of measurements which happen to be near a step in your bridge's behavior, an inadequate internal calibration may cause the measurements to have a double-valued characteristic. As a result, for maximum precision, internal calibrations should be performed every month or two even if the ambient temperature is constant.

A double-valued characteristic may also be observed on a finer scale as a result of transformer errors. For Option-E bridges, this double-valued characteristic is correctable by the Option-E transformer calibration described later. After calibration the remaining errors should be in the noise. The extreme stability of the ratio transformers should keep these errors low so that frequent transformer calibrations should not be needed and are therefore not recommended.

Deciding When to Calibrate/Verify

Traceability Calibration/Verification

If your application requires traceability, you will probably want to perform a complete verification/calibration every year or two. Experience has shown that the stability of the internal reference standards and of the ratio transformers in the AH 2500A is sufficient that a traceable verification/calibration performed every year or two is conservative. A change in these components that causes the bridge to fail its accuracy specification within three years is considered to be a *failure* of those components, not just a drift. Of course, calibration/verification must identify failures also. Therefore, critical applications must perform traceable verification/calibrations with a frequency related to the criticality of the application. The bottom line is that you must be the ultimate judge based on your requirements and experience.

Internal Consistency Calibration

While the reference capacitors and ratio transformers in the AH 2500A are very stable, there are many other components that are less stable. These components will drift over time and with changes in temperature. Fortunately, each of these components that can affect performance is automatically verified relative to the reference capacitors and ratio transformers when an internal verification is performed.

Without actually taking the time to perform an internal verification, there is no way to know for certain if an internal calibration should be done. However, it is possible to check the elapsed operating time and the change in temperature relative to when the last internal calibration was done. This is done using the SHOW CALIBRATE command introduced below.

Ambient Temperature and Internal Cal's

Unlike other high-precision instruments, the AH 2500A is capable of operating to its full specifications over a temperature range that is much wider than that found in calibration laboratories. The qualification to this statement is that for highest precision and linearity, an internal calibration should be performed after the bridge has stabilized at the temperature at which it is to be operated. If it was recently calibrated near this temperature, then a new calibration is unnecessary. The SHOW CAL command is very useful here for easily identifying whether the bridge is being operated near the temperature at which its last internal calibration was performed.

Comparison with the Previous Calibration Conditions

The approximate elapsed *operating* time and the change in temperature relative to when the last internal, capacitance and transformer calibrations were done can be determined by issuing the command:

$$\text{SHOW CALIBRATE}$$

The results of this command as reported to remote devices are shown in Figure 9-1. The results of the SHOW CAL command are displayable on the front panel in two or three lines of three windows each. A non-Option-E example is shown in Figure 9-2. Each window is accessible using the ⬆, ⬇, ⬅ and ➡ keys in the normal manner.

The first line gives the deviation of current conditions from those under which the previous internal calibration was made. The approximate elapsed *operating* time in hours from the last internal calibration is given following "CAL AGE =". The difference between the current temperature and that during the last internal calibration follows "TEMP =".

The second line specifies the same information relative to the capacitance calibration. This line additionally specifies whether the capacitance calibration in current use is the original one or an updated one. This is indicated with a label reading "ORIG" or "UPDT", respectively, preceding the "CAP" label. The meaning of these labels is discussed in "Selecting Update vs. Original Capacitance Calibration Data" on page 9-11.

The third line only appears on Option-E bridges. It contains transformer calibration information in exactly the same format as the second line.

```
DEV FROM LAST INT:      CAL AGE =    34 HRS      TEMP = -3.8 C      BIGGEST CHANGE = 36%

CAL        I DEV FROM   Q DEV FROM     I DEV FROM    Q DEV FROM     I RANGE     Q RANGE
POINT      LAST CAL     LAST CAL       ORIG CAL      ORIG CAL       USED        USED

R101         -34%          1%            -42%           2%          -23%         12%
```

Figure 9-3 Non-Option-E example of results of SHOW CAL 1 **command sent to remote devices**

```
 dEu  Fro       [ CAL AGE ]       [ tEПP ]        [ b CHAПGE ]
 LASt I nt            34 H            -3.8 C            36 PEr

 r IO I  -34     [ r IO I  -42 ]   [ r IO I  -23 ]
 LASt   O I        OrI G   O2        USEd   I2
```

Figure 9-4 Non-Option-E example of results of SHOW CAL 1 **command displayed on front panel**

Preliminaries

Before performing any verifications, the AH 2500A and its environment must be stable. The OVEN NOT READY indicator on the front panel must not be on. The bridge must have been powered on for at least one hour.

In addition, the bridge should be verified in a thermal environment that is as close as possible to that in which it will actually be operated. This means that the covers must be on the bridge, since that is presumably how it is normally operated. The bridge must be in the same physical orientation as it is normally operated. That is, it should not be verified while sitting on its side if it is normally operated in a horizontal position.

Carrying the thermal considerations one step further, the *very highest* precision requires that the bridge have its *internal* verification performed in its operating environment, not in a calibration lab unless that is where it is normally operated. This is particularly important if these environments might be significantly different. An example is the case where the bridge is normally operated in a rack on a factory floor. The rack is an additional enclosure that can trap heat and which will usually contain other instruments which are additional sources of heat. The rack environment may thus be substantially warmer than the calibration lab environment.

INTERNAL CALIBRATION

An internal verification checks for drift and temperature changes in dozens of internal components. It does this by intercomparing these components against the internal fused-silica capacitance standard and the main ratio transformer.

Simplified Procedure

The following pages describe not only how to perform an internal verification, but also how to interpret all of the information that such a verification can provide. If you know that you just want to perform an internal calibration without any verification checks or other data gathering or interpretation, then you can skip most of the next few pages. Simply do the following:

1. Issue the CALIBRATE 1 command described below.

2. Issue the SHOW CALIBRATE 1 command described below in "Internal Verification Results".

3. Check that the report produced in the previous step reveals no calibration point that exceeds 100% of its calibratable range as described in "Identifying the Point with the Largest Correction" on page 9-8.

4. Issue the STORE CALIBRATE 1 command followed by a passcode to permanently save the new verification data as described in "Saving the Internal Verification Data" on page 9-9.

Obtaining the Internal Verification Data

Obtaining the internal verification data only requires that a command be entered. No special external connections are required. The LOW input terminal is internally disconnected during the verification measurements so it doesn't matter what is connected to it. The HIGH output terminal is internally grounded so it doesn't matter what impedance is connected to it either. The command that initiates the internal verification measurement is:

<u>CALIBRATE</u> 1

The verification measurement procedure takes about eight minutes for non-Option-E bridges and 30 minutes for Option-E bridges. The front panel will display $CAL -$ $brAtE$ $bUSY$ during this process and will show $rEAdy$ when the procedure has successfully completed.

If the procedure fails, the front panel will show the message Int CAL $FAILurE$. This indicates that a hardware failure has occurred. If this happens, refer to Chapter 11 titled "Diagnosis and Repair".

Internal Verification Results

The kind of internal verification data that is reported depends on whether your bridge is an Option-E or not. Option-E bridges produce a 34 line report giving the status of every internal calibration point in the bridge. Non-Option-E bridges just give a summary of this report showing the largest current internal verification error. The one internal calibration point that is furthest from its nominal value is also shown.

To get a report summarizing the new internal verification data obtained with the CAL 1 command, issue the command:

<u>SH</u>OW <u>CAL</u>IBRATE 1

If you had not previously issued a CAL 1 command, the front panel will show the message CAL $dAtA$ $AbSEnt$ indicating that no new internal verification data exists.

Internal Verification Summary for Non-Option-E Bridges

On Non-Option-E bridges, the SHOW CALIBRATE 1 command will produce the report shown in Figure 9-3 on remote devices. The equivalent windows in Figure 9-4 can be shown on the front panel.

Full Internal Verification Report for Option-E Bridges

On Option-E bridges, the SHOW CALIBRATE 1 command will produce the report shown in Figure 9-5 on remote devices. An equivalent report can be shown on the front panel. The first two lines of the front panel report have the same format as the non-Option-E windows in Figure 9-4. All the remaining lines have the same format as the second line

in this figure and will show the same information as in Figure 9-5.

Verification Conditions: SH CAL 1, 2 or 3 vs SH CAL

The first two fields in the line of the SHOW CAL 1 (or SHOW CAL 2 or 3 commands introduced later) report beginning "DEV $FROM$" give the elapsed operating time and the temperature difference between the conditions used to obtain the currently stored calibration values and the conditions used to obtain the new verification data. Note that this is similar but not identical to the results reported by the SHOW CAL command. That command compares the conditions used to obtain the currently stored calibration data with *current* conditions. These two reports will give nearly identical results if the SHOW CAL command is issued soon before or after the CAL 1 command is executed (or CAL 2 or 3 commands introduced later). That way the time and temperatures will be the same. On the other hand, if the SHOW CAL command is issued at a different time or temperature from that of the CAL 1 (or 2 or 3) command, then the time and temperature results from the SHOW CAL and SHOW CAL 1 (or 2 or 3) commands will differ.

Checking the Biggest Cal Point Change

The last field in the first line of the report shown in Figure 9-3 or Figure 9-5 reports the percent deviation in the calibration point that had the biggest change between the currently stored internal calibration values and those just obtained with the CAL 1 command. This change is the value of most interest in the entire report. The larger this change is, the greater the need to update the internal calibration values.

This change is a combination of the effects of time and of any difference in the temperature at which the two sets of internal calibration data were obtained. If a significant change has occurred and it has been many months since an internal calibration has been done, then it is desirable to save a new calibration. On the other hand, if a significant change has occurred but an internal calibration was just done only days ago, then for non-Option-E bridges, the change is likely to be the result of temperature differences. In this case, it may make sense to save the new verification data only if you intend to operate the bridge at the new verification temperature. (Option-E bridges are temperature corrected so their internal calibrations are affected less by temperature.)

A change greater than 100% *requires* saving the new internal verification values *if* the specifications are not to be exceeded *at the temperature* at which the verification data was obtained.

CAL POINT	I DEV FROM LAST CAL	Q DEV FROM LAST CAL	I DEV FROM ORIG CAL	Q DEV FROM ORIG CAL	I RANGE USED	Q RANGE USED
C211	-8%	-2%	-7%	-2%	0%	-1%
CV11	-12%	-2%	-12%	-12%	0%	5%
R171	6%	-2%	11%	-2%	0%	-14%
R168	6%	1%	10%	0%	15%	3%
R160	-7%	-1%	-3%	-1%	15%	3%
R167	3%	0%	0%	1%	19%	2%
R159	-1%	-1%	5%	2%	12%	1%
R166	-4%	0%	-2%	-1%	19%	1%
R158	1%	1%	-7%	-1%	21%	2%
R164	-5%	-3%	0%	-3%	5%	-5%
R138	-19%	3%	3%	6%	6%	-3%
R162	-1%	-3%	-4%	-2%	5%	4%
R161	-2%	1%	-2%	-2%	2%	5%
QG01	2%	-1%	5%	-3%	-2%	2%
R184	-4%	0%	-8%	3%	0%	-2%
R178	5%	1%	7%	0%	-24%	0%
R183	1%	3%	-3%	0%	-18%	-1%
R177	1%	2%	0%	0%	-1%	-2%
R182	12%	3%	6%	3%	14%	-1%
R176	9%	-5%	-5%	-3%	15%	-1%
R181	10%	0%	-3%	-5%	8%	3%
R139	0%	0%	7%	-12%	11%	3%
R180	3%	-1%	-2%	0%	5%	-3%
R179	-1%	0%	2%	0%	7%	-4%
ZE01	2%	2%	2%	2%	-12%	14%
ZE02	10%	0%	10%	5%	-12%	14%
U407	0%	0%	0%	0%	-10%	0%
U406	0%	0%	0%	0%	-9%	0%
U416	3%	0%	3%	0%	-7%	0%

Figure 9-5 Option-E example of results of SHOW CAL 1 **command sent to remote devices**

Interpreting the Calibration Point Data

This section describes the meaning of the calibration point data for both internal verifications and for the Option-E transformer verifications discussed later.

The bottom line in Figure 9-3 and the bottom 29 lines in Figure 9-5 contain internal verification data. There are two lines above these bottom lines that provide headers for the columns of data. Figure 9-5 shows typical data for *every* internal calibration point for a typical Option-E bridge. Figure 9-3 shows only the *one* internal calibration point that is *furthest* from its nominal value for a non-Option-E bridge.

Figure 9-8 on page 9-14 shows typical transformer verification data for an Option-E bridge.

The Reference Labels

The first field in each line of the reports is the reference label for the calibration point. For many points, this number is identical to the reference label in the parts lists and schematic diagrams. For the remaining calibration points, no corresponding single parts exist. Table 9-1 identifies the components or assemblies which affect each internal calibration

point. For Option-E transformer verifications, Table 9-1 on page 9-7 contains the corresponding information.

Meaning of the "I" and "Q" Pairs

The remaining fields in the reports occur in "I" and "Q" pairs. These pairs represent the two components of a vector. Vector components are reported here because that is how the correction values are internally represented.

The "I" or in-phase value is that component of the error which is in phase with the desired output characteristic of the calibration point. The "Q" or quadrature value is that component of the error which differs in phase by 90 degrees with respect to the desired output characteristic of the calibration point.

In the case of a resistor, the in-phase error is in the resistance and the quadrature error is in the stray capacitance across the resistor. In the case of a capacitor, the in-phase error is in the capacitance and the quadrature error is in the loss of the capacitor. In the case of a ratio transformer, the in-phase error is that component of the divided voltage from a given tap that is in phase with the signal applied to the transformer. The quadrature error is the component of the divided voltage from this tap that is 90 degrees out of phase with respect to

Table 9-1 Components or assemblies which affect the internal calibration points

Calibration Points	In-phase tolerance equaling 100% of range	Ratio of range-used scale to non-Option-E in-phase deviation scales	Standard Deviation of scatter in deviation values	Corresponding components and assemblies which affect each internal calibration point
R171	0.06%	70	3%	Gain error in DAC driver circuit which includes C210B/C210C, R171B/R171A and U127
R161, R179	35%	2	7%	These resistor references have the same labels as in the parts lists and schematics.
R138, R139	7%	4	7%	
R162, R180	35%	4	7%	
R164, R181	7%	7	6%	
R177, R183	0.5%	15	4%	
R159, R167	0.5%	20	4%	
R160, R168	0.1%	30	4%	
R158, R166	5%	30	5%	
R176, R182	5%	30	10%	
R178, R184	0.35%	50	3%	
C211	60 ppm	70	4%	Capacitance ratio of C210A to C210B
CV11	0.08 ppm/V	2	7%	AC voltage coefficient of the capacitance of C210B
QG01	2%	70	3%	Output voltage of the quadrature generator circuit comprising U107 - U110 and related components
ZE01	3 μV in HDASUM signal	3	3%	Zero error in T101, magnetic field from T101 coupled into connecting circuitry on A101, C210 and A601, ground currents due to stray capacitances, loose board mounting screws, etc.
ZE02	3 μV in HDASUM signal	--	4%	Alternate measurement of ZE01 that confirms correct operation if range-used figures for ZE01 and ZE02 are nearly equal
U407	15 mV	3	3%	DC zero offset of U407 filter circuit
U406	15 mV	3	3%	DC zero offset of U406 filter circuit
U416	3 LSB	2	10%	DC zero offset of analog-to-digital converter U416

the signal applied to the transformer. Any three-terminal network is interpreted in a similar manner to this ratio transformer example.

The Range-Used Pair

The right-most I and Q pair in the reports gives *the* values used to make the firmware calibration corrections. These values are expressed as the percentage of the available firmware correction range that is required to compensate for the deviation of the part or assembly from its nominal value.

A value of 0% means that the calibration point has exactly the value that it is expected to have (as measured by the calibration circuitry of the bridge). For example, if R167 has an in-phase range-used value of 0% then its actual resistance equals its nominal resistance of 200kΩ to the limit of the bridge's internal intercomparison capability.

The Deviation Pairs

The first I and Q pair in each line of the reports gives the current change for this part relative to the *last* calibration value pair that is currently stored. For internal calibrations, it is this stored pair that is currently being used to make corrections. For Option-E transformer calibrations discussed later, this stored pair contains the Update calibration data.

The second I and Q pair in each line gives the current change for this part relative to the *original* calibration value pair that was first stored in the bridge when it was manufactured. For internal verifications, this stored pair of values is available for historical purposes only. It is not used to make any corrections. It is used to help determine what the total drift in this internal calibration point has been since the date of manufacture or the date of replacement of A101 or C210. For

Option-E transformer calibrations, this stored pair contains the Original calibration data.

A 0% deviation represents the best correction of which the calibration firmware is capable. By definition, the deviation of every internal verification value at the moment that the verification data is generated by the CAL 1 command is 0%.

Bases of Percent Scales Used

There are two different bases used for the percentage values given in this report. The percentages reported for the "I range used" are based on a scale where the limit of the calibratable range is ±100%. Only this column of values uses these percent scales. Each value in the "Q range used" column uses a scale that is half as sensitive as the corresponding value in the "I range used" column. These scales are the same for Option-E and non-Option-E bridges. For internal verifications, Table 9-1 lists the actual tolerance of the part or calibrated quantity which corresponds to 100% of the firmware calibratable in-phase range.

As an example, consider the resistor R158 which shows an in-phase correction value of 21% in Figure 9-5 on page 9-6. According to Table 9-1, this resistor is correctable up to ±5% of its nominal value. This means that the resistor actually deviates from its nominal value by 5×0.21 = 1.05% as measured by the bridge's intercomparison circuit.

All other values which are given as percentages in the internal verification report use a scale where 100% is a deviation of a verification value that will cause the bridge to function at the limit of one or more of its specifications. Since Option-E bridges have tighter specifications, their deviation scales are typically a factor of two smaller (more sensitive) than those for the non-Option-E bridges.

The deviation scales are smaller than the range-used scales. In other words, a given temperature change or drift in a calibration point will have a bigger effect in the deviation columns than in the range-used columns. For internal calibration points, a 1% change in an in-phase range-used value will be magnified in the corresponding in-phase deviation value by anywhere from two to seventy times. The exact magnification depends on the internal calibration point and is listed as a ratio in Table 9-1 for non-Option-E bridges. For internal calibration points, the ratios for Option-E bridges are obtained by multiplying the ratios in the table by two. For transformer calibration points, the magnification ratios are listed in Table 9-1 on page 9-7.

As with the range-used scales, each value in the Q-deviation columns uses a scale that is half as sensitive as the corresponding value in the I-deviation columns.

Scatter in the Deviation Values

If you try to study the verification deviation data (not the range used) you will soon discover that some of the numbers change significantly from one verification to the next. It is important to understand that many of the deviation values are highly magnified. In many cases, the noise in the input amplifier of the bridge determines the amount of scatter in the deviation values. It is this noise that causes the deviations to change from one verification to the next even when the bridge stays at a constant ambient temperature. As a result, it is not productive to try to draw conclusions about the verification data near the level of this noise.

The normal amount of scatter varies from one calibration point to another. The amount that is considered normal is given as a standard deviation in Table 9-1. If you find that any deviations for your bridge taken at constant temperature have a standard deviation that is higher than what is listed in the table by more than a factor of three then there is reason to suspect a problem in your bridge.

Identifying the Point with the Largest Correction

The last line in Figure 9-3 reports the one internal calibration point that is *furthest* from its nominal value. The corresponding line in Figure 9-5 can be identified as the one internal calibration point having the largest magnitude in the "I RANGE USED" and "Q RANGE USED" columns. In this example, that calibration point is R178 which has a magnitude of 24%. This calibration point has the largest correction value of all the internal calibration points in the bridge. Having a large correction value does not degrade the performance of the bridge provided that it does not exceed 100%.

If either the I or Q percent of range for this calibration point exceeds 100% and the internal verification was performed within the bridge's specified operating temperature range of 0 to 45 °C, then the bridge may be considered to have a hardware failure. The same is true for Option-E transformer verifications.

For points that exceed 100% of range, it will usually still be possible to perform a verification unless the 100% limit is greatly exceeded. The offending part should be identified and replaced before the bridge can be properly calibrated. See Chapter 11 titled "Diagnosis and Repair" for general instructions.

The reported percent-of-range-used includes both the change in the part since the time of first calibration during manufacture of the bridge *and* the initial tolerance of the part at the time that the bridge was manufactured. A calibration point may therefore report a substantial percentage but still be very stable (and thus fully acceptable). To identify a part as being unstable requires the information from several verification reports taken over a period of time. Only then can a possible drift in a calibration point be distinguished from the initial manufactured tolerance of a part.

It is important to understand that a part that appears to be less stable than others, might only appear that way over a limited range of ambient temperatures. A part that has a larger temperature coefficient than it should may not appear in this report over a narrow range of temperatures, yet might require a large correction at all other temperatures.

Effect of Temperature on Internal Verifications

The AH 2500A specifications assume an internal calibration at the ambient operating temperature. This is especially true for the non-Option-E version of the bridge.

The Option-E version of the bridge contains additional internal calibration data in the form of temperature coefficients (T/C's) for all internal calibration points. This T/C data is generated when the bridge is manufactured and is considered to be permanent unless A101 or C210 is replaced. This T/C data is used to adjust the internal calibration data so that it is correct for the temperature at which the bridge is actually operating.

The internal verification report generated by Option-E bridges shows the deviations *after* temperature corrections have been applied. These temperature corrections improve the accuracy of the internal calibration points by a factor in the range of six to twenty over that of the non-Option-E bridge. Since the deviation scale used in the Option-E bridges is twice as sensitive as that of the non-Option-E bridges, the reported deviation *percentages* due to changes in ambient temperature will be from three to ten times smaller for Option-E bridges than for non-Option-E bridges.

By obtaining and reporting internal verification data at several different ambient temperatures you should easily be able to observe the effect on the deviations of the calibration points for a non-Option-E bridge. Ambient temperature changes of 3 °C will cause deviations above the noise level of the data. Ambient temperature changes of 10 °C will likely cause deviations larger than 100% that will prevent the bridge from meeting its published specifications. If you try this same experiment on an Option-E bridge, you will have to use a significantly wider temperature range to observe equivalent effects.

Saving the Internal Verification Data

The internal verification data obtained with the CAL 1 command can permanently replace the current data by issuing the command:

STORE CALIBRATE 1

You will be prompted for a passcode immediately after issuing this command. You may enter any of the *three* allowed passcodes as explained in "THE CALIBRATION PASS-CODES" on page 9-17. This command takes a few seconds to execute and will display the r E A d Y prompt when it is finished. After this command is executed, all subsequent measurements will use the new calibration data. If *no* new internal verification data exists then the front panel will show the message C A L   d A t A   A b S E n t.

CAPACITANCE CALIBRATION

The capacitance calibration corrects for drift in the fused-silica standard inside the AH 2500A. This calibration requires the presence of new internal verification data. If no new internal verification data is present, then the capacitance verification will automatically generate (but not store) such data in addition to obtaining the capacitance verification data. For maximum precision, the capacitance verification should be performed under the same environmental conditions as a *new* internal verification. This is true even if you intend to store only the capacitance verification data and not the internal verification data.

Obtaining the Capacitance Verification Data.

Obtaining the capacitance verification data for the bridge requires that a high-accuracy capacitance transfer standard be connected to the bridge. Due to the extremely high accuracy that is possible with the AH 2500A, there is an issue of what is available to use as a capacitance standard.

You need access to one of three realistic transfer standard configurations. These are:

1. A high-accuracy, fused-silica standard capacitor such as an Andeen-Hagerling AH 1100/11A having a traceable calibration.

2. A gas-dielectric, stacked-plate capacitor such as a Model 1404 having a traceable calibration.

3. A second AH 2500A with a traceable calibration and a gas-dielectric, stacked-plate capacitor.

If you have access to the first kind of transfer standard and you are satisfied with its level of traceability, you can use such equipment to both verify and calibrate an AH 2500A to the limit of its specifications.

If you have access to the second kind of transfer standard, you can perform a *verification* of your AH 2500A, but only to an accuracy level of about 30 ppm. This is true even if the capacitor was freshly calibrated by a primary lab. The problem is that these capacitors are prone to suddenly changing their value in response to thermal and mechanical environmental stress by amounts as high as about 30 ppm. Unfortunately, such stresses tend to occur during shipping to and from the primary cal lab. Verification to 30 ppm may be sufficient for some applications, but it is more than an order of magnitude worse than the AH 2500A is capable of.

If you have access to the third transfer standard configuration, you can perform a verification/calibration that is nearly as good as in the first case. A gas-dielectric capacitor is quite suitable for making short-term transfers of capacitance values from one AH 2500A to another if the gas-dielectric capacitor is kept at a constant temperature and not moved. Ideally, the value of the gas-dielectric capacitor should be the

```
CAP UPDATE = 1
DEV FROM UPDT CAP:    CAL AGE =    345 HRS    TEMP = -5.1C    C =  -0.71 PPM
DEV FROM ORIG CAP:    CAL AGE = 12345 HRS     TEMP = -4.6C    C =  -0.71 PPM
```

Figure 9-6 Example of results of SHOW CAL 2 **command sent to remote devices**

```
┌─────────────┐
│ CAP         │
├─────────────┤
│ UPdALE  1   │
└─────────────┘
```

```
┌─────────────┐  ┌─────────────┐  ┌─────────────┐  ┌─────────────┐
│ dEu  Fro    │  │ CAL  AGE    │  │ tEMP        │  │ CAP         │
├─────────────┤  ├─────────────┤  ├─────────────┤  ├─────────────┤
│ UPdt CAP    │  │    345 H    │  │    -5.1 C   │  │  -0.71 PPM  │
└─────────────┘  └─────────────┘  └─────────────┘  └─────────────┘

┌─────────────┐  ┌─────────────┐  ┌─────────────┐  ┌─────────────┐
│ dEu  Fro    │  │ CAL  AGE    │  │ tEMP        │  │ CAP         │
├─────────────┤  ├─────────────┤  ├─────────────┤  ├─────────────┤
│ Ori G CAP   │  │  12345 H    │  │    -4.6 C   │  │  -0.71 PPM  │
└─────────────┘  └─────────────┘  └─────────────┘  └─────────────┘
```

Figure 9-7 Example of results of SHOW CAL 2 **command displayable on front panel**

same as the value of the capacitor that was used to calibrate the AH 2500A that is providing the traceable source value.

The value of your standard must be in the range of 0.5 to 1600 pF. Values of 10.0 pF and above are preferred since the measurement uncertainty at lower values will begin to limit the attainable accuracy. For example, a 1.0 pF standard will add 1 ppm to the uncertainty of the verification.

When you are ready to obtain the verification data, use a DCOAX-1-BNC to connect your capacitance transfer standard to your AH 2500A. If you use any other cable, it should be one meter long and must have an internal, coaxial shield with 100% coverage. If you use a pair of single cables, then they should be twisted around each other to minimize their inductance. Make sure that the CABLE command parameters are set correctly since this will cause an error otherwise.

If your transfer standard is another AH 2500A, use it to carefully measure your gas-dielectric capacitor, carefully record the value and finally connect the gas-dielectric capacitor to the AH 2500A to be verified/calibrated.

When the desired capacitor is connected, issue the command:

CALIBRATE 2 CALIBRATE *standardvalue*

where *standardvalue* is the value of the connected standard capacitor in picofarads. The value may be entered from remote devices in any floating-point or scientific notation. A bAd PAr error will be reported if *standardvalue* is not in the range of 0.5 to 1600 pF.

After this command is entered, the bridge will spend about 20 seconds making the verification measurement. If no new internal verification data exists, then about eight minutes will be added to this time for non-Option-E bridges and 30 minutes for Option-E bridges. The front panel will display CALbrALE bUSY during this time. The front panel will

show rEAdY when the procedure has successfully completed.

If the value of the connected standard as measured by the bridge disagrees with the Original calibration of the bridge by more than 0.01% then the message UPdt Std Error will be displayed on the front panel. An error of this magnitude is most likely due to entering an incorrect value for the connected transfer standard. Otherwise, such an error is considered to be a hardware failure and is beyond the correction ability of the bridge's firmware.

Capacitance Verification Report

To get a report summarizing the new capacitance verification data obtained with the CAL 2 command, issue the command:

SHOW CALIBRATE 2

This will produce the report shown in Figure 9-6 on remote devices. The equivalent windows in Figure 9-7 can be shown on the front panel. If you had not previously issued a CAL 2 CAL command, the front panel will show the message CAL dAtA AbSEnt indicating that no new capacitance verification data exists.

The second and third lines of the capacitance verification report are each similar to the first line of the internal verification report. The capacitance verification report has two lines instead of one because the AH 2500A maintains two sets of capacitance calibration data. One is the Update set and the other is the Original set. The bridge can use either set of data. The set in use is indicated by the first line of the report where a one indicates the Update set and a zero indicates the Original set. See "Selecting Update vs. Original Capacitance Calibration Data" below for more information.

C04

The relative time and temperature verification conditions for each of these two sets of data are given. The same comments apply to the SHOW CAL 2 command as were discussed for the SHOW CAL 1 command in "Verification Conditions: SH CAL 1, 2 or 3 vs SH CAL" on page 9-5.

Checking the Capacitance Verification Change

The most important numbers in the capacitance verification report are the ones at the end of the second and third lines. These show the deviation of the new verification capacitance value from the stored Update and Original capacitance calibration values, respectively. The deviations are given in ppm. These numbers give the factor by which every capacitance measurement taken by the bridge will be changed (relative to the old values) if the new verification data is saved.

You should understand that these deviations represent the sum of four sources of error:

1. The absolute error in the old calibration values (Original or Update).

2. The drift in the bridge in the time between obtaining the old calibration values and the new verification value.

3. The change in temperature of the bridge between the time that the old calibration values were obtained and the time that the new verification value was obtained. This introduces an error of as much as 0.03 ppm/°C for non-Option-E bridges or 0.01 ppm/°C for Option-E.

4. The absolute error in the new verification value.

Unfortunately, there is no way to know how much error was contributed by each source. A knowledge of the relative degree of confidence in each source is usually the most there is to go on. A high degree of confidence should be placed in the Original calibration value and in the bridge's ability to maintain that value. Deviations of the new verification value from the Original value of more than about *two* ppm should be treated with skepticism.

Saving the Capacitance Verification Data

The new capacitance verification data obtained with the CAL 2 command can permanently replace the current data by issuing the command:

STORE CALIBRATE 2

You will be prompted for a passcode immediately after issuing this command. You may enter either of the *two* allowed passcodes as explained in "THE CALIBRATION PASS-CODES" on page 9-17. This command takes a few seconds to execute and will display the r E A d Y prompt when it is finished. If *no* new capacitance verification data exists then the front panel will show the message C A L d A t A A b S E n t. This command does *not* store any internal verification data even though it may have generated such data.

The new verification data is immediately stored as Update capacitance calibration data. Executing this command will also *automatically* set the capacitance Update switch to a one. All subsequent measurements will use the new calibration data *only* if the Update/Original switch remains set to one (Update).

NOTE

*It is important to understand that the bridge maintains two sets of capacitance calibration data. The currently selected set determines which of two (usually totally different) calibration sources has calibrated the bridge. If this setting is not what you intend for it to be, then **your capacitance calibration source will not be what you think it is.***

Selecting Update vs. Original Capacitance Calibration Data

The AH 2500A maintains two sets of capacitance calibration data. One is the Update set and the other is the Original set. The bridge can use either set of data. The set currently in use is determined by the setting of the capacitance Update/Original switch. This is a firmware switch that is stored in the EEPROM with the other calibration data.

When the bridge is manufactured, the Update and Original calibration data sets are identical. If the bridge is later re-calibrated with new capacitance data, this data will overwrite the data in the Update capacitance set but not in the Original capacitance set. This allows the bridge to be re-calibrated without losing the Original calibration values. This is useful because the Original values should be very accurate and are therefore useful as references. It is also useful to keep the Original values for historical purposes.

The Update/Original capacitance switch may be changed with the following command:

STORE CALIBRATE 2 SPECIAL *update*

You will be prompted for a passcode immediately after issuing this command. You may enter either of the *two* allowed passcodes as explained in "THE CALIBRATION PASS-CODES" on page 9-17. The *update* parameter is entered as a "1" if the Update capacitance calibration data is to be used to take measurements. When *update* is entered as a "0", the Original capacitance calibration data will be used. The state of the Update/Original capacitance switch can be determined with the SHOW CALIBRATE and SHOW CALIBRATE 2 commands.

Saving All Verification Data

The new internal and capacitance verification data obtained with the CAL 1, CAL 2 and/or CAL 3 commands can permanently replace the current data by issuing the command:

<div align="center">STORE CALIBRATE</div>

Only new sets of verification data that are present will be stored. You will be prompted for a passcode immediately after issuing this command. You may enter either of the *two* allowed passcodes as explained in "THE CALIBRATION PASSCODES" on page 9-17. This command takes a few seconds to execute and will display the r E A d 9 prompt when it is finished. The new verification data is stored in the same way as if a STORE CAL 1, STORE CAL 2 and STORE CAL 3 command were all executed. This command *automatically* sets the capacitance Update switch if that data was stored. Similarly, the transformer Update switch is set if that data was stored. If *no* new verification data exists then the front panel will show the message C AL d AE A Ab5E nE.

TRANSFORMER CALIBRATION

The three ratio transformers (T101, T102 and T103) used in the AH 2500A are extremely linear and extremely stable. As a result, there is no provision to verify or calibrate these transformers in the non-Option-E version of the AH 2500A.

However, the Option-E version of the bridge allows verification and calibration of the linearity of the more critical taps of these transformers on T101 and T103. The linearity is checked by performing internal intercomparisons of transformer taps. No external reference transformer is used and no commercial ratio transformer has ever been made that is even close to being good enough for this purpose.

Obtaining Transformer Verification Data

Obtaining the transformer verification data requires first connecting a 1 pF to 1 µF three-terminal, six-decade capacitor box to the HIGH and LOW terminals of the bridge. The verification will go smoothly if this box is accurate to ±0.5 pF from 0 to 600 pF and to ±0.5% from 600 pF to 1 µF. However, *this box need not be traceable* since the calibrated values of its capacitors are *not* transferred to the bridge. It is the stability and settability of the capacitors in this box that are important.

Once this is done, the command that initiates the transformer verification procedure is:

<div align="center">CALIBRATION 3</div>

If internal verification data was recently generated then this command will quickly respond to a remote device with the prompt:

```
SET CAP    300000.0 >
```

or to the front panel display with the prompt:

```
 SEt  CAP
 300000.
```

If no new internal verification data exists, then about 30 minutes will be taken to create new internal verification data. The front panel will display C AL br AE E bU59 during this time.

When the prompt message finally appears, you must set the decade capacitor box to exactly the value that is given by the prompt. Then press the [STEP] key on the front panel or enter X or STEP from a remote device. If the measurement was successful, another prompt will appear having a different value from the last. If the measurement was unsuccessful, the prompt will be repeated. This will occur until a successful measurement is taken or you abort the procedure with a DEVICE CLEAR.

An unsuccessful measurement can be the result of a number of different flaws in the decade capacitor or the cables connecting it. One of the most likely problems is that the decade box is slightly out of calibration. If this is the problem, the repeated prompt will indicate whether you should raise or lower the setting of the decade box. If you should raise it, the front panel will display a "⌐" in the lower right corner and a remote device will show a "^" to the left of the ">". If you should lower it, the front panel will display a "-" in the lower right corner and a remote device will show a "-" to the left of the ">".

If neither character is shown, then the problem was too much noise in the measurements. Rotate the knobs of the decade box back and forth to clean them. Also make sure the coax cables are as far as possible from power transformers including the one in the left rear corner of the AH 2500A.

If none of these solutions work, abort the CAL 3 procedure and simply make an ordinary measurement of the decade capacitor at the setting that the CAL 3 command was calling for. If an error message is reported, then a gross problem exists. More likely, the decade capacitor is out of calibration so that an incorrect value was being set up. The decade capacitor can be re-calibrated or the value that is set up can be offset by the amount of error in the decade capacitor. The worst case occurs if the decade box has "holes" in its range so that it is impossible to set-up the required value. This can only be solved by re-calibrating or replacing the box.

You do not need to be concerned about the possibility of incorrectly calibrating the bridge as a result of selecting the wrong capacitance. Each transformer verification measurement is either passed or failed by the bridge. If it passes, the measurement was good enough even if the decade capacitor box was not accurate.

The CAL 3 command will prompt you a total of 20 times for new settings of the decade capacitor box. If you answer the prompts as soon as they appear, then the time taken to per-

form the CAL 3 will be about an hour. When you have successfully responded to all of these, the $r E H d Y$ prompt will appear on the front panel.

Transformer Verification Report

To get a report on Option-E bridges summarizing the new transformer verification data obtained with the CAL 3 command, issue the command:

SHOW CALIBRATE 3

If you had not previously completed the CAL 3 procedure, the front panel will show the message $E H L \quad d H E H$ $H b 5 E n E$ indicating that no new transformer verification data exists.

The SHOW CALIBRATE 3 command will produce the report shown in Figure 9-8 on page 9-14 on remote devices. An equivalent report can be shown on the front panel.

The first three lines of the report in Figure 9-8 contain the same kind of information as the three lines of the capacitance verification report in Figure 9-6 on page 9-10.

The first line indicates whether the Original or Update transformer calibration data is being used by the bridge. See "Selecting Update vs. Original Capacitance Calibration Data" on page 9-11.

The second and third lines of the transformer verification report show the elapsed time and temperature differences between the newly generated transformer verification data and the transformer data stored in the Update and Original sets. The same comments apply to the SHOW CAL 3 command as were discussed for the SHOW CAL 1 command in "Verification Conditions: SH CAL 1, 2 or 3 vs SH CAL" on page 9-5.

The bottom 34 lines contain the data for each transformer calibration point. These lines have the same basic structure and meaning as those in the internal verification report. They are discussed in "Interpreting the Calibration Point Data" on page 9-6 and in its subsections.

The transformer verification report shows four groups of calibration points. These are listed in Table 9-2 below. These are identified by type as to whether the data is used to verify *and* correct errors or whether the data is just used for verification.

Table 9-2 The transformer verification groups

Label	Transformer Verification Groups	Type
AT	Linearity of attenuator transformer taps	Cal
AL	Inductance of attenuator transformer taps	Ver
K	Series resistance of attenuator relays	Ver
MT	Linearity of main ratio transformer taps	Cal

Checking the Transformer Verification Data

As with the internal verification data, the percent of range used for both I and Q should be checked for every calibration point to verify that none exceed 100%. Similarly, the deviation of the newly generated verification data relative to the stored data that is currently used (Update or Original) should be checked for every calibration point. The I and Q percentages for each of these must also be less than 100% and preferably less than 30% for all points except MT01 and MT02 which should be less than 60%. Ratio transformers are very insensitive to temperature so the temperature at which the verifications are obtained should have little effect. If these checks pass, then you need not proceed any further with the transformer verification other than to save a copy of the verification report.

Calibration groups AT and MT are used to verify and, if needed, to correct the linearity of the main and attenuator ratio transformers (T101 and T103). These calibration points should be very stable to a level where they might never need to be stored. It is preferable not to arbitrarily store new transformer verification data unless the report indicates deviations larger than what could be expected from normal scatter in the data. Arbitrarily storing new transformer verification data introduces small changes into the bridge's characteristics without improving its performance. (This is different from the case of the internal calibrations where frequent calibrations are desirable.)

Calibration group AL is used to verify but not to correct the inductance of the attenuator taps. If the range-used percentages for these calibration points is too large, then there is a hardware problem in the bridge that must be repaired.

Calibration group K is used to verify but not to correct the resistance of the attenuator relays. These calibration points should be watched more closely than any others because experience has shown that these relays are the most unreliable component in the bridge. If a range-used percentage for one of these calibration points is too positive, then the corresponding relay must be replaced. Negative percentages indicate a problem with the relay connected to the next higher tap voltage, not with the relay having the negative percentage.

Only in-phase calibration point values are reported for the AL and K calibration groups. All quadrature values are always reported as zeros for these two groups.

Saving the Transformer Verification Data

The new transformer verification data obtained with the CAL 3 command can permanently replace the current data by issuing the command:

STORE CALIBRATE 3

You will be prompted for a passcode immediately after issuing this command. You may enter either of the *two* allowed passcodes as explained in "THE CALIBRATION PASSCODES" on page 9-17. This command takes a few seconds

```
TRANSF UPDATE = 0
DEV FROM UPDT TRF:    CAL AGE =    34 HRS      TEMP = -3.1 C
DEV FROM ORIG TRF:    CAL AGE  1214 HRS      TEMP =  4.5 C
```

CAL POINT	I DEV FROM LAST CAL	Q DEV FROM LAST CAL	I DEV FROM ORIG CAL	Q DEV FROM ORIG CAL	I RANGE USED	Q RANGE USED
AT10	-10%	1%	0%	-1%	-2%	-5%
AT09	-8%	3%	0%	0%	0%	-10%
AT08	-14%	4%	-6%	0%	-2%	-9%
AT07	-9%	4%	-4%	-4%	-1%	-2%
AT06	-8%	4%	-3%	-2%	0%	-2%
AT05	-5%	5%	0%	-3%	-10%	-5%
AT04	0%	1%	0%	-5%	-37%	-1%
AT03	-6%	1%	-1%	-2%	-50%	-2%
AT02	-15%	4%	-7%	-2%	-32%	0%
AT01	-13%	6%	-2%	-7%	-34%	-8%
AL07	0%	0%	-5%	0%	0%	0%
AL06	0%	0%	4%	0%	8%	0%
AL05	0%	0%	0%	0%	0%	0%
AL04	0%	0%	0%	0%	0%	0%
AL03	8%	0%	8%	0%	8%	0%
AL02	17%	0%	11%	0%	6%	0%
AL01	2%	0%	18%	0%	29%	0%
K117	0%	0%	12%	0%	-31%	0%
K118	0%	0%	-5%	0%	-4%	0%
K119	-10%	0%	0%	0%	-6%	0%
K120	0%	0%	14%	0%	-23%	0%
K133	0%	0%	0%	0%	0%	0%
K134	0%	0%	0%	0%	-10%	0%
K135	0%	0%	0%	0%	0%	0%
MT09	-5%	-6%	3%	-3%	9%	-17%
MT08	-8%	-3%	-10%	-4%	6%	-19%
MT07	-14%	-8%	-8%	4%	-31%	-31%
MT06	-7%	-3%	-14%	2%	-11%	-26%
MT05	-8%	4%	-6%	3%	1%	-29%
MT04	-15%	-5%	-12%	6%	4%	-16%
MT03	-14%	4%	-17%	3%	-26%	-35%
MT02	-4%	7%	20%	10%	6%	-33%
MT01	-9%	-7%	-27%	-12%	12%	-34%
MT11	4%	-1%	2%	-3%	0%	-13%

Figure 9-8 Example of results of SHOW CAL 3 **command to remote devices (Option-E only)**

to execute and will display the r E A d Y prompt when it is finished. If *no* new transformer verification data exists then the front panel will show the message C A L d A t A A b 5 E n t. This command *will* store the internal verification data that it used to make its measurements.

NOTE

It is important to understand that the bridge maintains two sets of transformer calibration data. The currently selected set determines which of two (usually totally different) calibration sources has calibrated the bridge. If this setting is not what you intend for it to be, then **your transformer calibration source will not be what you think it is**.

The new verification data is immediately stored as Update transformer calibration data. Executing this command will

automatically set the transformer Update switch to a one. All subsequent measurements will use the new calibration data *only* if the transformer Update/Original switch is left set to one (Update).

Selecting Update vs. Original Transformer Calibration Data

The AH 2500A with Option-E maintains two sets of transformer calibration data in the same manner that it maintains two sets of capacitance calibration data. (See "Selecting Update vs. Original Capacitance Calibration Data" on page 9-11.) One is the Update set and the other is the Original set. The bridge can use either set of data for its transformer corrections. The set currently in use is determined by the setting of the transformer Update/Original switch.

Table 9-3 Components or assemblies which affect the Option-E transformer calibration points

Calibration Points	Signal name from tap related to this cal point	In-phase tolerance equaling 100% of range	Ratio of range-used scale to non-Option-E deviation scales	Standard Deviation of scatter in deviation values	Corresponding components and assemblies which affect each internal calibration point
AT10	M-0.5	1.8 ppm	3.5		Absolute linearity correction of attenuator taps on T101 expressed as ppm of the voltage at the tap being corrected.
AT09	M-0.2	2.5 ppm	5	5%	
AT08	M-0.1	3.5 ppm			
AT07	M-0.05	5 ppm	7		
AT06	M-0.0167	7 ppm			
AT05	100T	10 ppm		5%	Absolute linearity correction of attenuator taps on T103 expressed as ppm of the voltage at the tap being corrected.
AT04	30T	18 ppm			
AT03	10T	25 ppm	7		
AT02	3T	35 ppm		7%	
AT01	1T	70 ppm		10%	
AL07	M-0.05	0.35 ppm		7%	Voltage error in T101 due to tap inductance in ppm of voltage at tap.
AL06	M-0.0167	0.5 ppm			
AL05	100T	1.3 ppm			Voltage error in T103 due to inductance of tap expressed as ppm of the voltage at the tap being corrected.
AL04	30T	1.8 ppm	2		
AL03	10T	2.5 ppm			
AL02	3T	3.5 ppm		10%	
AL01	1T	7 ppm			
K117	M-0.05	0.35Ω		7%	Excess resistance of attenuator relays. The nominal relay resistance is usually 0.075Ω but for some of these relays it may be as high as 0.15Ω. Labels are identical to those in Figure F-25 on page F-65.
K118	M-0.0167	0.25Ω			
K119	100T	0.18Ω	2		
K120	30T	0.13Ω			
K133-K135	10T, 3T, 1T	0.10Ω			
MT09-MT05	M0.9-M0.5	0.08 ppm	1.5	10%	Absolute linearity of main ratio transformer (T101) expressed as ppm of the voltage at the M1.0 tap
MT04	M0.4	0.08 ppm			
MT03	M0.3	0.06 ppm	2		
MT02	M0.2	0.04 ppm		15%	
MT01	M0.1	0.03 ppm		20%	
MT11	M-0.1	3.5 ppm	7	5%	Error in the voltage of M-0.1 tap relative to the average of the voltages between all the other adjacent taps of the main ratio transformer expressed in ppm of the M-0.1 tap.

The Update/Original transformer switch may be changed with the following command:

STORE CALIBRATE 3 SPECIAL *update*

You will be prompted for a passcode immediately after issuing this command. You may enter either of the *two* allowed passcodes as explained in "THE CALIBRATION PASSCODES" on page 9-17. The *update* parameter is entered as a

"1" if the Update transformer calibration data is to be used to take measurements. When *update* is entered as a "0", the Original transformer calibration data will be used.

The state of the Update/Original transformer switch can be determined with the SHOW CALIBRATE and SHOW CALIBRATE 3 commands. The SHOW CALIBRATE command when issued from an Option-E bridge reports an additional line as shown in Figure 9-1 on page 9-2.

LOSS VERIFICATION

This section describes how to verify the phase shifter circuitry in the bridge. There is no adjustment that can be made so this is a pass/fail test.

Finding a Suitable AC Resistor Standard

This verification requires a three-terminal AC resistance standard with a value of 10.000 kΩ and an accuracy of 0.005% (0.0025% for Option-E) at 1 kHz. The actual value is not critical, but the accuracy of the value is important. This is not a commonly available standard so several ways of finding such a standard will be described.

1. The most expensive solution is to identify a commercial product that meets these specifications and to buy it. There are products that are physically capable of meeting these specifications, but usually the published specifications do not make this clear. It will also be difficult to get direct calibrations of such products at 1 kHz. NIST is planning to offer such calibrations beginning in about 1995.

2. A slightly easier approach may be to use a resistance standard or decade resistor that is known to be very frequency independent from DC to 1 kHz. This can be used as a transfer standard to transfer the DC value to 1 kHz. There are commercial products that give the resistance error as a function of frequency. If such a product is calibrated at DC with an accurate standard, it will then be sufficient at 1 kHz. The initial accuracy and long-term stability of the transfer standard is not important since it will be calibrated anyway. The frequency independence is what matters.

   The transfer standard should be a three-terminal device which means that it should be fully shielded. Often, these products are housed in a metal case but use unshielded banana jack connectors. If a banana jack is provided that is grounded to the case and if it has a standard 0.75 inch spacing from one of the two jacks that connect to the resistance, then commonly available BNC-to-banana adapters can be used to connect the coaxial cables from the bridge to the resistance transfer standard. One Pomona Model 1645 BNC-female-to-shielded-dual-banana-plug adapter and one Pomona 1269 BNC-female-to-dual-banana-plug adapter will work. Since the resistance standard has only three banana jack posts, the ground on one of the banana plugs would not be connected to anything. The shielded adapter should be connected to the LOW terminal.

   Care should be used when a decade resistance box is used as the transfer standard. Boxes that have decade resistors above 10 kΩ per step may be too frequency dependent to use. Even though such higher values would not be needed for this test, their stray capacitance is present even if they are not switched in.

3. The least expensive approach is to make your own transfer standard. This is actually easy to do. The key component is a 10 kΩ resistor that is stable and frequency independent. Common resistors such as a type RN55C (50 ppm/°C) will work. A type RN55E (25 ppm/°C) will work better. A type RNC90Y will work very well. The lower their temperature coefficient, the easier it is to transfer a value from DC to 1 kHz without having to worry about room temperature changes.

   The best choice is to buy a high quality precision resistor that is already specified to the desired level of accuracy. Types that use the RNC90Y style construction are excellent. DO NOT use a wire wound resistor unless it is non-inductively wound. If your resistor has a metal case, the case must be grounded.

   An ordinary resistor is easily converted to a three-terminal one by installing the resistor in a metal box. A box with a female BNC connector at each end such as Pomona Model 2390 is suitable. The resistor should be located in the middle of the box to minimize stray capacitance to the box. DO NOT trim the value of the transfer resistor by paralleling with resistors having megohms of resistance. Such resistors are probably much more frequency dependent.

   Once this resistor box is calibrated at DC to an accuracy of 0.005% (0.0025% for Option-E), it is ready to use. A resistor box made this way should be calibrated at DC before *every* verification. Furthermore, if there is concern about its stability or about room temperature variations, then its value should be rechecked *after* the verification is performed.

Performing the Verification

Once a trustworthy resistance standard is in hand, the actual verification is simple to perform.

To do this, set the averaging time to seven and the loss units to series-kilohms. Connect the standard and take a few measurements. They should all read 10.000 kΩ to within 0.02% (0.01% for Option-E). If this check fails, it might be that the ambient temperature is now too different from that at which the last internal calibration was performed. If this check still fails after verifying the internal calibration, the loss measurements may be failing the accuracy specifications of the bridge. To correct this, the AH 2500A (or its main board) must be returned to the factory for repair. See "REPAIR SERVICE" on page 1-7 and "Main Board (A101) Removal and Installation" on page 12-8.

CHECK HIGH TERMINAL VOLTAGE

Issue the command $\boxed{\text{VOLTAGE}}$ $\boxed{1}$ $\boxed{5}$ $\boxed{\text{ENTER}}$ then take a measurement with nothing connected to the measurement terminals. This will leave the HIGH terminal with 15 volts present. Using an AC meter with an accuracy of 1% or better, measure the voltage from the HIGH terminal center conductor to ground. If the HIGH terminal output voltage is not within 5% of the nominal value (15 ±0.75 volts), it should be adjusted. The procedure for this is given in "Adjustment of HIGH Terminal Signal Level" on page 11-22.

CHECK THE BRIDGE FREQUENCY

At the time the output signal level is checked as directed in the previous section, the frequency of this signal can be checked also. This is done by simply connecting a digital frequency meter to the HIGH terminal and taking a reading. The frequency should read 1.0000 ±0.00005 kHz. If it is marginally outside the tolerance, then the 4.096 MHz crystal oscillator Y301 is out of tolerance. If it is off by factors of two, then there is a failure in the frequency division circuitry on the processor board A301 or the MUX board A401. See the chapter titled "Diagnosis and Repair" on page 11-1 for general repair information.

THE CALIBRATION PASSCODES

The AH 2500A uses three different passcodes to control access to the commands which change the calibration data. These passcodes are:

1. The Owner passcode. This is the highest level passcode. This passcode cannot be changed. It is accepted by every command which requires a passcode. It is the only passcode accepted by the STORE CALIBRATE CREATE commands which are used to change the other passcodes.

2. The Calibrator passcode. This is the intermediate level passcode. This passcode is accepted by every version of the STORE CALIBRATE command.

3. The User passcode. This is the lowest level passcode. This passcode is accepted *only* by the STORE CALIBRATE 1 command.

4. The Replace passcode. This is a *very special* repair passcode that *only* functions with *non*-option-E bridges. This passcode is only accepted by the STORE CALIBRATE 2 CALIBRATE *standardvalue* command. See "Main Board Installation Procedure" on page 12-8 or "Standard Capacitor Installation Procedure" on page 12-12 for more information.

These passcodes are intended to be applied in a specific way. The Owner passcode should be held by the owner of the bridge and revealed to no one else. If the owner of the bridge is the only user and the only person to ever perform a calibration, then this will usually be the only passcode that ever needs to be used.

If the owner wishes to assign the responsibility of fully calibrating the bridge to another person, then the owner should give that person the Calibrator passcode. The owner can change the Calibrator passcode after the person doing the calibrating is finished.

Some applications may require that an internal calibration be performed frequently. This will be especially true for high precision work or for operation where the bridge's internal calibration needs to track significant changes in ambient temperature. In such cases, the owner may want to allow the operator to perform internal calibrations only. The owner can do this by providing the operator with the User passcode. The owner can change the User passcode after the operator is finished taking measurements.

If the main board or capacitance standard is replaced, then the Replace passcode will be required to re-calibrate the bridge (if it is not an option-E). The consequences of using this passcode are that *totally new internal and capacitance calibrations are performed and all past calibration history is lost.* Due to the irreversible consequences of mis-using this capability, this passcode (and therefore the owner passcode) must be tightly controlled. Like the other changeable passcodes, the owner can give this passcode to a repair person. When the repair is finished, the owner should change the Replace passcode.

Changing the User Passcode

The User passcode can be changed with the command:

STORE CALIBRATE CREATE 1

After entering this command, you will be prompted for a passcode with the front panel message Onr $CodE$. You must enter the Owner passcode. If the wrong passcode is entered, the message bAd $PASSCodE$ will appear on the front panel.

After entering the correct Owner passcode, a second prompt will appear: USr $CodE$. You then enter a six digit number that you wish to be the new User passcode.

If you are working from a remote device, you will also be prompted for the Owner passcode. The characters that you enter for the passcode will not be echoed.

Changing the Calibrator Passcode

The Calibrator passcode can be changed with the command:

STORE CALIBRATE CREATE 2

This command functions identically to the STORE CALI-
BRATE CREATE 1 command except that after entering the
Owner passcode, you will be prompted with: $C\,AL\quad C\,od\,E$.
You then enter a six digit number that you wish to be the new
Calibrator passcode.

Changing the Replace Passcode

The Replace passcode can be changed with the command:

STORE CALIBRATE CREATE 3

This command functions identically to the STORE CALI-
BRATE CREATE 1 command except that after entering the
Owner passcode, you will be prompted with: $r\,PL\quad C\,od\,E$.
You then enter a six digit number that you wish to be the new
Replace passcode.

This chapter describes the detailed workings of the circuitry of the AH 2500A. If you have not read "BASIC BRIDGE CIRCUITS" on page 4-1 and preferably all of Chapter 4, "Measurement Essentials", you should do so before starting to read the analog circuit sections of this chapter. The basic bridge circuit that is used by the AH 2500A is explained and shown there in Figure 4-1 on page 4-1. The analog circuitry described in this chapter is an elaboration of the basic bridge shown in that figure.

This chapter describes the AH 2500A on two levels of detail. The higher level is based on block diagrams. There are two fundamental block diagrams presented: one is the Digital Circuits block diagram and the other is the Analog Circuits block diagram. The Analog block diagram is shown as two figures. One is the complete Analog Circuits Block Diagram shown in Figure F-2 on page F-5. The other is a more detailed diagram of the ratio transformer multiplying digital-to-analog converter shown in Figure 10-1 on page 10-3. These diagrams accurately reflect all circuits of the AH 2500A and should provide sufficient understanding of the internal hardware operation of the AH 2500A for all but repair purposes.

The lower level description of the circuitry is based on the schematic diagrams of the individual boards of the AH 2500A presented in Appendix F, "Drawings and Parts Lists". An understanding at this level of detail is intended for maintenance purposes or to grasp a fine point of the AH 2500A's operation.

CAUTION

*The descriptions given in this chapter are intended to help understand and maintain the instrument. Subtle design considerations are **not** discussed and therefore the information given here is not suitable for making modifications to the instrument. Consult the factory before attempting any possible modifications.*

Notation

A slash (/) is used to label signals that use a low voltage to represent a true condition.

Every schematic in Appendix F, "Drawings and Parts Lists", has a border showing the numbers one through four horizontally and the letters A through D vertically. These establish a course reference grid. The current chapter uses references such as "U335 in area 1A4" to mean that chip U335 is

located on the first page of the schematic in grid square A4. This same notation is also used within a multi-page schematic in places where signals go from one page to another. This helps locate the signal name on the referenced page.

DIGITAL CIRCUITS BLOCK DIAGRAM

The block diagram of the digital circuitry is shown in Figure F-1 on page F-3. This is a diagram of the circuitry contained on the processor, display and keypad circuit boards. The operation of the circuits is conventional and straightforward in most respects.

Buses

The diagram shows individual signal interconnections as single lines. Four groups of signal lines called buses are shown as double lines. Labels in each bus indicate the kind of signals in that bus. If not all the signals in a bus connect to a block, then labels in the stubs that connect the bus to the block indicate which lines from that bus actually connect to the block.

The names of the four major buses are Address, Data, Selection, and Control. The Address bus contains the sixteen processor address signals (A0-A15). The Data bus contains the eight processor data signals (D0-D7). The Selection bus contains a miscellaneous assortment of timing and selection signals. The Control bus contains four signals: reset (RESET), interrupt (IRQ), I/O clock (ϕ_s), and the read/not-write signal (R-/W). With the exception of the R-/W signal, the "high true" vs. "low true" distinction is ignored by the block diagrams and the related discussion.

Clock Signals

All clock frequencies in the AH 2500A except for the serial baud rates are derived from a single 4.096 MHz crystal oscillator (Y301). A binary frequency divider (U301) produces the 2.048 MHz clock signal for the processor. Another division by two followed by synchronization (U335) to the processor clock, provides the I/O clock (ϕ_s) for some of the interface circuits that connect to the processor. The binary frequency divider further divides the clock to create timing signals of eight and sixteen kilohertz (8F and 16F). These are sent to the analog measurement circuitry where they are used to derive the one kilohertz test frequency used by the AH 2500A.

Processor and Memory

A 6502 series microprocessor is used with three different kinds of memory (RAM, EPROM, and EEPROM) (U304-U308) to form the basic computing circuitry. A power-fail detection circuit (U318) will reset the processor if the 5 volt supply falls too low. This reset signal is also routed to all other circuits in the AH 2500A that need to be initialized if the power fails. A write protect circuit (U331) helps ensure that the EEPROM is not accidentally written to.

Timing and Selection Logic

This is the one block in the digital block diagram where the detail has been greatly abbreviated. The actual circuitry consists of a collection of many gates and decoders. This block generates the signals that allow the processor to select which block it is to transfer data to or from on any given clock cycle.

Rear Panel Interfaces

The GPIB (U323) and serial (U329) interfaces are each implemented with integrated circuits (IC's) designed specifically for these functions. The serial interface IC implements both an RS-232 and a 20 ma. current loop interface. The RS-232 transmit and receive data lines can be swapped under the control of a latch (U339). Additional RS-232 control lines (RI, DCD, CTS, DTR, and RTS) are optionally available for use. The sample switch interface is implemented with a multifunction IC (U326) called a PIA (Peripheral Interface Adapter) and some common line driver IC's (U327, U337 and U338). The external trigger input is readable by the processor using both one input of an octal latch (U320) and one special line to a PIA (U310).

Front Panel Keypad

The keypad is on a separate circuit board on the front panel connected to the processor board with a ribbon cable. The keypad switches (SW501-SW518) are connected in a two-dimensional array. This array is connected to a keypad encoder IC (U309). The keypad encoder is, in turn, connected to a PIA (U310) which provides the interface to the processor.

Front Panel Display

The display is on a separate circuit board on the front panel connected to the processor board with a ribbon cable. The display consists of eight, dual seven-segment LED displays (DS501-DS508) and two quad LED displays (DS509 and DS510). The seven-segment LED's are connected in a two-dimensional array which is driven using a multiplexed method. The anodes of the seven-segment displays are driven by transistors (Q501-Q504) which are controlled by a four-bit latch (U501). The cathodes of the seven-segment displays are driven directly by four octal latches (U503-U506). The two quad LED displays are driven directly (U507). All of

these latches are loaded from a single byte-wide latch (U317) and selected by signals from a decoder (U316).

Analog Measurement Interface

This interface (J303) connects to all of the analog measurement circuitry in the AH 2500A. The processor board uses an octal latching buffer (U311) to drive eight data lines (TD0-TD7) that provide control data to the analog measurement circuitry. Four address lines (A0-A3) and two selection lines (S2W and S3W) from the processor board allow control data to be multiplexed onto these eight data lines. A PIA (U310) provides a start-conversion signal (STCN) to an analog-to-digital converter.

The processor board can read ten lines of digitized data from the analog measurement circuitry. The most significant eight of these lines (AD2-AD9) are readable using a PIA (U310); the least significant two lines (AD0 and AD1) are readable using two bits of an octal latch (U320). Two more bits of this latch are used to read the level detection signals (LEV A and LEV B). Another bit reads timing information from the power line.

Option Board Interface

A connector (J317) on the processor board provides processor signals to allow operation of an internally mounted option board. These signals consist of the eight processor data lines (D0-D7), the four least significant processor address lines (A0-A3), three lines decoded from the processor address lines (S7, S12, S102) and the four control lines (RESET, R-/W, ϕ_s, and IRQ).

DIP Switch and Timers

A PIA (U326) allows the microprocessor to read an eight position DIP switch that is on the processor board. This PIA and U310 both have a pair of programmable, 16 bit, internal counter/timers that can interrupt the processor.

ANALOG CIRCUITS BLOCK DIAGRAMS

The main analog block diagram of the AH 2500A is shown in Figure F-2 on page F-5. This is a diagram of the circuitry contained on the multiplexer, main and preamp circuit boards and as part of the capacitance standard assembly. This diagram contains two major blocks that are essentially identical to one another. Each is called a "Ratio Transformer Multiplying Digital-to-Analog Converter" and is abbreviated as "RTMDAC" or just "DAC". An RTMDAC is shown in more detail in Figure 10-1 on page 10-3.

Many blocks are connected by short arrows with the word "control". These arrows are used to indicate the presence of binary control lines from the processor that set up functions in the associated block.
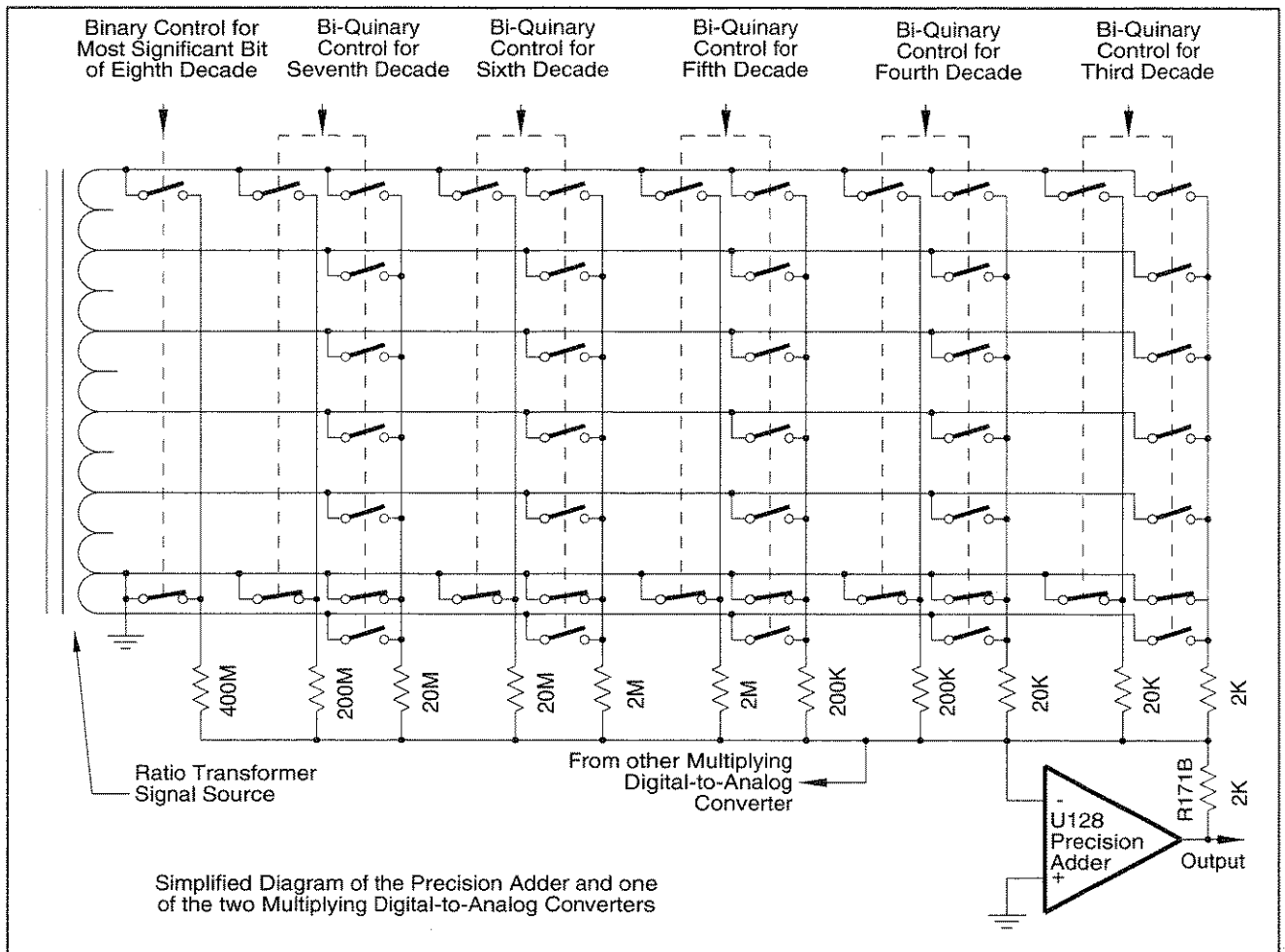
Figure 10-1 Ratio transformer multiplying D to A converter (RTMDAC)

If there is a "most important part" in the AH 2500A, it must be the main ratio transformer (T101) shown near the left side of the main analog block diagram, Figure F-2 on page F-5. As shown in the basic bridge circuit in Figure 4-1 on page 4-1, this transformer forms two of the four legs of the bridge. It also is responsible for the extremely high linearity and ratio stability of the AH 2500A.

Sine Synthesizer

The main ratio transformer must be energized with a high quality, one kilohertz, sine wave. To achieve good frequency stability, this sine wave is derived from the crystal-controlled processor clock. Two signals (8F and 16F) shown in the upper left corner of the main analog circuits block diagram come from the processor board. They are first processed by the alternate controller (U418 and U419) to create signals whose phase can periodically shift by 180°. This provides a way of rejecting external noise having frequencies near one kilohertz.

The sine synthesizer (U408) produces a simple analog combination of three digital signals from the alternate controller.

The signals needed to synchronize a phase-sensitive detector are also produced by U408. The full/half attenuator (Q101) allows the SYNTH signal to be passed unchanged or attenuated by one half under the control of the processor. The harmonics of the SYNTH signal are removed by the bandpass filter (U101) to produce the desired sine wave.

The main transformer drivers (U102, U103 and U104) provide the power required to drive T101 near its saturation voltage. Should anything load T101 to the extent that the drivers cannot fully energize the transformer, the overload detector (U105) will produce a signal that indicates a "high to ground short" problem.

Attenuator Leg of the Bridge

The lower left leg of the basic bridge circuit in Figure 4-1 on page 4-1 is the attenuator (ATN) leg. Effectively, the function of this leg is to select the range of capacitance or loss that the AH 2500A is to measure. This requires selecting one voltage from a wide range of transformer taps. That voltage is connected to the external DUT (Device Under Test) through the HIGH terminal on the rear panel of the bridge.

The attenuator must provide the widest possible range of voltages since it is this range that is largely responsible for the wide range of capacitances that the AH 2500A can measure. The higher attenuator voltages are provided by a winding on the main ratio transformer (T101) having six taps. To get much lower voltages, a *single* turn winding on the main transformer drives another transformer (T103) called the attenuator transformer. This 250 turn transformer divides the single turn voltage from the main transformer into an additional 250 parts. The attenuator transformer has five more taps that provide voltages as small as 1.0 or 0.5 millivolts.

All of the attenuator taps are selected using reed relays. These preserve the low output impedance of the two ratio transformers. This low impedance allows one to think of the DUT as being driven by the HIGH terminal of the bridge.

Variable Leg of the Bridge

The upper left leg of the basic bridge circuit in Figure 4-1 on page 4-1 is called the variable leg. It is the most complex leg. After the attenuator leg has been set to the optimum range that corresponds to the value of the DUT, the variable leg must be adjusted so as to reduce the bridge imbalance to a minimum.

Since the DUT will have both a capacitance and a loss, the variable leg must be able to independently balance both of these quantities. Since the AH 2500A uses capacitance (as opposed to resistance) standards as references, any current resulting from the capacitance of the DUT will have the same phase as currents flowing directly from T101 through the reference capacitors. Thus the part of the variable leg of the bridge that balances the capacitive current from the DUT is called the "in-phase" part. The loss current from the DUT is balanced by the "quadrature" part of the variable leg. The currents flowing in the quadrature leg are 90° out of phase with currents flowing in the in-phase leg.

In-Phase Relays and RTMDAC

The in-phase part of the variable leg can be adjusted to a precision of over seven decades. The two most significant decades (RD's) use reed relays that directly switch voltages from the main ratio transformer to reference capacitors A and B. These two decades are identical except that the reference capacitors differ by a factor of ten from each other. The current through a reference capacitor is very precisely proportional to the selected transformer voltage times the value of that reference capacitor.

The remaining decades use the in-phase RTMDAC, also called the "IDAC". Figure 10-1 on page 10-3 shows one of the RTMDAC's combined with the operational amplifier (U128). This amplifier, when combined with input and feedback resistors, forms a precision adder. The adder functions in the textbook manner where the output voltage is the sum of each input voltage multiplied by the feedback resistance (R171B) and divided by the corresponding input resistance.

This makes the precision adder and the associated input and feedback resistors, combined with the driven reference capacitor (C210C), functionally equivalent to a set of reference capacitors. The value of an equivalent reference capacitor is equal to the value of C210C times the value of R171B divided by the value of an input resistor.

To reduce the number of switching elements, each full decade in the RTMDAC's uses a bi-quinary scheme. This requires the ability to switch an input resistor of the adder to seven different ratio transformer taps related to each other by voltage ratios of -1, 0, 2, 4, 6, 8, and 10. A second input resistor that is ten times larger is switched to taps having voltage ratios of 0 or 10. Switching these two resistors to the available transformer tap combinations will give the equivalent of any integer ratio from -1 to 10. This gives a total of twelve choices, the same as with the two most significant relay decades. All switching in the RTMDAC's is done with CMOS analog switches rather than relays.

Quadrature Phase-Shifter and RTMDAC

The quadrature part of the variable leg (also called the "QDAC") is virtually identical to the in-phase part except for two important respects. First, the quadrature part lacks the two most significant relay decades found in the in-phase part. This prevents the AH 2500A from measuring large capacitors that also have a high loss. However, large, quality capacitors are not likely to have a high loss.

Second, the ratio transformer that drives the QDAC is not the main ratio transformer (T101), but rather an auxiliary one (T102) driven by a signal that is accurately shifted in phase by 90°. This phase-shifted RTMDAC driving a reference capacitor is functionally equivalent to an un-phase-shifted RTMDAC driving a reference resistor. The QDAC is virtually identical to the IDAC.

The signal that drives T102 is created with a precision phase-shifting circuit (U106-U110) known as the Series/Parallel/-Bypass circuit or S/P/B. This is actually composed of two independent 90° phase shifters operated in parallel with one another. The advantage of having two occurs if they can also be connected in series with each other. A series connection (made with Q103 and Q106 closed and Q102, Q104 and Q105 open) causes them to produce an output signal that is 180° out of phase with their input signal. If the input and output signals have the same amplitude and if they are combined in an adder, the output of the adder will be zero when the phase has been accurately shifted by 180°. If the 90° phase shifters are adjustable, this provides a way of calibrating them so that the sum of their phase shifts is correct. A parallel connection of the two (made with Q102, Q104 and Q106 closed and Q103 and Q105 open) then provides a much more accurate 90° phase shift.

C04

Preamp

The function of the preamplifier is to amplify the wide range of imbalance voltages that can exist at the center node of the bridge, particularly the nanovolt level signals that occur when the bridge is nearly balanced. With no DC bias voltage applied, the bias enable relay (K602) connects the center node of the bridge directly to one end of the DUT via the LOW terminal. While taking measurements, the operate/calibrate relay connects the input of the preamplifier to the DUT. If a charged capacitor is connected to the input of the bridge, the DC on low detector will report that condition. This detector will also report the presence of low frequency AC noise.

The output of the preamplifier is further amplified by a wide-range, programmable gain amplifier (ACG). The ratio of the minimum to the maximum gain of this amplifier is ten thousand. The signal is then passed through a two-stage, one kilohertz, bandpass filter. Only signals near one kilohertz remain. Finally, the signal is monitored by a dual-level peak detector.

In the event that measurements are to be made with a DC bias applied to the DUT, the bias enable relay (K602) will insert a blocking capacitor between the DUT and the input of the preamplifier. The same relay also connects the DC bias input to the DUT through a bleeder resistor. Another relay (K603) allows a choice of two different values of the bleeder resistor (R643 and R644).

Detector, Multiplexer and A/D.

The output of the peak detector goes to the input of a phase-sensitive detector. This circuit produces two output signals. One is proportional to a component of the detector input signal that has a specific phase with respect to the SYNTH signal. The other is proportional to the component of the input signal that is shifted in phase by 90° relative to the first component. Each of these signals is passed through a low-pass filter (U406 and U407) to remove the remnants of the one kilohertz signals. The resulting signals (I and Q) are used to determine the relative amounts of imbalance in the in-phase and quadrature sections of the bridge. These and six other signals are switched one at a time through the eight-input multiplexer (MUX) (U410) to a programmable gain amplifier (DCG) (U411 and U412). The gain is set to maximize the signal levels for measurement by the following analog-to-digital converter (U416). This A/D measures the residual I and Q imbalance signals of the bridge. These can be used to calculate the three least significant digits of capacitance and loss measurements reported by the AH 2500A.

The A/D also measures the other six inputs to the multiplexer, several of which have already been identified. The TEMP signal comes from a thermistor in the area of the RTMDAC's and is used to make temperature corrections. The OVEN signal indicates whether the oven in which the reference capacitors reside is at operating temperature. The PWRMON signal monitors a combination of power supply voltages. The M0.1R signal allows direct measurement of the main ratio transformer sine wave.

Internal Calibration

To achieve the highest possible accuracy without using any more high precision components in its construction than necessary, the AH 2500A uses sophisticated firmware to internally and automatically calibrate components of lesser precision. These components are calibrated against the very stable ratio transformers and against the largest reference capacitor. The largest reference capacitor is, in turn, intended to be periodically calibrated against primary or other very accurate standards. The interconnections needed to perform these internal calibrations are all shown in the block diagrams.

Every full decade in the variable leg of the bridge has the ability to select transformer taps having ratios of -1 and 10. This feature allows adjacent decades to be compared. If a given decade is set to -1 and the adjacent decade of lesser significance is set to 10, the sum of the results should be zero. The summation occurs at the center node of the bridge. Any non-zero result that is present here can be amplified and measured by the preamplifier and A/D. The magnitude of the result is stored by the processor and is used to correct the decade of lesser significance. This scheme allows calibration of all the decades relative to the most significant one. The quadrature decades may be calibrated against the in-phase decades by bypassing the 90° phase shifters. This is done by closing Q105 and opening Q104 and Q106.

POWER SUPPLY

The power supply schematic is shown in Figure F-7 on page F-19. The power supply is a simple linear type to minimize the creation of unnecessary electrical noise (EMI). The power supply consists of a power line module, a transformer, and a printed circuit board. The power line module allows the selection of four different line voltages with which to power the AH 2500A. These different operating voltages are obtained by connecting the two primary windings of the transformer in series or parallel and by connecting to either all the turns of one of these windings or to 83% of the turns. The power line module is located on the rear panel of the AH 2500A and contains an easily accessible fuse.

The power transformer has two center-tapped secondary windings. One of these windings feeds a full-wave diode bridge (U704). The two outputs of this bridge each charge a 3300 μF capacitor (C705 and C706). These capacitors provide two sources of unregulated power of about +24 and -24 volts. Each of these sources feeds a regulator, (U701 and U702) the outputs of which provide a source of regulated +12 and -12 volt power.

The other winding of the transformer feeds two diodes that charge a 15,000 μF capacitor (C711). Three capacitors (C703, C704, and C715) plus a resistor (R702) are present to attenuate EMI generated by the AH 2500A processor that might otherwise be conducted outside through the line cord. The voltage on C711 is regulated by U703 to provide five
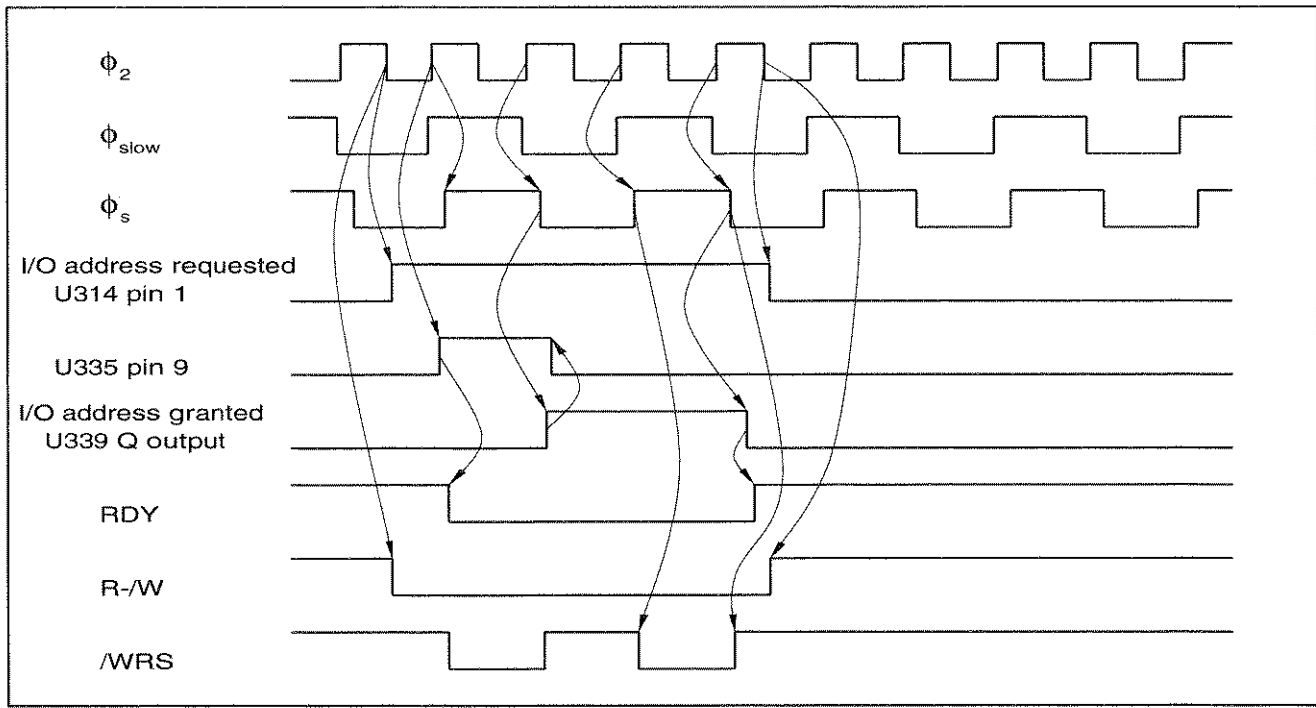
Figure 10-2 I/O timing signals

volt power for the logic circuits of the AH 2500A. A crowbar circuit (Q701, VR701, R701, and C714) protects the logic circuits from overvoltage in the event that U703 fails. The crowbar works by detecting an overvoltage and responds by shorting the 5 volt supply to ground. This happens within microseconds and will cause the fuse (F702) to open.

PROCESSOR BOARD

The processor board contains essentially all of the high speed digital logic used in the AH 2500A. It is located on the top side of the AH 2500A chassis.

Clock Circuits

The circuitry described in this section is on the fourth sheet of the four processor board schematics in Figure F-12 on page F-31

The ultimate source of all clock signals in the AH 2500A except for the serial baud rates is a 4.096 MHz crystal oscillator (Y301).

The other clocks are derived from this by a binary divider IC (U301). Two of these clocks are ϕ_o and ϕ_{slow} which are used on the processor board. The remaining two clocks are 8F and 16F which are eight and sixteen kilohertz. These are sent to the analog measurement circuitry where they are used to derive the one kilohertz test frequency used by the AH 2500A. The 2.048 MHz clock, ϕ_o, directly drives the microprocessor. The 1.024 MHz clock, ϕ_{slow}, is supplied to the timing circuits described below.

I/O Timing Circuits

The circuitry described in this section is on sheet one of the processor board schematics in Figure F-9 on page F-25.

All of the I/O (input/output) circuits use signals derived from a 1 MHz clock rather than from the 2 MHz clock that the processor uses. (For timing purposes, the EEPROM is considered to be an I/O circuit.) Some special circuitry is used to create the 1 MHz signals and to synchronize them to the 2 MHz signals. A "D" flip-flop (U335 in area 1A4) uses ϕ_2 from the processor to clock ϕ_{slow} to produce ϕ_s. This synchronizes ϕ_s to ϕ_2. The relationship of these three clock signals to one another is shown by the top three traces in Figure 10-2. All I/O circuits that require a clock that is synchronized to the processor use ϕ_s.

Every time an I/O circuit is addressed, the processor is forced to perform the read or write cycle at half its normal speed. This ensures that the cycle occurs at a speed that is compatible with the I/O circuit. Figure 10-2 shows the relationships between the required signals. When an I/O circuit address is requested by the processor, some address decoding logic (U314 pin 1 in area 1B2) indicates this by producing the signal shown in the figure. This signal causes the output of a "D" flip-flop (U335 pin 9 in area 1A3) to go high on the next rising edge of ϕ_2 as shown in the figure. The output of this flip-flop causes a gate (U334 pin 8 in area 1A3) to pull the RDY line low. The processor will not change its address, data, and read/write lines as long as the RDY line is low.

The next negative-going transition of ϕ_s sets a J-K flip-flop (U339 in area 1A3). The signal produced by the Q output of this flip-flop is shown in the figure. This signal is what grants the I/O address by enabling the I/O address decoder logic. Setting U339 immediately resets U335. Since U339 also drives U334, the RDY line continues to be held low.

The next negative-going transition of ϕ_s clears the J-K flip-flop (U339). This disables the I/O address decoding logic. It also causes the RDY line to go high allowing the processor to complete the current read or write cycle.

If a write cycle is in progress, the R-/W line will go low as shown in the figure. One of the signals generated during a write cycle is /WRS. As shown in the figure, this is a double pulse. Only the second of the two pulses causes data to be written. The first pulse never has any effect because it does not overlap the I/O address granted signal (U339 pin 3). The same situation exists with /RDS which also occurs as a double pulse.

Reset Circuit

The reset circuit is in area 1A2 of the processor board drawings. It is composed of U318, R301, C301, VR301, and R302. The 3.3 volt zener diode (VR301) drops the 5 volt power supply level so that pin 2 of U318 can monitor that level. If the supply falls too low, pin 2 will cause U318 to trigger. This causes U318 to discharge C301 and the U318 output to go from low to high. The output will go low again after the 5 volt power supply is high enough and C301 has had time to recharge through R301. The RESET signal generated by U318 is used to reset the entire AH 2500A. It is also used to hold /WR and the EEPROM write enable circuit (U331) disabled until the 5 volt power is stable.

Selection Logic

Three decoder IC's and an assortment of gates mostly on sheets one and four of the processor board schematics in Figure F-9 on page F-25 and Figure F-12 on page F-31 are used to generate the signals needed to allow the processor to select the various memory and I/O devices.

Starting with the most significant address lines (A14 and A15), a 1 of 4 decoder (1/2 of U303 in area 1B3) is used to divide the 65536 byte address space of the processor into four equal address ranges. A given output of the decoder is true for addresses falling within one of these four address ranges. The three decoder outputs (pins 5, 6 and 7) that are true (low) for the three highest address ranges are used to select the three EPROM memories. Using hexadecimal numbers, these ranges are 4000-7FFF, 8000-BFFF, and C000-FFFF. The lowest address range (0000-3FFF) causes pin 4 of U303 to be low. This range is further subdivided.

All of the remaining discussion under the Selection Logic heading assumes that an address within the range 0000-3FFF has been selected. If address line A12 or A13 is false (low) then the output (pin 11) of U334 will be low. This will make

pin 8 of a gate (U332 in area 1B2) true (low) for all addresses in the range 0000-2FFF. The signal from this pin is used to select the RAM memory IC (U308 in area 1C1). This gives a usable RAM memory space of 6144 bytes.

If address lines A12 and A13 are both true (high) then the output (pin 3) of U315 will be true (low). This will make pin 1 of U314 true (high) for all addresses in the range 3000-3FFF. The signal from this pin is used to select the other half of the 1 of 4 decoder IC (U303 in area 1B2). The decoder further subdivides the 3000-3FFF range.

All of the remaining discussion under the Selection Logic heading further assumes that an address within the range 3000-3FFF has been selected. The enable input of U303 (pin 15) is used as a timing qualifier so that the outputs of U303 can never be true during the time when the address lines are changing. This makes these outputs "clean" so that they can be used to perform triggering in addition to selection.

Pin 13 of U303 is used as an enabling input rather than as an address input. This means that U303 actually functions as a 1 of 2 decoder and therefore only output pins 9 and 10 can be used. Address line A11 determines which of the two outputs is true. If the address is in the range 3800-3FFF, pin 9 is true (low). This is used to select the 2048 bytes in the EEPROM. If the address is in the range 3000-37FF, pin 10 is true (low). This address range is further subdivided.

All of the remaining discussion under the Selection Logic heading further assumes that an address within range 3000-37FF has been selected. A 1 of 8 decoder (U322 in area 1B2) is used to decode 1/16 of this address range. Two gates (U332) and two enable inputs on U322 are used to enable U322 when A8, A9 and A10 are false (low) and A7 is true. This enables U322 only for addresses in range 3080-30FF.

Pin 7 of U322 is true (low) creating /S7 which is used for selection on the option board for addresses in the range 30F0-30FF.

Pin 9 of U322 is true (low) creating /S6 which is used to select the PIA U310 for addresses in the range 30E0-30EF.

Pin 10 of U322 is true (low) creating /S5 which is used to select the UART (U329 in area 2C2) and the GPIB controller (U323 in area 2B4) for addresses in the range 30D0-30DF. The UART has a second chip select input (pin 2) tied to address line A3 so that the UART is selected for addresses in the range 30D8-30DF. Since A2 is not used, the UART actually can be selected by two functionally equivalent address ranges: 30D8-30DB and 30DC-30DF. Address line A3 also goes to a gate (U330 in area 2D3). The output of this gate enables the GPIB controller for addresses in the range 30D0-30D7.

Pin 11 of U322 is true (low) creating /S4 which is used to select the PIA U326 for addresses in the range 30C0-30CF.

Pins 12 and 13 of U322 are true (low) creating signals which are used to enable a pair of gates (U321 in area 1A1). These gates qualify the selection signals with a write strobe signal (/WRS) so that selection occurs only during a processor write cycle. The outputs of these gates (/S2W and /S3W) are further decoded by logic on the multiplexer board which loads the numerous latches on the analog boards. If either /S2W and /S3W becomes true, U315 in area 1A1 creates DATLAT, the falling edge of which passes the corresponding byte of data through an intermediate buffer (U311 in area 3D2). The rising edge latches the data. Addresses in the range of 30A0-30AF and 30B0-30BF cause /S2W and /S3W, respectively, to become true.

Pin 15 of U322 is true (low) creating a signal which is used to enable a gate (U314 in area 1A1) for addresses in the range 3080-308F. This gate qualifies this signal with a write strobe signal (/WRS) so that DISLAT is true only during a processor write cycle. The rising edge of this signal is used to pass the corresponding byte of data through an intermediate buffer (U317 in area 2C4). The falling edge latches the data. The same signal also enables a 1 of 8 decoder (U316 in area 2D4) which further subdivides the 3080-308F address range. Address line A3 is tied to the low-true enable input (pin 4) of U316 so that the decoded outputs are only true for addresses in the range 3080-3087. Seven of the eight outputs of this decoder are used to strobe the various latches on the front panel display board.

Pin 14 of U322 is true (low) creating /S1 which is further decoded by a 1 of 4 decoder (1/2 of U313 in area 4C2) for addresses in the range 3090-309F.

Pin 6 of U313 is true (low) creating /S12 which is used for selection on the option board for addresses in the range 3098-309B. Pin 4 of U313 is true (low) creating /S10 which is further decoded by another 1 of 4 decoder (the other half of U313 in area 4C2) for addresses in the range 3090-3093.

Pin 9 of U313 is true (low) only for address 3093 creating /EEWREN which triggers the EEPROM write-enable monostable circuit (U331 in area 1C1). Pin 10 of U313 is true (low) creating /S102 which is used for selection on the option board only for address 3092. Pin 11 of U313 is true (low) only for address 3091 creating /S101 which enables an octal buffer (U320 in area 3A4) to pass data from the analog boards through to the processor data lines.

Memory

The AH 2500A uses three 16K byte EPROM (electrically-programmable, read-only memory) IC's (U305-U307 in area 1D2 and 1D3) operating in the address range 4000-FFFF. A single 8K byte RAM (Random-Access Memory) IC (U308 in area 1D1) operates in the address range 0000-1FFF. Actually the decoding is for addresses 0000-2FFF so that address range 0000-0FFF is indistinguishable from range 2000-2FFF.

A single 2K EEPROM (Electrically-Erasable, Programmable, Read-Only Memory) IC (U304 in area 1D2) operates in the address range 3800-3FFF. This kind of non-volatile memory storage is used in the AH 2500A so as to avoid the use of batteries. The limitation with this kind of memory is that it is only guaranteed to function reliably for 10,000 write cycles. For that reason, extensive error checking is incorporated into the firmware of the AH 2500A to ensure the integrity of the data. Since all the calibration data for the AH 2500A resides in this EEPROM, two protection schemes are used to protect the reliability of this data. First, the write-enable input to the EEPROM (pin 21) can only be activated after having previously set a monostable (U331 in area 1B1). In other words, the firmware can only write to the EEPROM after having first written to U331. Furthermore, the write operation to the EEPROM must occur shortly after the write operation to U331 otherwise the monostable will time-out thus preventing the EEPROM from being written to. The second protection scheme uses the reset signal (/RESET) to immediately clear U331 as soon as a low voltage condition is detected on the 5 volt power supply. This disables the write enable signal to the EEPROM under questionable power conditions.

Software Timers

Timing information used by the firmware is available from the two PIA's (U310 and U326). These each have a comprehensive internal timing divider circuit that is accessible to the microprocessor. These timers are capable of interrupting the processor after a programmable time interval has elapsed.

Serial Interfaces

The serial interface IC (U329 in area 2C2) implements both an RS-232 and a 20 ma. current loop interface. Four type 1489 RS-232 receiver logic elements (U328 in area 2C2) and three type 1488 RS-232 driver logic elements (U327 in area 2B2) are used to create an RS-232 interface using RI, DCD, CTS, DTR, and RTS control lines in addition to the transmit and receive data lines. The control lines need not be used and can be disabled by tying them high using JP312-JP314. JP310 can be used to ignore RI and receive DSR instead.

For convenience, the RS-232 transmit and receive data lines can be swapped using a bit in the AH 2500A BAUD command. This is done using a relay (K301 in area 2A1-2C1) which is controlled by a latch (U339 in area 2C3). The latch is at the same processor address as the EEPROM write protect monostable and is set or reset depending on the contents of data lines D0 and D1. A transistor (Q302 in area 2A1) provides the drive current for the relay.

Sample Switch

The sample switch port is a general purpose interface having eight parallel output lines and one output control line. The latter is intended to serve as a strobe line. These nine lines are all taken from a PIA (U326 in area 4D4). These signals serve as inputs to type 1488 line drivers (U327, U337 and U338 in area 4D3) which provide levels at the rear panel connector of about +12 and -12 volts. All the major power supplies of the AH 2500A are available at this port so that limited amounts of power can be provided to external devices. See Appendix D, "Sample Switch Port" for a complete description of how to make connection to this interface and of how to use the AH 2500A to control these lines.

FRONT PANEL
(KEYPAD AND DISPLAY BOARDS)

The display and keypad boards are mounted directly behind the front panel of the AH 2500A. The keypad board simply holds the switches in place and connects them in a two-dimensional array. The two pages of schematics for these boards start with Figure F-15 on page F-37.

Most of the display board is used to mount and drive eight dual seven-segment, common anode, LED displays. The sixteen seven-segment digits are wired in an array of four groups having four digits each. The anodes of every fourth digit are tied together. Four power transistors (Q501-Q504 in area 1C2) each drive one of these groups of anodes from the 5 volt power supply. An octal latch (U501 in area 1D4) controls these four transistors.

The cathodes of identical segment positions of the first four digits are tied together; the cathodes of identical segment positions of the fifth through eight digits are tied together, and so on. Since each digit has a decimal point, each of these groups of four sequential digits has eight cathode lines whose currents must be selectively sunk to ground. This is done with four octal latches (U503-U506), one for each group of sequential digits. The current through each group of four LED's is limited by an 82 Ω resistor in series with each output of each of these four octal latches. The resistors are contained in four resistor networks (RN501-RN504).

There are thus a total of five octal latches that control the seven-segment displays; four that sink the cathode currents and half of a fifth one that controls the anode currents. The microprocessor illuminates the seven-segment displays every fourth digit at a time. It does this by loading the four octal latches that control the cathodes with the data for every fourth digit. It then turns on the anode driver for 2.1 milliseconds. This illuminates the desired LED segments. The microprocessor clears the data in the octal latches anytime from 0.1 to 2.1 milliseconds after having been loaded, depending on the value of the Brightness *level* parameter. Since the data is inverted, the display is blanked for the remainder of the 2.1 millisecond period. The microprocessor performs this operation every 2.1 milliseconds, four times, before the cycle

repeats. The cycle occurs 120 times per second which is fast enough that the viewer is not aware that the segments are not being simultaneously illuminated.

The display segments are not designed to be driven continuously at the current levels used by the AH 2500A without causing possible damage to them. A monostable (U502 in 1D3) protects against this event by shutting down the anode drivers unless the microprocessor is continuously active. The eight remaining LED's on the display board are driven from an octal latch (U507 in 2D4) in a non-multiplexed manner. The variable brightness feature of the display is achieved by having the microprocessor vary the fraction of the time during each display cycle when the LED's are illuminated.

PREAMP BOARD

The two page schematic of the preamp board begins with Figure F-28 on page F-73.The circuits on the preamplifier (preamp) board are discussed in the order in which the signal flows through them. In addition, since the output of the preamplifier board goes directly to the multiplexer board, the discussion of this signal flow continues immediately in the next section on the multiplexer board.

Input Protection

Protection circuitry at the input of the preamp is essential not only to protect the preamplifier circuitry against excessive voltages applied to the LOW terminal of the AH 2500A, but also to protect the fused-silica reference capacitors which are connected directly to the LOW terminal. The reference capacitors are protected by a gas-discharge device (E601 in area 1C4) that will attempt to limit the LOW terminal voltage to less than 140 volts with respect to ground. This not only protects against excess voltages applied to the LOW terminal, but also against those applied to the DC BIAS input.

The FET (Q601 in 1D2) at the input of the preamp must be protected against relatively low voltages. This is done using two diode strings, one for positive overloads (Q603, CR603 and CR604) and one for negative overloads (Q602, CR605 and CR606). These diode strings will clamp the input voltage to about ±2 volts. The current through these diode strings is limited by a series resistor (R645 (or L601 in older bridges)) and by a lamp (DS601). The lamp provides additional protection for large overloads since its resistance may then increase substantially.

A second lamp (DS602 in 1C4) protects the operate/calibrate relay (K601 in 1C3) contacts. In calibrate mode, this relay shorts the LOW terminal to ground through DS602. If the AH 2500A were measuring a charged capacitor at the moment that K601 was closed, essentially the full charge of the capacitor would be absorbed by DS602. (The HIGH terminal has very low impedance and would dissipate very little of the charge.)

DC Bias

The DC bias circuitry in shown in area 1D3. The original values of the bleeder resistors (R643 and R644) are 1.0 megohm and 100 megohms, but these can be removed and other values substituted. A two stage filter (R640, C621, R642 and C622) reduces any noise that might be present in an external bias power supply. If K603 is closed to select the lower of the two bleeder resistors, R642 is shunted by R641 so that the filter resistance does not contribute significantly to the bleeder resistance.

Operate/Calibrate Relay

To perform internal calibrations, the LOW terminal of the AH 2500A must be disconnected from the internal circuitry. Energizing the Operate/Calibrate relay (K601 in area 1C3) causes this disconnection. The relay also shorts the LOW terminal to ground through DS602 so that no signal from the LOW terminal can be capacitively coupled across the open relay contacts.

In addition, the relay connects the preamp input (and thus the center node of the basic bridge) to a 2.2 kΩ resistor (R637). The other end of this resistor can be switched to ground under processor control by Q608. The shunting action of this resistor causes a substantial reduction of the voltage at the input to the preamp. This ability is needed by certain test routines whose action would otherwise overload the preamp.

Preamplifier

The preamp is basically a two stage, low noise, complementary-pair FET amplifier (Q601 and Q606 in 1D1 and 1D2). The N-channel/P-channel FET-pair provides good rejection of DC power supply variations. The clamping diode (Q604) across Q601 improves recovery from overload voltages.

DC on Low Detector

A transistor (Q605 in 1D2) and amplifier (U601 in 1B2) are used to detect the presence of DC voltages on the LOW terminal. When detected, U601 drives the LOW terminal through a 200 megohm resistance (R609 plus R610) to attempt to discharge small DC voltages that may be present across the DUT. For larger DC voltages on the LOW terminal, the output of U601 will be greater. This will cause the LOW terminal to be driven harder through a 250 kΩ resistance (R638 and R639) as a result of turning on one of two diodes (Q602 or Q603). This ensures that larger excess DC voltages are removed quickly. Filter capacitors (C605 and C608) prevent noise from being fed back to the input of the preamp.

The output of U601 also passes through a two stage, low pass, RC filter (R612, C607, R611 and C606). This signal (DCONL) is sent to the A/D on the multiplexer board where its voltage can be read by the processor. This allows the processor to detect and report situations where a persistent DC

voltage exists on the LOW terminal. An adjustment (R615 in 1B1) allows setting DCONL to zero when the LOW terminal voltage is zero.

Programmable Gain Amplifier

To accommodate the wide range of voltages present on the LOW terminal, a programmable (variable) gain amplifier (ACG) follows the preamp. This is implemented using an operational amplifier (op-amp) and a 1-of-8 CMOS analog switch (U602 and U603 in 2C3 and 2C4). The processor uses the analog switch to set the value of the feedback resistance for the op-amp. The switch shunts the unused part of the feedback resistance. The smallest feedback resistance is set with a trimpot to compensate for the variability of the internal resistance of the analog switch. The gain of this stage is simply the sum of all the unshunted feedback resistors (R616-R625) divided by the 30 kΩ input resistor (R608).

Bandpass Filter

The signal from the programmable gain amplifier is passed to a two stage filter to limit the signal to frequencies near 1.0 kHz. Each stage (U604 and U605) is an infinite-gain, multiple-feedback filter. Additional gain is provided by the following stage of amplification (U606). This stage produces the PAMPOUT signal which goes to the peak detectors on the multiplexer board.

MULTIPLEXER BOARD

The two page schematic of the multiplexer board begins with Figure F-18 on page F-45. Most of the circuitry on the multiplexer board is used to process the PAMPOUT signal from the preamp board. As a result, the discussion of the signal flow in the preamp board continues, in order, below.

The multiplexer board circuitry also helps create the main 1.0 kHz test frequency used by the AH 2500A. The discussion of the generation of the test frequency starts with the Sine Synthesizer section and continues in the order of the signal flow into the description of the main board.

In addition, the logic used by the processor to select all the analog circuitry is on this board.

Peak Detectors

Two comparators (U401 in area 1C4) are set to switch at about 1.2 volts and four volts to monitor the PAMPOUT signal. If a positive peak voltage greater than 1.2 volts occurs in the PAMPOUT signal, the output at U401, pin 7, will become negative. This will set the latch (U402, pin 8) making LEV A true if it is not already. Similarly, if a positive peak voltage greater than four volts occurs in the PAMPOUT signal, the output at U401, pin 1, will become negative. This will set the latch (U402, pin 6) making LEV B true if it is not already. LEV A and LEV B are digital signals which go directly to the

processor board. A low-pass filter (R405 and C421) ensures that unusually fast noise does not set the peak detectors.

Phase-Sensitive Detector

The PAMPOUT signal passes through a low-pass filter (R406 and C401 in 1D3) and is buffered by an op-amp (U403) configured as a follower. A second op-amp (U404) provides an inverted version of the same signal.

The heart of the phase-sensitive detector is a four-channel analog switch (U405 in 1D2). This switch acts on the normal and inverted PAMPOUT signals to produce two output signals. One of these signals (I) is proportional to the component of PAMPOUT that is late in phase by 45° with respect to the SYNTH signal. The other output signal (Q) is proportional to the component of PAMPOUT that is early in phase by 45° relative to the SYNTH signal. The 90° relationship between I and Q is important, but the phase relationship of these two signals relative to the SYNTH signal is arbitrary but must be constant.
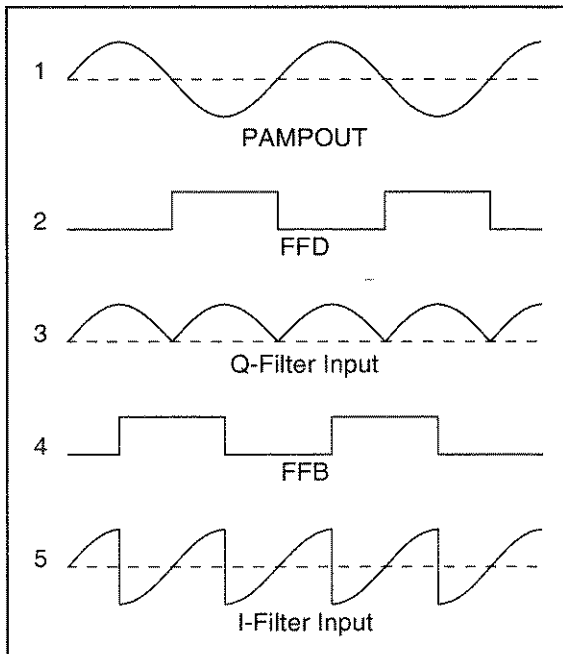
Figure 10-3 Phase sensitive detector waveforms

The way in which the analog switch accomplishes the detection process is better understood by referring to the waveforms in Figure 10-3. Waveform 1 is an example of how the PAMPOUT signal will sometimes appear. In this example, waveform 1 is out of phase with waveform FFD. Waveform FFD is one of the square waves generated by the sine synthesizer shift register (U408 in 1B3). When low, this signal turns on the section 3 switch of U405, passing the positive peak of waveform 1 to the input of the Q low-pass filter (U406 in 1D1).

When waveform 2 is high, the complement of the FFD signal turns on the section 1 switch of U405, passing the positive peak of the inversion of waveform 1 to the input of the Q filter (U406). The shape of the signal that results at the input of the Q filter is shown as waveform 3 in the same figure. Notice that all of the area between the signal and the zero axis is above the axis. This means that the filtered signal (Q) will have a substantial DC component.

Now consider what happens to the I signal in response to waveform 1. Waveform 1 in this example is shifted in phase by 270° with respect to waveform FFB. Waveform FFB is another of the square waves generated by the synthesizer shift register (U408). When low, this signal turns on the section 4 switch of U405, passing a positive-going crossing of waveform 1 to the input of the I low-pass Chebychev filter (U407 in 1C1). When waveform 4 is high, the complement of the FFB signal turns on the section 2 switch of U405, passing a positive-going crossing of the inversion of waveform 1 to the input of the I filter. The shape of the signal that results at the input of the I filter is shown as waveform 5 in the figure. Notice that half of the area between the signal and the zero voltage axis is above the axis and the other half is below. The area above the axis will tend to cancel the area below so that the filtered signal (I) will have no DC component.

The FFB signal is fixed in phase (early by 45°) with respect to the SYNTH signal and the FFB and FFD signals are shifted in phase by 90° relative to each other. Thus the I and Q signals are the results of detecting quadrature related components of the PAMPOUT signal relative to the SYNTH signal.

Multiplexer

The multiplexer (MUX in area 2D3) uses a common 1-of-8 CMOS analog switch. Its input sources are identified in the discussion on the Analog Block Diagram in "Detector, Multiplexer and A/D." on page 10-5.

Programmable Gain Amplifier

The op-amp (U411 in 2D3) and 1-of-8 analog switch (U412) create a programmable gain, DC amplifier (DCG). The processor can set the gain to be one, two, four or eight. The analog switch connects the negative input of the op-amp to a tap on a series connected string of resistors (R426-R429). The feedback resistance between the output (pin 6) and the negative input (pin 2) of the op-amp divided by the input resistance from the negative input (pin 2) of the op-amp to ground gives the gain of the amplifier. Unity gain is a special case which is achieved by connecting R433 directly between the output and the negative input with no input resistor connected to ground. The remaining four switches in U412 are not used.
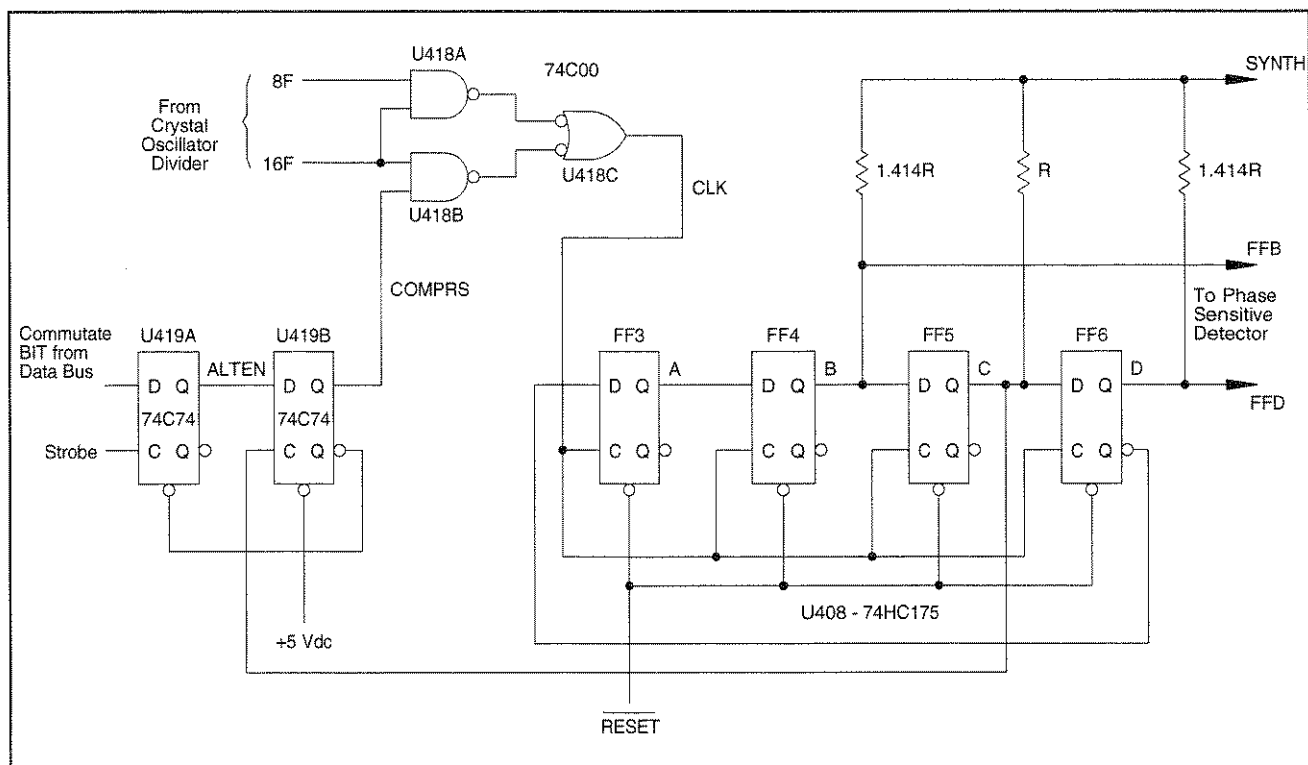
Figure 10-4 Sine synthesizer logic

Analog-to-Digital Converter

The single chip analog-to-digital converter (A/D) (U416 in 2C2) produces a ten-bit output on ten signal lines. The result is available 10 to 30 μseconds after the start conversion signal (STCN) goes low. If the converter type is an AD573N, the data ready output (pin 18) drives the hi and lo byte enable lines (pins 19 and 20) to enable the ten data output lines.

Selection Logic

Also on the multiplexer board is the logic that the processor uses to select all of the registers that control the analog boards. This logic is on sheet two of the multiplexer schematics shown in Figure F-19 on page F-47. This is just a continuation of the address decoding done on the processor board to create /S2W. Two 1-of-8 decoders (U417 and U420 in area 2A3) are used to create /S50-/S5A having addresses of 30A0-30AA. All are used as low true signals except for /S54 which is inverted by U418 to create S54. The addresses 30AB-30BF are not used. These are associated with the unconnected outputs of U420 and the partially decoded signal (/S3W) from the processor.

Sine Synthesizer

The sine synthesizer (U408 in 1B3) is found on the first sheet of the multiplexer board schematics. It and the alternate controller (U418 and U419) are also shown, more clearly, in the schematic of Figure 10-4.

The heart of the sine synthesizer is a four bit shift register whose fourth bit complemented output is fed back to the input of the first bit. This causes the shift register to continually cycle through eight states. The waveforms created by each bit are shown in Figure 10-5 on page 10-13. To always obtain the waveforms shown, it is essential that the shift register be initialized with the /RESET line.

By combining the signals from the shift register in the appropriate ratios, a good approximation of a sine wave is easily created. The AH 2500A combines the B, C and D waveforms so that the contribution from C and D is equal but the contribution from B is $\sqrt{2}$ times C or D. This is done by using 100 kΩ resistors (R423 and R425) for C and D but a 69.8 kΩ resistor (R424) for B. The summing point of these three resistors is the SYNTH node. The SYNTH waveform is shown in Figure 10-5. The relationship between the steps in the SYNTH waveform and signals B, C and D is easy to see.

The SYNTH signal is routed through J410 in 2A4 to the main board where it ultimately drives the main transformer. The J420 connector in 1A1 is reserved for an option board that provides fine control of the voltage level of the SYNTH signal (and thus of the signal applied to the DUT). A dedicated regulator (U409 in 1C3) powers U408 to ensure that the B, C and D signals are stable and noise-free.
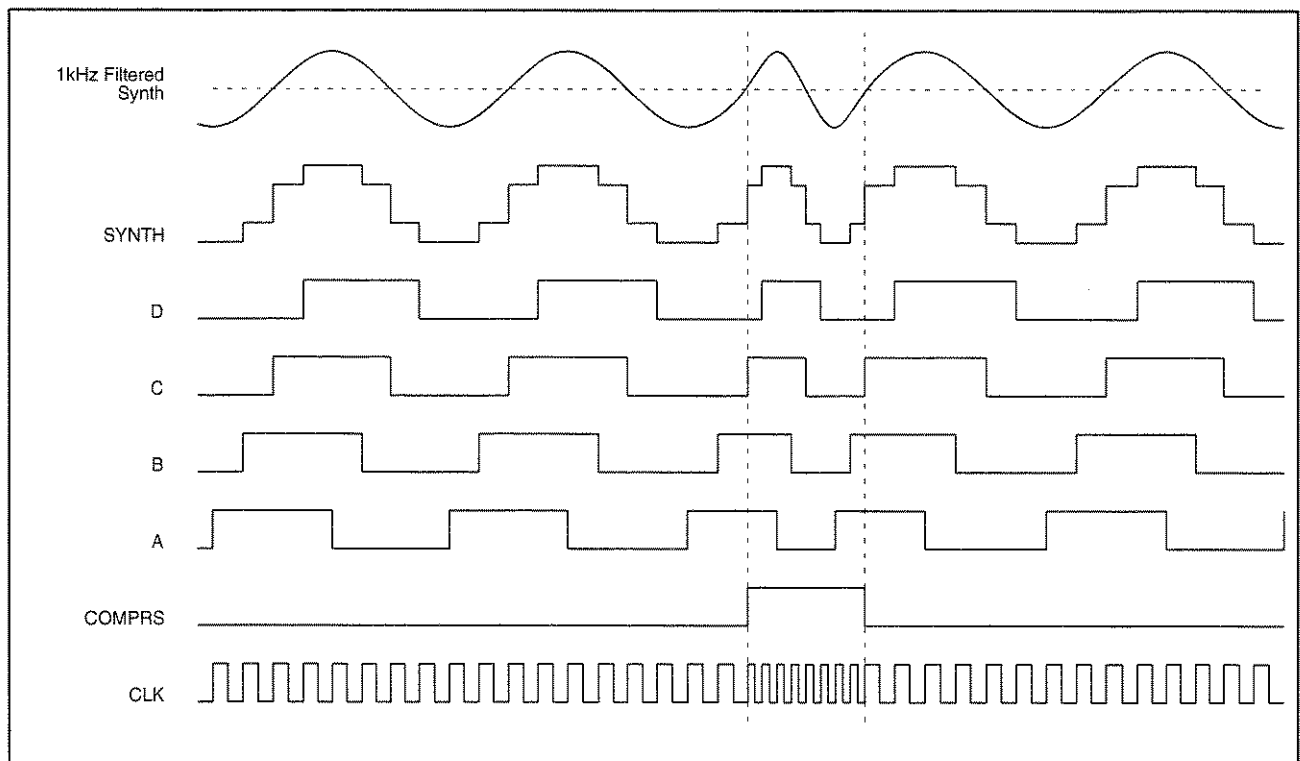
Figure 10-5 Sine synthesizer waveforms

Alternate Controller

The function of the alternate controller (U419) is to periodically shift the phase of the SYNTH signal by 180°. It does this by briefly doubling the clock frequency of the synthesizer shift register (U408). This causes one full cycle (1.0 ms.) of the sine wave to occur in half the time it normally would (0.5 ms.). The periodicity with which this occurs is entirely under the control of the processor using firmware timers.

When the processor decides that it is time to shift the phase of SYNTH, it sets the first alternate controller flip-flop (U419A) creating ALTEN. The second flip-flop (U419B) holds off the effects of ALTEN until bit C of the synthesizer shift register makes a positive transition. This makes COMPRS go true synchronously with the shift register. The COMPRS signal enables the gates (U418) so that exactly four extra clock pulses from the 16F clock are inserted between the clock pulses in the 8F clock pulse train. These signals are shown in Figure 10-5. This briefly doubled clock frequency causes the synthesizer shift register to shift at twice its normal rate. This, in turn, causes the SYNTH signal to be created at twice its normal rate. This effectively inserts one cycle of a 2.0 kHz sine wave precursor into the normal 1.0 kHz SYNTH signal. Every time this is done the phase of SYNTH will shift by 180°. The effect is easy to see in Figure 10-5.

MAIN BOARD

The main board and the standard cell assembly form three of the four legs of the basic bridge shown in Figure 4-1 on page 4-1. Only the leg which contains the DUT is not on the main board because the DUT is external to the bridge. The six page detailed schematic of the main board begins with Figure F-21 on page F-57.

The discussion of the generation of the 1.0 kHz test frequency starts with the Sine Synthesizer section in the multiplexer board description and continues in the order of the signal flow immediately below.

Full/Half Attenuator

The full/half attenuator allows the processor to control whether the main transformer has the maximum allowable voltage applied or only half of that value. This is used to provide a wider selection of voltages from the HIGH terminal of the bridge than is possible with the taps on the main and attenuator transformers alone. It also provides a way of checking the voltage coefficient of the AH 2500A since it can change the voltage applied to the entire bridge. Such a change will not affect the balance point of the bridge if the voltage coefficient is zero.

The state of the attenuator is controlled by a latch which produces the signal FULSIG (pin 15 of U112 in area 2B4). When this signal is false (low), the P-channel FET (Q101 in area 1C3) is non-conducting and no attenuation of the

SYNTH signal occurs. When FULSIG is true (high), Q101 conducts causing an AC current to flow from the SYNTH signal through a 1 µF capacitor (C103) and 8.66 kΩ resistor (R101) to ground. This additional current flow doubles the existing flow to ground (mostly through an 0.022 µF capacitor (C102)) and thereby reduces the signal level at the junction of C102 and C103 to half its unattenuated value.

Bandpass Filter

A bandpass filter greatly reduces the harmonics that exist in the SYNTH signal. Those harmonics are large for the seventh and above. This conventional filter is built using U101, C102, C104, R102, and R103 in area 1D3.

Main Transformer and Driver

The input to the main transformer driver is an adjustable gain stage (U102, R104, R105 and R109 in area 1D3). The variable resistor (R104) is used to set the voltage that drives the main transformer (T101) so that the maximum voltage available from the HIGH terminal of the AH 2500A is 15 volts. The main transformer is designed so that it begins to saturate at only a few volts above that level.

A low-pass RC filter composed of a 12.1 kΩ resistor and an 0.022 µF capacitor (R108 and C110 in area 1D2) further removes harmonics from the original SYNTH signal so that an excellent quality sine wave is produced.

The forty turn primary of the main transformer (T101 in 1D1) is driven by a push-pull amplifier (U103 and U104 in areas 1D2 and 1C1) which produces a 10 volt RMS signal across it. A 22 µF blocking capacitor (C108) prevents any DC currents from flowing through T101. This blocking capacitor and other stray impedances introduce voltage drops in the driving circuit that make the sine wave across the primary of T101 less perfect than it would otherwise be. To correct these errors, an error amplifier (U105) compares the difference between the desired sine wave and the actual main transformer voltage as measured from a tap (QIN). The error amplifier magnifies the error voltage by a factor of ten and applies the resulting correction voltage to the push-pull amplifier through a 100 kΩ resistor (R110).

In addition, the correction voltage (if any) is rectified by a diode (CR103) which charges a 0.1 µF capacitor (C111). This rectified voltage is used to create the OVRLD signal which can be read by the processor using the A/D on the multiplexer board. The presence of an OVRLD signal indicates that T101 is overloaded, usually as a result of too much current flowing from the HIGH terminal to ground. When this occurs, the processor reports the "high to ground short" error by placing an "H" in the upper right corner of the front panel capacitance display. A resistor divider (R117 and R118) ensures that the OVRLD signal does not exceed the range of the inputs of the multiplexer (U410) on the multiplexer board.

The main ratio transformer (T101) has five windings. The most important characteristic of T101 is that the voltage per turn for every turn of every winding is the same. This is true for every turn to an extremely high degree of precision. This is true even if some current is being drawn from the transformer causing the voltage per turn to decrease slightly; the voltage per turn will decrease equally for all turns. Only if excessive currents are drawn will the voltage per turn start to become unequal among the windings.

Quadrature Phase Shifter

As explained in the section "Quadrature Phase-Shifter and RTMDAC" on page 10-4, the quadrature phase shifter actually consists of two identical, independent, 90° phase shifters which are normally connected in parallel with each other. Each of these phase shifters consists, in turn, of two 45° phase shifters (U107 & U108 in area 2D3 and U109 & U110 in area 2C3) connected in series. Each 45° phase shifter consists of an RC network (R120 & C114, etc.) followed by a high input impedance amplifier (U107, etc.). The RC network does the actual phase shifting, while the amplifiers produce a low output impedance to drive the next stage. The amplifiers (U107 and U109) associated with the first stage 45° phase shifters are simply follower circuits. The amplifiers (U108, R124 & R125 and U110, R134 & R136) associated with the second stage, 45° phase shifters provide a gain of two to restore the signal level lost by the two RC networks. The resistance in the second stage RC networks is composed of two resistors (R197 & R123 and R132 & R133). The first of each of these two resistors is selected at the time of manufacture to get a total phase shift of 90° from the output of the series connected 45° phase shifters.

The 90° phase shifters are switched into their various configurations using FET switches. N-channel FET switches (Q103 and Q105) are used when a positive control voltage should *close* a switch. P-channel FET switches (Q102, Q104 and Q106) are used when a positive control voltage should *open* a switch.

The control voltages are produced using two identical circuits ((Q107 and Q108) and (Q109 and Q110) in area 2B3). These circuits convert the 0 to +5 volt range from the processor controlled latch (U112) to signals having a range of -24 to +24 volts. The operation of the first of these two identical circuits is described below.

When the processor sets pin 10 of U112 to 0 volts, this causes no current to flow through R143 into the base of Q107 which turns Q107 off. With Q107 off, no current flows through R144 into the base of Q108 turning Q108 off also. With Q108 off, there is no current through R146 which makes the collector of Q108 equal to the negative supply voltage of -24 volts.

When the processor sets pin 10 of U112 to + 3 to +5 volts, this causes a current to flow through R143 into the base of Q107 which turns Q107 on. With Q107 on, a current flows through R144 into the base of Q108 turning Q108 on also.

With Q108 on, its collector voltage is equal to the positive supply voltage of +24 volts.

Quadrature Transformer Driver

The quadrature transformer driver (U111 in area 2C2) gets its input signal from the output of the quadrature phase shifter. This 2 volt rms signal is obtained directly or indirectly (depending on the setting of the quadrature phase shifter) from the 0.8 tap of the IDAC winding of the main ratio transformer, T101. The function of the quadrature transformer driver is both to provide sufficient current to drive the quadrature ratio transformer (T102) and to accurately amplify the signal from the quadrature phase shifter by 1.25 so that the voltages across the IDAC winding of T101 and the QDAC winding of T102 are equal to within about 0.1%.

The 2 volt signal from the quadrature phase shifter goes to pin 3 of U111 where it is compared against the signal on pin 2 of U111 which comes from the 0.8 tap (QSENS) on the quadrature ratio transformer, T102. The output of U111 on pin 6 produces a signal with an amplitude that causes the voltage across T102 (QDRV) to be 2.5 volts. It is the 1.25 turns ratio of the 1.0 to 0.8 taps of T102 that causes U111, pin 6, to drive T102 so that the QDRV voltage is precisely correct (2.5 volts rms).

A blocking capacitor (C120) is in series with T102 to prevent any significant DC current from flowing through T102. Diodes (CR109, CR110) limit the voltage that can exist across C120.

The two op-amps (U148A & B in 2A1) are used to correct for DC offset voltages in the amplifiers of the quadrature phase shifter. The quadrature phase shifter is DC coupled to the quadrature transformer driver so that the driver will amplify any DC offsets fed to its input. To cancel these, the output of U111 is connected to an integrator (U148B). The integrated output is inverted (U148A) and fed to the negative input of U111 in such a way as to cancel any DC voltages applied to the positive input of U111. The integrator output continually adjusts until there is no DC voltage at the input to U148A. This insures that the blocking capacitor, C120, has only a very small DC voltage across it so that the diodes, CR109 and CR110, do not conduct.

RTMDAC's

The basic operation of the RTMDAC's is discussed in the section "In-Phase Relays and RTMDAC" on page 10-4.

The IDAC and the QDAC of the main board schematics in Figure F-23 on page F-61 and Figure F-24 on page F-63, respectively, are very similar to each other. They may, at first, appear to be very different from the simplified diagram in Figure 10-1 on page 10-3, but schematically, they are very similar to that figure. The schematics look different from the simplified diagram because the signal lines in the schematics are bussed and because the analog switch IC's are shown in the schematics rather than the individual switching elements.

There are two kinds of analog switch IC used. One is the 4053 which can connect one of two inputs to a common output. The other is the 4051 which can connect one of eight inputs to a common output. The 4053's are used in the "bi" part of the bi-quinary switching scheme. The 4051's are used in the "quinary" part of the bi-quinary switching scheme. In addition to their quinary function of selecting the five 0.2, 0.4, 0.6, 0.8 and 1.0 taps of the ratio transformers, each 4051 also can select the 0.0 tap (ground) and the -0.1 tap. Thus each 4051 actually selects a total of seven taps.

The processor controls each bi-quinary decade by loading a four-bit latch consisting of a 74HC175. Three of these bits are used to control one 4051 and the fourth bit is used to control one section of a 4053.

The biggest difference between the simplified diagram in Figure 10-1 and the actual schematic is in the large value resistors shown on the simplified diagram. The schematics do not show any large value resistors. Instead, they show resistive dividers that accomplish the same thing. These dividers allow smaller resistors to be tied to the common terminals of the analog switches of lesser significance.

The two RTMDAC's share a single precision adder (U128 in area 3B1). The entire switched resistor network of both RTMDAC's feeds into the input of U128. Similarly, two resistive dividers are each shared by both RTMDAC's. The divider using R163 and R165 (in area 3B3) and other resistors causes any 2 MΩ resistors that are tied to the common point between R163 and R165 to have the same effect as a 20 MΩ resistor connected directly to the negative input of U128. Similarly, the divider using R137 and R140 (in area 3B3) and other resistors causes any 1 MΩ resistors that are tied to the common point between R137 and R140 to have the same effect as a 200 MΩ resistor connected directly to the negative input of U128. The operation of this area of the circuit is much easier to understand by referring to the simplified diagram in Figure 10-1.

For most of each RTMDAC, the on-resistance of the analog switches is large compared to the resistors in series with them so that the effects of the on-resistance can be ignored. However, for the most significant two decades this is not true. As a result, these decades use follower IC's consisting of LM310's and LM318's to reduce the effective output impedance of the analog switches substantially below that of the analog switches by themselves.

All of the analog switches in the RTMDAC's are powered from ±5 volt supplies provided by two regulators (U129 and U130 in area 3A4). These supplies are used because the voltage capabilities of the analog switches are not sufficient to operate from ±12 volt supplies.

Decade Relay Banks

The basic operation of the decade relay banks (RD's) is discussed in the section "In-Phase Relays and RTMDAC" on page 10-4 and is shown in the Analog Circuits Block Diagram Figure F-2 on page F-5. The schematic is in the upper half of sheet five of the main board schematic drawings shown in Figure F-25 on page F-65. The Analog Block Diagram shows the analog part of this circuit without any simplifications.

A CD4514 one-of-sixteen latching decoder (U144 and U145 in area 5D1 and 5D3) controls each decade. These decoders can be loaded directly from the processor. Twelve of the sixteen output lines from each decoder drive ULN2803A drivers which, in turn, drive the relay coils. The processor can close one relay in each bank at a time.

Attenuator

The basic operation of the attenuator (ATN) is discussed in the section "Attenuator Leg of the Bridge" on page 10-3. and is shown in the Analog Circuits Block Diagram in Figure F-2 on page F-5. The schematic is in the lower left corner of sheet five of the main board schematic drawings shown in Figure F-25 on page F-65. The Analog Block Diagram shows the analog part of this circuit without any significant simplifications. The selection of the attenuator relays uses U146 and occurs in exactly the same manner as described above for the decade relay banks.

Oven Controller

The oven controller controls the power that keeps the standard cell assembly at a very constant and repeatable temperature when the AH 2500A is operating. The schematic for the oven controller is located on sheet six of the main board schematic diagrams shown in Figure F-26 on page F-67.

The oven controller is a purely linear design. Its input is taken from a high-stability resistance bridge (R201, R202, R203 and RT201 in area 6C4) located on the standard cell assembly. The voltage at the junction of R203 and the thermistor, RT201, is an indication of the cell temperature. The magnitude of this negative voltage decreases as the cell temperature increases. The processor monitors this voltage and hence the cell temperature via the OVEN line. Resistors R201 and R202 form a high stability divider against which to compare the cell temperature. The objective is to raise the temperature of the cell until the voltage at the center points of the two arms of the bridge is precisely equal.

The high precision op-amp (U201) compares the two halves of the resistance bridge. This op-amp is configured as an integrator using an 0.47 μF capacitor (C202) and a 33 MΩ resistor (R206) to produce a long time constant. As the cell reaches its operating temperature, the output of U201 will stabilize at a DC level which reflects the amount of power needed to keep the cell at its operating temperature.

The next stage (U202) is a linear amplifier with several lead and lag circuits that are needed to make the controller stable. The dynamic behavior of the controller is designed to be underdamped, with the oscillations falling at least a factor of three on every cycle. A resistor (R210) biases the positive input of U202 slightly negatively so that the output of U202 is also shifted negatively. This is done because U202 operates from symmetrical plus and minus 12 volt power supplies but drives a power circuit operating between ground and -24 volts. The op-amp, U202, drives a transistor (Q203) which gives an additional gain of about ten. The transistor, Q203, drives a darlington transistor pair (Q201 and Q202) which control the current through the heater on the cell. The power transistor, Q201, is located on the cell since a significant amount of power is dissipated by this transistor which helps to heat the cell.

STANDARD CELL ASSEMBLY

The standard cell assembly consists of three fused-silica capacitors enclosed in a hermetically sealed cell. This cell is located in an insulated box which allows the cell to be very precisely temperature controlled. A flexible circuit is attached to this cell that holds and makes connection to some of the parts associated with the oven controller described above.

Reference Capacitors

The three reference capacitors (C210A, C210B and C210C) are connected to the rest of the bridge as discussed in the section "In-Phase Relays and RTMDAC" on page 10-4 and as shown in the Analog Circuits Block Diagram in Figure F-2 on page F-5. The details of the interconnections are shown in area 5B2 in Figure F-25 on page F-65.

The three reference capacitors are tied to a common point (STCOM). This is carefully shielded and brought out of the standard cell oven box through a coaxial cable to the preamp board. The other ends of the three reference capacitors are brought out of the standard cell oven box via the flexible circuit. A connector (P214) on the end of the flexible circuit plugs into the main board.

Chapter 11   Diagnosis and Repair

The purpose of this chapter is to describe how to repair an
AH 2500A that is suspected of having a problem. If there is
no reason to suspect that a problem exists, then there will be
little reason to read any of this chapter.

If you believe that your AH 2500A is functioning properly,
but you wish to verify this, see Chapter 9, "Verification/Cali-
bration". It is important to know that the function of calibrat-
ing or verifying a bridge is a totally different operation from
the diagnostic tests described in this chapter.

The routines that verify the AH 2500A perform *very demand-
ing* tests that will only pass if the bridge is performing to its
published specifications. On the other hand, the diagnostic
tests described in this chapter perform few demanding tests.
Almost all of these tests are *simple* in nature. Each test is
designed to exercise as little circuitry as possible so that if a
test fails, only a small amount of circuitry is suspect.

REPAIR PHILOSOPHY

You can approach the problem of diagnosing and repairing
the AH 2500A in at least four different ways or in any combi-
nation thereof. These are:

1. Send the bridge to the factory for repair.

2. Identify the subassembly that needs repair and send that
   to the factory.

3. Identify and replace the subassembly that has failed.

4. Identify and replace the specific component that has
   failed (resistor, IC, etc.).

Which of these you choose will depend on the time and
expense involved in shipping to and from the factory, your
ability to stock spare subassemblies, and your access to local
repair expertise.

Table 11-1 Some abbreviations used in this chapter

Abbreviation	Full name	Description	Applies to
=>	Implies	One thing *implies* another thing	relationships
ACG	AC Gain	The variable gain control circuit in the preamp	U602, U603, U609
A/D	Analog-to-Digital Converter	The 10-bit analog-to-digital converter used to read most signals in the bridge	U416
ATN	ATteNuator	The circuit used to drive the HIGH terminal	U146, K113-120, etc
DAC	Digital-to-Analog Converter	The RTMDAC circuit used to precisely select voltages from the main and quadrature transformers. See "RTMDAC's" on page 10-15.	Sheets 3 & 4 of main board schematics
DCG	DC Gain	The variable gain control circuit on MUX board	U411, U412, U413
FS	Full Scale	The largest signal that can be measured by the A/D	U416
IDAC	In-phase DAC	The half of the RTMDAC that selects voltages from the main ratio transformer	Sheet 3 of main board schematics
max	maximum	Usually used to mean the larger of two signals	
MSD	Most Significant Decade	The most significant decade of one of the DAC's	U122, U138
MSRD	Most Sig. Relay Decade	The most significant relay decade	U145, K121-132
MUX	MUltipleXer	The circuit that selects the signal read by the A/D	U410
p/o	part of	Only part of the item following "p/o" is applicable	
QDAC	Quadrature DAC	The half of the RTMDAC that selects voltages from the quadrature ratio transformer	Sheet 4 of main board schematics
RD	Relay Decade	One of two groups of twelve relays used to select voltages from the main ratio transformer	U144, K101-112, U145, K121-132
S/P/B	Series/Parallel/Bypass	The circuit used to create signals that are phase-shifted by 180°, 90°, and 0° respectively	Sheet 2 of main board schematics

The repair philosophy of this chapter supports all of the above options. The self-tests built into the AH 2500A are capable of localizing many failures well enough to be able to perform repairs by replacing either the lowest level part that has failed or the subassembly that contains the part. Whether this is practical or not depends upon the particular failure and your available expertise.

Consult the Factory

If you are able to, a brief discussion with the factory (via phone or fax) will often determine whether or not a problem is easy to fix locally. Since the factory maintains historical failure statistics, the factory can often help by identifying a particular part that is the likely source of failure

PRELIMINARY TROUBLESHOOTING

If you believe your bridge has a problem and you have not read this chapter previously, you will want to familiarize yourself with this section first.

Abbreviations Used

There are a number of terms used in this chapter to describe, primarily, different major sections of the circuitry in the bridge. Some of these terms are too long to use frequently so a number of abbreviations have been defined to use in their place. Table 11-1 lists these abbreviations. In addition, many signal names are used that are not listed in this table but which are found in Chapter 10, "Circuit Descriptions" and in the schematics in Appendix F, "Drawings and Parts Lists". Major subassembly names and their reference numbers are shown in Figure 11-3 and Figure 11-4 at the end of this chapter.

Recommended Tools and Equipment

The following list gives the minimum tool and equipment requirements needed to diagnose a problem in the AH 2500A.

1. Phillips #2 screwdriver

2. Multimeter with an AC voltage accuracy of 1% and an input impedance of at least 10 megohms.

3. Metered and current limited 0-250VDC, variable, lab power supply.

4. BNC to dual male banana plug cable to connect power supply to a female BNC jack.

5. Triggered DC-50 MHz oscilloscope and probe

6. 1000 pF three-terminal capacitor

7. Andeen-Hagerling DCOAX-1-BNC (or equivalent) coaxial cable pair with male BNC ends.

8. Two BNC Tee adapters

9. One BNC 50Ω terminator

10. One male BNC to binding-post adapter.

11. One 2 kΩ and one 10 kΩ 5% carbon resistor

12. Tools suitable for soldering and unsoldering parts on printed circuit boards.

While there are certainly other items that might be useful, if the ones listed aren't sufficient to find the problem, chances are that other or more powerful tools won't either. The kinds of problems that may be encountered require the skill to be in the technician, not the equipment.

Before You Start

Significant diagnostic work can be performed on an AH 2500A on either of two levels.

1. *All* of the diagnostic self-test routines can be performed without removing the covers of the bridge. Thus, you may be able to isolate the area in which a failure has occurred *without* opening the bridge.

2. After everything possible has been done with the covers still on the bridge, further diagnostic and repair work can only be done by working inside. This should only be done by an experienced technician in order to protect both the worker and the equipment.

WARNING !

Voltages high enough to cause a serious shock may be present in three areas of the bridge. All but the DC bias connector are normally covered even when the top and bottom covers of the bridge have been removed. However, further disassembly can expose these voltages. These exist in the area of the power line module, the front panel power switch, and in the preamp box and on the DC bias connector if an external DC bias is applied. See Figure 11-3 and Figure 11-4 at the end of this chapter for the location of these four areas.

Understanding the Circuitry

Any serious troubleshooting requires a good understanding of how the suspected circuits operate. The relevant sections of Chapter 10, "Circuit Descriptions" should be read. The relevant parts of the block diagrams and schematics in Appendix F, "Drawings and Parts Lists" should be studied before attempting any repairs.

Removal of Covers

While the removal of covers is fairly straightforward, there are a few tricks that will make the job easier and will reduce the chances of damaging the bridge in the process. For the reasons given in the caution message below, it is important to understand the correct way to remove the covers so that unnecessary disassembly is avoided.

Table 11-2 Actions to take in response to possible failure symptoms

Symptoms	Possible problems	Actions to take
No indicators illuminate on the bridge front panel.	No power from line.	Check power line.
	Bridge fuse is blown.	Replace fuse with proper size. See "Checking/Replacing the Fuse" on page 1-6.
Bridge fuse blows soon after power-on.	Bridge power supply (A701) is overloaded.	Unplug A701 output P702. If fuse still blows, repair or replace A701 or T701. Otherwise, further isolate the excess load by unplugging other subassemblies.
	Bridge power supply is defective.	Repair or replace A701 or T701.
No indicators illuminate on the bridge front panel, but fuse is OK and power line has power.	Processor bd. (A301) failed. A501 unplugged	Check the 5V power supply at connector J302 on A301. If it is within 4%, repair or replace A301.
	Five volt power supply is bad on A701.	Check/replace 5V PS fuse (F702). Check/replace 5V regulator (U703) and diodes CR701 and CR702
Bridge does not indicate completion of the power-on self tests by putting a message on the front panel display.	Processor board (A301) failure.	Check the 5V power supply at connector J302 on A301. If it is within 4%, repair or replace A301.
Bridge completes power-on self-tests but reports an error message on its display.	The reported error message indicates the problem.	The power-on self tests are identical to the group one diagnostic tests explained in section "Processor and Front Panel Tests" on page 11-14. Refer to that section to proceed further.
Bridge completes the power-on self-tests successfully by reporting CPU $tESt$ $PRSSEd$ on front panel display, but won't accept commands from the front panel keypad.	Keypad (A502) is locked out, keypad is defective or U309 or U310 on processor board (A301) is defective.	Press $\boxed{LOCAL}$. If L $OCRL$ $Locout$ appears then Nremote and Nlocout *states* are set in the Baud 1 parameter set. Clear these settings from a remote port or set position 1 of SW301 on, apply power to the bridge, press $\boxed{FUNC}$ $\boxed{STORE}$ $\boxed{FUNC}$ $\boxed{BAUD}$ $\boxed{1}$ $\boxed{ENTER}$, and reset position 1 of SW301 off. Check/replace W506, U309 or U310. Otherwise replace A502 or A301.
Bridge gets an H error indication on the front panel with each measurement result.	HIGH terminal is overloaded by a low impedance to ground.	Disconnect the HIGH and LOW cables to the bridge.
Bridge gets an H error indication on the front panel with each measurement result with nothing connected to the HIGH and LOW terminals.	An ATN or RD relay is stuck closed, HIGH terminal voltage set too high	Run the Relay Decade and Attenuator diagnostic tests with particular attention to the stuck reed tests. If these pass, refer to "Adjustment of HIGH Terminal Signal Level" on page 11-22
Bridge gets error message (other than H) on the front panel with each measurement result and with nothing connected to the HIGH and LOW terminals.	A problem exists somewhere in the measurement circuitry in A101, A401, A601, C210, or interconnecting cables.	Perform the tests described in "Checking Power Supply Voltages" on page 11-4. If these are correct, then run all the diagnostic self-tests described in this chapter. Actions to be taken in response to tests that fail are described with the individual test descriptions.
Bridge may appear to be working, but fails calibration/verification.		
OVEN NOT READY front panel indicator never goes out.	The oven, its controller, or the oven monitor has drifted or failed.	Run the diagnostic self-tests. If they pass, the oven or its control circuit on the main board is bad.
Bridge exhibits an intermittent failure.	A loose or corroded contact or mechanical damage exists somewhere.	Run all non-interventional diagnostic self-tests and any that require intervention that are suspected of being relevant. While running these tests, subject the instrument to whatever environmental stress seems to trigger the intermittent behavior. The most common stresses that cause intermittents are vibration and temperature changes.

CAUTION

Unlike many low-frequency instruments, the chassis of the AH 2500A is considered to be part of its precision measurement circuitry. For this reason, the screws that hold the printed circuit boards and the various mechanical parts together must be considered to be critical components. Not only must every single screw that is removed be replaced, but these screws must be torqued to the values listed herein using a calibrated torque screwdriver where specified. It is extremely important that all work inside the AH 2500A strictly follow the procedures in Chapter 12, "Disassembly/ Reassembly".

Ground Reference Points

Every printed circuit board assembly except for the power supply and keypad has a convenient ground post. This pro-vides for easy connection of a ground test lead such as that on an oscilloscope probe. The post is a round turret-style and is identical on all boards. This post style is not used for any other purpose in the bridge. The recommended ground refer-ence point on the power supply is the negative end of the largest capacitor C711. This end is in the middle of the board. All ground reference points are identified in Figure 11-3 on page 11-40 and Figure 11-4 on page 11-41 at the end of this chapter.

Troubleshooting Basic Symptoms

If your bridge exhibits a specific symptom, you should look up the recommended actions to take in Table 11-2. This table will direct you to try some additional manual tests or to begin performing the diagnostic self-tests. Whatever actions are suggested by this table should be performed before trying any diagnostic self-tests. Conclusions suggested later, related to self-test failures, *assume* that this table has been consulted.

Checking Power Supply Voltages

The voltages produced by all the power supplies and power regulators in the AH 2500A are easily checked. All but two power sources are required to have a tolerance of ±4%. The remaining two are the unregulated sources labeled as +24V and -24V. In reality, they may range in magnitude from 20 to 32 volts depending largely on the power line voltage. The points that are recommended for checking these voltages are identified in Figure 11-3 on page 11-40 and Figure 11-4 on page 11-41 at the end of this chapter.

Any power sources found to be out of tolerance *must* be fixed before proceeding with any further tests. In many cases, a failed regulator is the problem, but you must also be on the lookout for excess loading of a power source. Power is pro-vided to the SAMPLE SWITCH connector, so that is a possi-ble source of excess loading if anything is connected to it.

The bridge contains three unregulated power supplies (+8V, +24V, -24V), from which ten regulated voltages are gener-ated. The +8V supply is internal to the the the power supply board (A701).

DIAGNOSTIC TEST ESSENTIALS

The AH 2500A contains about 350 individual self-tests that it can perform. These are arranged into over 50 groups. The names of these groups are listed in Table 11-6 on page 11-11.

The purpose of these tests is *not* to verify that the bridge is operating properly. The purpose is to help find and fix a prob-able failure that has previously been determined to exist.

Most of these tests are very simple and can be executed rap-idly and repeatedly to create signals that are easily observ-able and interpretable on an oscilloscope, if needed. The measurement circuitry is reset at the beginning of each test so that a scope loop can be set up that sees all signals involved in performing each test. Each test functions *independently* of all other tests.

Initiating Self-tests: the TEST command

All of the self-tests are initiated with the following command syntax:

TEST [*testgrouplo.testlo* [*.testgrouphi.testhi*]]
[REPEAT [*count*]]

where the test parameters have the following meanings:

testgrouplo	The number of the group containing the first test to be executed.
testlo	The number within the first group of the first test to be executed
testgrouphi	The number of the group containing the last test to be executed.
testhi	The number within the last group of the last test to be executed
count	The number of times the entire range of specified tests is to be executed. If REPEAT with no *count* is entered, the tests will be executed indefinitely.

The test parameter options allow the following possibilities:

1. Issue the TEST command with no parameters. This causes all tests that do not require intervention or observation to be executed.
   Example: TEST

2. Issue the TEST command with only the *testgrouplo* parameter. This causes only the tests having that test group number to be executed.
   Example: TEST 62

3. Issue the TEST command with the *testgrouplo.testlo* parameters. This causes only the one specified test to be executed.
   Example: TEST 62.2

4. Issue the TEST command with the *testgrouplo* then *testgrouphi* parameters. This causes all the tests having those test group numbers plus all test groups in between to be executed.
   Example: TEST 62..70

5. Issue the TEST command with the *testgrouplo.testlo* then *testgrouphi.testhi* parameters. This causes all the tests from the lowest number specified to the highest number specified inclusive to be executed.
   Example: TEST 62.2.70.2

6. All of the above five forms of the TEST command may optionally be followed with REPEAT and an optional repeat count to specify the number of times the tests are to be executed.
   Example: TEST 62..65 REPEAT 3000

The range of valid test group numbers is not contiguous. As a result, it is possible to enter test number ranges that do not start and/or end on a valid test group number. Nevertheless, there may be executable test numbers within the entered range. If such tests are found, they will be executed. If not, a bAd PAr error will be reported.

Execution of the tests can be aborted at any time with the DEVICE CLEAR command.

Recommended Command Sequence

The TEST command by itself is the easiest version of the command to run since it requires no external hardware. It executes most important tests except for those in one group: the attenuator tests. The command sequence TEST; TEST 91..94; STEP provides the most powerful test sequence that is also easy to run. This sequence can be set up and then left to run once without intervention. These commands can also be used to make a simple program that can be run repetitively. A program is required if repetition is desired since the test REPEAT qualifier applies only to the TEST command and not to a multiple command line such as this sequence.

Performing the 90 series tests requires some external parts which are described in "The External PI Network" on page 11-37. The 90 series tests will prompt you to connect this network. If you connect the network before issuing the command sequence, you can end the sequence with the STEP command so that the tests won't stop to issue a prompt.

Format of the Test Results

As explained later, you can chose whether all tests or just failed tests report a result. A result contains three or four basic kinds of information.

1. The number of the test that was executed is reported along with a count of the number of times that the tests have been repeated.

2. The reported result gives two values which form a window. A third value is reported which indicates that the test passed if the value is within the window and that the test failed otherwise.

3. Most of the result consists of test variables that show the exact state of every settable bit in the measurement circuitry of the bridge at the time when the test completed. This information can be important for establishing the exact state of the bridge if a failure occurs.

4. The number of tests that have failed (FCNT) and the group and number of the last test to have failed (LTF) are reported on the front panel display. FCNT is zeroed and LTF is cleared each time a TEST command is executed unless the command is part of a program. In that case, FCNT and LTF are initialized only at the beginning of the root program. This allows failure information to accumulate in programs which contain complicated test sequences.

All of the variables reported by each test result are listed in Table 11-3. The format of these variables is given in this table and the number of characters used to report each variable is indicated by the number of letters in the entries in the format column. The way in which these variables are formatted on the front panel and on remote devices is given in the next two sections. The values that each of these test variables can have are listed in Table 11-4 on page 11-8. The precise effect of setting a variable to each value is also listed in this table.

Front Panel Format

Each test result is displayed on the front panel as six separate windows in the order and format shown below. You can examine each window in the usual manner by pressing the ◄ and ► keys each time you want to advance from one window to the next.

Twelve of the variables have labels preceding them. These are r :, ESE :, Lo :, $pfpf$:, H_I :, G, C, A, E, b, $FCnE$:, and LEF :. These are all constants except for $pfpf$.

The default window visible in the front panel display while tests are running is the first one which shows the repeat count and the group and number of the currently executing test. This window gives a real-time display of the progress of the tests.

In addition, the ◄ and ► keys may be used to move through the six display windows while the tests are actually running. This allows monitoring vvv while repeating a single test to check for sensitivity to various stimuli in real-time.

```
┌─────────────────────┐
│  r :  ccccc          │
├─────────────────────┤
│  ESE : gg.nn         │
└─────────────────────┘

    ┌─────────────────────┐
    │  pfpf : vvv          │
    ├─────────────────────┤
    │  Gpd    Cm           │
    └─────────────────────┘

        ┌─────────────────────┐
        │  H_I  :  hhh         │
        ├─────────────────────┤
        │  Lo  :  lll          │
        └─────────────────────┘

            ┌─────────────────────┐
            │  Aa     Et           │
            ├─────────────────────┤
            │  bb   f   s          │
            └─────────────────────┘

                ┌──────────────────────────┐
                │  r₁r₂i₁i₂i₃i₄i₅i₆          │
                ├──────────────────────────┤
                │  q₁q₂q₃q₄q₅q₆              │
                └──────────────────────────┘

                    ┌─────────────────────┐
                    │  FCnE : eee          │
                    ├─────────────────────┤
                    │  LEF : gg.nn         │
                    └─────────────────────┘
```
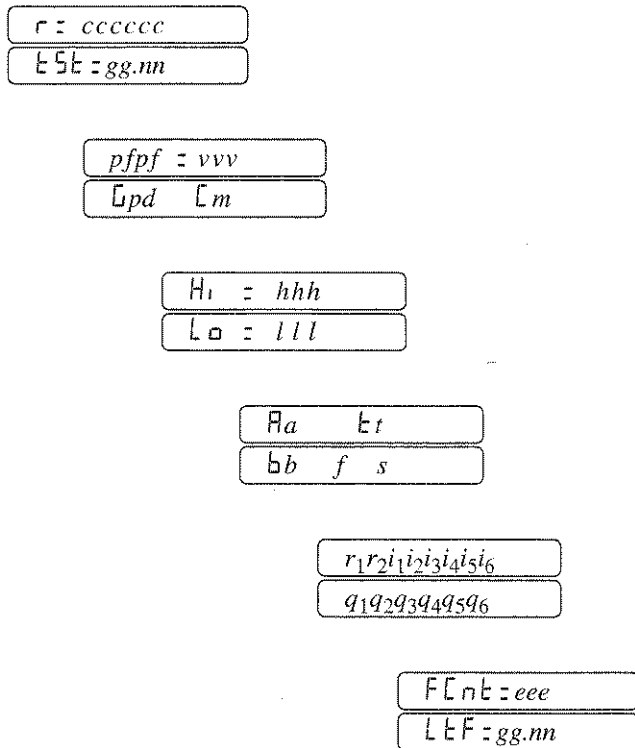
Remote Device Format

Each test result is sent to a remote device as a *single* line having the format shown below.

R=$ccccc$ TST=$gg.nn$ LO=lll pfpf=vvv HI=hhh Gpd
      Cm Aa Tt Bb f s $r_1r_2i_1i_2i_3i_4i_5i_6$ $q_1q_2q_3q_4q_5q_6$

Most of the test variables are decimal, but a, r, i and q can also have some hexadecimal values. Ten of the variables have labels preceding them. These are TST=, LO=, $pfpf$=, HI=, G, C, A, T and B. These are all constants except for $pfpf$.

Table 11-3 Test variables reported by the TEST results

Format	Name	Description
$ccccc$	Repeat count (R=)	Shows number of times the test(s) have been executed
$gg.nn$	Test (TST=)	Shows test group.number of currently executing test
hhh	Hi limit	High limit of test window
lll	Lo limit	Low limit of test window
$pfpf$	PASS/ FAIL	Indicates whether vvv was within the test window
vvv	Value	Value measured or derived from running the test. Holds End or 000 on the summary line.
p	ACG (G=)	Preamp AC gain setting
d	DCG (G=)	DC gain setting
m	MUX(C=)	MUX channel selected
a	ATN (H=)	Attenuator tap selected
t	Test/Cal relay (T=)	Test/Cal relay and shunt resistor states
b	Bias (B=)	DC bias relay states
f	Full/Half	Test signal amplitude
s	S/P/B	Quadrature phase shifter setting
r_1r_2	RD	Relay decade positions selected
$i_1i_2i_3i_4i_5i_6$	IDAC	In-phase DAC setup value
$q_1q_2q_3q_4q_5q_6$	QDAC	Quadrature DAC setup value
eee	Error count (FCNT=)	Shows the number of tests that have failed since the start of a TEST or PROGRAM command.
$gg.nn$	Test (LTF=)	Shows test group.number of the Last Test Failure.

Format of the Summary Line

After the last test in *each* test cycle has been executed and optionally reported, a summary line may optionally be sent to remote devices. After the last test in the *last* test cycle of a repeated test has been executed and reported, one summary line will be sent to the front panel.

The repeat count, the failure count, and the group and number of the last test failure are reported. These are described in more detail in item four of "Format of the Test Results" on page 11-5. The SHOW TEST command can report all of the available information about the last test failure.

Front Panel Format

The format of the summary line on the front panel display is:

```
┌─────────────────┐   ┌─────────────────┐
│  r =  ccccc      │   │  F[nt =eee      │
└─────────────────┘   └─────────────────┘
┌─────────────────┐   ┌─────────────────┐
│  t5t =End        │   │  LtF =gg.nn     │
└─────────────────┘   └─────────────────┘
```

The t5t =End words distinguish the first window of the summary line from that of an ordinary result line.

Remote Device Format

The format of the summary line on a remote device is:

R=ccccc TST=99.99 FCNT=eee LTF=gg.nn

The test group and number is always 99.99 on this line (rather than END) so that it is easily identified as the summary line by a program running on a remote device.

Reviewing the Last Test Failure: the SHOW TEST command

The data for the last test that failed can be re-displayed by issuing the command:

SHOW TEST

This command does not provide any new information, it only re-displays exactly the test failure result line and most recent summary line that was previously shown. It is useful if the failed test was not printed or if the front panel display was not set to halt on a test failure. This command allows test failure data to be retrieved even though it may have been accidentally or intentionally overwritten by other results on the front panel. If no test failure occurred, then the test group and number will be 0.0.

This command is also useful at the end of a program or multi-command line to guarantee that a result will be sent to a GPIB controller. It also forces a summary line to be sent in case the "reported results" parameter discussed below is set to one to disable the summary line.

Selection of Options: the TEST FORMAT command

You have a choice of several options in the way the TEST command is executed. These are:

- The TEST command can be set to halt on several different conditions. Generally, front panel operation requires that testing stop so that a test result on the front panel is not overwritten by later information. Since this is not usually an issue for results sent to a remote device, testing there should automatically resume after each test failure is reported.

- The TEST command can be set to report the results from all tests or just from those that failed. Usually, only failed tests are of interest, but sometimes it is useful to see how the test variables were set when a test passed. Knowing why one test passed can help understand why another test failed.

- The TEST command can be set so that it not only reports no results at all, but so that the bridge does not even make any readings with its A/D unless such measurements are critical for the test to be useful. By not making any readings, the number of data and strobe signals sent to the measurement circuitry per test cycle is greatly reduced. This is essential if an oscilloscope is to be able to easily show only the signals most relevant to a particular test. See "Making Measurements on a Specific Test State" on page 11-14.

These options may be selected with the command:
TEST FORMAT hoc.rpr

where hoc is the "halt on condition" parameter and rpr is the "reported results" parameter.

The hoc parameter can be set to the values below. The effects of each setting are listed.

0   Test execution does not stop until all tests are finished.

1   Execution of the tests will halt on every occurrence of an error report (test FAIL).

2   Execution of the tests will halt on every occurrence of any test result.

≥ 3   Halt after entered number of test failures has occurred. Any number from 3 to 999 may be entered.

Pressing [STEP] on the front panel causes tests to continue.

When tests are executed from a remote device and a "halt on condition" occurs, the normal ">" prompt is replaced with a "+" prompt. Either the STEP or X command can be issued in response to this prompt to cause the tests to continue.

The default value of the hoc parameter is stored in the BASIC 0 parameter file as a zero.

The rpr parameter can be set to the values below. The effects of each setting are listed.

0   No test results are measured or reported. The word 5[0PE is displayed in place of pfpf = vvv on the front panel. See "Observing Tests with an Oscilloscope" on page 11-14.

1   Only error results are sent to remote devices. All results, failed or not, are shown on the front panel.

2   Only error results and the test summary line are sent to remote devices. All test results, failed or not, are shown on the front panel.

3   All results, failed or not, are sent to remote devices and are shown on the front panel.

For *rpr*=1, the SHOW TEST command can be used at the end of a test or series of tests to force a summary line to be sent. This will guarantee that a message is sent to the GPIB. However, if an indefinite REPEAT has been specified and no test failure occurs, no message will ever be sent.

For *rpr*=2 or 3, the optional summary line is reported after each test cycle specified by the REPEAT count.

If tests are being executed from within a program, then summary lines are not shown on the front panel. The SHOW TEST command can be used at the end of a program to force the summary line to appear on the front panel.

The default value of the *rpr* parameter is stored in the BASIC 0 parameter set as a two.

Table 11-4 Test variable values showing functions and activated parts & pin numbers. (Column 1 of 5)

Variable value	Part-pin selected	Function
pfpf = PASS	N/A	"PASS" indicates that *vvv* was within the test window
pfpf = FAIL	N/A	"FAIL" indicates that *vvv* was outside the test window
$p = 0$	U603-13	ACG is set to the minimum
$p = 1$	U603-14	ACG is 10/3× the min.
$p = 2$	U603-15	ACG is 10× the min.
$p = 3$	U603-12	ACG is 100/3× the min.
$p = 4$	U603-1	ACG is 100× the min.
$p = 5$	U603-5	ACG is 1000/3× the min.
$p = 6$	U603-2	ACG is 1000× the min.
$p = 7$	U603-4	ACG is 10000/3× the min.
$p = 8$	U603 N/C	ACG is 10000× min.
$d = 0$	U412-13	Set DCG to 1×
$d = 1$	U412-14	Set DCG to 2×
$d = 2$	U412-15	Set DCG to 4×
$d = 3$	U412-12	Set DCG to 8×
$m = 0$	U410-13	Selects I channel from the phase sensitive detector
$m = 1$	U410-14	Selects Q channel from the phase sensitive detector
$m = 2$	U410-15	Selects PWRMON signal
$m = 3$	U410-12	Selects the OVRLD signal
$m = 4$	U410-1	Selects the DCONL signal
$m = 5$	U410-5	Selects the TEMP signal
$m = 6$	U410-2	Selects the M 0.1 R signal
$m = 7$	U410-4	Selects the OVEN signal
$a = 0$	K136	Sets ATN to 0.0 V

Table 11-4 Test variable values showing functions and activated parts & pin numbers. (Column 2 of 5)

Variable value	Part-pin selected	Function
$a = 1$	K135	Sets ATN to 0.001 V (*f*=F)
$a = 2$	K134	Sets ATN to 0.003 V (*f*=F)
$a = 3$	K133	Sets ATN to 0.01 V (*f*=F)
$a = 4$	K120	Sets ATN to 0.03 V (*f*=F)
$a = 5$	K119	Sets ATN to 0.1 V (*f*=F)
$a = 6$	K118	Sets ATN to 0.25 V (*f*=F)
$a = 7$	K117	Sets ATN to 0.75 V (*f*=F)
$a = 8$	K115	Sets ATN to 1.5V (*f*=F)
$a = 9$	K116	Sets ATN to 3.0V (*f*=F)
$a = A$	K114	Sets ATN to 7.5V (*f*=F)
$a = B$	K113	Sets ATN to 15 V (*f*=F)
$a = C$	none	Sets ATN to open
$t = 0$	U610	Test relay K601 is open and Q608 is not conducting
$t = 1$	U610-10	Test relay K601 is closed and Q608 is not conducting
$t = 2$	U610-2,10	Test relay K601 is closed and Q608 is conducting
$b = 0$	U610	Bias enable relay K602 and bias resistor selector K603 are open
$b = 1$	U610-7	Bias enable relay K602 is closed and bias resistor selector K603 is open
$b = 2$	U610-7,15	Bias enable relay K602 and bias resistor selector K603 are closed
$f = H$	U112	Sine generator set to Half
$f = F$	U112-15	Sine generator set to Full
$s = S$	U112-10	Q103 and Q106 conduct; Q102, Q104 and Q105 do not conduct; 180° phase shift
$s = P$	U112	Q102, Q104 and Q106 conduct; Q103 and Q105 do not conduct; 90° phase shift
$s = B$	U112-2,10	Q103 and Q105 conduct; Q102, Q104 and Q106 do not conduct; 0° phase shift
$r_1 = 0$	K131	Switch M0.0 to C210A
$r_1 = 1$	K130	Switch M0.1 to C210A
$r_1 = 2$	K129	Switch M0.2 to C210A
$r_1 = 3$	K128	Switch M0.3 to C210A
$r_1 = 4$	K127	Switch M0.4 to C210A

Variable value	Part-pin selected	Function
$r_1 = 5$	K126	Switch M0.5 to C210A
$r_1 = 6$	K125	Switch M0.6 to C210A
$r_1 = 7$	K124	Switch M0.7 to C210A
$r_1 = 8$	K123	Switch M0.8 to C210A
$r_1 = 9$	K122	Switch M0.9 to C210A
$r_1 = A$	K121	Switch M1.0 to C210A
$r_1 = C$	U145-14	No connection to C210A
$r_1 = F$	K132	Switch M-0.1 to C210A
$r_2 = 0$	K111	Switch M0.0 to C210B
$r_2 = 1$	K110	Switch M0.1 to C210B
$r_2 = 2$	K109	Switch M0.2 to C210B
$r_2 = 3$	K108	Switch M0.3 to C210B
$r_2 = 4$	K107	Switch M0.4 to C210B
$r_2 = 5$	K106	Switch M0.5 to C210B
$r_2 = 6$	K105	Switch M0.6 to C210B
$r_2 = 7$	K104	Switch M0.7 to C210B
$r_2 = 8$	K103	Switch M0.8 to C210B
$r_2 = 9$	K102	Switch M0.9 to C210B
$r_2 = A$	K101	Switch M1.0 to C210B
$r_2 = C$	U144-14	No connection to C210B
$r_2 = F$	K112	Switch M-0.1 to C210B
i_1 is even	U124-2	Switch IP 0.0 to U126 pin 3
i_1 is odd	U124-1	Switch IP 1.0 to U126 pin 3
$i_1 = 0$ or 1	U122-13	Switch IP 0.0 to U127 pin 3
$i_1 = 2$ or 3	U122-14	Switch IP 0.2 to U127 pin 3
$i_1 = 4$ or 5	U122-15	Switch IP 0.4 to U127 pin 3
$i_1 = 6$ or 7	U122-12	Switch IP 0.6 to U127 pin 3
$i_1 = 8$ or 9	U122-1	Switch IP 0.8 to U127 pin 3
$i_1 = A$ or B	U122-5	Switch IP 1.0 to U127 pin 3
$i_1 = E$ or F	U122-4	Switch IP-0.1 to U127 pin 3
i_2 is even	U124-5	Switch IP 0.0 to R167
i_2 is odd	U124-3	Switch IP 1.0 to R167
$i_2 = 0$ or 1	U121-13	Switch IP 0.0 to U125 pin 3
$i_2 = 2$ or 3	U121-14	Switch IP 0.2 to U125 pin 3
$i_2 = 4$ or 5	U121-15	Switch IP 0.4 to U125 pin 3
$i_2 = 6$ or 7	U121-12	Switch IP 0.6 to U125 pin 3
$i_2 = 8$ or 9	U121-1	Switch IP 0.8 to U125 pin 3
$i_2 = A$ or B	U121-5	Switch IP 1.0 to U125 pin 3
$i_2 = E$ or F	U121-4	Switch IP-0.1 to U125 pin 3

Variable value	Part-pin selected	Function
i_3 is even	U124-12	Switch IP 0.0 to R166
i_3 is odd	U124-13	Switch IP 1.0 to R166
$i_3 = 0$ or 1	U120-13	Switch IP 0.0 to R159
$i_3 = 2$ or 3	U120-14	Switch IP 0.2 to R159
$i_3 = 4$ or 5	U120-15	Switch IP 0.4 to R159
$i_3 = 6$ or 7	U120-12	Switch IP 0.6 to R159
$i_3 = 8$ or 9	U120-1	Switch IP 0.8 to R159
$i_3 = A$ or B	U120-5	Switch IP 1.0 to R159
$i_3 = E$ or F	U120-4	Switch IP-0.1 to R159
i_4 is even	U123-12	Switch IP 0.0 to R164
i_4 is odd	U123-13	Switch IP 1.0 to R164
$i_4 = 0$ or 1	U119-13	Switch IP 0.0 to R158
$i_4 = 2$ or 3	U119-14	Switch IP 0.2 to R158
$i_4 = 4$ or 5	U119-15	Switch IP 0.4 to R158
$i_4 = 6$ or 7	U119-12	Switch IP 0.6 to R158
$i_4 = 8$ or 9	U119-1	Switch IP 0.8 to R158
$i_4 = A$ or B	U119-5	Switch IP 1.0 to R158
$i_4 = E$ or F	U119-4	Switch IP-0.1 to R158
i_5 is even	U123-2	Switch IP 0.0 to R162
i_5 is odd	U123-1	Switch IP 1.0 to R162
$i_5 = 0$ or 1	U154-13	Switch IP 0.0 to R138
$i_5 = 2$ or 3	U154-14	Switch IP 0.2 to R138
$i_5 = 4$ or 5	U154-15	Switch IP 0.4 to R138
$i_5 = 6$ or 7	U154-12	Switch IP 0.6 to R138
$i_5 = 8$ or 9	U154-1	Switch IP 0.8 to R138
$i_5 = A$ or B	U154-5	Switch IP 1.0 to R138
$i_5 = E$ or F	U154-4	Switch IP-0.1 to R138
$i_6 = 0$	U123-5	Switch IP 0.0 to R161
$i_6 = 5$	U123-3	Switch IP 1.0 to R161
q_1 is even	U143-5	Switch Q 0.0 to U141 pin 3
q_1 is odd	U143-3	Switch Q 1.0 to U141 pin 3
$q_1 = 0$ or 1	U138-13	Switch Q 0.0 to U140 pin 3
$q_1 = 2$ or 3	U138-14	Switch Q 0.2 to U140 pin 3
$q_1 = 4$ or 5	U138-15	Switch Q 0.4 to U140 pin 3
$q_1 = 6$ or 7	U138-12	Switch Q 0.6 to U140 pin 3
$q_1 = 8$ or 9	U138-1	Switch Q 0.8 to U140 pin 3
$q_1 = A$ or B	U138-5	Switch Q 1.0 to U140 pin 3
$q_1 = E$ or F	U138-4	Switch Q-0.1 to U140 pin 3
q_2 is even	U143-12	Switch Q 0.0 to R183

Table 11-4 Test variable values showing functions and activated parts & pin numbers. (Column 5 of 5)

Variable value	Part-pin selected	Function
q_2 is odd	U143-13	Switch Q 1.0 to R183
$q_2 = 0$ or 1	U137-13	Switch Q 0.0 to U139 pin 3
$q_2 = 2$ or 3	U137-14	Switch Q 0.2 to U139 pin 3
$q_2 = 4$ or 5	U137-15	Switch Q 0.4 to U139 pin 3
$q_2 = 6$ or 7	U137-12	Switch Q 0.6 to U139 pin 3
$q_2 = 8$ or 9	U137-1	Switch Q 0.8 to U139 pin 3
$q_2 = A$ or B	U137-5	Switch Q 1.0 to U139 pin 3
$q_2 = E$ or F	U137-4	Switch Q-0.1 to U139 pin 3
q_3 is even	U143-2	Switch Q 0.0 to R182
q_3 is odd	U143-1	Switch Q 1.0 to R182
$q_3 = 0$ or 1	U136-13	Switch Q 0.0 to R177
$q_3 = 2$ or 3	U136-14	Switch Q 0.2 to R177
$q_3 = 4$ or 5	U136-15	Switch Q 0.4 to R177
$q_3 = 6$ or 7	U136-12	Switch Q 0.6 to R177
$q_3 = 8$ or 9	U136-1	Switch Q 0.8 to R177
$q_3 = A$ or B	U136-5	Switch Q 1.0 to R177
$q_3 = E$ or F	U136-4	Switch Q-0.1 to R177
q_4 is even	U142-2	Switch Q 0.0 to R181
q_4 is odd	U142-1	Switch Q 1.0 to R181
$q_4 = 0$ or 1	U135-13	Switch Q 0.0 to R176
$q_4 = 2$ or 3	U135-14	Switch Q 0.2 to R176
$q_4 = 4$ or 5	U135-15	Switch Q 0.4 to R176
$q_4 = 6$ or 7	U135-12	Switch Q 0.6 to R176
$q_4 = 8$ or 9	U135-1	Switch Q 0.8 to R176
$q_4 = A$ or B	U135-5	Switch Q 1.0 to R176
$q_4 = E$ or F	U135-4	Switch Q-0.1 to R176
q_5 is even	U142-12	Switch Q 0.0 to R180
q_5 is odd	U142-13	Switch Q 1.0 to R180
$q_5 = 0$ or 1	U155-13	Switch Q 0.0 to R139
$q_5 = 2$ or 3	U155-14	Switch Q 0.2 to R139
$q_5 = 4$ or 5	U155-15	Switch Q 0.4 to R139
$q_5 = 6$ or 7	U155-12	Switch Q 0.6 to R139
$q_5 = 8$ or 9	U155-1	Switch Q 0.8 to R139
$q_5 = A$ or B	U155-5	Switch Q 1.0 to R139
$q_5 = E$ or F	U155-4	Switch Q-0.1 to R139
$q_6 = 0$	U142-5	Switch Q 0.0 to R179
$q_6 = 5$	U142-3	Switch Q 1.0 to R179

THE INDIVIDUAL DIAGNOSTICS

This section describes the self-tests initiated by the TEST command. Included are what each individual diagnostic self-test does, what parts are tested and what parts are suspect when a test fails. This information is presented in a number of sections, each of which contains a table which covers a different major body of tests. In some cases, little more than is contained in each table is needed, but special setup and interpretation instructions are given where appropriate. The sections, tables, and test groups and numbers in the tables are presented in the order in which the tests are executed. All test group titles are listed in Table 11-6.

Effective use of these tests assumes that you have read "PRELIMINARY TROUBLESHOOTING" on page 11-2 and "DIAGNOSTIC TEST ESSENTIALS" on page 11-4 with special attention to Table 11-2 on page 11-3.

Information Common to all the Tests

Reference Numbers

Most of the test descriptions in the tables contain reference designators to specific parts in the AH 2500A. These reference numbers are identified on the parts lists and schematics in Appendix F, "Drawings and Parts Lists". The system used to assign the reference numbers is identified in Table 11-5.

Table 11-5 Identification of reference number series

Reference number series	Associated printed circuit board or assembly
1xx	Main PC board except for oven circuit
2xx	Capacitance standard assembly and oven circuit on main board
3xx	Processor PC board
4xx	Multiplexer PC board
5xx	Front panel PC boards
6xx	Preamp PC board
7xx	Power supply PC board and transformer
9xx	Chassis and related parts

Ordering of the Tests

The order in which the tests have been designed to execute is important because the conclusions drawn about a test are based on the assumption that all previous tests *probably* passed. In practice, this means that the first test to fail (i.e. the one having the lowest number) is the one most likely to indicate the source of a failure. All subsequent test failures may merely be indirect consequences of the first test failure. Parts and/or signals listed as being suspect on FAIL assume that all previous tests have passed. Otherwise, parts listed previously are also suspect.

Table 11-6 Test groups executed by the TEST command, showing those requiring intervention or observation. (Column 1 of 2)

Test group	Test group title	Intr/ obs	Assemblies tested
1	Test processor board circuits	I	A301
2	Test front panel display LED segments	O	A501, A301
10	Test ability of some TDx lines to transmit data		A301, A401, A101
11	Test power monitor (PWRMON) and power supply quality		A401, A701, A301
12	Test all DCG settings and value of OVEN monitor line		A401, A101, C210
13	Test bridge temperature (TEMP) value		A401, A101
20	Test DC BIAS circuit series resistance	I	A601
21	Test that preamp can handle high DC bias voltages	I	A601
22	Test operation of calibration & test relay (K601)	I	A601
23	Test ability to operate upper half of bridge		A401, A101, A601
24	Isolate excess noise	I	A401, A101, A601
25	Test preamp shunt		A601
26	Test DC on LOW input detector (DCONL)		A401, A601
30	Test that level detection latches (LEVA & LEVB) will latch in clear state		A401
31	Test that level detection latches (LEVA & LEVB) will set and stay set		A401
32	Test for noise quality		A401, A601
33	Test phase sensitive detector		A401
34	Test A/D for missing codes		A401, A301
40	Test ability to set sine generator to full/half and test waveform symmetry		A401, A101
41	Test main ratio transformer overload (OVRLD) detector	I	A401, A101
50	Test LOW ACG against IDAC		A601, A101
51	Test HIGH ACG against IDAC		A601, A101
52	Test LOW ACG against QDAC		A601, A101
53	Test HIGH ACG against QDAC		A601, A101
60	Test that each switch element in MSD of IDAC can cause a change		A101
61	Test that each switch element in second MSD of IDAC can cause a change		A101
62	Test that each switch element in third MSD of IDAC can cause a change		A101
63	Test that each switch element in fourth MSD of IDAC can cause a change		A101
64	Test that each switch element in fifth MSD of IDAC can cause a change		A101
65	Test that each switch element in MSD of QDAC can cause a change		A101
66	Test that each switch element in second MSD of QDAC can cause a change		A101
67	Test that each switch element in third MSD of QDAC can cause a change		A101
68	Test that each switch element in fourth MSD of QDAC can cause a change		A101
69	Test that each switch element in fifth MSD of QDAC can cause a change		A101
70	Test gain ratios of MSD of IDAC		A101
71	Test gain ratios of second MSD of IDAC		A101
72	Test gain ratios of third MSD of IDAC		A101
73	Test gain ratios of fourth MSD of IDAC		A101
74	Test gain ratios of fifth MSD of IDAC		A101

Test group	Test group title	Intr/ obs	Assemblies tested
75	Test gain ratios of MSD of QDAC		A101
76	Test gain ratios of second MSD of QDAC		A101
77	Test gain ratios of third MSD of QDAC		A101
78	Test gain ratios of fourth MSD of QDAC		A101
79	Test gain ratios of fifth MSD of QDAC		A101
80	Test magnitude of S/P/B quadrature generator settings		A101
81	Test phase of S/P/B quadrature generator settings		A101
82	Test MSRD for a stuck closed relay		A101
83	Test second MSRD for a stuck closed relay		A101
84	Test MSRD for any change between open and selected states		A101
85	Test second MSRD for any change between open and selected states		A101
86	Test relative signal levels from MSRD		A101
87	Test relative signal levels from second MSRD		A101
90	Test ATN for presence of any stuck closed relays		A101
91	Test ATN for stuck closed relays and set up for meter measurement	I	A101
92	Test ATN for a stuck open or closed relay	I	A101
93	Test ATN setup for voltage ratios tests	I	A101
94	Test ATN for correct voltage ratios	I	A101

Test Descriptions

The test descriptions given for the tests in the following tables are necessarily brief. They contain enough information to identify what each test does, but not enough to fully define the test. More information is contained in the test results which show the test setup when the test completed. Note that the descriptions in the tables describe what the *bridge* will do, not what the *operator* is to do.

Most tests except for those in "Processor and front panel tests" on page 11-13 *end* by having the A/D make a reading. Since this usually happens, the *last* A/D reading of a test is not explicitly described. However, a number of tests take *two* A/D readings. In this case, the first reading is described and the second is implied. The internal test setup for the second reading is assumed to be the same as that for the first unless described otherwise.

Most tests read the I *and* Q MUX channels. For these tests, the MUX test variable is reported in the test results as zero (I) if the I channel reading was the larger of I and Q. Otherwise MUX is reported as one (Q). This is true even if *vvv* contains a derived value rather than a direct reading of the I or Q channels.

Tests that Require Operator Intervention

Most of the self-tests can be performed without operator intervention and so can be run individually or in groups for long periods of time, if desired. Tests that require operator intervention or observation are labeled with an I or an O respectively in Table 11-6. Tests requiring intervention will display a request on the front panel and send it to the remote devices. After the request has been satisfied, pressing the STEP key on the front panel will cause tests to continue. The STEP or X command on GPIB devices and the STEP command or the X key on RS-232 devices will have the same effect.

The prompt that is sent or displayed usually requires that just one action be performed before the STEP key is pressed to continue. In some cases, more than one action is required. In these cases, the prompt will indicate only the *last* action that is to be performed. It is up to the operator to be aware of tests that require more than one action. An example is the "DC BIAS Resistor Tests" on page 11-16. Both of these tests require that an external shunt be connected, an external DC voltage be applied, and finally that a meter reading be taken. The prompt rEAd ULt For r643 is asking only for the last action, but all three actions must be completed before the STEP key is pressed to continue the tests.

Table 11-7 Processor and front panel tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
1	***Test processor board circuits***		
1.1	Prompt with "ARE YOU SURE?", write then read and compare the 6551 UART registers. On error, show: $UArt\ Error$	U329	U301-304, U307, U308, U314, U315, U322, U329, etc.
1.2	Prompt with "ARE YOU SURE?", compare frequencies of system vs. UART clocks. On error, show: $FrE9\ rto\ Error$	Y301, Y302	U301, U329, Y301, Y302
1.4	Prompt with "ARE YOU SURE?", write then read and compare the U326 command and status registers. On error, show: $6522\ Err\ U326$	U326	U322, U326, U332
1.5	Prompt with "ARE YOU SURE?", write then read and compare the U310 command and status registers. On error, show: $6522\ Err\ U310$	U310	U310, U322, U332
1.6	Prompt with "ARE YOU SURE?", verify the checksum of the U305 EPROM. On error, show: $CHECSUN\ Err\ U305$	U305	U305, U303
1.7	Prompt with "ARE YOU SURE?", verify the checksum of the U306 EPROM. On error, show: $CHECSUN\ Err\ U306$	U306	U306, U303
1.8	Prompt with "ARE YOU SURE?", verify the checksum of the U307 EPROM. On error, show: $CHECSUN\ Err\ U307$	U307	U307, U303
1.9	Prompt with "ARE YOU SURE?", write then read all but the lowest addresses of the RAM. On error, show: $HI\ rAN\ Error$	U308 data	U308
1.10	Prompt with "ARE YOU SURE?", verify that each RAM address is unique. On error, show: $dUAL\ Adr\ Error$	U308 address	U308
1.11	Prompt with "ARE YOU SURE?", verify all checksummed blocks and complemented bytes in EEPROM. On error, show: $EEPrON\ Error\ HH$ where "HH" represents the failing block number in hexadecimal. See Table 11-19 on page 11-42 for more information about the failing block number.	U304	U304, U303, U315
1.12	Prompt with "ARE YOU SURE?", verify that unenabled writes to the EEPROM do not cause data to change. On error, show: $EEPrON\ SAFE\ Err$	p/o U330, U331	U330, U331, U319
1.13	Prompt with "ARE YOU SURE?", write then read and compare the GPIB command and status registers. On error, show: $GPIb\ Error$	U323	U323, U322
1.14	Prompt with "ARE YOU SURE?", test ability of U326 to generate interrupts. On error, show: $IntEruPt\ Error$	U326	U326, U302
2	***Test front panel display LED segments***		
2.1	Illuminate each segment in front panel display one-by-one. Watch to see that one and only one illuminates.	Display board (A501) No error message given	A501, U316, U317

Making Measurements on a Specific Test State

When each test is finished executing, it leaves the bridge in the final configuration for that test. This is the configuration shown in the test result line. This allows meter or logic probe measurements to be made on the bridge as it was configured for the last test of a series.

Observing Tests with an Oscilloscope

Any test may be configured to repeat continuously using the REPEAT option of the TEST command. This causes repetitive signals to be generated in the circuitry that a given test is exercising. A triggered oscilloscope can examine these signals by triggering each time the test starts over. A trigger signal is provided for this purpose on pin nine of U420. This point is identified in Figure 11-3 on page 11-40.

The quality of the scope loop signal may be enhanced by issuing the T E F0 . 0 command described in "Selection of Options: the TEST FORMAT command" on page 11-7. This will run the tests at maximum speed and will minimize the other strobe and data signals that would otherwise appear on the oscilloscope.

Processor and Front Panel Tests

Processor Tests

The processor tests are the most basic of all the tests because if these do not pass, it may not even be possible to run any other tests. It is this group of tests that is executed immediately after the AH 2500A powers on. Test group 1 in Table 11-7 on page 11-13 describes these tests.

If these tests are initiated by the TEST command the prompt Ar E You Sur E will appear on the front panel. You must press the YES key (1) if you want the tests to be executed. This question is asked because everything stored in RAM will be initialized when these tests are run. GPIB and RS-232 communications will also be initialized. Due to the special nature of these tests, they are only reported to the front panel. If the processor tests pass, the message CPU tESt PASSEd appears on the front panel display when all the tests are finished. The display will be blank until then but the column of LED indicators to the right will be active. If any tests fail, the first test to fail will report an error message to the front panel. These messages and their meanings are all listed in Table 11-7 on page 11-13. The format of these error messages is totally different from all others generated by the TEST command.

Front Panel Tests

Test 2.1 can be run if the front panel display appears to have a problem. This test will illuminate each LED in the column to the right of the numeric displays and also each segment of every LED digit. This test does not report any errors and therefore has no value unless its effects are carefully observed by watching the front panel.

The test tries to illuminate one and only one LED at a time. The display should be watched carefully for cases where more than one LED becomes lit. If this occurs, some kind of short or addressing problem is to be suspected. If a single LED segment does not light when it should, the failure is in that segment or the connection to it. If groups of LED's fail to light, then the failure is in the driver circuits.

MUX and A/D Tests

These are the very first tests performed on any of the measurement circuitry. The measurement circuitry is considered to consist of the MUX board (A401), the main board (A101), the preamp board (A601) and the capacitance standard assembly (C210).

First Attempt to Use any Measurement Data and Strobe Lines.

The first tests will use data (TDx) and strobe lines (Sxx) that have not been previously tested so these tests must be as simple as possible. Test group 10 changes some MUX and DCG settings, exercising /S57, TD0, TD1, TD2, TD6 and TD7 in the process. The test passes if the A/D can see any change. The A/D need not work very well for these tests to pass, but it must be able to take a reading.

NOTE

Tests 10.5 and 10.6 can not be expected to pass until the oven has reached its normal operating temperature.

First Attempt to Use MUX, DCG and A/D to get an Accurate Number.

Test group 11 uses the A/D to read the PWRMON signal. This signal is a combination of the +5, +12, -12 power supply voltages. Since you have already checked these voltages using the instructions in "Checking Power Supply Voltages" on page 11-4, test 11.1 is the first attempt to use the MUX, DCG and A/D to get an accurate reading of a DC voltage level.

Test 11.2 simply doubles the DCG relative to the last test to build confidence that the A/D and DCG are working.

Power Supply Quality Tests

The last test of group 11 takes a hard look at the PWRMON signal for the presence of ripple. This is the first time the A/D is required to make many measurements in a single test.

If these tests pass, it means that either the power supplies are working well or that the A/D is not working well enough to see smaller changes.

Table 11-8 First MUX and A/D tests (A401)

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
10	*Test ability of some TDx lines to transmit data*		
10.1	Leave U410 MUX inputs A, B & C clear; Read I	U416 A/D sees less than half of F.S.	Preamp, MUX boards
10.2	Set U410 MUX input B	U416 A/D sees a change	TD0, U311, U410, U411, U413, U416
10.3	Set U410 MUX input A & B	U416 A/D sees a change	TD1, U311, U410, U411, U413, U416
10.4	Set U410 MUX input A & B & C	U416 A/D sees a change	TD2, U311, U410, U411, U413, U416
10.5	Select OVEN with U410 MUX, set U412 DCG switch input A. This changes DC gain from 1 to 2	U416 A/D sees a change	TD6, U311, U410, U411, U413, U416
10.6	Select OVEN with U410 MUX, set U412 DCG switch input B. This changes DC gain from 1 to 4	U416 A/D sees a change	TD7, U311, U410, U411, U413, U416
11	*Test power monitor (PWRMON) and power supply quality*		
11.1	Set U410 MUX to PWRMON input, DCG=1	+5, +12, -12 P. S., A/D gets 1st accurate number	U410-416
11.2	Set U410 MUX to PWRMON input, DCG=2	U416 input overloads	U411, U412, U414
11.3	Set U410 to PWRMON input, DCG=1	Power ripple acceptable	Power supply, U416
12	*Test all DCG settings and value of OVEN monitor line*		
12.1	Select OVEN, Compare DCG=1 against DCG=2	Relative DCG 1/2	U410-416
12.2	Select OVEN, Compare DCG=2 against DCG=4	Relative DCG 2/4	U410-416
12.3	Select OVEN, Compare DCG=4 against DCG=8	Relative DCG 4/8	U410-416
12.4	Select OVEN with U410 MUX, Set DCG=1	DCG=1, A/D value	U410-416, OVEN
12.5	Select OVEN with U410 MUX, Set DCG=2	DCG=2, A/D value	U410-416, OVEN
12.6	Select OVEN with U410 MUX, Set DCG=4	DCG=4, A/D value	U410-416, OVEN
12.7	Select OVEN with U410 MUX, Set DCG=8	DCG=8, A/D value	U410-416, OVEN
13	*Test bridge temperature (TEMP) value*		
13.1	Select TEMP with U410 MUX	TEMP in range	RT101, R131, U410, U129, U130

Complete DCG vs. A/D Tests Using OVEN Line

Test group 12 checks all of the DCG (DC Gain) settings using the A/D. The first three tests compare the ratios of adjacent DCG settings using the A/D to make the measurements. Each test requires that the A/D be working well enough to take two measurements whose ratio is 1/2. Because these are ratio measurements, the OVEN signal voltage is not important but it must produce values within the A/D's range.

NOTE

Test group 12 can not be expected to pass until the oven has reached its normal operating temperature.

The last group of four tests measures the OVEN line at the four different DCG settings. These tests assume that the OVEN line voltage is accurately known since they try to make four different, accurate readings of the OVEN line with the A/D. Since these are effectively comparisons of the A/D against the DCG, a failure could be from either of these or from an inaccurate OVEN value. The next section explains how to directly measure the value of the OVEN voltage.

Manual Oven Circuit Tests

The OVEN voltage should be -0.537 V ±5%. This can be measured at the negative end of C201 on the main board as shown in Figure 11-4 at the end of this chapter. If this voltage is out of tolerance, either the oven assembly (C210) is bad or the related circuitry on A101 is defective. If the oven controller is functioning, the OVEN voltage will be identical (after

warm-up) with the R201/R202 reference voltage on pin 6 of J114 shown in the same figure. If the oven controller is functioning, the voltage driving Q201 will be 2 to 7V more positive than the –24V power supply (after oven warm-up). This can be measured on pin 3 of J114 shown in the figure. If the oven controller is suspected of having dynamic control problems, the signal to look at is pin 6 of U202 which is shown in the figure. If there are any signals here which are changing at a rate faster than 1 Hz, then the controller has a problem.

Measure the TEMP Line

Test group 13 simply measures the TEMP line and verifies that the voltage that indicates the temperature of the bridge is within a very wide window. This is another test to verify that the MUX will switch to the desired input.

Preamp Tests

The preamp tests differ from the tests in other test sections because the preamp tests require many external setups. Furthermore, each external setup is different from all the other preamp setups.

WARNING !

The voltages used in these tests present a shock hazard. The voltage to which you set your DC power supply will also be present at several points inside the bridge as shown in Figure 11-4 at the end of this chapter.

CAUTION

The voltages used in this test can cause serious damage to your bridge if improperly applied. Make sure that these voltages are only applied to the DC BIAS input connector. As an added precaution, you can set the current-limit on the power supply as low as possible while still maintaining the required test voltage.

NOTE

Removal and replacement of the preamp cover and disassembly and reassembly of the preamp must be done according to the procedures in Chapter 12, "Disassembly/Reassembly" with special attention to "HIGH and LOW Cable (W902 and W901) Removal and Installation" on page 12-11.
Subtle performance degradation may occur otherwise.

DC BIAS Resistor Tests

The value of the series bias resistors (R643 and R644) can be directly measured externally with an ohmmeter. The value of these resistors is 1 and 100 megohms, respectively. The ohmmeter used must be able to measure resistance at least as high as the higher value expected to be found. Unfortunately, ohmmeters that can read this high are not found in many labs, so a different way of measuring the resistors will be described here.

The following measurement procedure is required when the AH 2500A displays each prompt that results from running test group 20:

1. Wait for the prompt for the test to appear (RERD ULT FOR R643 or R644>).

2. Shunt the LOW terminal to ground with 10 kΩ. Use a BNC to banana-jack adapter with a 10 kΩ resistor between the posts. WARNING! If the resistor fails to make connection, one banana post will have the full voltage that is applied to the DC BIAS input

3. Use a power supply to connect a 100V level between the DC BIAS input and ground.

4. Read the voltage across the 10 kΩ resistor.

5. Remove the DC bias and the 10 kΩ shunt.

6. Press the $\boxed{\text{STEP}}$ key to continue execution of the tests.

The 10 kΩ resistor and R643 or R644 form a voltage divider which divides the applied 100 volts to the level read by the meter. If R644 is 100 megohm, the voltage will be divided by 10000 and test 20.1 passes if the meter reads between about 0.008 and 0.0012 volts. If R643 is 1 megohm, the voltage will be divided by about 100 and test 20.2 passes if the meter reads between about 0.9 and 1.1 volts.

Measuring these resistors can be useful not only for checking the proper functioning of the preamp circuitry, but also to see if either series resistor has been changed by someone and if so, to what value. See "Optimizing the Series Resistance" on page 4-14 for more information.

If the value of R643 or R644 are not correct or not what is desired, the original resistors may be shunted or replaced with other values. These resistors may be located by reference to the preamp assembly drawing in Figure F-27 on page F-72. Next to each resistor is a pair of forked solder terminals. Any resistor soldered to these terminal pairs will parallel the corresponding original resistor. You may add or replace these resistors with any value of your choice providing that it is not less than 10kΩ. An original resistor can be replaced by clipping its leads to remove it. Its replacement would then be soldered into the adjacent forked terminals.

Table 11-9 Preamp tests (A601)

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
20	**Test DC BIAS circuit series resistance**		
20.1	Select high impedance bias with K602 on, K603 off, prompt with message: r E A d U L t F o r r 6 4 4. Operator then applies 100 V to the DC BIAS input, shunts the LOW terminal with 10 kΩ to ground and reads the voltage there.	K602 closes, K603 open, high impedance BIAS connection is made, R644	C619, U610, K602, K603, R644
20.2	Select low impedance bias with K602 on, K603 on, prompt with message: r E A d U L t F o r r 6 4 3. Operator then applies 100 V to the DC BIAS input, shunts the LOW terminal with 10 kΩ to ground and reads the voltage there.	K602, K603 both close, low impedance BIAS connection is made, R643	C619, U610, K602, K603, R643
21	**Test that preamp can handle high DC bias voltages**		
21.1	Prompt for connection of 100 volts to DC BIAS input with message: r E A d L o 1 0 0 U. Operator tests for 100 volts on LOW input. Wait for [STEP] key to be pressed after connection. Prompt to disconnect setup with d I 5 C o n n 5 E t U P. See WARNING! and Caution statements in text.	DCONL not detected, C619 blocks DC voltage	C619, U610, K601, K602, K603
21.2	Prompt for connection of 250 volts to DC BIAS input with message: C o n n d C t o b I A 5. Operator tests for no more than 180 volts on LOW terminal. Wait for [STEP] key to be pressed after connection. Prompt for disconnection of setup with d I 5 C o n n 5 E t U P. See WARNING! and Caution statements in text.	E601 limits voltage	C619, U610, K602, K603
22	**Test operation of calibration & test relay (K601)**		
22.1	Prompt for connection of 100 volts to DC BIAS input with message: r E A d L o c 0 0 1 5 U. Operator tests LOW terminal for less than 0.015 volts.	DS602 is good, K601 closes.	DS602, K601, Q607, U610

DC BIAS High Voltage Tests

If the AH 2500A is working correctly, it should be possible to apply DC bias voltages to the DC BIAS input with no observable effect on the measurement circuitry.

The following procedure is used to run test 21.1:

1. Wait for the prompt r E A d   L o   1 0 0 U to appear.

2. Connect a voltmeter between the LOW input terminal and ground. A BNC to banana-jack adapter might be helpful here. The input impedance of the meter must be known and must be at least 10 megohms.

3. Use a power supply to connect a 100 V level between the DC BIAS input and ground. WARNING! 100 V should also be present on whatever you have connected to the LOW terminal.

4. Read the voltage on the meter.

5. Press the [STEP] key to cause the test routine to complete the test by checking the DCONL signal.

6. When the d I   5 C o n n   5 E t U P prompt appears, disconnect the meter and power supply from the bridge.

7. Press the [STEP] key to report the test result or to continue execution of tests.

You should have measured exactly the same voltage on the LOW terminal as you connected to the DC BIAS connector if your meter has an infinite input impedance. If your meter has a 10 megohm input impedance, you should have measured a voltage that is about 91% of that which you connected to the DC BIAS connector. The test routine checks the DCONL line to ensure that the applied DC voltage is totally blocked by C619 from entering the high gain amplifier.

Test 21.2 is similar to the previous test except that the voltage applied to the DC BIAS connector is higher. This test checks that it is possible to moderately exceed the upper limit on the DC bias voltage specification without causing damage to the bridge.

WARNING !

The voltages used in these tests present a shock hazard. The voltage to which you set your DC power supply will also be present at several points inside the bridge as shown in Figure 11-4 at the end of this chapter.

The following procedure is used to run test 21.2:

1. Wait for the prompt `Conn dC to bIAS` to appear.

2. Connect a voltmeter between the LOW input terminal and ground. A BNC to banana jack adapter might be helpful here. The input impedance of the meter must be known and must be at least 10 megohms.

3. Connect a variable, metered, 250 volt lab power supply between the DC BIAS input and ground. WARNING! The voltage applied by this supply will also be present on whatever you have connected to the LOW terminal.

4. Slowly increase the voltage of the power supply while watching its voltmeter and the one you have connected to the LOW input terminal. Somewhere in the range of 100 to 180 volts, your voltmeter should suddenly drop in value and then remain constant while you continue to increase the voltage of your lab supply. Note the voltage on your meter just before the sudden drop occurred.

NOTE

As you increase the voltage, the overvoltage protector (E601) should discharge. This drops the voltage significantly in an extremely short time and generates a large transient. This transient will sometimes cause the latches controlling the preamp relays (K601, K602 and K603) to change state. Anomalous behavior resulting from this is considered acceptable since the transient itself is an abnormal condition.

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5. Press the STEP key to cause the test routine to complete the test.

6. When the `dISConn SEtUP` prompt appears, disconnect the meter and power supply from the bridge.

7. Press the STEP key to continue execution of tests. The bridge always reports a PASS for this test since it makes no measurements.

The voltage read on the LOW terminal in step four of the procedure must not exceed 180 volts. This voltage should be lower than that applied by the power supply because the overvoltage protector (E601) should limit the voltage. It is extremely important that this protector work correctly since it protects the capacitance standard (C210) from excessive voltages and static discharges.

CAUTION

The voltages used in this test can cause serious damage to your bridge if improperly applied. Make sure that these voltages are only applied to the DC BIAS input connector. As an added precaution, you can set the current-limit on the power supply as low as possible while still maintaining the required test voltage.

Calibration and Test Relay

The calibration and test relay (K601) must close if many of the remaining self-tests are to pass. This relay disconnects the LOW input terminal from the bridge circuitry and allows a shunt (R637) to be placed across the preamp input. When this relay closes, any charge that exists on an externally connected capacitor is discharged into DS602.

The following procedure is used to run test 22.1:

1. Wait for the prompt `rEAd Lo c0.015U` to appear.

2. Connect a voltmeter between the LOW input terminal and ground. A BNC to banana-jack adapter might be helpful here.

3. Use a power supply to connect a 100V level between the DC BIAS input and ground.

4. Verify that the meter reads less than 0.015 volts.

5. Disconnect the meter and power supply from the bridge.

6. Press the STEP key to continue execution of tests.

If the voltage in step four was correct, DS602 is good and K601 closed. No PASS/FAIL result is reported by the bridge for this test.

First Tests of Upper Half of Bridge

At this point, as many tests of relatively simple circuits have been done as possible and it is time to make the first test of the bridge as a whole, minus the attenuator (ATN) circuits. The upper half of the bridge is shown as legs one and three in Figure 4-1 on page 4-1. Test group 23 requires no intervention.

Zero Test

Test 23.1 appears to be simple because it merely requires a roughly zero result. However, this is the first test to use the RD's and DAC to drive a signal through the capacitance standard (C210), into the preamp and through the phase-sensitive detector to the I and Q channels of the MUX. Even though the driving signal is intended to be zero, any failure of one of the large number of components in the RD's and DAC could cause this assumption to be false. The preamp must also be sufficiently quiet (low noise) for the test to pass.

Since so many parts are involved for the first time in test 23.1, it is impractical to suggest where to look for the cause of a failure without performing more tests. A very useful manual test that should be performed only if test 23.1 fails, is to run test 24.1 with the LOW terminal input shorted to ground. The resistance of this short is not critical, but must not contain loops that might pick up noise. A zero-ohm terminator is perfect for the job.

Table 11-10 First system tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
23	*Test ability to operate upper half of bridge*		
23.1	With DAC and RD's at zero, read max of I & Q channels with U410 MUX, ACG=0.	If preamp and detector have gain then DAC and RD's can produce zero	See manual test described in text
23.2	Set 2nd MSRD to 0.1, MSD of IDAC and QDAC to 1.0, ACG=0, read max of I & Q channels with U410 MUX	A/D sees maximum signal	U401, U402, DAC, Preamp board
24	*Isolate excess noise*		
24.1	Prompt to short LOW input to ground with message: �5hort Lo to Gnd. With DAC and RD's at zero, read max of I & Q channels with U410 MUX, ACG=0. K601 connects preamp to LOW input.	Preamp and detector are not noisy. (Preamp cover must be on)	A401, A601. FAIL on last test & PASS here => A101
25	*Test preamp shunt*		
25.1	Set 2nd MSRD to 0.1, MSD of IDAC and QDAC to 1.0, ACG=0, read max of I & Q; then enable Q608 shunt	R637 shunt kills preamp gain by expected ratio	U610, Q608, Q609, K601 contacts
26	*Test DC on LOW input detector (DCONL)*		
26.1	With DAC and RD's at zero, shunt enabled, ACG=0, read DCONL with A/D	DCONL is near zero, K601 is energized, R615 is set correctly	U601, K601, K602, DS601, related preamp parts, U410
26.2	Set 2nd MSRD to 0.1, MSD of IDAC and QDAC to 1.0, ACG=0, shunt disabled, scan DCONL with A/D to measure peak-to-peak value	DCONL circuit passes a signal of expected size; K602 not energized	U601, K601, K602, DS601, related preamp parts, U410

TEST 24.1 REPEAT should be run with this short in place. If the test continues to fail, the preamp is too noisy or is picking up a stray signal or the phase-sensitive detector is generating a signal that isn't supposed to be there. At this point, an oscilloscope might be helpful for tracing the source of the extraneous signal.

If the test passes with the short in place, the DAC or RD's are not able to set up a zero value. This kind of failure will probably be narrowly isolated by later self-tests.

Non-zero Test

Test 23.2 is the first test to use the RD's and DAC to select a non-zero signal from the main ratio transformer and send it through the capacitance standard (C210), into the preamp and through the phase-sensitive detector to the I and Q channels of the MUX. The number of components that could cause this test to fail is even larger than in the previous test. Now the main ratio transformer must be energized with a sinewave signal and all the circuitry of the previous test must be able to pass a signal. (The previous test will pass if any of its circuits are dead.)

If this test fails, most subsequent tests will fail also, but the generator tests of test group 40 will be meaningful. They will demonstrate whether the main ratio transformer is energized or not.

If the main ratio transformer is energized, it is unlikely that the signal is not reaching the preamp. The reason is that both the DAC and RD's are selecting signals from the main ratio transformer. This provides three independent paths to the preamp. Thus, if the transformer is energized and the test is failing, the problem is likely to be in the preamp or in the phase-sensitive detector on the MUX board. This is an excellent opportunity to use an oscilloscope to trace the problem. The signal levels fed to the preamp are large enough to be visible on a scope throughout the entire signal path. The output signal from the preamp (PAMPOUT) is measurable on the MUX board at the point shown in Figure 11-3 at the end of this chapter. This signal should be a 1 kHz square wave with a peak-to-peak amplitude of 22 volts ±15%. If this signal is non-existent, then the problem must be in the preamp. Otherwise, the problem is on the MUX board.

Preamp Shunt Test

In order to perform the RD, ATN and some other tests, the gain of the preamp must be reduced below its normal minimum. This is accomplished by shunting the preamp input to ground with a resistor (R637) using Q608 as the switch. Test 25.1 checks that this shunt is able to reduce the preamp gain by a sufficient amount. If this test fails, the shunt circuit is the problem.

Table 11-11 Level detector tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
30	**Test that level detection latches (LEVA & LEVB) will latch in clear state**		
30.1	Leave DAC and RD's at 0, ACG=0 Assert, then unassert /CLR1 on mux board.	LEVA stays latched in clear state	U401, U402, Preamp board
30.2	Leave DAC and RD's at 0, ACG=0 Assert, then unassert /CLR1 on mux board.	LEVB stays latched in clear state	U401, U402, Preamp board
31	**Test that level detection latches (LEVA & LEVB) will set and stay set**		
31.1	Set 2nd MSRD to 0.1, MSD of IDAC and QDAC to 1.0, ACG=0, then clear MSRD, IDAC and QDAC	LEVA stays latched in set state	U401, U402, DAC, Preamp board
31.2	Set 2nd MSRD to 0.1, MSD of IDAC and QDAC to 1.0, ACG=0, then clear MSRD, IDAC and QDAC	LEVB stays latched in set state	U401, U402, DAC, Preamp board

DC on LOW Input Detector Tests

Test group 26 checks that the DCONL signal detects positive and negative DC voltages on the LOW input and that DCONL does not detect any DC when none is present. This is done by applying a large AC signal to the preamp input and then verifying that the DCONL signal detects it.

NOTE

Removal and replacement of the preamp cover and disassembly and reassembly of the preamp must be done according to the procedures in Chapter 12, "Disassembly/Reassembly" with special attention to "HIGH and LOW Cable (W902 and W901) Removal and Installation" on page 12-11. Subtle performance degradation may occur otherwise.

A marginal failure of test 26.1 indicates that trimpot R615 may need to be adjusted. This is done by issuing the command TEST 2 6 • 1 REPEAT ENTER. The → key can then be used to make the front panel show the second window in the test result which contains the DCONL value as read by the A/D. The trimpot may then be adjusted while watching the DCONL value in the upper display. The allowable window values for DCONL are shown in the third window of the test result. If the DCONL value cannot be brought within the acceptable window of values, then a hardware failure has occurred.

MUX Board Tests Requiring a Good Preamp

Tests of Level Detection Latches

Test group 30 tests the ability to latch and hold the two level detection latches in the clear state. A failure here could be a result of an inability to stay latched in the clear state or from a false signal detection. If test 23.1 passed, the preamp should not be producing enough signal to set the level detectors.

Test group 31 does essentially the opposite of the previous test. This group checks the ability of these latches to set and then to stay set. If test 23.2 passed, the preamp should be producing enough signal to set the level detectors and any failure should, therefore, be in the level detector or latches themselves.

Tests Using Noise

The tests described in Table 11-12 all require some fairly random noise. The source of this noise is intended to be predominantly Johnson noise from the input stage of the preamp. These tests configure the bridge to feed zero signal to the preamp input and to set the preamp gain high enough to see a significant amount of noise from the input stage.

Noise Quality Tests

Test group 32 verifies that the preamp can generate noise. This is the first test that requires the preamp to have a very high gain. If good (random, white) noise is being generated, the signals from the I and Q channels of the phase-sensitive detector will have a DC level that is small compared with the peak voltage. The test fails if this is not true. (A constant sinewave will have an almost pure DC output.)

If no tests have previously failed, a failure of this test indicates that the preamp probably doesn't have enough gain to generate the required noise level. An oscilloscope can show whether the preamp output (PAMPOUT) has sufficient noise. The noise should be in the range of 1 to 5 volts peak-to-peak. This test point is identified as PAMPOUT in Figure 11-3 at the end of this chapter. If the noise is not as high as it should be, then the problem is in the preamp.

Table 11-12 Tests using noise

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
32	*Test for noise quality*		
32.1	Select I channel with U410, set ACG to 8, enable shunt	Average level of noise is small relative to peak	U403-409, Preamp board
32.2	Select Q channel with U410, set ACG to 8, enable shunt	Average level of noise is small relative to peak	U403-409, Preamp board
33	*Test phase sensitive detector*		
33.1	Select and read I channel with U410, set ACG to 8, enable shunt; then select and read Q channel	I vs. Q amplitudes are roughly equal	U404, U405, U406, U407, U410
33.2	Select and read Q channel with U410, set ACG to 8, enable shunt; then select and read I channel	Q vs. I amplitudes are roughly equal	U404, U405, U406, U407, U410
34	*Test A/D for missing codes*		
34.1	Set ACG=8, DCG=8, so A/D reads noise at 100+% of FS from I channel, then take many readings	A/D has no missing codes	U404, U405, U406, U407, U410

Phase-Sensitive Detector Test

Assuming that the noise generated by the preamp is truly random, it will not be synchronized with the bridge's one kilohertz test signal. This means that the amount of noise detected by the I and Q channels of the phase-sensitive detector should be equal. Test group 33 tests for this situation. The two tests in this group are identical except that the first exits with the I channel selected by the MUX and the second exits with the Q channel selected.

A failure of this test may indicate that phase-sensitive detector is not working correctly, but it might also indicate that the noise used as a test source has been contaminated by a leak from the bridge's one kilohertz test signal.

Do a Rigorous Test of the A/D

Test group 34 uses noise to test for the presence of every code from the A/D. Since the noise is expected to be random, making a large number of readings with the A/D should eventually provide statistics on the occurrence of every single output code that the A/D is supposed to be able to produce. The test passes if no missing codes are found.

If the test fails, and $vvv=0$, then missing codes were found by the test. If $vvv \neq 0$, then vvv contains a hexadecimal number showing which of the parallel lines from the A/D did not change. The number can range from 001 to 3FF. A value of 001 means that the least significant output line from the A/D did not change. A 002 means that the second least significant didn't change. A 004 means that the third least significant didn't change. A 200 means that the most significant didn't change. If more than one line is stuck then vvv will be the hexadecimal sum of the individual failures.

The most common cause of failure is the A/D itself. However, if any of its parallel data output lines are reported as being stuck, an oscilloscope or logic probe can observe whether the A/D data output lines toggle while this test is running. If they do, then the problem may be that U310 or U320 on A301 is not able to read some of these lines.

Generator Tests

These are all non-interventional tests except for the last one.

Main Transformer Signal Readings

Test group 40 checks the ability to drive the main ratio transformer with a sinewave at half and full signal levels. The peak-to-peak amplitude and symmetry about zero of the signal are read by the A/D at both full and half levels.

If all four tests fail, either the transformer is not being driven at all or the M0.1R signal is not being selected by the MUX. If both amplitude tests fail, but the symmetry tests pass, the problem is likely to be in U101 or U102 or the transformer is overloaded which the next test group will detect. If one of the amplitude tests passes and the other fails, the problem is likely to be in the FULL/HALF circuit composed of U112 and Q101. If the symmetry tests fail, the cause is likely to be one of the push-pull drivers (U103 or U104) of the main ratio transformer.

Main Transformer Overload Detector Tests

Test group 41 checks the ability to detect when excess current is required to drive the main ratio transformer. The circuit using U105 accomplishes this by creating the OVRLD signal which is read by the A/D via the MUX.

If test 41.2 fails when no overload is expected to be present, either the OVRLD detector is generating a false signal or the transformer current really is excessive. Excess current can be

Table 11-13 Main ratio transformer generator and driver tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
40	***Test ability to set sine generator to full/half and test waveform symmetry***		
40.1	Select M 0.1 R with U410 MUX, leave generator level at half, measure sinewave peak-to-peak volts with A/D	Main transformer has expected voltage level	U410, U102, U103, U104, U105
40.2	Select M 0.1 R with U410 MUX, leave generator level at half, measure sinewave symmetry with A/D	Main transformer signal is symmetric	U410, U102, U103, U104, U105
40.3	Select M 0.1 R with U410 MUX, set generator level to full, measure sinewave peak-to-peak volts with A/D	Main transformer has expected voltage level	U410, U102, U103, U104, U105
40.4	Select M 0.1 R with U410 MUX, set generator level to full, measure sinewave symmetry with A/D	Main transformer signal is symmetric	U410, U102, U103, U104, U105
41	***Test main ratio transformer overload (OVRLD) detector***		
41.1	Select OVRLD with U410 MUX, set ATN selector U146 to open, set RD selectors U144, U145 to open	OVRLD signal is not generated on no overload	U102-U105, U144-152, K101-136
41.2	Select OVRLD with U410 MUX, set ATN selector U146 to 15V, prompt to load HIGH to ground with a terminator using the message: `Conn tEr to HI GH`. Measure OVRLD after operator presses STEP key. Prompt for disconnection of setup with `dISConn SEtUP`.	OVRLD signal is generated on overload	U105, U146, U147, U152

caused by a short of some kind in the main ratio transformer or misadjustment of trimpot R104, but it is most commonly caused by a relay that is stuck closed in the RD's or ATN circuits. Stuck relays in these circuits are specifically dealt with by test groups 82 through 92. The procedure for adjusting R104 is given in the next section.

Test 41.2 is used to verify that an overload can be created and detected. This test requires that an external load with a sufficiently low resistance be placed between the HIGH terminal and ground. An ordinary 50Ω BNC terminator plugged into the HIGH terminal is all that is needed. The following procedure is used:

1. Wait for the prompt `Conn tEr to HI GH` to appear.

2. Plug a 50Ω BNC terminator into the HIGH terminal.

3. Press the STEP key to cause the test routine to complete the test by checking the OVRLD signal.

4. When the `dISConn SEtUP` prompt appears, unplug the 50Ω terminator from the HIGH terminal.

5. Press the STEP key to report the test result or to continue execution of tests.

A failure of this test is probably in the U105 overload detection circuit. However, since no ATN tests have been previously performed, a failure could also result from no overload being generated if K113 does not close.

Adjustment of HIGH Terminal Signal Level

Trimpot R104 on the main board adjusts the HIGH terminal output voltage. If this voltage is set too high, the OVRLD signal may be generated. The trimpot is identified in Figure 11-4 at the end of this chapter.

Issuing the command TEST 9 0 • 1 ENTER will cause the HIGH terminal to be driven by its maximum signal level of 15 volts. It will remain at this level even after the test is finished. The HIGH terminal output voltage can be measured with respect to ground with a voltmeter having an AC voltage accuracy of 1% or better. The trimpot should be set so the meter reads 15 volts ±5%.

Preamp vs. DAC Tests

These two sets of tests are the most complete check of the ACG (AC Gain) circuit in the preamp. These tests verify that each gain setting of the ACG circuit works and has nominally the right gain. Each ACG setting is also tested to see that it has the correct gain ratio relative to its neighbors.

The tests are performed by using the DAC to generate different test voltages. Since the DAC is essentially untested at this point, the ACG tests are also the most significant tests of the DAC performed thus far. For this reason, the entire set of tests is performed twice, once using the IDAC as the signal source and once using the QDAC. This way, both sets of tests must have similar failures before the ACG circuit is the main suspect.

Table 11-14 Preamp versus DAC tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
50	***Test LOW ACG against IDAC***		
50.1	Set ACG to zero, adjust IDAC so A/D reads max of I & Q channels at ~25% of FS	ACG and IDAC work at these settings	U602, U603, U609, preamp, IDAC
50.2	Set ACG to zero, adjust IDAC so A/D reads ~25% of FS, then set ACG to one	ACG one/zero magnitude ratio is acceptable	U602, U603, U609
50.3	Set ACG to one, adjust IDAC so A/D reads max of I & Q channels at ~25% of FS	IDAC sig. level approx. right at this gain setting	IDAC
50.4	Set ACG to one, adjust IDAC so A/D reads ~25% of FS, then set ACG to two	ACG two/one magnitude ratio is acceptable	U602, U603, U609
50.5	Set ACG to two, adjust IDAC so A/D reads max of I & Q channels at ~25% of FS	IDAC sig. level approx. right at this gain setting	IDAC
50.6	Set ACG to two, adjust IDAC so A/D reads ~25% of FS, then set ACG to three	ACG three/two magnitude ratio is acceptable	U602, U603, U609
51	***Test HIGH ACG against IDAC***		
51.1	Set ACG to three, enable shunt, adjust IDAC so A/D reads max of I & Q channels at ~25% of FS	IDAC sig. level approx. right at this gain setting	U602, U603, U609, preamp, IDAC
51.2	Set ACG to three, enable shunt, adjust IDAC so A/D reads ~25% of FS, then set ACG to four	ACG four/three magnitude ratio is acceptable	U602, U603, U609
51.3	Set ACG to four, enable shunt, adjust IDAC so A/D reads max of I & Q channels at ~25% of FS	IDAC sig. level approx. right at this gain setting	IDAC
51.4	Set ACG to four, enable shunt, adjust IDAC so A/D reads ~25% of FS, then set ACG to five	ACG five/four magnitude ratio is acceptable	U602, U603, U609
51.5	Set ACG to five, enable shunt, adjust IDAC so A/D reads max of I & Q channels at ~25% of FS	IDAC sig. level approx. right at this gain setting	IDAC
51.6	Set ACG to five, enable shunt, adjust IDAC so A/D reads ~25% of FS, then set ACG to six	ACG six/five magnitude ratio is acceptable	U602, U603, U609
51.7	Set ACG to six, enable shunt, adjust IDAC so A/D reads max of I & Q channels at ~25% of FS	IDAC sig. level approx. right at this gain setting	IDAC
51.8	Set ACG to six, enable shunt, adjust IDAC so A/D reads ~25% of FS, then set ACG to seven	ACG seven/six magnitude ratio is acceptable	U602, U603, U609
51.9	Set ACG to seven, enable shunt, adjust IDAC so A/D reads max of I & Q channels at ~25% of FS	IDAC sig. level approx. right at this gain setting	IDAC
51.10	Set ACG to seven, enable shunt, adjust IDAC so A/D reads ~25% of FS, then set ACG to eight	ACG eight/seven magnitude ratio is acceptable	U602, U603, U609
51.11	Set ACG to eight, enable shunt, adjust IDAC so A/D reads max of I & Q channels at ~25% of FS	IDAC sig. level approx. right at this gain setting	IDAC
52	***Test LOW ACG against QDAC***		
52.1	Set ACG to zero, set S/P/B to B, adjust QDAC so A/D reads max of I & Q channels at ~25% of FS	ACG and QDAC work at these settings	U602, U603, U609, preamp, QDAC
52.2	Set ACG to zero, adjust QDAC so A/D reads ~25% of FS, then set ACG to one	ACG one/zero magnitude ratio is acceptable	U602, U603, U609
52.3	Set ACG to one, adjust QDAC so A/D reads max of I & Q channels at ~25% of FS	QDAC sig. level approx. right at this gain setting	QDAC
52.4	Set ACG to one, adjust QDAC so A/D reads ~25% of FS, then set ACG to two	ACG two/one magnitude ratio is acceptable	U602, U603, U609

Table 11-14 Preamp versus DAC tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
52.5	Set ACG to two, adjust QDAC so A/D reads max of I & Q channels at ~25% of FS	QDAC sig. level approx. right at this gain setting	QDAC
52.6	Set ACG to two, adjust QDAC so A/D reads ~25% of FS, then set ACG to three	ACG three/two magnitude ratio is acceptable	U602, U603, U609
53	***Test HIGH ACG against QDAC***		
53.1	Set ACG to three, enable shunt, adjust QDAC so A/D reads max of I & Q channels at ~25% of FS	QDAC sig. level approx. right at this gain setting	U602, U603, U609, preamp, QDAC
53.2	Set ACG to three, enable shunt, adjust QDAC so A/D reads ~25% of FS, then set ACG to four	ACG four/three magnitude ratio is acceptable	U602, U603, U609
53.3	Set ACG to four, enable shunt, adjust QDAC so A/D reads max of I & Q channels at ~25% of FS	QDAC sig. level approx. right at this gain setting	QDAC
53.4	Set ACG to four, enable shunt, adjust QDAC so A/D reads ~25% of FS, then set ACG to five	ACG five/four magnitude ratio is acceptable	U602, U603, U609
53.5	Set ACG to five, enable shunt, adjust QDAC so A/D reads max of I & Q channels at ~25% of FS	QDAC sig. level approx. right at this gain setting	QDAC
53.6	Set ACG to five, enable shunt, adjust QDAC so A/D reads ~25% of FS, then set ACG to six	ACG six/five magnitude ratio is acceptable	U602, U603, U609
53.7	Set ACG to six, enable shunt, adjust QDAC so A/D reads max of I & Q channels at ~25% of FS	QDAC sig. level approx. right at this gain setting	QDAC
53.8	Set ACG to six, enable shunt, adjust QDAC so A/D reads ~25% of FS, then set ACG to seven	ACG seven/six magnitude ratio is acceptable	U602, U603, U609
53.9	Set ACG to seven, enable shunt, adjust QDAC so A/D reads max of I & Q channels at ~25% of FS	QDAC sig. level approx. right at this gain setting	QDAC
53.10	Set ACG to seven, enable shunt, adjust QDAC so A/D reads ~25% of FS, then set ACG to eight	ACG eight/seven magnitude ratio is acceptable	U602, U603, U609
53.11	Set ACG to eight, enable shunt, adjust QDAC so A/D reads max of I & Q channels at ~25% of FS	QDAC sig. level approx. right at this gain setting	QDAC

Failures of only one set of tests imply that there is a problem in the DAC. This is not of much concern at this point because much more specific DAC tests are performed later and these tests should be of more help in localizing DAC problems.

A failure of both of the low gain ratio tests 50.2 and 52.2 indicates that the trimpot R624 may need adjustment. This is done by issuing the command [TEST] [5] [0] [•] [2] [REPEAT] [ENTER]. (Test 52.2 should work equally well.) If "halt on error" is set, use [TEST] [FORMAT] [0] [ENTER] to reset this bit so the gain ratio will be shown continuously even if it is causing an error. The [→] key can then be used to make the front panel show the second window in the test result which contains the gain ratio value as read by the A/D. The trimpot may then be adjusted while watching the gain ratio value in the upper display. The allowable window values for the gain ratio are shown in the third window of the test result. If the gain ratio value cannot be brought within the acceptable window of values, then a hardware failure has occurred.

Main Board Tests

At this point, if all prior tests have been run, then all have been completed on all major assemblies except for the main board. Except as noted, all the main board tests are designed to localize problems on the main board. Failures of any of these tests are not likely to help identify failures on other boards.

There are many simple, independent, firmware testable circuits on the main board. As a result, most of the likely failures on this board can be repaired without replacing the board.

The main board tests assume that the rest of the bridge is functioning because most of the other circuits are required to do the main board tests. All but the ATN tests use the bridge in its test/calibration mode which closes the test/calibration relay (K601) in the preamp. This disconnects the LOW terminal so that it doesn't matter what is externally connected to it. Otherwise, these tests operate the bridge in its normal manner. This involves selecting particular DAC and RD set-

Table 11-15 Comprehensive DAC tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
60	***Test that each switch element in MSD of IDAC can cause a change***		
60.1	Set IDAC MSD to IP 0.0 using U122, ACG=0, A/D reads max of I & Q; then set U122 to IP 1.0	A/D sees a change => U122 pin 5 connects	U118, U122, U127
60.2	Set IDAC MSD to IP 0.0 using U122, ACG=0, A/D reads max of I & Q; then set U122 to IP 0.8	A/D sees a change => U122 pin 1 connects	U118, U122, U127
60.3	Set IDAC MSD to IP 0.0 using U122, ACG=0, A/D reads max of I & Q; then set U122 to IP 0.6	A/D sees a change => U122 pin 12 connects	U118, U122, U127
60.4	Set IDAC MSD to IP 0.0 using U122, ACG=0, A/D reads max of I & Q; then set U122 to IP 0.4	A/D sees a change => U122 pin 15 connects	U118, U122, U127
60.5	Set IDAC MSD to IP 0.0 using U122, ACG=0, A/D reads max of I & Q; then set U122 to IP 0.2	A/D sees a change => U122 pin 14 connects	U118, U122, U127
60.6	Set IDAC MSD to IP 0.0 using U122, ACG=0, A/D reads max of I & Q; then set U122 to IP -0.1	A/D sees a change => U122 pin 4 connects	U118, U122, U127
60.7	Set IDAC MSD to IP 0.0 using U124, ACG=0, A/D reads max of I & Q; then set U124 pin 1 to IP 1.0	A/D sees a change => U124 pin 1 connects	U118, U124, U126
61	***Test that each switch element in second MSD of IDAC can cause a change***		
61.1	Set IDAC 2nd MSD to IP 0.0 using U121, ACG=0, A/D reads max of I & Q; then set U121 to IP 1.0	A/D sees a change => U121 pin 5 connects	U117, U121, U125
61.2	Set IDAC 2nd MSD to IP 0.0 using U121, ACG=0, A/D reads max of I & Q; then set U121 to IP 0.8	A/D sees a change => U121 pin 1 connects	U117, U121, U125
61.3	Set IDAC 2nd MSD to IP 0.0 using U121, ACG=0, A/D reads max of I & Q; then set U121 to IP 0.6	A/D sees a change => U121 pin 12 connects	U117, U121, U125
61.4	Set IDAC 2nd MSD to IP 0.0 using U121, ACG=0, A/D reads max of I & Q; then set U121 to IP 0.4	A/D sees a change => U121 pin 15 connects	U117, U121, U125
61.5	Set IDAC 2nd MSD to IP 0.0 using U121, ACG=0, A/D reads max of I & Q; then set U121 to IP 0.2	A/D sees a change => U121 pin 14 connects	U117, U121, U125
61.6	Set IDAC 2nd MSD to IP 0.0 using U121, ACG=0, A/D reads max of I & Q; then set U121 to IP -0.1	A/D sees a change => U121 pin 4 connects	U117, U121, U125
61.7	Set IDAC 2nd MSD to IP 0.0 using U124, ACG=0, A/D reads max of I & Q; then set U124 pin 3 to IP 1.0	A/D sees a change => U124 pin 3 connects	U117, U124
62	***Test that each switch element in third MSD of IDAC can cause a change***		
62.1	Set IDAC 3rd MSD to IP 0.0 using U120, set ACG=2, A/D reads max of I & Q; then set U120 to IP 1.0	A/D sees a change => U120 pin 5 connects	U116, U120
62.2	Set IDAC 3rd MSD to IP 0.0 using U120, set ACG=2, A/D reads max of I & Q; then set U120 to IP 0.8	A/D sees a change => U120 pin 1 connects	U116, U120
62.3	Set IDAC 3rd MSD to IP 0.0 using U120, set ACG=2, A/D reads max of I & Q; then set U120 to IP 0.6	A/D sees a change => U120 pin 12 connects	U116, U120
62.4	Set IDAC 3rd MSD to IP 0.0 using U120, set ACG=2, A/D reads max of I & Q; then set U120 to IP 0.4	A/D sees a change => U120 pin 15 connects	U116, U120
62.5	Set IDAC 3rd MSD to IP 0.0 using U120, set ACG=2, A/D reads max of I & Q; then set U120 to IP 0.2	A/D sees a change => U120 pin 14 connects	U116, U120
62.6	Set IDAC 3rd MSD to IP 0.0 using U120, set ACG=2, A/D reads max of I & Q; then set U120 to IP -0.1	A/D sees a change => U120 pin 4 connects	U116, U120
62.7	Set IDAC 3rd MSD to IP 0.0 using U124, set ACG=2, A/D reads max of I & Q; then set U124 pin 13 to IP 1.0	A/D sees a change => U124 pin 13 connects	U116, U124

Table 11-15 Comprehensive DAC tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
63	*Test that each switch element in fourth MSD of IDAC can cause a change*		
63.1	Set IDAC 4th MSD to IP 0.0 using U119, set ACG=4, A/D reads max of I & Q; then set U119 to IP 1.0	A/D sees a change => U119 pin 5 connects	U115, U119
63.2	Set IDAC 4th MSD to IP 0.0 using U119, set ACG=4, A/D reads max of I & Q; then set U119 to IP 0.8	A/D sees a change => U119 pin 1 connects	U115, U119
63.3	Set IDAC 4th MSD to IP 0.0 using U119, set ACG=4, A/D reads max of I & Q; then set U119 to IP 0.6	A/D sees a change => U119 pin 12 connects	U115, U119
63.4	Set IDAC 4th MSD to IP 0.0 using U119, set ACG=4, A/D reads max of I & Q; then set U119 to IP 0.4	A/D sees a change => U119 pin 15 connects	U115, U119
63.5	Set IDAC 4th MSD to IP 0.0 using U119, set ACG=4, A/D reads max of I & Q; then set U119 to IP 0.2	A/D sees a change => U119 pin 14 connects	U115, U119
63.6	Set IDAC 4th MSD to IP 0.0 using U119, set ACG=4, A/D reads max of I & Q; then set U119 to IP -0.1	A/D sees a change => U119 pin 4 connects	U115, U119
63.7	Set IDAC 4th MSD to IP 0.0 using U123, set ACG=4, A/D reads max of I & Q; then set U123 pin 13 to IP 1.0	A/D sees a change => U123 pin 13 connects	U115, U123
64	*Test that each switch element in fifth MSD of IDAC can cause a change*		
64.1	Set IDAC 5th MSD to IP 0.0 using U154, set ACG=6, A/D reads max of I & Q; then set U154 to IP 1.0	A/D sees a change => U154 pin 5 connects	U153, U154
64.2	Set IDAC 5th MSD to IP 0.0 using U154, set ACG=6, A/D reads max of I & Q; then set U154 to IP 0.8	A/D sees a change => U154 pin 1 connects	U153, U154
64.3	Set IDAC 5th MSD to IP 0.0 using U154, set ACG=6, A/D reads max of I & Q; then set U154 to IP 0.6	A/D sees a change => U154 pin 12 connects	U153, U154
64.4	Set IDAC 5th MSD to IP 0.0 using U154, set ACG=6, A/D reads max of I & Q; then set U154 to IP 0.4	A/D sees a change => U154 pin 15 connects	U153, U154
64.5	Set IDAC 5th MSD to IP 0.0 using U154, set ACG=6, A/D reads max of I & Q; then set U154 to IP 0.2	A/D sees a change => U154 pin 14 connects	U153, U154
64.6	Set IDAC 5th MSD to IP 0.0 using U154, set ACG=6, A/D reads max of I & Q; then set U154 to IP -0.1	A/D sees a change => U154 pin 4 connects	U153, U154
64.7	Set IDAC 5th MSD to IP 0.0 using U123, set ACG=6, A/D reads max of I & Q; then set U123 pin 1 to IP 1.0	A/D sees a change => U123 pin 1 connects	U153, U123
64.8	Set IDAC 5th MSD to IP 0.0 using U123, set ACG=6, A/D reads max of I & Q; then set U123 pin 3 to IP 1.0	A/D sees a change => U123 pin 3 connects	U112, U123
65	*Test that each switch element in MSD of QDAC can cause a change*		
65.1	Set QDAC MSD to IP 0.0 using U138, ACG=0, A/D reads max of I & Q; then set U138 to IP 1.0	A/D sees a change => U138 pin 5 connects	U134, U138, U140
65.2	Set QDAC MSD to IP 0.0 using U138, ACG=0, A/D reads max of I & Q; then set U138 to IP 0.8	A/D sees a change => U138 pin 1 connects	U134, U138, U140
65.3	Set QDAC MSD to IP 0.0 using U138, ACG=0, A/D reads max of I & Q; then set U138 to IP 0.6	A/D sees a change => U138 pin 12 connects	U134, U138, U140
65.4	Set QDAC MSD to IP 0.0 using U138, ACG=0, A/D reads max of I & Q; then set U138 to IP 0.4	A/D sees a change => U138 pin 15 connects	U134, U138, U140
65.5	Set QDAC MSD to IP 0.0 using U138, ACG=0, A/D reads max of I & Q; then set U138 to IP 0.2	A/D sees a change => U138 pin 14 connects	U134, U138, U140
65.6	Set QDAC MSD to IP 0.0 using U138, ACG=0, A/D reads max of I & Q; then set U138 to IP -0.1	A/D sees a change => U138 pin 4 connects	U134, U138, U140

Table 11-15 Comprehensive DAC tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
65.7	Set QDAC MSD to IP 0.0 using U143, ACG=0, A/D reads max of I & Q; then set U143 pin 3 to IP 1.0	A/D sees a change => U143 pin 3 connects	U134, U143, U141
66	***Test that each switch element in second MSD of QDAC can cause a change***		
66.1	Set QDAC 2nd MSD to IP 0.0 using U137, ACG=0, A/D reads max of I & Q; then set U137 to IP 1.0	A/D sees a change => U137 pin 5 connects	U133, U137, U139
66.2	Set QDAC 2nd MSD to IP 0.0 using U137, ACG=0, A/D reads max of I & Q; then set U137 to IP 0.8	A/D sees a change => U137 pin 1 connects	U133, U137, U139
66.3	Set QDAC 2nd MSD to IP 0.0 using U137, ACG=0, A/D reads max of I & Q; then set U137 to IP 0.6	A/D sees a change => U137 pin 12 connects	U133, U137, U139
66.4	Set QDAC 2nd MSD to IP 0.0 using U137, ACG=0, A/D reads max of I & Q; then set U137 to IP 0.4	A/D sees a change => U137 pin 15 connects	U133, U137, U139
66.5	Set QDAC 2nd MSD to IP 0.0 using U137, ACG=0, A/D reads max of I & Q; then set U137 to IP 0.2	A/D sees a change => U137 pin 14 connects	U133, U137, U139
66.6	Set QDAC 2nd MSD to IP 0.0 using U137, ACG=0, A/D reads max of I & Q; then set U137 to IP -0.1	A/D sees a change => U137 pin 4 connects	U133, U137, U139
66.7	Set QDAC 2nd MSD to IP 0.0 using U143, ACG=0, A/D reads max of I & Q; then set U143 pin 13 to IP 1.0	A/D sees a change => U143 pin 13 connects	U133, U143
67	***Test that each switch element in third MSD of QDAC can cause a change***		
67.1	Set QDAC 3rd MSD to IP 0.0 using U136, ACG=2, A/D reads max of I & Q; then set U136 to IP 1.0	A/D sees a change => U136 pin 5 connects	U132, U136
67.2	Set QDAC 3rd MSD to IP 0.0 using U136, ACG=2, A/D reads max of I & Q; then set U136 to IP 0.8	A/D sees a change => U136 pin 1 connects	U132, U136
67.3	Set QDAC 3rd MSD to IP 0.0 using U136, ACG=2, A/D reads max of I & Q; then set U136 to IP 0.6	A/D sees a change => U136 pin 12 connects	U132, U136
67.4	Set QDAC 3rd MSD to IP 0.0 using U136, ACG=2, A/D reads max of I & Q; then set U136 to IP 0.4	A/D sees a change => U136 pin 15 connects	U132, U136
67.5	Set QDAC 3rd MSD to IP 0.0 using U136, ACG=2, A/D reads max of I & Q; then set U136 to IP 0.2	A/D sees a change => U136 pin 14 connects	U132, U136
67.6	Set QDAC 3rd MSD to IP 0.0 using U136, ACG=2, A/D reads max of I & Q; then set U136 to IP -0.1	A/D sees a change => U136 pin 4 connects	U132, U136
67.7	Set QDAC 3rd MSD to IP 0.0 using U143, ACG=2, A/D reads max of I & Q; then set U143 pin 1 to IP 1.0	A/D sees a change => U143 pin 1 connects	U132, U143
68	***Test that each switch element in fourth MSD of QDAC can cause a change***		
68.1	Set QDAC 4th MSD to IP 0.0 using U135, ACG=4, A/D reads max of I & Q; then set U135 to IP 1.0	A/D sees a change => U135 pin 5 connects	U131, U135
68.2	Set QDAC 4th MSD to IP 0.0 using U135, ACG=4, A/D reads max of I & Q; then set U135 to IP 0.8	A/D sees a change => U135 pin 1 connects	U131, U135
68.3	Set QDAC 4th MSD to IP 0.0 using U135, ACG=4, A/D reads max of I & Q; then set U135 to IP 0.6	A/D sees a change => U135 pin 12 connects	U131, U135
68.4	Set QDAC 4th MSD to IP 0.0 using U135, ACG=4, A/D reads max of I & Q; then set U135 to IP 0.4	A/D sees a change => U135 pin 15 connects	U131, U135
68.5	Set QDAC 4th MSD to IP 0.0 using U135, ACG=4, A/D reads max of I & Q; then set U135 to IP 0.2	A/D sees a change => U135 pin 14 connects	U131, U135
68.6	Set QDAC 4th MSD to IP 0.0 using U135, ACG=4, A/D reads max of I & Q; then set U135 to IP -0.1	A/D sees a change => U135 pin 4 connects	U131, U135

Table 11-15 Comprehensive DAC tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
68.7	Set QDAC 4th MSD to IP 0.0 using U142, ACG=4, A/D reads max of I & Q; then set U142 pin 1 to IP 1.0	A/D sees a change => U142 pin 1 connects	U131, U142
69	***Test that each switch element in fifth MSD of QDAC can cause a change***		
69.1	Set QDAC 5th MSD to IP 0.0 using U155, ACG=6, A/D reads max of I & Q; then set U155 to IP 1.0	A/D sees a change => U155 pin 5 connects	U114, U155
69.2	Set QDAC 5th MSD to IP 0.0 using U155, ACG=6, A/D reads max of I & Q; then set U155 to IP 0.8	A/D sees a change => U155 pin 1 connects	U114, U155
69.3	Set QDAC 5th MSD to IP 0.0 using U155, ACG=6, A/D reads max of I & Q; then set U155 to IP 0.6	A/D sees a change => U155 pin 12 connects	U114, U155
69.4	Set QDAC 5th MSD to IP 0.0 using U155, ACG=6, A/D reads max of I & Q; then set U155 to IP 0.4	A/D sees a change => U155 pin 15 connects	U114, U155
69.5	Set QDAC 5th MSD to IP 0.0 using U155, ACG=6, A/D reads max of I & Q; then set U155 to IP 0.2	A/D sees a change => U155 pin 14 connects	U114, U155
69.6	Set QDAC 5th MSD to IP 0.0 using U155, ACG=6, A/D reads max of I & Q; then set U155 to IP -0.1	A/D sees a change => U155 pin 4 connects	U114, U155
69.7	Set QDAC 5th MSD to IP 0.0 using U142, ACG=6, A/D reads max of I & Q; then set U142 pin 13 to IP 1.0	A/D sees a change => U142 pin 13 connects	U114, U142
69.8	Set QDAC 5th MSD to IP 0.0 using U142, ACG=6, A/D reads max of I & Q; then set U142 pin 3 to IP 1.0	A/D sees a change => U142 pin 3 connects	U113, U142
70	***Test gain ratios of MSD of IDAC***		
70.1	Set MSD of IDAC to IP 1.0 using U122, set ACG=2, enable shunt, A/D reads max of I & Q	IDAC sees reasonable signal at this setting	U118, U122, U127
70.2	Set IDAC MSD to IP 1.0 using U122, set ACG=2, enable shunt, A/D reads max of I & Q; then set U122 to IP 0.8	IDAC MSD generates correct 10/8 ratio	U118, U122, U127
70.3	Set IDAC MSD to IP 0.8 using U122, set ACG=2, enable shunt, A/D reads max of I & Q; then set U122 to IP 0.6	IDAC MSD generates correct 8/6 ratio	U118, U122, U127
70.4	Set IDAC MSD to IP 0.6 using U122, set ACG=2, enable shunt, A/D reads max of I & Q; then set U122 to IP 0.4	IDAC MSD generates correct 6/4 ratio	U118, U122, U127
70.5	Set IDAC MSD to IP 0.4 using U122, set ACG=3, enable shunt, A/D reads max of I & Q; then set U122 to IP 0.2	IDAC MSD generates correct 4/2 ratio	U118, U122, U127
70.6	Set IDAC MSD to IP 0.2 using U122, set ACG=3, enable shunt, A/D reads max of I & Q; then set U122 to IP -0.1	IDAC MSD generates correct 2/1 ratio	U118, U122, U127
70.7	Set IDAC MSD to IP 0.2 using U122, set ACG=3, enable shunt, A/D reads max of I & Q; then set U122 to IP 0.0 & set U124 pin 15 to IP 1.0	IDAC MSD generates correct 2/1 ratio	U118, U124, U126
71	***Test gain ratios of second MSD of IDAC***		
71.1	Set MSD of IDAC to IP -0.1 using U122, enable shunt, set ACG=4, A/D reads max of I & Q, then set U122 to IP 0.0 and set 2nd MSD of IDAC to IP 1.0 using U121	IDAC MSD relative to 2nd MSD generates correct 1/1 ratio	U117, U121, U125
71.2	Set IDAC 2nd MSD to IP 1.0 using U121, enable shunt, set ACG=4, A/D reads max of I & Q; then set U121 to IP 0.8	IDAC 2nd MSD generates correct 10/8 ratio	U117, U121, U125
71.3	Set IDAC 2nd MSD to IP 0.8 using U121, enable shunt, set ACG=4, A/D reads max of I & Q; then set U121 to IP 0.6	IDAC 2nd MSD generates correct 8/6 ratio	U117, U121, U125
71.4	Set IDAC 2nd MSD to IP 0.6 using U121, enable shunt, set ACG=4, A/D reads max of I & Q; then set U121 to IP 0.4	IDAC 2nd MSD generates correct 6/4 ratio	U117, U121, U125

Table 11-15 Comprehensive DAC tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
71.5	Set IDAC 2nd MSD to IP 0.4 using U121, enable shunt, set ACG=5, A/D reads max of I & Q; then set U121 to IP 0.2	IDAC 2nd MSD generates correct 4/2 ratio	U117, U121, U125
71.6	Set IDAC 2nd MSD to IP 0.2 using U121, enable shunt, set ACG=5, A/D reads max of I & Q; then set U121 to IP -0.1	IDAC 2nd MSD generates correct 2/1 ratio	U117, U121, U125
71.7	Set IDAC 2nd MSD to IP 0.2 using U121, enable shunt, set ACG=5, A/D reads max of I & Q; then set U121 to IP 0.0 and set U124 pin 4 to IP 1.0	IDAC 2nd MSD generates correct 2/1 ratio	U117, U124
72	***Test gain ratios of third MSD of IDAC***		
72.1	Set 2nd MSD of IDAC to IP -0.1 using U121, set ACG=1, A/D reads max of I & Q; then set U121 to IP 0.0 and set 3rd MSD of IDAC to IP 1.0 using U120	IDAC 2nd MSD relative to 3rd MSD generates correct 1/1 ratio	U116, U120
72.2	Set IDAC 3rd MSD to IP 1.0 using U120, set ACG=1, A/D reads max of I & Q; then set U120 to IP 0.8	IDAC 3rd MSD generates correct 10/8 ratio	U116, U120
72.3	Set IDAC 3rd MSD to IP 0.8 using U120, set ACG=1, A/D reads max of I & Q; then set U120 to IP 0.6	IDAC 3rd MSD generates correct 8/6 ratio	U116, U120
72.4	Set IDAC 3rd MSD to IP 0.6 using U120, set ACG=1, A/D reads max of I & Q; then set U120 to IP 0.4	IDAC 3rd MSD generates correct 6/4 ratio	U116, U120
72.5	Set IDAC 3rd MSD to IP 0.4 using U120, set ACG=2, A/D reads max of I & Q; then set U120 to IP 0.2	IDAC 3rd MSD generates correct 4/2 ratio	U116, U120
72.6	Set IDAC 3rd MSD to IP 0.2 using U120, set ACG=2, A/D reads max of I & Q; then set U120 to IP -0.1	IDAC 3rd MSD generates correct 2/1 ratio	U116, U120
72.7	Set IDAC 3rd MSD to IP 0.2 using U120, set ACG=2, A/D reads max of I & Q; then set U120 to IP 0.0 and set U124 pin 14 to IP 1.0	IDAC 3rd MSD generates correct 2/1 ratio	U116, U124
73	***Test gain ratios of fourth MSD of IDAC***		
73.1	Set 3rd MSD of IDAC to IP -0.1 using U120, set ACG=3, A/D reads max of I & Q, then set U120 to IP 0.0 and set 4th MSD of IDAC to IP 1.0 using U119	IDAC 3rd MSD relative to 4th MSD generates correct 1/1 ratio	U115, U119
73.2	Set IDAC 4th MSD to IP 1.0 using U119, set ACG=3, A/D reads max of I & Q; then set U119 to IP 0.8	IDAC 4th MSD generates correct 10/8 ratio	U115, U119
73.3	Set IDAC 4th MSD to IP 0.8 using U119, set ACG=3, A/D reads max of I & Q; then set U119 to IP 0.6	IDAC 4th MSD generates correct 8/6 ratio	U115, U119
73.4	Set IDAC 4th MSD to IP 0.6 using U119, set ACG=3, A/D reads max of I & Q; then set U119 to IP 0.4	IDAC 4th MSD generates correct 6/4 ratio	U115, U119
73.5	Set IDAC 4th MSD to IP 0.4 using U119, set ACG=4, A/D reads max of I & Q; then set U119 to IP 0.2	IDAC 4th MSD generates correct 4/2 ratio	U115, U119
73.6	Set IDAC 4th MSD to IP 0.2 using U119, set ACG=4, A/D reads max of I & Q; then set U119 to IP -0.1	IDAC 4th MSD generates correct 2/1 ratio	U115, U119
73.7	Set IDAC 4th MSD to IP 0.2 using U119, set ACG=4, A/D reads max of I & Q; then set U119 to IP 0.0 and set U123 pin 14 to IP 1.0	IDAC 4th MSD generates correct 2/1 ratio	U115, U123
74	***Test gain ratios of fifth MSD of IDAC***		
74.1	Set 4th MSD of IDAC to IP -0.1 using U119, set ACG=5, A/D reads max of I & Q, then set U119 to IP 0.0 and set 5th MSD of IDAC to IP 1.0 using U154	IDAC 4th MSD relative to 5th MSD generates correct 1/1 ratio	U153, U154

Table 11-15 Comprehensive DAC tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
74.2	Set IDAC 5th MSD to IP 1.0 using U154, set ACG=5, A/D reads max of I & Q; then set U154 to IP 0.8	IDAC 5th MSD generates correct 10/8 ratio	U153, U154
74.3	Set IDAC 5th MSD to IP 0.8 using U154, set ACG=5, A/D reads max of I & Q; then set U154 to IP 0.6	IDAC 5th MSD generates correct 8/6 ratio	U153, U154
74.4	Set IDAC 5th MSD to IP 0.6 using U154, set ACG=5, A/D reads max of I & Q; then set U154 to IP 0.4	IDAC 5th MSD generates correct 6/4 ratio	U153, U154
74.5	Set IDAC 5th MSD to IP 0.4 using U154, set ACG=6, A/D reads max of I & Q; then set U154 to IP 0.2	IDAC 5th MSD generates correct 4/2 ratio	U153, U154
74.6	Set IDAC 5th MSD to IP 0.2 using U154, set ACG=6, A/D reads max of I & Q; then set U154 to IP -0.1	IDAC 5th MSD generates correct 2/1 ratio	U153, U154
74.7	Set IDAC 5th MSD to IP 0.2 using U154, set ACG=6, A/D reads max of I & Q; then set U154 to IP 0.0 and set U123 pin 15 to IP 1.0	IDAC 5th MSD generates correct 2/1 ratio	U153, U123
74.8	Set IDAC 5th MSD to IP 1.0 using U123 pin 15, set ACG=6, A/D reads max of I & Q; then set U123 pin 15 to IP 0.0 and set IDAC 6th MSD using U123 pin 4 to IP 1.0	IDAC 5th MSD relative to 6th MSD generates correct 2/1 ratio	U112, U123
75	**Test gain ratios of MSD of QDAC**		
75.1	Set MSD of QDAC to Q 1.0 using U138, set ACG=2, enable shunt, A/D reads max of I & Q channels	QDAC sees reasonable signal at this setting	U134, U138, U140
75.2	Set QDAC MSD to Q 1.0 using U138, set ACG=2, enable shunt, A/D reads max of I & Q; then set U138 to Q 0.8	QDAC MSD generates correct 10/8 ratio	U134, U138, U140
75.3	Set QDAC MSD to Q 0.8 using U138, set ACG=2, enable shunt, A/D reads max of I & Q; then set U138 to Q 0.6	QDAC MSD generates correct 8/6 ratio	U134, U138, U140
75.4	Set QDAC MSD to Q 0.6 using U138, set ACG=2, enable shunt, A/D reads max of I & Q; then set U138 to Q 0.4	QDAC MSD generates correct 6/4 ratio	U134, U138, U140
75.5	Set QDAC MSD to Q 0.4 using U138, set ACG=3, enable shunt, A/D reads max of I & Q; then set U138 to Q 0.2	QDAC MSD generates correct 4/2 ratio	U134, U138, U140
75.6	Set QDAC MSD to Q 0.2 using U138, set ACG=3, enable shunt, A/D reads max of I & Q; then set U138 to Q -0.1	QDAC MSD generates correct 2/1 ratio	U134, U138, U140
75.7	Set QDAC MSD to Q 0.2 using U138, set ACG=3, enable shunt, A/D reads max of I & Q; then set U138 to Q 0.0 and set U143 pin 4 to Q 1.0	QDAC MSD generates correct 2/1 ratio	U134, U143, U141
76	**Test gain ratios of second MSD of QDAC**		
76.1	Set MSD of QDAC to Q -0.1 using U138, enable shunt, set ACG=4, A/D reads max of I & Q, then set U138 to Q 0.0 and set 2nd MSD of QDAC to Q 1.0 using U137	QDAC MSD relative to 2nd MSD generates correct 1/1 ratio	U133, U137, U139
76.2	Set QDAC 2nd MSD to Q 1.0 using U137, enable shunt, set ACG=4, A/D reads max of I & Q; then set U137 to Q 0.8	QDAC 2nd MSD generates correct 10/8 ratio	U133, U137, U139
76.3	Set QDAC 2nd MSD to Q 0.8 using U137, enable shunt, set ACG=4, A/D reads max of I & Q; then set U137 to Q 0.6	QDAC 2nd MSD generates correct 8/6 ratio	U133, U137, U139
76.4	Set QDAC 2nd MSD to Q 0.6 using U137, enable shunt, set ACG=4, A/D reads max of I & Q; then set U137 to Q 0.4	QDAC 2nd MSD generates correct 6/4 ratio	U133, U137, U139
76.5	Set QDAC 2nd MSD to Q 0.4 using U137, enable shunt, set ACG=5, A/D reads max of I & Q; then set U137 to Q 0.2	QDAC 2nd MSD generates correct 4/2 ratio	U133, U137, U139
76.6	Set QDAC 2nd MSD to Q 0.2 using U137, enable shunt, set ACG=5, A/D reads max of I & Q; then set U137 to Q -0.1	QDAC 2nd MSD generates correct 2/1 ratio	U133, U137, U139

Table 11-15 Comprehensive DAC tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
76.7	Set QDAC 2nd MSD to Q 0.2 using U137, enable shunt, set ACG=5, A/D reads max of I & Q; then set U137 to Q 0.0 and set U143 pin 14 to Q 1.0	QDAC 2nd MSD generates correct 2/1 ratio	U133, U143
77	***Test gain ratios of third MSD of QDAC***		
77.1	Set 2nd MSD of QDAC to Q -0.1 using U137, set ACG=1, A/D reads max of I & Q; then set U137 to Q 0.0 and set 3rd MSD of QDAC to Q 1.0 using U136	QDAC 2nd MSD relative to 3rd MSD generates correct 1/1 ratio	U132, U136
77.2	Set QDAC 3rd MSD to Q 1.0 using U136, set ACG=1, A/D reads max of I & Q; then set U136 to Q 0.8	QDAC 3rd MSD generates correct 10/8 ratio	U132, U136
77.3	Set QDAC 3rd MSD to Q 0.8 using U136, set ACG=1, A/D reads max of I & Q; then set U136 to Q 0.6	QDAC 3rd MSD generates correct 8/6 ratio	U132, U136
77.4	Set QDAC 3rd MSD to Q 0.6 using U136, set ACG=1, A/D reads max of I & Q; then set U136 to Q 0.4	QDAC 3rd MSD generates correct 6/4 ratio	U132, U136
77.5	Set QDAC 3rd MSD to Q 0.4 using U136, set ACG=2, A/D reads max of I & Q; then set U136 to Q 0.2	QDAC 3rd MSD generates correct 4/2 ratio	U132, U136
77.6	Set QDAC 3rd MSD to Q 0.2 using U136, set ACG=2, A/D reads max of I & Q; then set U136 to Q -0.1	QDAC 3rd MSD generates correct 2/1 ratio	U132, U136
77.7	Set QDAC 3rd MSD to Q 0.2 using U136, set ACG=2, A/D reads max of I & Q; then set U136 to Q 0.0 and set U143 pin 15 to Q 1.0	QDAC 3rd MSD generates correct 2/1 ratio	U132, U143
78	***Test gain ratios of fourth MSD of QDAC***		
78.1	Set 3rd MSD of QDAC to Q -0.1 using U136, set ACG=3, A/D reads max of I & Q; then set U136 to Q 0.0 and set 4th MSD of QDAC to Q 1.0 using U135	QDAC 3rd MSD relative to 4th MSD generates correct 1/1 ratio	U131, U135
78.2	Set QDAC 4th MSD to Q 1.0 using U135, set ACG=3, A/D reads max of I & Q; then set U135 to Q 0.8	QDAC 4th MSD generates correct 10/8 ratio	U131, U135
78.3	Set QDAC 4th MSD to Q 0.8 using U135, set ACG=3, A/D reads max of I & Q; then set U135 to Q 0.6	QDAC 4th MSD generates correct 8/6 ratio	U131, U135
78.4	Set QDAC 4th MSD to Q 0.6 using U135, set ACG=3, A/D reads max of I & Q; then set U135 to Q 0.4	QDAC 4th MSD generates correct 6/4 ratio	U131, U135
78.5	Set QDAC 4th MSD to Q 0.4 using U135, set ACG=4, A/D reads max of I & Q; then set U135 to Q 0.2	QDAC 4th MSD generates correct 4/2 ratio	U131, U135
78.6	Set QDAC 4th MSD to Q 0.2 using U135, set ACG=4, A/D reads max of I & Q; then set U135 to Q -0.1	QDAC 4th MSD generates correct 2/1 ratio	U131, U135
78.7	Set QDAC 4th MSD to Q 0.2 using U135, set ACG=4, A/D reads max of I & Q; then set U135 to Q 0.0 and set U142 pin 15 to Q 1.0	QDAC 4th MSD generates correct 2/1 ratio	U131, U142
79	***Test gain ratios of fifth MSD of QDAC***		
79.1	Set 4th MSD of QDAC to Q -0.1 using U135, set ACG=5, A/D reads max of I & Q; then set U135 to Q 0.0 and set 5th MSD of QDAC to Q 1.0 using U155	QDAC 4th MSD relative to 5th MSD generates correct 1/1 ratio	U114, U155
79.2	Set QDAC 5th MSD to Q 1.0 using U155, set ACG=5, A/D reads max of I & Q; then set U155 to Q 0.8	QDAC 5th MSD generates correct 10/8 ratio	U114, U155
79.3	Set QDAC 5th MSD to Q 0.8 using U155, set ACG=5, A/D reads max of I & Q; then set U155 to Q 0.6	QDAC 5th MSD generates correct 8/6 ratio	U114, U155

Table 11-15 Comprehensive DAC tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
79.4	Set QDAC 5th MSD to Q 0.6 using U155, set ACG=5, A/D reads max of I & Q; then set U155 to Q 0.4	QDAC 5th MSD generates correct 6/4 ratio	U114, U155
79.5	Set QDAC 5th MSD to Q 0.4 using U155, set ACG=6, A/D reads max of I & Q; then set U155 to Q 0.2	QDAC 5th MSD generates correct 4/2 ratio	U114, U155
79.6	Set QDAC 5th MSD to Q 0.2 using U155, set ACG=6, A/D reads max of I & Q; then set U155 to Q -0.1	QDAC 5th MSD generates correct 2/1 ratio	U114, U155
79.7	Set QDAC 5th MSD to Q 0.2 using U155, set ACG=6, A/D reads max of I & Q; then set U155 to Q 0.0 and set U142 pin 14 to Q 1.0	QDAC 5th MSD generates correct 2/1 ratio	U114, U142
79.8	Set QDAC 5th MSD to Q 1.0 using U142 pin 14, set ACG=6, A/D reads max of I & Q; then set U142 pin 14 to Q 0.0 and set QDAC 6th MSD using U142 pin4 to Q 1.0	QDAC 5th MSD relative to 6th MSD generates correct 2/1 ratio	U113, U142

tings, the precision sum of which produces a result at the input of the preamp. This sum is amplified, detected, and then read by the A/D for comparison against a window of acceptable values.

Test for Stuck DAC Switches

This large body of tests consisting of groups 60 to 69 checks each bit position of the DAC one at a time. Each of these tests simply looks for *any* change to occur as a result of changing the given analog switch from the zero voltage transformer tap to each of the other taps. Each test passes provided that a detectable change occurred. These tests are intended to find any analog switch elements that do not change in response to a command from the microprocessor.

A failure of a *single* test indicates a failed analog switch element or its connection to the transformer. In this case, the exact pin number associated with the failure is identified by the test.

A failure of *several* closely related tests requires identifying the meaning of the pattern of the failures. The pattern is likely to indicate a failure of the latch that controls the analog switch, of the interconnection between the two, or of a digital input of the analog switch.

All of these tests are looking for differences relative to the case where all DAC control digits are set to zero. As a result, the case of an analog switch stuck while connected to a transformer zero line is not explicitly reported. However, this case will produce its own characteristic symptoms. These symptoms show up as the failure of *all* other tests that try to produce a change relative to the stuck zero line.

Check Voltage Ratios from DAC

The second large body of tests consisting of groups 70 to 79 checks the ratios of voltages selected from the transformers. For the most part, the tests compare voltage ratios of adjacent transformer taps. The tests start with the highest transformer tap to the MSD of the IDAC. Selection of this tap is compared against the tap having the next lower voltage. The A/D checks that the ratio of these voltages is approximately correct. The comparison process continues with each pair of adjacent transformer taps, going from the MSD of the IDAC through the least significant. The process is repeated in precisely the same way for the QDAC.

A failure in these test groups with no failure in groups 60 to 69 may indicate a change in an associated precision DAC resistor, but this is not likely. The reason is that while these groups of tests check the resistors much better than the previous groups of tests, the resistors are still crudely measured relative to that done by the verification process described in "INTERNAL CALIBRATION" on page 9-4.

A more likely cause of failure is some kind of addressing problem. The previous body of tests looked for *any* change at all. The current body of tests look for the *right* change. This means that the current body of tests will detect a situation where the wrong transformer line was selected. These tests will also detect a situation where more than one transformer line is somehow selected (presumably with more than one analog switch IC).

Magnitude Test of S/P/B Generator

Test group 80 compares the magnitude but not the phase of the three different settings of the S/P/B quadrature generator against a single setting of the IDAC. The IDAC setting is first read by the A/D to verify that a reasonable signal level exists there to make comparisons against. Each of the remaining

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Table 11-16 S/P/B quadrature generator tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
80	*Test magnitude of S/P/B quadrature generator settings*		
80.1	Set MSD of IDAC to IP 1.0 using U122, A/D reads max of I & Q channels	IDAC makes reasonable signal at this setting	U118, U122, U127, U128
80.2	Set MSD of IDAC to IP 1.0 using U122, A/D reads max of I & Q channels, then reset IDAC, set S/P/B to S and MSD of QDAC to IP 1.0 using U138	A/D reads equal signals from IDAC vs. QDAC with S/P/B = S	U118, U122, U127, U134, U138, U140, U107-U112, U148
80.3	Set MSD of IDAC to IP 1.0 using U122, A/D reads max of I & Q channels, then reset IDAC, set S/P/B to P and MSD of QDAC to IP 1.0 using U138	A/D reads equal signals from IDAC vs. QDAC with S/P/B = P	U118, U122, U127, U134, U138, U140, U107-U112, U148
80.4	Set MSD of IDAC to IP 1.0 using U122, A/D reads max of I & Q channels, then reset IDAC, set S/P/B to B and MSD of QDAC to IP 1.0 using U138	A/D reads equal signals from IDAC vs. QDAC with S/P/B = B	U118, U122, U127, U134, U138, U140, U107-U112, U148
81	*Test phase of S/P/B quadrature generator settings*		
81.1	Set IDAC MSD to IP -0.1, ACG=4, A/D reads max of I & Q; Set S/P/B to B, set QDAC 2nd MSD to Q 1.0, and ACG=6	A/D sees at least a factor of ten decrease	U107-U112, U148, U122, U127, U139
81.2	Set IDAC MSD to IP 1.0, ACG=2, A/D reads max of I & Q; Set S/P/B to S, set QDAC MSD to Q 1.0 and ACG=4	A/D sees at least a factor of ten decrease	U107-U112, U148, U121, U125, U139
81.3	Set IDAC MSD to IP 1.0, ACG=2, A/D reads I & Q; Set S/P/B to P, set QDAC MSD to Q 1.0 and clear IDAC	90° phase shift calculated between A/D rdgs.	U107-U112, U148, U121, U125, U139
81.4	Set S/P/B to P, set QDAC MSD to Q 1.0, ACG=2, A/D reads I & Q; Then clear QDAC, set IDAC MSD to IP 1.0	90° phase shift calculated between A/D rdgs.	U107-U112, U148, U121, U125, U139

three tests note that level, then read the corresponding QDAC level for each of the S/P/B settings. The difference resulting from each of these three comparisons is calculated and checked to see if it falls within the expected window.

A failure of test 80.1 indicates a problem localized only to the circuitry associated with U122. A failure of all of the remaining three tests probably indicates a problem localized only to the circuitry associated with U138. A failure of only one or two of the last three tests indicates a failure of the corresponding circuitry in the S/P/B generator in Figure F-22 on page F-59.

Phase Tests of S/P/B Generator

Test group 81 is a more demanding set of tests of the S/P/B generator than the previous group. The first pair are null tests.

Test 81.1 is a precise null comparison of an IDAC setting against a QDAC setting with S/P/B set to Bypass. If all the DAC tests passed, this test is likely to do so also. If not, only the small amount of circuitry associated with Q105 is suspect. In Bypass mode, the quadrature generator is not connected at all which is why this test tends to be easy to pass.

Test 81.2 is another precise null comparison similar to 81.1, but S/P/B is set to Series. This time the QDAC is driven with a signal that is phase shifted by 180° relative to that driving the IDAC. This requires that the quadrature generator phase shifters be operable and that the circuitry which switches them work also. A failure of this test after passing the test 81.1 indicates a problem in the quadrature generator.

Tests 81.3 and 81.4 set S/P/B to Parallel which is the normal operating mode. In this case the QDAC is driven by a signal that is precisely phase shifted by 90° relative to that in the IDAC. These tests check to see if signals coming from these two sources are related to each other by approximately 90°. These two tests are identical except that the setup order is reversed between the two. This allows both test configurations to be reported. A failure of this test after passing tests 81.1 and 81.2 indicates a problem in the quadrature generator or its switching circuitry.

Test Relay Decade (RD) for Stuck Relays

Test groups 82 and 83 use the overload detector (U105) to identify a stuck relay in either relay decade. These tests try to find a situation where more than one relay can be closed in a given RD. If this occurs, the closed relays will directly short a winding of the main ratio transformer, requiring much more than the normal current to drive the transformer.

Table 11-17 Relay Decade (RD) tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
82	**Test MSRD for a stuck closed relay**		
82.1	Set MSRD to M1.0, 2nd MSRD open, set MUX to OVRLD	Suspect on PASS: K121	If a relay in this
82.2	Set MSRD to M0.9, 2nd MSRD open, set MUX to OVRLD	Suspect on PASS: K122	decade is stuck
82.3	Set MSRD to M0.8, 2nd MSRD open, set MUX to OVRLD	Suspect on PASS: K123	closed, the symptom
82.4	Set MSRD to M0.7, 2nd MSRD open, set MUX to OVRLD	Suspect on PASS: K124	will be that OVRLD
82.5	Set MSRD to M0.6, 2nd MSRD open, set MUX to OVRLD	Suspect on PASS: K125	will be detected for
82.6	Set MSRD to M0.5, 2nd MSRD open, set MUX to OVRLD	Suspect on PASS: K126	every test for this
82.7	Set MSRD to M0.4, 2nd MSRD open, set MUX to OVRLD	Suspect on PASS: K127	decade except for
82.8	Set MSRD to M0.3, 2nd MSRD open, set MUX to OVRLD	Suspect on PASS: K128	the one that is really
82.9	Set MSRD to M0.2, 2nd MSRD open, set MUX to OVRLD	Suspect on PASS: K129	stuck. In other
82.10	Set MSRD to M0.1, 2nd MSRD open, set MUX to OVRLD	Suspect on PASS: K130	words, if just one
82.11	Set MSRD to M0.0, 2nd MSRD open, set MUX to OVRLD	Suspect on PASS: K131	test passes, the
82.12	Set MSRD to M-0.1, 2nd MSRD open, set MUX to OVRLD	Suspect on PASS: K132	*passed* relay is bad.
83	**Test second MSRD for a stuck closed relay**		
83.1	Set 2nd MSRD to M1.0, MSRD open, set MUX to OVRLD	Suspect on PASS: K101	If a relay in this
83.2	Set 2nd MSRD to M0.9, MSRD open, set MUX to OVRLD	Suspect on PASS: K102	decade is stuck
83.3	Set 2nd MSRD to M0.8, MSRD open, set MUX to OVRLD	Suspect on PASS: K103	closed, the symptom
83.4	Set 2nd MSRD to M0.7, MSRD open, set MUX to OVRLD	Suspect on PASS: K104	will be that OVRLD
83.5	Set 2nd MSRD to M0.6, MSRD open, set MUX to OVRLD	Suspect on PASS: K105	will be detected for
83.6	Set 2nd MSRD to M0.5, MSRD open, set MUX to OVRLD	Suspect on PASS: K106	every test for this
83.7	Set 2nd MSRD to M0.4, MSRD open, set MUX to OVRLD	Suspect on PASS: K107	decade except for
83.8	Set 2nd MSRD to M0.3, MSRD open, set MUX to OVRLD	Suspect on PASS: K108	the one that is really
83.9	Set 2nd MSRD to M0.2, MSRD open, set MUX to OVRLD	Suspect on PASS: K109	stuck. In other
83.10	Set 2nd MSRD to M0.1, MSRD open, set MUX to OVRLD	Suspect on PASS: K110	words, if just one
83.11	Set 2nd MSRD to M0.0, MSRD open, set MUX to OVRLD	Suspect on PASS: K111	test passes, the
83.12	Set 2nd MSRD to M-0.1, MSRD open, set MUX to OVRLD	Suspect on PASS: K112	*passed* relay is bad.
84	**Test MSRD for any change between open and selected states**		
84.1	Set MSRD to open, enable Q608 shunt, A/D reads max of I & Q	MSRD generates reasonable open signal	K121-132, U145, U149, U150
84.2	Set MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M1.0	A/D sees any change, K121, p/o U145, U149	K121, U145, U149
84.3	Set MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.9	A/D sees any change, K122, p/o U145, U150	K122, U145, U150
84.4	Set MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.8	A/D sees any change, K123, p/o U145, U149	K123, U145, U149
84.5	Set MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.7	A/D sees any change, K124, p/o U145, U150	K124, U145, U150
84.6	Set MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.6	A/D sees any change, K125, p/o U145, U149	K125, U145, U149
84.7	Set MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.5	A/D sees any change, K126, p/o U145, U150	K126, U145, U150

Table 11-17 Relay Decade (RD) tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
84.8	Set MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.4	A/D sees any change, K127, p/o U145, U149	K127, U145, U149
84.9	Set MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.3	A/D sees any change, K128, p/o U145, U150	K128, U145, U150
84.10	Set MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.2	A/D sees any change, K129, p/o U145, U150	K129, U145, U150
84.11	Set MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.1	A/D sees any change, K130, p/o U145, U150	K130, U145, U150
84.12	Set MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.0	A/D sees any change, K131, p/o U145, U150	K131, U145, U150
84.13	Set MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M-0.1	A/D sees any change, K132, p/o U145, U150	K132, U145, U150
85	***Test second MSRD for any change between open and selected states***		
85.1	Set 2nd MSRD to open, enable Q608 shunt, A/D reads max of I & Q	MSRD generates reasonable open signal	K101-112, U144, U149, U151
85.2	Set 2nd MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M1.0	A/D sees any change, K101, p/o U144, U149	K101, U144, U149
85.3	Set 2nd MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.9	A/D sees any change, K102, p/o U144, U151	K102, U144, U151
85.4	Set 2nd MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.8	A/D sees any change, K103, p/o U144, U151	K103, U144, U151
85.5	Set 2nd MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.7	A/D sees any change, K104, p/o U144, U151	K104, U144, U151
85.6	Set 2nd MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.6	A/D sees any change, K105, p/o U144, U151	K105, U144, U151
85.7	Set 2nd MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.5	A/D sees any change, K106, p/o U144, U151	K106, U144, U151
85.8	Set 2nd MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.4	A/D sees any change, K107, p/o U144, U149	K107, U144, U149
85.9	Set 2nd MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.3	A/D sees any change, K108, p/o U144, U151	K108, U144, U151
85.10	Set 2nd MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.2	A/D sees any change, K109, p/o U144, U149	K109, U144, U149
85.11	Set 2nd MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.1	A/D sees any change, K110, p/o U144, U151	K110, U144, U151
85.12	Set 2nd MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.0	A/D sees any change, K111, p/o U144, U149	K111, U144, U149
85.13	Set 2nd MSRD to open, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M-0.1	A/D sees any change, K112, p/o U144, U151	K112, U144, U151
86	***Test relative signal levels from MSRD***		
86.1	Set MSRD to M1.0, enable Q608 shunt, A/D reads max of I & Q	MSRD generates signal, K121, p/o U145, U149	K121, U145, U149
86.2	Set MSRD to M1.0, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.9	MSRD generates 9<10, K122, p/o U145, U150	K122, U145, U150

Table 11-17 Relay Decade (RD) tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
86.3	Set MSRD to M0.9, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.8	MSRD generates 8<9, K123, p/o U145, U149	K123, U145, U149
86.4	Set MSRD to M0.8, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.7	MSRD generates 7<8, K124, p/o U145, U150	K124, U145, U150
86.5	Set MSRD to M0.7, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.6	MSRD generates 6<7, K125, p/o U145, U149	K125, U145, U149
86.6	Set MSRD to M0.6, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.5	MSRD generates 5<6, K126, p/o U145, U150	K126, U145, U150
86.7	Set MSRD to M0.5, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.4	MSRD generates 4<5, K127, p/o U145, U149	K127, U145, U149
86.8	Set MSRD to M0.4, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.3	MSRD generates 3<4, K128, p/o U145, U150	K128, U145, U150
86.9	Set MSRD to M0.3, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.2	MSRD generates 2<3, K129, p/o U145, U150	K129, U145, U150
86.10	Set MSRD to M0.2, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.1	MSRD generates 1<2, K130, p/o U145, U150	K130, U145, U150
86.11	Set MSRD to M0.1, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.0	MSRD generates 0<1, K131, p/o U145, U150	K131, U145, U150
86.12	Set MSRD to M0.0, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M-0.1	MSRD generates 0<1, K132, p/o U145, U150	K132, U145, U150
87	***Test relative signal levels from second MSRD***		
87.1	Set MSRD to M0.1, enable Q608 shunt, A/D reads max of I & Q; then set MSRD to M0.0, 2nd MSRD to M1.0 and again read max of I & Q	2nd MSRD relative to MSRD makes 1/1 ratio, K101, p/o U144, U149	K101, U144, U149
87.2	Set 2nd MSRD to M1.0, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.9	2nd MSRD makes 9<10, K102, p/o U144, U151	K102, U144, U151
87.3	Set 2nd MSRD to M0.9, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.8	2nd MSRD makes 8<9, K103, p/o U144, U151	K103, U144, U151
87.4	Set 2nd MSRD to M0.8, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.7	2nd MSRD makes 7<8, K104, p/o U144, U151	K104, U144, U151
87.5	Set 2nd MSRD to M0.7, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.6	2nd MSRD makes 6<7, K105, p/o U144, U151	K105, U144, U151
87.6	Set 2nd MSRD to M0.6, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.5	2nd MSRD makes 5<6, K106, p/o U144, U151	K106, U144, U151
87.7	Set 2nd MSRD to M0.5, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.4	2nd MSRD makes 4<5, K107, p/o U144, U149	K107, U144, U149
87.8	Set 2nd MSRD to M0.4, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.3	2nd MSRD makes 3<4, K108, p/o U144, U151	K108, U144, U151
87.9	Set 2nd MSRD to M0.3, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.2	2nd MSRD makes 2<3, K109, p/o U144, U149	K109, U144, U149
87.10	Set 2nd MSRD to M0.2, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.1	2nd MSRD makes 1<2, K110, p/o U144, U151	K110, U144, U151
87.11	Set 2nd MSRD to M0.1, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M0.0	2nd MSRD makes 0<1, K111, p/o U144, U149	K111, U144, U149
87.12	Set 2nd MSRD to M0.0, enable Q608 shunt, A/D reads max of I & Q; then set 2nd MSRD to M-0.1	2nd MSRD makes 0<1, K112, p/o U144, U151	K112, U144, U151

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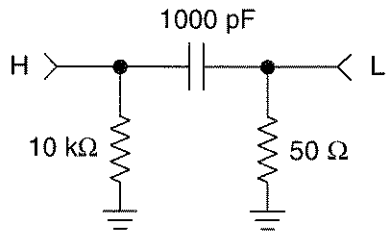
Figure 11-1 Schematic of PI network

These tests operate by closing each relay in a RD one at a time. If any relay in that decade is stuck closed, then *all* the tests for that decade will fail (detect an overload) *except* for the test that attempts to close the relay that is stuck closed. Closing the relay that is already stuck closed will be the only test in the group which has only one relay closed, all other tests will have two closed (assuming only one relay is stuck closed).

Test Decade Relay Positions for any Change

Test groups 84 and 85 check for any relay that is stuck closed *or* open. This is done by comparing the case where all relays are open with the cases where each relay is closed one at a time. The tests look for *any* change at all between the two cases. If any change is seen, then the selection logic is capable of selecting something and a relay is capable of going from open to closed.

Test Adjacent Relays for Relative Signal Level

Test groups 86 and 87 check each RD to ensure that of any two adjacent relays, the one intended to connect to the higher transformer tap generates a signal level that is higher also.

A failure of these tests only, probably indicates that the selection logic is not selecting the right relays.

Attenuator Tests

All but the first two (group 90) attenuator (ATN) tests require the connection of an external PI network between the HIGH and LOW terminals. Even though these tests require intervention, they are important tests and should be run if a problem is suspected, especially if an "H" error is being reported during normal measurements.

The External PI Network

When these tests are run, they will display a message on the front panel showing: ⌐onn PI HI to Lo. At this time the PI network must be connected. The network consists of a 1000 ±20% pF capacitor connected between the HIGH and LOW terminals. The HIGH terminal is shunted to ground with a 10 kΩ resistor. The LOW terminal is shunted to ground by a shielded 50Ω resistor. The schematic of this network is shown in Figure 11-1.
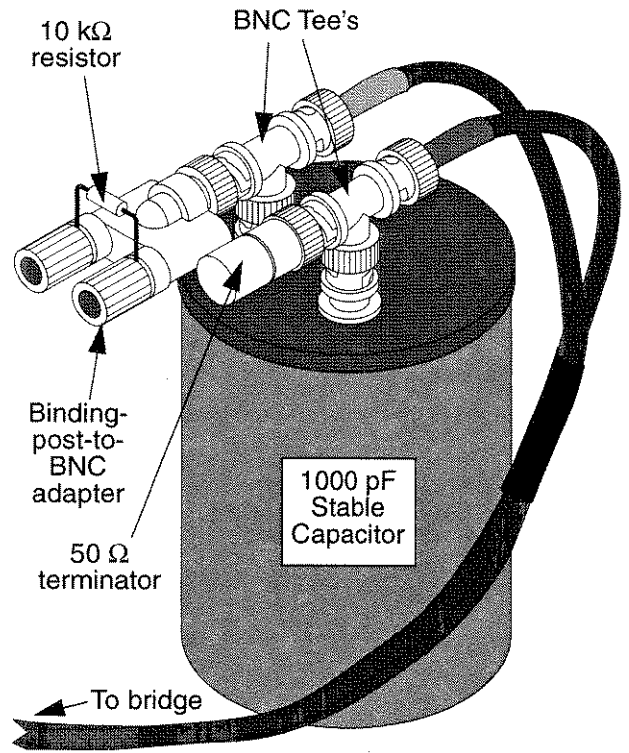
Figure 11-2 Picture of a typical PI network

The suggested physical configuration will have a dual BNC cable connecting a three-terminal, 1000 pF capacitor to the bridge. One BNC Tee must be inserted in series with each side of this cable. It doesn't matter which end of the cable the Tee's are on, but the capacitor end is probably more convenient. A 50 Ω BNC terminator is plugged into the Tee on the LOW side. A terminator is used here because it is an easy way to connect a shielded shunt resistor to the sensitive LOW input. A BNC to binding-post adapter should be plugged into the Tee connected to the HIGH side. An ordinary 10 kΩ resistor should be connected between the adapter's binding posts. Shielding of the 10 kΩ resistor is not needed due to the low impedance of the HIGH terminal. A picture of the suggested implementation of the network is shown in Figure 11-2.

The physical implementation described above uses only components that may be purchased off-the-shelf. Other physical implementations of the PI network will also work, provided that they are stable and do not allow the LOW input to pick up noise.

Test for Any Stuck Closed Relays in ATN

Test group 90 uses the overload detector to check for the presence of a stuck closed relay in the attenuator. Each of these two tests simply closes one of the two highest ATN relays and then checks the OVRLD line. If any other ATN relay is also closed, OVRLD will show it. This test does not identify which relay was stuck closed, only that one or more are stuck closed somewhere in the attenuator. Nevertheless, this information is useful when combined with the results of

Table 11-18 Attenuator tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
90	***Test ATN for presence of any stuck closed relays***		
90.1	Set both RD's open, ATN to 15V tap, set MUX to OVRLD	no OVRLD => no ATN relays stuck closed	U146, U147, U152, K113-120, K133-36
90.2	Set both RD's open, ATN to 7.5V tap, set MUX to OVRLD		
91	***Test ATN for stuck closed relays and set up for meter measurement***		
91.1	Prompt for connection of PI network with message: ⌐ o ⌐ ⌐ P I H I ⌐ o L o, set ATN to open, A/D reads max of I & Q	No ATN relays 0.03V or greater stuck closed	U146, U147, U152, K113-120, K133-36
92	***Test ATN for a stuck open or closed relay***		
92.1	Prompt for connection of PI network, set ATN to open, A/D reads both I & Q, then set ATN to 15V tap	All taps open vs. ATN at 15V tap changes reading	U146, U152, K113 stuck open or closed
92.2	Prompt for connection of PI network, set ATN to open, A/D reads both I & Q, then set ATN to 7.5V tap	All taps open vs. ATN at 7.5V tap changes reading	U146, U152, K114 stuck open or closed
92.3	Prompt for connection of PI network, set ATN to open, A/D reads both I & Q, then set ATN to 3.0V tap	All taps open vs. ATN at 3.0V tap changes reading	U146, U152, K116 stuck open or closed
92.4	Prompt for connection of PI network, set ATN to open, A/D reads both I & Q, then set ATN to 1.5V tap	All taps open vs. ATN at 1.5V tap changes reading	U146, U152, K115 stuck open or closed
92.5	Prompt for connection of PI network, set ATN to open, A/D reads both I & Q, then set ATN to 0.75V tap	All taps open vs. ATN at 0.75V changes reading	U146, U147, K117 stuck open or closed
92.6	Prompt for connection of PI network, set ATN to open, A/D reads both I & Q, then set ATN to 0.25V tap	All taps open vs. ATN at 0.25V changes reading	U146, U147, K118 stuck open or closed
92.7	Prompt for connection of PI network, set ATN to open, A/D reads both I & Q, then set ATN to 0.1V tap	All taps open vs. ATN at 0.1V tap changes reading	U146, U152, K119 stuck open or closed
92.8	Prompt for connection of PI network, set ATN to open, A/D reads both I & Q, then set ATN to 0.03V tap	ATN taps open vs. ATN at 0.03V changes reading	U146, U152, K120 stuck open or closed
92.9	Prompt for connection of PI network, set ATN to open, A/D reads both I & Q, then set ATN to 0.01V tap	All taps open vs. ATN at 0.01V changes reading	U146, U152, K133 stuck open or closed
92.10	Prompt for connection of PI network, set ATN to open, A/D reads both I & Q, then set ATN to 0.003V tap	All taps open vs. ATN at 0.003V changes reading	U146, U147, K134 stuck open or closed
92.11	Prompt for connection of PI network, set ATN to open, A/D reads both I & Q, then set ATN to 0.001V tap	All taps open vs. ATN at 0.001V changes reading	U146, U147, K135 stuck open or closed
92.12	Prompt for connection of PI network, set ATN to open, A/D reads both I & Q, then set ATN to 0.0V tap	All taps open vs. ATN at 0.0V changes reading	U146, U152, K136 stuck open or closed
93	***Test ATN setup for voltage ratios tests***		
93.1	Prompt for connection of PI network, set ATN to 15V tap; A/D reads max of I & Q; exit reporting I	A/D reads within expected range	U146, U152, K113
93.2	Prompt for connection of PI network, set ATN to 15V tap; A/D reads max of I & Q; exit reporting Q	A/D reads within expected range	U146, U152, K113
94	***Test ATN for correct voltage ratios***		
94.1	Prompt for connection of external PI network, set ATN to 15V tap, A/D reads max of I & Q; then set ATN to 7.5V tap	15/7.5 ratio is correct	U146, U152, K113, K114
94.2	Prompt for connection of external PI network, set ATN to 7.5V tap, A/D reads max of I & Q; then set ATN to 3.0V tap	7.5/3.0 ratio is correct	U146, U152, K114, K116
94.3	Prompt for connection of external PI network, set ATN to 3.0V tap, A/D reads max of I & Q; then set ATN to 1.5V tap	3.0/1.5 ratio is correct	U146, U152, K115, K116

C04

Table 11-18 Attenuator tests

Test no.	Description	Parts/signals verified on PASS	Parts/signals suspect on FAIL
94.4	Prompt for connection of external PI network, set ATN to 1.5V tap, A/D reads max of I & Q; then set ATN to 0.75V tap	1.5/0.75 ratio is correct	U146, U147, U152, K115, K117
94.5	Prompt for connection of external PI network, set ATN to 0.75V tap, A/D reads max of I & Q; then set ATN to 0.25V	0.75/0.25 ratio is correct	U146, U147, K117, K118
94.6	Prompt for connection of external PI network, set ATN to 0.25V tap, A/D reads max of I & Q; then set ATN to 0.1V tap	0.25/0.1 ratio is correct	U146, U147, U152, K118, K119
94.7	Prompt for connection of external PI network, set ATN to 0.1V tap, A/D reads max of I & Q; then set ATN to 0.03V tap	0.1/0.03 ratio is correct	U146, U152, K119, K120
94.8	Prompt for connection of external PI network, set ATN to 0.03V tap, A/D reads max of I & Q; then set ATN to 0.01V	0.03/0.01 ratio is correct	U146, U152, K120, K133
94.9	Prompt for connection of external PI network, set ATN to 0.01V tap, A/D reads max of I & Q; then set ATN to 0.003V	0.01/0.003 ratio is correct	U146, U147, U152, K133, K134
94.10	Prompt for connection of external PI network, set ATN to 0.003V tap, A/D reads max of I & Q; then set ATN to 0.001V	0.003/0.001 ratio is correct	U146, U147, K134, K135
94.11	Prompt for connection of external PI network, set ATN to 0.001V tap, A/D reads max of I & Q; then set ATN to 0.0V	0.001>0.0	U146, U147, U152, K135, K136

test group 92 since that group is unable to distinguish a stuck closed relay from one that is stuck open.

Test for Specific Stuck Closed or Open Relays

Two test groups are involved here. Test group 91 has one preliminary test that basically checks that the external PI network produces the expected signal levels. This test will also fail if certain ATN relays are stuck closed, but the previous test group is more suitable for this purpose.

This test is also useful because it leaves all the attenuator relays open when it is finished. This means that a meter reading of the AC voltage on the HIGH terminal should be less than 0.3 mV provided that the meter is shunted by a 2kΩ resistor. If a higher voltage is read by the meter, then it is because an attenuator relay is stuck closed. The voltage read by the meter should be exactly the same as the transformer tap voltage selected by the stuck relay. The relationship between transformer tap voltages and the relays that select these is given in test group 92 of Table 11-18. For example, suppose the meter reads 1.5 volts. Then test number 92.4 shows that the 1.5 V transformer tap is selected by relay K115 and that is the relay that is stuck.

Test group 92 contains tests that check each ATN relay one by one. These tests check for any relay that is stuck closed *or* open. Each test first sets all ATN relays open, then reads the same I and Q signals that were read in the previous test group (91). Each test then compares these I and Q baseline readings with I and Q readings taken with one relay closed. If *any* change in the I or Q readings is detected, the test passes. The detection of a change indicates that the selection logic is

capable of selecting something and a relay is capable of going from open to closed.

Check Attenuator Voltage Ratios

Test groups 93 and 94 compare the voltages produced by adjacent attenuator settings. Test group 93 just uses the A/D to measure both phases resulting from setting the ATN to 15 V. The higher of these values is also measured as the starting point for test group 94. This is done by test 94.1 which checks the 15/7.5 ratio.

Test group 93 is not very useful by itself for checking the attenuator, however, it is unique because it sets up the whole bridge circuit in a way that allows some exploration. The effects of creative modification of the PI network can be observed in the two-phase readings that are taken by the A/D and reported by this test group.

In each test of group 94, the A/D reads the voltages produced by adjacent attenuator settings, calculates the ratio and compares it against the expected value. These tests are not intended to detect small errors in the ratios; that is the job of the verification/calibration routines. A failure of these tests only, probably indicates that the selection logic is not selecting the right relays.

NOTE

Some attenuator voltages might be half of what you expect. Check the Full/Half setting (f) in the result line. If it is zero, then the voltage at the HIGH terminal will be half of the nominal tap voltage label.

Front of AH 2500A
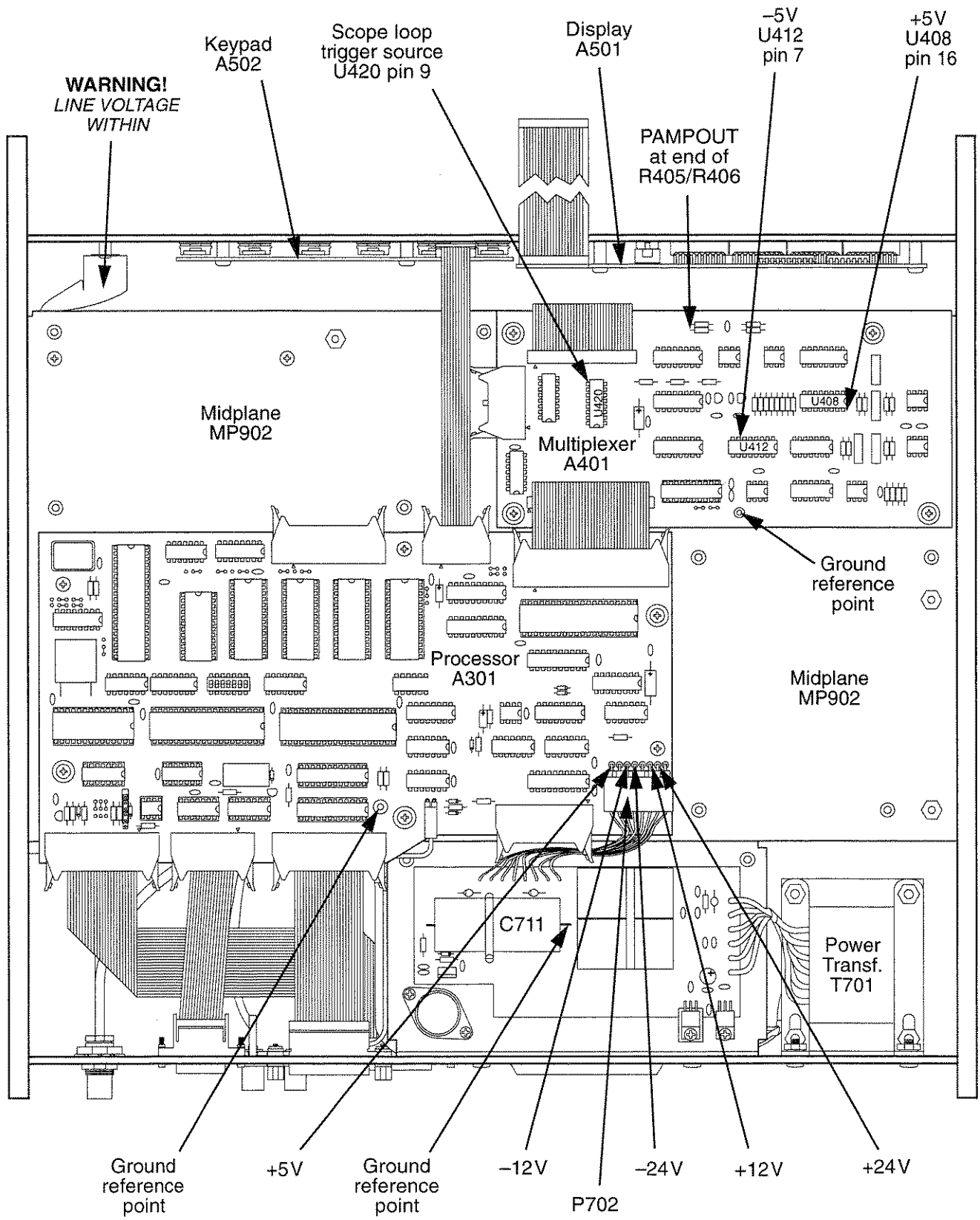
Figure 11-3 AH 2500A top view showing power and other test points

Front of AH 2500A

R104

Ground
reference
point

+5V
U122
pin 16

−5V
U122
pin 7

Base of Q201,
pin 3 of J114

−0.537 V
C201
OVEN

R201/R202
reference,
pin 6 of J114

+18V
Anode of
CR104

Capacitance
standard
C210

WARNING!
*BIAS VOLTAGE
MAY BE
PRESENT*

R624

Preamp
A601

Main board A101

Power Supply A701

Power
Transf.
T701

Power line
input module

Dynamic
oven point
U202 pin 6

WARNING!
*LINE VOLTAGE
WITHIN*

−5V
U603
pin 7

Ground
reference
point

WARNING!
*BIAS VOLTAGE
MAY BE
PRESENT*

+5V
U603
pin 16

R615

Figure 11-4 AH 2500A bottom view showing power and other test points

Table 11-19 EEPROM (U304) errors, consequences and repair procedures

Power-on error	Execution error	Effect of error	Repair procedure
`EEProM` `Error hh` where hh = `00 - 1b`	`CAL dAtA` `Error 0`	Measurements are not possible	Non-option-E: Re-write the Original calibration data by performing the operation described in step 13 of "Standard Capacitor Installation Procedure" on page 12-12. Option-E: The EEPROM must be replaced at the factory.
`EEProM` `Error hh` where hh = `1C - 25`	`CAL dAtA` `Error 1`	Measurements are not possible	Non-option-E: Re-write the Internal calibration data by performing the procedure described in "INTERNAL CALIBRATION" on page 9-4. (A capacitance calibration will also generate the Internal calibration data.) Option-E: Same as non-Option-E. (A transformer calibration will also generate and store the internal cal data.)
`EEProM` `Error 26`	`CAL dAtA` `Error 2`	Measurements are not possible	Non-option-E: Re-write the Capacitance Update calibration data by performing the procedure described in "CAPACITANCE CALIBRATION" on page 9-9. Option-E: Same as non-Option-E.
`EEProM` `Error hh` where hh = `27 - 2d`	`CAL dAtA` `Error 3`	Measurements are not possible	Non-option-E: Does not apply Option-E: Re-write the Transformer Update calibration data by performing the procedure described in "TRANSFORMER CALIBRATION" on page 9-12.
`EEProM` `Error hh` where hh = `2E - 75`	`EEProM` `Error 2E`	File operations are not possible	Initialize the file space by performing the DELETE command with no qualifiers.
`EEProM` `Error hh` where hh = `76 - 77`	None	Bridge is totally inoperable	The EEPROM must be replaced.
`EEProM` `Error 80`	None	Bridge is totally inoperable	The EEPROM must be replaced.
`EEProM` `Error 81`	None	Elapsed hours timer is inoperable	The EEPROM must be replaced if the timer is to work.
`EEProM` `Error 82`	None	Correct passcodes are not accepted	Non-option-E: Re-enter the User, Calibrator and Replace passcodes described in "THE CALIBRATION PASSCODES" on page 9-17. Option-E: Re-enter the User and Calibrator passcodes

Chapter 12   Disassembly/Reassembly

This chapter describes how to remove and replace all the major subassemblies that comprise the AH 2500A. For an experienced technician, much of what is described here will be obvious. However, there are a number of subtleties that are specific to the AH 2500A that must be correctly dealt with if the instrument is not to be damaged and its performance is not to be impaired. For this reason, no matter how much experience you may have, you are cautioned to read the sections in this chapter that apply to any repairs that you attempt to perform.

WARNING !

The information in this section is for the use of trained service personnel only. Electrical shock and other hazards may be present. Do not attempt to perform these procedures unless you are qualified to do so. Remove the power line cord before removing the covers or removing or replacing any boards.

Tools and Equipment Required

You need the following tools to perform the disassembly/reassembly procedures that follow.

1. #2 Phillips head screwdriver.

2. Small flat blade screwdriver.

3. Torque screwdriver set to 18 in-lbs (200 N-cm) with a #2 Phillips bit.

4. Right-angle torque wrench set to 18 in-lbs (200 N-cm) with a #2 Phillips bit.

5. Right-angle torque wrench set to 75 in-lbs (800 N-cm) with a deep 5/8 inch (16 mm) hex socket.

6. Diagonal cutters.

7. Integrated circuit insertion/extraction tool for 24 & 28-pin IC for replacing firmware.

8. Soldering equipment if you are replacing the power supply (A701) assembly.

Integrated Circuit Removal Techniques

It is easy to damage a printed circuit board in the process of trying to remove an integrated circuit (IC). The damage usually results from trying to "save" the IC which requires heating all of its pins simultaneously. This is a difficult process which always applies more heat to the circuit board than is needed and often applies enough to cause damage.

Since the AH 2500A circuit boards are much more valuable than any IC on them, no attempt should ever be made to "save" an IC. With this philosophy, any DIP IC can easily be removed with a minimal possibility of damaging the circuit board that it is on. The steps in this process are:

1. Working from the parts-side of the circuit board with a fine pair of diagonal cutters, clip each lead of the IC that is to be removed. The clipping must be done as close to the *body* of the IC as possible. When all are clipped, the (now leadless) body of the IC will come right out.

2. A soldering iron can now heat each lead from the solder-side of the circuit board while a fine pair of pliers used from the parts-side of the board pulls the clipped lead from the plated-through hole when the solder has melted.

3. The solder is now ready to be removed from the holes, but no flux is on the solder. This will make it flow with more difficulty than otherwise. Applying a little fresh rosin-core solder to each hole will greatly improve the solder's ability to flow.

4. A solder-sucker can now remove the solder from each plated-through hole. The fresh flux applied in the previous step should cause the cleared holes to be clean and shiny.

CAUTION

To prevent static damage to the instrument, always observe the following anti-static techniques when handling any boards or assemblies.

Anti-static Handling Techniques

Electrostatic discharge (ESD) can be a cause of electronic component failure. It can occur at static levels below human perception and can affect both passive and active devices. The following guidelines should be observed when handling assemblies used in the AH 2500A.

1. The workbench should be covered with a conductive mat that is connected to earth ground through a 1 Megohm resistor.

2. You should wear a conductive wrist strap that is attached to earth ground through a 1 megohm resistor.

3. Metal equipment at the workstation must be grounded, including shelving and soldering and de-soldering equipment. One common ground should be provided at the workstation.

4. Non-conductors such as plastics and cardboard should not be present at the workstation and there should not be rugs or carpet on the floor.

5. Anti-static material should always be used for shipping, storing and transporting electronic assemblies.

Hardware Used for Disassembly and Reassembly

Table 12-1 lists the hardware used in the disassembly/reassembly procedures described in this chapter.

CAUTION

*The chassis of the AH 2500A forms an integral part of its circuitry. Printed circuit boards and other components must make very low resistance contact at their points of attachment to the chassis. All screws that are loosened must be re-tightened to the value of torque specified by the procedures. Failure to do so can cause subtle performance problems. (**Don't** even think about not installing all the screws!)*

Screws holding printed circuit boards will become looser with time due to relaxation in the circuit board. This is acceptable, but only emphasizes the need to fully tighten any screws that are loosened during repair.

Table 12-1 Hardware used in disassembly/ reassembly

Part	Used for
6-32 x 1/4 Phillips pan-head screw	Mounting Keypad and Display boards. Securing HIGH coaxial cable shield.
6-32 x 1/4 Phillips oval-head screw	Large, brown, vinyl-covered side panels.
6-32 x 3/8 Phillips oval-head screw	Small, brown, vinyl-covered side covers.
6-32 x 1/2 Phillips oval-head screw	Top and bottom bezels.
6-32 x 7/16 Phillips truss-head screw	Top and bottom covers.
6-32 x 3/8 Phillips pan-head screw	Mounting all boards except Keypad and Display boards. Securing LOW input shield, standard capacitor coax shield, and bias coax shield. Front feet.
8-32 x 3/8 Phillips pan-head screw	Preamp cover. Power supply assembly mounting. Lockwashers required with power supply.

...but I've *never* put all the screws back, much less tightened them to the specified torque...

Figure 12-1 Consequences of sloppy workmanship

REMOVAL AND INSTALLATION PROCEDURES

Removal and Installation of Covers

Prior to Cover Removal

1. Remove all external equipment connections from the AH 2500A.

2. Disconnect the power line cord from the AH 2500A.

Top Cover Removal Procedure

1. Place the instrument top side up with the front panel facing you.

2. Identify the two bezel screws with the help of Figure 12-2. Loosen these screws two turns.

3. Remove the four screws holding the large, brown top cover.

4. Refer to Figure 12-2. Place the instrument on end as shown in the figure, with the front panel facing down and the top cover facing you.

5. Remove the top cover by pulling straight up.

Bottom Cover Removal Procedure

1. Place the instrument bottom side up with the front panel facing you.

2. Loosen the two bottom bezel screws two turns. These screws are in a position opposing that shown in Figure 12-2.

3. Remove the four bottom cover screws holding the large, brown bottom cover.

4. Refer to Figure 12-2. Place the instrument on end as shown in the figure, with the front panel facing down but with the bottom cover facing you.

5. Remove the bottom cover by pulling straight up. If you feel resistance at about the position of the cover shown in the figure, check to see if the screws holding the front feet are interfering with the edge of the midplane or with the rear panel. If they are, pull the center of the bottom cover toward you enough to allow the screws to clear the midplane or rear panel. The midplane is easily identified as MP902 in the exploded parts view Figure F-3 on page F-9.
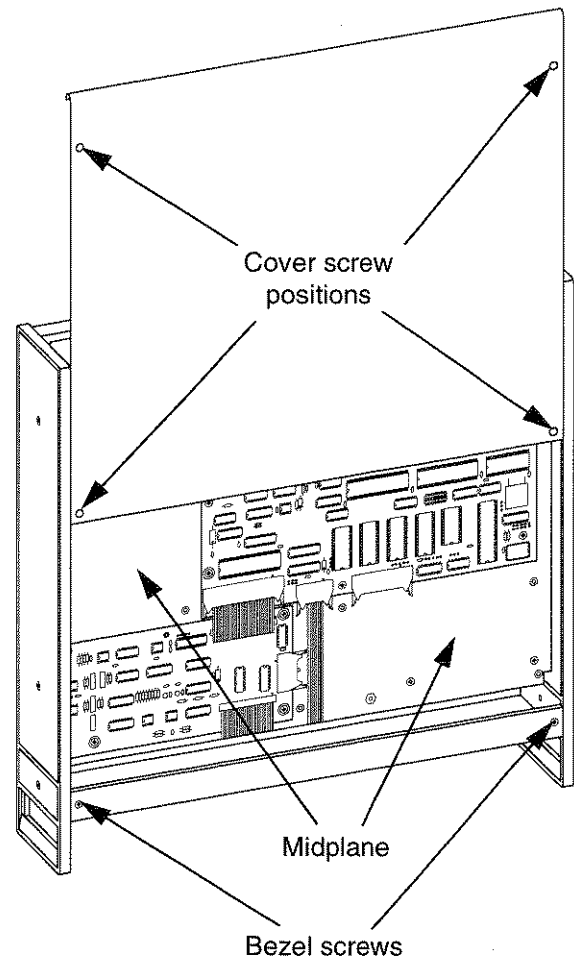
Figure 12-2 Cover removal and installation

Top Cover Installation Procedure

1. Refer to Figure 12-2. Place the instrument on end with the front panel facing down and the top of the bridge facing you.

2. Install the top cover by sliding it *straight* down. If you feel resistance, be sure that the cover is straight. Slight misalignment is enough to cause it to bind in its track.

3. Place the bridge top side up with the front panel facing you.

CAUTION

Over-tightening the cover screws may permanently deform the cover. Use only enough force to tighten the screws and not deform the cover. DO NOT use a torque screwdriver on these screws.

---

4. Install but do not tighten the four 6-32 x 7/16 truss-head top cover screws.

5. Securely tighten the two screws holding the bezel.

A701 to Midplane screws (underside)

A301

J302

Midplane
(MP902)

Cut here to
remove A701

Transformer
T701

Cable ties

Power switch
cable (W701)

A701

External trigger
cable (W918)

A701 to Backpanel screws
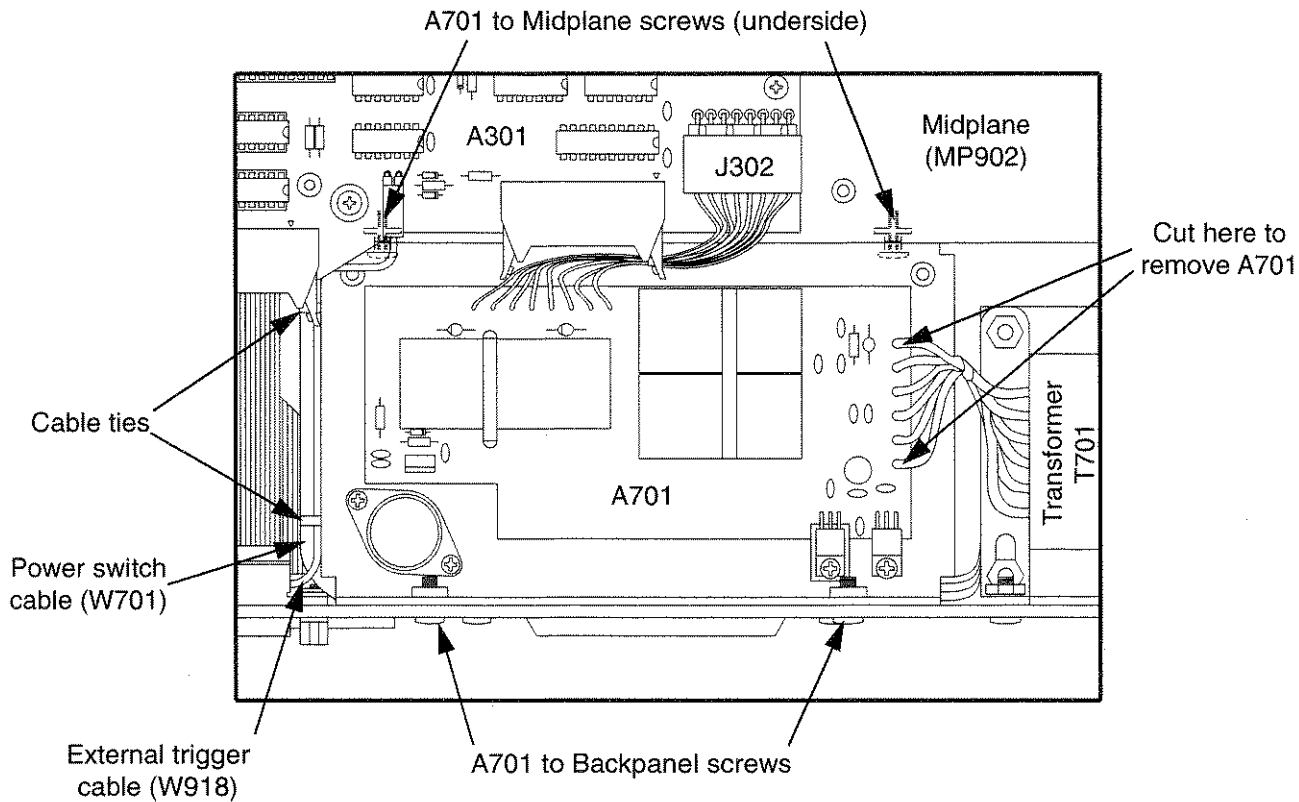
Figure 12-3 Power supply assembly (A701) detail

6. Tighten the four top cover screws. See the caution above.

7. Calibration requirements for replacement of individual subassemblies are given in the associated procedures. If you are uncertain as to whether you have done anything that may require additional calibration, it is a good idea to perform verifications on the bridge as described in Chapter 9, "Verification/Calibration".

Bottom Cover Installation Procedure

1. Refer to Figure 12-2. Place the bridge on end as shown in the figure with the front panel facing down but with the bottom of the bridge facing you.

2. Install the bottom cover by sliding it *straight* down. If you feel resistance, be sure that the cover is straight. Slight misalignment is enough to cause it to bind in its track. If you still feel resistance, check to see if the screws holding the front feet are interfering with the midplane or the rear panel. If they are, pull the center of the bottom cover towards you enough to allow the screws to clear the edge of the midplane or rear panel. The midplane is easily identified as MP902 in the exploded parts view Figure F-3 on page F-9.

3. Place the bridge bottom side up with the front panel facing you.

4. Install but do not tighten the four 6-32 x 7/16 truss-head top cover screws.

CAUTION

Over-tightening the cover screws may permanently deform the cover. Use only enough force to tighten the screws and not deform the cover. DO NOT use a torque screwdriver on these screws.

---

5. Securely tighten the two screws holding the bezel.

6. Tighten the four bottom cover screws. See the caution above.

7. Calibration requirements for replacement of individual subassemblies are given in the associated procedures. If you are uncertain as to whether you have done anything that may require additional calibration, it is a good idea to perform verifications on the bridge as described in Chapter 9, "Verification/Calibration".

Power Supply (A701) Removal and Installation

Power Supply Removal Procedure

1. Remove the top and bottom covers using the procedures in "Removal and Installation of Covers" on page 12-3.

2. Place the bridge bottom side up with the rear panel facing you.

3. Refer to Figure 12-3. Remove the two screws and lockwashers holding the power supply assembly to the midplane.

4. Place the bridge top side up with the rear panel facing you.

5. Unplug the power connector that is attached to J302 on the processor board (A301).

6. Using a pair of diagonal cutters, cut off the six wire leads from the power transformer secondary windings as close to the power supply board as possible.

7. Using a pair of diagonal cutters, cut off and remove the two cable ties holding the power switch cable (W701) and external trigger coaxial cable (W918).

8. Remove the two screws and lockwashers holding the power supply assembly (A701) to the rear panel and remove the power supply assembly from the bridge.

Power Supply Installation Procedure

1. Place the bridge top side up with the rear panel facing you.

2. Carefully strip 1/8 inch of insulation from the ends of the power transformer leads. This must be done *very* gently since the leads are easily pulled out of the transformer.

3. Refer to Figure 12-3. Orient the power supply assembly (A701) and place it into the bridge chassis. Install the two 8-32 x 3/8 pan-head screws and two #8 lockwashers that attach the power supply assembly to the rear panel. The lockwashers go on the outside of the back panel.

4. Plug the power connector from the power supply assembly into J302 of the processor board (A301).

5. Put the stripped ends of the power transformer leads into the holes on the power supply board according to the wire color codes near the holes. These will be soldered to the opposite side of the board.

6. Turn the bridge over so the bottom is facing up and the rear panel is towards you.

7. Install the two 8-32 x 3/8 pan-head screws and two #8 lockwashers that attach the power supply assembly to

the midplane. The lockwashers must be directly under the heads of the screws.

8. Stand the bridge with the front panel facing down and the bottom of the bridge towards you.

9. Using a torque wrench, tighten these two screws and the two that attach the power supply to the rear panel to 18 in-lbs (200 N-cm).

10. Lay the bridge down with the bottom facing up and the rear panel towards you.

11. Solder the six wires from the power transformer secondary windings to the pads of the printed circuit board.

12. Using two cable ties, secure the power switch cable and the external trigger cable to the power supply assembly at each of the two sets of holes in the power supply frame.

13. Check the power supply voltages using the procedure described in "Checking Power Supply Voltages" on page 11-4.

14. If the voltages are now correct, then install the covers using the procedures in "Removal and Installation of Covers" on page 12-3.

15. If no other change was made to the bridge, the calibration should not have changed. Refer to Chapter 9, "Verification/Calibration" if you need to verify this.

Processor Board (A301) Firmware Replacement

Firmware Replacement Information

The firmware for the AH 2500A consists of one EEPROM (U304) and three ROMs (U305, U306 and U307). located on the processor board (A301).

The EEPROM contains factory generated information that is unique to a particular bridge and is usually replaced only if a failure occurs.

The three ROMs contain the operating firmware for the bridge and are always replaced as a complete set. There are several ROM versions of these sets. The correct set to use depends on the serial number of the bridge.

CAUTION

Observe the handling methods described in "Anti-static Handling Techniques" on page 12-2 when replacing any of the firmware components.

The procedures below describe replacing both the EEPROM and the ROM sets. If you are replacing only the EEPROM or only the ROM sets, skip the steps that are not appropriate.

Firmware Removal Procedure

1. Remove the top cover using the "Top Cover Removal Procedure" on page 12-3.

2. Place the bridge top side up with the rear panel facing you.

3. Refer to Figure 12-5 on page 12-14. Locate the processor board (A301) and on it locate the EEPROM and socket labeled U304. Using an integrated circuit extractor or a small flat-blade screwdriver, carefully pry the EEPROM loose. Make sure it comes straight up out of its socket to avoid bending the pins in case you should need to re-install it later.

4. Locate the three ROMs and sockets labeled U305, U306 and U307. Using an integrated circuit extractor or a small flat-blade screwdriver, carefully pry the three ROMs loose. Make sure they come straight up and out of their sockets to avoid bending the pins in case you should need to re-install them later.

Firmware Installation Procedure

1. Locate the socket labeled U304 on the processor board (A301). Remove the EEPROM labeled U304 from the conductive foam it is shipped in and orient it so the semicircular notch indicating pin 1 faces towards you. The notched end of the EEPROM will match up with the notch symbol silkscreened underneath the socket if the EEPROM is oriented properly. Align the pins and insert the EEPROM into the socket U304.

2. Locate the sockets labeled U305, U306 and U307 on the processor board (A301). Remove the three ROMs labeled U305, U306 and U307 from the conductive foam they are shipped in and orient them so the semicircular notch indicating pin 1 faces towards you. The notched end of the ROMs will match up with the notch symbols silkscreened underneath the sockets if the ROMS are oriented properly. Align the pins and insert the ROM labeled U305 into the socket labeled U305. Do the same with U306 and U307.

3. Install the top cover using the "Top Cover Installation Procedure" on page 12-3.

4. If the ROMs were replaced by others with the same version numbers, then the bridge should be ready to operate. If the version was different, or if the EEPROM was replaced, then follow the instructions that come with the replacement parts.

Processor Board (A301) Removal and Installation

Processor Board Removal Procedure

1. To replace the processor board *without* replacing the firmware, first perform the "Firmware Removal Procedure", then skip to step four of this procedure.

2. To replace the processor board *and* the firmware it contains, start with this step. Remove the top cover using the "Top Cover Removal Procedure" on page 12-3.

3. Place the bridge top side up with the rear panel facing you.

4. Refer to Figure 12-5 on page 12-14. Unplug the power supply power connector from J302.

5. Unlatch and unplug the six ribbon cable assemblies in the following order from J306, J304, J303, J313, J305, and J312. Unplug the external trigger cable (W918) from J318.

6. Remove the six screws holding the processor board and remove the board.

Processor Board Installation Procedure

1. Place the bridge top side up with the rear panel facing you.

2. Refer to Figure 12-5 on page 12-14. Orient the processor board (A301) and install the six 6-32 x 3/8 pan-head mounting screws.

3. Using a torque screwdriver, tighten the six screws to 18 in-lbs (200 N-cm).

4. Plug the external trigger cable (W918) into J318 of the processor board. The orientation of the plug in the socket does not matter.

5. Plug in and latch the ribbon cable from the keypad assembly (A502) into J306.

6. Plug in and latch the ribbon cable from the multiplexer assembly (A401) into J303.

7. Plug in and latch the ribbon cable from the display assembly (A501) into J304.

8. Plug in and latch the GPIB cable assembly (W913) into J313.

9. Plug in and latch the sample switch cable assembly (W905) into J305.

10. Plug in and latch the RS-232 cable assembly (W912) into J312.

11. Plug in the power supply (A701) power connector into J302.

12. If the processor board does not have the firmware installed, follow the "Firmware Installation Procedure" otherwise install the top cover using the "Top Cover Installation Procedure" on page 12-3.

13. If the firmware was reused, the bridge should be operational. Refer to Chapter 9, "Verification/Calibration" if you need to verify this.

Display Board (A501) Removal and Installation

Display Board Removal Procedure

1. Remove both covers using the procedures in "Removal and Installation of Covers" on page 12-3.

2. Place the bridge bottom side up with the rear panel facing you.

3. Remove the two screws holding the lower edge of the display board.

4. Place the bridge top side up with the rear panel facing you.

5. Remove the two screws holding the top bezel and remove the top bezel.

6. Refer to Figure 12-5 on page 12-14. Unlatch and unplug the ribbon cable from J304 on the processor board (A301).

7. Remove the two screws holding the upper edge of the display board and remove the board.

Display Board Installation Procedure

1. Refer to Figure 12-5 on page 12-14. Orient the display board (A501) and install it from the top side of the bridge. Install the two pan-head 6-32 x 1/4 screws that hold the upper edge of the board in place.

2. Plug the display board ribbon cable into J304 on the processor board and latch it.

3. Place the bridge bottom side up with the rear panel facing you. Install the two pan-head 6-32 x 1/4 screws that hold the lower edge of the board.

4. Place the bridge on end with the front panel facing down and the bottom facing you. While supporting the front panel from below so as not to bend it, tighten the two lower screws to 18 in-lbs (200 N-cm). The front panel is easily supported by squeezing it with one hand up against the bottom bezel.

5. Turn the bridge so the front panel is facing down and the top is facing you. While again supporting the front panel from below, tighten the two upper screws to 18 in-lbs (200 N-cm).

6. Install the top bezel but do not tighten the screws.

7. Install the covers using the procedures in "Removal and Installation of Covers" on page 12-3.

8. Use the test in "Test front panel display LED segments" on page 11-13 to check the operation of the display.

Keypad Board (A502) Removal and Installation

Keypad Board Removal Procedure

1. Remove both covers using the procedures in "Removal and Installation of Covers" on page 12-3.

2. Place the bridge bottom side up with the rear panel facing you.

3. Refer to Figure 12-6 on page 12-15. Remove the bottom bezel (MP921).

4. Remove the two screws holding the lower edge of the keypad board.

5. Place the bridge top side up with the rear panel facing you.

6. Refer to Figure 12-5 on page 12-14. Unlatch and unplug the ribbon cable from J306 on the processor board.

7. Remove the two screws holding the upper edge of the keypad board and remove the board.

Keypad Board Installation Procedure

1. Place the bridge top side up with the rear panel facing you.

2. Refer to Figure 12-6 on page 12-15. Orient the keypad board (A502) and install it from the top side of the bridge. Install the two pan-head 6-32 x 1/4 screws that hold the upper edge of the board in place.

3. Plug the ribbon cable into J306 on the processor board (A301) and latch it.

4. Place the bridge bottom side up with the rear panel facing you. Install the two pan-head 6-32 x 1/4 screws that hold the lower edge of the board.

5. Turn the bridge so the front panel is facing down and the top is facing you. While supporting the front panel from below so as not to bend it, tighten the two upper screws to 18 in-lbs (200 N-cm). The front panel is easily supported by squeezing it with one hand up against the top bezel.

6. Turn the bridge so the front panel is facing down and the bottom is facing you. While again supporting the front panel from below, tighten the two upper screws to 18 in-lbs (200 N-cm).

7. Turn the bridge so the bottom side is up and the front panel is facing you. Install the bottom bezel but do not tighten the screws.

8. Install both covers using the procedures in "Removal and Installation of Covers" on page 12-3.

Multiplexer Board (A401) Removal and Installation

Multiplexer Board Removal Procedure

1. Remove both covers using the procedures in "Removal and Installation of Covers" on page 12-3.

2. Place the bridge bottom side up with the front panel facing you.

3. Refer to Figure 12-6 on page 12-15. Unlatch and unplug the ribbon cable that is attached to J110 on the main board (A101).

4. Place the bridge with the top side up and the front panel facing you.

5. Refer to Figure 12-5 on page 12-14. Unlatch and unplug the display board ribbon cable from J304 on the processor board to allow access to J303 on the processor board.

6. Unlatch and unplug the ribbon cable that is attached to J303 on the processor board (A301).

7. Remove the four screws holding the multiplexer board and remove the board.

Multiplexer Board Installation Procedure

1. Place the bridge top side up with the front panel facing you.

2. Refer to Figure 12-5 on page 12-14. Orient the multiplexer board (A401) and install it from the top side of the bridge. Route the ribbon cable from J410 on the multiplexer board down between the display board and the midplane. This cable will be attached to the main board (A101) later. Install the four 6-32 x 3/8 pan-head screws to hold the multiplexer board in place.

3. Tighten all four screws to 18 in-lbs (200 N-cm).

4. Plug the ribbon cable from J403 on the multiplexer board (A401) into J303 on the processor board (A301) and latch it.

5. Plug the display board ribbon cable into J304 on the processor board and latch it.

6. Turn the bridge over so the bottom side is up and the front panel is facing you.

7. Refer to Figure 12-6 on page 12-15. Plug the ribbon cable from J410 on the multiplexer board into J110 on the main board (A101) and latch it.

8. If the multiplexer board has been replaced with a different one or if U409 has been replaced on it, the calibration of the HIGH terminal output voltage must be checked/adjusted. The procedure for this is given in "Adjustment of HIGH Terminal Signal Level" on page 11-22.

9. Install both covers using the procedures in "Removal and Installation of Covers" on page 12-3.

10. Replacement of the multiplexer board requires that an internal calibration be performed on the bridge. See "INTERNAL CALIBRATION" on page 9-4. No other calibration is affected.

Main Board (A101) Removal and Installation

Note that the main board is replaceable with a *different* main board *only* if the bridge is *not* an Option-E. Due to the special equipment and calibration procedures required, replacement of an Option-E main board can only be done at the factory.

Main Board Removal Procedure

1. Remove the bottom cover using the "Bottom Cover Removal Procedure" on page 12-3.

2. Place the bridge bottom side up with the rear panel facing you.

3. Refer to Figure 12-6 on page 12-15. Unplug the HIGH coaxial cable (W902) center conductor pin from socket J111.

4. Remove the screw holding the HIGH coaxial cable (W902) shield near socket J111. Set this screw aside for later. It is shorter than all the other main board screws.

5. Unlatch and unplug the preamp (A601) ribbon cable from J107.

6. Unlatch and unplug the ribbon cable from the multiplexer board (A401) from J110.

7. Unplug the flexible circuit connector on the standard capacitor (C210) from J114 on the main board.

8. Remove the nine screws holding the main board to the midplane and remove the main board.

Main Board Installation Procedure

1. Place the bridge bottom side up with the rear panel facing you.

2. Orient the main board (A101) as shown in Figure 12-6 on page 12-15. Install the nine 6-32 x 3/8 pan-head screws holding the main board to the midplane. Then tighten these screws to 18 in-lbs (200 N-cm).

3. Plug the ribbon cable from the multiplexer board (A401) into J110 and latch it.

4. Plug the ribbon cable from the preamp board (A601) into J107 and latch it.

5. Plug the flexible circuit connector on the standard capacitor into J114 on the main board.

6. Install the 6-32 x 1/4 pan-head screw holding the HIGH coaxial cable (W901) shield near socket J111 and then tighten it to 18 in-lbs (200 N-cm).

CAUTION

DO NOT use a longer screw to hold the HIGH coaxial cable (W901) shield. This shield terminal must not short to the midplane or subtle problems will occur. A longer screw could also distort or break the main board.

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7. Plug in the HIGH coaxial cable center conductor pin into socket J111.

8. If the main board has been replaced with a different one or if the main generator circuit on page one of the main board schematics has been repaired, the calibration of the HIGH terminal output voltage must be checked/adjusted. The procedure for this is given in "Adjustment of HIGH Terminal Signal Level" on page 11-22.

9. Install the bottom cover using the "Bottom Cover Installation Procedure" on page 12-4.

10. If the original main board has been re-installed, then only an internal calibration need be performed. An internal calibration is especially important if any parts were replaced. See "INTERNAL CALIBRATION" on page 9-4 for an explanation of this procedure.

11. If this is a non-Option-E bridge and the original board was replaced with a different board, then an extensive internal and capacitance recalibration of the bridge is required. This is done by performing the capacitance calibration setup as described in "Obtaining the Capacitance Verification Data." on page 9-9. When the setup is ready and bridge is stable, do not use the calibration command given in that section. Instead, use the command:

STORE CALIBRATE 2
    CALIBRATE *standardvalue*

You will be prompted for the Replace passcode with the prompt r P̅L̅ C o d E. After you enter this special passcode, the bridge will spend about eight minutes making the calibration measurement. The front panel will display C̅A̅L̅ b r A̅ t̅ E̅ b U̅ S̅ Y̅ during this time and will show r E̅ A̅ d̅ Y̅ when the procedure has successfully completed. At this time, the bridge will contain all new

internal and capacitance calibration data stored in its EEPROM. Any previous calibration data will be gone.

CAUTION

Re-calibrating the main board is an irreversible procedure that destroys the original calibration done at the time of manufacture of the bridge. Execution of this procedure is intended only for the case where the main board or the capacitance standard have been replaced with different assemblies.

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12. If there is any reason to believe that the main board is not fully functional after having been re-installed, it may be desirable to verify the loss calibration as described in "LOSS VERIFICATION" on page 9-16.

Preamp Board (A601) Removal and Installation

Preamp Board Removal Procedure

1. Remove the bottom cover using the "Bottom Cover Removal Procedure" on page 12-3.

2. Place the bridge bottom side up with the rear panel facing you. Refer to Figure 12-6 on page 12-15.

3. **Mark the preamp cover top** so it can be replaced with the same side up. Remove the four screws holding the preamp cover to the preamp enclosure.

4. Refer to Figure 12-4. Unplug the LOW coaxial cable (W901) center conductor pin from J608.

5. Unplug the standard capacitor (C210) coaxial cable center conductor pin from J609.

6. Remove the screw holding the LOW coaxial cable shield (W901) and the standard capacitor (C210) coaxial cable shield.

7. Unlatch and unplug the ribbon cable going to J107 on the main board (A101).

8. Unplug the DC bias coaxial cable (W619) center conductor pin from J619.

9. Remove the screw holding the DC bias coaxial cable (W619) shield near J619.

10. Remove the four screws holding the preamp board (A601) and remove the board.
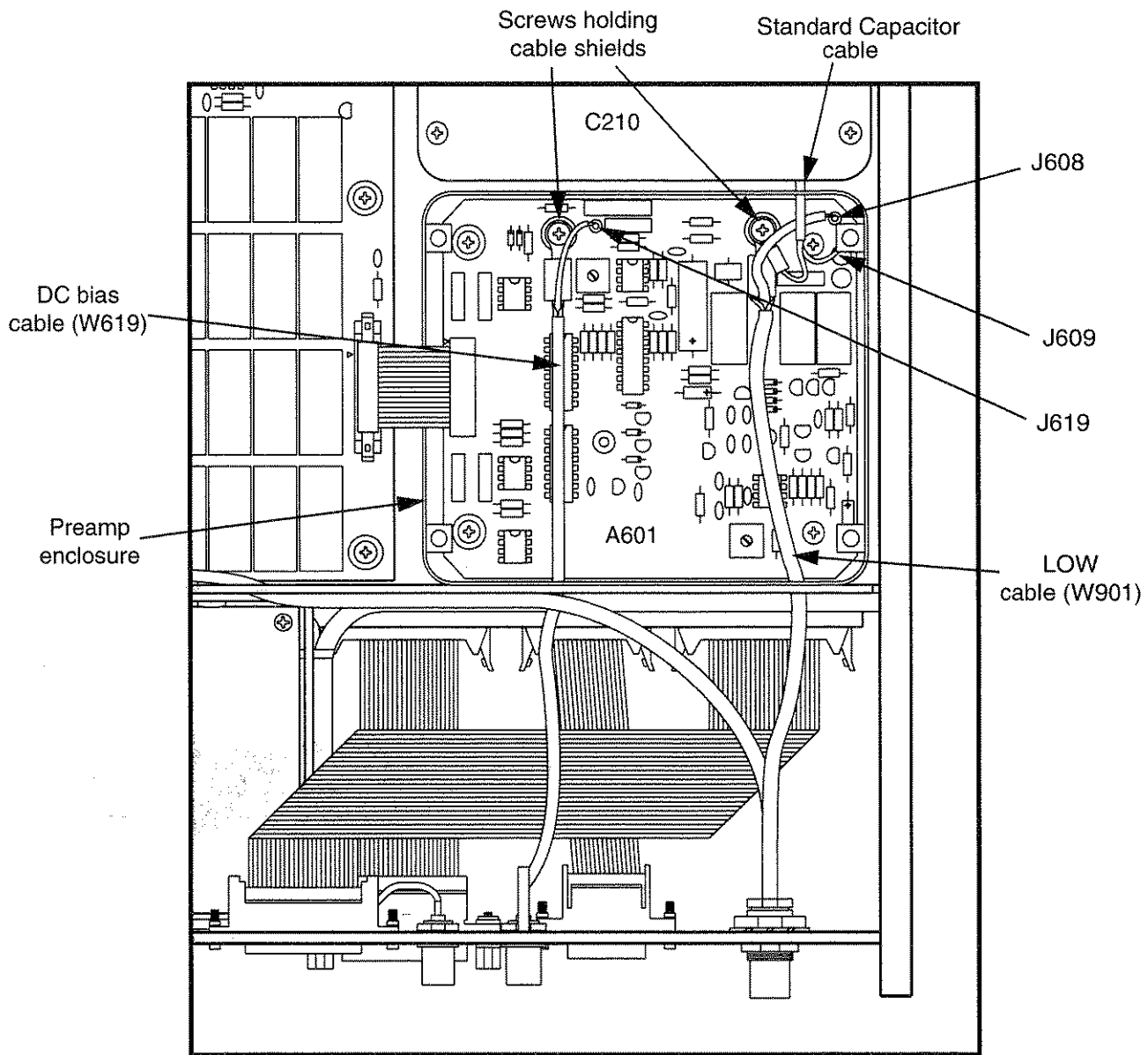
Figure 12-4 Preamp assembly (A601) detail

Preamp Board Installation Procedure

1. Place the bridge bottom side up with the rear panel facing you.

2. Orient the preamp board (A601) as shown in Figure 12-4 and install the four 6-32 x 3/8 pan-head screws holding the preamp board. Tighten these screws to 18 in-lbs (200 N-cm).

3. Install the 6-32 x 3/8 pan-head screw holding the DC bias coaxial cable (W619) shield near J619 and tighten it to 18 in-lbs (200 N-cm). Hold the terminal lug as the screw is being tightened so that the lug doesn't rotate against other parts.

4. Plug the DC bias coaxial cable center conductor pin into J619.

5. Plug the preamp board ribbon cable into J107 on the main board (A101).

6. Install the 6-32 x 3/8 pan-head screw holding the LOW coaxial cable (W901) shield and the standard capacitor (C210) coaxial cable shield. The lug on the LOW terminal cable shield should be next to the board and the lug on the standard capacitor cable shield should be on top. Orient the LOW cable and lugs as shown in the figure. Tighten the screw to 18 in-lbs (200 N-cm) while maintaining the lug orientations.

7. Install the LOW coaxial cable center conductor pin into J608.

8. Route the standard capacitor cable center conductor over the top of the LOW terminal cable center conductor and install the pin into J609.

9. Replacement of the preamp does *not* require adjustment of the two trimpots on the board. These are set at the factory and only require adjustment if the diagnostic self-tests indicate a problem.

10. Orient the preamp cover with your marked side up. This is done to ensure that the anodizing does not prevent the cover from making good electrical contact with the preamp enclosure. Install the four 8-32 x 3/8 pan-head preamp cover screws hand tight. DO NOT overtighten or use a torque screwdriver. The cover will be distorted if excess torque is used.

NOTE

If the preamp cover does not make good electrical contact with the preamp enclosure, the preamp will not be adequately shielded. This can cause measurements to be noisier than they should be. If poor electrical contact is suspected, the anodizing can be broken through by rotating the four preamp screws back and forth as they are being tightened.

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11. Install the bottom cover using the "Bottom Cover Installation Procedure" on page 12-4.

12. Replacement of the preamp board requires that an internal calibration be performed on the bridge. See "INTERNAL CALIBRATION" on page 9-4.

HIGH and LOW Cable (W902 and W901) Removal and Installation

HIGH and LOW Cable Removal Procedure

1. Perform steps 1-6 of the "Preamp Board Removal Procedure" on page 12-9.

2. Refer to Figure 12-6 on page 12-15. Unplug the HIGH coaxial cable (W902) center conductor pin from socket J111.

3. Remove the screw holding the HIGH coaxial cable (W902) shield near socket J111. Set this screw aside for later. It is shorter than all the other main board screws.

4. Using a pair of diagonal cutters, cut off and remove the two cable ties that hold the HIGH coaxial cable to the midplane.

5. Using a socket wrench with a 5/8 inch deep socket, remove the two nuts that hold the BNC connectors at the ends of W901 and W902 to the rear panel.

6. Remove the HIGH cable (W902) and its lockwasher.

7. Loosen the plastic bushing at the point where the LOW cable (W901) passes through the preamp enclosure. Remove the LOW cable and its lockwasher taking the bushing with them.

HIGH and LOW Cable Installation Procedure

1. Place the bridge bottom side up with the rear panel facing you.

2. Refer to Figure 12-6. Put the HIGH cable (W902) in place and route it through the long, rectangular hole in the midplane. Place the special large lockwasher between the BNC connector and the inside of the rear panel. Make sure that this area is clean and shiny since extremely good electrical contact is required.

3. Install the nut that holds the BNC connector at the end of W902 to the rear panel. Using a torque wrench with a 5/8 inch deep socket, tighten the nut to 75 in-lbs (800 N-cm).

4. Install the 6-32 x 1/4 pan-head screw holding the HIGH coaxial cable (W902) shield near socket J111 and then tighten it to 18 in-lbs (200 N-cm).

CAUTION

DO NOT use a longer screw to hold the HIGH coaxial cable (W901) shield. This shield terminal must not short to the midplane or subtle problems will occur. A longer screw could also distort or break the main board.

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5. Plug in the HIGH coaxial cable center conductor pin into socket J111.

6. Use two small cable ties to hold the HIGH cable at each end of the long hole in the midplane through which this cable passes. Each tie should go through a pair of small holes in the midplane.

7. Refer to Figure 12-4. Put the LOW cable with its lockwasher and plastic bushing in place. The special large lockwasher goes between the BNC connector and the inside of the rear panel. Snap the bushing into the hole in the preamp enclosure through which the LOW cable passes.

8. Install the nut that holds the BNC connector at the end of W901 to the rear panel. Using a torque wrench with a 5/8 inch deep socket, tighten the nut to 75 in-lbs (800 N-cm).

9. Complete this procedure by performing steps 6-11 of the "Preamp Board Installation Procedure" on page 12-10.

Standard Capacitor (C210) Removal and Installation

Note that the standard capacitor is replaceable with a *different* standard capacitor *only* if the bridge is *not* an Option-E. Due to the special equipment and calibration procedures required, replacement of an Option-E standard capacitor can only be done at the factory.

NOTE

Do not open the standard capacitor assembly. There are no user-serviceable parts inside the standard capacitor assembly and opening it will void your warranty. All repairs to the standard capacitor assembly must be done by the factory.

Standard Capacitor Removal Procedure

1. Remove both covers using the procedures in "Removal and Installation of Covers" on page 12-3.

2. Remove the processor board (A301) using the "Processor Board Removal Procedure" on page 12-6.

3. Place the bridge bottom side up with the rear panel facing you.

4. **Mark the preamp cover top** so it can be replaced with the same side up. Remove the four screws holding the preamp cover to the preamp enclosure.

5. Unplug the standard capacitor (C210) coaxial cable center conductor pin from J609 on the preamp board (A601).

6. Remove the screw holding the LOW input coaxial cable shield and the standard capacitor coaxial cable shield near J608 on the preamp board (A601).

7. Unplug the standard capacitor's flexible circuit connector from J114 on the main board (A101).

8. Place the bridge on edge so the right side is down and the front panel is facing you.

9. While holding the standard capacitor so it doesn't fall, remove the four screws on the top side of the midplane that hold the standard capacitor assembly.

10. Carefully feed the standard capacitor coaxial cable through the hole in the preamp enclosure and remove the standard capacitor from the bridge.

Standard Capacitor Installation Procedure

1. Place the bridge on edge so the right side is down and the front panel is facing you.

2. Orient the standard capacitor assembly as in Figure 12-6 on page 12-15. Feed the standard capacitor coaxial cable through the hole in the preamp enclosure and align the standard capacitor over the mounting holes in the midplane.

3. Hold the standard capacitor in position and install the four mounting screws from the top side of the midplane, through the midplane and into the standard capacitor mounting holes.

4. Place the bridge top side up with the front panel facing you and then tighten the four standard capacitor mounting screws to 18 in-lbs (200 N-cm).

5. Install the processor board (A301) using the "Processor Board Installation Procedure" on page 12-6

6. Place the bridge bottom side up with the rear panel facing you.

7. Plug the standard capacitor's flexible circuit connector into J114 on the main board (A101).

8. Refer to Figure 12-4 on page 12-10. Install the 6-32 x 3/8 pan-head screw holding the LOW input coaxial cable shield and the standard capacitor coaxial cable shield on the preamp board (A601). The lug on the LOW terminal cable shield should be next to the board and the lug on the standard capacitor cable shield should be on top. Orient the LOW cable and lugs as shown in the figure. Tighten the screw to 18 in-lbs (200 N-cm) while maintaining the lug orientations.

9. Plug the standard capacitor (C210) coaxial cable center conductor pin into J609 on the preamp board (A601).

10. Orient the preamp cover with your marked side visible. This is done to ensure that the anodizing does not prevent the cover from making good electrical contact with the preamp enclosure. Install the four 8-32 x 3/8 pan-head preamp cover screws hand tight. DO NOT overtighten or use a torque screwdriver. The cover will be distorted if excess torque is used.

NOTE

If the preamp cover does not make good electrical contact with the preamp enclosure, the preamp will not be adequately shielded. This can cause measurements to be noisier than they should be. If poor electrical contact is suspected, the anodizing can be broken through by oscillating the four preamp screws back and forth as they are being tightened.

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11. Install both covers using the procedures in "Removal and Installation of Covers" on page 12-3.

12. If the original standard capacitor has been re-installed, then a capacitance verification should be performed. See "CAPACITANCE CALIBRATION" on page 9-9 for an explanation of this procedure.

13. If this is a non-Option-E bridge and the original standard capacitor was replaced with a different one, then an extensive internal and capacitance recalibration of the bridge is required. This is done by performing the capacitance calibration setup as described in "Obtaining the Capacitance Verification Data." on page 9-9. When the setup is ready and bridge is stable, do not use the calibration command given in that section. Instead, use the command:

    STORE CALIBRATE 2
                    CALIBRATE *standardvalue*

You will be prompted for the Replace passcode with the prompt r PL CodE. The Owner passcode will not also be accepted here unless it is the same as the Replace passcode. After you enter this special passcode, the bridge will then spend about eight minutes making the calibration measurements. The front panel will display CAL br AtE bUSY during this time and will show r EAdY when the procedure has successfully completed. At this time, the bridge will contain all new internal and capacitance calibration data stored in its EEPROM. Any previous calibration data will be gone.

CAUTION

Re-calibrating the standard capacitor is an irreversible procedure that destroys the original calibration done at the time of manufacture of the bridge. Execution of this procedure is intended only for the case where the main board or the capacitance standard have been replaced with different assemblies.

Side Casting (MP913) Removal and Installation

Side Casting Removal Procedure

1. Remove the top and bottom covers using the procedures in "Removal and Installation of Covers" on page 12-3.

2. Place the bridge with the side facing up that has the casting to be removed.

3. Refer to the exploded parts view Figure F-3 on page F-9. Locate parts MP913 and MP914 in the lower left corner of the figure. Remove the two oval-head screws holding the brown vinyl-covered side panel (MP914) to the casting and remove the panel.

4. Locate the small brown cover panel MP915 (or ear MP910 if you are using rack-mounting) in the figure. Remove the screw holding MP915 (two screws for MP910) to the casting and remove the panel or ear.

5. Remove the eight flat-head screws that hold the side casting (MP913) to the rest of the instrument and remove the casting. The bridge should be handled with care at this point since the front panel is now only supported at one end.

Side Casting Installation Procedure

1. Place the bridge with the side facing up that to receive the side casting.

2. Refer to the exploded parts view Figure F-3 on page F-9. Put the side casting (MP913) in place so that the grooves that hold the top and bottom covers face toward the interior of the bridge. (There is only one kind of side casting as opposed to having right and left versions.)

3. Install the eight flat-head 6-32 x 3/8 screws to hold the casting. Tighten all eight screws to 18 in-lbs (200 N-cm). Be sure to observe the note about screws and their tightening on page 2 of this chapter.

4. Put the small brown cover panel MP915 (or ear MP910 if you are using rack-mounting) in place. Install the 6-32 x 3/8 oval-head screw to hold MP915 (or the two 10-32 oval-head screws to hold MP910) to the casting and tighten securely.

5. Put the brown vinyl-covered side panel (MP914) in place. Install the two 6-32 x 1/4 oval-head screws to hold the side panel to the casting and tighten securely.

6. Install the top and bottom covers using the procedures in "Removal and Installation of Covers" on page 12-3.

Processor Board (A301)   Keypad Board (A502)   P504 shown unplugged from J304   Display Board (A501)   Multiplexer Board (A401)

J410

Midplane (MP902)

J317   J306   J303

U304 U305 U306 U307

Midplane (MP902)

J318   J302

J312   J305   J313   J304

RS-232 Cable (W912)   Sample Switch Cable (W905)   GPIB Cable (W913)   External Trigger Cable (W918)   Power Supply Assy (A701)   Power Transformer (T701)
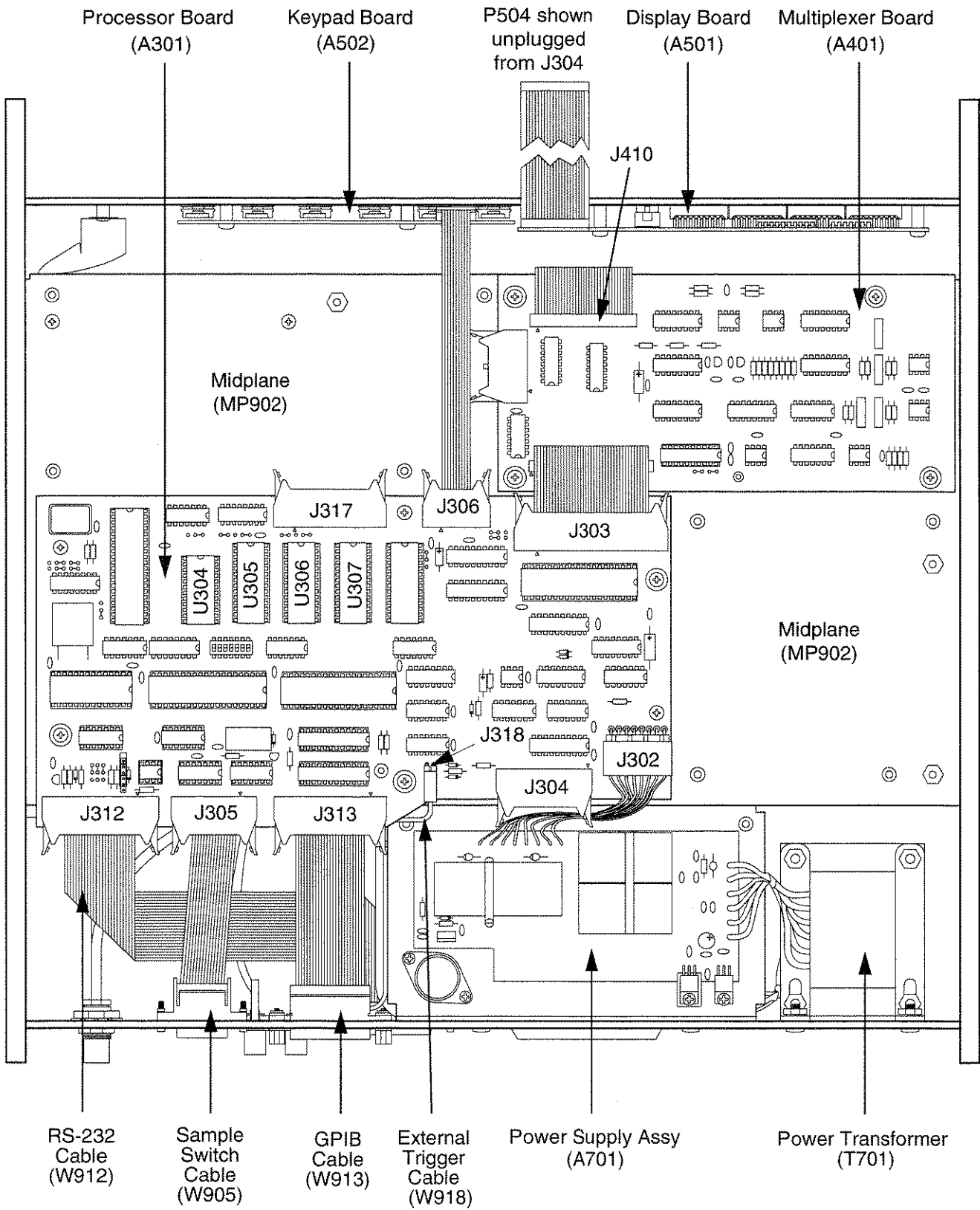
Figure 12-5 AH 2500A top view with bezel removed.

C04
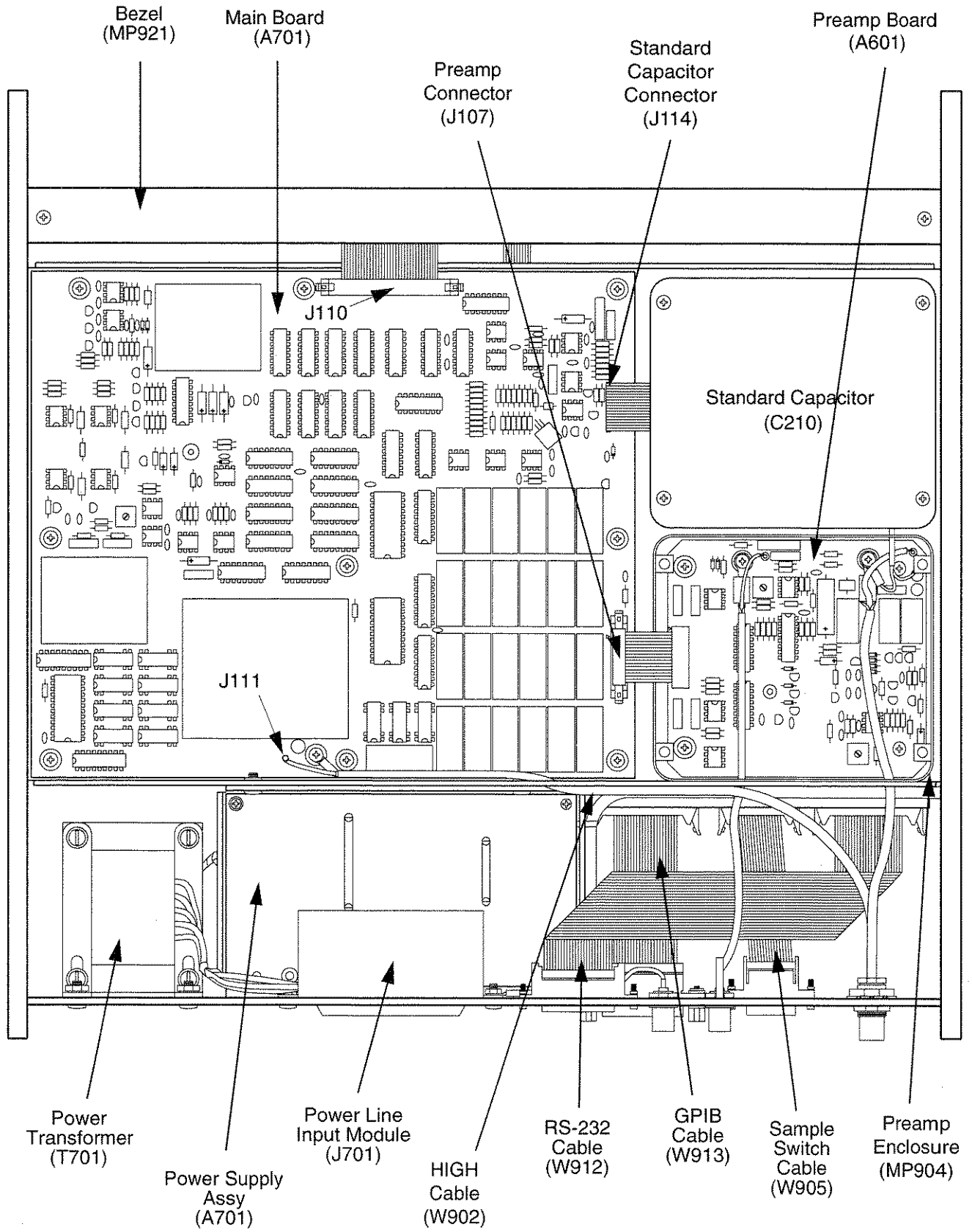
Figure 12-6 AH 2500A bottom view with bezel in place.

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Glossary

Accuracy   The degree to which a measuring device agrees with accepted standards.

A/D   Analog-to-Digital converter. An integrated circuit inside the bridge that digitizes analog signals.

Bridge   This term is used interchangeably with "AH 2500A" to identify the instrument. The term also has a more specific meaning when it is used to identify a particular electrical circuit having four legs, a generator and a detector.

Calibration   Used here to mean the process of adjusting or correcting the bridge so that it meets its specifications. Most corrections are stored in EEPROM memory.

Chassis   The collection of metal parts that comprise the frame or box of the AH 2500A.

Current parameter set   One of the four sets of parameters that directly control the settings used by the bridge.

DAC   Digital-to-Analog-Converter. In this manual, DAC refers to a special circuit that generates precise AC voltages controlled by digital signals from a microprocessor.

Dielectric   The material that exists in the electric field of a capacitor.

Display   Refers to the LED display on the front panel of the bridge.

DUT   The Device Under Test being measured by the bridge.

EEPROM   An Electrically-Erasable, PROgrammable, non-volatile Memory integrated circuit used for semi-permanent data storage in the bridge.

EPROM   An ultraviolet-Erasable, PROgrammable Memory integrated circuit used for permanent storage of the firmware that runs the bridge.

External trigger input   A BNC connector on the back of the bridge that can receive pulses for the purpose of synchronizing AH 2500A commands.

File   A collection of data stored in EEPROM or ROM memory. This data can consist of parameter sets or programs.

File type   A file can be of one of five types. These types describe the kind of data in the file. The types are:Basic, Gauge, Baud, Bus and Program.

Firmware   The program code that is executed by the microprocessor in the bridge. This code is contained in three EPROM's and tells the microprocessor how to make the bridge work.

Fused-silica capacitance standard   A special capacitor that uses fused silica as its dielectric to achieve a very stable capacitance value.

GPIB   Stands for General Purpose Instrument Bus. This is a convenient abbreviation for the instrument communications bus defined by the IEEE-488.1 standard.

HIGH terminal   The terminal on the back of the bridge that provides a low-impedance signal with which to drive the unknown impedance.

IEEE-488.1   This is a standard defined by the Institute of Electrical and Electronic Engineers to describe the popular method of interconnecting test equipment for control purposes. The standard was previously called the IEEE-488-1978.

IEEE-488.2   This is a newer standard defined by the Institute of Electrical and Electronic Engineers to extend the IEEE-488.1 standard. The newer standard covers standard codes, formats, protocols, and common commands.

Keypad   The three by six array of buttons on the front panel of the AH 2500A.

LED   A Light Emitting Diode produces light and is used as an indicator. These are used to create the front panel display of the AH 2500A.

Line   Describes a single line of data sent to remote devices or displayed on the front panel in one or more windows.

Linearity   The degree to which an increase or decrease in an actual quantity is exactly proportionally represented in the corresponding measured quantity. In other words, if an actual quantity doubles in size, how exactly does the measure of that quantity also double. (This is measurement linearity.)

Loss   The component of the impedance which is 90° out of phase with respect to the capacitive component.

LOW terminal   The terminal on the back of the bridge that provides a high-impedance input to connect to the unknown impedance.

Non-volatile memory   Any memory that does not loose its contents when power is lost.

Option-E   An optionally available version of the AH 2500A that offers Enhanced precision and calibration features.

Parameter   An AH 2500A variable that you can set to various values with a command. Every parameter is part of a set. Each parameter controls a particular aspect of the

bridge's operation when the parameter is in the current parameter set.

Parameter set A collection of AH 2500A parameters. There are four kinds of parameter sets used by the bridge: Basic, Gauge, Baud, and Bus. These can be stored and recalled for later use.

PPM Parts Per Million. This is equal to 0.0001%.

Precision A loosely defined term meaning "exact".

Program Means a list of AH 2500A commands that have been entered into memory and which can be executed by the bridge. "Macro" is a commonly used synonym.

Query command An IEEE-488.2 concept meaning any command that will send a result to a remote device when the command is issued from that device. Non-query commands send no results.

RAM Stands for "Random Access Memory" and is used as the bridges working memory. Its contents are lost when power is lost.

Ratio transformer A special transformer that divides AC voltages with great linearity and stability.

Remote device This IEEE 488.1 term is used from the perspective of the bridge. It refers to any device connected to the bridge with which data is being exchanged. This can be a controller, logger or an intermediate interface. The remote device can be connected to the serial or GPIB port.

Resolution The smallest change that can be detected in a measured quantity.

ROM Stands for "Read Only Memory". It refers to memory whose contents cannot be changed by any means. The term is also used more loosely to include EPROM memory.

Sample A synonym for DUT, unknown, unknown sample etc. (An A/D can also "sample" a signal, but this is a totally different meaning of the word.)

Stability The ability to remain constant with time. In the case of the AH 2500A, stability is considered to be independent of temperature. In other words, comparisons of stability are made without changing the temperature.

Temperature coefficient The change in a quantity for a unit change in its temperature.

Three-terminal impedance An impedance that uses two signal terminals and a ground terminal. Usually, the impedance between the two signal terminals is desired and the impedances between either signal terminal and ground are parasitic. In the case of the AH 2500A, the ground terminal is always intended to connect to a shield and a three-terminal impedance is usually thought of as a shielded two-terminal impedance.

Two-terminal impedance An impedance that is only defined between two signal terminals.

Unknown A convenient abbreviated term for "unknown sample", "unknown capacitance", "unknown loss", "unknown impedance", "DUT" etc.

Unknown capacitance The quantity or device being measured by the bridge.

Unknown impedance The quantity or device being measured by the bridge.

Unknown loss The quantity or device being measured by the bridge.

Unknown sample The quantity or device being measured by the bridge.

Verification Used here to mean the process of gathering and presenting data that indicates how close the bridge meets its specifications.

Window Sometimes there is more information on a line to be displayed on the front panel of the bridge than will fit at one time. This information is divided into groups which can be shown one at a time. Each group is called a "window" and consists of the contents of the upper and lower front panel LED displays. You can move right and left one at a time through the windows by pressing the ⬅ and ➡ keys.

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Calibration Data, Notes, Etc.

This tab section is reserved for your convenience. It may be
useful for storing calibration certificates, calibration data, and
any other notes related to your AH 2500A.

This chapter contains the detailed descriptions for all commands used in the AH 2500A capacitance bridge.

CONVENTIONS USED

The command syntax descriptions use the conventions below.

Most commands start with a root command word and are followed by various combinations of command qualifier words and parameter values.

Command words are shown as COMMAND.

UNDERLINES are used to indicate the minimum number of characters that can be typed to execute a command when operating the bridge from a remote device.

Front panel keypad command and qualifier words and numbers are shown enclosed in a box to indicate a key or sequence of keys to be pressed to enter a command. The ENTER key is an example.

Some commands have command qualifiers that limit the action of the command to a specific display or device. An example is the CAP and LOSS qualifiers which can select either the capacitance (upper) display or loss (lower) display. Another example is the BAUD and BUS qualifiers which limit the action of a command to the RS-232 or GPIB ports, respectively. The BAUD and BUS words are also used as root command words.

Most commands have one or more parameters associated with them. Parameters that you can enter are shown *like this*. When entering a parameter *like this*, you substitute an actual value.

Parameters and command qualifiers may be required or optional, depending on the particular command. Required parameters and command qualifiers are shown without surrounding brackets.

Brackets [ ] are used to indicate that the enclosed parameter or command qualifier is optional. You can select any or all optional parameters or command qualifiers. Some of these options are nested, in which case an inner option cannot be selected unless all outer options surrounding it are also used.

Parameters and command qualifiers may be part of a list separated by the word "or". You can make one choice from the list.

Some commands have a different syntax depending on whether they are entered from the front panel or from a remote device. These are noted in the command descriptions. An example is the CABLE command.

Positional Parameters

Certain commands used in the AH 2500A have multiple parameters associated with them. An example of this kind of command is the BAUD command which has several communications parameters associated with it. The values for those parameters must be entered in a specific order. When you want to enter values other than the leading value or values, periods (.) are used as placeholders for the missing values. For example, *length* is the fourth parameter for the BAUD command. If you want to change the *length* parameter and leave the other parameters as they are, you must enter BAUD RATE • • • 7 to change the length to 7 bits. The three periods in this example act as placeholders for the *rate*, *DTE* and *parity* parameters. These three parameters are left unchanged when this command is executed. This scheme saves having to re-enter parameters that you do not wish to change. Positional parameters are indicated with periods between the parameter names in the command descriptions.

Numeric Entry Notation

Most parameters are entered as integers or occasionally as alphanumeric strings.

Some parameters can be entered with a decimal point as a part of the number. Such parameters can be entered in two basically different notation formats. One is as a floating point number which simply consists of some digits and one decimal point. An example is "123.45678". The other format consists of a signed mantissa and a signed exponent separated by an "E". An example is "+12.345678E+01" Parameters that will automatically accept values in either of these formats are identified by "(floating point)" at the end of the header line for that parameter. For more information on notation formats, see "Numeric Notation" on page 5-8.

COMMANDS

The following pages contain all of the commands used in the AH 2500A. Most of the paragraph headings should be self-explanatory. Query commands are discussed in "Aborting Commands" on page 2-6, in "Query Commands" on page 6-3 for the GPIB port and in "Query Commands" on page 7-10 for the serial port.

ALTERNATE

Description

Periodically reverses the applied 1 kHz test signal at the interval specified. This makes the test signal distinguishable from external interference near 1 kHz. The bridge can then reject the interference.

Syntax

ALTERNATE *altexp*

Parameters   *altexp*

The *altexp* (alternate exponent) parameter specifies the interval at which the test signal reverses or alternates according to the table below.

Table A-1 Alternate time periods

Altexp	Alternate time period
0	Alternating disabled
1	0.25 seconds
2	0.50
3	1.00
4	2.00
5	4.00
6	8.00
7	16.00

Default Value   0   (Disabled)

Parameter Set   Gauge

Query Cmd?   No

Comments

* Rejects noise due to signals with harmonics near 1 kHz.
* Particularly useful in regions of the world with 50 Hz power frequency.

Front Panel Examples

[FUNC] [ALTERNATE] [3] [ENTER]
Alternate the applied test signal once per second.

[SHOW] [FUNC] [ALTERNATE] [ENTER]
Displays the following window:

```
    ALtrnAtE
    3
```

Remote Device Examples

>AL 5
Alternate the applied test signal every four seconds.

>AL 0
Turn alternate feature off.

>SH AL
  ALTERNATE   ALTEXP=0
>

References

See "REJECTING INTERFERING SIGNALS" on page 4-8.

Related Commands   none

Description
Determines the time used to make a measurement.

Syntax

AVERAGE *averexp*

Parameters   *averexp*
The allowable *averexp* (average time exponent) parameter values and their corresponding warm-start measurement times are listed in the following table:

Table A-2 Measurement times

Aver exp	Number of samples	Sample Time	Approximate warm-start measurement time
0	1	0.01 sec.	0.04 sec.
1	1	0.05	0.08
2	1	0.10	0.14
3	2	0.10	0.25
4	4	0.10	0.5
5	8	0.10	1
6	16	0.10	2
7	32	0.10	4
8	64	0.10	8
9	128	0.10	15
10	256	0.10	30
11	512	0.10	60
12	1024	0.10	120
13	2048	0.10	250
14	4096	0.10	500
15	8192	0.10	1000

Default Value   4   (0.5 sec. measurement time.)

Parameter Set   Gauge

Query Cmd?   No

Comments
* Lengthening the averaging time reduces the effects of random noise at the expense of measurement speed.

Front Panel Examples

[AVERAGE TIME] [5] [ENTER]
Set the average time parameter to five which gives a total measurement time of about one second.

[SHOW] [AVERAGE TIME] [ENTER]
Displays the following window:

```
 AUErAGE

 5
```

Remote Device Examples

>AU 7
Set the averaging time to approximately four seconds.

>SH AU
 AUERAGE   AUEREXP=7
>

References
See "MEASUREMENT SPEED VS. MEASUREMENT FLUCTUATION" on page 4-5 and specifically "Averaging Time" on page 4-6.

Related Commands   none

BAUD

Description

Set the communications parameters for the serial interface.

Syntax

BAUD *rate . DTE . parity . length . stop . fill . echo*

Parameters

rate
is the baud rate in bits/sec and can be one of the following:
50, 75, 110, 135, 150, 300, 600, 1200, 1800, 2400, 3600,
4800, 7200, or 9600. The default is 9600.

DTE
selects whether the RS-232 port on the bridge is configured
as "Data Terminal Equipment" (DTE) or "Data Communica-
tions Equipment" by reversing pins 2 and 3 of the RS-232
connector. When set to 0 it is configured as DCE; when set to
1 it is configured as DTE. The default is 1 (DTE).

parity
controls a parity bit in each character that is sent. It can be set
to 0 for no parity, 1 for odd parity, or 2 for even parity. The
default is 0 for no parity.

length
is the optional number of data bits in each serial character,
and can be optionally set to 7, or 8. The default is 8.

stop
controls the number of stop bits ending each character. This
may be set to 1 or 2, which usually represents 1 or 2 stop bits
respectively. An exception occurs when setting the number of
bits to 2. When the word length is 8 and parity is odd or even,
1 bit is sent. The default is 1.

fill
is the optional number of null characters sent at the end of
each line, and can range from 0 to 9 characters. The default is
0.

echo
optionally determines whether commands are echoed back to
the serial device. A one enables echoing and a zero disables
it. The default is one.

Default Values 96.1.0.8.1.0.1
Also see individual parameters above.

Parameter Set Baud

Query Cmd? No

Comments

* The settings of this command affect *only* serial port
  operations.

Front Panel Examples

[FUNC] [BAUD RATE] [1] [2] [0] [0] [ENTER]
Sets baud rate to 1200 baud.

[FUNC] [BAUD RATE] [•] [•] [•] [•] [•] [•] [0] [ENTER]
Disable echoing.

[SHOW] [FUNC] [BAUD RATE] [ENTER]
Displays the following windows:

bAUd	r t.t.PL.S.F.E
12. 10.8. 10.0	12. 10.8. 10.0

Only the first two digits of the baud rate are reported by the
BAUD command. These windows are actually the first result
line from the SHOW *set* command described on page A-39.

Remote Device Examples

```
>BAU 300           (Set baud rate to 300 baud.)

>BAU ...7          (Set bits/character to seven.)

>SH BAU
BAUD               RATE=30 DTE=1 PAR=0 LEN=7
                           STP=1 FIL=0 ECH=1
DEFINE             ERASE=^U DEL=DEL BACKSP=^H
                           DCL=^E TERM=PRINTER
NREMOTE            STATE=0
NLOCKOUT           STATE=0
LOG BAUD           CONTENT=0
>
```

The SHOW BAUD command shows all the parameters in
the Baud parameter set rather than just those entered by the
BAUD command. Only the first two digits of the baud rate
are reported by the SHOW command.

References

See Chapter 7, "Serial/RS-232 Remote Operation" and spe-
cifically "SERIAL COMMUNICATION PARAMETERS"
on page 7-6.

Related Commands

DEFINE, LOCAL, NLOCKOUT, LOGGER BAUD,
NREMOTE

Description

Enables or disables a user-supplied DC bias voltage of up to ±100 VDC to be applied to the measured unknown. The external source is connected to the rear panel DC BIAS input. This command also selects the value of an internal resistor that is placed in series with the externally applied voltage source.

Syntax

BIAS *enable*

Parameters   *enable*

The *enable* choices are:

0   Disabled (no series resistor connected)

1   100 megohm series resistor connected

2   1 megohm series resistor connected

The *enable* choices are numbered in order of ability to feed increased levels of current into the unknown.

Default Value   0   (Disabled)

Parameter Set   Gauge

Query Cmd?   No

Comments

*   Useful when measuring capacitances that exhibit DC voltage-dependent properties.

WARNING !

The voltage that you apply to the DC bias input will be passed to the LOW input terminal. From there it will go to whatever unknown impedance and fixture you have connected. Be sure that your fixture and cable are constructed in a manner that will prevent personal contact with any applied, high DC voltages. The frame of the fixture and the shield of the cable should be grounded.

CAUTION

The voltage connected to the DC bias input appears directly across the internal fused-silica capacitance standard. Application of voltages significantly in excess of 100 volts may damage or destroy the standard.

Front Panel Examples

[DC BIAS] [2] [ENTER]
Enables DC bias and selects the 1 MΩ series resistor.

[SHOW] [DC BIAS] [ENTER]
Displays the following window:

```
┌─────────────────┐
│   dc bIAS        │
├─────────────────┤
│   2             │
└─────────────────┘
```

Remote Device Examples

>BI 1
Enables DC bias and selects the 100 MΩ series resistor.

>SH BI
DC BIAS   ENABLE=1
>

References

See "UNKNOWNS WITH DC VOLTAGE" on page 4-13 and especially "Applying a DC Bias Voltage" on page 4-13.

Related Commands   none

BRIGHTNESS

Description

Sets the brightness of the front panel capacitance and/or loss displays and the status and units indicators.

Syntax

BRIGHTNESS [CAP or LOSS] *level*

Qualifiers

CAP   Parameters will apply to the capacitance display only.

LOSS   Parameters will apply to the loss display only.

None   Parameters will apply to both capacitance and loss displays.

Parameters   *level*

The *level* parameter must be a number from 0 to 9. Zero turns the display off and sets the indicators to the same brightness as level one. Numbers from 1 to 9 correspond to increasing brightness with 9 being the maximum brightness.

Default Value   5   (Medium brightness)

Parameter Set   Basic

Query Cmd?   No

Comments

- If power is applied to the bridge, there is always at least one LED illuminated on the front panel. This fact can be used as a power indicator.

Front Panel Examples

[FUNC] [BRIGHTNESS] [CAP] [9] [ENTER]
Sets the brightness of the upper display to the maximum. Leaves the lower display unchanged.

[SHOW] [FUNC] [BRIGHTNESS] [ENTER]
Displays the following window:

```
 bri Ght
 C9 L5
```

The brightness level of the upper display is shown as C 9; that of the lower display as L 5.

Remote Device Examples

```
>BR 0
```
Sets the brightness level of both displays to the minimum.

```
>SH BR
 BRIGHTNESS      C=0  L=0
>
```

References

See "KEYPAD AND DISPLAYS" on page 2-1 and "Setting Display Brightness – An Example" on page 2-4.

Related Commands none

Description
Sets the communications parameters for the GPIB (IEEE-488) port.

Syntax

BUS *priaddr . secaddr . ton . compat . prompts*

Parameters

priaddr
is the primary GPIB bus address. It can have any value from 0 to 30. The default primary address is 28 with no secondary GPIB address.

secaddr
is an optional secondary GPIB bus address and can range from 0 to 30. If no secondary address is entered, then a secondary GPIB address will not be recognized. To disable a previously entered secondary address, the dot separator is immediately followed by the [ENTER] key or an end-of-line. The default is no secondary address.

ton
is the optional GPIB "talk only" switch. When set to one, results can be sent to a "listen only" device such as a printer or logger. It is normally set to zero, which is the default value.

compat
selects compatibility mode when set to one. In compatibility mode, all status byte values are reported in binary-weighted-decimal and all result lines are separated with semicolons. With compatibility mode off, all status byte values are reported in binary and all result lines are separated with CR and LF characters. All messages are terminated with CR, LF^END no matter how compatibility mode is set. The default value is zero.

prompts
makes all prompt messages available to the GPIB when set to a one. This is intended for use with the interactive mode of operation. The RDY status bit is used to distinguish a prompt message from all others. The default value is zero.

Default Values   28. .0.1.0; See above.

Parameter Set   Bus

Query Cmd?   No

Comments
- The settings of this command affect only GPIB operations.

Front Panel Examples
[FUNC] [BUS ADDR] [2] [2] [ENTER]
Sets the primary bus address to 22.

[FUNC] [BUS ADDR] [•] [•] [•] [0] [ENTER]
Disable compatibility mode.

[SHOW] [FUNC] [BUS ADDR] [ENTER]
Displays the following windows:

bUS Addr		Pri.SC.t.C.P
22. .0.0.0		22. .0.0.0

The [←] and [→] keys are used to select which of the two windows is displayed. These windows are actually the first result line from the SHOW *set* command described on page A-39.

Remote Device Examples

```
>BU  .15..1
```
Set the secondary address to 15 and enable compatibility mode.

```
>SH BU
 BUS ADDR      PRI=28 SEC=15
                      TON=0 CPT=1 PRP=0
 SRE           MAU=0 EXE=0 RDY=1 PON=0
                      URQ=0 CME=0 OMR=1
 LOGGER        CONTENT=0
>
```
The SHOW BUS command shows all the parameters in the Bus parameter set rather than just those entered by the BUS command.

References
See "BUS CONFIGURATION PARAMETERS" on page 6-1, "GPIB DATA LOGGING" on page 6-15, and "STATUS REPORTING" on page 6-5.

Related Commands
LOGGER BUS, SHOW STATUS, SRE, USER

CABLE

Description
Compensates for the characteristics of longer cables or cables used to connect the bridge to larger capacitances.

Remote Syntax

CABLE LENGTH *length*
or
CABLE RESISTANCE *resistance*
or
CABLE INDUCTANCE *inductance*
or
CABLE CAPACITANCE *capacitance*

Front Panel or Remote Syntax

CABLE 1 CABLE *length*
or
CABLE 2 CABLE *resistance*
or
CABLE 3 CABLE *inductance*
or
CABLE 4 CABLE *capacitance*

Parameters
length   (Floating Point)
is the length (in meters) of the coaxial cable pair connected between the bridge and the device under test. The length can be entered to the nearest hundredth of a meter up to a maximum length of 999.99 meters. The default length is one meter.

resistance   (Floating Point)
is the resistance (in milliohms) of the center conductor of one meter of cable. The value of resistance can range from 0 to 9999.0 milliohms per meter. The default resistance is 40 milliohms per meter.

inductance   (Floating Point)
is the inductance (in microhenries) per meter of cable. The value of inductance can range from 0.00 to 99.99 microhenries per meter. The default value is 1.10 microhenries per meter.

capacitance   (Floating Point)
is the capacitance (in picofarads) per meter of cable. The value of capacitance can range from 0.0 to 999.9 picofarads per meter. The default value is 70.0 picofarads per meter.

Parameter Set   Gauge

Query Cmd?   No

References
See "CABLE ERROR CORRECTIONS" on page 8-6.

Front Panel Examples

[FUNC] [CABLE] [1] [FUNC] [CABLE] [3] [ENTER]
Sets the bridge to compensate for a 3 meter cable length.

[FUNC] [CABLE] [2] [FUNC] [CABLE] [3] [.] [1] [ENTER]
Sets the bridge to compensate for cable with resistance of 3.0 milliohms per meter. (The result is rounded.)

[SHOW] [FUNC] [CABLE] [ENTER]
Displays the following windows:

```
 [ CAb LEn ]
 [   3.00   ]
```

[↓]

```
 [ CAb rES ]
 [    3.    ]
```

[↓]

```
 [ CAb Ind ]
 [   1.10   ]
```

[↓]

```
 [ CAb CAP ]
 [   70.0   ]
```

Remote Device Examples

>CAB LEN 10
Sets the bridge to compensate for a 10 meter cable length.

>CABL 2 CAB 6.0E+01
Sets the bridge to compensate for 60 milliohms per meter.

```
>SH CAB
 CABLE          LENGTH= 10.00   M
 CABLE          RESISTANCE/M= 60.0    MO
 CABLE          INDUCTANCE/M= 1.10    UH
 CABLE          CAPACITANCE/M= 70.0   PF
>
```

Comments
- The CABLE commands are only useful for high *accuracy* measurements of larger capacitance values or with longer cable lengths.

- As the syntax definitions show, issuing commands from a remote device allows using the words LENGTH, RESISTANCE, INDUCTANCE and CAPACITANCE instead of the numbers 1, 2, 3 and 4.

- Longer cables also cause a zero error. The ZERO SINGLE command is used to make this correction.

Related Commands ZERO

CALIBRATE

Description
Causes the bridge to produce correction values for one of three different kinds of calibrations/verifications.

Syntax

CALIBRATE 1

creates verification data for many internal calibration points.

or

CALIBRATE 2 CALIBRATE *standardvalue*

creates capacitance verification data to calibrate the AH 2500A against an external standard capacitor. The external standard must have a value in the range of 0.5 to 1600 pF.

or

CALIBRATE 3

creates verification data for the ratio transformers, only in Option-E bridges. The CALIBRATE 3 command requires a 1pF to 1µF three-terminal decade capacitance box. As this command executes, you are prompted to set up various values in the decade box.

Parameters   *standardvalue*   (Floating Point)
The *standardvalue* parameter is the **exact** value of the external standard capacitor connected to the bridge.

Default Value   None

Parameter Set   None

Query Cmd?   No

Comments
* The subject of calibration must be thoroughly understood before using these commands. It is essential to first read much of Chapter 9, "Verification/Calibration".

Front Panel Examples

[FUNC] [CALIBRATE] [2] [FUNC] [CALIBRATE]
[9] [9] [•] [9] [9] [ENTER]

Create capacitance calibration data using an external standard capacitor which has an accurately known and traceable value of 99.99000 pF.

See the SHOW CALIBRATE command for more information.

Remote Device Examples

```
>CAL 2 CAL 10.00034
```
Use a 10.00034 pF external standard.

```
>CAL 3
SET CAP     300000.0 >
SET CAP     300000.0^>     (Set the value higher)
SET CAP     100000.0 >
SET CAP     100000.0->     (Set the value lower)
SET CAP     30000.0 >
SET CAP     30000.0 >      (Reduce the noise)
SET CAP     10000.0 >
SET CAP     3000.0 >
SET CAP     1500.0 >
SET CAP     750.0 >
SET CAP     370.0 >
SET CAP     52.0 >
SET CAP     101.0 >
SET CAP     150.0 >
SET CAP     199.0 >
SET CAP     248.0 >
SET CAP     297.0 >
SET CAP     346.0 >
SET CAP     395.0 >
SET CAP     445.0 >
SET CAP     494.0 >
SET CAP     197.0 >
SET CAP     99.0 >
>
```

See the SHOW CALIBRATE commands for more information about reporting calibration data.

References
See "Obtaining the Internal Verification Data" on page 9-5, "Obtaining the Capacitance Verification Data." on page 9-9 and "Obtaining Transformer Verification Data" on page 9-12.

Related Commands
SHOW CALIBRATE, STORE CALIBRATE, STORE CALIBRATE CREATE, STORE CALIBRATE SPECIAL

CLEAR

Description
Clears a partially entered command.

Front Panel Syntax

[FUNC] [CLEAR]

Serial Device Syntax

^U

Parameters   None

Default Value
The front panel syntax is not user-selectable. Almost any character can be selected for this function from the serial port. Ctrl-U is the default.

Query Cmd?   No

Comments
- The serial device syntax is not recognized when sent from a GPIB controller. Such controllers usually provide their own methods for editing commands.

Front Panel Examples

[FUNC] [STORE] [FUNC] [CALIBRATE]

```
[ CALbrAtE        ]
[                 ]
```

[FUNC] [CLEAR]

```
[ rEAdY           ]
[                 ]
```

The clear function was used to abort entry of the STORE CALIBRATE command.

Serial Device Examples

```
>PROGRAM AVERAGE 345^U
>
```

Entry of the command was aborted with the ^U character (which is not actually shown).

References
See "Correcting Erroneous Input – Examples" on page 2-4 and "Erasing Lines" on page 7-11.

Related Commands
DEFINE

Description

Initiates measurements which are taken continuously, one after another. The time from the start of one measurement to the start of the next may be entered.

Syntax

CONTINUOUS [*interval*]

Parameters   *interval*   (Floating Point)

This optional parameter is the time from the start of one measurement to the start of the next entered in seconds and tenths of seconds. The maximum time interval is 99,999,999 seconds.

Default Value   0   (Runs as fast as averaging time will permit)

Parameter Set   None

Query Cmd?   Yes

Since the CONTINUOUS command is a query command, any command will interrupt execution of the CONTINU-OUS command. However, the bridge will revert to taking measurements continuously after the interrupting command (other than SINGLE or Q) finishes executing.

Comments

- The SINGLE or Q commands will cause continuous measurements to stop after taking one more measurement.

- If the *interval* parameter is zero, measurements are taken at the maximum rate allowable by the AVERAGE command's *averexp* parameter.

- If the *interval* parameter does not exceed the averaging time, then the latter will determine the rate at which measurements are made.

- The CONTINUOUS key on the front panel is shared with the ➡ key. To issue the CONTINUOUS command from the front panel, you will often have to press the ENTER key first.

- The quickest way to stop the CONTINUOUS command is with a DEVICE CLEAR command.

Front Panel Examples

CONTINUOUS 3 ENTER

Takes a measurement every three seconds.

| 12.298653 | | 5=01 |
| 0.02977 | | U=1.50 |

| 123.22100 | | 5=01 |
| 0.02910 | | U=1.50 |

| 122.22083 | | 5=01 |
| 0.03002 | | U=1.50 |

| 123.22083 | | 5=01 |
| 0.02980 | | U=1.50 |

The left window shows the capacitance and loss. The right window shows the sample number and the voltage used to make the measurement. The ⬅ and ➡ keys are used to select which window of each pair is shown in the front panel display.

SINGLE
Stops taking measurements.

Remote Examples

```
>C0
 C=10.342956 PF L=0.0004591 NS
 C=10.342958 PF L=0.0004592 NS
>C=10.342958 PF L=0.0004592 NS
>
```

The Q command (which does not echo to the serial port) was used to abort the CONTINUOUS command. Measurements were being taken as fast as the averaging time setting would allow.

References

See "MAKING CONTINUOUS MEASUREMENTS" on page 2-7 and "Taking Measurements Continuously" on page 4-4.

Related Commands

AVERAGE, Q, SINGLE

DEFINE

Description

Allows redefinition of certain special purpose ASCII key codes used with the serial port. These are particularly useful with remote video terminals attached to the serial port.

Syntax

DEFINE ERASE *erasechar*

or

DEFINE DELETE *delchar*

or

DEFINE BACKSPACE *backspchar*

or

DEFINE DCL *devclrchar*

or

DEFINE TERMINAL *termtype*

Parameters

The key code required by the first four versions of the DEFINE command may be entered in one of three ways. It may be entered directly by simply pressing the key which produces the desired code. If it is to be a control key, it may be entered as the corresponding letter preceded by an up arrow (^). Finally, it may be entered as the word DELETE if it is to be the ASCII "delete" character. Some characters may not be chosen including ^A, ^J, ^M, ^Q and ^S.

erasechar
Is the key code that causes the current command line on a remote video terminal to be erased. The default erase line character is control U (^U).

delchar
Is the key code that causes the character to the left of the cursor on a printing or video terminal to be erased. The default delete character is the ASCII delete (or rubout) key.

backspchar
Is the key code that causes the cursor on a video terminal to backspace one character position. The backspace is used in combination with the delete key to remove the deleted character from the screen of a video terminal. The default backspace character is control H (^H).

devclrchar
Is the key code that aborts execution of all currently queued commands. The default device clear character is control E (^E).

termtype
Tells the bridge whether a video terminal or hard-copy printer is attached to the serial port. When configured as a printer, character deletion uses backslashes (\) to delineate any characters that were deleted by the delete key. The *termtype* parameter is entered as either VIDEO or PRINTER. The default terminal type is PRINTER.

Default Value   See individual parameters above.

Front Panel Examples

The DEFINE command cannot be entered nor can its parameters be shown from the front panel.

Serial Remote Device Examples

```
>DEF DEL ^H
```
Set delete key code to be control H.

```
>DEF TE P
```
Define terminal as a hardcopy printer.

```
>SH DEF
 DEFINE   ERASE=^U DEL=DEL BACKSP=^H
                   DCL=^E TERM=PRINTER
>
```

Parameter Set   Baud

Query Cmd?   No

Comments

* The DEFINE command has no value with a GPIB controller since the characters affected are only recognized from the serial port. GPIB controllers usually have their own methods for editing commands.

References

See "Correcting Typing Errors" on page 7-10.

Related Commands

BAUD, CLEAR, DELETE, DEVICE CLEAR

Description

Deletes the last character typed from a remote terminal or the last numeric digit or decimal point entered from the front panel.

Front Panel Syntax

[DEL]

Serial Device Syntax

delchar

The *delchar* is definable using the DEFINE command. In other words, you can select which key serves as the delete key. There is usually a key intended to perform this function.

Parameters   None

Default Value

Serial device syntax uses the ASCII "delete" character.

Query Cmd?   No

Comments

- The serial device Delete key code is not recognized when sent from a GPIB controller. Such controllers usually provide their own methods for editing commands.

- The DELETE *character* command shares the [DEL] key label on the front panel with the DELETE *file* command, but otherwise, these commands have no connection with each other.

Front Panel Examples

[REFERENCE] [CAP] [3] [•] [1] [1] [1]

```
[ CAP            ]
[         3.I I I ]
```

[DEL] [DEL] [DEL] [DEL]

```
[ CAP            ]
[              3  ]
```

[1] [•] [1] [1]

```
[ CAP            ]
[         3 I.I I ]
```

The [DEL] key was pressed four times to delete ". I I I". The deleted characters were replaced with " I. I I" so as to move the decimal point right by one place relative to the original entry.

Remote Device Examples

>RFER\REF\EF
>

The delete key was pressed four times to back up to the "FE" that was reversed during entry.

References

See "Correcting Erroneous Input – Examples" on page 2-4.

Related Commands

DEFINE

DELETE *file*

Description
Deletes a parameter or program file in EEPROM memory.

Syntax

DELETE [BASIC, GAUGE, BAUD, BUS
                        or PROGRAM] [*filename*]

Qualifiers

BASIC   Delete Basic parameter file(s).

GAUGE   Delete Gauge parameter file(s).

BAUD   Delete Baud parameter file(s).

BUS   Delete Bus parameter file(s).

PROGRAM   Delete Program file(s).

None   Delete *all* files of *all* filetypes and initialize
               the file space.

Parameters   *filename*
This is the name of the file to be deleted. The name has only
digits and contains no more than eight. If *filename* is not
entered, then all files of the specified type will be deleted.
The ARE YOU SURE? prompt will be shown if *filename* is
not entered. You must answer YES or [YES] to this prompt if
the operation is to complete. If you are working from the
GPIB and are not using prompts, your reply to the ARE YOU
SURE? prompt can be appended as "; YES" to your com-
mand. For example, DELETE PROGRAM; YES.

Default Value   None

Parameter Set   None

Query Cmd?   No

Comments

- If you are unsure what filenames can be deleted, issue
  the DIRECTORY command to get a list of all of them.

- If you are unsure of the contents of a particular file, you
  can use the SHOW command to examine the contents.

- The DELETE *character* command shares the [DEL] key
  label on the front panel with the DELETE *file* com-
  mand, but otherwise, these commands have no connec-
  tion with each other.

References
See Chapter 3, "Parameter and Program Files" and specifi-
cally "Deleting Files" on page 3-9.

Related Commands
DIRECTORY, RECALL, SHOW, STORE

Front Panel Examples
[DIR] [ENTER]
Displays the following windows:

```
┌──────────────────────┐
│   GAUGE              │
├──────────────────────┤
│   I                  │
└──────────────────────┘
```

[↓]

```
┌──────────────────────┐
│   bASI C            │
├──────────────────────┤
│   I                  │
└──────────────────────┘
```

[↓]

```
┌──────────────────────┐
│   bASI C            │
├──────────────────────┤
│   I                  │
└──────────────────────┘
```

The second [↓] had no effect which shows that only two files
exist in EEPROM memory.

[DEL] [GAUGE] [ENTER]

```
┌──────────────────────┐
│   ArE YOU           │
├──────────────────────┤
│   SUrE              │
└──────────────────────┘
```

[YES] [ENTER]
Deletes all Gauge parameter files.

[DIR] [ENTER]
Displays only the following window:

```
┌──────────────────────┐
│   bASI C            │
├──────────────────────┤
│   I                  │
└──────────────────────┘
```

[↓]

```
┌──────────────────────┐
│   bASI C            │
├──────────────────────┤
│   I                  │
└──────────────────────┘
```

Now only one file exists in EEPROM memory.

Remote Examples

```
>SHOW PROGRAM 14
 AUER 7
 SI
>DELETE PR 14
>SH PR 14
 FILE NOT FOUND
>
```

This example shows that initially there is a two-line program
in EEPROM memory. The program is then deleted. Another
SHOW command is then not able to find a program file hav-
ing a filename of "14".

DEVICE CLEAR

Description
Immediately aborts execution of any command or program. The bridge is left in a state that should accept a new command.

Front Panel Syntax

FUNC CLEAR FUNC CLEAR

Serial Device Syntax

devclrchar

The *devclrchar* is definable using the DEFINE command. In other words, you can select which key serves as the device clear key.

Default Value
Serial device syntax uses the ASCII control E (^E) character.

GPIB Device Syntax

DCL or SDC universal IEEE-488.1 bus commands

Parameters   None

Query Cmd?   No

Comments
* The GPIB syntax that issues a Device CLear (DCL) or Selective Device Clear (SDC) bus command is dependent on the controller. Consult your controller manual for this syntax.

Front Panel Examples

FUNC CLEAR FUNC CLEAR

```
dEUI CE
CLEAr
```

ENTER

```
rEAdY
```

The device clear function was used to abort something. The ENTER key was then pressed to get the r E A d Y prompt.

Serial Device Examples

```
>HOLD 0
^E
>
```

The HOLD 0 command caused the bridge to hold for an external trigger pulse. The hold condition was aborted by entering the ^E character.

References
See "Device Clear Commands" on page 6-15 and "Aborting Command Execution" on page 7-11.

Related Commands DEFINE

DIRECTORY

Description

Lists a directory of the files stored in the EEPROM memory. The information consists of the file type and file number.

Syntax

DIRECTORY [BASIC, GAUGE, BAUD,
                              BUS or PROGRAM]

Qualifiers

BASIC   List only Basic parameter files.

GAUGE   List only Gauge parameter files.

BAUD   List only Baud parameter files.

BUS   List only Bus parameter files.

PROGRAM   List only Program files.

None   List all files of all filetypes.

Parameters   None

Query Cmd?   Yes

Comments

- The file numbers can be as long as eight digits.
- If no files exist, the error message "FILE NOT FOUND" or "29" will be reported.

Front Panel Examples

[DIR] [ENTER]

```
 bUS
```
```
  1
```

[↓]

```
 Proᴳ
```
```
 10
```

[↓]

```
 Proᴳ
```
```
 22
```

[↓]

```
 Proᴳ
```
```
 22
```

The third [↓] did not reveal a fourth file. Therefore, the [DIR] command has revealed that there are three files in the EEPROM memory, one contains a bus parameter set and the other two are programs. This bus parameter set is number one which is one of the non-volatile, power-on sets.

Remote Device Examples

```
>DI
 BUS        1
 PROG       10
 PROG       22
>DIR BUS
 BUS        1
>DI PROGRAM
 PROG       10
 PROG       22
>
```

References

See "Listing the File Names" on page 3-8.

Related Commands

DELETE *file*, PROGRAM, RECALL, STORE

FORMAT

Description

Controls the format of results which are sent to serial or GPIB ports. Front panel results are not affected.

Syntax

FORMAT *smp.cap.los.vlt.msg.lbl.pun.ffd*

Parameters

smp enables sending the sample field when set.

cap enables sending the capacitance field when set.

los enables sending the loss field when set.

vlt enables sending the voltage field when set.

msg enables an error *message* to be sent when set, or an error *code* to be sent when clear.

lbl enables labels to be sent.

pun enables IEEE-488.2 compatible punctuation when set.

ffd fixes field widths when set.

Default Value 0.1.1.1.1.1.0.1

Parameter Set Basic

Query Cmd? No

Comments

- Each of the eight required binary parameters is entered as either one or zero. A one enables printing of the corresponding field, label, message or punctuation. A zero disables it.

- Labels consist of the field identifier (S=, C=, L= etc.) and the measurement units (PF, NS and V, for example). Labels in SHOW command results are affected also.

- If ASCII error messages are enabled, errors are reported as messages *following* the result line. If ASCII error messages are disabled, then the result line will be *preceded* by a two digit error code. The error code will be zero if there are no errors.

- The effect of IEEE-488.2 compatible punctuation is to substitute commas for spaces as field separators and to enclose messages and other string variables in quotes.

- When *ffd* is zero, no fill spaces are sent. These spaces keep the measurement results aligned in neat columns.

Front Panel Examples

FUNC FORMAT [•] [•] [•] [0]
Displays the following window:

```
┌──────────────────┐
│  For NAt         │
└──────────────────┘
┌──────────────────┐
│        . . .0    │
└──────────────────┘
```

ENTER

```
┌──────────────────┐
│  r E A d y       │
└──────────────────┘
┌──────────────────┐
│                  │
└──────────────────┘
```

The *vlt* parameter was set to zero, eliminating the voltage field. The ENTER key was pressed to complete the command and get the r E A d y prompt.

SHOW FUNC FORMAT ENTER
Displays the following windows:

```
┌──────────────────┐   ┌──────────────────┐
│  For NAt         │   │  S.C.L.U.N.L.P.F  │
└──────────────────┘   └──────────────────┘
┌──────────────────┐   ┌──────────────────┐
│ 0. 1. 10. 1. 10. 1│   │ 0. 1. 10. 1. 10. 1│
└──────────────────┘   └──────────────────┘
```

The [←] and [→] keys are used to select which of the two windows is displayed.

Remote Examples

```
>SH FO
 FORMAT   SMP=0 CAP=1 LOS=1 VLT=0
                   MSG=1 LBL=1 PUN=0 FFD=1
>SI
 C=10.342956 PF L=0.0004591 NS OVEN
>FORMAT ....0                      (Set msg to zero.)
>SH FO
 FORMAT   SMP=0 CAP=1 LOS=1 VLT=0
                   MSG=0 LBL=1 PUN=0 FFD=1
>SI
15 C=10.342958 PF L=0.0004592 NS
>
```

The FORMAT command was used to change from sending an error message (OVEN) at the end of the result line to reporting an error code (15) at the beginning.

References
See "REMOTE DEVICE FORMATS" on page 5-5.

Related Commands FORMAT SPECIAL, PLACES

FORMAT SPECIAL

Description

Controls the numeric notation of results which are sent to the serial or GPIB ports. Front panel results are not affected.

Syntax

FORMAT SPECIAL *notation*

Parameters   *notation*

Specifies the type of numeric notation to be used for capacitance, loss, voltage and cable results. The *notation* parameter can be set to 0, 1 or 2. The notations are:

    0   Floating-point notation

    1   Scientific notation

    2   Engineering notation

Default Value   0   (floating-point notation)

Parameter Set   Basic

Query Cmd?   No

Comments

* Only *results* are affected by this command. The notation of numeric values that are *entered* is automatically detected and appropriately interpreted.

Front Panel Examples

[FUNC] [FORMAT] [FUNC] [SPECIAL] [0] [ENTER]
Sets the notation to floating-point.

[SHOW] [FUNC] [FORMAT] [FUNC] [SPECIAL] [ENTER]
Displays the following window:

```
┌─────────────────┐
│  For∏Ał         │
├─────────────────┤
│  SPEC      0    │
└─────────────────┘
```

Remote Examples

```
>FO SP 0
>SI
 C=843.318636 PF L=0.03721 NS
>FO SP 1
>SI
 C=8.43318630E+02 PF L=3.756E-02 NS
>FO SP 2
>SI
 C=843.318681E+00 PF L=37.44E-03 NS
>SH FO SP
 FORMAT SP       N=2
>
```

The above examples show floating-point, scientific, and engineering notation results, respectively.

References

See "Numeric Notation" on page 5-8.

Related Commands FORMAT, PLACES

Description

Execution of this command causes the bridge to do nothing further for either a specified period of time or until an external trigger pulse is received.

Syntax

<u>HO</u>LD *delay*

Parameters

delay   (Floating Point)

This parameter is the delay time until the bridge is to execute the next command. The maximum delay time is 99,999,999 seconds. If this parameter is entered as a zero, then the bridge will wait indefinitely until an external trigger pulse is received. The delay may be entered to the nearest tenth of a second.

Default Value   None

Parameter Set   None

Query Cmd?   No

Comments

- Once this command is executed, it can only complete normally or be aborted with a DEVICE CLEAR command.

- This command and particularly its delay feature are mainly useful with the PROGRAM commands.

- Additional commands may be entered following the HOLD command, but they will not be executed until the HOLD command finishes.

- The HOLD 0 command is the *only* command that responds to external trigger pulses.

- When the HOLD command is active, the word "HOL d" will usually be displayed on the front panel followed by the remaining delay time, if any was entered. The exception occurs when the HOLD command *immediately* follows a query command within a program. In this case, the front panel display continues to show the result produced by the query command instead. This allows the HOLD command to control the length of time that results generated by programs are displayed.

Front Panel Examples

FUNC HOLD 3 0 ENTER

```
┌─────────────────────┐
│      HOL d          │
├─────────────────────┤
│              29.2   │
└─────────────────────┘
```

The HOLD command begins executing immediately after being entered. The time remaining is shown on the display as 29.2 seconds.

Remote Examples

```
>HO 50
>SI;SI
 C=28843.316E+00 PF L=537.43E-03 NS
 C=28843.317E+00 PF L=537.44E-03 NS
>
```

In the above example, the HOLD command specified a delay time of 50 seconds before executing the next command line. During the delay, no prompt appears and no commands other than a DEVICE CLEAR will produce an immediate response. The two SINGLE commands were entered before the delay time expired and thus were not echoed to the serial port as they were entered. They were echoed and began executing the moment the delay time expired.

```
>HO 50
>SI
>SI
 C=28843.315E+00 PF L=537.43E-03 NS
>
```

This second example is almost identical to the first, but only one measurement result is produced instead of two even though two SINGLE commands were entered. Since SINGLE is a query command, the second command interrupted and aborted the first.

```
>HO 0;SI
>C=28843.317E+00 PF L=537.44E-03 NS
>
```

In this third example, the HOLD command specified that an external trigger must occur before continuing. A single measurement was taken as soon as a trigger pulse occurred. Until the occurrence of a trigger pulse, no prompt would appear, but any subsequent command entry would abort the HOLD command. This would occur since the presence of the SI command makes the line a query command line.

References

See "TIMING IN PROGRAMS" on page 3-13 and "Initiating with an External Trigger Signal" on page 4-4.

Related Commands   PROGRAM, HOLD SPECIAL

HOLD SPECIAL

Description
This command determines what happens to external trigger pulses that arrive when no HOLD 0 command has been executed to receive them. This command allows such pulses to be buffered or to report an error. Execution of this command clears the trigger buffer.

Syntax

HOLD SPECIAL *trigbuf*

Parameters   *trigbuf*
This causes external trigger pulses to be buffered as they come in if *trigbuf* is set to a 1.

Default Value   1   (Buffer the pulses)

Parameter Set   Basic

Query Cmd?   No

Comments
- With *trigbuf* set to one, the trigger buffer can hold up to 255 unprocessed trigger events. Any trigger pulses that occur which would cause this number to overflow are ignored.

- With *trigbuf* set to zero, any unexpected trigger pulses that are received will be reported as an "E" error as part of the next measurement result. This will appear in the upper right corner of the front panel display. This error is not possible with *trigbuf* set to one. This error event can be detected only by taking a measurement.

- The SHOW command only reports the parameter associated with the HOLD SPECIAL command, not the one associated with the HOLD command.

Front Panel Examples

[FUNC] [HOLD] [FUNC] [SPECIAL] [0] [ENTER]

Set the *trigbuf* parameter to zero to disable trigger buffering.

[SHOW] [FUNC] [HOLD] [FUNC] [SPECIAL] [ENTER]

```
┌─────────────────────┐
│   HOLd buF           │
├─────────────────────┤
│        0             │
└─────────────────────┘
```

Use the SHOW command to see that the *trigbuf* parameter is zero.

[SINGLE]   (Take a measurement and show in window below.)

```
┌─────────────────────┐
│  95 183 12E          │
├─────────────────────┤
│  002774              │
└─────────────────────┘
```

Note that an "E" is shown in the upper right corner of the display indicating that an unexpected external trigger pulse was received.

Remote Examples
```
>HO SP 1
>SH HO SP
 HOLD SPEC    TRIGBUF=1
>
```

References
See "Handling Unexpected Trigger Pulses" on page 3-14.

Related Commands HOLD

Description

When executed from the front panel, this command returns the bridge to the Local state if it was in *either* the GPIB or Serial Remote states. It is used to allow commands to be entered from the front panel.

Front Panel Syntax

LOCAL

Serial Device Syntax

LOCAL

Parameters

No parameters are entered. This command resets the parameter associated with the NREMOTE command.

Default Value   0   (Local)

Parameter Set   Baud

Query Cmd?   No

Comments

- While in the Local state, commands may be entered from the front panel or either remote port.

- The REMOTE indicator LED is not illuminated when the bridge is in the Local state.

- The LOCAL front panel key will have no effect if either the GPIB or serial remote devices has put the bridge into a Remote With Lockout state.

- The LOCAL command should not be issued to the bridge from a GPIB controller since such controllers have their own set of commands for such functions. The GPIB controller command may have the same spelling but its command would be issued to the controller, not to the bridge. The controller should have a command that allows it to issue a GTL (Go To Local) bus command to change the bridge from the GPIB Remote state to the GPIB Local state.

- Issuing the LOCAL command from the serial port only reverses the effects of an NREMOTE command issued from the serial port. The LOCAL command, when issued from the GPIB port, will have no effect on Remote states created by the Serial port or by the GPIB port.

Front Panel Examples

If the REMOTE indicator is on, pressing the LOCAL key will either cause the indicator to extinguish or the message below will appear:

```
LOCAL
Locout
```
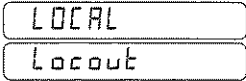
This message means that the front panel cannot be operated until the remote device unlocks it.

Serial Remote Examples

```
>NREM                                (Enter Remote state)
>SH NREM
 NREMOTE        STATE=1
>LOC                                 (Exit Remote state)
>SH NREM
 NREMOTE        STATE=0
>
```

The LOCAL command reversed the effect of the NREMOTE command. The SHOW command reports the effects of the LOCAL command on the Nremote command parameter.

References

See "STATES AND INDICATORS" on page 6-2 and "LIMITING FRONT PANEL ACCESS" on page 7-11.

Related Commands NLOCKOUT, NREMOTE

LOGGER

Description

This command allows the selection of what front panel initiated commands and results are to be logged to the GPIB and/or serial ports.

Syntax

LOGGER (BAUD or BUS) *content*

Qualifiers

BAUD   The *content* parameter will affect data logged to the serial port only.

BUS   The *content* parameter will affect data logged to the GPIB port only.

Parameters   *content*

Specifies what information is logged to a remote port according to the table below.

Table A-3 Content parameter values

Content	Messages sent to logger
0	None (logging is disabled)
1	Measurement results only
2	All results
3	All commands and all results

Default Values   Baud: 0, Bus: 1

All logging disabled to the serial port; logging enabled to the GPIB port of measurement results only.

Parameter Set   Baud, Bus

Query Cmd?   No

Comments

- "Measurement results only" (*content*=1) refers to logging only the sample number, capacitance, loss and voltage values and error messages.

- "All results" (*content*=2) refers to measurement, calibration and test results and also results from the DIRECTORY command and all versions of the SHOW command.

- "All commands and results" (*content*=3) refers to all results logged with *content*=2. In addition, commands entered from the front panel are themselves logged.

- Logging to the GPIB channel can be done by connecting a "listen only" device. This requires that the AH 2500A be placed in the "talk only" state using the BUS command.

Front Panel Examples

[FUNC] [LOGGER] [FUNC] [BAUD] [2] [ENTER]

This causes all results to be logged to the serial port.

[SHOW] [FUNC] [LOGGER] [ENTER]

```
    LOG bAUd
   Contnt  2
```

[↓]

```
    LOG bUS
   Contnt  1
```

Remote Device Examples

```
>LOG BU 1          (Enable logging of measurement
                   results only to the GPIB port.)
>LOG BA 0          (Stop logging to the serial port.)
>SH LOG
 LOG BAUD     CONTENT=0
 LOG BUS      CONTENT=1
>
```

References

See "GPIB DATA LOGGING" on page 6-15 and "SERIAL DATA LOGGING" on page 7-13.

Related Commands BUS

Description

Prevents the front panel [LOCAL] key from changing the bridge from a Serial Remote State to a Serial Local State.

Syntax

NLOCKOUT

or

NLOCKOUT HALT

Qualifiers

If HALT *is not* entered, the bridge will enter the Serial Local State with Lockout or the Serial Remote State with Lockout. If HALT *is* entered, the bridge will enter the Serial Local State or the Serial Remote State.

Parameters

No parameters are entered. However, the SHOW BAUD and SHOW NLOCKOUT commands will report a one if the NLOCKOUT command has been executed and a zero if the NLOCKOUT HALT command was executed.

Default Value   0   (not locked out)

Parameter Set   Baud

Query Cmd?   No

Comments

- This command is intended to be issued only from a remote serial device. It is not available from the front panel and has no effect from the GPIB port.

- When in the Remote Serial State, this command causes all front panel keys to be ignored until a LOCAL or NLOCKOUT HALT command is issued from the controlling serial device.

- The NLOCKOUT command should not be issued to the bridge from a GPIB controller since such controllers have their own set of commands for such functions. The GPIB controller command may have similar spelling but its command would be issued to the controller, not to the bridge.

Front Panel Examples

The NLOCKOUT command is not available from the front panel. It can, however, be shown from the front panel. Enter the key sequence:

[SHOW] [FUNC] [BAUD] [ENTER] [↓]

and get:

```
 nLocout
 StAtE   0
```

Serial Remote Examples

```
>SH NREM;SH NLOC             (Start with Local state,
 NREMOTE      STATE=0         front panel is fully
 NLOCKOUT     STATE=0         operable.)
>NREM                        (Enter Remote state,
>SH NREM;SH NLOC              front panel except
 NREMOTE      STATE=1         [LOCAL] key is
 NLOCKOUT     STATE=0         inoperable.)
>NLOC                        (Enter Remote With
>SH NR;SH NL                  Lockout state, front
 NREMOTE      STATE=1         panel and [LOCAL] key
 NLOCKOUT     STATE=1         are inoperable.)
>LOCAL                       (Enter Local With
>SH NR;SH NL                  Lockout state, front
 NREMOTE      STATE=0         panel is fully operable.)
 NLOCKOUT     STATE=1
>NRE                         (Enter Remote With
>SH NR;SH NL                  Lockout state, front
 NREMOTE      STATE=1         panel and [LOCAL] key
 NLOCKOUT     STATE=1         are again inoperable.)
>LOC;NLOC HALT               (Enter Local state,
>SH NR;SH NL                  front panel is fully
 NREMOTE      STATE=0         operable.)
 NLOCKOUT     STATE=0
>
```

The above examples demonstrate all combinations of the Serial Remote and Serial Lockout states.

References

See "LIMITING FRONT PANEL ACCESS" on page 7-11 and specifically "Setting the Serial Lockout States" on page 7-12 and "Clearing the Serial Lockout States" on page 7-12.

Related Commands LOCAL, NREMOTE

NREMOTE

Description

Places the bridge in the *Serial* Remote State. This state disables all front panel keys except the LOCAL key. The LOCAL key is also disabled if the NLOCKOUT command has been issued.

Syntax

NREMOTE

Parameters

No parameters are entered. However, the SHOW BAUD and SHOW NREMOTE commands will report a one if this command has been executed and a zero if the LOCAL command was executed.

Default Value   0   (Local)

Parameter Set   Baud

Query Cmd?   No

Comments

- This command is intended to be issued only from a remote serial device. It is not available from the front panel and has no effect from the GPIB port.

- The REMOTE indicator LED is illuminated when the bridge is in the Serial Remote State.

- This command causes front panel keys to be ignored until the LOCAL front panel key is pressed (if lockout is not in effect) or until a LOCAL command is issued from the controlling serial device.

- The NREMOTE command should not be issued to the bridge from a GPIB controller since such controllers have their own set of commands for such functions. The GPIB controller command may have similar spelling but its command would be issued to the controller, not to the bridge.

Front Panel Examples

The NREMOTE command is not available from the front panel.

Serial Remote Examples

```
>NREM                               (Enter Remote state)
>SH NREM
 NREMOTE        STATE=1
>LOCA                               (Exit Remote state)
>SH NREM
 NREMOTE        STATE=0
>
```

The SHOW command reports the effects of the NREMOTE command on its parameter.

References

See "LIMITING FRONT PANEL ACCESS" on page 7-11 and specifically "Selecting the Serial Remote States" on page 7-12.

Related Commands LOCAL, NLOCKOUT

Description
Controls the number of significant digits reported for capacitance and/or loss measurements to the front panel and remote devices.

Syntax

PLACES [CAP or LOSS] *digits*

Qualifiers

CAP The *digits* parameter will apply to capacitance results only.

LOSS The *digits* parameter will apply to loss results only.

None The *digits* parameter will apply to both capacitance and loss results.

Parameters *digits*
The number of significant digits (from 1 to 9) reported for capacitance and/or loss.

Default Value 9, 9
(Maximum number of significant digits for both capacitance and loss.)

Parameter Set Basic

Query Cmd? No

Comments
- The AH 2500A reports measurement values so that all digits displayed are meaningful or significant. The *digits* parameter can cause the bridge to round the result to a lower number of significant digits, but cannot cause it to display more digits than are meaningful.

Front Panel Examples

[FUNC] [PLACES] [3] [ENTER]
Sets the number of significant places to three.

[SHOW] [FUNC] [PLACES] [ENTER]
Displays the following window:

```
  PLACES
   C3 L3
```

[ENTER]
[SINGLE]

```
   843.
  0.03 73
```

[FUNC] [PLACES] [CAP] [5] [ENTER]
Sets the number of significant capacitance places to five.

[SINGLE]

```
  84392
  0.0373
```

Remote Examples
```
>SH PL
 PLACES      C=9 L=9
>SI
 C=843.318636 PF L=0.03721 NS
>PL C 6
>SH PL
 PLACES      C=6 L=9
>SI
 C=843.318 PF L=0.03721 NS
>
```
The above examples show the effects of changing the capacitance places from nine to six. Notice that the setting of the number of places is not the limiting factor for the loss result since only four places are shown.

References
See "SIGNIFICANT DIGITS" on page 5-1 and specifically "Setting a Limit on the Significant Digits" on page 5-1.

Related Commands
FORMAT, FORMAT SPECIAL

PROGRAM CREATE

Description
This command is used to create a program.

Syntax

PROGRAM CREATE

.
.
.

blank line ends entry

A program is created by first issuing this command. The command lines of the program are entered next. When all the lines of the program have been entered, program entry is terminated by entering a blank program line.

Parameters   None

Query Cmd?   No

Comments

- The commands below are not allowed in programs:
  DELETE
  DELETE PROGRAM
  PROGRAM CREATE
  RECALL PROGRAM
  STORE PROGRAM

- Programs can call subprograms to a nesting depth of eight.

- Individual programs cannot be edited. However, a program can contain many short subprograms, each of which is easy to delete and re-create.

- There are no conditional commands for programs to use.

- No form of the STORE command is allowed in a program that repeats.

Front Panel Examples

FUNC PROGRAM FUNC CREATE ENTER

```
rEAdY Pr
```

UNITS 2 ENTER
FUNC HOLD 0 ENTER
SINGLE ENTER
ENTER   (Terminate program entry.)

```
rEAdY
```

This program sets units to 2 (dissipation factor), waits for an external trigger pulse to occur and then takes a single measurement.

Remote Examples

```
>PROGRAM CREATE
#AVERAGE 7
#HOLD 900
#SINGLE
#ZERO SINGLE
#ZERO
#HOLD 180
#SINGLE
#
>
```

References
See "WORKING WITH PROGRAMS" on page 3-10 and specifically "Creating Programs" on page 3-10.

Related Commands
PROGRAM execute, RECALL PROGRAM, SHOW PROGRAM, STORE PROGRAM, TRG

C04

Description

Executes programs in single-step, non-stop and repetitive modes.

Syntax

PROGRAM [*filename*] [SINGLE]
[CONTINUOUS *interval*] [REPEAT [*count*]]

Qualifiers

None

Execute the specified program once.

SINGLE

Inclusion of this qualifier causes the program to stop on every occurrence of a query result. Pressing the [STEP] key on the front panel keypad will cause the program to continue.

CONTINUOUS

This qualifier causes the number following it to be interpreted as the *interval* parameter.

REPEAT

Including this qualifier causes the program to be executed repetitively.

Parameters

filename
is the name of the file to be executed. If *filename* is not entered, the current program will be executed.

interval   (Floating Point)
specifies the time interval between initiation of execution of contained query commands and/or subprograms. The time *interval* is issued in seconds to the nearest tenth. The maximum value is 99,999,999 seconds.

count
is the number of times the program is to be executed. If *count* is not entered, the program will be executed repeatedly until aborted by a DEVICE CLEAR command or query interrupt.

Query Cmd?

A program is considered to be a query command and is therefore query interruptible if it or any of its subprograms contain a query command.

Default Value   None

References

See "WORKING WITH PROGRAMS" on page 3-10 and specifically "Executing Programs" on page 3-12.

Related Commands

DIRECTORY, PROGRAM CREATE,
SHOW PROGRAM, TRG

Front Panel Examples

[FUNC] [SHOW] [PROGRAM] [7] [5] [ENTER]

```
    H0
    0
```

[↓]

```
    5/

```

[ENTER]
[FUNC] [PROGRAM] [7] [5] [FUNC] [REPEAT] [ENTER]

```
  2 1.749274
    0.004768
```

This program takes a single measurement every time an external trigger pulse occurs.

Remote Examples

```
>SHOW PROGRAM 40
 SINGLE
 ZERO SINGLE
 ZERO
 PROGRAM 50 REPEAT 2
>SHOW PROGRAM 50
 SAMPLE 1
 SINGLE
 SAMPLE 2
 SINGLE
>PROGRAM 40
 S= 3 C= 12.149284 PF L= 0.0000005 DS
 S= 3 C= 0.0000000 ZPF L= 0.0000000 ZDS
 S= 1 C= 900.64128 ZPF L= 0.0000055 ZDS
 S= 2 C= 781.33979 ZPF L= 0.0000029 ZDS
 S= 1 C= 900.64142 ZPF L= 0.0000054 ZDS
 S= 2 C= 781.33981 ZPF L= 0.0000032 ZDS
>
```

In the example above, program 40 is executed once. It calls program 50 and executes it twice. A zero value is taken from sample 3 and used to correct readings from samples 1 and 2.

Comments

- An executing program is indicated by a flashing of the current units LED indicator.

- Any version of this command can be included in a program. Programs can call subprograms to a nesting depth of eight. The parameter settings entered with this command are *not* passed through to subprograms. Subprograms will use their own execution parameters.

Q

Description

Causes the bridge to execute a single measurement by pressing only *one* key on the keyboard of a remote serial device. If continuous readings were being taken, then the Q command aborts them after taking another measurement.

Syntax   Q   (no RETURN key is used)

Parameters   None

Query Cmd?   Yes

Comments

- The Q command is *not* equivalent to the TRG or GPIB GET commands.

- The Q command is shortened from "Question".

- The Q command produces exactly the same result as the SINGLE command but is more convenient to use from the serial port than the SINGLE command.

- This command will only work in an AH 2500A program if it is not the first character. A space can precede it if you desire to enter it by itself on a program line.

Front Panel Examples

The ⌈SINGLE⌉ key is used on the front panel instead of Q.

Serial Remote Examples

```
>SI
 C=843.318636 PF L=0.03721 NS
>SI
 C=843.318642 PF L=0.03722 NS
>C=843.318647 PF L=0.03734 NS
>C=843.318652 PF L=0.03715 NS
>C=843.318661 PF L=0.03721 NS
>
```

The last three measurement results above were initiated with the Q command. Notice that the command was not echoed. Unlike the SINGLE commands further above, the Q command also did not cause any wasteful, nearly blank lines to be printed.

References

See "Taking Measurements One at a Time" on page 4-4.

Related Commands   CONTINUOUS, SINGLE, TRG

Description

Recalls previously stored parameter and program files into current, executable RAM memory.

Syntax

RECALL (BASIC, GAUGE, BAUD, BUS
                          or PROGRAM) *filename*

Qualifiers

BASIC	Recall a file containing Basic parameters.
GAUGE	Recall a file containing Gauge parameters.
BAUD	Recall a file containing Baud parameters.
BUS	Recall a file containing Bus parameters.
PROGRAM	Recall a file containing a program.

Parameters   *filename*

This is the name of the file to be recalled. The name has only digits and contains no more than eight.

Default Value   None

Parameter Set   None

Query Cmd?   No

Comments

- Recalling one of the parameter files (BASIC, GAUGE, BAUD or BUS) causes the parameters in that file to copied to the current parameters. This allows the copied parameters to be edited.

- Unlike parameter files, the only purpose in recalling a program file is to store it under a different filename. There is no way to edit a program file. Such files can only be created and deleted.

- If you are unsure what filenames are available for recall, use the DIRECTORY command to get a list of all that have been stored.

- If you are unsure of the contents of a particular file, you can use the SHOW command to examine the contents.

- In addition to the filenames listed by the DIRECTORY command, a filename of "0" exists in ROM for each of the four parameter file types.

Front Panel Examples

[SHOW] [FUNC] [PLACES] [ENTER]
Displays the following window:

```
  PLACES
   [3  L3
```

[ENTER]
[FUNC] [RECALL] [BASIC] [0] [ENTER]
Recalls the BASIC 0 parameter file which includes the Places parameters.

[SHOW] [FUNC] [PLACES] [ENTER]
Displays the following window showing that the Places parameters have been replaced with those from the BASIC 0 parameter file:

```
  PLACES
   [9  L9
```

Remote Examples

```
>SHOW PROGRAM
>RECALL PROGRAM 8
>SH PR
 AVERAGE 8
 SI
>
```

The above example shows that initially there is no program in RAM. Program 8 is then recalled and a second SHOW command reveals that the contents of program 8 are in RAM memory.

References

See Chapter 3, "Parameter and Program Files" and specifically "Using the Contents of a Parameter File" on page 3-9.

Related Commands

DIRECTORY, SHOW, STORE

REFERENCE *enable*

Description

Changes bridge mode between "Absolute result mode" and "Reference result mode". Reference result mode reports deviation results as simple or percent differences referenced to capacitance or loss values of your choice.

Syntax

REFERENCE [CAP or LOSS]

or

REFERENCE HALT

The first form of the command enables Reference result mode and the second form disables it.

Qualifiers

CAP   Causes Reference result mode to apply to capacitance results. The loss result mode is not affected.

LOSS   Causes Reference result mode to apply to loss results. The capacitance result mode is not affected.

None   Causes Reference result mode to apply to both capacitance and loss results.

Parameters

No parameters are entered. However, the SHOW REFERENCE command will show a one on the REF ON line if Reference result mode is in effect and a zero if not. This is shown independently for both capacitance and loss fields.

Default Value   0, 0   (Absolute result mode for both capacitance and loss.)

Parameter Set   Gauge

Query Cmd?   Yes

Comments

- Enabling Reference result mode is a separate operation from entering the Reference value(s).

- Reference capacitance and loss can be entered (and stored) and not be enabled. Enabling Reference result mode later will then automatically report the difference of the measured value(s) from the Reference value(s).

- When any form of the REFERENCE *enable* command is issued it will re-display the last measurement taken with the new Reference settings in effect.

- This command operates similarly to the ZERO *enable* command.

Front Panel Examples

SINGLE   (Take measurement in window below.)

```
  7 14.50208
    0.02925
```

REFERENCE SINGLE ENTER   (Get measured values.)
REFERENCE ENTER   (Show the differences.)

```
  00.00000
   0.00000
```

SINGLE   (Show new measurement results below.)

```
  - 0.000048
    0.000 14
```

This shows the changes between the SINGLE measurements.

Remote Examples

```
>REF CAP 700
>REF LOSS 0.028
>SI
 C= 734.498542 PF L= 0.02824 NS
>REF CAP
 C= 34.498542 RPF L= 0.02824 NS
>REF LOSS
 C= 34.498542 RPF L= 0.00024 RNS
>REF HALT
 C= 734.498542 PF L= 0.02824 NS
>SI
 C= 734.498561 PF L= 0.02873 NS
>
```

Reference values were manually entered and a measurement taken. Reference mode was first enabled for capacitance, then loss was included. The results of these changes were automatically reported after each change. Reference mode was then exited causing the same result to be reported as for the original measurement. The result is *exactly* the same since no *new* measurement was taken. The actual measurement which follows shows small changes due to noise.

References

See "Reference Result Mode" on page 5-2 and specifically "Enabling Reference Result Mode" on page 5-3 and "Disabling Reference Result Mode" on page 5-3.

Related Commands

REFERENCE FORMAT, REFERENCE *value*, ZERO *value* and ZERO *enable*.

Description

Selects whether Reference result mode reports simple differences or percent differences.

Syntax

REFERENCE FORMAT [CAP or LOSS] *percent*

Qualifiers

CAP Causes the *percent* parameter which is entered to apply only to the capacitance field.

LOSS Causes the *percent* parameter which is entered to apply only to the loss field.

None Causes the *percent* parameter which is entered to apply to both the capacitance and loss fields.

Parameters   *percent*

Percent differences are reported when *percent* is a one. Simple differences are reported when *percent* is a zero.

Default Value   0, 0   (Simple differences for both capacitance and loss.)

Parameter Set   Gauge

Query Cmd?   No

Comments

- Percent format causes the Reference value to first be subtracted from each measurement. The difference is then divided by the Reference value and multiplied by 100. The calculation always starts with the current units, but the final result is dimensionless, of course.

- The effects of the REFERENCE FORMAT command can be observed by issuing the REFERENCE command. This will report the current measurement results in the current differences format.

- Results reported as percentages have special labeling on both the front panel display and remote devices.

- Selecting simple versus percent differences is a separate operation from enabling Reference result mode and from entering the Reference value(s).

- The kind of differences to report for capacitance and loss can be entered (and stored) and not be enabled. Enabling Reference result mode later will then automatically report the desired kind of differences of the measured value(s) from the Reference value(s).

Front Panel Examples

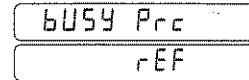[SINGLE]

[REFERENCE] [SINGLE] [ENTER]   (Get measured values.)

[REFERENCE] [FUNC] [FORMAT] [CAP] [1] [ENTER]

[REFERENCE] [ENTER]

Enable Reference mode for both and re-display the results.

| 000.00000 |
| 0.00000 |

[SINGLE]   (bUSY is displayed until measurement finishes.)

| bUSY Prc |
| rEF |

| -0.000007 |
| 0.00014 |

The bUSY display shows the result mode indicators.

Remote Examples

```
>REF CAP 700
>REF LOSS 0.028
>SI
 C= 734.498542 PF L= 0.02824 NS
>REF
 C= 34.498542 APF L= 0.00024 ANS
>REF FOR 1           (Change the differences format.)
>REF                 (Show the effects of the change.)
 C= 4.6968837 %PF L= 0.85 %NS
>SI
 C= 4.6969147 %PF L= 0.83 %NS
>
```

Reference values were manually entered and a measurement taken. Reference mode was enabled and reported the simple differences between the entered and measured values. The difference format was then changed to percent. Issuing the REFERENCE command again reported new results. The unit labels indicate which modes are active for each line. Finally, a new measurement was taken with percent differences still enabled.

References

See "Reference Result Mode" on page 5-2 and specifically "Selecting Reference Percent Format" on page 5-3 and "Indication of Reference Result Mode" on page 5-3.

Related Commands

REFERENCE *enable*, REFERENCE *value*, ZERO *value* and ZERO *enable*.

REFERENCE *value*

Description
Provides manual and automatic ways to enter capacitance and/or loss Reference values.

Syntax

> REFERENCE (CAP or LOSS) *refvalue*

is used to enter Reference values manually, or

> REFERENCE [CAP or LOSS] SINGLE

uses the last-measured capacitance and/or loss values as Reference values. These last-measured values are taken after any possible Zero corrections are applied.

Qualifiers

CAP   Causes the value entered as *refvalue* or the last capacitance value measured to be used as the capacitance Reference.

LOSS   Causes the value entered as *refvalue* or the last loss value measured to be used as the loss Reference.

None   Causes both of the last-measured capacitance and loss values to be used as Reference values. This is only true for the REFERENCE SINGLE command; entering a *refvalue* requires a CAP or LOSS qualifier.

Parameters   *refvalue*   (Floating Point)
This is the value of the capacitance or loss to be used as a Reference. The value is assumed to be entered in the current units. The maximum value that can be entered in any units is 99,999,999.

Default Value   0, 0
(Reference values for capacitance and loss are both zero.)

Parameter Set   Gauge

Query Cmd?   No

Comments
* Entering the Reference value(s) is a separate operation from actually using them by enabling Reference result mode. This makes it easier to enter and exit Reference result mode.
* This command is similar to the ZERO *value* command.
* The bridge performs all Reference calculations *after* performing any Zero calculations that might be enabled.

Front Panel Examples

FUNC RECALL GAUGE 0 ENTER

SINGLE   (Takes measurement in window below.)

```
 7 145.0208
  002925
```

REFERENCE SINGLE ENTER   (Get measured values.)
REFERENCE CAP ENTER
Enable Reference result mode for capacitance only.

```
 00.00.0000
  000000
```

SHOW REFERENCE ENTER   (Show the effects.)

```
 7 145.0208          rEF
  0.02925            0.02925
```

⬇

```
  rEF  Fr Nt
   CD  LD
```

⬇

```
  rEF  on
   CI  LD
```

This example shows all the front panel Reference windows.

Remote Examples
```
>RECALL GAUGE 0     (Initialize Reference parameters.)
>REF CAP 700
>REF LOSS 0.03
>SH REF
 REFERENCE  C=700.00000 PF L=0.0300000 NS
 REF FORMAT C=0 L=0
 REF ON     C=0 L=0
>
```
The capacitance and loss Reference values were manually entered. All the Reference parameters were then reported.

References
See "Reference Result Mode" on page 5-2 and specifically "Entering Reference Values Manually" on page 5-2 and "Entering Reference Values Automatically" on page 5-3.

Related Commands
REFERENCE *enable*, REFERENCE FORMAT, ZERO *value* and ZERO *enable*.

Description

Causes the bridge to reset.

Syntax

RST

Parameters

None

Query Cmd?

No

Comments

- The effect of this AH 2500A command is to put all higher control sections of the bridge except for the serial and GPIB interfaces into the same state as at power-on.

- Bridge parameters in the Basic and Gauge parameter sets are set to their power-on values as contained in the parameter sets numbered zero or one. Parameters in the current Bus and Baud parameter sets are not initialized.

- The GPIB PON status bit is *not* set when this command is executed.

- The RST command produces exactly the same result as the SPECIAL HALT command.

- The power-on program does not execute in response to the RST command.

Front Panel Examples

This command is not available in this syntax from the front panel. However, execution of this command from remote devices will show the front panel message below:

```
rESEt
```

Remote Device Examples

```
>SH BASIC
BRIGHTNESS    C=5 L=5
FORMAT        SMP=1 CAP=1 LOS=1 VLT=1
                  MSG=1 LBL=1 PUN=0 FFD=1
FRMT SPEC     N=0
HOLD SPEC     TRIGBUF=1
PLACES        C=0 L=9
SAMPLE        NUMBER=01
SAMPLE HLD    TIME= 0.10    SEC
TEST FRMT     HOC=0 RPR=2
UNITS         L=1
>RST
>SH BASIC
BRIGHTNESS    C=5 L=5
FORMAT        SMP=0 CAP=1 LOS=1 VLT=1
                  MSG=1 LBL=1 PUN=0 FFD=1
FRMT SPEC     N=0
HOLD SPEC     TRIGBUF=1
PLACES        C=9 L=9
SAMPLE        NUMBER=01
SAMPLE HLD    TIME= 0.00    SEC
TEST FRMT     HOC=1 RPR=2
UNITS         L=1
>
```

The contents of the current Basic parameter set is shown before and after execution of the RST command. This command resets the parameters to their default values.

References

See "INITIALIZING THE BRIDGE" on page 6-14 and specifically "The RST Command" on page 6-15.

Related Commands

DEVICE CLEAR, SPECIAL HALT

SAMPLE

Description

Selects which external unknown sample to measure. Operates only in conjunction with the sample switch port.

Syntax

SAMPLE *number*

Parameters   *number*

This specifies the number of the sample to be measured. It can have any value from 1 to 64. However, values of this parameter larger than eight will cause all sample switch data lines to be false. Values from one to eight will cause one of the eight sample switch data lines to be true. The number of the selected sample switch data line is one less than the value of the *number* parameter.

Default Value   1

Parameter Set   Basic

Query Cmd?   No

Comments

- With an external sample switch, this command provides for unattended measurements of multiple unknown samples. The PROGRAM commands of the bridge combined with a logging device can do this. Alternatively, a remote GPIB or serial controller can also work.

- The control lines provided on the sample switch port are intended for controlling sample switches. However, a custom designed interface could be created to control many other simple devices.

- The operation of the SAMPLE HOLD command should be understood if only to insure that its delay time has not been left set to a needlessly large value.

- This command will be accepted in place of a STEP or X command in response to a prompt from a TEST or CALIBRATE 3 command.

Front Panel Examples

[SAMPLE] [6] [ENTER]   (Select sample number 6.)

[SHOW] [SAMPLE] [ENTER]

```
  SAMPLE
    6
```

Remote Device Examples

```
>SA  1                        (Select sample number 1.)
>SI
 S=  1  C=  734.498542  PF  L=  0.02824    DS
>SA  2                        (Select sample number 2.)
>SI
 S=  2  C=  900.64128   PF  L=  0.0000055  DS
>SA  3                        (Select sample number 3.)
>SI
 S=  3  C=  781.33981   PF  L=  0.0000032  DS
>SA  4                        (Select sample number 4.)
>SI
 S=  4  C=  440.18054   PF  L=  0.0000062  DS
>SH  SA
 SAMPLE      NUMBER=  4
>
```

This is an example of the most common usage of the SAMPLE command where four samples are measured in sequence.

References

See Appendix D, "Sample Switch Port" and specifically "Selecting a Sample Switch Position" on page D-1.

Related Commands

PROGRAM, SAMPLE HOLD, STEP, X

Description

Specifies a time delay that automatically occurs after each execution of the SAMPLE command. This provides a settling time for sample switch relays to stabilize after being switched.

Syntax

SAMPLE HOLD *delay*

Parameters

delay (Floating Point)

This *delay* parameter is entered in seconds to the nearest hundredth.

Default Value

0.0

Parameter Set

Basic

Query Cmd?

No

Comments

- The *delay* time specified by this command occurs as a part of the SAMPLE command. That command will not finish until the delay time has expired. This holds off any further operations.

- The *delay* time occurs every time the SAMPLE command is executed and is therefore the same no matter what sample number has been selected. If some samples require a longer settling time than others, additional settling time can be provided by executing the HOLD command after executing the SAMPLE command for the slower samples.

- If the SAMPLE command is executed with a long delay time, you must wait for this time to elapse or abort the SAMPLE command with a DEVICE CLEAR command.

Front Panel Examples

[SAMPLE] [FUNC] [HOLD] [•] [0] [3] [ENTER]

[SHOW] [SAMPLE] [FUNC] [HOLD] [ENTER]

```
5AMP HLd
0.03
```

Remote Examples

```
>SA HO 0.1
>SH SA HO
 SAMPLE HLD DELAY= 0.10      SEC
>
```

References

See "Signal Timing" on page D-1 and specifically "Changing the Settling Time" on page D-2.

Related Commands   HOLD, SAMPLE

SHOW CALIBRATE

Description

Compares verification data just produced by the CAL 1, CAL 2, or CAL 3 commands against data that is stored from past calibrations.

Syntax

SHOW CALIBRATE [1, 2 or 3]

Qualifiers

None

Reports current bridge conditions relative to those at the time of the last calibrations.

1

Reports bridge conditions at the time of a recently performed CAL 1 command relative to those at the time of the last internal calibration. For non-Option-E bridges, this command also reports the internal calibration point that had the biggest change between those at the time of a recently performed CAL 1 command relative to those at the time of the last internal calibration. If the AH 2500A has Option-E, then the change in *all* other internal calibration points is also reported.

2

Reports bridge conditions at the time of a recently performed CAL 2 command relative to those at the time of both the stored Original and Update capacitance calibrations. This command also reports the deviation in the capacitance obtained with the recent CAL 2 command relative to those at the time of both the stored Original and Update capacitance calibrations.

3

This command is available on Option-E bridges only. It reports bridge conditions at the time of a recently performed CAL 3 command relative to those at the time of both the stored Original and Update transformer calibrations. This command also reports the deviation in all the transformer calibration points obtained with the recent CAL 3 command relative to those at the time of both the stored Original and Update transformer calibrations.

Parameters   None

Default Value   None

Query Cmd?   Yes

Comments

* The subject of calibration must be thoroughly understood before use of these commands is attempted. It is essential to first read much of Chapter 9, "Verification/Calibration".

Front Panel Examples

[SHOW] [FUNC] [CALIBRATE] [2] [ENTER]

See Figure 9-2 on page 9-2, Figure 9-4 on page 9-4, and Figure 9-7 on page 9-10 for examples of the results reported by these commands on the front panel.

Remote Device Examples

>SH CAL 1

See Figure 9-1 on page 9-2, Figure 9-3 on page 9-4, Figure 9-6 on page 9-10 and Figure 9-8 on page 9-14 for examples of the results reported by these commands to remote devices.

References

See "Comparison with the Previous Calibration Conditions" on page 9-3, "Internal Verification Results" on page 9-5, "Capacitance Verification Report" on page 9-10 and "Transformer Verification Report" on page 9-13

Related Commands

CALIBRATE, STORE CALIBRATE
STORE CALIBRATE CREATE,
STORE CALIBRATE SPECIAL

Description

Reports parameter values associated with individual commands. These parameter values are reported from current parameter sets only. The parameter set types from which values can be reported are Basic, Gauge, Baud and Bus.

Syntax

SHOW *individual*

Qualifiers

individual   Name of the command that sets the parameter that is to be reported.

Query Cmd?   Yes

Comments

- Pressing ENTER will abort a multi-line show that is in progress on the front panel.

- Pressing ← or → moves the front panel display left or right from window to window on a given line.

- Pressing ↑ or ↓ moves the front panel display from result line to result line.

Front Panel Examples

Front panel examples of the SHOW *individual* command are given for every parameter throughout this command reference. Refer to the page having the associated command name heading.

SHOW UNITS ENTER

```
   Un, t5
   L I
```

ENTER

```
   r E Rd y

```

The value of the units parameter was reported.

Remote Device Examples

Remote device examples of the SHOW *individual* command are given for every parameter throughout this command reference. Refer to the page having the associated command name heading.

```
>SHOW HOLD SPECIAL
 HOLD SPEC          TRIGBUF=1
>HO SPECIAL 0
>SH HO SPEC
 HOLD SPEC          TRIGBUF=0
>RECALL BASIC 0
>SH HO SPEC
 HOLD SPEC          TRIGBUF=1
>
```

The above example first shows the current TRIGBUF value. This parameter is set to zero in the current parameter set and the parameter is shown again. The default Basic parameter set is then recalled. The original SHOW command is repeated to see that the current value of the TRIGBUF parameter was changed again by the recall operation.

References

See Chapter 3, "Parameter and Program Files" for more examples.

Related Commands SHOW *set*

SHOW PROGRAM

Description
Reports the contents of the current program or of any program file.

Syntax

SHOW PROGRAM [*filename*]

Parameters   *filename*
This is the name of the file from which the program is to be read. The name has only digits and contains no more than eight.

Default Value
If no *filename* is entered, the contents of the current program are reported.

Query Cmd?   Yes

Comments

- On the front panel display, the contents of each line of a program file are shown in a group of from one to three windows. The next window to the right is used to display a line number for the command. As usual, each window of a line can be shown one-by-one by pressing the ⬅ or ➡ keys. The ⬆ and ⬇ keys are used to go from one command line to the next.

- Only the leading characters of each command word will be reported even though many more may have been entered.

- Pressing the ENTER key will abort the SHOW command at any time on the front panel.

- If you are unsure of what program files have been stored, the DIRECTORY PROGRAM command can be used to list them.

References
See "WORKING WITH PROGRAMS" on page 3-10 and specifically "Showing the Contents of Program Files" on page 3-11.

Related Commands
DIRECTORY, PROGRAM CREATE, PROGRAM execute

Front Panel Examples

SHOW FUNC PROGRAM ENTER

| Uni | | I |
| 2 | | |

⬇

| HOL | | 2 |
| 0 | | |

⬇

| SI Π | | 3 |
| | | |

ENTER

| rEAdY |
| |

The contents of the current program created on the front panel in the example given in the PROGRAM CREATE command description on page A-26 are shown above. Each line can have as many as four windows, but only two are reported in this example. For convenience, the right-most window assigns a line number for the command line.

Remote Device Examples

```
>SHOW PROGRAM
 AVE 7
 HOL 900
 SIN
 ZER SIN
 ZER
 HOL 180
 SIN
>
```

The contents of the current program created on a remote device in the example given in the PROGRAM CREATE command description on page A-26 are shown above.

Description

Reports the entire contents of the selected parameter set. This set can be either a current set or any stored parameter set. The parameter set types from which values can be reported are Basic, Gauge, Baud and Bus.

Syntax

SHOW [BASIC, GAUGE, BAUD or BUS [*filename*]]

Qualifiers

None   The parameters to be reported will be read from the current Gauge parameter set. No *filename* will be accepted.

BASIC   All parameters in the specified file having a Basic filetype will be reported.

GAUGE   All parameters in the specified file having a Gauge filetype will be reported.

BAUD   All parameters in the specified file having a Baud filetype will be reported.

BUS   All parameters in the specified file having a Bus filetype will be reported.

Parameters   *filename*

This is the name of the file from which the parameters are to be read. The name has only digits and contains no more than eight.

Default Value

If no *filename* is entered, the parameters in the selected *current* parameter set type are reported.

Query Cmd?   Yes

Comments

- Pressing ENTER will abort a multi-line SHOW command that is in progress on the front panel.

- Pressing the ← or → keys moves from window to window on a given line on the front panel. The ↑ and ↓ keys are used to go from one result line to the next.

- If you are unsure what filenames and types are available to be read, issue the DIRECTORY command to get a list of all that have been stored.

References

See "Exploring a List with the SHOW command" on page 2-5.

Related Commands

DIRECTORY, SHOW *individual*

Front Panel Examples

Front panel examples of the SHOW *individual* command are given for every parameter in this command reference. Refer to the page having the associated command name heading. Space does not permit showing whole sets here.

Remote Device Examples

```
>SH BASIC 0
BRIGHTNESS     C=5 L=5
FORMAT         SMP=0 CAP=1 LOS=1 ULT=1
                  MSG=1 LBL=1 PUN=0 FFD=1
FRMT SPEC      N=0
HOLD SPEC      TRIGBUF=1
PLACES         C=9 L=9
SAMPLE         NUMBER= 1
SAMPLE HLD     DELAY= 0.00    SEC
TEST FRMT      HOC=0 RPR=2
UNITS          L=1
>SH GAU 0
ALTERNATE      ALTEXP=0
AVERAGE        AVEREXP=4
DC BIAS        ENABLE=0
CABLE          LENGTH= 1.00    M
CABLE          RESISTANCE/M= 40.0    MO
CABLE          INDUCTANCE/M= 1.10    UH
CABLE          CAPACITANCE/M= 70.0   PF
REFERENCE      C= 0.0000000 PF
                       L= 0.00000000 NS
REF FORMAT     C=0 L=0
REF ON         C=0 L=0
TRACKING       THRESHOLD=0
VOLTAGE        HIGHEST= 15.0    U
ZERO           C= 0.0000000 PF
                       L= 0.00000000 NS
ZERO ON        C&L=0
>SH BAU 0
BAUD           RATE=96 DTE=1 PAR=0 LEN=8
                  STP=1 FIL=0 ECH=1
DEFINE         ERASE=^U DEL=DEL BACKSP=^H
                  DCL= ^E TERM=PRINTER
NREMOTE        STATE=0
NLOCKOUT       STATE=0
LOG BAUD       CONTENT=0
>SH BU 0
BUS ADDR       PRI=28 SEC=
                  TON=0 CPT=0 PRP=0
SRE            MAU=0 EXE=0 RDY=0 PON=0
                  URQ=0 CME=0 ONR=0
LOG BUS        CONTENT=1
>
```

The above results show an example of each of the four parameter filetypes as reported to a remote device.

SHOW SPECIAL

Description

Reports current status and configuration information about the bridge. This information includes the contents of its GPIB status byte, the approximate elapsed time since the bridge was manufactured, its serial number, the version of its firmware (ROM), and its internal hardware and firmware options.

Syntax

SHOW SPECIAL

Parameters   None

Parameter Set   Special

Query Cmd?   Yes

Comments

- Pressing ENTER will abort a multi-line show that is in progress on the front panel.

- Pressing the ← or → keys moves from window to window on a given line on the front panel. The ↑ and ↓ keys are used to go from one result line to the next.

- Unlike the SHOW STATUS command, the SHOW SPECIAL command does not clear the event status bits in the GPIB status byte.

- If the *compat* bit is set in the Bus communications parameter byte then the status lines in the results shown in the examples at the right will be different. On the front panel the status line will appear as:

STATUS	bdECIMAL
8	8

On remote devices the status line will look like:

```
STATUS        BWDECIMAL=  8
```

Front Panel Examples

SHOW FUNC SPECIAL ENTER gives:

STATUS		M.M.E.r.P.U.C.O
0.0.0.0. 1.0.0.0		0.0.0.0. 1.0.0.0

↓ gives:

ELAPSEd
Hr 1422

↓ gives:

SEr nUM
0 1000

↓ gives:

rOM UErS
AA 123

↓ gives:

OPtionS
E-------

The upper half of the window at the top right shows the first letter of the label of each of the bits in the GPIB status byte. This makes it easier to identify the bits in the bottom half of the window.

Remote Device Examples

```
>SH SPEC
  STATUS      MAU=0 MSS=0 EXE=0 RDY=0
              PON=0 URQ=0 CME=0 ONR=0
  ELAPSED     TIME=1234 HRS
  SERIAL      NUMBER=654321
  ROM         VERSION=AA123
  OPTIONS     TYPE=E-------
>
```

References

See "Special Parameter Set" on page 3-7.

Related Commands   SHOW STATUS

Description
Reports the GPIB status byte and clears the four event status bits in the status byte.

Syntax

SHOW STATUS

Parameters   None

Default Value   None

Parameter Set   Special

Query Cmd?   Yes

Comments

- The contents of the status byte are reported as a string of eight binary bits unless compatibility mode is enabled. Compatibility mode causes the contents to be reported as a binary-weighted-decimal integer.

- The meaning of each bit is shown in Table A-4 below.

- The MAV and RDY bits will always be zero when read with the SHOW STATUS command.

Front Panel Examples
Available from the front panel only as one line of the result from the SHOW SPECIAL command.

Remote Examples

```
>SH STAT
 STATUS    MAV=0 MSS=1 EXE=0 RDY=0
                 PON=1 URQ=0 CME=0 ONR=1
>SH STAT           (Check again to see what was cleared
                    by first SHOW STATUS.)
 STATUS    MAV=0 MSS=1 EXE=0 RDY=0
                 PON=0 URQ=0 CME=0 ONR=1
>BUS ...1          (Set compatibility mode.)
>SH STAT
 STATUS    BWDECIMAL=65
```

References
See "STATUS REPORTING" on page 6-5 and specifically "Reading the Status with a Command" on page 6-6. See also "STATUS REPORTING" on page 6-5.

Related Commands   BUS, SRE, USER

Table A-4 Status byte register bits reported by SHOW STATUS command.

Bit	Label	Name	Set when	Cleared when	Generates SRQ when
0	ONR	Oven Not Ready	Oven temperature is abnormal	Oven temperature returns to normal	set or cleared
1	CME	CoMmand Error	An error in the entry of a command occurred. See Appendix B, "Error Messages" for a list.	SHOW STATUS or RST is executed	set
2	URQ	User ReQuest	The USER command is executed	SHOW STATUS or RST is executed	set
3	PON	Power-ON	Bridge power comes on	SHOW STATUS or RST is executed	set
4	RDY	ReaDY for command	A command line finishes its execution; see "INTERACTIVE OPERATION" on page 6-12	A new command line is received	set
5	EXE	EXecution Error	An error occurred executing a command. See Appendix B, "Error Messages" for a list.	SHOW STATUS or RST is executed	set
6	MSS	Master Summary Status	Inclusive OR of the bit-wise combination of bits 1-7 of the SB and SRE registers is true or when the ONR status bit changes while the corresponding ONR bit in SRE register is set.	Inclusive OR of SB and SRE is false	N/A, see RQS bit
7	MAV	Message AVailable	A message is available in the GPIB output buffer	No message is in the GPIB output buffer.	set

SINGLE

Description

Causes the bridge to take a single measurement. If continuous readings were being taken, then the SINGLE command aborts them after taking another measurement.

Syntax

SINGLE

Parameters

None

Query Cmd?

Yes

Comments

- The Q command produces exactly the same result as the SINGLE command and is more convenient to use from the serial port.
- The SINGLE command is *not* equivalent to the TRG or GPIB GET commands.

Front Panel Examples

[SINGLE]   (Take a measurement and show in window below.)

```
 95 183 125        5:0 1
 002 774           U: 150
```

The left window shows the capacitance and loss. The right window shows the sample number and the voltage used to make the measurement. The [◄] and [►] keys are used to move between these two windows.

Remote Device Examples

```
>SI
 C=843.318636 PF L=0.03721 NS
>SI
 C=843.318642 PF L=0.03722 NS
>
```

References

See "Taking Measurements One at a Time" on page 4-4.

Related Commands   CONTINUOUS, Q, TRG

Description
Causes the bridge to reset.

Syntax

SPECIAL HALT

Parameters   None

Query Cmd?   No

Comments

- The effect of this AH 2500A command is to put all higher control sections of the bridge except for the serial and GPIB interfaces into the same state as at power-on.

- Bridge parameters in the Basic and Gauge parameter sets are set to their power-on values as contained in the parameter sets numbered zero or one. Parameters in the current Bus and Baud parameter sets are not initialized.

- The GPIB PON status bit is *not* set when this command is executed.

- The SPECIAL HALT command produces exactly the same result as the RST command.

- The power-on program does not execute in response to the RST command.

- A rE5Et message appears on the front panel when this command is executed.

Front Panel Examples

FUNC SPECIAL HALT ENTER

Shows the front panel message below:

```
rE5Et
```

Remote Device Examples

>SP HA
>

References
See "PARAMETER SET INITIALIZATION" on page 3-10, "INITIALIZING THE BRIDGE" on page 6-14 and specifically "The RST Command" on page 6-15.

Related Commands   DEVICE CLEAR, RST

SRE

Description

Sets and clears bits in the GPIB service request enable mask byte.

Syntax

$$\underline{SRE} \ mav \ . \ exe \ . \ rdy \ . \ pon \ . \ urq \ . \ cme \ . \ onr$$

or

$$\underline{SRE} \ bwdmask$$

The first version of the command accepts binary bits specifying which enable bits are to be set or cleared. The period following *mav* must always be entered. Each of the seven positional parameters is entered as either a one or a zero. A one enables the service request bit and a zero disables it.

The second version accepts a standard GPIB binary-weighted-decimal representation of the enable mask. Any value from 0 to 255 is allowed.

Parameters

The table below gives the relationship between the binary parameters in the first version of the SRE command to the status bit name. The binary weight of each status bit name is also given for use with the second version of the command.

Table A-5 Service Request Enable mask register bit definitions and functions

Bit	Label	Name	Generates SRQ when	Binary weight
0	*onr*	Oven Not Ready	set or cleared	1
1	*cme*	CoMmand Error	set	2
2	*urq*	User ReQuest	set	4
3	*pon*	Power-ON	set	8
4	*rdy*	ReaDY for command	set	16
5	*exe*	EXecution Error	set	32
7	*mav*	Message AVailable	set	128

Default Value   0   (No service requests enabled.)

Parameter Set   Bus

Query Cmd?   No

Front Panel Examples

Not enterable from the front panel, but can be shown.

$\boxed{\text{SHOW}}$ $\boxed{\text{FUNC}}$ $\boxed{\text{BUS ADDR}}$ $\boxed{\text{ENTER}}$ $\boxed{\downarrow}$ gives:

| SrE |
| 0. 0.0.0.0.0 |

| N. E.r.P.U.C.O |
| 0. 0.0.0.0.0 |

The $\boxed{\leftarrow}$ and $\boxed{\rightarrow}$ keys are used to select which of the two windows is displayed.

Remote Device Examples

```
>SHOW SRE
 SRE         MAV=0 EXE=0 RDY=0 PON=0
             URQ=0 CME=0 ONR=0
>SRE .1..1..1        (Enable EXE, PON and CME.)
>SHOW SRE
 SRE         MAV=0 EXE=1 RDY=0 PON=1
             URQ=0 CME=1 ONR=0
>SRE 1.0             (Enable MAV, disable EXE.)
>SHOW SRE
 SRE         MAV=1 EXE=0 RDY=0 PON=1
             URQ=0 CME=1 ONR=0
>SRE 17              (Set bwdmask to exactly 17.)
>SHOW SRE
 SRE         MAV=0 EXE=0 RDY=1 PON=0
             URQ=0 CME=0 ONR=1
>BUS ...1            (Set compatibility mode.)
>SHOW SRE
 SRE         BWDECIMAL=17
>
```

This example shows how to both change and show mask settings in both binary and binary-weighted-decimal. Changing mask bits with the binary entry method is also demonstrated.

Comments

- The first (binary) version of the SRE command allows setting and/or clearing only the bits to be changed. The second (binary-weighted-decimal) version deletes the old mask and replaces it with the mask that is entered.

- This command can only be entered from a remote device and is only useful with a GPIB controller.

- When a *bwdmask* entry is translated to binary, the bit positions that are ones will cause the corresponding service requests to be allowed. The only exception is bit position six which is ignored.

References

See "STATUS REPORTING" on page 6-5 and specifically "Service Requests" on page 6-7.

Related Commands BUS, SHOW STATUS, USER

Description

Steps through operations when using the CALIBRATE 3, TEST or PROGRAM commands.

Syntax   STEP

Parameters   None

Query Cmd?

Execution of the STEP command usually produces a query result, but this is dependent on what root command is being executed. The TEST command, for example, can be set to halt on every test without sending a result.

Comments

- The X command produces exactly the same result as the STEP command and is more convenient to use from the serial port.

- In most cases, this command is used in conjunction with the front panel to cause the bridge to continue after you have observed a result on the display. In some cases, this command tells the bridge to continue after waiting for you to perform an external action. The latter occurs with the CALIBRATE 3 and TEST commands.

- The STEP command will do nothing if there is no active root command waiting for input. This allows the STEP command to be used in programs where the need for it may be uncertain. It should cause no harm if it is not needed.

- A STEP command following a program will not be processed even if the program contains a command that is looking for STEP as a reply. In other words, in the command line PROGRAM; STEP, the STEP will never have any effect no matter what the contents of the program.

Front Panel and Remote Device Examples

For some examples see "DC BIAS High Voltage Tests" on page 11-17 and "Obtaining Transformer Verification Data" on page 9-12.

References

See "Single-Step Mode" on page 3-12, Chapter 9, "Verification/Calibration" and "Selection of Options: the TEST FORMAT command" on page 11-7.

Related Commands

CALIBRATE, PROGRAM, SAMPLE, TEST, X

STORE

Description

Stores a current parameter set or program in EEPROM memory.

Syntax

STORE (BASIC, GAUGE, BAUD, BUS
or PROGRAM) *filename*

Qualifiers

BASIC   Save the current Basic parameter set to a file.

GAUGE   Save the current Gauge parameter set to a file.

BAUD   Save the current Baud parameter set to a file.

BUS   Save the current Bus parameter set to a file.

PROGRAM   Save the current program to a file.

Parameters   *filename*

This is the name of the file to be stored. The name can contain only digits and can have no more than eight. The name "0" is reserved for files stored in ROM. Parameter files stored with the name "1" will be recalled upon power-on. A program file stored with the name "1" will executed upon power-on. A program file stored with the name "2" will executed upon reception of a TRG command or a GPIB bus GET command.

Default Value   None

Parameter Set   None

Query Cmd?   No

Comments

- If you are unsure of what filenames are already in use, issue the DIRECTORY command to get a list of all that have been stored.

- Storing a new file using a name and type that already exists will cause the old file to be overwritten with the new one. No warning is given when this happens.

- If you are unsure of the contents of a particular file, you can use the SHOW command to examine the contents.

Front Panel Examples

[SHOW] [GAUGE] [1] [ENTER]
Displays the following window:

```
┌─────────────────────┐
│    ALtrnAtE         │
├─────────────────────┤
│    0                │
└─────────────────────┘
```

[FUNC] [ALTERNATE] [4] [ENTER]
Sets the alternate parameter to 4.

[FUNC] [STORE] [GAUGE] [1] [ENTER]
Stores the current Gauge parameter set including the alternate parameter into Gauge file 1.

[SHOW] [GAUGE] [1] [ENTER]
Displays the following window showing that the alternate parameter in the GAUGE 1 file has changed from zero to four:

```
┌─────────────────────┐
│    ALtrnAtE         │
├─────────────────────┤
│    4                │
└─────────────────────┘
```

Remote Device Examples

```
>SHOW PROGRAM 15
 FILE NOT FOUND
>SH PR
 AVER 8
 SI
>STORE PR 15
>SHOW PR 15
 AVER 8
 SI
>
```

This example shows that initially there is no program with a file name of "15", but that there is a two-line program in RAM. The current program is then stored in program file 15. Another SHOW command reveals that the contents of the current program are now also in program file 15.

References

See Chapter 3, "Parameter and Program Files" and specifically "Adding Files" on page 3-8.

Related Commands

DELETE *file*, DIRECTORY, RECALL, SHOW

Description

Causes the AH 2500A to save the verification values obtained with the CALIBRATION commands.

Syntax

STORE CALIBRATE [1, 2, or 3]

this is the commonly used command version. It performs the functions listed in the qualifiers section below.

or

STORE CALIBRATE 2 CALIBRATE *standardvalue*

this version of the command is extremely specialized. It is used only for total re-calibration of a non-Option-E bridge after either the capacitance standard or the main board have been replaced.

Qualifiers

None
Overwrites the previous calibration data with whatever new verification data has been produced by the last CAL 1, 2, and/or 3 commands.

1
Overwrites only the previous internal calibration data with that produced by the last CAL 1 command.

2
Overwrites only the previous Update capacitance calibration data with that produced by the last CAL 2 command.

3
Overwrites only the previous Update transformer calibration data with that produced by the last CAL 3 command. This command is available with Option-E bridges only.

Parameters   None

Query Cmd?   No

References

See "Saving the Internal Verification Data" on page 9-9, "Saving the Capacitance Verification Data" on page 9-11, "Saving the Transformer Verification Data" on page 9-13, "Saving All Verification Data" on page 9-12, "Main Board Installation Procedure" on page 12-8, and "Standard Capacitor Installation Procedure" on page 12-12.

Front Panel Examples

| FUNC | STORE | FUNC | CALIBRATE | 2 | ENTER |

```
┌─────────────────────┐
│      PA55C0dE        │
├─────────────────────┤
│                     │
└─────────────────────┘
```

| 1 | 2 | 3 | 4 | 5 | 6 |

```
┌─────────────────────┐
│      PA55C0dE        │
├─────────────────────┤
│       123456         │
└─────────────────────┘
```

| ENTER |

This example shows the passcode prompt resulting from the entry of a STO CAL 2 command. This is followed by the entry of the "123456" passcode. The Update capacitance calibration data is overwritten after the ENTER key is pressed.

Remote Device Examples

```
>STO CAL 1
PASSCODE>171717  (The passcode is not actually echoed.)
>
```
Saves new internal calibration data.

Comments

* The subject of calibration must be thoroughly understood before using these commands is attempted. It is essential to first read much of Chapter 9, "Verification/Calibration".

* Every version of this command requires the entry of a passcode. Entry of three bad passcodes in a row will cause all further passcodes to be rejected until power-on occurs.

* If either the capacitance or transformer Update data is stored, the corresponding *update* parameter is set to one.

* Storing new capacitance or transformer calibration values will change the actual calibration of the bridge *only* if the corresponding *update* parameter has a value of one.

Related Commands

CALIBRATE, SHOW CALIBRATE, STORE CALIBRATE CREATE, STORE CALIBRATE SPECIAL

STORE CALIBRATE CREATE

Description
Allows creating new calibration passcodes.

Syntax

> STORE CALIBRATE CREATE (1, 2 or 3)

Qualifiers
1
Allows changing the User passcode if you know the Owner passcode.

2
Allows changing the Calibrator passcode if you know the Owner passcode.

3
Allows changing the Replace passcode if you know the Owner passcode. This qualifier is only available on *non-*Option-E bridges.

Parameters
There are no parameters, but you will be prompted for old and new passcodes after issuing this command.

Query Cmd?   No

Comments
- Passcodes entered in response to a prompt on remote serial devices will not be echoed.
- The passcodes can be entered as a part of the command on the same line by separating the command and its passcodes with semicolons. Passcodes entered this way *will* be echoed to a serial device.
- Entry of three bad passcodes in a row will cause all further passcodes to be rejected until power-on occurs.

Related Commands
CALIBRATE, SHOW CALIBRATE
STORE CALIBRATE 1,2,3
STORE CALIBRATE SPECIAL

References
See "Changing the User Passcode" on page 9-17, "Changing the Calibrator Passcode" on page 9-18, and "Changing the Replace Passcode" on page 9-18.

Front Panel Examples

FUNC STORE FUNC CALIBRATE FUNC CREATE
ENTER

$$\boxed{\mathsf{Onr\ CodE}}$$
$$\boxed{}$$

1 2 3 4 5 6

$$\boxed{\mathsf{Onr\ CodE}}$$
$$\boxed{\mathsf{123456}}$$

ENTER

$$\boxed{\mathsf{USr\ CodE}}$$
$$\boxed{}$$

3 1 4 1 5 9

$$\boxed{\mathsf{USr\ CodE}}$$
$$\boxed{\mathsf{314159}}$$

ENTER

This example shows the Owner passcode prompt resulting from the entry of a STO CAL CR 1 command. This is followed by the entry of a "123456" Owner passcode. In this example the bridge accepted this as the correct passcode and responded with the prompt for the User passcode. This is followed by the entry of a new "314159" User passcode. The old User passcode is replaced with the new "314159" User passcode after the ENTER key is pressed.

Remote Device Examples

>STO CAL CREATE 2
OWNER CODE>123456
CALIBRATOR CODE>171717

Change the Calibrator passcode to "171717". The passcodes above are not actually echoed if the remote device is connected to the serial port.

>STO CAL CR 2;123456;171717
This performs the same function as the previous example.

Description

Selects the source of data for the capacitance or transformer calibrations. You can select the original calibration done at the time of manufacture or a later, updated calibration.

Syntax

STORE CALIBRATE (2 or 3) SPECIAL *update*

changes the *update* parameters one at a time. Requires the Owner or Calibrator passcode.

Qualifiers

2

Allows changing the capacitance calibration *update* parameter.

3

Allows changing the transformer calibration *update* parameter for Option-E bridges only.

Parameters   *update*

When set to a one, an *update* parameter causes the bridge to use the corresponding Update calibration data. When cleared to a zero, the *update* parameter causes the bridge to use the corresponding Original calibration data.

Default Value   None

Parameter Set   None

Query Cmd?   No

Comments

- The function of the *update* parameter must be thoroughly understood before changing it.

- Passcodes entered on remote serial devices in response to a passcode prompt will not be echoed.

- The STORE CALIBRATE command automatically sets the corresponding *update* parameter(s) to one if new capacitance or transformer data is stored.

- Entry of three bad passcodes in a row will cause all further passcodes to be rejected until power-on occurs.

References

See "Selecting Update vs. Original Capacitance Calibration Data" on page 9-11 and "Selecting Update vs. Original Capacitance Calibration Data" on page 9-11.

Related Commands

CALIBRATE, SHOW CALIBRATE
STORE CALIBRATE
STORE CALIBRATE CREATE

Front Panel Examples

FUNC STORE FUNC CALIBRATE 2 FUNC SPECIAL
0 ENTER

```
┌────────────────────┐
│   PASSCOdE         │
├────────────────────┤
│                    │
└────────────────────┘
```

1 2 3 4 5 6

```
┌────────────────────┐
│   PASSCOdE         │
├────────────────────┤
│        123456      │
└────────────────────┘
```

ENTER

```
┌────────────────────┐
│   rEAdY            │
├────────────────────┤
│                    │
└────────────────────┘
```

In the above example the capacitance calibration is set to Original. This example shows the passcode prompt resulting from the entry of a STORE CALIBRATE 2 SPECIAL command. This is followed by the entry of "123456" which was accepted as the correct passcode.

SHOW FUNC CALIBRATE 2 ENTER

```
┌────────────────────┐
│   CAP              │
├────────────────────┤
│   UPdAtE  0        │
└────────────────────┘
```

This example shows the value of the capacitance *update* parameter as the first window of a multi-window result. This command will show this window only if calibration data has been generated. The SHOW CAL command will report the *update* parameters even if no data has been generated.

Remote Device Examples

```
>STO CAL 2 SPECIAL 1
PASSCODE>123456      (Passcode is not actually echoed.)
>
```

The capacitance calibration *update* parameter is set above so that the Update capacitance calibration data is used.

```
>SHO CAL 2
CAP UPDATE = 1
DEV FROM UPDT CAP:    CAL AGE =    345 HRS
            TEMP = -5.1C    C =   -0.71 PPM
DEV FROM ORIG CAP:    CAL AGE = 12345 HRS
            TEMP = -4.6C    C =   -0.71 PPM
>
```

The above example shows the value of the capacitance *update* parameter on the first line of the three line result.

TEST

Description
Performs diagnostic tests on the internal circuitry of the bridge. Effective use of this command requires an understanding of Chapter 11, "Diagnosis and Repair".

Syntax

TEST [*testgrouplo*.*testlo* [.*testgrouphi*.*testhi*]]
                                        [REPEAT [*count*]]

Qualifiers

REPEAT   Specifies that the selected tests are to be executed more than once.

None   Specifies that the selected tests are to be executed only once.

Parameters

testgrouplo   The number of the group containing the first or only test to be executed.

testlo   The number within the first or only group of the first or only test to be executed

testgrouphi   The number of the group containing the last test to be executed.

testhi   The number within the last group of the last test to be executed

count   The number of times all the specified tests are to be executed. If no *count* is entered, the tests are executed indefinitely.

Query Cmd?
Yes, but if *rpr*=1 then a SHOW TEST command should be added to the command line to guarantee a result. For example: TEST; SH TE.

Comments

- The TEST command word by itself causes all tests to be executed that do not require intervention. This is the only version of the command that will skip such tests.

- The command sequence TEST; TEST 91..94 is the most powerful test sequence that is also easy to run.

- Each test result is reported in six windows on the front panel. These may be viewed one-by-one by pressing the [←] and [→] keys while tests are running or after they finish. This allows real-time monitoring of the results.

- The SHOW TEST command will re-display the failure report for the last test that failed.

- Certain tests can erase or overwrite RAM memory. In these cases, you are prompted with an "Are You Sure?" message. This must be answered with a YES to allow the test to proceed.

Front Panel Examples

[FUNC] [TEST] [FUNC] [REPEAT] [5] [ENTER]

| 00000002 |
| tSt: 90.1 |

| FAIL 137 |
| G01   C3 |

| Hi : 004 |
| Lo : 000 |

| Ab   t1 |
| b0   F   P |

| CC000000 |
| 000000 |

| FCnt:001 |
| LtF: 90.1 |

The above example shows the failure report for test 90.1 which failed on the second of five passes.

| 00000005 | | FCnt:001 |
| tSt:End | | LtF: 90.1 |

The above two windows are the summary line that was reported after the five test passes completed.

Remote Device Examples

```
>TEST FORMAT .2     (Report failed tests and summary
                     lines.)
>TEST 50..55        (Run test groups 50 through 55.)
 0000000 TST=52.4 LO=097 PASS=016 HI=103
      G21 C0 A0 T1 B0 F P 00000000 07F000
 0000001 FCNT=001 LTF=52.4
>
```

This example shows a typical test failure and summary line resulting from a failed test execution. The FAIL=001 indicates that only one test failed, which was test 52.4.

References
See Chapter 11, "Diagnosis and Repair" and specifically "Initiating Self-tests: the TEST command" on page 11-4.

Related Commands
CALIBRATE, SHOW CALIBRATE, STEP, TEST FORMAT, X

Description
Determines which test results are reported and what conditions cause execution of the tests to halt (pause).

Syntax

TEST FORMAT *hoc.rpr*

Parameters

hoc
The "halt on condition" parameter can be set to the values below. The effects of each setting are listed. If an *hoc* condition occurs, a "+" prompt will be sent to remote devices. The STEP or X commands may be entered in response to this prompt to cause execution to continue.

0 Test execution does not halt until all tests are finished.

1 Execution of the tests will halt on every occurrence of an error report (test FAIL).

2 Execution of the tests will halt on every occurrence of any test result.

≥ 3 Halt after the entered number of test failures has occurred. Any number from 3 to 999 may be entered.

rpr
The "reported results" parameter can be set to the values below. The effects of each setting are listed.

0 No test results are measured or reported. The word 5ℂ0𝖯𝖤 is displayed in place of the upper line of the PASS/FAIL window on the front panel.

1 Only any error result lines are sent to remote devices. All results, failed or not, are shown on the front panel. To guarantee that a message is sent to a GPIB controller, SH TE should be appended to the command line.

2 Only error results and the test summary line are sent to remote devices. All test results, failed or not, are shown on the front panel.

3 All results, failed or not, are sent to remote devices and are shown on the front panel.

Default Value	0.2	(Do not halt on error, send error results and summary lines to remote devices.)

Parameter Set   Basic

Query Cmd?   No

Comments

• The "halt on condition" feature is essential for reading individual error results from the front panel. Most of these would be overwritten in less than a second otherwise.

Front Panel Examples

FUNC	TEST	FUNC	FORMAT	•	1	ENTER

SHOW	FUNC	TEST	FUNC	FORMAT	ENTER

```
  ┌──────────────────┐     ┌──────────────────┐
  │   tSt  FrПt       │     │   hoc   rPr      │
  ├──────────────────┤     ├──────────────────┤
  │   hО    r 1       │     │   hО    r 1      │
  └──────────────────┘     └──────────────────┘
```

In the example above, the *rpr* parameter was set to a one. The Test Format parameters were then shown.

Remote Device Examples

```
>TEST FORMAT .1
>SHOW TEST FORMAT
 TEST FRMT    HOC=0 RPR=1
>TEST 50
 0000000 TST=50.2 LO=095 FAIL=092 HI=105
       G11 C0 A0 T1 B0 F P 00020000 000000
>TEST FORMAT .2
>TEST 50
 0000000 TST=50.2 LO=095 FAIL=092 HI=105
       G11 C0 A0 T1 B0 F P 00020000 000000
 0000001 FCNT=001 LTF=50.2
>TEST FORMAT .3
>TEST 50
 0000000 TST=50.1 LO=025 PASS=167 HI=400
       G01 C0 A0 T1 B0 F P 00030000 000000
 0000000 TST=50.2 LO=095 FAIL=092 HI=105
       G11 C0 A0 T1 B0 F P 00020000 000000
 0000000 TST=50.3 LO=025 PASS=185 HI=400
       G11 C0 A0 T1 B0 F P 00010000 000000
 0000000 TST=50.4 LO=097 PASS=100 HI=103
       G21 C0 A0 T1 B0 F P 00006000 000000
 0000000 TST=50.5 LO=025 PASS=166 HI=400
       G21 C0 A0 T1 B0 F P 00003000 000000
 0000000 TST=50.6 LO=097 PASS=100 HI=103
       G31 C0 A0 T1 B0 F P 00002000 000000
 0000001 FCNT=001 LTF=50.2
>
```

This example shows typical results obtained for three different settings of the *rpr* parameter. The result from the first TEST 50 command reports just the error result for the one test that failed. Results from the second show the failed test and the summary line. Results from the third show all tests that were executed and the summary line.

References
See Chapter 11, "Diagnosis and Repair" and specifically "Selection of Options: the TEST FORMAT command" on page 11-7.

Related Commands   STEP, TEST, X

TRACK

Description

Enables and disables tracking mode. Also sets the threshold at which tracking will occur. Tracking mode allows the bridge to automatically switch to the highest measurement rate of about 25 per second to track a quickly changing unknown.

Syntax

TRACK *threshold*

or

TRACK HALT   or   TRACK 0

The syntax on the first line simultaneously enables tracking mode and sets the tracking *threshold*. Either syntax on the second line disables tracking mode.

Parameters   *threshold*

The *threshold* is an integer ranging from 0 to 5. A zero value disables tracking mode. A non-zero value enables tracking mode. A non-zero *threshold* is a measure of the maximum rate at which the capacitance can change before tracking takes over. The smaller the *threshold*, the more likely tracking will take over and the less likely that it will revert to the current averaging time setting.

It is not possible to provide a simple relationship between the *threshold* and the rate of change of the unknown. The *threshold* is only a relative parameter. Incrementing the *threshold* by one increases the rate at which the capacitance may change without tracking occurring by a factor of approximately three. Increasing the *threshold* by two increases this rate by a factor of 10. The *threshold* can change the rate by a factor of 100.

Default Value   0   (Tracking disabled)

Parameter Set   Gauge

Comments

- Tracking mode works with both SINGLE and CONTINUOUS commands.

- If the unknown changes by a substantial capacitance or loss ratio, the bridge may interrupt the high speed measurement and spend about 0.5 second to make some internal adjustments. It will then continue taking readings at the high rate.

- When the bridge switches to making measurements at a high rate, this is indicated with a "⊦" in the upper right corner of the front panel display and with a "T" message to remote devices.

Front Panel Examples

[FUNC] [TRACK] [1] [ENTER]
[FUNC] [SHOW] [TRACK] [ENTER]

```
    ⊦r Ac
      1
```

[CONTINUOUS] [ENTER]

```
   959.05977
    0.03172
```

```
   939.329 ⊦
    0.03
```

The first measurement window shows a full-precision result, the second shows a tracking result with reduced precision and the tracking indicator visible in the upper right corner.

Remote Device Examples

```
>TRA 5
>SHOW TRACK
 TRACKING          THRESHOLD=5
>CO
 C= 939.033362 PF L= 0.030000     NS
 C= 939.033365 PF L= 0.030010     NS
 C= 939.033371 PF L= 0.030026     NS
 C= 938.81     PF L= 0.1          NS T
 C= 935.570    PF L= 0.10         NS T
 C= 931.63     PF L= 0.1          NS T
 C= 923.8      PF L= 0.0          NS T
 C= 915.66     PF L= 0.00         NS T
 C= 914.99     PF L= 0.00         NS T
 C= 914.72     PF L= 0.10         NS T
 C= 914.50     PF L= 0.1          NS T
>TRA HA
>
```

This example shows three full-precision measurements followed by eight high speed measurements. Notice the difference in the rate of change of the capacitance in the two cases.

Query Cmd?   No

References

See "Auto Switching to High Speed" on page 4-7 and specifically "Using Tracking Mode" on page 4-7.

Related Commands

AVERAGE TIME, CONTINUOUS

Description

The TRG command produces exactly the same result as the GPIB bus GET command. Both of these execute a PRO-GRAM 2 command. Since a program can contain any AH 2500A command or combination of commands, the TRG or GET commands provide a convenient way of initiating any bridge operation.

Syntax   TRG

Parameters   None

Default Value   If a PROGRAM 2 file does not exist, a SINGLE command will be executed every time a TRG or GET command is issued.

Query Cmd?   Dependent upon the contents of program number two.

Comments

- The TRG command is *not* equivalent to the SINGLE command. However, the TRG command can function identically if program number two does not exist or if it consists of one SINGLE command.

Front Panel Examples

This command word is not available from the front panel. However, if a program filename of "2" exists, the same result is produced with the key sequence:

PROGRAM [2] ENTER

Remote Device Examples

```
>PR CREATE
#SA 1;SI
#SA 2;SI
#SA 3;SI
#SA 4;SI
#
>STORE PROGRAM 2
>TRG
 S= 1 C= 843.318636 PF L= 0.03721 NS
 S= 2 C= 431.587114 PF L= 0.01378 NS
 S= 3 C= 187.615845 PF L= 0.00831 NS
 S= 4 C= 52.827906  PF L= 0.00558 NS
>
```

The above example shows the creation of a program that automatically selects sample numbers one through four and takes one measurement after the selection of each sample. The program was stored into program set number two and a TRG command was issued that caused the program to be executed.

References

See "WORKING WITH PROGRAMS" on page 3-10 and especially "The TRG/GET Program" on page 3-13. See also "Initiating with a TRG/GET Program" on page 4-4.

Related Commands

Q, PROGRAM *execute*, SINGLE

UNITS

Description
Selects the units that will be used to report the *loss* component of the measurements.

Syntax

<u>UN</u>ITS *lossunit*

Parameters   *lossunit*
The list below gives the corresponding units for the respective *lossunit* numbers.

1 - Nanosiemens   (nS)

2 - Dissipation factor (tan δ)   (dimensionless)

3 - Series resistance in kilohms   (kΩ)

4 - Parallel resistance in gigohms   (GΩ)

5 - G/ω   (jpF)

Default Value   1   (nanosiemens)

Parameter Set   Basic

Query Cmd?   Yes

Comments

* When any form of the UNITS command is issued it will re-display the last measurement taken with the new units setting in effect.

* Capacitance is *always* displayed in units of picofarads or as percent deviation from a Reference value.

* Loss is always displayed in one of the five units in the list above or as percent deviation from a Reference value.

* The *lossunit* parameter values one through four are in the same order as the top-to-bottom ordering of the front panel unit indicator labels.

* The fifth *lossunit* parameter value is indicated on the front panel by displaying the two middle loss unit LED's.

* Changing the *lossunit* parameter will not usually cause the capacitance value to change. However, the series capacitance value of lossy unknowns is different from the parallel capacitance value. This is demonstrated in "Front Panel Examples" on this page.

References
See "DECIDING WHICH UNITS TO USE" on page 4-10 and specifically "Changing the Loss Units" on page 4-12.

Related Commands   None

Front Panel Examples

[UNITS] [1] [ENTER]

```
  5068.8658
   1492.437
```

[UNITS] [2] [ENTER]

```
  5068.8658
   0.0468603
```

[UNITS] [3] [ENTER]

```
  5069.9965
   1.468 122
```

[UNITS] [4] [ENTER]

```
  5068.8658
   0.0006700
```

[UNITS] [5] [ENTER]

```
  5068.8658
   2375287
```

[SHOW] [UNITS] [ENTER]

```
   Uni t5
    L 5
```

Note that UNITS 3 affected the capacitance value also.

Remote Device Examples

```
>UNITS 1
 C= 454.688993 PF L= 0.01744      NS
>UNIT 2
 C= 454.688993 PF L= 0.00000611   DS
>UNI 3
 C= 454.688993 PF L= 0.002137     KO
>UN 4
 C= 454.688993 PF L= 57.34        GO
>UN 5
 C= 454.688993 PF L= 0.002776     GW
>
```

This shows a single measurement result reported in all five of the possible loss units. The automatic re-display feature of the UNITS command is very useful here.

C04

Description

Execution of this command sets the User ReQuest (URQ) bit in the GPIB status byte. This provides a means by which a user-specified event can be signaled to a remote controller.

Syntax

<div align="center">

USER

</div>

Parameters   None

Query Cmd?   No

Comments

- This command cannot be entered from the front panel.
- The URQ bit is cleared by the execution of a SHOW STATUS or RST command.
- The USER command is primarily useful when the AH 2500A is connected to a GPIB controller, but it may also be useful with the front panel or serial port. Although the USER command cannot be executed directly from the front panel, it *can* be included in a program which *is* executable from the front panel.
- This command is probably most useful when included in an AH 2500A program.

Front Panel Examples

Not available, unless included in an AH 2500A program.

Remote Device Examples

```
>SH STA
 STATUS      MAU=0 MSS=0 EXE=0 RDY=0
                    PON=1 URQ=0 CME=0 ONR=0
>USER
>SH STA
 STATUS      MAU=0 MSS=0 EXE=0 RDY=0
                    PON=0 URQ=1 CME=0 ONR=0
>
```

This example shows that the USER command sets the URQ bit.

```
>PROG CREATE
#HOLD 0
#USER
#SINGLE
#
>
```

In the example above, a program is entered which waits for an external trigger pulse and then sets the URQ bit when a pulse arrives. This can inform a controller when a trigger has *started* a measurement.

```
>PROG CR
#CAL 1
#USER
#
>
```

In the example above, a program is entered which starts an internal calibration and then sets the URQ bit when the calibration command is finished.

References

See "STATUS REPORTING" on page 6-5 and specifically "A User Settable Status Bit" on page 6-6.

Related Commands

PROGRAM, SHOW STATUS, SRE

VOLTAGE

Description
Limits the amplitude of the 1 kHz test voltage applied by the bridge to the device under test.

Syntax
VOLTAGE *highest*

Parameters
highest   (Floating Point)

This is the maximum AC voltage in volts RMS that the bridge will apply to the DUT. Any voltage may be entered, but the bridge will limit the maximum measurement voltage to a value equal to or below the amount specified. Table A-6 below lists the actual RMS voltages that the AH 2500A uses.

Table A-6 Capacitance and loss ranges for the available limiting voltages.

Limit (volts)	Capacitance range (pF)		Loss range (nS)	
	From	To	From	To
*15.00	-8	+80	-0.4	+4
*7.50	-16	+160	-0.8	+8
3.75	-16	+160	-0.8	+8
*3.00	-40	+400	-2	+20
*1.50	-80	+800	-4	+40
*0.750	-160	+1600	-8	+80
0.375	-160	+1600	-8	+80
*0.250	-480	+4800	-24	+240
0.125	-480	+4800	-24	+240
*0.100	-1200	+12 000	-60	+600
0.050	-1200	+12 000	-60	+600
*0.030	-4000	+40 000	-200	+2000
0.015	-4000	+40 000	-200	+2000
*0.010	-12 000	+120 000	-600	+6000
0.0050	-12 000	+120 000	-600	+6000
*0.0030	-40 000	+400 000	-2000	+20 000
0.0015	-40 000	+400 000	-2000	+20 000
*0.0010	-120 000	+1 200 000	-6000	+60 000
0.0005	-120 000	+1 200 000	+6000	+60 000

Default Value   15 volts

Parameter Set   Gauge

Query Cmd?   No

Related Commands None

Front Panel Examples

[VOLTAGE] [5] [ENTER]   (Set highest voltage to 5 volts.)

[SHOW] [VOLTAGE] [ENTER]

> ```
> |  UOL E AGE  |
> |    3.75     |
> ```

The voltage was limited to 5 volts but the bridge selected the next lower value of 3.75 volts as the maximum.

[SINGLE]   (Take measurement in windows below.)

> ```
> |  95 1.83 125  |     |   5:0 1   |
> |   0.02774     |     |   U: 1.50 |
> ```

The value of capacitance measured caused the actual voltage used to be 1.50 volts. The [←] and [→] keys are used to select which of the above windows is shown.

Remote Device Examples

```
>U 1                 (Set the voltage to no more than one volt.)
>SI
   C= 93.8724 PF    L= 0.0008 GW    U=0.75 U
>SH U
   UOLTAGE    HIGHEST= 0.75 U
>
```

The voltage was selected to be one volt. From the table, the highest voltage that is equal to or less than one volt is 0.75 which is what the bridge chose as its upper limit. The measurement that was taken actually used 0.75 volts since the capacitance value was below 1600 pF.

Comments
- Transient voltages as high as 0.1 volts can occur no matter what the maximum voltage is set to.
- The voltage limits marked with asterisks (*) are preferred voltage limits since they are made using higher generator voltages. This results in better signal to noise ratios.

References
See "VOLTAGE OF THE TEST SIGNAL" on page 4-12 and specifically "Limiting the Test Voltage" on page 4-13.

Description
Steps through operations when using the CALIBRATE 3, PROGRAM or TEST commands. This occurs by pressing *only* the X key on the keyboard of a remote serial device.

Syntax   X   (no RETURN key is used)

Parameters   None

Query Cmd?
Execution of the X command usually produces a query result, but this is dependent on what root command is being executed. The TEST command, for example, can be set to halt on every test without sending a result.

Comments
* The X command produces exactly the same result as the STEP command but is more convenient to use from the serial port than the STEP command.

* This command tells the bridge to continue after waiting for you to perform an external action. The latter occurs with the CALIBRATE 3 and TEST commands.

* The X command is shortened from "eXecute".

* The X command will do nothing if there is no active root command waiting for input. This allows the X command to be used in programs where the need for it may be uncertain. It should cause no harm if it is not needed.

* This command will only work in an AH 2500A program if it is not the first character. A space can precede it if you desire to enter it by itself on a program line.

* An X command following an AH 2500A program will not be processed even if the program contains a command that is looking for X as a reply. In other words, in the command line "PROGRAM;X", the X will never have any effect no matter what the contents of the program.

Front Panel Examples
The [STEP] key is used instead on the front panel.

Serial Remote Examples
For some examples see "DC BIAS High Voltage Tests" on page 11-17 and "Obtaining Transformer Verification Data" on page 9-12.

References
See "Single-Step Mode" on page 3-12, "Selection of Options: the TEST FORMAT command" on page 11-7, and Chapter 9, "Verification/Calibration".

Related Commands
CALIBRATE, PROGRAM, SAMPLE, STEP, TEST

ZERO *enable*

Description
Changes the result mode between Absolute result mode and Zero compensation result mode. Zero result mode compensates for residual capacitance and *parallel* loss effects that are usually inherent in test fixtures.

Syntax

<div align="center">

ZERO

or

ZERO HALT

</div>

The first form of the command enables Zero result mode and the second form disables it.

Parameters
No parameters are entered. However, the SHOW ZERO command will show a one on the ZERO ON line if Zero result mode is in effect and a zero if not.

Default Value   0   (Absolute result mode)

Parameter Set   Gauge

Query Cmd?   Yes

Comments
* Enabling Zero result mode is a separate operation from entering the Zero values.

* Zero compensation capacitance and loss values can be entered (and stored) without being enabled. Subsequent enabling of Zero result mode will then use the Zero compensation values to correct the measured values.

* When any form of the ZERO *enable* command is issued it will re-display the last measurement taken with the new Zero compensation settings in effect.

* This command is similar to REFERENCE *enable*.

* Zero result mode is identical to Reference result mode in many ways, but the mathematical compensation performed in Zero result mode is much more than just a simple subtraction. The compensation calculation performed is dependent upon the units currently in use and can be complicated. The calculations require *both* capacitance and loss Zero values. Thus, the Zero result mode differs from the Reference result mode by not allowing you to enter a capacitance value without a corresponding loss value or vice-versa.

* Zero result mode may be used in combination with Reference result mode. They will each function independently of the other.

Front Panel Examples

[SINGLE]   (Take measurement in window below.)

<div align="center">

| 7 1450208 |
| 0.02925 |

</div>

[ZERO] [SINGLE] [ENTER]   (Get measured values.)

[ZERO] [ENTER]   (Show the differences.)

<div align="center">

| 000.00000 |
| 0.00000 |

</div>

[SINGLE]   (Show new measurement results below.)

<div align="center">

| - 0.000048 |
| 0.000 14 |

</div>

This shows the changes between [SINGLE] measurements.

Remote Device Examples

```
>ZERO CAP 700 LOSS 0.0000046
>SI
 C= 744.17194  PF L= 0.0000051   DS
>Z
 C= 44.171937 ZPF L= 0.0000138 ZDS
>Z HALT
 C= 744.17194  PF L= 0.0000051   DS
>SI
 C= 744.17205  PF L= 0.0000055 DS
>
```

Zero compensation values were manually entered and a measurement taken. Zero result mode was enabled causing the compensated version of the previous result to be reported. Zero result mode was then exited causing the same result to be reported as for the original measurement. The result is *exactly* the same since no new measurement was yet taken.- The actual measurement which follows shows small changes that are likely due to noise.

Notice that the Zero compensated result was L= 0.0000138 ZDS whereas Reference result mode would have reported L= 0.0000005 RDS. This is an example of how different these two result modes can be.

References
See "Zero Compensation Result Mode" on page 5-4 and specifically "Enabling Zero Result Mode" and "Disabling Zero Result Mode".

Related Commands
REFERENCE *enable* and ZERO *value*.

Description

Provides manual and automatic ways to enter capacitance and loss Zero compensation values.

Syntax

ZERO CAP *capvalue* LOSS *lossvalue*

is used to enter Zero compensation values manually, or

ZERO SINGLE

uses the last-measured capacitance and loss values before any Reference corrections have been applied.

Parameters

capvalue (Floating Point)
This is the value of the capacitance to be used as a Zero compensation value. The value is assumed to be entered in the current units. The maximum value that can be entered is 99,999,999.

lossvalue (Floating Point)
This is the value of the loss to be used as a Zero compensation value. The maximum value that can be entered in any units is 99,999,999.

Default Value 0, 0

(The default Zero compensation values for capacitance and loss are both zero.)

Parameter Set Gauge

Query Cmd? No

Comments

- Entering the Zero compensation values is a separate operation from actually using them by enabling Zero result mode. This makes it easier to enter and exit Zero result mode.

- This command is similar to the REFERENCE *value* command.

- The bridge performs all Zero calculations *before* performing any Reference calculations that might be enabled.

References

See "Zero Compensation Result Mode" on page 5-4 and specifically "Entering Zero Values Manually" and "Entering Zero Values Automatically".

Related Commands

REFERENCE *enable* and ZERO *enable*.

Front Panel Examples

[SINGLE]   (Takes measurement in window below.)

```
   14.502 08
   0.029 25
```

[ZERO] [SINGLE] [ENTER]   (Get measured values.)

[ZERO] [ENTER]   (Enable Zero result mode and show compensated result.)

```
   00.00 0000
   0.000 00
```

[SHOW] [ZERO] [ENTER]   (Show the effects.)

```
   14.502 08          2Er0
   0.029 25           0.029 25
```

[↓]

```
   2Er0 on
   1
```

[ENTER]

```
   rEAdy

```

This example shows all the front panel Zero result mode windows above.

[SINGLE]   (Takes measurement in window below.)

```
  - 0.000 07
    0.000 02
```

This result was compensated using the entered Zero values.

Remote Examples

```
>ZERO CAP 4.5 LOSS 0.0025
>SH Z
 ZERO       C=4.50000000 PF L=0.0025000 NS
 ZERO ON    C&L=0
>
```

The capacitance and loss Zero compensation values were manually entered. The SHOW command then confirmed their values, showing maximum precision results since there is no uncertainty in an entered result. Zero result mode is currently disabled as indicated by "C&L=0".

This appendix explains the various error messages and codes that can occur in the process of normal operation of the AH 2500A. Error messages that occur as a result of executing the self-test routines after power-on or by issuing the TEST command are explained in Chapter 11 titled "Diagnosis and Repair". The section "Processor and Front Panel Tests" on page 11-14 contains Table 11-7 on page 11-13 which lists the possible power-on self-test messages.

Error Messages vs. Error Codes

Error messages are always reported as English text on the front panel. Results sent to remote devices can also report error messages as text or as a decimal error code. The way to choose which form is to be sent is explained in "Error Messages vs. Error Codes" on page 5-6.

This appendix contains three tables of error messages. The content of the first table (Table B-1) is identical with the combined contents of the second two tables (Table B-2 and Table B-3). The difference is that the first table is arranged alphabetically and the remaining two are arranged by error code.

Measurement vs. Command/Data Errors

The error messages may be divided into two types. One error type results from an inability of the bridge to make a valid measurement. These are usually the result of connecting an unknown impedance that the bridge is unable to measure. However, these can also indicate a problem with the bridge if the unknown impedance is good.

The second kind of error is a result either of entering an improper command or as a result of problems associated with reading, moving or storing data within the bridge.

Measurement errors are listed separately in Table B-2 on page B-6 arranged by error code. Command/data errors are listed separately in Table B-3 on page B-8 and are also arranged by error code.

Error vs. Informative/Prompt Messages

The first three tables in this appendix list error messages. Table B-4 on page B-10 lists some informative messages and prompts. Informative messages are only sent to the front panel display. These are often used to explain what the bridge is currently doing, especially for time consuming operations that give no other indication. Prompts tell you what to do next. Prompts for the TEST and CALIBRATE 3 commands are not included in this table.

GPIB Status Bits

Errors cause one (and only one) of three bits in the GPIB status byte to be set. These are the CME (CoMmand Error), EXE (EXecution Error) and ONR (Oven Not Ready) error bits. Which of these bits is set by a given error is indicated in the first column of all tables in this appendix. See "STATUS REPORTING" on page 6-5 for more information about status bits.

The Meaning of Measurement Errors

When the AH 2500A senses that it cannot provide meaningful measurement values, it attempts to identify and report the nature of the problem in the form of one of about a dozen error messages. This is a difficult and imperfect process due to the poorly defined nature of some of the error conditions that can occur at the measurement terminals of the bridge. Thus the error messages will correctly describe the error condition most of the time, particularly if a well defined sample is present. The remainder of the time these messages may not always be helpful. The error messages are not intended to identify the nature of strange or unusual samples.

Some measurement errors or conditions are reported to the front panel as a single letter which appears in the upper right corner of the display. These are shown in the tables here as a display filled with eights except for the upper right corner.

Numeric Errors

Another kind of error can occur when a number is generated that is too big to work with or to report. This can occur even when a valid measurement has been made. The cause is usually the result of a division. This kind of error can easily occur when units of tan δ, R_P, C_S, and R_S have been selected. Changing the units should convert the result to a reportable value.

When an error of this type occurs, all nines are displayed in the upper and/or lower displays of the front panel. On a remote device, all nines will be reported in the mantissa of the number.

Note that this error differs from that where a greater than symbol precedes the number. The greater than symbol indicates a *range* of values having a reported minimum absolute value and a maximum absolute value that is infinite. All nines indicates a *single* value that is too large to report.

Table B-1 Error messages arranged alphabetically

Error code / Status bit / Remote error message	Front panel error message	Explanation
01 EXE AC ON L INPUT	`AC on L` `InPut`	Too much externally generated noise with a frequency below 100 Hz is being sensed at the measurement terminals. This kind of noise is almost always caused by excess coupling to the AC power lines. See "Low Frequency Noise" on page 2-8.
18 EXE AMBIGUOUS WORD: AAA		Not enough letters were entered for this command to be distinguishable from another, similar command. The questionable letters follow the error message as "AAA". This error cannot occur on the front panel. See "Command Word Entry" on page 6-3 or "Command Word Entry" on page 7-9.
19 CME BAD PARAMETER: BB	`bAd PAr`	A valid command was entered, but the parameter that followed was either of the wrong type (alpha vs. numeric) or it was out of range.
20 CME BAD PASSCODE	`bAd` `PASSCOdE`	The passcode that was entered in response to the passcode prompt was not correct. If three incorrect passcodes are entered in a row, then all subsequent passcode entries will report this error until the bridge's power is cycled.
None	`button` `buF FULL`	This message will be briefly displayed when the front panel keypad buffer is full. This can occur when a number of commands are entered but are not able to be executed. This happens when these commands follow a non-query command such as HOLD.
21 CME CAL DATA ABSENT	`CAL dAtA` `AbSEnt`	The command that was entered requires that new calibration data be present in RAM. The corresponding CALIBRATE command must be executed first.
22 EXE CAL DATA ERROR: C	`CAL dAtA` `Error C`	A checksum error has occurred while reading the calibration data from the EEPROM. C can be 0, 1, 2, or 3 for errors in the Original, Internal, Capacitance Update, or Transformer Update sections of the EEPROM, respectively. If this error repeats on subsequent power-ons, see Table 11-19 on page 11-42 for repair information.
03 EXE CAP TOO HIGH	`CAP too` `HI GH`	The capacitance of the unknown impedance exceeds the maximum that the AH 2500A can measure. The most positive measurable capacitance is 1.2 µF.
04 EXE CAP TOO NEG	`CAP too` `nEG`	The capacitance of the unknown impedance is more negative than what the AH 2500A can measure. The most negative measurable capacitance is -0.12 µF
26 CME CMD NOT OPERABLE	`Cnd not` `OPErAbLE`	The command that was entered is not compatible with the options present on this bridge or with the ROM version that is installed. This error also occurs if execution of a STORE command is attempted in a program or subprogram executed with a REPEAT or CONTINUOUS qualifier.

Table B-1 Error messages arranged alphabetically

Error code / Status bit / Remote error message	Front panel error message	Explanation
05　　　　　　EXE DC ON L INPUT	```dc on L``` ```InPut```	There is an unallowable DC component to the voltage on the LOW terminal. If this voltage is supposed to be present, then the BIAS command can be used to block the DC component.
27　　　　　　EXE E	```8888888E``` ```88888888```	An external-trigger overrun has occurred. The bridge received at least one external trigger pulse but no HOLD 0 command was waiting for it. This can only occur when the *trigbuf* parameter associated with the HOLD SPECIAL command is zero. The "E" message is only reported following a measurement result. See "Handling Unexpected Trigger Pulses" on page 3-14.
28　　　　　　EXE EEPROM ERROR: HH	```EEProM``` ```Error HH```	A checksum error has occurred while reading the EEPROM during power-on. If this repeats on subsequent power-ons, see Table 11-19 on page 11-42 for repair information.
06　　　　　　EXE ERRATIC INPUT	```ErrAtic``` ```InPut```	The software is unable to properly balance the bridge due to excess noise or a rapidly changing unknown sample.
07　　　　　　EXE EXCESS NOISE	```ECCESS``` ```nOISE```	Too much externally generated noise with a frequency near 1 kHz is being picked up at the measurement terminals. See "High Frequency Noise" on page 2-8.
29　　　　　　CME FILE NOT FOUND	```FILE not``` ```Found```	A file number was entered that did not match any file number in memory having the requested file type. Use the DIR command to see what files are in memory. See "WORKING WITH FILES" on page 3-8.
09　　　　　　EXE H TO GND SHORT	```8888888H``` ```88888888```	The impedance between the HIGH terminal and ground is too low. Check that these terminals are not shorted together. Measurement results are still reported when this error occurs. The error is indicated on the front panel by showing an "H" in the upper right corner of the display. See "High to Ground Short" on page 2-9.
10　　　　　　EXE H TO L SHORT	```H to L``` ```Short```	The impedance between the HIGH and LOW terminals is very low. Check that these terminals are not shorted together. See "High to Low Shorts" on page 2-9.
31　　　　　　CME ILLEGAL WORD: XXX		The command word that was entered is not one that is recognized by the AH 2500A. This error cannot occur on the front panel. See "Command Word Entry" on page 6-3 or "Command Word Entry" on page 7-9.

Table B-1 Error messages arranged alphabetically

Error code Status bit Remote error message	Front panel error message	Explanation
11 EXE INDETERM OFFSCALE	`IndEtErN` `OFFSCALE`	The unknown impedance appears to be off-scale but is either so far off or so unusual that the nature of the off-scale condition is indeterminate.
32 EXE INT CAL FAILURE	`Int CAL` `FAILurE`	A hardware fault has caused the internal calibration procedure to fail.
12 EXE L TO GND SHORT	`L to Gnd` `Short`	The impedance between the LOW terminal and ground is too small. Check that these terminals are not shorted together. This error message will not appear unless the measurement begins with a cold start. See "Low to Ground Short" on page 2-9.
38 CME LINE TOO LONG		The command message entered was too long. Command lines may not exceed 78 characters in length.
13 EXE LOSS TOO HIGH	`LOSS too` `HIGH`	The loss of the unknown impedance exceeds the maximum that the AH 2500A can measure. The most positive measurable conductance is 60,000 nS.
14 EXE LOSS TOO NEG	`LOSS too` `nEG`	The loss of the unknown impedance is more negative than what the AH 2500A can measure. The most negative measurable conductance is -6000 nS.
33 EXE OUT OF SPACE	`Out oF` `SPACE`	The store command you attempted requires more memory than is available. To make more room, delete some parameter sets or some programs.
15 ONR OVEN		The oven containing the internal capacitance standard is not at its operating temperature. This error is shown on the front panel with the OVEN NOT READY indicator. Either the bridge has not warmed up yet or it is in an environment that is too hot or too cold. You can take measurements with this error, but they will be less accurate.
34 CME PROG NEST ERROR	`PrG nESt` `Error`	A program tried to call a sub-program that was already nested to the maximum depth of eight. Don't nest your programs so deeply. Did a program call itself? See "Nesting Considerations" on page 3-11.
35 CME SYNTAX ERROR: SSS	`SYNtACS` `Error`	The command that was entered may have used valid command words, but either an expected word was not found or an unexpected word was found. The word "SSS" is where the problem occurred. If you are having trouble using the front panel, make sure it displays `rEAdY` before you start entering a command.

Table B-1 Error messages arranged alphabetically

Error code Status bit Remote error message	Front panel error message	Explanation
16 T	8888888t 88888888	This single letter message, which is always preceded by a measurement result, indicates that the measurement was taken in tracking mode since the sample value was changing. This is not an error; it is an indicator. See "Auto Switching to High Speed" on page 4-7.
37 EXE UPDATE STD ERROR	UPdt Std Error	The value entered for the external calibration capacitor is in disagreement with the original value by more than 0.01%. Either the incorrect value was entered, the calibration capacitor is seriously in error or the bridge needs repair.

Table B-2 Measurement error messages arranged by error code

Error code Status bit Remote error message	Front panel error message	Explanation
01 EXE AC ON L INPUT	AC on L InPut	Too much externally generated noise with a frequency below 100 Hz is being sensed at the measurement terminals. This kind of noise is almost always caused by excess coupling to the AC power lines. See "Low Frequency Noise" on page 2-8.
03 EXE CAP TOO HIGH	CAP too HI GH	The capacitance of the unknown impedance exceeds the maximum that the AH 2500A can measure. The most positive measurable capacitance is 1.2 µF.
04 EXE CAP TOO NEG	CAP too nEG	The capacitance of the unknown impedance is more negative than what the AH 2500A can measure. The most negative measurable capacitance is -0.12 µF
05 EXE DC ON L INPUT	dc on L InPut	There is an unallowable DC component to the voltage on the LOW terminal. If this voltage is supposed to be present, then the **BIAS** command can be used to block the DC component.
06 EXE ERRATIC INPUT	ErrAtic InPut	The software is unable to properly balance the bridge due to excess noise or a rapidly changing unknown sample.
07 EXE EXCESS NOISE	ECCESS nOISE	Too much externally generated noise with a frequency near 1 kHz is being picked up at the measurement terminals. See "High Frequency Noise" on page 2-8.
09 EXE H TO GND SHORT	8888888H 88888888	The impedance between the HIGH terminal and ground is too low. Check that these terminals are not shorted together. Measurement results are still reported when this error occurs. The error is indicated on the front panel by showing an "H" in the upper right corner of the display. See "High to Ground Short" on page 2-9.
10 EXE H TO L SHORT	H to L Short	The impedance between the HIGH and LOW terminals is very low. Check that these terminals are not shorted together. See "High to Low Shorts" on page 2-9.
11 EXE INDETERM OFFSCALE	IndEtErn OFFSCALE	The unknown impedance appears to be off-scale but is either so far off or so unusual that the nature of the off-scale condition is indeterminate.
12 EXE L TO GND SHORT	L to Gnd Short	The impedance between the LOW terminal and ground is too small. Check that these terminals are not shorted together. This error message will not appear unless the measurement begins with a cold start. See "Low to Ground Short" on page 2-9.

Table B-2 Measurement error messages arranged by error code

Error code Status bit Remote error message	Front panel error message	Explanation
13 EXE LOSS TOO HIGH	`LOSS too` `HIGH`	The loss of the unknown impedance exceeds the maximum that the AH 2500A can measure. The most positive measurable conductance is 60,000 nS.
14 EXE LOSS TOO NEG	`LOSS too` `nEG`	The loss of the unknown impedance is more negative than what the AH 2500A can measure. The most negative measurable conductance is -6000 nS.
15 ONR OVEN		The oven containing the internal capacitance standard is not at its operating temperature. This error is shown on the front panel with the OVEN NOT READY indicator. Either the bridge has not warmed up yet or it is in an environment that is too hot or too cold. You can take measurements with this error, but they will be less accurate.
16 T	`888888 t` `88888888`	This single letter message, which is always preceded by a measurement result, indicates that the measurement was taken in tracking mode since the sample value was changing. This is not an error; it is an indicator. See "Auto Switching to High Speed" on page 4-7.

Table B-3 Command and data error messages arranged by error code

Error code Status bit Remote error message	Front panel error message	Explanation
18 CME AMBIGUOUS WORD: *AAA*		Not enough letters were entered for this command to be distinguishable from another, similar command. The questionable letters follow the error message as "*AAA*". This error cannot occur on the front panel. See "Command Word Entry" on page 6-3 or "Command Word Entry" on page 7-9.
19 CME BAD PARAMETER: *BB*	bAd PAr	A valid command was entered, but the parameter that followed was either of the wrong type (alpha vs. numeric) or it was out of range.
20 CME BAD PASSCODE	bAd PASSCOdE	The passcode that was entered in response to the passcode prompt was not correct. If three incorrect passcodes are entered in a row, then all subsequent passcode entries will report this error until the bridge's power is cycled.
None	button buF FULL	This message will be briefly displayed when the front panel keypad buffer is full. This can occur when a number of commands are entered but are not able to be executed. This happens when these commands follow a non-query command such as HOLD.
21 CME CAL DATA ABSENT	CAL dAtA AbSEnt	The command that was entered requires that new calibration data be present in RAM. The corresponding CALIBRATE command must be executed first.
22 EXE CAL DATA ERROR: *C*	CAL dAtA Error C	A checksum error has occurred while reading the calibration data from the EEPROM. *C* can be 0, 1, 2, or 3 for errors in the Original, Internal, Capacitance Update, or Transformer Update sections of the EEPROM, respectively. If this error repeats on subsequent power-ons, see Table 11-19 on page 11-42 for repair information.
26 CME CMD NOT OPERABLE	Cnd not OPErAbLE	The command that was entered is not compatible with the options present on this bridge or with the ROM version that is installed. This error also occurs if execution of a STORE command is attempted in a program or subprogram executed with a REPEAT or CONTINUOUS qualifier.
27 EXE E	8888888E 88888888	An external-trigger overrun has occurred. The bridge received at least one external trigger pulse but no HOLD 0 command was waiting for it. This can only occur when the *trigbuf* parameter associated with the HOLD SPECIAL command is zero. The "E" message is only reported following a measurement result. See "Handling Unexpected Trigger Pulses" on page 3-14.
28 EXE EEPROM ERROR: *HH*	EEProM Error HH	A checksum error has occurred while reading the EEPROM at power-on. If this repeats on subsequent power-ons, see Table 11-19 on page 11-42 for repair information.

Table B-3 Command and data error messages arranged by error code

Error code Status bit Remote error message	Front panel error message	Explanation
29 CME FILE NOT FOUND	`FILE not` `Found`	A file number was entered that did not match any file number in memory having the requested file type. Use the DIR command to see what files are in memory. See "WORKING WITH FILES" on page 3-8.
31 CME ILLEGAL WORD: XXX		The command word that was entered is not one that is recognized by the AH 2500A. This error cannot occur on the front panel. See "Command Word Entry" on page 6-3 or "Command Word Entry" on page 7-9.
32 EXE INT CAL FAILURE	`Int CAL` `FAILurE`	A hardware fault has caused the internal calibration procedure to fail.
33 EXE OUT OF SPACE	`Out of` `SPACE`	The store command you attempted requires more memory than is available. To make more room, delete some parameter sets or some programs.
34 CME PROG NEST ERROR	`PrG nESt` `Error`	A program tried to call a sub-program that was already nested to the maximum depth of eight. Don't nest your programs so deeply. Did a program call itself? See "Nesting Considerations" on page 3-11.
35 CME SYNTAX ERROR: SSS	`SYntACS` `Error`	The command that was entered may have used valid command words, but either an expected word was not found or an unexpected word was found. The word "SSS" is where the problem occurred. If you are having trouble using the front panel, make sure it displays `rEAdY` before you start entering a command.
37 EXE UPDATE STD ERROR	`UPdt Std` `Error`	The value entered for the external calibration capacitor is in disagreement with the original value by more than 0.01%. Either the incorrect value was entered, the calibration capacitor is seriously in error or the bridge needs repair.
38 CME LINE TOO LONG		The command message entered was too long. Command lines may not exceed 78 characters in length.

Table B-4 Some informative messages and prompts arranged alphabetically

Remote prompt	Display message	Meaning
00		No Error
ARE YOU SURE?	`ArE YOU` `SUrE`	Some commands ask this question before beginning an irreversible operation such as erasing memory to confirm that you really want to perform the operation. Answer with a "Y" or a "1" if you want to continue.
	`bUSY`	A measurement is in progress. See "Indication of Reference Result Mode" on page 5-3 and "Indication of Zero Result Mode" on page 5-5 for an explanation of the alternate forms of this message.
CAL CODE>	`CAL CodE`	This is a prompt requesting entry of the Calibrator passcode.
	`CALbrAtE` `bUSY`	A calibration operation is in progress.
	`dEUICE` `CLEAr`	A DEVICE CLEAR operation has been executed.
	`GPIb Out` `buF FuII`	The GPIB output buffer is full. This can only occur after a result has begun to be read by the GPIB controller or logger. If the controller or logger then reads no more of the result over a period of ten seconds then this message will appear on the front panel. It will go away if the controller or logger resumes reading the message.
	`LOCAL` `Locout`	This message appears on the front panel display if the ⎡LOCAL⎤ key has been pressed but a remote device has locked out the other channels.
ONR CODE>	`Onr CodE`	This is a prompt requesting entry of the Owner passcode.
PASSCODE>	`PASSCOdE`	Any attempt to permanently change the calibration of the bridge requires that a passcode be entered. This message is the prompt that requests that code.
RPL CODE>	`rPL CodE`	This is a prompt requesting entry of the Replace passcode.
USR CODE>	`USr CodE`	This is a prompt requesting entry of the User passcode.

Appendix C   Performance Specifications

INTERPRETING THE SPECIFICATIONS

The performance specifications of the AH 2500A are given in the form of a fairly complicated set of equations. These equations, taken by themselves, are not easy to interpret. However, they do provide specifications that are an unusually precise description of an electronic instrument.

To more easily interpret these equations, each of them has been converted to two contour plot graphs which constitute the body of this appendix. These are explained later in "CONTOUR PLOT SPECIFICATIONS" on page C-7.

Notation

The specifications are grouped according to whether the unknown is modeled as a resistor in parallel with a capacitor or in series with it.

Parallel:

"C"   is the value of the unknown (parallel) capacitance in picofarads (pF= 10^{-12} F). Also used are attofarads (aF = 10^{-6} pF) and microfarads (μF = 10^{6} pF).

"G"   is the value of the unknown loss expressed as a conductance in nanosiemens (nS = 10^{-9} S).

"D"   is the value of the unknown loss expressed as a dissipation factor (tan δ). D has no units.

"R_p"   is the value of the unknown loss expressed as a parallel resistance in gigohms (GΩ = $10^{9}\Omega$).

Series:

"C_S"   is the value of the unknown series capacitance in picofarads (pF = 10^{-12} F).

"R_S"   is the value of the unknown loss expressed as a series resistance in kilohms (kΩ = 10^{3} Ω).

Misc.:

"t_b"   is the minimum selectable time between consecutive measurements in seconds.

"V"   is the AC test signal voltage in volts applied across the unknown. You may select its upper limit to have any value listed in the AC Test Signal Voltages table.

"ppm"   means Parts Per Million.

The Meaning of the Uncertainties

The expressions on the following pages for accuracy, linearity, stability, resolution, and temperature coefficient give absolute rather than statistical uncertainties. Absolute uncertainties are the most conservative of those in common use. Andeen-Hagerling, Inc. guarantees repair within the warranty period of any AH 2500A whose measured errors repeatedly exceed these uncertainties.

Evaluation of Expressions

The expressions may be evaluated for particular values of capacitance (C or C_S), loss (G, D, R_P or R_S), test voltage (V), and measurement time (t). Only the resolution expressions contain the measurement time. However, the other uncertainty expressions assume that the measurement time has been set to be long enough so that these other uncertainties are not limited by the resolution specification. In other words, specifications such as accuracy may be limited by the resolution rather than the accuracy expression if the measurement time is set too short.

Most of the uncertainty expressions can be evaluated by direct substitution of the values of capacitance, loss and voltage as if they were read directly from the AH 2500A. The bridge reports these values in the units given in the notation section above. Some expressions also require the dissipation factor, D, which, if it is not directly available, can be calculated using one of the following relations:

$$D = G/2\pi C, \quad D = 1/2\pi CR_P \quad \text{or} \quad D = 2\pi \times 10^{-6} C_S R_S$$

For low values of capacitance and loss, the maximum allowable test voltage that you set (usually 15 volts) can be substituted for every occurrence of V in the uncertainty expressions. For larger values of capacitance and loss, if the voltage value is not read from a bridge, then the value of V automatically chosen by the AH 2500A must be determined from the AC Test Signal Voltages table.

The following equations may be used to convert to the units of C and G used in the table from units other than those used in the table.

Given units of: D use $G = 2\pi CD$
R_P $G = 1/R_P$
R_S $G = 2\pi C_S D/(1+D^2)$
C_S $C = C_S/(1+D^2)$

Accuracy, stability, linearity and resolution specifications assume a recent internal calibration at the operating temperature.

Figure C-1 Range of dissipation factor vs. capacitance

The measurable values of C and D are enclosed within the shaded area.
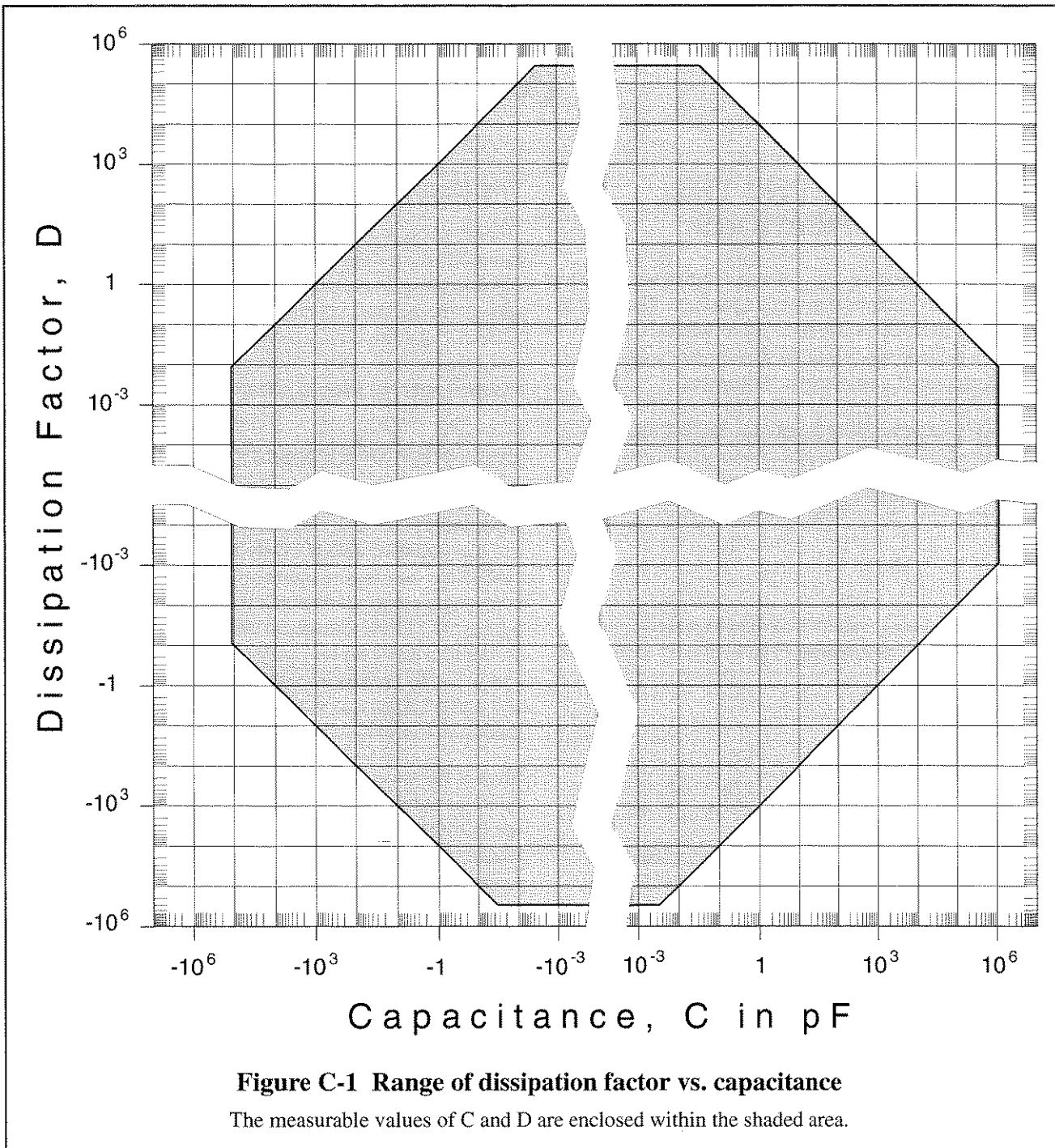
RANGE*

Parallel:

C: $-0.0012/|D|$ μF to $+0.012/|D|$ μF for $D \geq 0.01$

   -0.12 μF to $+1.2$ μF for $-0.001 \leq D < 0.01$

   -0.12 μF to $+0.0012/|D|$ μF for $-0.1 \leq D < -0.001$

   $-0.012/|D|$ μF to $+0.0012/|D|$ μF for $D < -0.1$

   The capacitance range is also shown graphically in Figure C-1.

G: -6000 nS to $+60\ 000$ nS

D: See Figure C-1.

R_P: -1.7×10^{-4} GΩ to -1.7×10^{6} GΩ
   and $+1.7 \times 10^{-5}$ GΩ to $+1.7 \times 10^{6}$ GΩ

Series:

C_S: See Figure C-2.

R_S: See Figure C-2.

*The ranges of all measurable variables except R_P cover a region defined by negative numbers for the lower limit and positive numbers for the upper limit. This is due to the
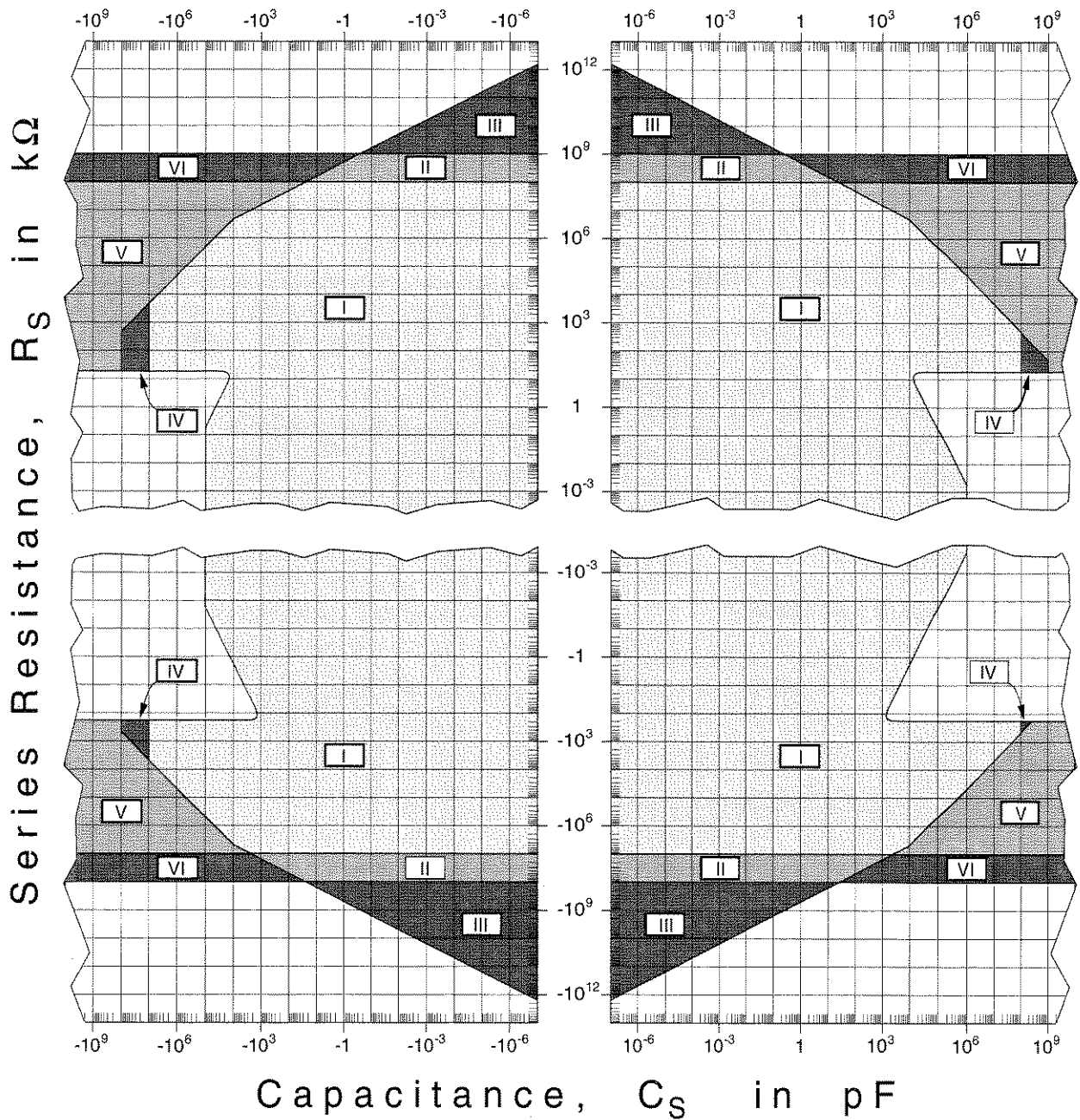
Figure C-2 Range of series resistance vs. series capacitance

The values of C_S and R_S are measurable in the six shaded regions above. In five of these regions, one or both of the measured values are too large to report on the bridge's display. In three of these five regions, one or both values are also too large to send to any remote devices. The table at the right shows what can be reported in each region. A "Display" entry means that the result can be shown on the bridge's display. A "Remotes" entry means that the result can be reported to an RS-232 or IEEE-488 device.

	C_S	R_S
I	Display & Remotes	Display & Remotes
II	Display & Remotes	Remotes only
III	Display & Remotes	Neither
IV	Remotes only	Display & Remotes
V*	Neither	Display & Remotes
VI*	Neither	Remotes only

*Regions V and VI extend to infinity to the right and left because the resistance associated with an infinite C_S is measurable even though C_S itself is not reportable.

AH 2500A's ability to measure both positive and negative values of capacitance and loss. Other instruments which only measure positive values have ranges which cover a region defined by small positive numbers for the lower limits to large positive numbers for the upper limits. For the AH 2500A, the small numbers which correspond to the lower limits of other instruments are given by the AH 2500A's resolution specifications in absolute units.

MEASUREMENT TIME

The time required to take a measurement is $t_b = 0.05 \times 2^T$ seconds where T is an integer that you select which can range from 0 to 15. (T is the *averexp* parameter in the AVERAGE command. The first measurement on a given unknown requires a minimum of 1/2 second.)

REPORTING LIMITATIONS

Front Panel Display Limitations

This specification results from the fact that the front panel display may further limit the range and resolution of the capacitance and loss.

Capacitance:

0.1 aF is the best display resolution for C and C_S.

Loss:

G: 10^{-7} nS is the best conductance display resolution.

D: 10^{-7} is the best dissipation display resolution.

R_S: 10^{-7} kΩ is the best series resistance display resolution.

R_P: 10^{-7} GΩ is the best parallel resistance display resolution.

Remote Device Reporting Limitations

Capacitance:

0.01 aF is the best resolution for C and C_S.

Loss:

G: 10^{-8} nS is the best conductance resolution.

D: 10^{-8} is the best dissipation resolution.

R_S: 10^{-7} kΩ is the best series resistance resolution.

R_P: 10^{-8} GΩ is the best parallel resistance resolution.

NON-OPTION-E SPECIFICATIONS OF PRECISION

Resolution

Resolution is the smallest statistically *repeatable* difference in readings that is *guaranteed* to be measurable at *every* capacitance or loss value. Useful resolution is typically a factor of ten better.

The resolution performance is expressed below in two ways. The first group of specifications is expressed in absolute units. The second expresses the resolution as a fraction of the reported number.

Resolution in Absolute Units

Parallel:

C: $\{0.15C + 50DC + [7.5(1+n_C) + n_VC]/V\} \times 10^{-6}$ pF

G: $\{50G + C + 5 \times 10^{-5}C^2$
$+ [50(1+n_C) + 6n_VC]/V\} \times 10^{-6}$ nS

D: $\{8 \times 10^{-6}C + (1+D^2)^{1/2}[0.15 + 50D$
$+ (7.5(1+n_C)/C + n_V)/V]\} \times 10^{-6}$

R_P: $R_P\{50 + R_P[C + 5 \times 10^{-5}C^2$
$+ (50(1+n_C) + 6n_VC)/V]\} \times 10^{-6}$ GΩ

Series:

C_S: $\{0.15 + 50D + [7.5(1+n_C)(1+D^2)/C_S$
$+ n_V]/V\}C_S \times 10^{-6}$ pF

R_S: $\{1.3 + 50R_S + [0.15 + [7.5(1+n_C)(1+D^2)/C_S$
$+ n_V]/V]R_S/D\} \times 10^{-6}$ kΩ

where $n_C = 1.4t^{-1/2}$ and $n_V = 0.01(R_S+10)^{1/2}(1+D^2)^{1/2}t^{-1/2}$.

$t = t_b$ except when $t_b = 0.05$ in which case $t = t_b/4$.

The series resistance R_S may be calculated for the parallel expressions using $R_S = 1.6 \times 10^5 D/C(1+D^2)$.

Resolution in ppm

Parallel:

C: $0.15 + 50D + [7.5(1+n_C)/C + n_V]/V$

G: $50 + \{C + 5 \times 10^{-5}C^2 + [50(1+n_C) + 6n_VC]/V\}/G$

D: $\{8 \times 10^{-6}C + (1+D^2)^{1/2}[0.15 + 50D$
$+ (7.5(1+n_C)/C + n_V)/V]\}/D$

R_P: $50 + R_P\{C + 5 \times 10^{-5}C^2 + [50(1+n_C) + 6n_VC]/V\}$

Series:

C_S: $0.15 + 50D + [7.5(1+n_C)(1+D^2)/C_S + n_V]/V$

R_S: $1.3/R_S + 50 + \{0.15 + [7.5(1+n_C)(1+D^2)/C_S$
$+ n_V]/V\}/D$

Accuracy

The accuracy following a calibration is given in ppm.

Parallel:

C: $\pm\{5 + 200D + (0.2 + 7.5/C)/V\}$

G: $\pm\{200 + [13C + 0.002C^2 + (45 + 0.12C)/V]/G\}$

D: $\pm\{2 + 3\times10^{-4}C + (1+D^2)^{1/2}[200D$
$$+ (0.02 + 7.5/C)/V]\}/D$$

R_P: $\pm\{200 + [13C + 0.002C^2 + (45 + 0.12C)/V]R_P\}$

Series:

C_S: $\pm\{5 + 200D + [0.2 + 7.5(1+D^2)/C_S]/V\}$

R_S: $\pm\{200 + 50/R_S + [2 + (0.02 + 7.5(1+D^2)/C_S)/V]/D\}$

The length of the cables connecting the AH 2500A to the capacitance being measured has a negligible effect on the accuracy for *small* capacitances. This assumes that the coaxial shield on these cables has 100% coverage. If uncorrected by the CABLE command, cables similar to RG-58 will increase the capacitance readings by about 40 ppm per meter of cable pair and per µF of capacitance being measured.

The accuracy Y years following calibration may be calculated from the expression A + YS where A is the desired accuracy expression from above and S is the corresponding stability per year below.

Stability

The stability is given in ppm per year.

Parallel:

C: $\pm\{1 + 30D + (0.01 + 2.5/C)/V\}$

G: $\pm\{30 + [2C + 3\times10^{-4}C^2 + (15 + 0.06C)/V]/G\}$

D: $\pm\{0.3 + 5\times10^{-5}C + (1+D^2)^{1/2}[30D$
$$+ (0.01 + 2.5/C)/V]\}/D$$

R_P: $\pm\{30 + [2C + 3\times10^{-4}C^2 + (15 + 0.06C)/V]R_P\}$

Series:

C_S: $\pm\{1 + 30D + (0.01 + 2.5(1+D^2)/C_S)/V\}$

R_S: $\pm\{30 + 8/R_S + [0.3 + (0.01 + 2.5(1+D^2)/C_S)/V]/D\}$

Non-linearity

Non-linearity is the deviation from a best fit straight line through a plot of the measured quantity versus the actual quantity. The test signal voltage is assumed to be constant. The non-linearity is given in ppm.

Parallel:

C: $\pm\{0.15 + 50D + 7.5/CV + 15\times10^{-6}C\}$

G: $\pm\{50 + [C + 5\times10^{-5}C^2 + 50/V]/G\}$

D: $\pm\{8\times10^{-6}C + (1+D^2)^{1/2}[0.15 + 50D + 7.5/CV]\}/D$

R_P: $\pm\{50 + R_P[C + 5\times10^{-5}C^2 + 50/V]\}$

Series:

C_S: $\pm\{0.15 + 50D + 7.5(1+D^2)/C_SV$
$$+ 15\times10^{-6}C_S/(1+D^2)\}$$

R_S: $\pm\{1.3/R_S + 50 + [0.15 + 7.5(1+D^2)/C_SV]/D\}$

Temperature Sensitivity

The temperature coefficient relative to a change in ambient temperature is given in ppm per °C.

Parallel:

C: $\pm\{0.025 + 30D + 0.002/V + 15/(0.15 + CV)\}$

G: $\pm\{30 + [0.2 + 2\times10^{-5}C + 0.012/V]C/G$
$$+ 100/(1 + GV)\}$$

D: $\pm\{[0.03 + 3\times10^{-6}C + (1+D^2)^{1/2}(30D + 0.002/V)]/D$
$$+ 15/(0.15 + CV) + 15/(0.15 + CDV)\}$$

R_P: $\pm\{30 + [0.2 + 2\times10^{-5}C + 0.012/V]CR_P$
$$+ 100/(1 + V/R_P)\}$$

Series:

C_S: $\pm\{0.025 + 30D + 0.002/V + 100/[1$
$$+ 6C_SV/(1+D^2)]\}$$

R_S: $\pm\{30 + 0.5/R_S + (0.03 + 0.002/V)/D$
$$+ 30/[0.15(1+D^2) + C_SV]$$
$$+ 100/[1 + 10^6VD^2/(1+D^2)R_S]\}$$

Power Line Sensitivity

The sensitivity to changes in the power line voltage is given in ppm.

Capacitance:

± 0.002 ppm per 1% change in line voltage

Loss:

Not measurable

TEST SIGNAL VOLTAGES

Any voltage listed below may be selected. The capacitance and loss ranges measurable at the selected voltage are shown. The AH 2500A will automatically use the lesser of your selected voltage or the highest voltage listed in the table which provides sufficient range to be able to measure the capacitance and loss of the unknown. The voltages listed have tolerances of $\pm 5\%$

Table C-1 Capacitance and loss ranges for the available limiting voltages.

Limit (volts)	Capacitance Range (pF)		Loss Range (nS)	
	From	To	From	To
15.00	-8	+80	-0.4	+4
7.50	-16	+160	-0.8	+8
3.75	-16	+160	-0.8	+8
3.00	-40	+400	-2	+20
1.50	-80	+800	-4	+40
0.750	-160	+1600	-8	+80
0.375	-160	+1600	-8	+80
0.250	-480	+4800	-24	+240
0.125	-480	+4800	-24	+240
0.100	-1200	+12 000	-60	+600
0.050	-1200	+12 000	-60	+600
0.030	-4000	+40 000	-200	+2000
0.015	-4000	+40 000	-200	+2000
0.010	-12 000	+120 000	-600	+6000
0.0050	-12 000	+120 000	-600	+6000
0.0030	-40 000	+400 000	-2000	+20 000
0.0015	-40 000	+400 000	-2000	+20 000
0.0010	-120 000	+1 200 000	-6000	+60 000
0.0005	-120 000	+1 200 000	+6000	+60 000

OPTION-E SPECIFICATIONS OF PRECISION

The AH 2500A with **Option E** enhances the precision of the bridge. These enhanced specifications are listed below. All other specifications remain unchanged. Notes related to the specifications below may be found in the specifications for the standard version of the bridge on the previous pages.

Resolution

Resolution in Absolute Units

Parallel:

C: $\{0.07C + 20DC + (7.5(1+n_C) + n_VC)/V\} \times 10^{-6}$ pF

G: $\{20G + 0.4C + 5 \times 10^{-5}C^2$
$\quad + (50(1+n_C) + 6n_VC)/V\} \times 10^{-6}$ nS

D: $\{8 \times 10^{-6}C + (1+D^2)^{1/2}[0.07 + 20D$
$\quad + (7.5(1+n_C)/C + n_V)/V]\} \times 10^{-6}$

R_P: $R_P\{20 + R_P[0.4C + 5 \times 10^{-5}C^2$
$\quad + (50(1+n_C) + 6n_VC)/V]\} \times 10^{-6}$ GΩ

Series:

C_S: $\{0.07 + 20D + [7.5(1+n_C)(1+D^2)/C_S$
$\quad + n_V]/V\}C_S \times 10^{-6}$ pF

R_S: $\{1.3 + 20R_S + \{0.07 + [7.5(1+n_C)(1+D^2)/C_S$
$\quad + n_V]/V\}R_S/D\} \times 10^{-6}$ kΩ

Resolution in ppm

Parallel:

C: $0.07 + 20D + [7.5(1+n_C)/C + n_V]/V$

G: $20 + \{0.4C + 5 \times 10^{-5}C^2 + [50(1+n_C) + 6n_VC]/V\}/G$

D: $\{8 \times 10^{-6}C + (1+D^2)^{1/2}[0.07 + 20D$
$\quad + (7.5(1+n_C)/C + n_V)/V]\}/D$

R_P: $20 + R_P\{0.4C + 5 \times 10^{-5}C^2 + [50(1+n_C) + 6n_VC]/V\}$

Series:

C_S: $0.07 + 20D + [7.5(1+n_C)(1+D^2)/C_S + n_V]/V$

R_S: $1.3/R_S + 20 + \{0.07 + [7.5(1+n_C)(1+D^2)/C_S$
$\quad + n_V]/V\}/D$

Non-linearity

Non-linearity is the deviation from a best fit straight line through a plot of the measured quantity versus the actual quantity. The test signal voltage is assumed to be constant. The non-linearity is given in ppm.

Parallel:

C: $\pm\{0.07 + 20D + 7.5/CV + 5 \times 10^{-6}C\}$

G: $\pm\{20 + [0.4C + 5 \times 10^{-5}C^2 + 50/V]/G\}$

D: $\pm\{8 \times 10^{-6}C + (1+D^2)^{1/2}[0.07 + 20D + 7.5/CV]\}/D$

R_P: $\pm\{20 + R_P[0.4C + 5 \times 10^{-5}C^2 + 50/V]\}$

Series:

$$C_S: \pm\{0.07 + 20D + 7.5(1+D^2)/C_SV$$
$$+ 5\times10^{-6}C_S/(1+D^2)\}$$

$$R_S: \pm\{1.3/R_S + 20 + [0.07 + 7.5(1+D^2)/C_SV]/D\}$$

Accuracy

The accuracy following a calibration is given in ppm.

Parallel:

$$C: \pm\{3 + 100D + (0.01 + 7.5/C)/V\}$$

$$G: \pm\{100 + [13C + 0.002C^2 + (45 + 0.06C)/V]/G\}$$

$$D: \pm\{2 + 3\times10^{-4}C + (1+D^2)^{1/2}[100D$$
$$+ (0.01 + 7.5/C)/V]\}/D$$

$$R_P: \pm\{100 + [13C + 0.002C^2 + (45 + 0.06C)/V]R_P\}$$

Series:

$$C_S: \pm\{3 + 100D + [0.01 + 7.5(1+D^2)/C_S]/V\}$$

$$R_S: \pm\{100 + 50/R_S + [2 + (0.01 + 7.5(1+D^2)/C_S)/V]/D\}$$

Stability

The stability is given in ppm per year.

Parallel:

$$C: \pm\{0.5 + 20D + (0.003 + 2.5/C)/V\}$$

$$G: \pm\{20 + [2C + 2\times10^{-4}C^2 + (15 + 0.02C)/V]/G\}$$

$$D: \pm\{0.3 + 3\times10^{-5}C + (1+D^2)^{1/2}[20D$$
$$+ (0.003 + 2.5/C)/V]\}/D$$

$$R_P: \pm\{20 + [2C + 2\times10^{-4}C^2 + (15 + 0.02C)/V]R_P\}$$

Series:

$$C_S: \pm\{0.5 + 20D + [0.003 + 2.5(1+D^2)/C_S]/V\}$$

$$R_S: \pm\{20 + 5/R_S + [0.3 + [0.003$$
$$+ 2.5(1+D^2)/C_S]/V]/D\}$$

Temperature Sensitivity

The temperature coefficient relative to a change in ambient temperature is given in ppm per °C.

Parallel:

$$C: \pm\{0.008 + 10D + 0.001/V + 2/(0.15 + CV)\}$$

$$G: \pm\{10 + [0.2 + 2\times10^{-5}C + 0.006/V]C/G$$
$$+ 15/(1 + GV)\}$$

$$D: \pm\{[0.03 + 3\times10^{-6}C + (1+D^2)^{1/2}(10D + 0.001/V)]/D$$
$$+ 2(0.15 + CV) + 2/(0.15 + CDV)\}$$

$$R_P: \pm\{10 + [0.2 + 2\times10^{-5}C + 0.006/V]CR_P$$
$$+ 15/(1 + V/R_P)\}$$

Series:

$$C_S: \pm\{0.008 + 10D + 0.001/V + 15/[1 + 6C_SV/(1+D^2)]\}$$

$$R_S: \pm\{10 + 0.5/R_S + (0.03 + 0.001/V)/D$$
$$+ 4/[0.15(1+D^2) + C_SV]$$
$$+ 15/[1 + 10^6VD^2/(1+D^2)R_S]\}$$

CONTOUR PLOT SPECIFICATIONS

The following thirty pages contain an elaboration of the non-option-E specification-of-precision expressions presented in the previous pages. Each expression is represented by two contour plots. One kind of plot shows contours of the expression for a *set* of fixed uncertainty values but always using the maximum allowable signal voltage which is automatically chosen by the bridge. These contours are not smooth everywhere; features resembling steps are common in them. These steps occur where the bridge changes the test signal voltage so that it is always at a maximum.

The other kind of plot shows contours for a *single* value of uncertainty but using the set of every primary voltage that the bridge can be set to. Each contour in this kind of graph has a unique pattern that is used to identify the voltage of the test signal. A legend that associates each pattern with its voltage appears to the right of the graph.

The relationship between the two kinds of graphs is more easily understood by looking at an example. Compare Figure C-7 on page C-10 with Figure C-8 on page C-10. More specifically, compare the 0.03% contour of the first graph with *all* the contours of the second graph. Notice that *all* the contours of the second graph have an accuracy of 0.03%. You can see that the 0.03% contour of the first graph follows the outermost perimeter of the sum of all the contours in the second graph. This occurs because the bridge automatically chooses its test voltages so as to cover the widest possible range for a given accuracy.

The darkly shaded regions on the graphs show the limits of the AH 2500A's range. Unless otherwise noted, the more lightly shaded regions with Roman numeral labels correspond to similarly labeled regions in Figure C-2 on page C-3. This is the graph showing the range of series resistance vs. series capacitance.

Below each graph is the mathematical expression which was used to create it. Each of these expressions is mathematically identical to the non-option-E expressions given earlier in this appendix. However, each expression is expanded from its single-line format so that it is much easier to read. Plotting was done with n_C and n_V equal to zero which closely approximates setting the averaging time exponent to seven or higher.

Each graph typically took hours to calculate using a custom-written program running under MatLab software on a Macintosh computer. Another, more popularized piece of software, took days instead of hours to finish and was therefore rejected for this application. MatLab produced a PostScript result which was then edited using Adobe Illustrator software.
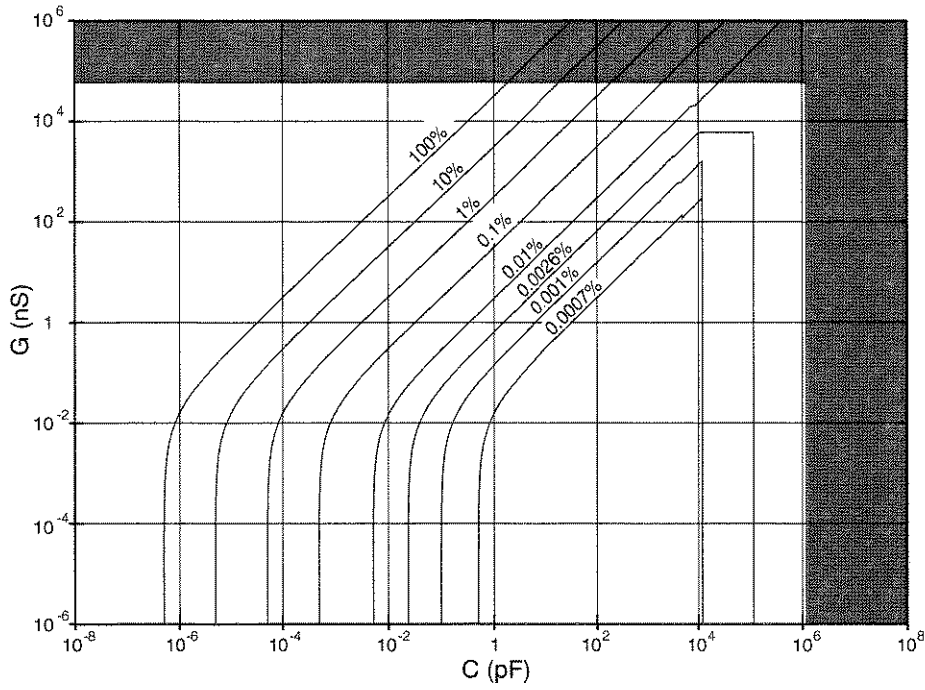
Figure C-3 Accuracy of C vs. C and G using maximum voltages.
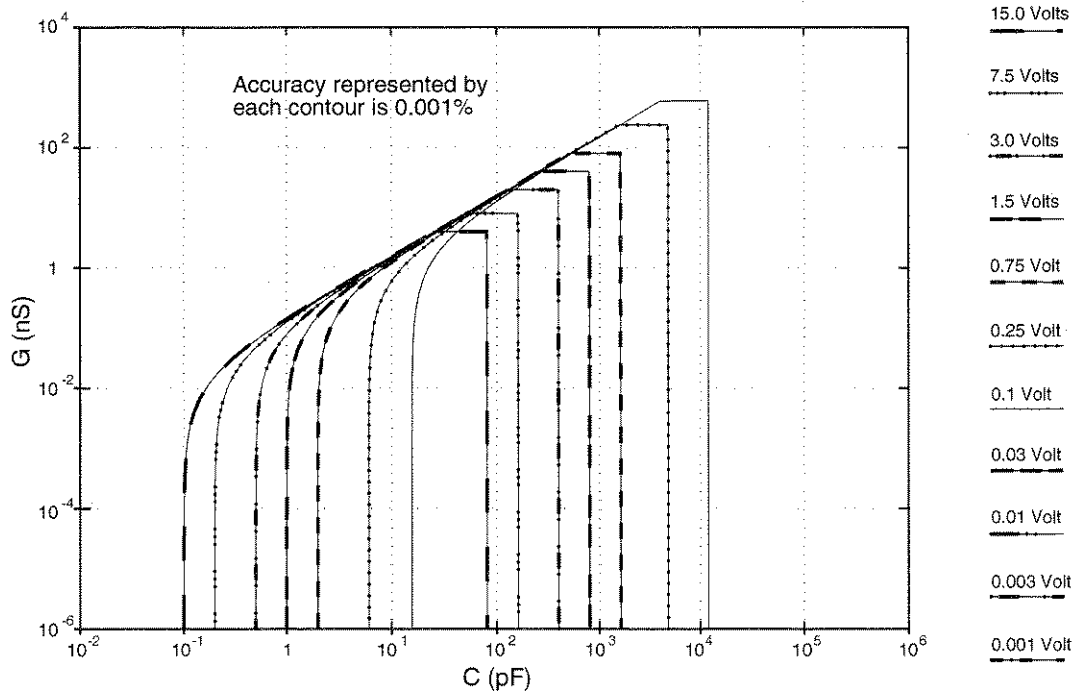
Figure C-4 Accuracy of C vs. C and G using selected voltages.

$$\pm \left[5 + 200D + \frac{0.2 + \dfrac{7.5}{C}}{V} \right] \qquad \text{Eq. C-1}$$
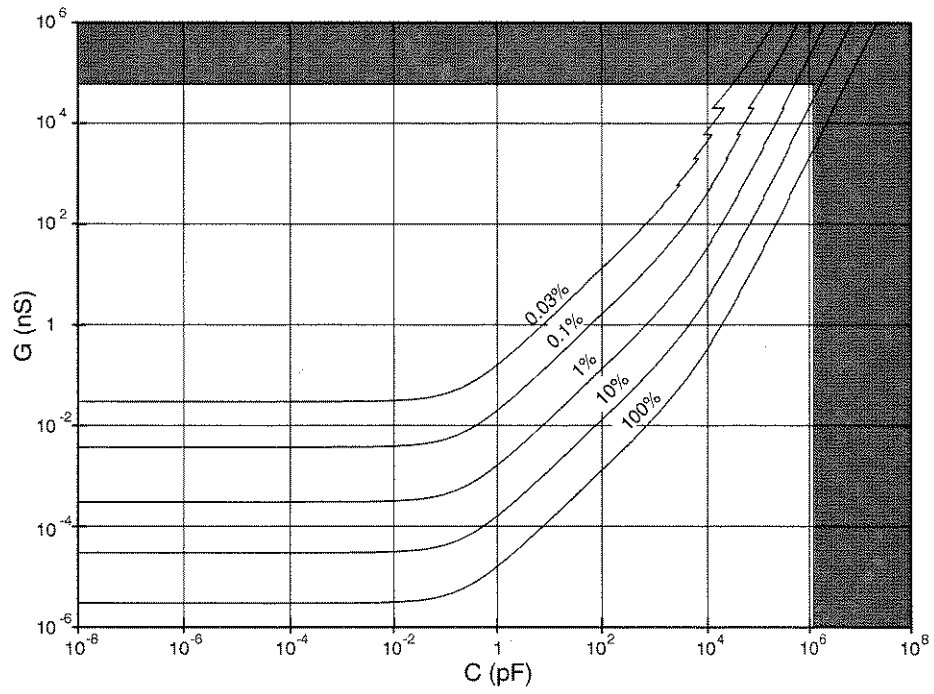
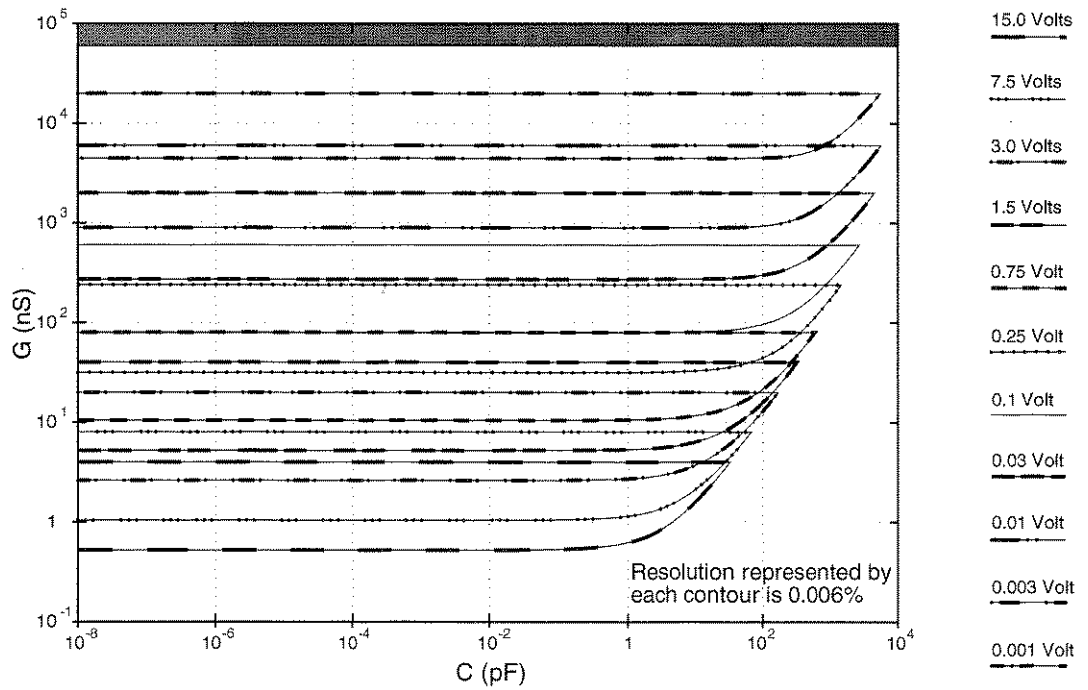**Figure C-5 Accuracy of G vs. C and G using maximum voltages**
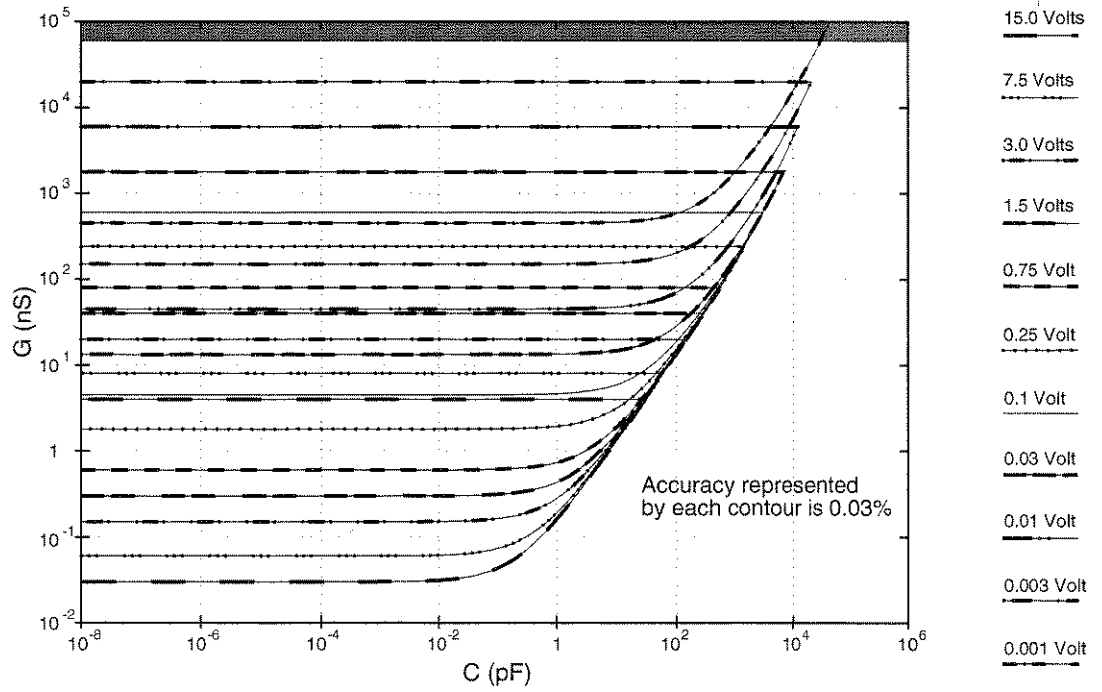
Figure C-6 Accuracy of G vs. C and G using selected voltages.

$$\pm\left[200 + \frac{13C + 0.002C^2 + \dfrac{45 + 0.12C}{V}}{G}\right] \qquad \text{Eq. C-2}$$
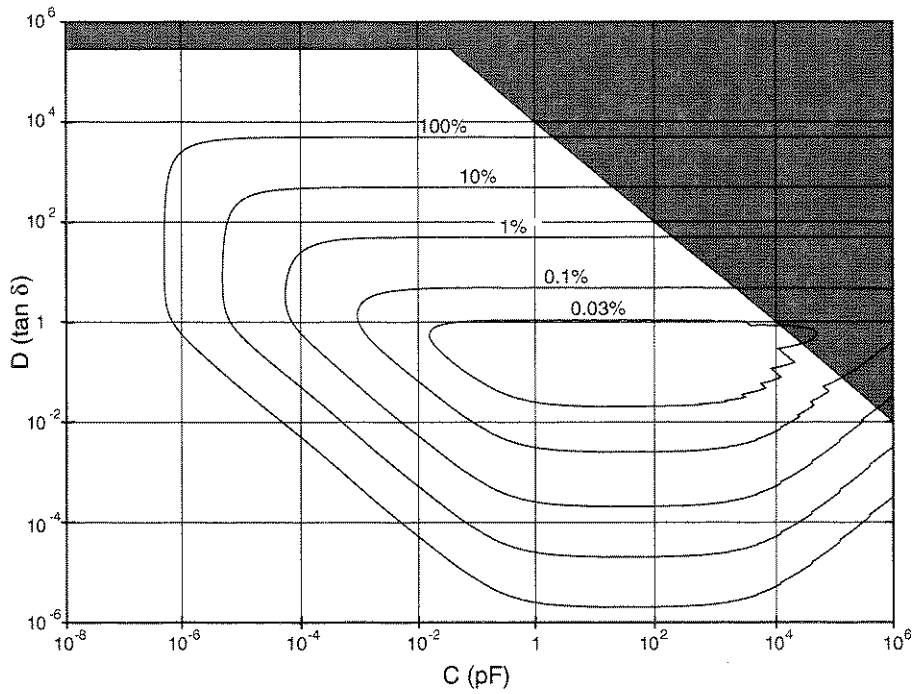
Figure C-7 Accuracy of D vs. C and D using maximum voltages.
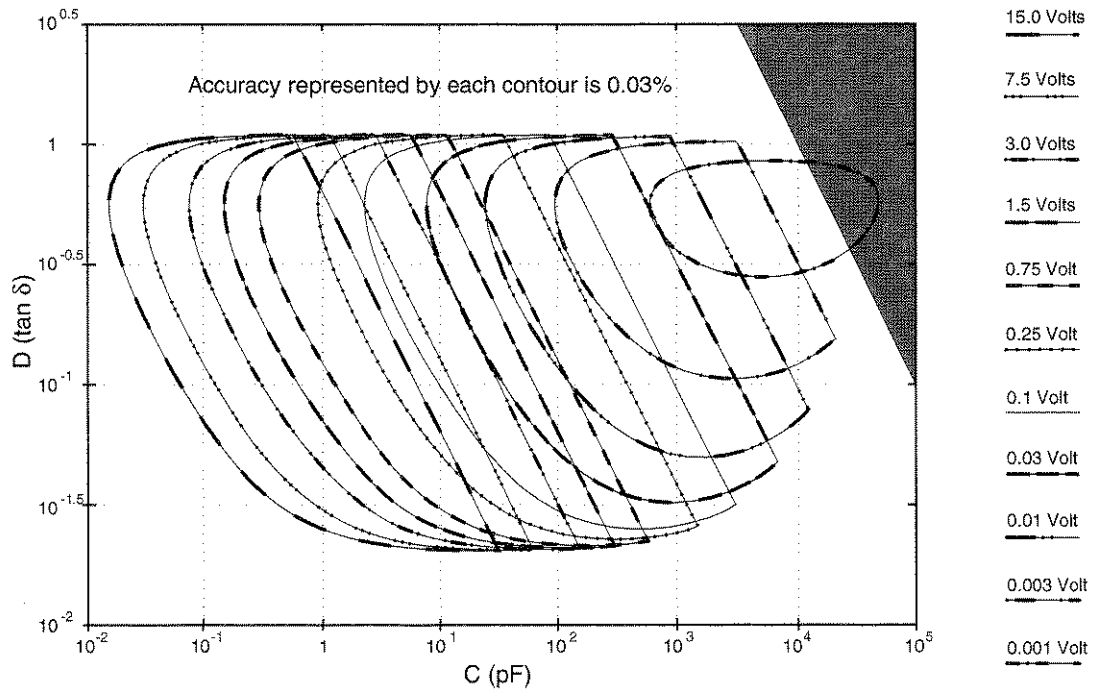
Figure C-8 Accuracy of D vs. C and D using selected voltages.

$$\pm\frac{1}{D}\left[2 + 3\times10^{-4}C + (1 + D^2)^{1/2}\left(200D + \frac{0.02 + \frac{7.5}{C}}{V}\right)\right] \qquad \text{Eq. C-3}$$
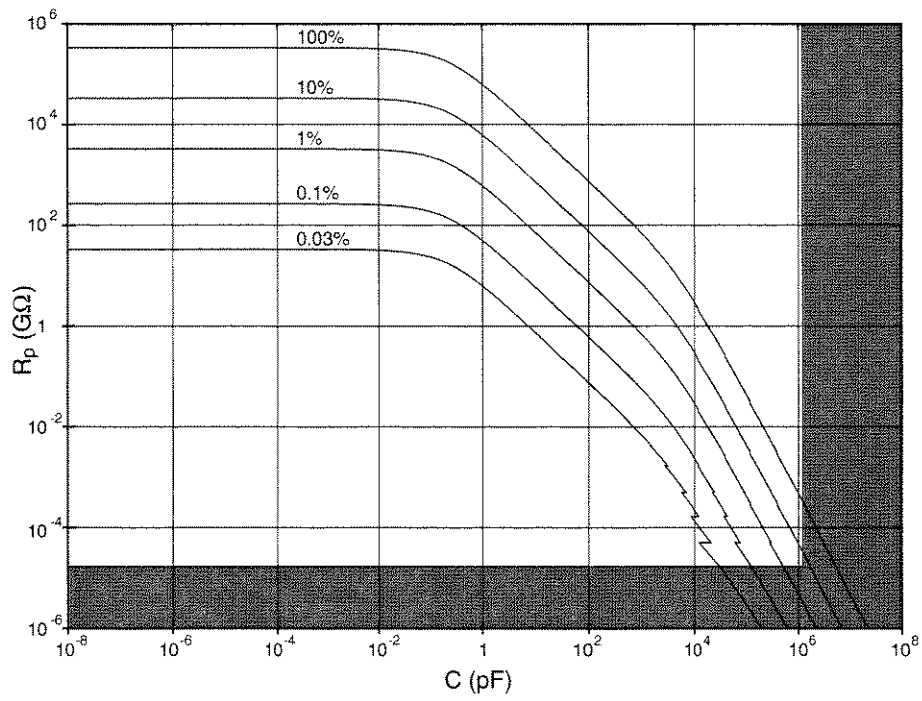
Figure C-9 Accuracy of R_p vs. C and R_p using maximum voltages
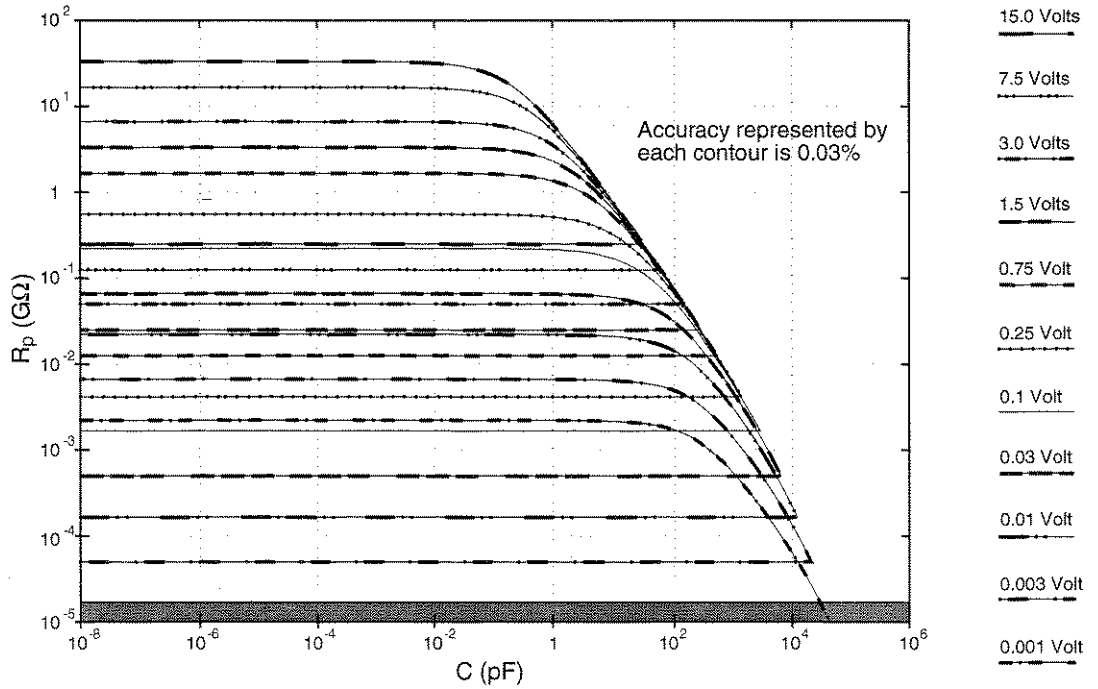
Figure C-10 Accuracy of R_p vs. C and R_p using selected voltages.

$$\pm\left[200 + R_P\left(13C + 0.002C^2 + \frac{45 + 0.12C}{V}\right)\right]$$ Eq. C-4
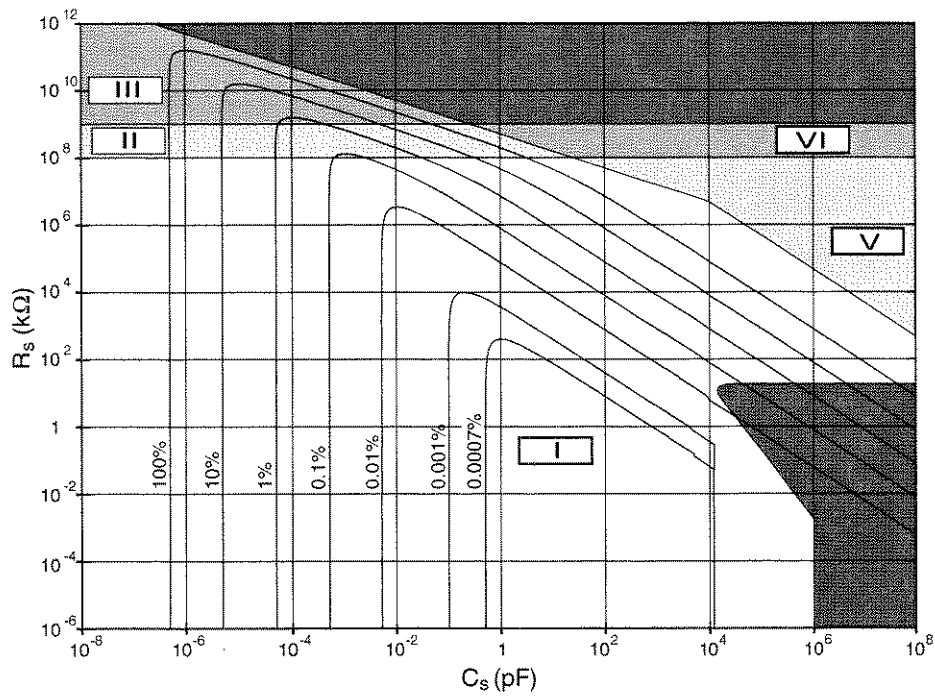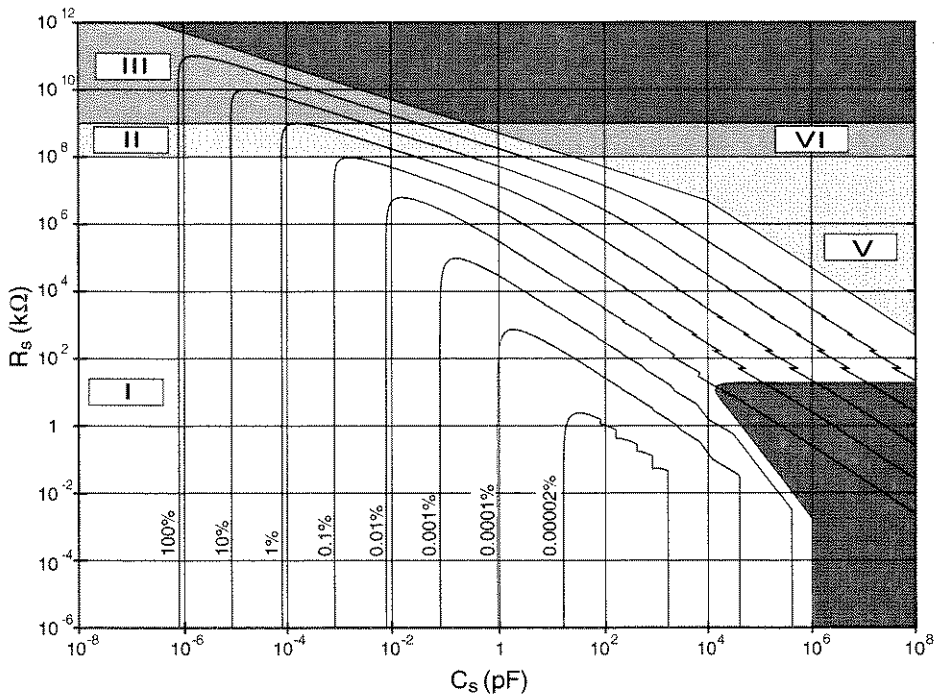
Figure C-11 Accuracy of C_s vs. C_s and R_s using maximum voltages.
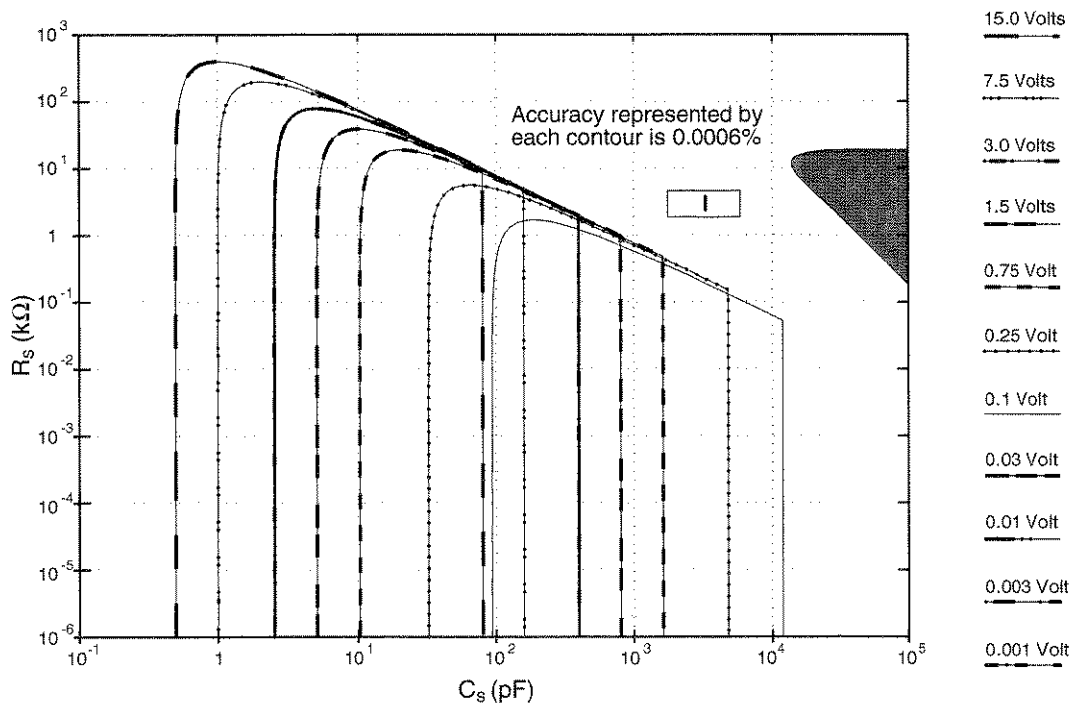
Figure C-12 Accuracy of C_s vs. C_s and R_s using selected voltages.

$$\pm \left[5 + 200D + \frac{0.2 + \dfrac{7.5\,(1 + D^2)}{C_S}}{V} \right] \qquad \text{Eq. C-5}$$
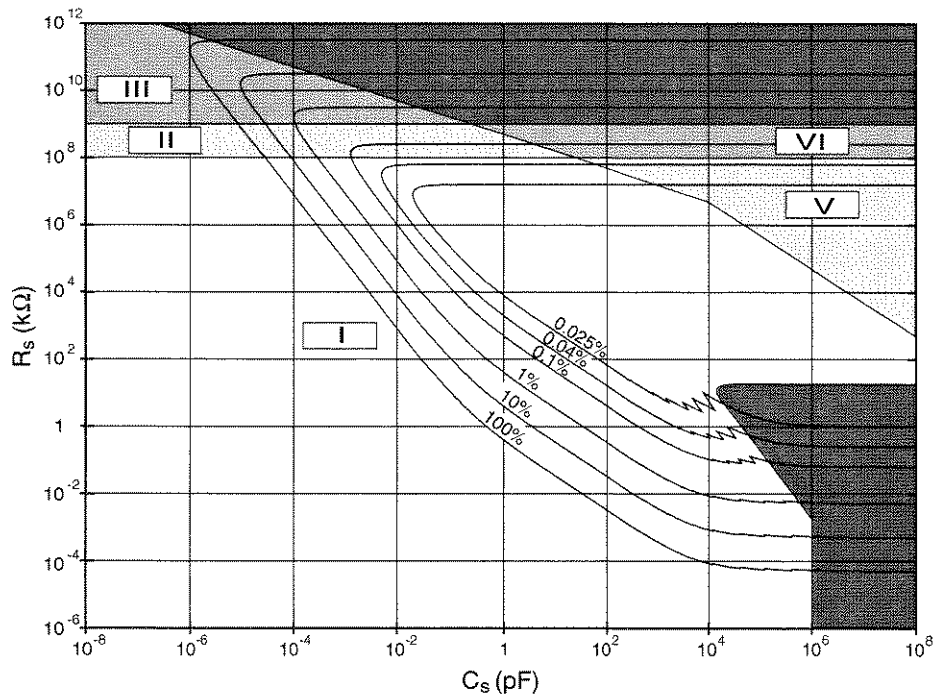
Figure C-13 **Accuracy of R_S vs. C_S and R_S using maximum voltages**
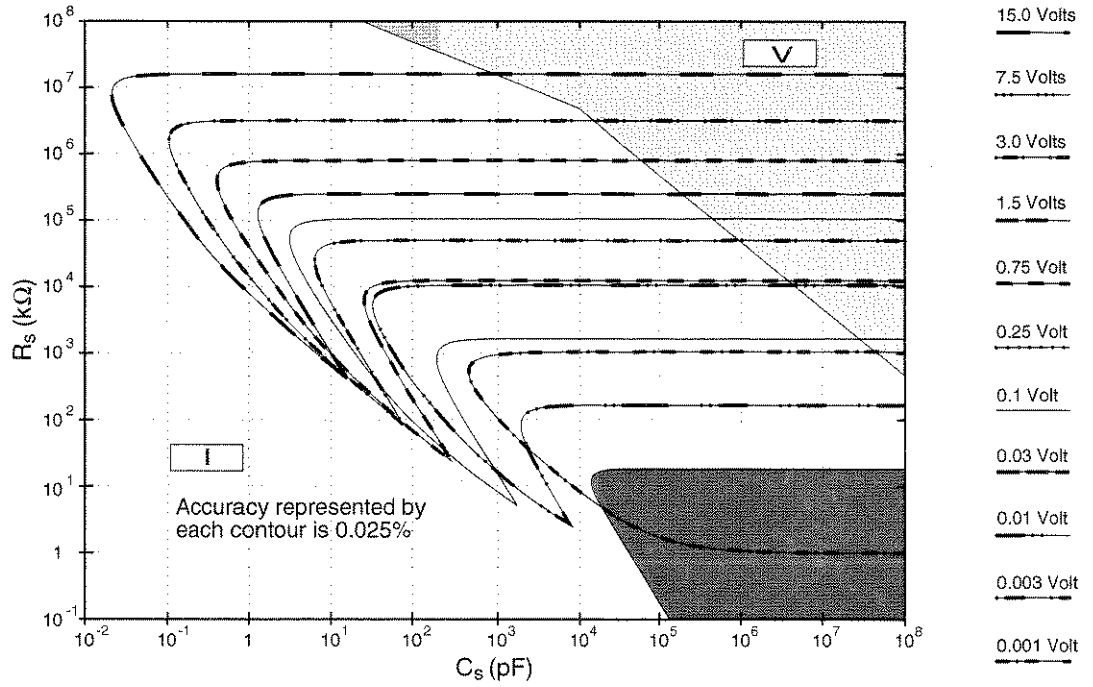
Figure C-14 **Accuracy of R_S vs. C_S and R_S using selected voltages.**

$$\pm \left[200 + \frac{50}{R_S} + \frac{2}{D} + \frac{0.02 + \frac{7.5 \left(1 + D^2 \right)}{C_S}}{DV} \right] \qquad \text{Eq. C-6}$$
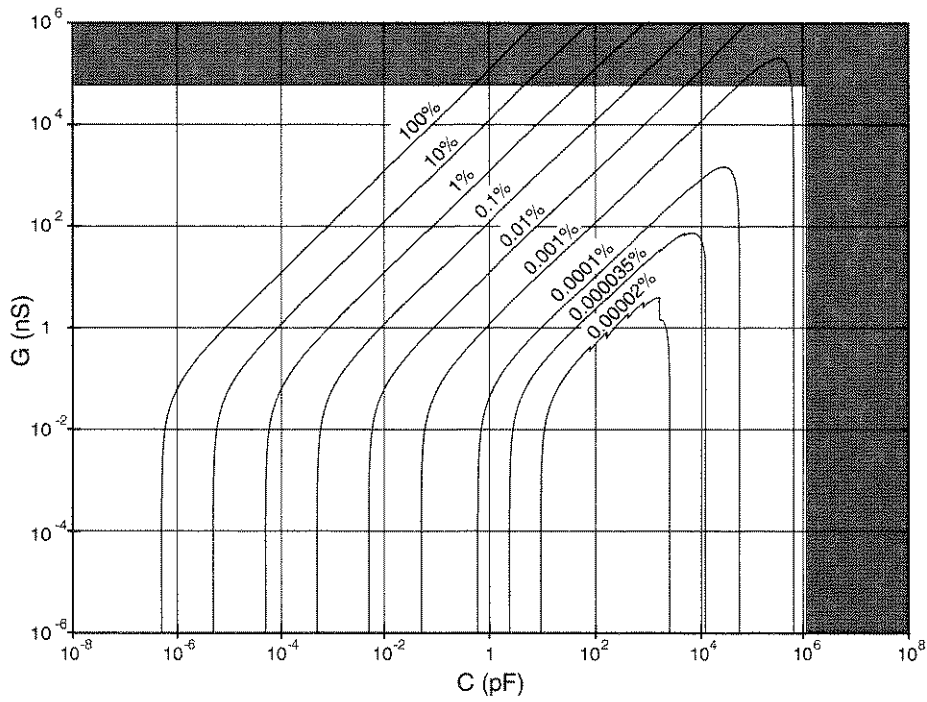
Figure C-15 Non-linearity of C vs. C and G using maximum voltages.
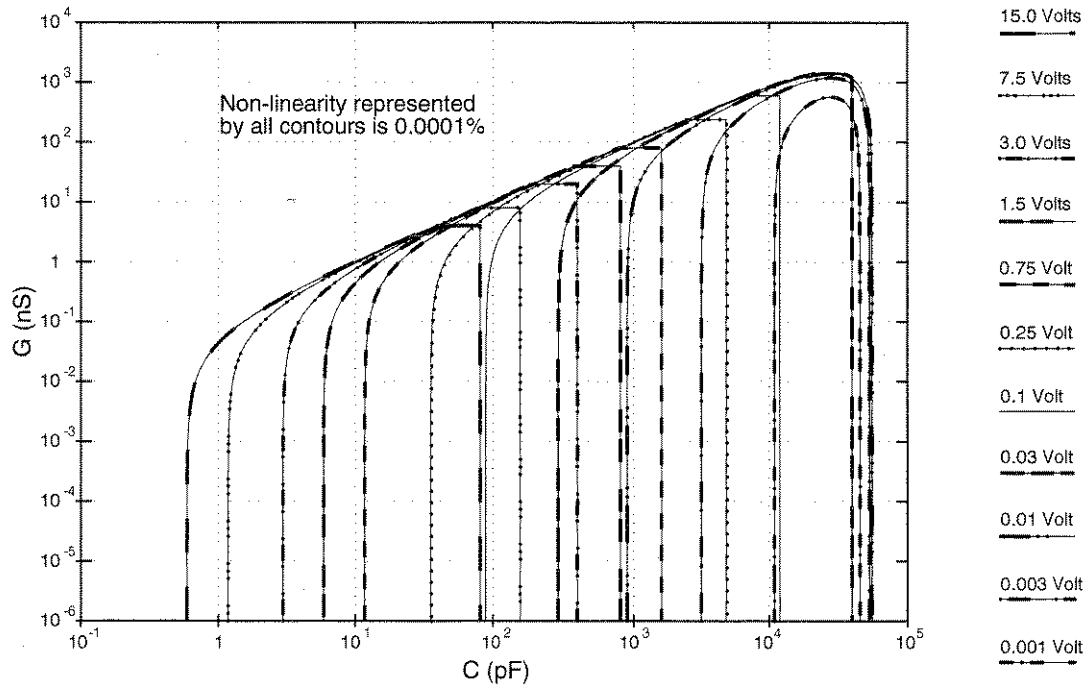
Figure C-16 Non-linearity of C vs. C and G using selected voltages.

$$\pm\left[0.15 + 50D + \frac{7.5}{CV} + 15\times10^{-6}C\right] \qquad \text{Eq. C-7}$$
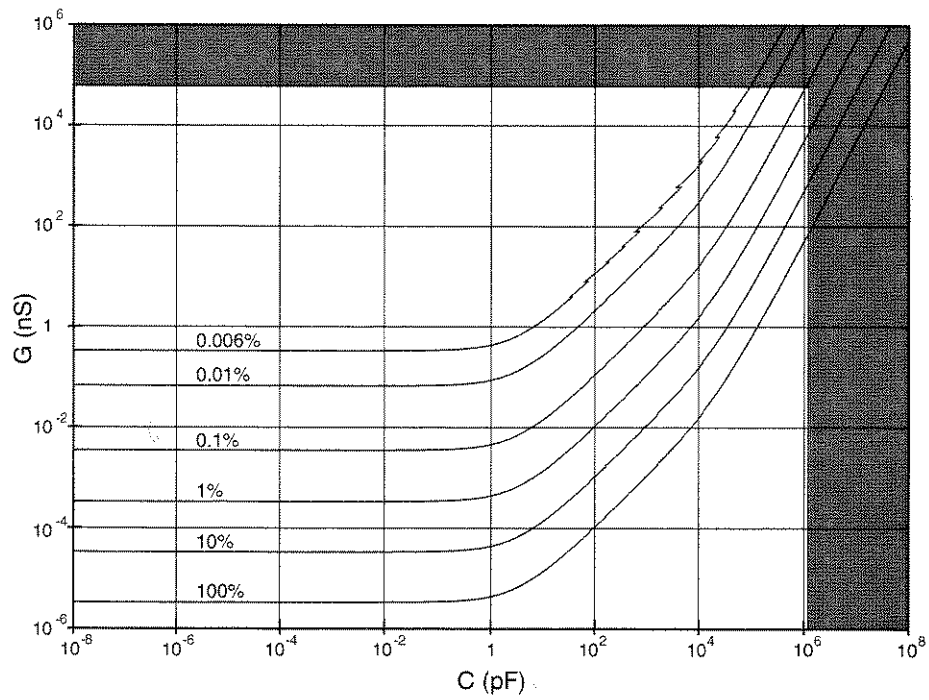
Figure C-17 Non-linearity of G vs. C and G using maximum voltages.
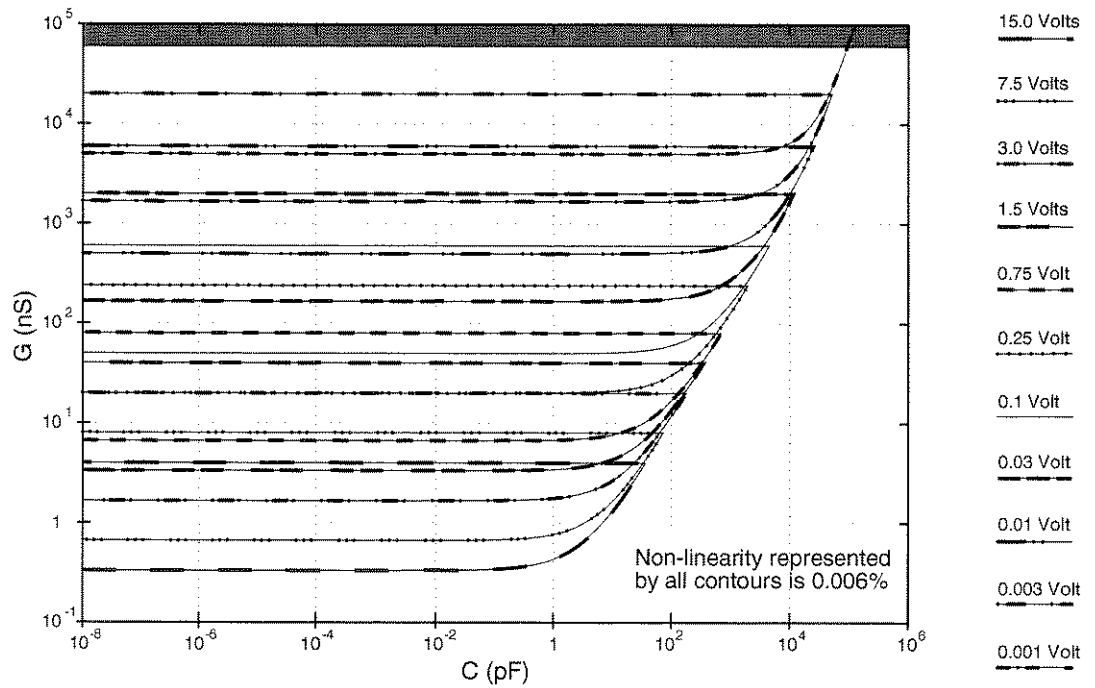
Figure C-18 Non-linearity of G vs. C and G using selected voltages.

$$\pm\left[50 + \cfrac{C + 5\times10^{-5}C^2 + \cfrac{50}{V}}{G}\right] \qquad \text{Eq. C-8}$$
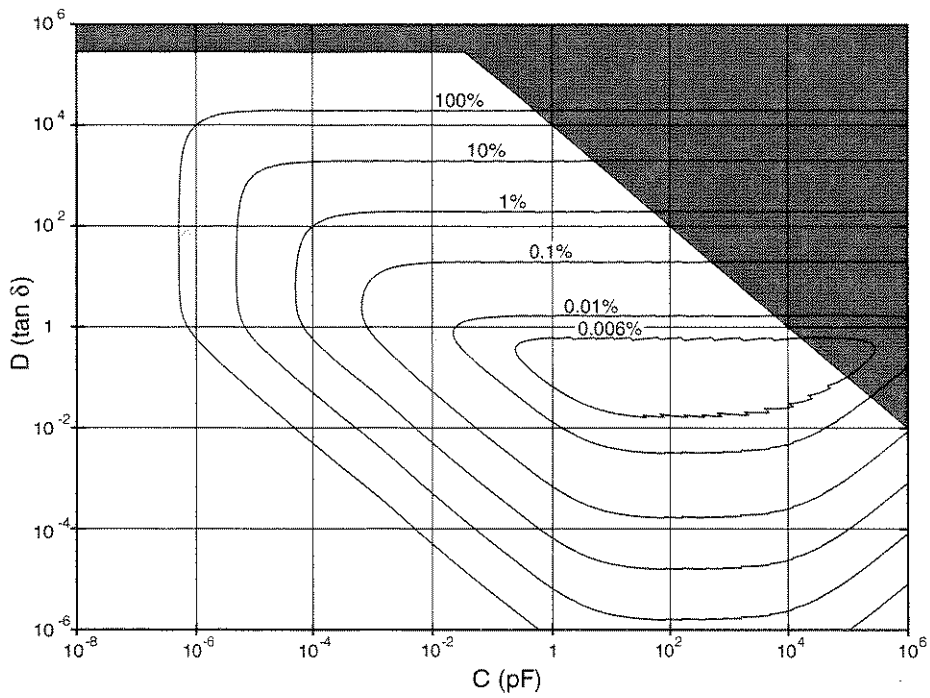
Figure C-19 Non-linearity of D vs. C and D using maximum voltages.
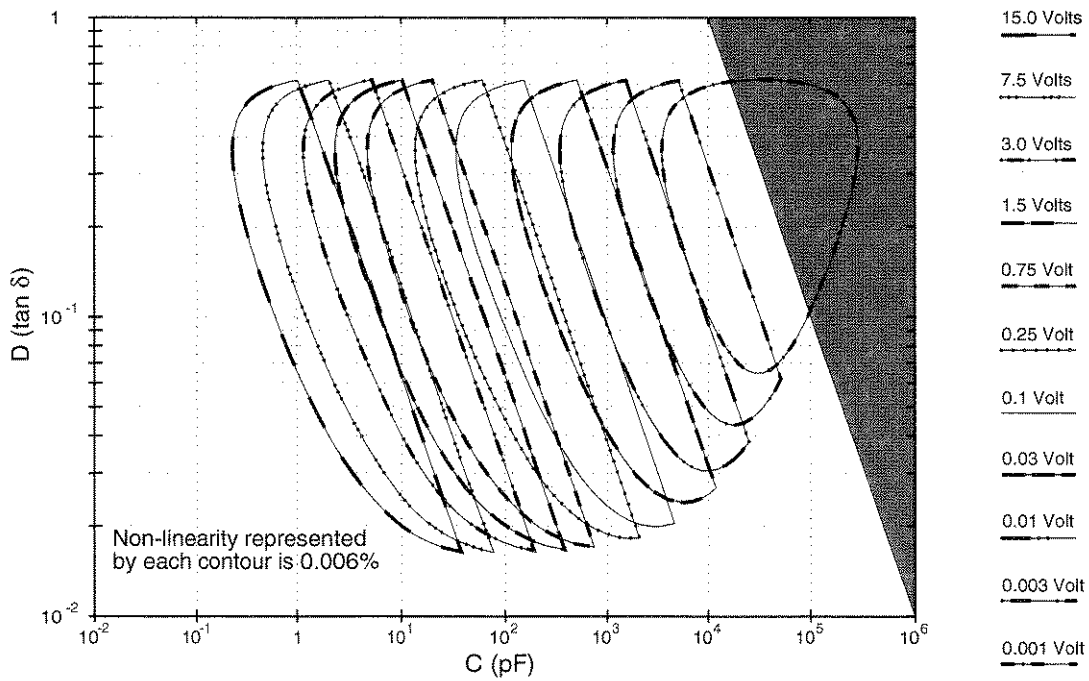
Figure C-20 Non-linearity of D vs. C and D using selected voltages.

$$\pm \left[\frac{8 \times 10^{-6} C + \left(1 + D^2\right)^{1/2} \left(0.15 + 50D + \frac{7.5}{CV}\right)}{D} \right] \qquad \text{Eq. C-9}$$
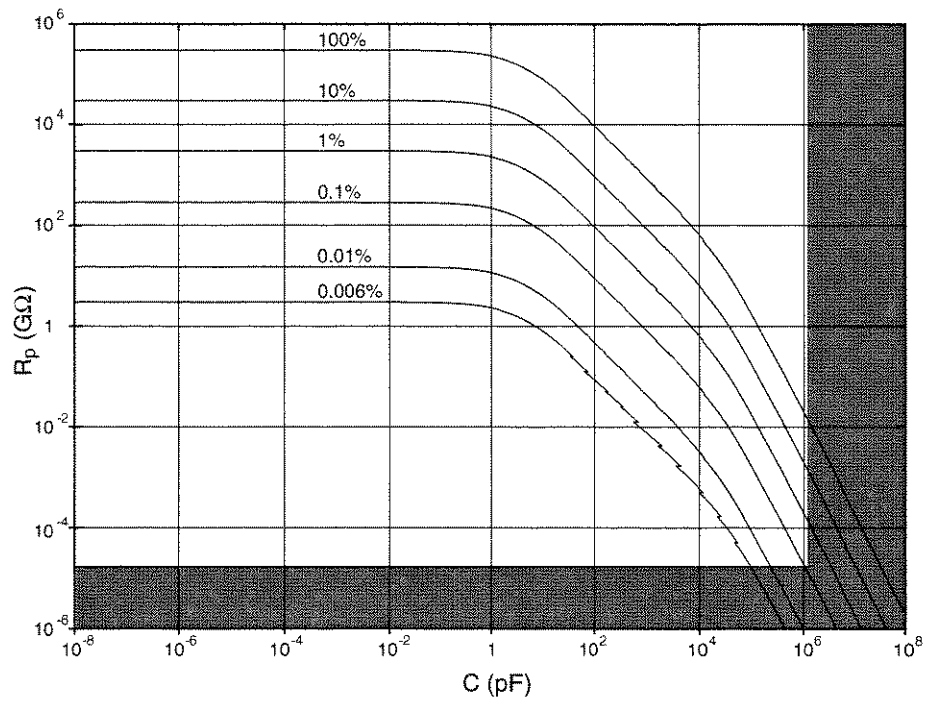
Figure C-21 Non-linearity of R_p vs. C and R_p using maximum voltages.
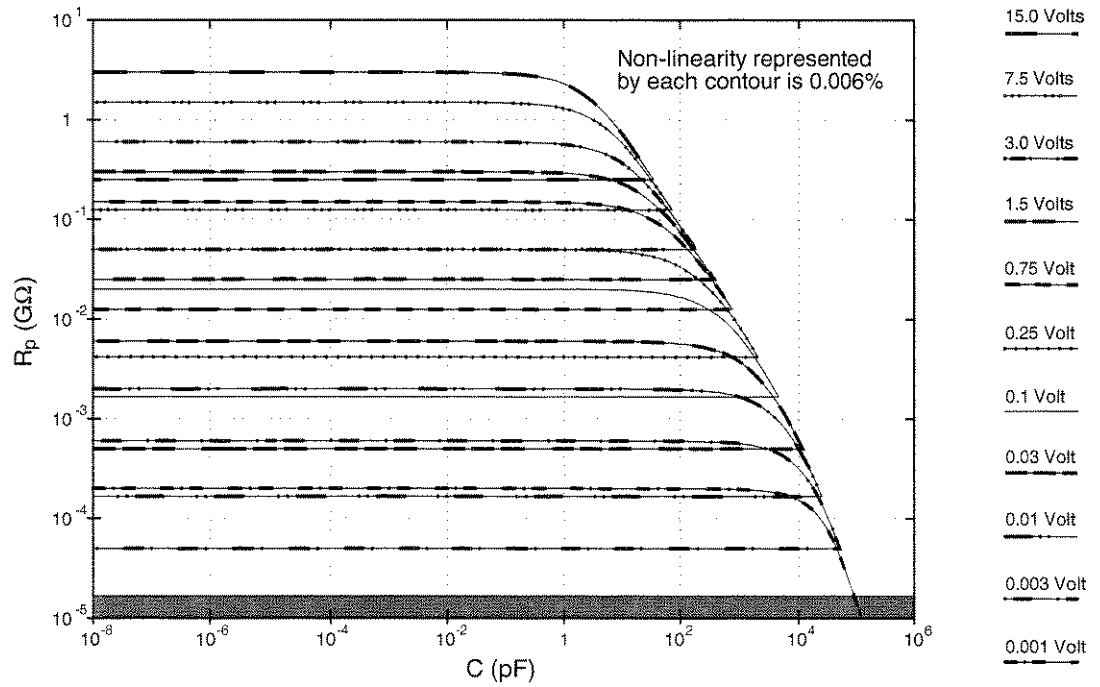
Figure C-22 Non-linearity of R_p vs. C and R_p using selected voltages.

$$\pm\left[50 + R_P\left(C + 5\times10^{-5}C^2 + \frac{50}{V}\right)\right]$$

Eq. C-10
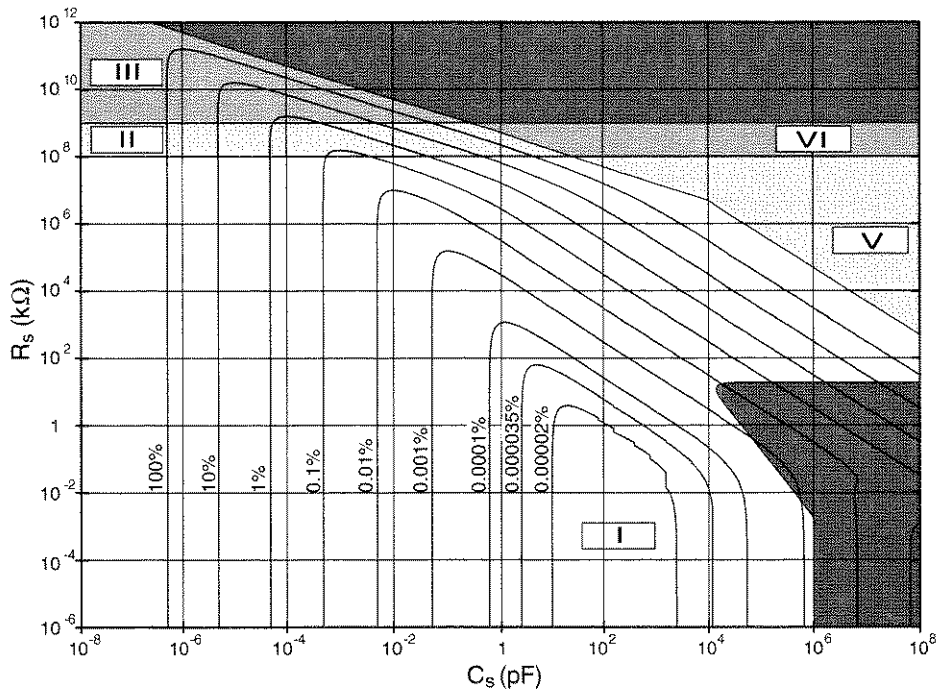
Figure C-23 Non-linearity of C_S vs. C_S and R_S using maximum voltages.
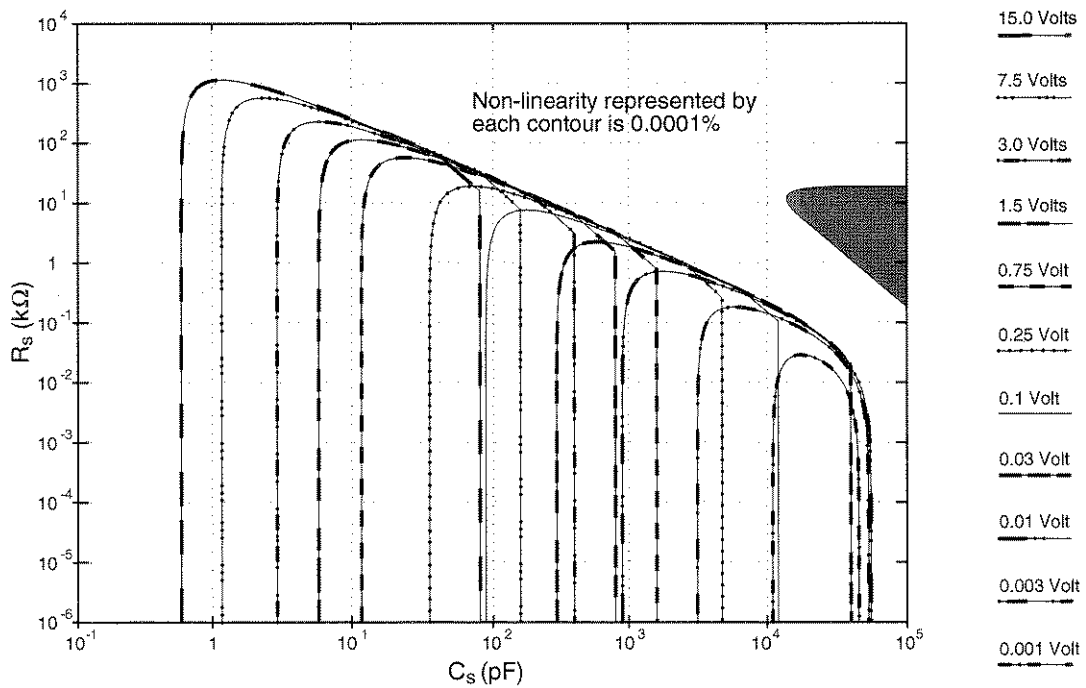
Figure C-24 Non-linearity of C_S vs. C_S and R_S using selected voltages.

$$\pm \left[0.15 + 50D + \frac{7.5\,(1+D^2)}{C_S V} + \left(\frac{15 \times 10^{-6} C_S}{1+D^2} \right) \right] \qquad \text{Eq. C-11}$$
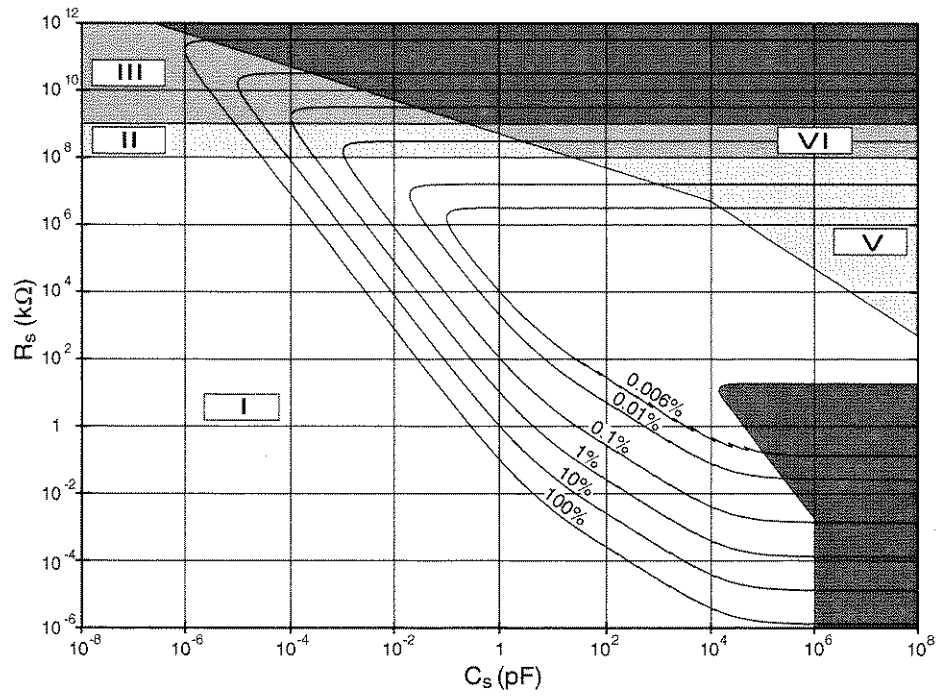
Figure C-25 Non-linearity of R_s vs. C_s and R_s using maximum voltages.
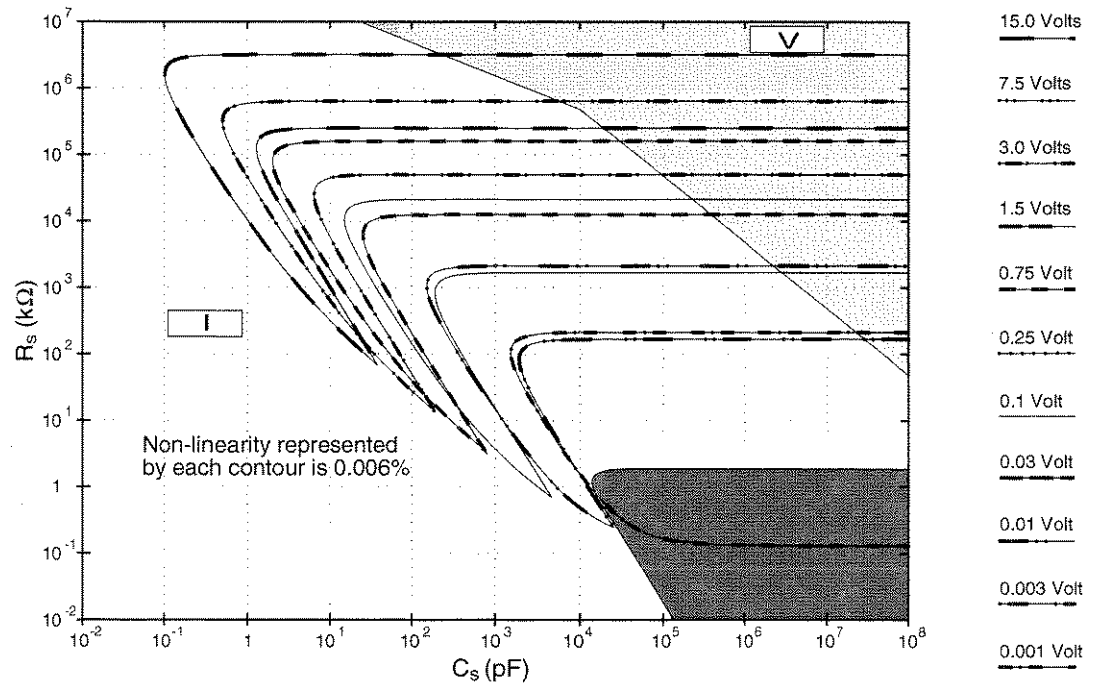
Figure C-26 Non-linearity of R_s vs. C_s and R_s using selected voltages.

$$\pm\left[\frac{1.3}{R_S} + 50 + \frac{0.15 + \dfrac{7.5\,(1 + D^2)}{C_S V}}{D}\right] \qquad \text{Eq. C-12}$$
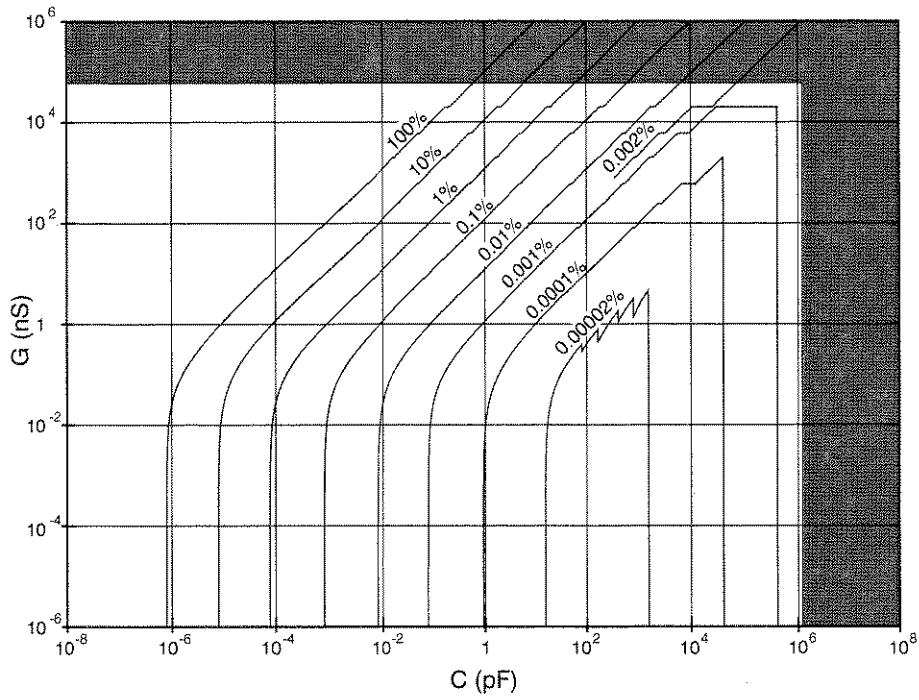
Figure C-27 Resolution of C vs. C and G using maximum voltages.
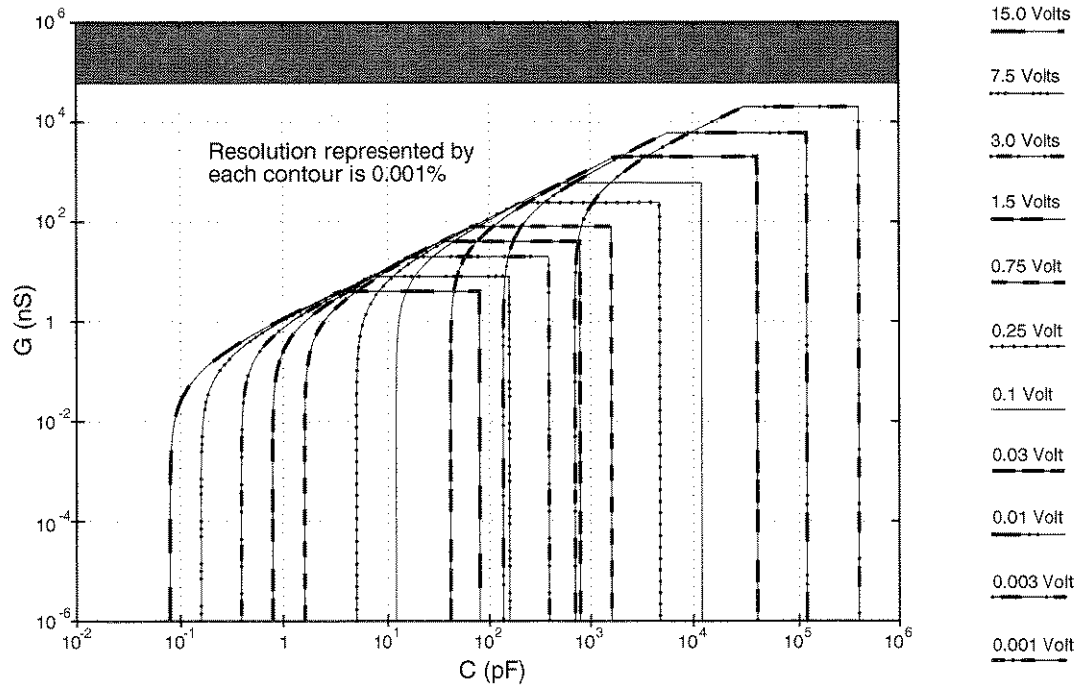
Figure C-28 Resolution of C vs. C and G using selected voltages.

$$0.15 + 50D + \frac{7.5\dfrac{(1 + n_C)}{C} + n_V}{V} \qquad \text{Eq. C-13}$$
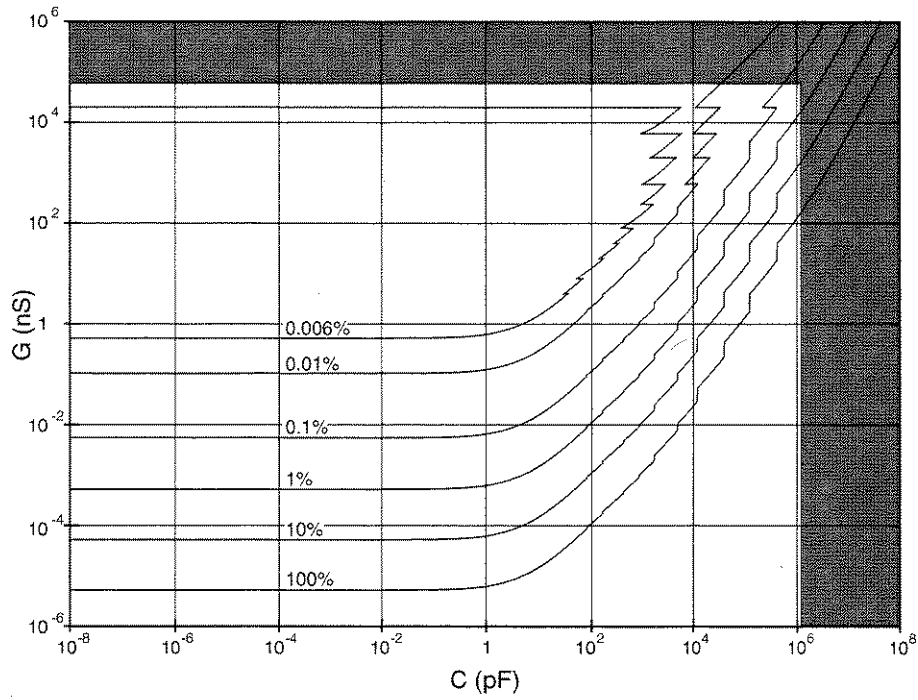
Figure C-29 Resolution of G vs. C and G using maximum voltages.

Figure C-30 Resolution of G vs. C and G using selected voltages.

$$50 + \frac{C + 5\times10^{-5}C^2 + \dfrac{50\left(1 + n_C\right) + 6n_V C}{V}}{G} \qquad \text{Eq. C-14}$$
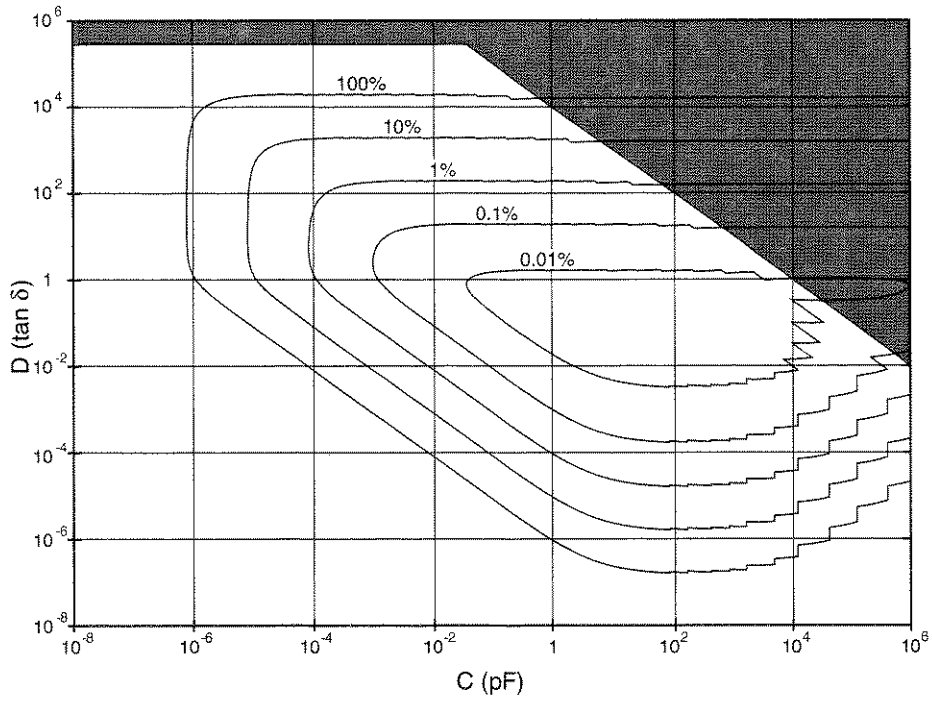
Figure C-31 Resolution of D vs. C and D using maximum voltages.
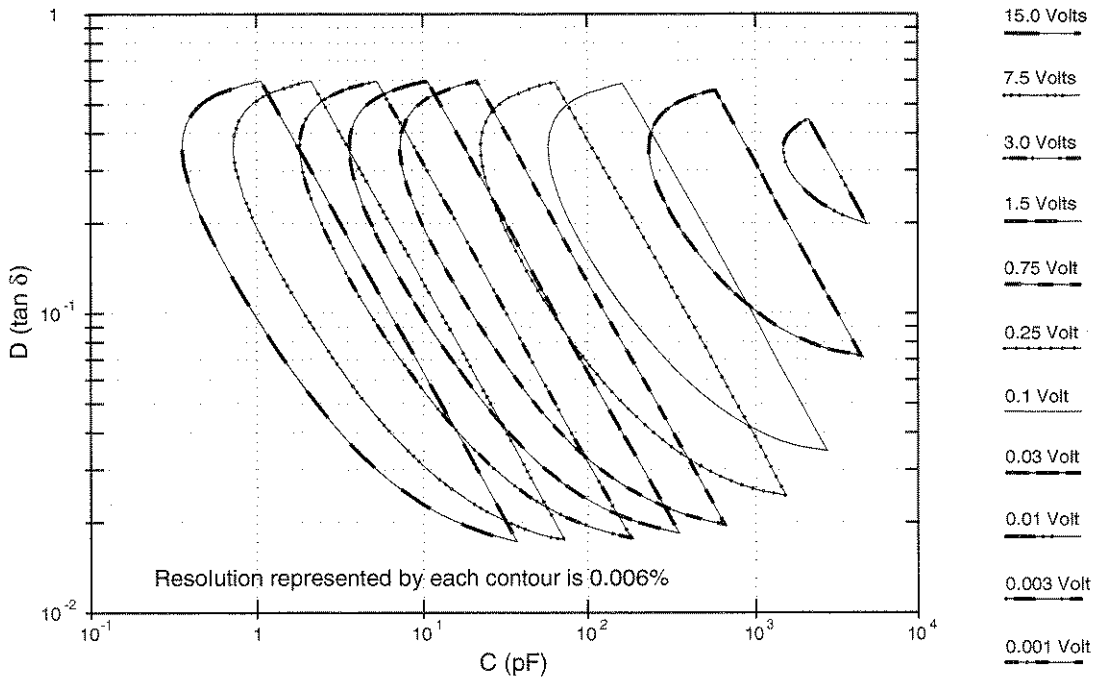
Figure C-32 Resolution of D vs. C and D using selected voltages.

$$\frac{1}{D}\left[8\times10^{-6}C + \left(1+D^2\right)^{1/2}\left\{ 0.15 + 50D + \frac{\dfrac{7.5\left(1+n_C\right)}{C}+n_V}{V}\right\} \right] \qquad \text{Eq. C-15}$$
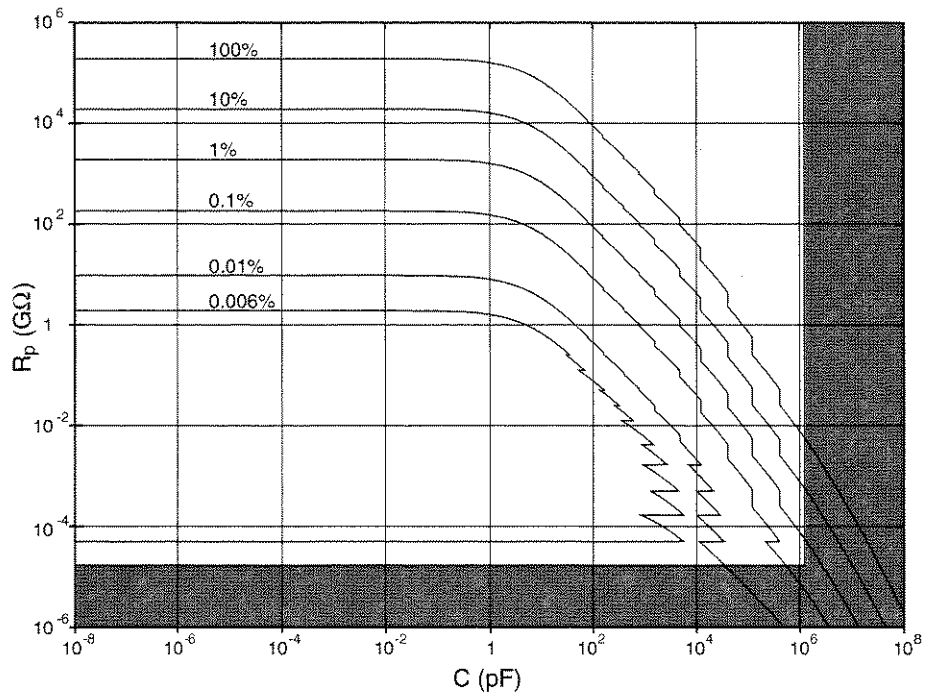
Figure C-33 Resolution of R_p vs. C and R_p using maximum voltages.
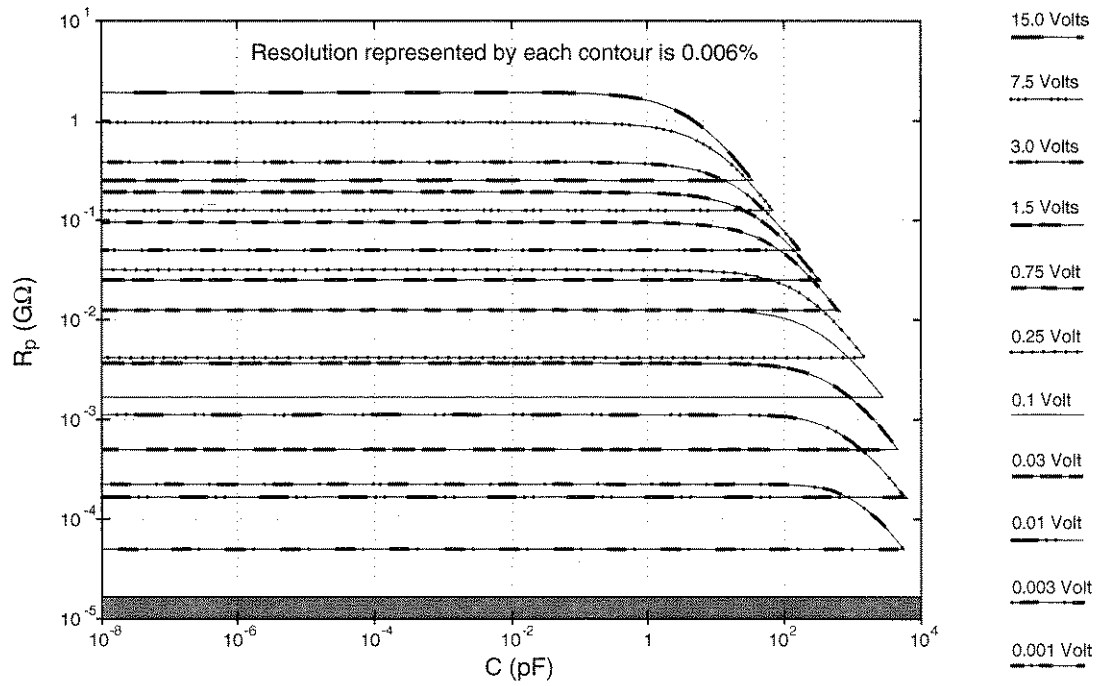
Figure C-34 Resolution of R_p vs. C and R_p using selected voltages.

$$50 + R_P \left[C + 5 \times 10^{-5} C^2 + \frac{50\,(1 + n_C) + 6 n_V C}{V} \right] \qquad \text{Eq. C-16}$$

Figure C-35 Resolution of C_s vs. C_s and R_s using maximum voltages.
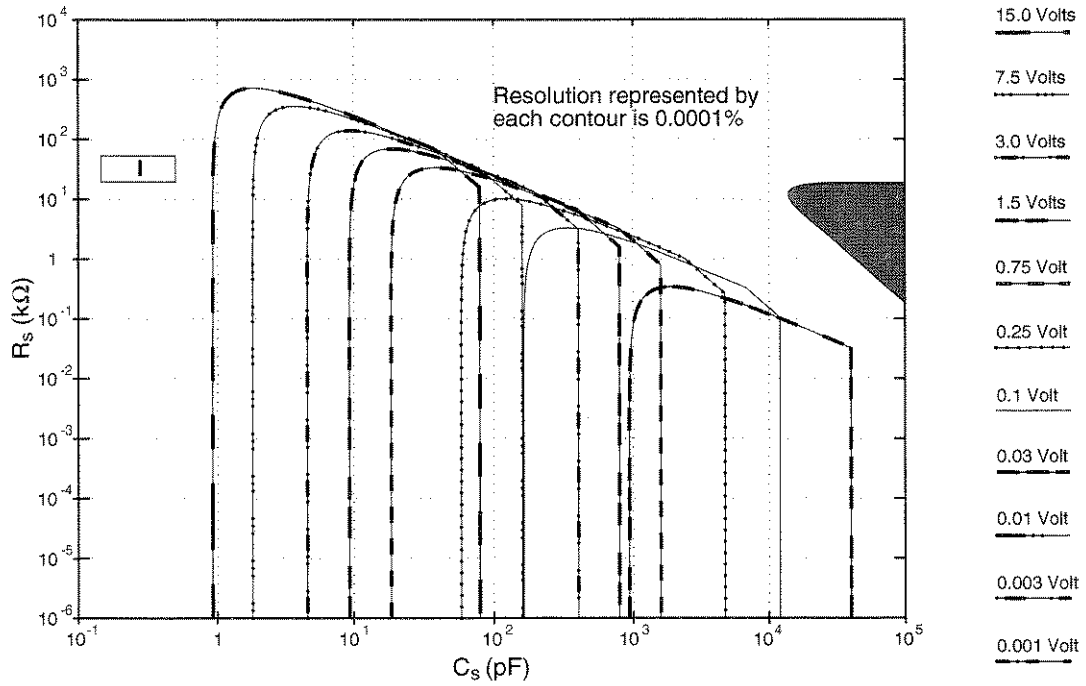
Figure C-36 Resolution of C_s vs. C_s and R_s using selected voltages.

$$0.15 + 50D + \frac{7.5\dfrac{(1 + n_C)\,(1 + D^2)}{C_S} + n_V}{V} \qquad \text{Eq. C-17}$$
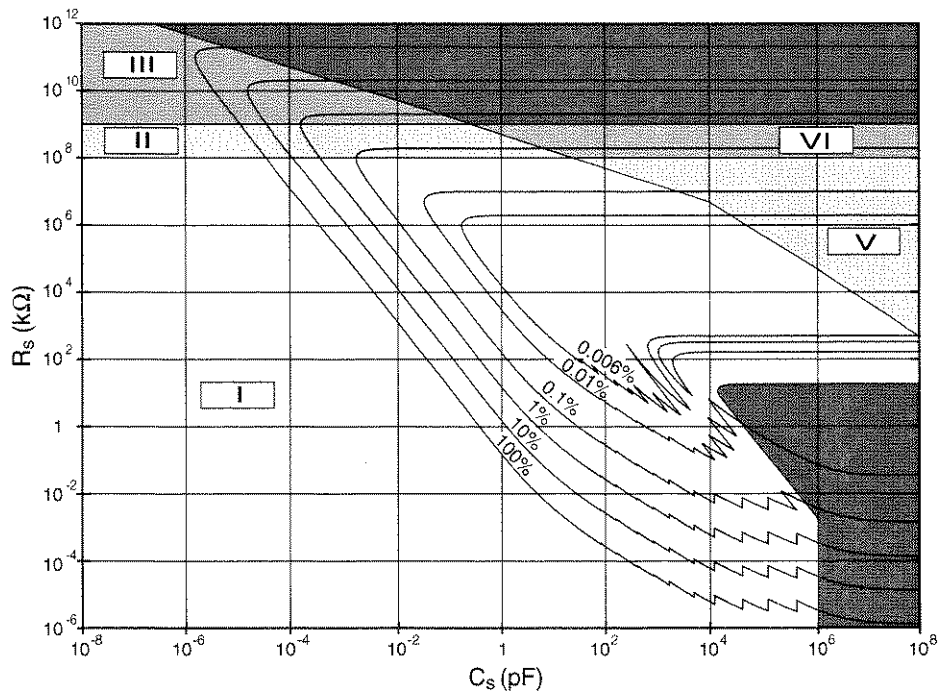
Figure C-37 Resolution of R_S vs. C_S and R_S using maximum voltages.
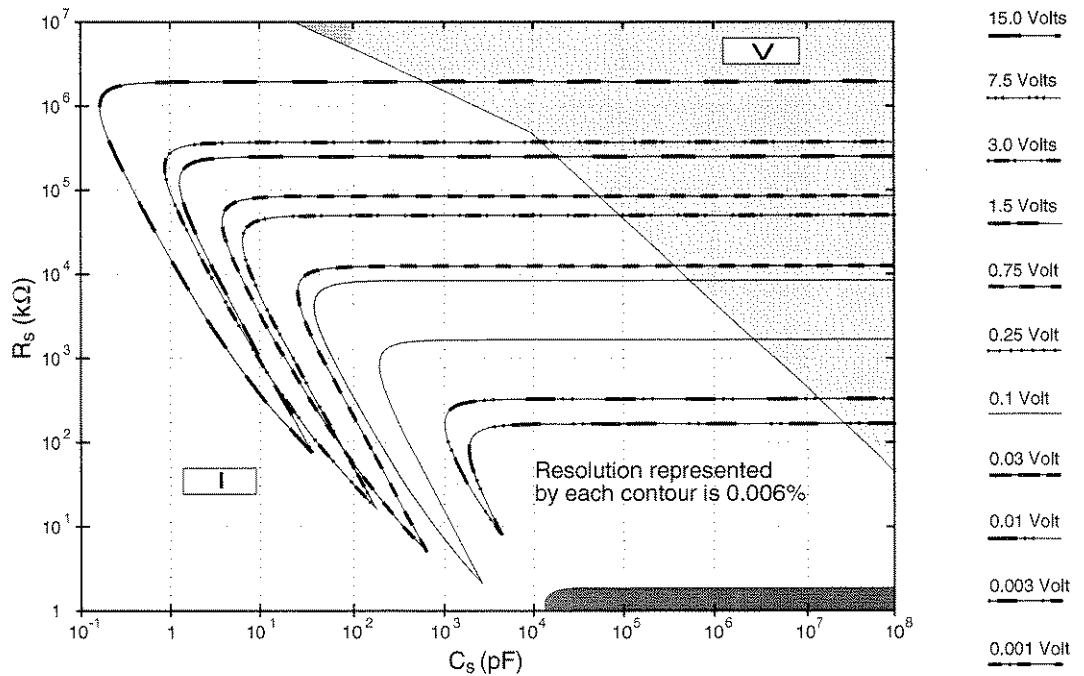
Figure C-38 Resolution of R_S vs. C_S and R_S using selected voltages.

$$\frac{1.3}{R_S} + 50 + \frac{0.15}{D} + \frac{\dfrac{7.5\,(1+n_C)\,(1+D^2)}{C_S} + n_V}{DV} \qquad \text{Eq. C-18}$$
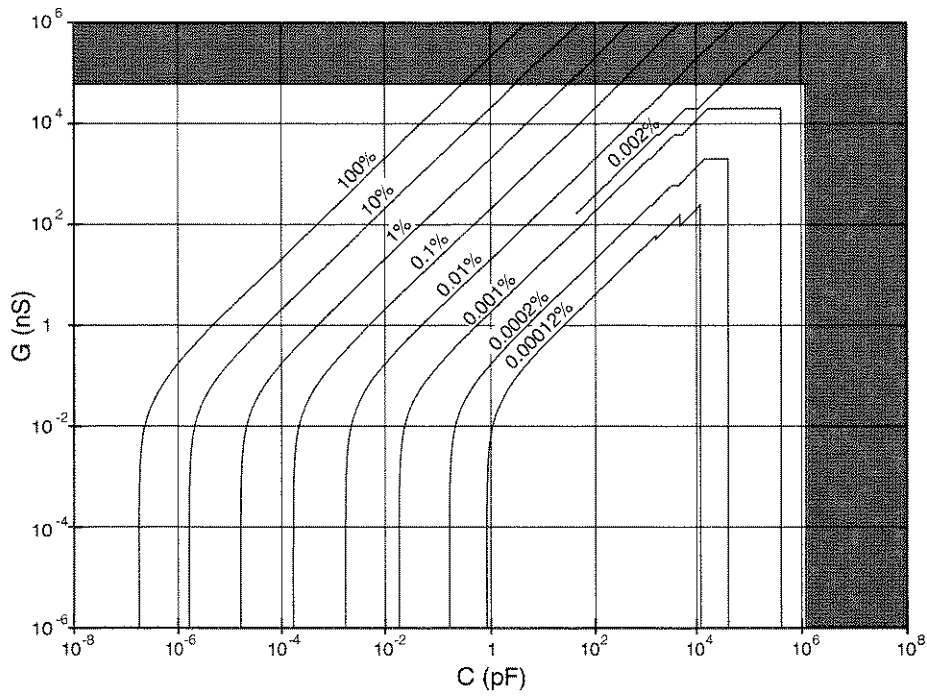
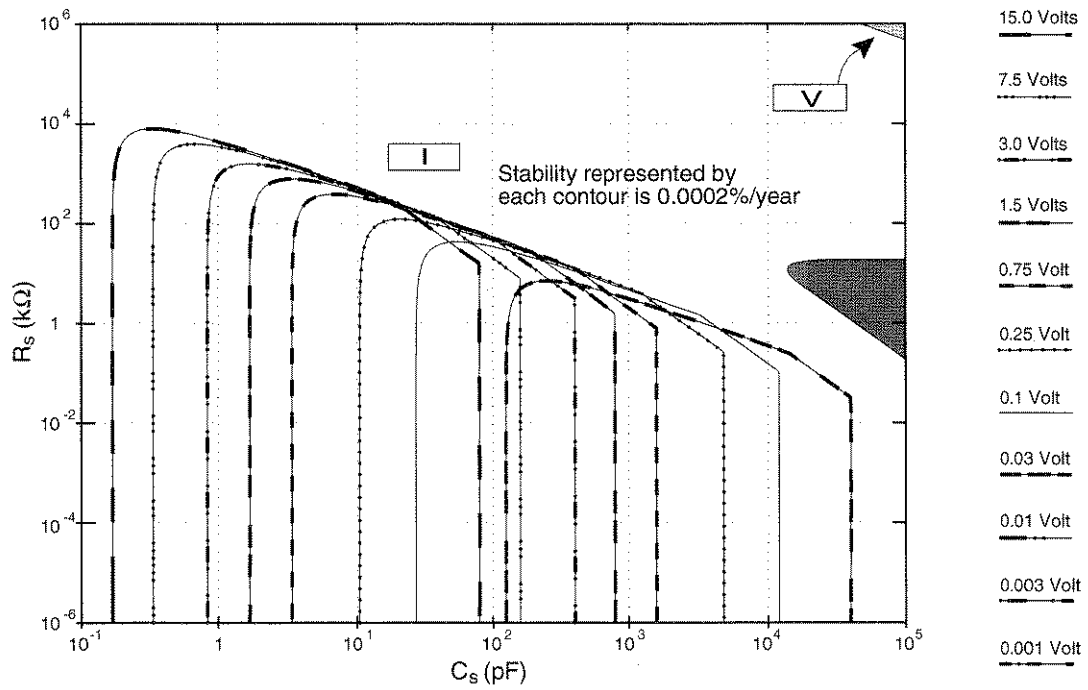**Figure C-39 Stability per year of C vs. C and G using maximum voltages.**
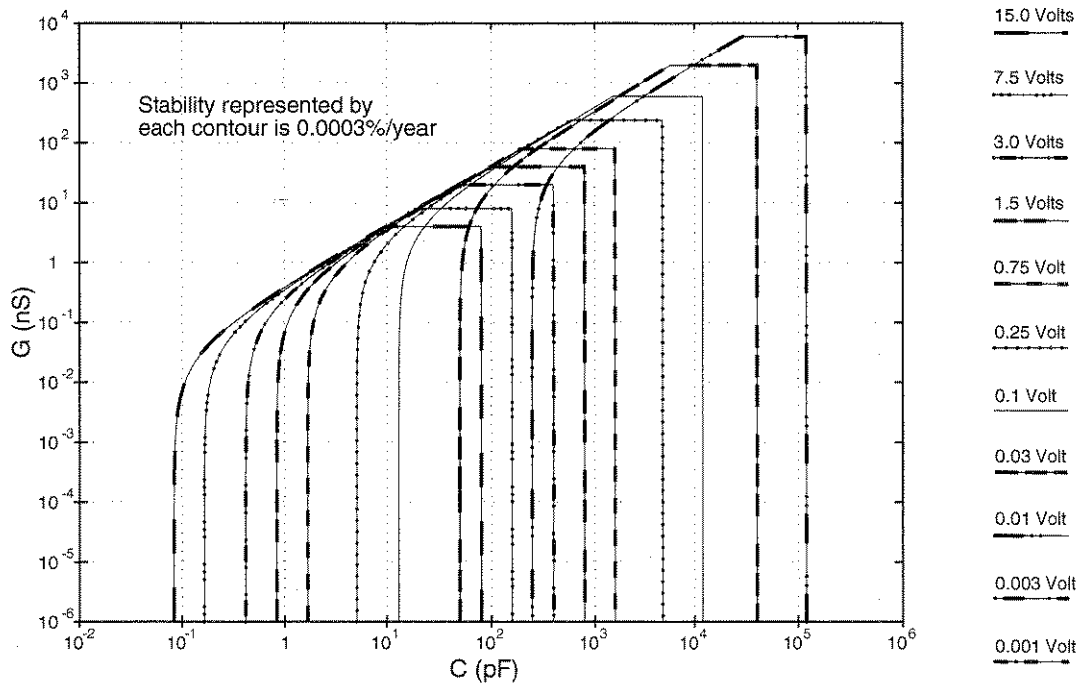
Figure C-40 Stability per year of C vs. C and G using selected voltages.

$$\pm \left[1 + 30D + \frac{0.01 + \dfrac{2.5}{C}}{V} \right] \qquad \text{Eq. C-19}$$
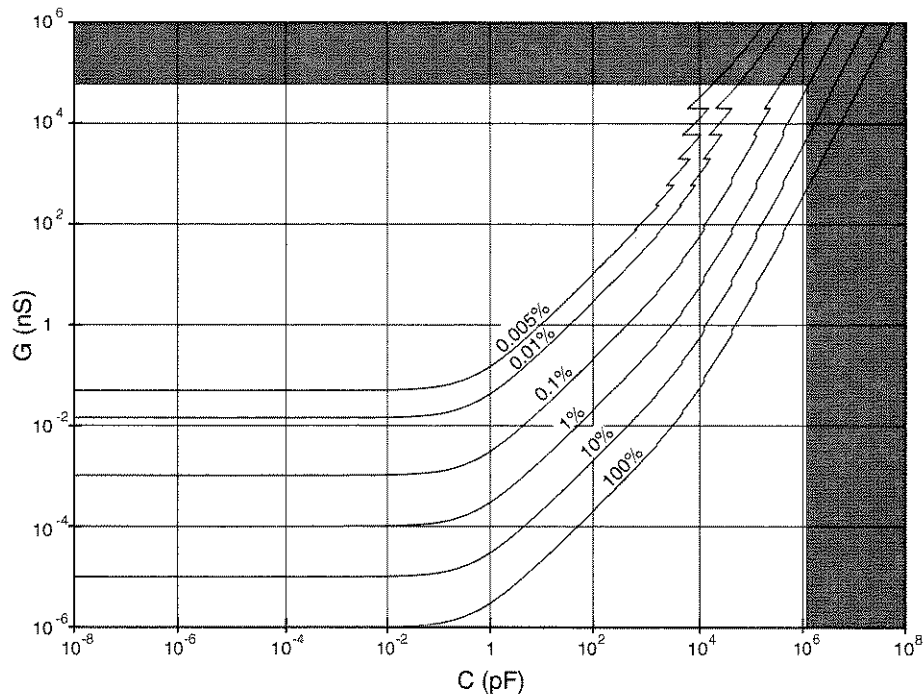
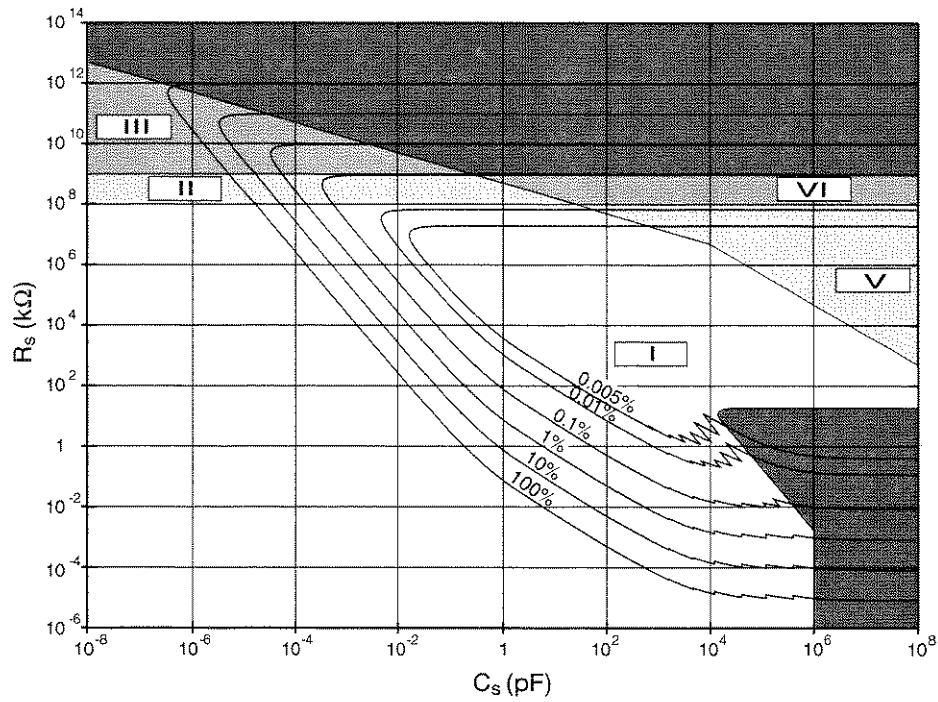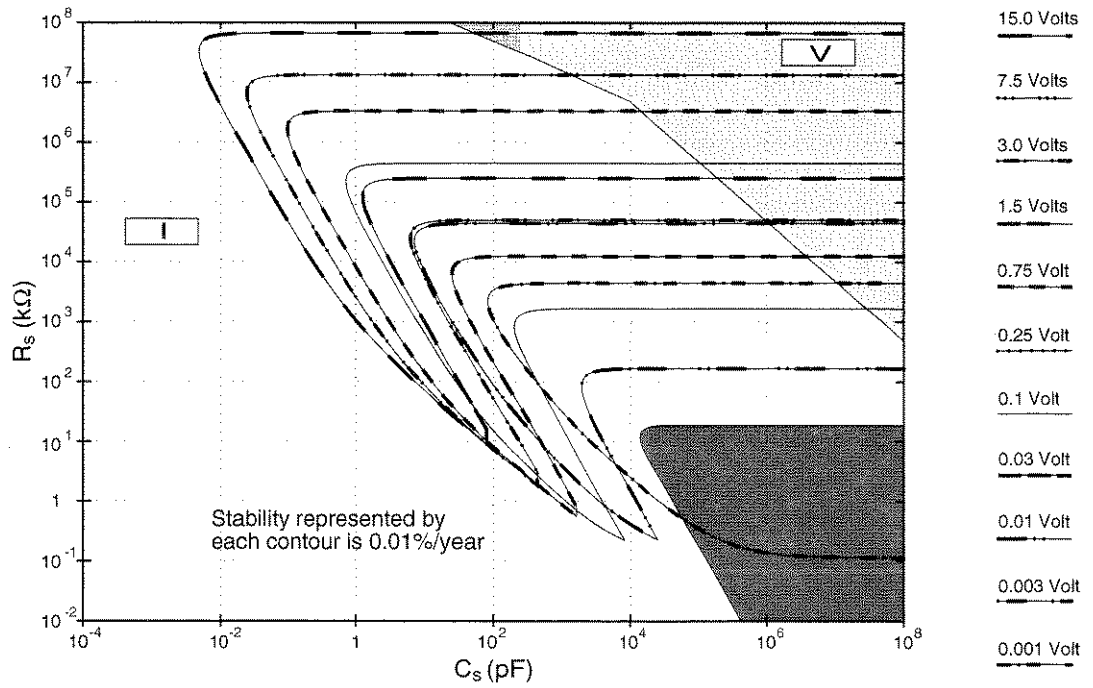**Figure C-41 Stability per year of G vs. C and G using maximum voltages.**
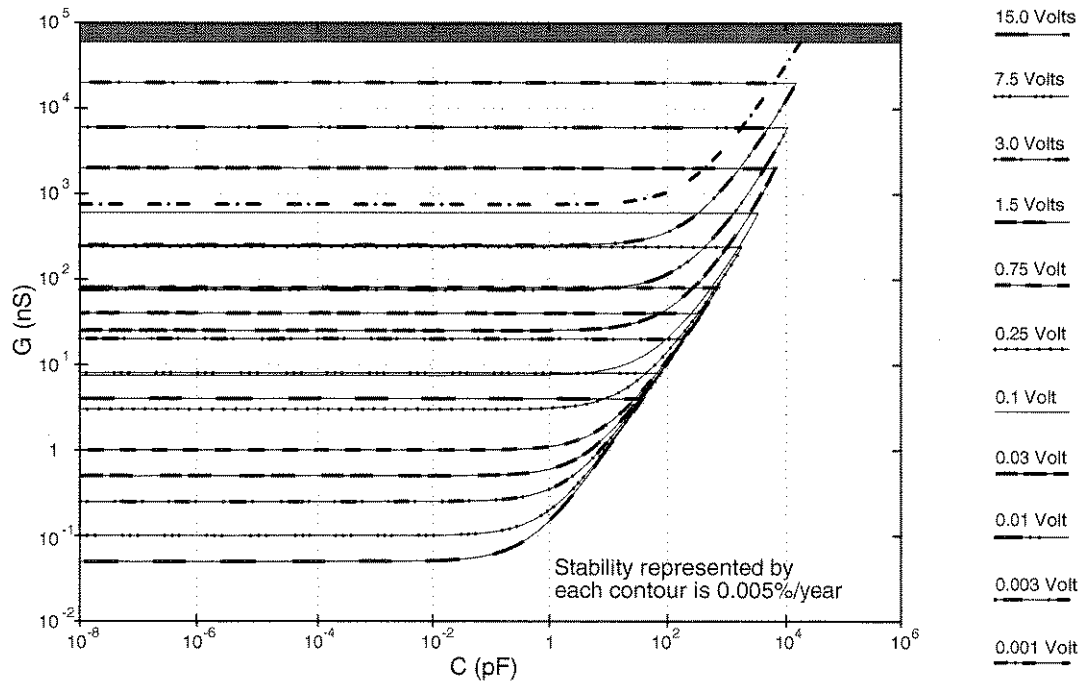
Figure C-42 Stability per year of G vs. C and G using selected voltages.

$$\pm\left[30 + \frac{2C + 3\times 10^{-4} C^2 + \dfrac{15 + 0.06C}{V}}{G} \right] \qquad \text{Eq. C-20}$$
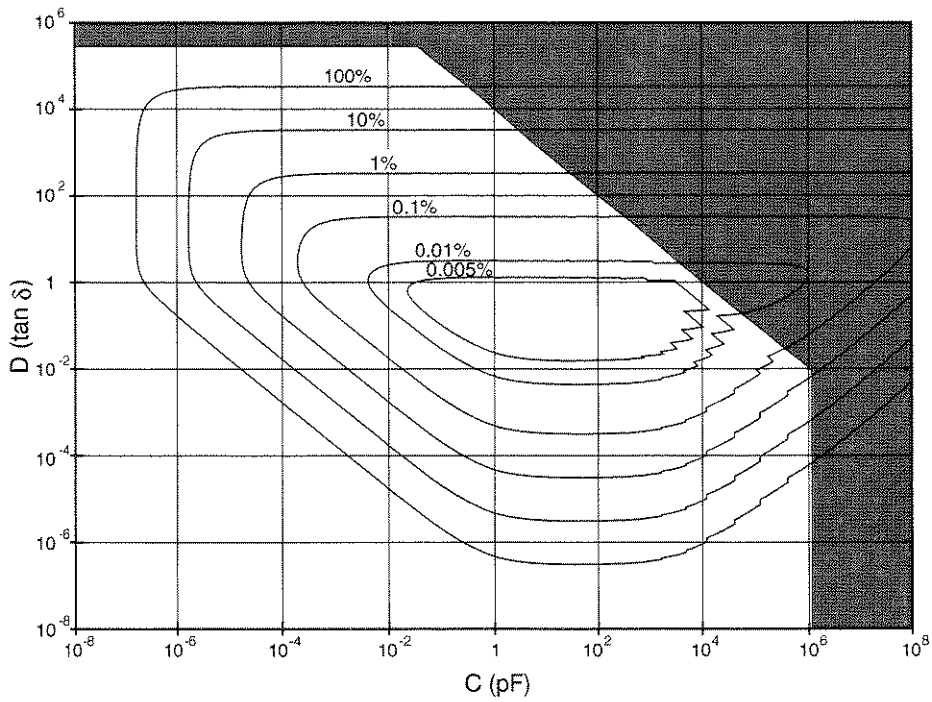
Figure C-43 Stability per year of D vs. C and D using maximum voltages.
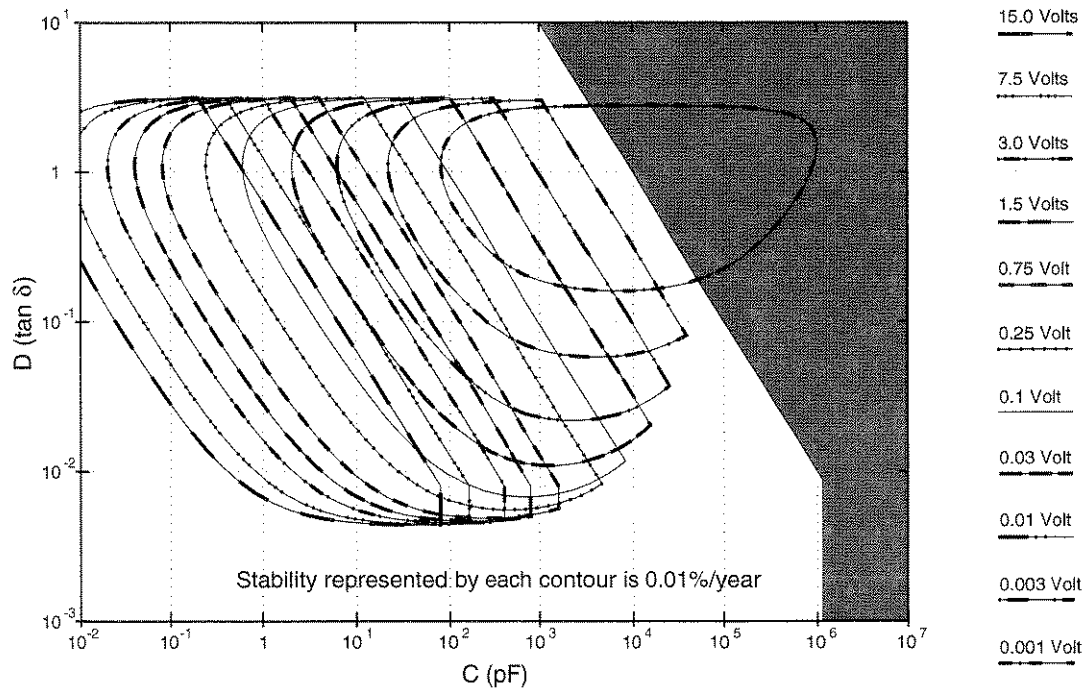
Figure C-44 Stability per year of D vs. C and D using selected voltages.

$$\pm\frac{1}{D}\left[0.3 + 5\times10^{-5}C + \left(1 + D^2\right)^{1/2}\left(30D + \frac{0.01 + \frac{2.5}{C}}{V}\right)\right] \qquad \text{Eq. C-21}$$
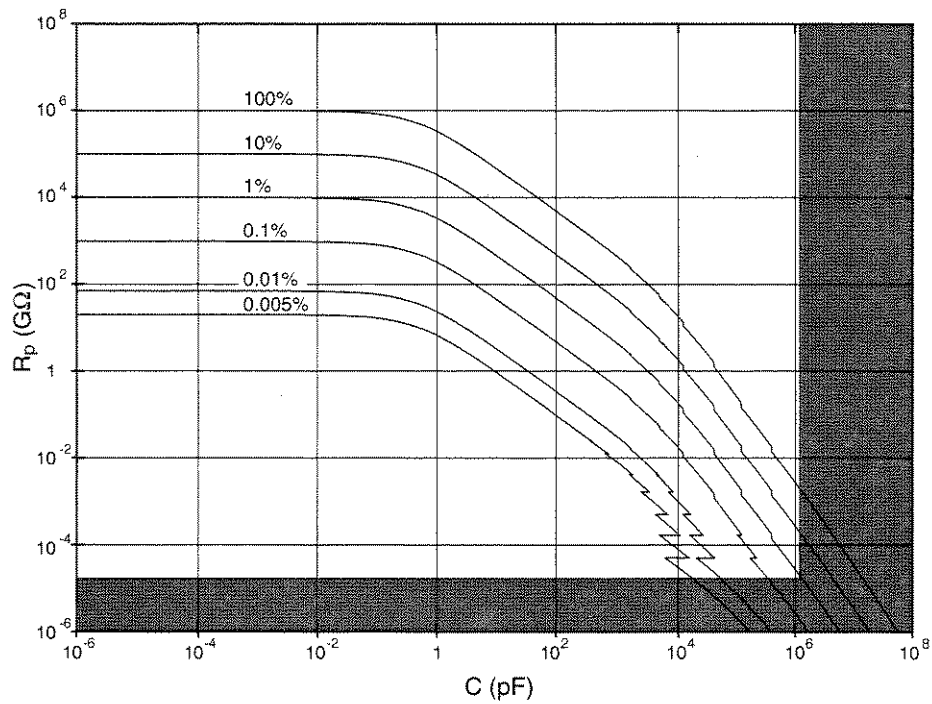
Figure C-45 Stability per year of R_p vs. C and R_p using maximum voltages.
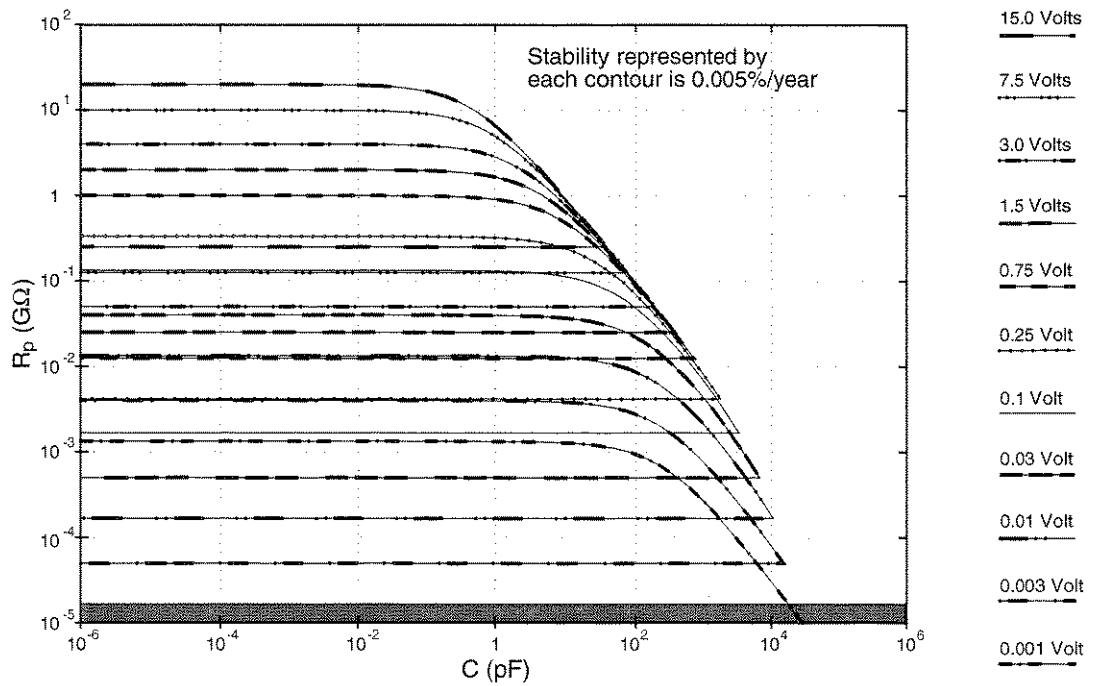
Figure C-46 Stability per year of R_p vs. C and R_p using selected voltages.

$$\pm\left[30 + R_P\left(2C + 3{\times}10^{-4}C^2 + \frac{15 + 0.06C}{V}\right)\right] \qquad \text{Eq. C-22}$$
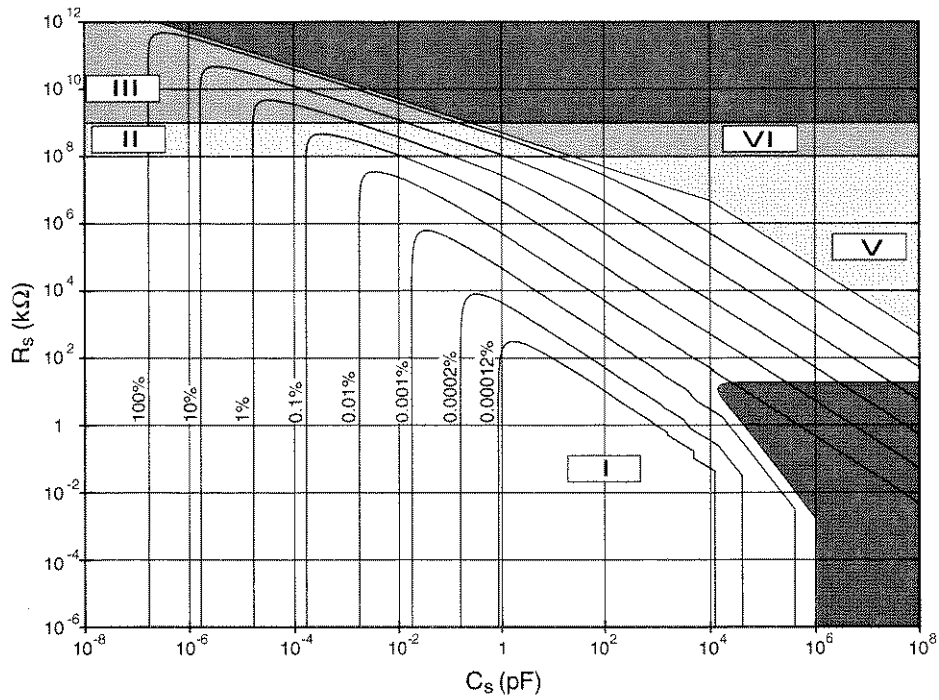
Figure C-47 Stability per year of C_s vs. C_s and R_s using maximum voltages.

Figure C-48 Stability per year of C_s vs. C_s and R_s using selected voltages.

$$\pm \left[1 + 30D + \frac{0.01 + \dfrac{2.5\,(1 + D^2)}{C_S}}{V} \right] \qquad \text{Eq. C-23}$$

Figure C-49 Stability per year of R_s vs. C_s and R_s using maximum voltages.

Figure C-50 Stability per year of R_s vs. C_s and R_s using selected voltages.

$$\pm \left[30 + \frac{8}{R_S} + \frac{0.3}{D} + \frac{0.01 + \frac{2.5\,(1 + D^2)}{C_S}}{DV} \right] \qquad \text{Eq. C-24}$$
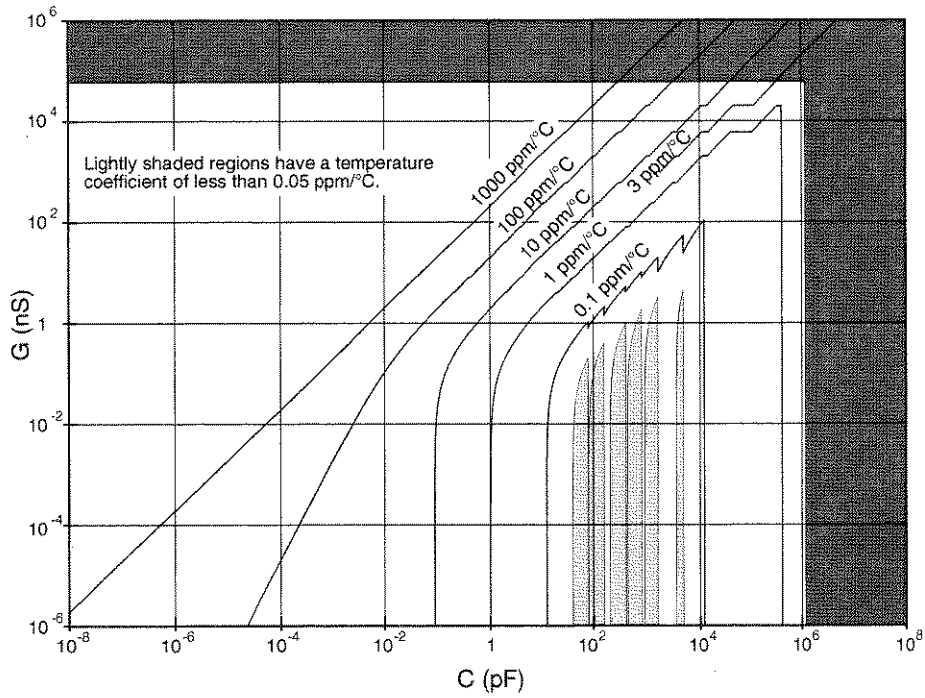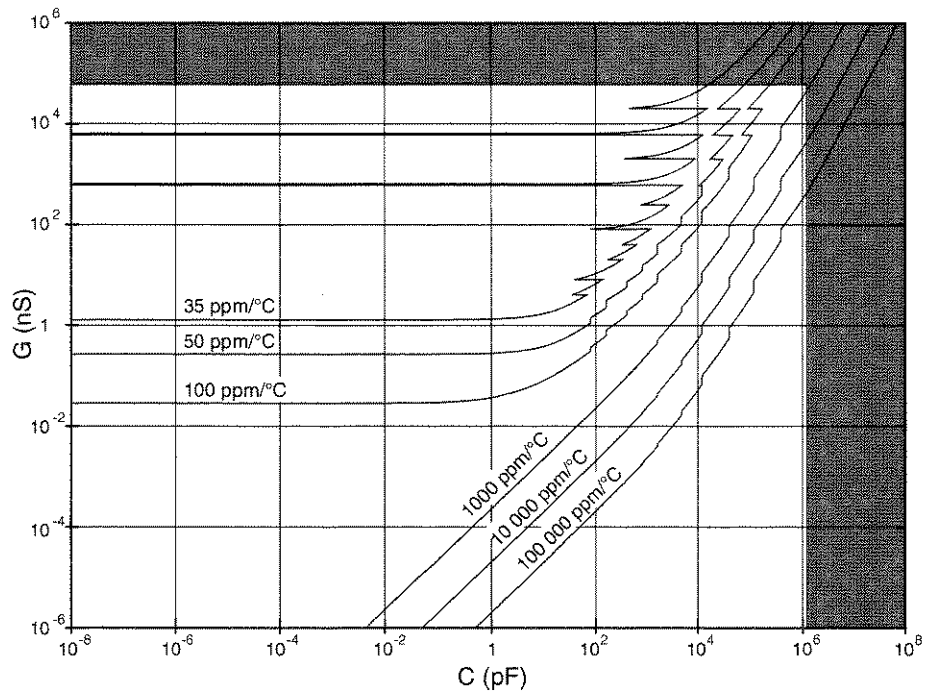
Figure C-51 Temperature coefficient of C vs. C and G using maximum voltages.
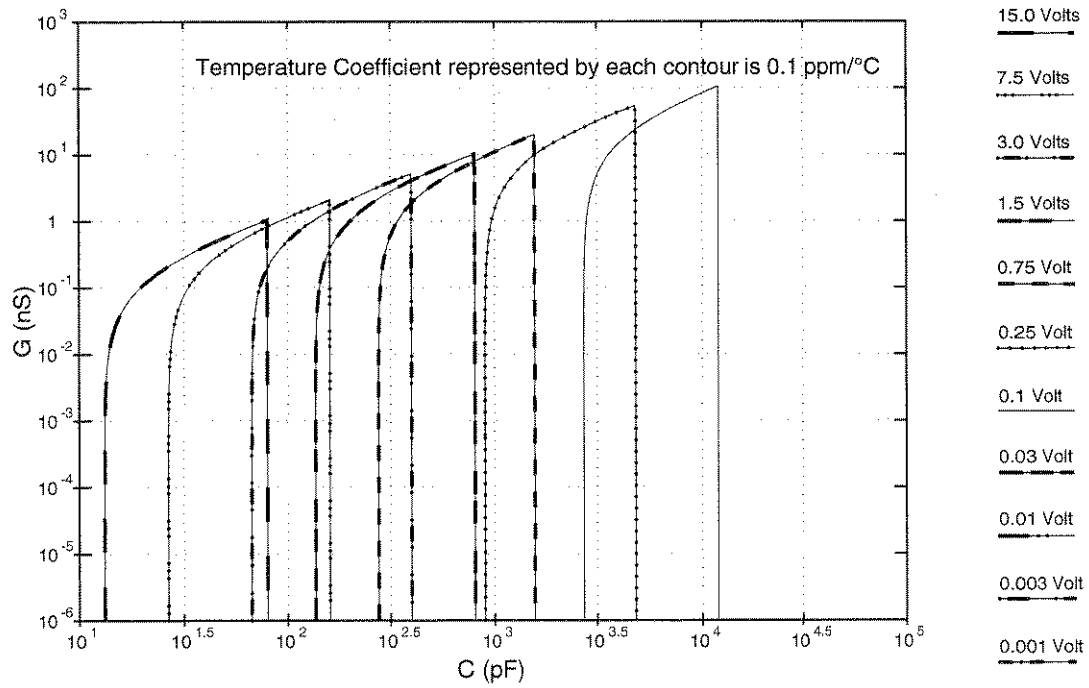
Figure C-52 Temperature coefficient of C vs. C and G using selected voltages.

$$\pm\left[0.025 + 30D + \frac{0.002}{V} + \frac{15}{0.15 + CV}\right] \qquad \text{Eq. C-25}$$

Figure C-53 Temperature coefficient of G vs. C and G using maximum voltages.
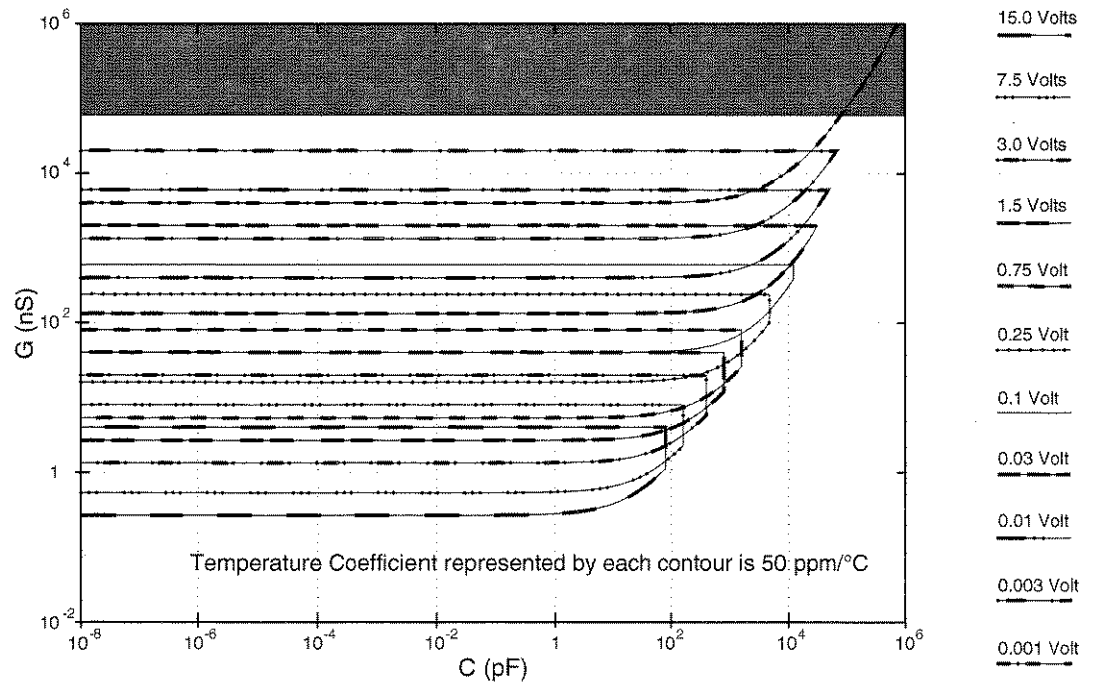

Figure C-54 Temperature coefficient of G vs. C and G using selected voltages.

$$\pm\left[30 + \frac{C\left(0.2 + 2\times10^{-5}C + \dfrac{0.012}{V}\right)}{G} + \frac{100}{1 + GV}\right] \qquad \text{Eq. C-26}$$
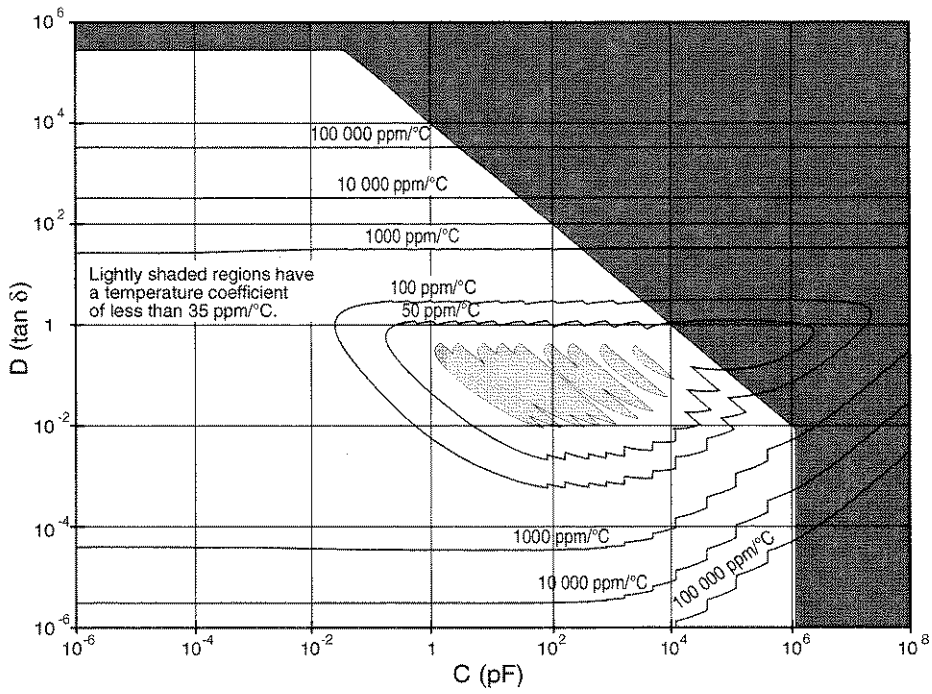
Figure C-55 Temperature coefficient of D vs. C and D using maximum voltages.
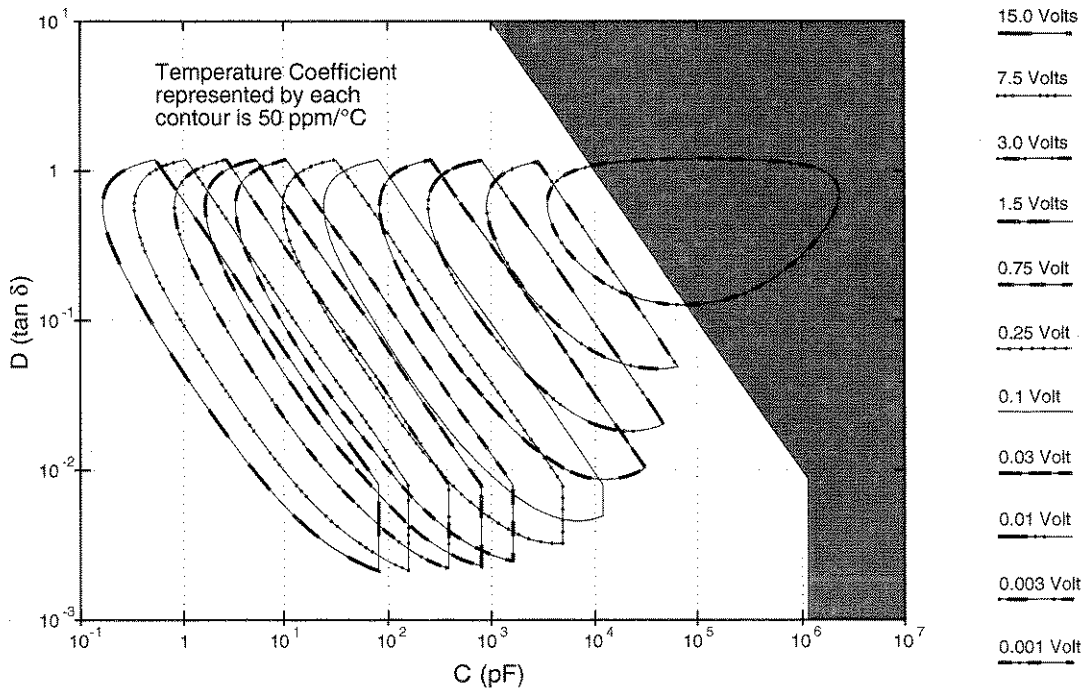

Figure C-56 Temperature coefficient of D vs. C and D using selected voltages.

$$\pm \left[\frac{0.03 + 3\times10^{-6}C + (1+D^2)^{1/2}\left(30D + \dfrac{0.002}{V}\right)}{D} + \frac{15}{0.15+CV} + \frac{15}{0.15+CDV} \right] \qquad \text{Eq. C-27}$$
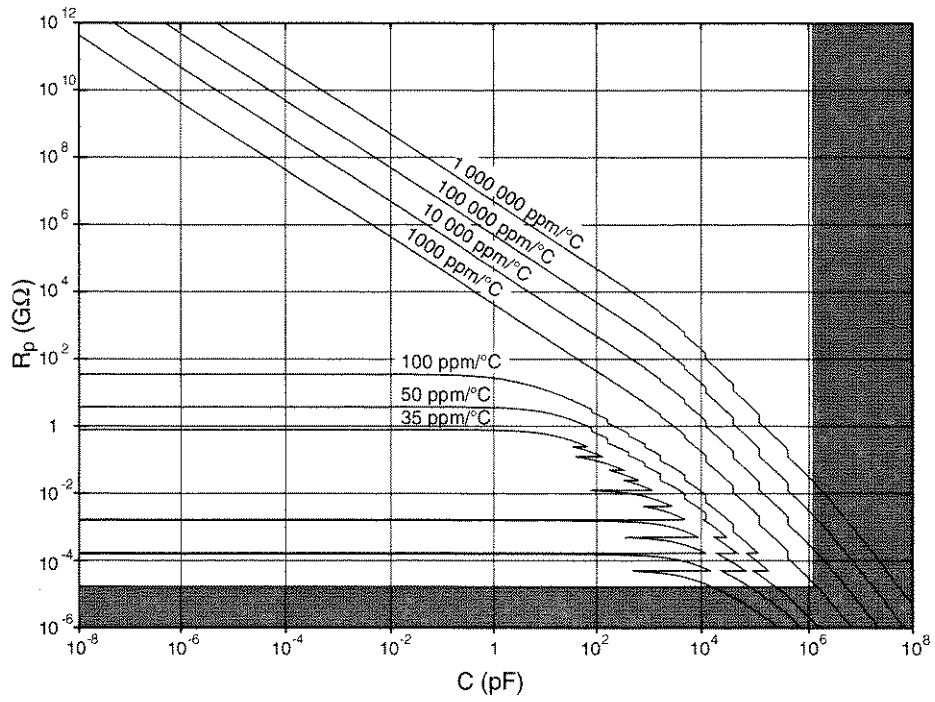
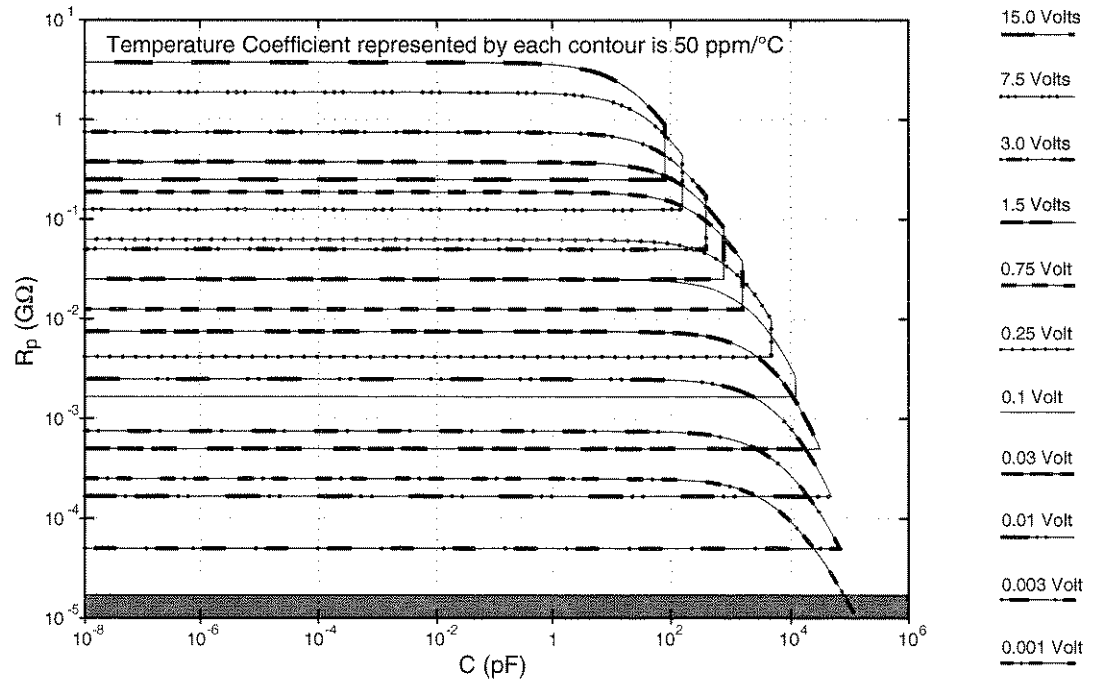**Figure C-57 Temperature coefficient of R_p vs. C and R_p using maximum voltages.**

Figure C-58 Temperature coefficient of R_p vs. C and R_p using selected voltages.

$$\pm\left[30 + CR_P\left(0.2 + 2\times10^{-5}C + \frac{0.012}{V}\right) + \frac{100}{1 + \frac{V}{R_P}}\right] \qquad \text{Eq. C-28}$$
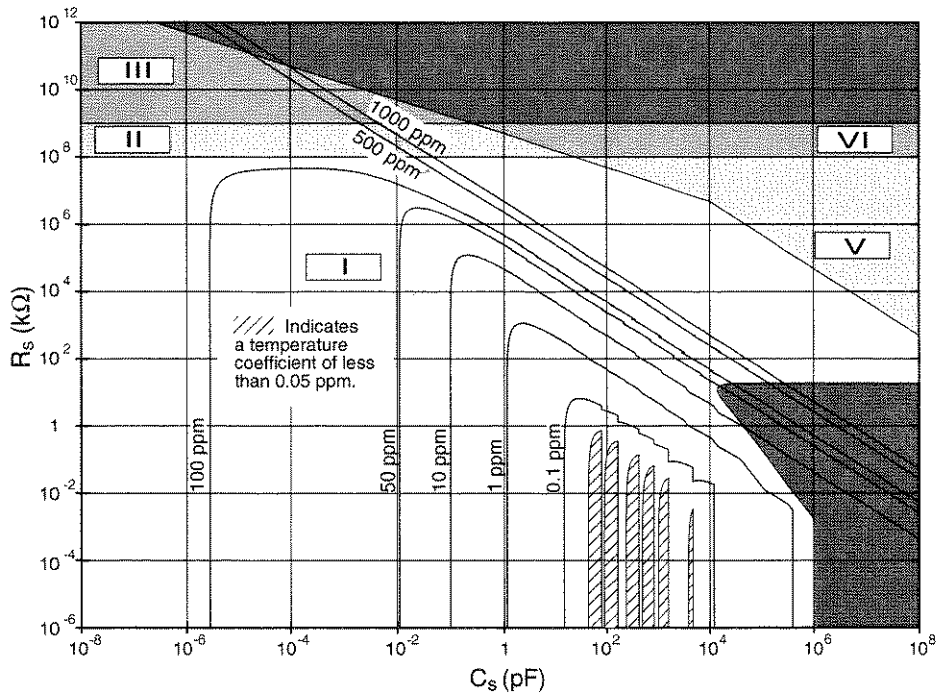
Figure C-59 Temperature coefficient of C_S vs. C_S and R_S using maximum voltages.
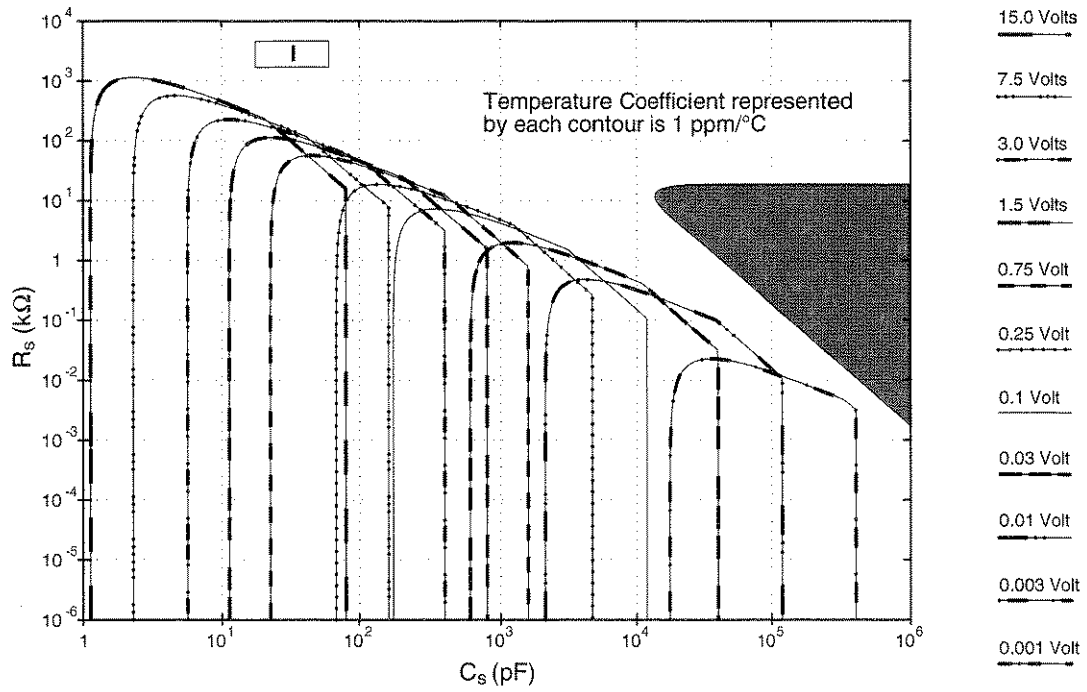

Figure C-60 Temperature coefficient of C_S vs. C_S and R_S using selected voltages.

$$\pm \left[0.025 + 30D + \frac{0.002}{V} + \frac{100}{1 + \dfrac{6C_S V}{1 + D^2}} \right] \qquad \text{Eq. C-29}$$

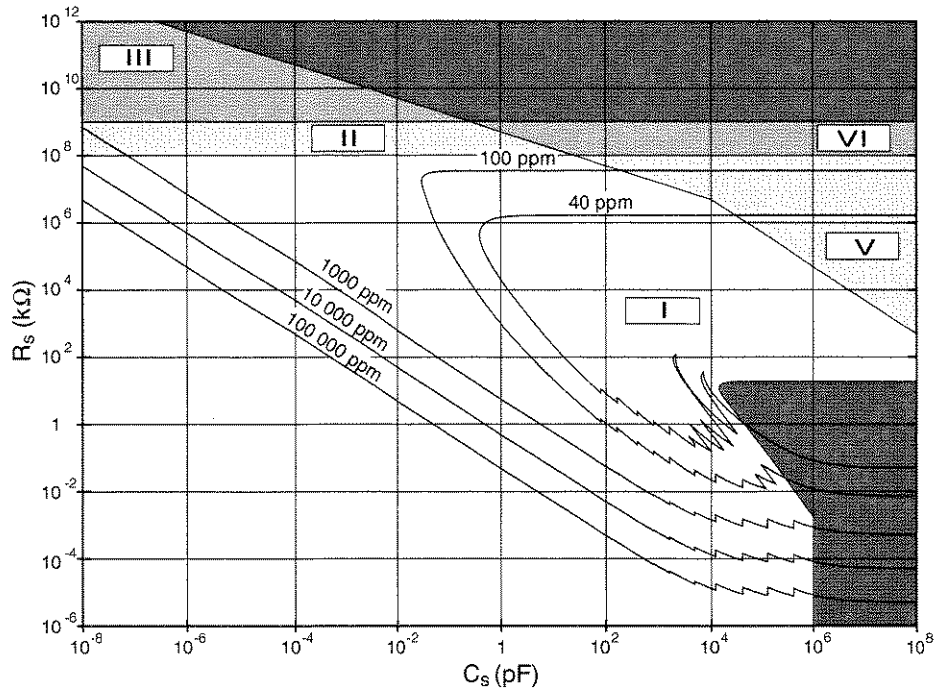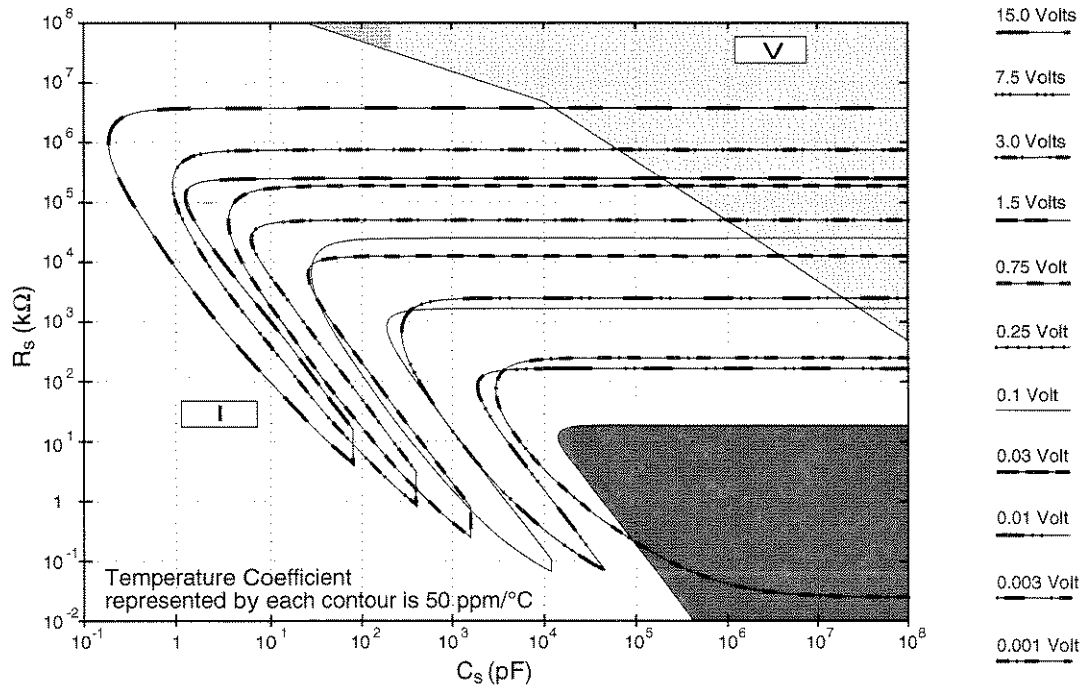**Figure C-61 Temperature coefficient of R_s vs. C_s and R_s using maximum voltages.**

Figure C-62 Temperature coefficient of R_s vs. C_s and R_s using selected voltages.

$$\pm \left[30 + \frac{0.5}{R_S} + \frac{0.03 + \frac{0.002}{V}}{D} + \frac{30}{0.15\left(1 + D^2\right) + C_S V} + \frac{100}{1 + \frac{1 \times 10^6 V D^2}{\left(1 + D^2\right) R_S}} \right] \qquad \text{Eq. C-30}$$

The AH 2500A incorporates a connector on its rear panel that is intended to provide signals to control an external coaxial switch. Such a switch is useful for selecting among several unknown samples. An AH 2500A command is provided to allow program control of such a switch.

At the time of publication of this manual, Andeen-Hagerling does not manufacture a sample switch. However, such a product is planned. If you are interested, watch for announcements.

In the meantime, the sample switch port can be used to control sample switches of your own design. It is also not difficult to build an interface to commercially available products if you have some electronics experience.

Basic Operation

The sample switch port is a parallel port with eight data lines and a strobe line. These lines use RS-232 drivers that produce ±12 volt signal levels. Five power lines are also present. These can provide up to 100 mA of current to external devices. The two 24 volt power supplies are unregulated. The other three supplies are well regulated.

The eight data lines are decoded so that only one line is true at a time. The lines are high-true which means that one line will always produce +12 volts and all the rest will produce -12 volts. These data lines can be connected directly to non-inverting relay driver circuits with no further decoding or other logic. This allows one of up to eight relays to be selectively closed.

Connector Description

The connector on the backpanel is a fifteen pin female "D" style. The pinout of this connector is given in Table D-1.

Selecting a Sample Switch Position

The data line that is true is selected with the following command:

<center>SAMPLE number</center>

The *number* parameter specifies the sample to be measured. It can have any value from 1 to 64, however, values of this parameter larger than eight will cause all sample switch data lines to be false. Values from one to eight will cause one of the eight sample switch data lines to be true. The number of the selected sample switch signal name is one less than the value of the *number* parameter. These values are listed in

Table D-1 Sample switch connector pinouts

Pin No.	Signal Name	Signal Description	True for *number*
1	SD0	Sample Switch Data 0	1
2	SD2	Sample Switch Data 2	3
3	SD4	Sample Switch Data 4	5
4	SD6	Sample Switch Data 6	7
5	GND	Ground	
6	+5V	+5 Volt Power	
7	+24V	+24 Volt Power	
8	+12V	+12 Volt Power	
9	SD1	Sample Switch Data 1	2
10	SD3	Sample Switch Data 3	4
11	SD5	Sample Switch Data 5	6
12	SD7	Sample Switch Data 7	8
13	SC	Sample Switch Data Valid	
14	-12V	-12 Volt Power	
15	-24V	-24 Volt Power	

Table D-1. The default value of the sample switch *number* parameter stored in the BASIC 0 parameter file is 1.

The utility of the SAMPLE command may be greatly enhanced when used with the AH 2500A's PROGRAM features. Obviously, the SAMPLE command is also useful when incorporated into programs run on remote controllers.

Signal Timing

The sample switch port has two timing issues. One is the timing of the strobe line relative to the data lines. The other is amount of time to wait after changing the sample switch setting before taking a measurement. This is called the settling time.

The Strobe Line Timing

If the sample switch data lines directly control relay driver circuits with no logic in between, then the Sample Switch Data Valid line will not be used. On the other hand, if the data from the sample switch data lines is to be externally latched, then the Sample Switch Data Valid line will be required to strobe the latch.

The Data Valid line is true when the sample switch data is stable and false when it may not be. The Data Valid line goes false (-12V) 250 microseconds before the data lines change. It goes true again (+12V) 250 microseconds after they change. If the data is to be strobed into a latch, this would normally be done by using the false-to-true transition of the Data Valid line.

Changing the Settling Time

A time delay can be specified that automatically occurs after each execution of the SAMPLE command. This provides a settling time for sample switch relays to stabilize after being switched. The syntax of the command that specifies this delay is:

<div align="center">

SAMPLE <u>HOLD</u> *delay*

</div>

This *delay* parameter is entered in seconds to the nearest hun-dredth.

The SAMPLE command will not finish until the delay time has expired. This holds off any further operations.

The *delay* time is the same no matter what sample number has been selected. If some samples require a longer settling time than others, additional settling time can be provided by executing the HOLD command after executing the SAMPLE command for the slower samples.

If the SAMPLE command is executed with a long delay time, you must wait for this time to elapse or abort the SAMPLE command with a DEVICE CLEAR command.

The default value of the sample switch *delay* parameter stored in the BASIC 0 parameter file is 0.0 seconds.

This appendix is reserved for options that will become available for the AH 2500A.