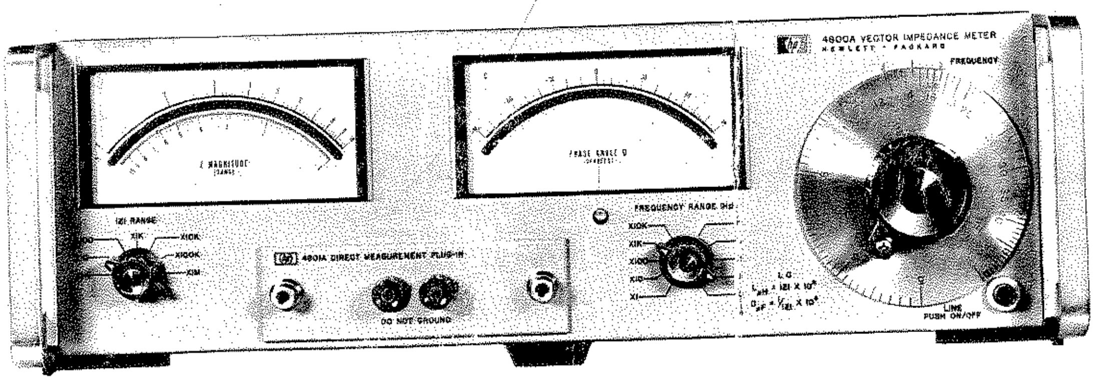
OPERATING AND SERVICE MANUAL

VECTOR IMPEDANCE METER
4800A
PLUG-IN
4801A



HEWLETT PACKARD

OPERATING AND SERVICE MANUAL

MODEL 4800A
VECTOR IMPEDANCE METER
WITH
MODEL 4801A
PLUG-IN

SERIALS PREFIXED: 816

Section VI contains information which adapts this manual to earlier Serial Numbers.

Green Pond Road Rockaway, New Jersey, U.S.A.

04800-91014 Printed: May 1968

TABLE 1-1. SPECIFICATIONS

FREQUENCY CHARACTERISTICS.

RANGE: 5 Hz to 500 kHz in five bands; 5 to 50 Hz, 50 to 500 Hz, 0.5 to 5 kHz, 5 to 50 kHz, and 50 to 500 kHz.

ACCURACY: ±4% from 5 Hz to 50 Hz, ±2% from 50 Hz to 500 kHz, ±1% at 15.92 on FREQUENCY dial from 159.2 Hz to 159.2 kHz, ±2% at 15.92 Hz.

MONITOR OUTPUT: level; 0.2 V rms minimum; source impedance: 600 ohms in series with 50 μF.

IMPEDANCE MEASUREMENT CHARACTERISTICS.

RANGE: 1 ohm to 10 megohms in seven ranges: 10 ohms, 100 ohms, 1 K ohms, 10 K ohms, 100K ohms, 1 megohm and 10 megohms full scale.

ACCURACY: ±5% of reading.

PHASE ANGLE MEASUREMENT CHARACTERISTICS.

RANGE: 0° to ±90°

ACCURACY: ±6°

CALIBRATION: increments of 5°

DIRECT INDUCTANCE MEASUREMENT CAPABILITIES.

RANGE: 1 μH to 100,000 H, direct reading at decades multiples of 15.92 Hz.

ACCURACY: ±7% of reading for Q greater than 10 from 159.2 Hz to 159.2 kHz; ±8% of reading for Q greater than 10 at 15.92 Hz.

DIRECT CAPACITANCE MEASUREMENT CAPABILITIES.

RANGE: 0.1 pF to 10,000 μF, direct reading at decade multiples of 15.92 Hz.

ACCURACY: ±7% of reading for D less than 0.1 from 159.2 Hz to 159.2 kHz, ±8% of reading for D less than 0.1 at 15.92 Hz.

MEASURING TERMINAL SIGNAL CHARACTERISTICS.

WAVESHAPE: Sinusoidal.

SIGNAL LEVEL: 2.7 mV rms 1 ohm to 1 K ohm, approx. 2.7 mV rms 1000 ohms to 10,000 ohms, approx. 27 mV rms 10,000 ohms to 100,000 ohms, approx. 270 mV rms 100,000 ohms to 1 megohm. approx. 2.7 V rms 1 megohm to 10 megohms.

EXTERNAL OSCILLATOR REQUIREMENTS.

LEVEL: 0.8 V rms ±5%

RECORDER OUTPUTS.

FREQUENCY: level; 0 to 1 volt nominal; source impedance, 0 to 1000 ohms nominal, proportional to FREQUENCY dial rotation.

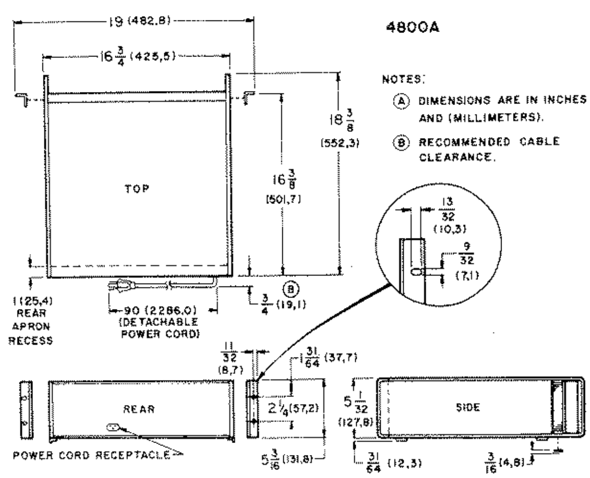
IMPEDANCE: level: 0 to 1 volt nominal; source impedance, 1000 ohms nominal.

PHASE ANGLE: level: 0 to ±0.9 volts nominal; source impedance, 1000 ohms nominal.

GENERAL.

ACCESSORIES FURNISHED: 13525A Calibration Resistor, 00610A Terminal Shield, circuit board extender, rack mounting kit.

DIMENSIONS:



WEIGHT: net 25 lbs (11.3kg), shipping 36 lbs (16.2kg).

POWER: 105 to 125 volts or 210 to 250 volts, 50 to 400 Hz, 27 w.

SECTION I
GENERAL INFORMATION

1-1. DESCRIPTION

1-2. The Model 4800A Vector Impedance Meter (Figure 1-1) is a self-contained instrument designed to measure complex impedances for a wide variety of applications. Impedance magnitude is measured from 1 ohm to 10 megohms in seven ranges and phase angle from -90 degrees to +90 degrees. The measurement frequency is adjustable from 5 Hz to 500 kHz in five ranges. Complete specifications are given in Table 1-1.

1-3. Impedance of components, complex networks, and other two-terminal devices is measured by connecting the "unknown" to the terminals of the 4801A Direct Measurement Plug-in furnished with the Vector Impedance Meter. After selecting the desired test frequency and adjusting the impedance range switch, both the impedance magnitude in ohms and phase angle in degrees are read directly on front panel meters.

1-4. The 4800A injects a signal from an internal oscillator into the "unknown" and monitors the voltage and current. In the first three impedance ranges the current is maintained at a constant level and the voltage is measured, providing a signal proportional to the impedance magnitude. In the upper four impedance ranges the voltage is maintained at a constant level and the current is measured, providing a signal inversely proportional to the impedance magnitude. A phase detector measures the phase difference between the current and voltage.

1-5. The 4800A is equipped with analog outputs for the impedance magnitude, phase angle, and frequency parameters. These outputs may be used to obtain permanent traces on a two-pen X-Y recorder. The analog outputs can also be connected to a digital voltmeter for a high resolution digital readout with excellent repeatability.

1-6. ACCESSORIES FURNISHED

1-7. An -hp- 00610A Terminal Shield (Figure 1-2) is supplied with the 4800A to reduce terminal capacitance by a factor of one hundred below unshielded terminal capacitance. An -hp- 13525A Calibration Resistor (Figure 1-3) is supplied to provide a convenient check of impedance measurement accuracy. In addition, an -hp- 5060-0775 Rack Mounting Kit and -hp- 5060-0049 Circuit Board Extender are also supplied.

1-8. INSTRUMENT IDENTIFICATION

1-9. Each Model 4800A carries a two-section, eight-digit serial number (000-00000) which is stamped on a plate fastened to the rear panel. The five-digit number is an identification unique to each

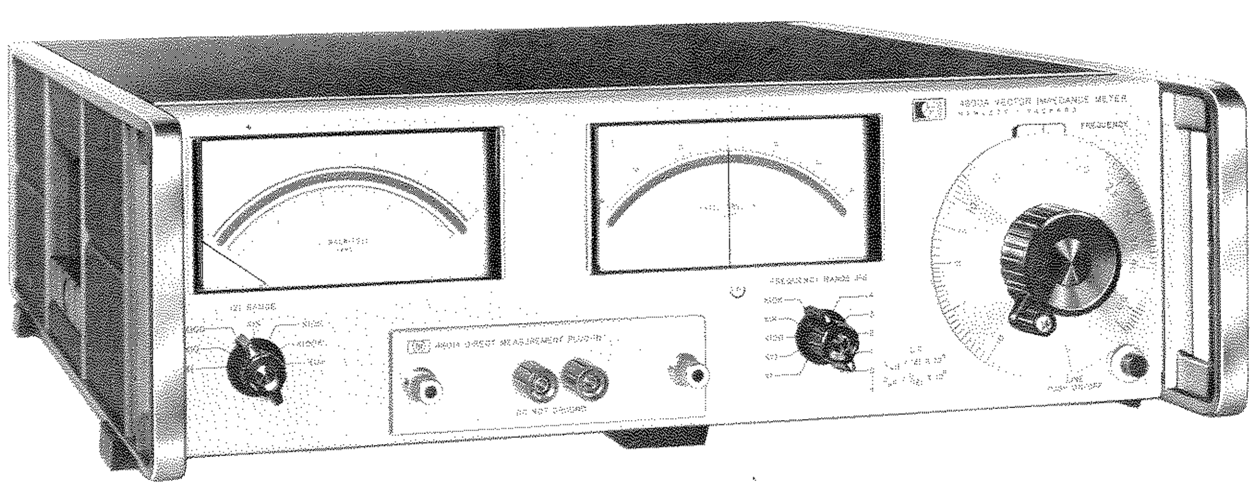


Figure 1-1. Model 4800A Vector Impedance Meter

instrument, and the three-digit number is a serial prefix used to document instrument revisions.

1-10. When the SERIALS PREFIXED number on the title page of this manual is the same as the first three digits of the instrument serial number, the manual applies directly to the instrument. A change sheet will be included with the manual for newer instruments having a higher serial prefix than shown on the title page. If a change sheet is missing, it can be supplied by any Hewlett-Packard Sales and Service Office listed at the back of this manual.

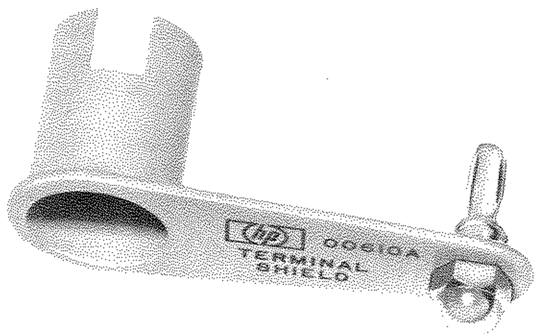


Figure 1-2. 00610A Terminal Shield

Figure 1-3. 13525A Calibration Resistor

SECTION II
INSTALLATION

2-1. INITIAL INSPECTION

2-2. MECHANICAL CHECK. If damage to the shipping carton is evident, ask that the carrier's agent be present when the instrument is unpacked. Inspect the instrument for scratches, dents, broken knobs and switches, and any other mechanical damage. Also check the cushioning material for signs of severe stress as an indication of rough handling in transit.

2-3. PERFORMANCE CHECK. The electrical performance of the 4800A should be verified as soon as possible after receipt. A performance check that is suitable for initial inspection is contained in Section V.

2-4. CLAIM FOR DAMAGE. If, upon receipt, the 4800A is damaged or fails to meet performance specifications, notify the carrier and the nearest Hewlett-Packard Sales and Service Office immediately (A list of offices is provided at the back of this manual). Retain the shipping carton and padding material for the carrier's inspection. The sales and service office will arrange for the repair or replacement of the instrument without waiting for the claim against the carrier to be settled.

2-5. PREPARATION FOR USE

2-6. POWER REQUIREMENTS

2-7. The 4800A requires a power source of 105 to 125 V or 210 to 250 V, 50 to 400 Hz, which can supply approximately 27 watts.

2-8. 115/230 VOLT OPERATION

2-9. A two-position slide switch, located on the rear panel, permits operation from either a 115 or 230 volt power source. Before connecting the 4800A to the power source, check that the number visible on the slide switch matches the nominal line voltage of the source. If required, slide the switch to the other position using a thin-bladed screwdriver.

2-10. When the instrument leaves the factory, the proper fuse is installed for 115-volt operation. An envelope containing a fuse for 230-volt operation is attached to the front handle. Markings on the rear panel adjacent to the fuse holder indicate the correct fuse rating for operation from either power source. Make sure that the correct fuse is installed if the position of the slide switch is changed.

2-11. POWER CABLE

2-12. To protect operating personnel, the National Electrical Manufacturers' Association (NEMA) recommends that instrument panels and cabinets be grounded. The 4800A is equipped with a detachable, three-conductor power cable which, when plugged into an appropriate receptacle, grounds the panel and cabinet of the instrument. The offset pin on the power cable three-prong connector is the ground pin.

2-13. To preserve the protective feature when operating the instrument from a two-contact outlet, use a three-prong adapter (-hp- Stock No. 1251-0048) and connect the green pigtail on the adapter to ground.

2-14. COOLING

2-15. During operation of the 4800A, the temperature of the surrounding air should not exceed 55°C (131°F). Clearance at the rear and sides of the cabinet should be provided to maintain adequate cooling. The clearances provided by the plastic feet in bench stacking and the filler strips used in rack mounting are adequate for the top and bottom cabinet surfaces.

2-16. BENCH OPERATION

2-17. The 4800A has plastic feet which provide clearance for air circulation beneath the instrument during bench operation. The feet are also designed to make all full width -hp- modular cabinet instruments, such as the 4800A, self-aligning when stacked. In addition, a fold-away tilt stand is provided which permits inclining the instrument for ease in adjusting controls.

2-18. RACK MOUNTING

2-19. The 4800A can be modified for rack mounting by removing the plastic feet and tilt stand from the bottom, and by adding a filler strip and two rack mounting flanges to the front panel. These parts and the attaching hardware are contained in the rack mounting kit (-hp- Stock No. 5060-0775) which is furnished with the instrument. The kit and installation instruments are shown in Figure 2-1.

2-20. REPACKAGING FOR RESHIPMENT

2-21. The original shipping carton and packing material should be used for repackaging. A Hewlett-Packard Sales and Service Office will provide information and recommendations on materials to be used if the original packaging materials are not available or reusable.

The packaging materials should include the following:

- a double-walled carton

- heavy paper or cardboard to protect all instrument surfaces

- extra material around projecting parts of instrument

- at least four inches of tightly-packed shock-absorbing material surrounding the instrument

- durable shipping tape to securely seal the carton

NOTE

If the instrument is to be shipped to a Hewlett-Packard Sales and Service Office, attach a tag showing owner, model number, complete serial number, and repairs required. Mark the shipping container FRAGILE to ensure careful handling. In any correspondence, refer to the instrument by model number and full serial number.

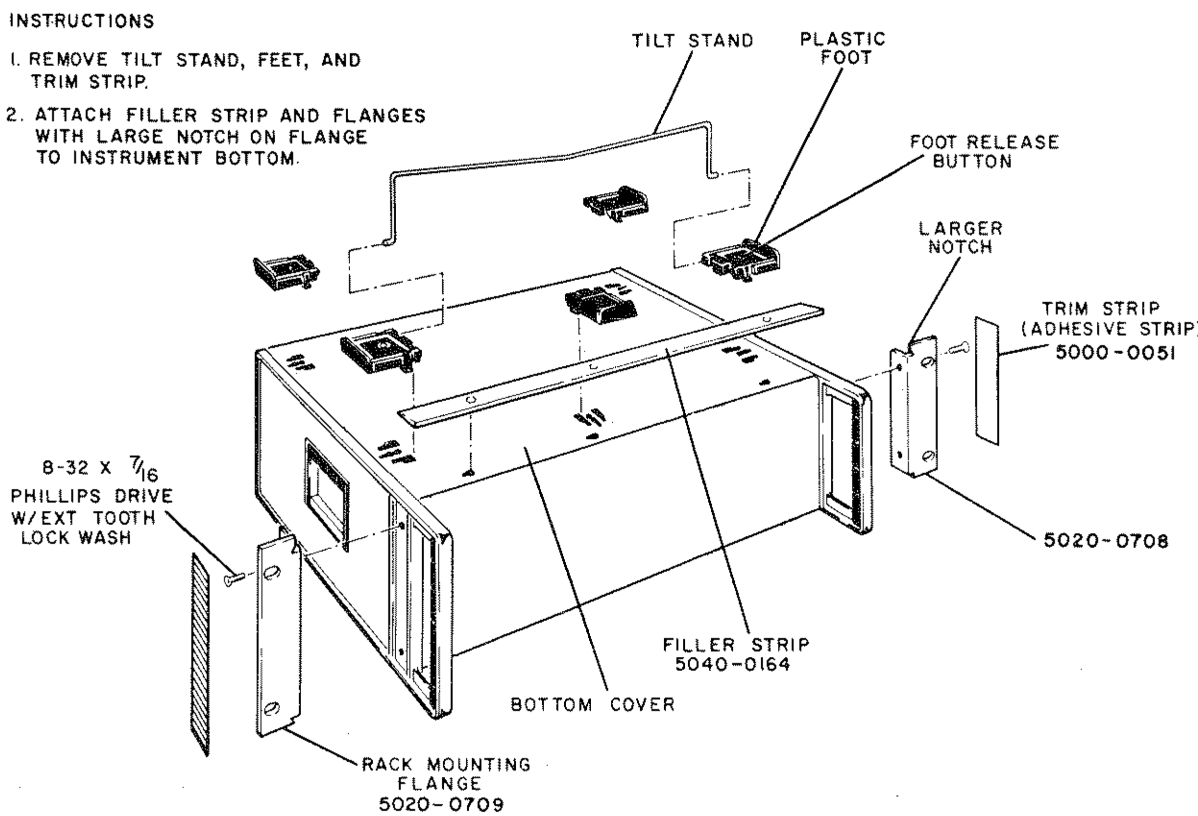


Figure 2-1. Rack Mounting Installation Diagram

SECTION III
OPERATION

3-1. INTRODUCTION

3-2. The 4800A Vector Impedance Meter measures impedance directly by injecting a signal into the "unknown" and comparing the ratio of voltage to current. Depending on the impedance range, either the voltage or current is held constant by an automatic leveling control circuit (ALC). Impedance is directly proportional to voltage with the current held constant, and inversely proportional to current with the voltage held constant. Phase angle is measured by comparing the phase relationship between the voltage and current waveforms. Impedance magnitude is measured from 1 ohm to 10 megohms in seven decade ranges; phase angle is indicated from -90 degrees to +90 degrees.

3-3. The Z MAGNITUDE meter has two scales: a direct-reading black scale used with the black engraved Z RANGE positions X1, X10, and X100, and an inverse-reading red scale used with the red engraved Z RANGE positions X1K, X10K, X100K, and X1M. An off-scale reading to the right, with the Z RANGE switch at a black engraved position, indicates the range is too low and the switch should be advanced clockwise. An off-scale reading to the right, with the Z RANGE switch at a red engraved position, indicates the range is too high and the switch should be turned counterclockwise.

NOTE

> After changing ranges, allow a few seconds for circuits to return from an overload condition; if pointer does not indicate on scale, change to the next range.

3-4. The analog outputs on the rear panel provide dc voltages proportional to Z MAGNITUDE meter deflection, PHASE ANGLE meter deflection, and FREQUENCY dial rotation.

3-5. OPERATING CONTROLS

3-6. Figures 3-1 and 3-2 identify and briefly describes the purpose of each panel control, switch, and connector.

3-7. SLIDERULE CALCULATOR

3-8. A slide rule calculator has been included with this manual to simplify the more common conversions and calculations that arise with impedance measurements. One side of the slide rule is a Vector Impedance Calculator that resolves the impedance vector Z into its resistive and reactive components. The other side of the slide rule is a Capacitance-Inductance Reactance Calculator that is especially useful for solving resonant frequency problems. The calculator may also be used as a scale factor "nomograph" when direct-reading component measurements are being made with the 4800A (see Paragraph 3-10). The simple instructions necessary to use the calculators are printed on the slide rule.

3-9. MEASUREMENT PROCEDURES

3-10. MEASURING L AND C

3-11. The 4800A provides readings in capacitance and inductance when the FREQUENCY dial is set to the "LC" mark (15.92). Thus, at the frequencies 15.92 Hz, 159.2 Hz, 1.592 kHz, and 159.2 kHz, readings on the Z MAGNITUDE meter scales can be converted to microfarads or microhenries using the "LC" formulas engraved on the front panel, and components may be measured directly. Table 3-1 gives the scale factors that apply when the 4800A is operated in this mode.

Example 1: A coil indicating 800 ohms on the Z MAGNITUDE meter with the FREQUENCY RANGE switch set to X10 (n = 3), has a value of:

$$L_{\mu H} = Z \times 10^n$$

$$L_{\mu H} = 800 \times 10^3$$

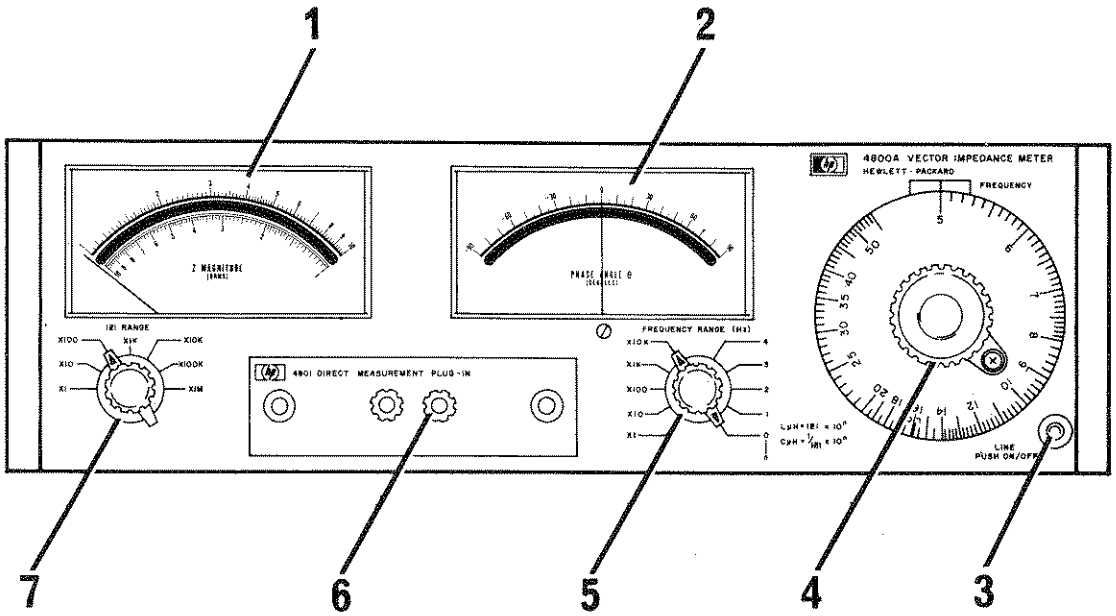
$$L = 0.8 \text{ H}$$

Example 2: A capacitor indicating 30 K ohms on the Z MAGNITUDE meter with the FREQUENCY RANGE switch set to X1K (n = 1), has a value of:

$$C_{\mu F} = \frac{1}{Z} \times 10^n$$

$$C_{\mu F} = \frac{1}{30 \text{ K}} = 10^1$$

$$C = 333 \text{ pF}$$



1. Z MAGNITUDE (OHMS) Meter - indicates impedance magnitude on two scales; a direct-reading black scale used with Z RANGE positions X1, X10, and X100, and an inverse-reading red scale used with Z RANGE positions X1K, X10K, X100K, and X1M.

2. PHASE ANGLE (DEGREES) Meter - indicates impedance phase angle from -90 degrees to +90 degrees.

3. LINE PUSH ON/OFF Switch - combination line power switch and power on indicator; push-button glows when line power is applied.

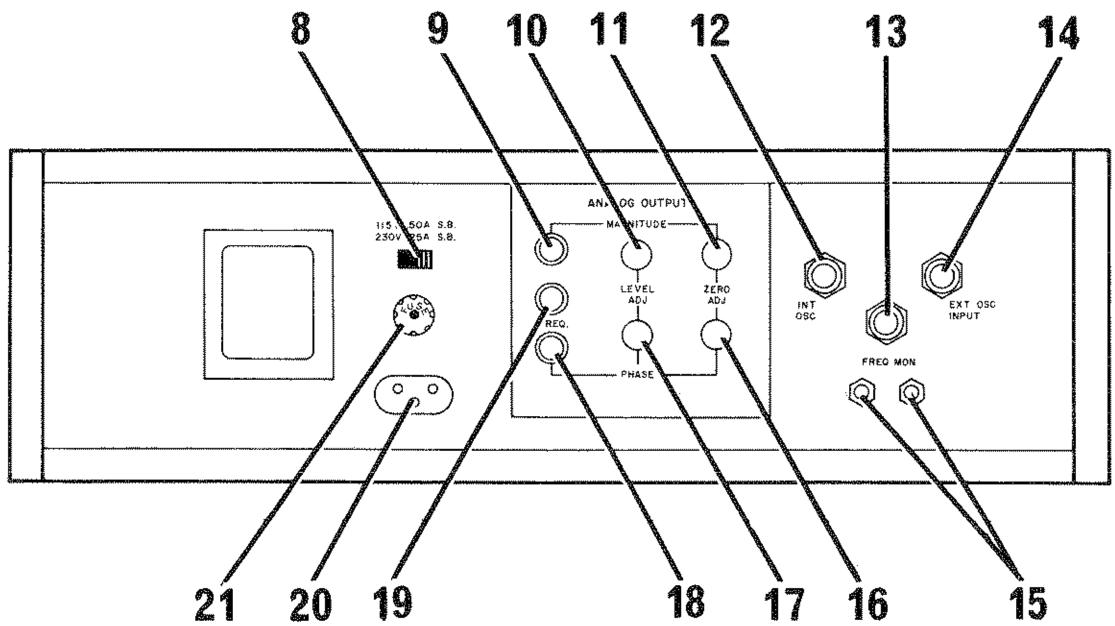
4. FREQUENCY Control - selects test frequency from five available ranges. When dial is set at "LC" mark(15.92), impedance scales on Z MAGNITUDE meter are calibrated in microhenries or microfarads and components may be measured directly.

5. FREQUENCY RANGE (Hz) Switch - selects one of five available test frequency ranges: X1, X10, X100, X1K, and X10K. Switch also indicates exponent (0-4) required to compute "LC" formulas.

6. Measuring Terminals - ungrounded terminals used to connect component to be tested.

7. Z RANGE Switch - selects one of seven available impedance magnitude ranges.

Figure 3-1. 4800A Front Panel Operating Controls



8. 115/230 V Slide Switch - matches instrument to nominal line voltage.

9. MAGNITUDE - ANALOG OUTPUT Connector - dc output (0 to 1 V nominal) proportional to Z MAGNITUDE meter deflection. Source impedance for analog voltage is 1 K ohms.

10. MAGNITUDE - LEVEL ADJ - adjusts X-Y plot at full scale deflection of Z MAGNITUDE meter (1 V nominal).

11. MAGNITUDE - ZERO ADJ - adjusts X-Y plot at 1/10 full scale deflection of Z MAGNITUDE meter (0.1 V nominal).

12. INT OSC Connector - output of internal test oscillator.

13. FREQ MON Connector - output of internal test oscillator for counter readout.

14. EXT OSC INPUT Connector - for application of external test oscillator. Input requirements are 0.8 V ±5% into 20 K ohms.

15. Banana jacks for storing 13525A Calibration Resistor.

16. PHASE - ZERO ADJ - adjusts X-Y plot at zero degree deflection of PHASE ANGLE meter.

17. PHASE - LEVEL ADJ - adjusts X-Y plot at +90 degree deflection of PHASE ANGLE meter.

18. PHASE - ANALOG OUTPUT Connector - dc output (0 to ± 0.9 V nominal) proportional to PHASE ANGLE meter deflection. Source impedance for analog voltage is 1 K ohms.

19. FREQ-ANALOG OUTPUT Connector - dc output (0 to 1 V nominal) proportional to FREQUENCY control rotation.

20. Power Connector - provides for connection of ac power line.

21. Line Fuse - correct fuse rating is indicated on rear panel.

Figure 3-2. 4800A Rear Panel Operating Controls

Table 3-1. Scale Factors for Direct LC Measurements

Z Range	Direct Reading C Range	Direct Reading L Range
X1	10 μF to 100 μF	100 μH to 1 mH
X10	1 μF to 10 μF	1 mH to 10 mH
X100	0.1 μF to 1 μF	10 mH to 100 mH
X1K	0.01 μF to 0.1 μF	100 mH to 1 H
X10K	1000 pF to 0.01 μF	1 H to 10 H
X100K	100 pF to 1000 pF	10 H to 100 H
X1M	10 pF to 100 pF	

3-12. MEASUREMENTS INVOLVING DC BIAS

3-13. If it is necessary to make impedance measurements in the presence of dc bias, a blocking capacitor must be used to isolate the dc from the 4800A. The impedance of the capacitor must be small compared to that of the device under test. This can be verified with the 4800A. Since the dc bias supply appears in parallel with the unknown, the impedance of this portion of the circuit must be high with relation to the unknown. If this condition cannot be achieved, the bias supply impedance will reduce the impedance of the unknown. This reading can be corrected, however, by making a separate measurement of the bias supply impedance and then correcting the data. The bias supply must be ungrounded unless the regulating resistor is very large. A large resistor with a grounded supply will isolate the 4800A test signal from ground.

3-14. TRANSFORMER MEASUREMENTS

3-15. The 4800A has the capability to quickly characterize transformers by providing a plot of vector impedance as a function of frequency. Measurements that can be made include the primary inductance, primary resistance, secondary inductance, secondary resistance, and turns ratio.

3-16. MEASUREMENTS WITH AC OR NOISE SIGNALS PRESENT

3-17. Measurements with external ac or noise signals present require the use of careful techniques. The impedance measuring circuits of the 4800A may amplify an unwanted signal to the same order of magnitude as the internal test signal. This situation will result in a completely spurious impedance reading. The condition is generally easy to recognize, however, since it will become difficult to obtain a stable on-scale reading of either impedance or phase, or both. To help eliminate interference from unwanted signals, bandpass filtering is used for each frequency range. Interference can sometimes be effectively filtered by choosing a frequency two decades away from the unwanted signal. In measurements where interfering noise is likely, such as with antennas, electrical isolation is often necessary. In addition, devices which have the property of converting some other parameter to electrical energy must be isolated from excitation. For instance, a piezoelectric transducer will have to be isolated from mechanical vibration to prevent the generation of unwanted signals.

3-18. ANALOG OUTPUT MEASUREMENTS

3-19. The 4800A analog outputs may be used to drive the -hp- Model 136A Two-Pen X-Y Recorder. This will provide a continuous record of impedance and phase as a function of various parameters, such as frequency or bias current. Paragraphs 3-20 through 3-22 describe the analog output adjustment procedures for X-Y recording. The analog outputs may also be connected to an -hp- Model 3440A Digital Voltmeter, providing a digital readout for greater resolution. In addition, an ideal go-no-go impedance checkout system can be obtained by combining the 4800A with the -hp- Model 3434A Comparator.

3-20. FREQUENCY ANALOG OUTPUT. To calibrate the X-axis of an X-Y recorder to a given dial frequency, proceed as follows:

NOTE

The FREQ ANALOG OUTPUT has no exact mathematical relationship to the frequency dial but it is approximately logarithmic.

a. Connect FREQ output to the recorder X-axis input.

b. With recorder pens raised, rotate 4800A FREQUENCY dial from "5" to "50" and mark desired frequency points on the recorder paper.

NOTE

Once this frequency calibration has been accomplished, it need not be repeated for subsequent plots. The original calibration may be transferred from one plot to the next.

3-21. MAGNITUDE ANALOG OUTPUT. This procedure adjusts the MAGNITUDE ZERO ADJ and LEVEL ADJ for proper X-Y recorder operation. Proceed as follows:

a. Set 4800A controls as follows:

Z RANGE	X10
FREQUENCY RANGE	X1K
FREQUENCY dial	"LC" (15.92)

b. Connect dc voltmeter to MAGNITUDE output and a 0.1 uF capacitor to measurement terminals.

c. Adjust FREQUENCY dial for a reading of 10.0 on the Z MAGNITUDE meter black scale.

d. Adjust MAGNITUDE LEVEL ADJ for 1.0 V on voltmeter.

e. Change Z RANGE to X100.

f. Adjust FREQUENCY dial for a reading of 1.0 on the Z MAGNITUDE meter black scale.

g. Adjust MAGNITUDE ZERO ADJ for 0.1 V on voltmeter; due to interaction between controls, this procedure must be repeated until desired accuracy is achieved.

NOTE

The MAGNITUDE output voltage is directly proportional to readings on the black meter scale ranges and inversely proportional to readings on the red meter scale ranges.

3-22. PHASE ANALOG OUTPUT. This procedure adjusts the PHASE LEVEL ADJ and ZERO ADJ for proper X-Y recorder operation. Proceed as follows:

a. Set 4800A controls as follows:

Z RANGE	X1K
FREQUENCY RANGE	X100
FREQUENCY dial	"LC" (15.92)

b. Connect dc voltmeter to PHASE output and 1 KΩ Calibration resistor to measurement terminals.

c. Adjust PHASE ZERO ADJ for O V on voltmeter.

d. Connect a 0.1 μF capacitor to measurement terminals.

e. Adjust PHASE LEVEL ADJ for -0.9 V on voltmeter; due to interaction between controls, this procedure must be repeated until desired accuracy is achieved.

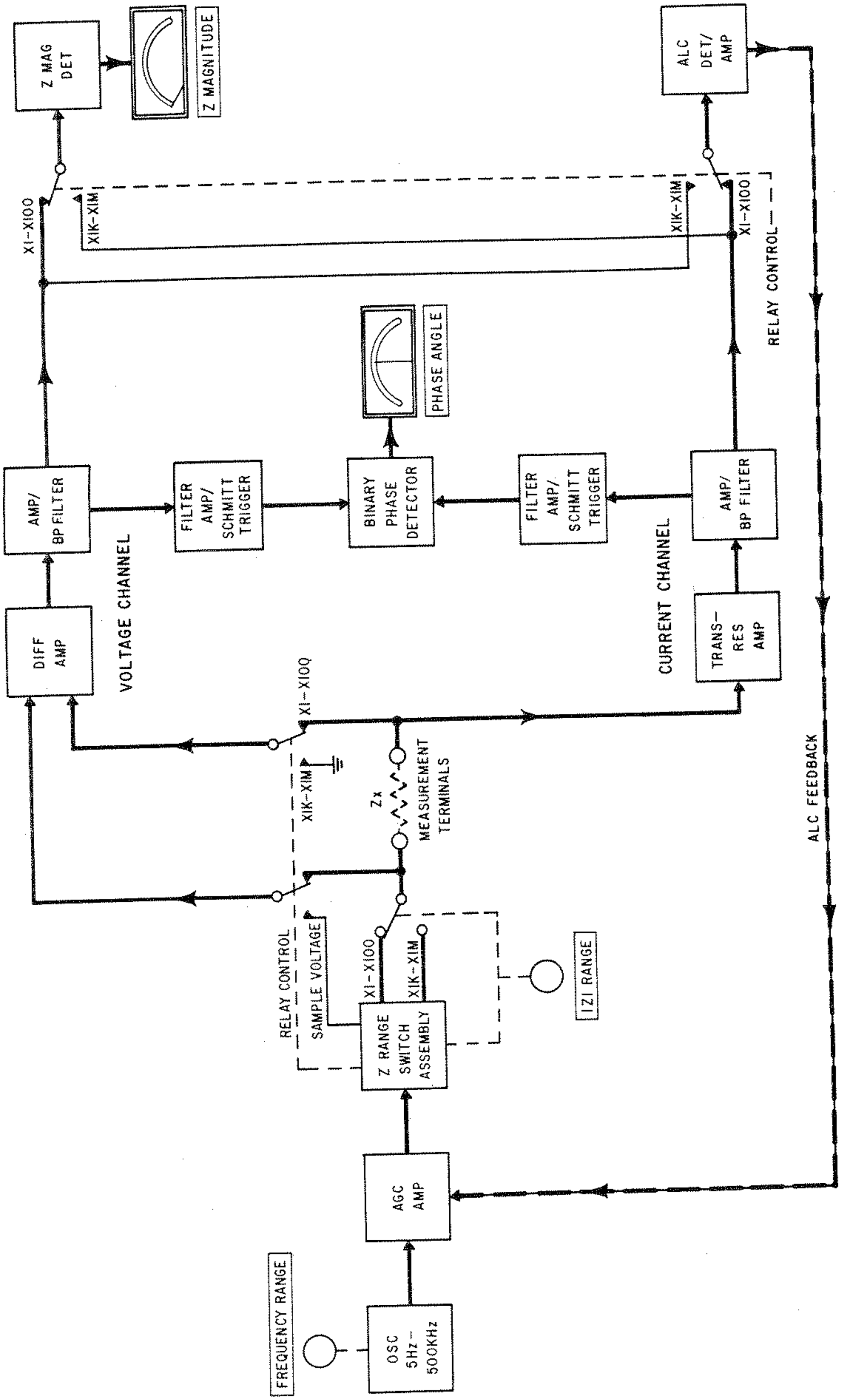


Figure 4-1. 4800A Block Diagram

SECTION IV
PRINCIPLES OF OPERATION

4-1. INTRODUCTION

4-2. The 4800A Vector Impedance Meter measures impedance magnitude and phase angle of passive components and networks over an adjustable frequency range of 5 Hz to 500 kHz. Impedances up to 1 K ohms are measured by passing a predetermined constant current through the "unknown" and measuring the voltage across it; this voltage is proportional to impedance magnitude. Impedances between 1 K ohms and 10 megohms are measured by applying a predetermined constant voltage across the "unknown" and measuring the current through it; this current is inversely proportional to impedance magnitude. Phase angle measurements are obtained by comparing the relative phase between the voltage and current by means of a phase detector.

4-3. The following paragraphs describe, at a block diagram level, the overall relationship between the major functional groups of the 4800A. Detailed descriptions of the individual circuits are provided in Section VII by means of text overlays adjacent to corresponding schematics.

4-4. OVERALL DESCRIPTION

4-5. A simplified block diagram (Figure 4-1) illustrates 4800A operation in the first three decade ranges of the Z RANGE switch. In these ranges a constant current is applied to the "unknown" at the measurement terminals, and the voltage across the "unknown" is measured.

4-6. An oscillator provides a test signal within the frequency range of 5 Hz to 500 kHz, as determined by the FREQUENCY RANGE switch and FREQUENCY dial, to an AGC amplifier. The AGC amplifier holds the signal current through the Z RANGE switch and the "unknown" at a constant level by means of an ALC feedback loop. This current is applied to a transresistance amplifier which provides an output voltage proportional to the current flowing in the "unknown". The voltage is amplified, filtered, and forwarded through relay contacts to an ALC amplifier/detector. A detected leveling signal is then fed back to the AGC amplifier.

4-7. In the first three impedance ranges the voltage across the "unknown" is applied to a differential amplifier through two sets of relay contacts. The output of the differential amplifier is amplified, filtered, and forwarded through relay contacts to a Z magnitude detector. Output from the detector is proportional to the impedance of the "unknown" which is indicated on the Z MAGNITUDE meter.

4-8. When the 4800A is operated in the upper four ranges of the Z RANGE switch, the relay contacts switch to their alternate positions, and the voltage is held constant while the current through the "unknown" is measured. This current is applied to the Z magnitude detector through relay contacts. Output from the detector is inversely proportional to the impedance of the "unknown" which is indicated on the Z MAGNITUDE meter.

4-9. The voltage is maintained at a constant level during 4800A operation in the higher impedance ranges by a sample voltage that is applied to the differential amplifier. The output of the amplifier is forwarded through relay contacts to the ALC detector/amplifier. A detected leveling signal is then fed back to the AGC amplifier.

4-10. Phase angle is measured the same way in both the constant current and constant voltage modes of operation. Signals from the current and voltage channels are filtered to improve signal-to-noise ratio and then converted to pulses in Schmitt trigger circuits (zero-crossing detectors). The output pulses from the Schmitt triggers drive a binary phase detector, which provides an output voltage proportional to the phase difference between the two channels. A zero-center PHASE ANGLE meter reads this voltage as phase angle in degrees.