Model 1502

Thermometer
User Manual

HART
SCIENTIFIC

Rev. 27292

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1 Instrument Description

The Hart Model 1502 is a low cost high accuracy digital thermometer. Its unique combination of features makes it suitable for a wide variety of applications from laboratory measurement to industrial processes. Features of the 1502 include:

- Light weight, small and portable
- Handsome, sturdy construction
- wide range, 200°C to 850°C
- better than ±0.05°C accuracy
- Resolution of 0.001 degree (0.01 above approx. 150°C)
- Programmable probe constants: standard constants R_0, ALPHA; IPTS-68 constants R_0, ALPHA, DELTA, A_4, C_4: ITS-90 constants R(273), A_7, B_7, C_7, A_4, B_4
- IPTS-68 to ITS-90 temperature scale conversion
- Battery backup for programmed data
- Single keystroke selects display units: °C, °F, °K, or resistance in ohms
- Large bright green 8-digit LED display
- Serial RS232 communications
- Optional IEEE488 communications
- Detachable, interchangeable power cord
- 230 VAC operation available

The 1502 thermometer is designed to be used with a 4wire 100 ohm platinum probe which connects to the back of the thermometer with a common 5 pin DIN plug. The 1502 may be programmed with the calibration constants of the probe for optimum accuracy.

The 1502 is built using the latest technology in digital and analog electronics. The digital temperature measurement and display functions and the programming operations are controlled by an 8bit microcontroller. The speed and power of the microcontroller are well suited for the complex algorithms which convert the probe resistance measurements to a temperature value using the programmed probe parameters. A batterybacked RAM chip allows the programming information to be retained even after the power is switched off.

The analog portion of the 1502 electronic circuits performs the function of measuring the resistance of the temperature probe with high accuracy. A constant DC current source supplies a small current of 1 mA. to the probe sensor minimizing the self-heating error. The voltage on the sensor is amplified by a variable-gain amplifier with compensation for probe lead resistance. An analog-to-digital converter (ADC) device converts the amplified voltage signal to a digital code with 18 bits of resolution.

The 1502 was designed and manufactured for high reliability and long lasting trouble free operation. It uses the latest in precision integrated circuits and components and is carefully assembled, calibrated, and tested by experienced technicians.

2 Warranty and Specifications

2.1 Warranty

Hart Scientific, Inc. warrants each of its products to be free from defects in material and workmanship. Our obligation under this warranty is to repair or replace any instrument or part thereof which, within 3 years after shipment, proves defective upon examination. We will pay local domestic surface freight costs.

To exercise this warranty, write or call Hart Scientific. You will be given prompt assistance and shipping instructions.

2.2 Specifications

Measurement resistance range	0Ω to 150Ω, 140Ω to 400Ω (autoranging)
Probe type	100Ω nominal, 4-wire
Measurement temperature range	Calendar-Van Dusen equation, -200°C to 850°C IPTS-68 equation, -183°C to 630°C ITS-90 equation, -189°C to 660°C
Measurement resolution	below 100°C, 0.001°C above 100°C, 0.01°C
Accuracy	0.02°C typical 0.05°C maximum
Repeatability	0.01°C typical 0.02°C maximum
Stability	0.03°C/yr
Ambient drift	0.0005°C/°C typical
Lead compensation	0.008°C/Ω typical
Measurement current	1.25 mA
Operating range	0°C to 60°C
Temperature conversion	Calendar-Van Dusen: R0, ALPHA, DELTA, BETA IPTS-68: R_0, ALPHA, DELTA, A_4, C_4 ITS-90: R(273), A_7, B_7, C_7, A_4, B_4
Display units	°C, °F, K, Ω
Digital filter	1-pole, programmable time constant, 0.05°C reset threshold
Communications	RS-232 (DB9 connector), IEEE-488 (optional)
Probe connection	5-pin 240° DIN
Power	105 to 130 V AC, 50-60 Hz. (230 V AC optional)
Size	2.7" H x 6.5" W x 8.8" D
Weight	3.25 lbs.
Storage temperature	-20°C to 70°C

Table 1. Specifications

3 Description of Parts

The various parts of the 1502 Thermometer are described below.

1. Power connector

At the back of the thermometer is the power connector. The detachable power cord provided connects to the thermometer here. The cord should be plugged into the mains supply of the appropriate voltage. Additional or special power cords are available from Hart Scientific.

2. Power switch

The power switch for the thermometer is also located at the back. A 1/4 amp internal fuse provides protection in the unlikely event of circuit component failure.

3. Probe connector

On the back of the thermometer is the connector where the probe plugs in. This is a common 5pin DIN socket. Plug the thermometer in carefully observing the correct orientation and without using excessive force. DIN plugs for the user's own probes may be supplied by Hart Scientific. Wiring for the probe is shown in the appendix.

4. Serial connector

Located on the back of the thermometer is a 9pin D connector for interface to a RS232 communication device such as a computer or terminal.

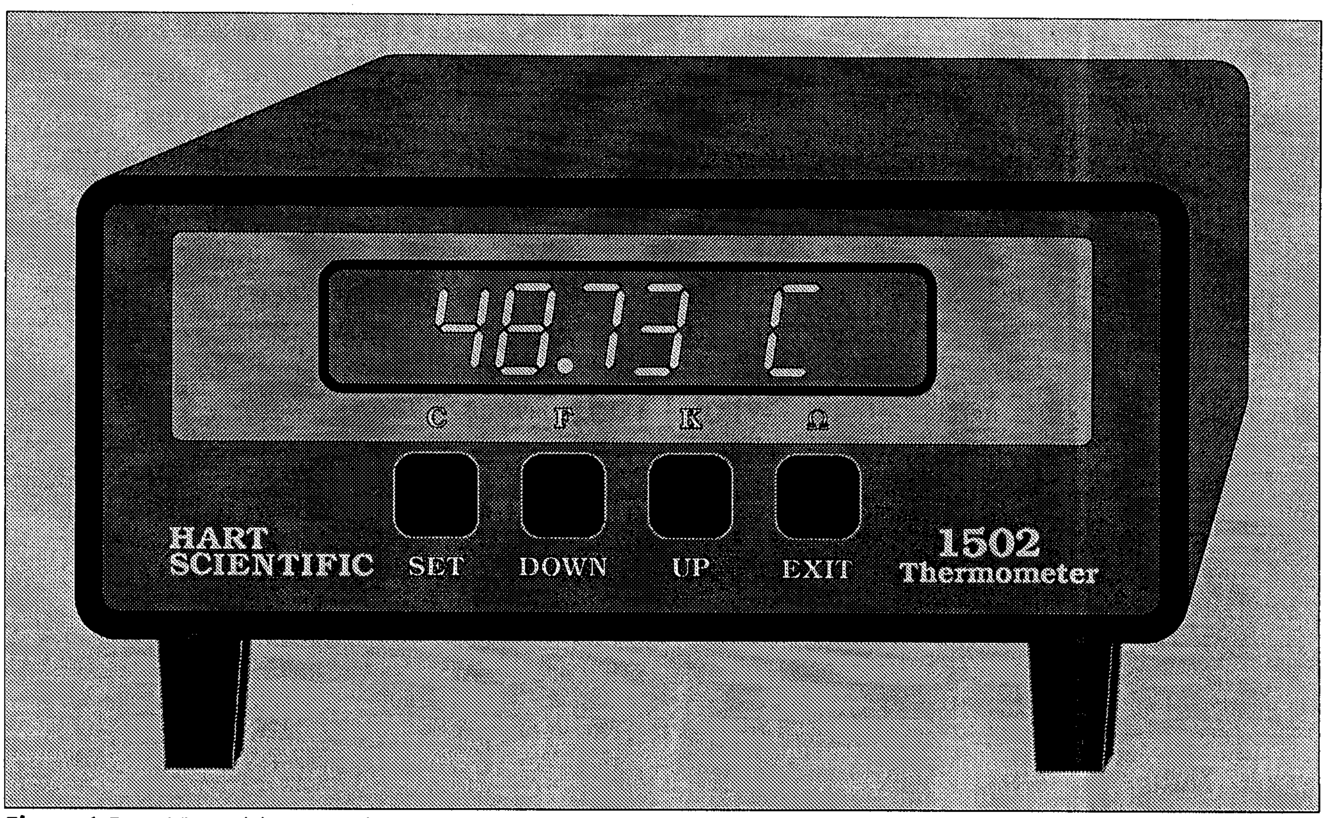

Figure 1 Front View of the 1502 Thermometer.

5. IEEE488 connector (optional)

Above the serial connector at the back of the thermometer is located the IEEE488 connector when the interface is provided as an option.

6. Rear label

On the rear panel is located the serial number of the thermometer. Also noted is the nominal power supply voltage at which the thermometer was configured at the factory to operate. If the user sets the thermometer to operate at a different voltage, then the new voltage should be written here instead.

7. LED display

On the front panel is the 8digit LED display. Normally this displays the probe temperature. The display is also used in programming to view and edit the probe constants or other parameters.

8. Control keys

On the front panel are four buttons marked "C"/"SET", "F"/"DOWN", "K"/"UP", and "Ω"/"EXIT". The "C", "F", "K", and "Ω" buttons are used to select the display units degrees C, F, K, or resistance in ohms. The "DOWN" and "UP" buttons are also used in programming to decrement or increment the values of parameters. "SET" is used to select parameters to program and to enter the values of parameters. "EXIT" is used to skip parameters and to return to the temperature display function.

9. Feet

Underneath the thermometer are two folding feet. They may be folded down to raise the front of the thermometer for better viewing.

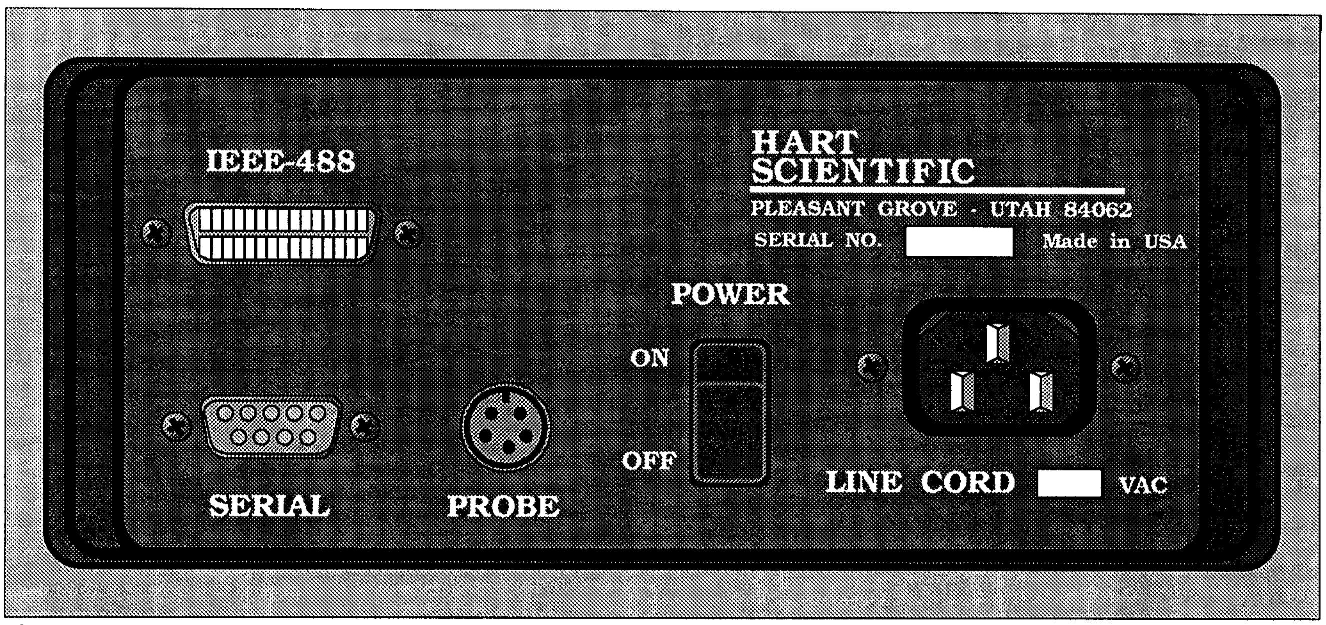

Figure 2 Rear Panel of the 1502 Thermometer.

4 Operation

4.1 Probe

The PRT probe is plugged into the DIN socket labeled "PROBE" at the back of the thermometer. The probe should have a platinum type sensor with a nominal resistance of 100 ohms. Probes of various styles and grades are available from Hart Scientific. DIN connectors are also available upon request for use with the customer's own probes. Refer to appendix A (Section 7) for proper probe wiring. For best accuracy a 4wire probe should be used. Plug the probe in gently, carefully observing the correct orientation of the connector pins.

***CAUTION** The precision probes used with the 1502 thermometer are delicate. Handle the probes with care. Do not allow probes to be knocked, bent, or stressed. Rough handling may cause damage to the probe resulting in loss of accuracy or failure.*

4.2 Power

Connect the thermometer to a power source of voltage within 10% of the nominal voltage specified on the back of the thermometer. Normally this will be 115 V AC (50/60 Hz). Use the power cord provided with the instrument. Flip the power switch at the back of the thermometer to the "ON" position. The thermometer will power up and begin to display the temperature or resistance of the probe depending on the units chosen.

4.3 Selecting display units

The 1502 thermometer is able to display temperatures in units of degrees Celsius (C), Fahrenheit (F), and Kelvin (K, indicated on the display by "A") or resistance in ohms (Ω, indicated on the display by "o"). The units are switched by simply pressing the appropriately marked button. The units may also be selected via the serial or IEEE488 interfaces.

4.4 Thermometer programming

Before accurate measurements can be made with the 1502 thermometer the instrument may require a small amount of software setup and programming. Data must be entered in which describes the characteristics of the probe used by means of numeric probe parameters. The user may desire to optimize performance of the instrument by adjusting the digital filter parameter. If the serial or IEEE488 digital interfaces are

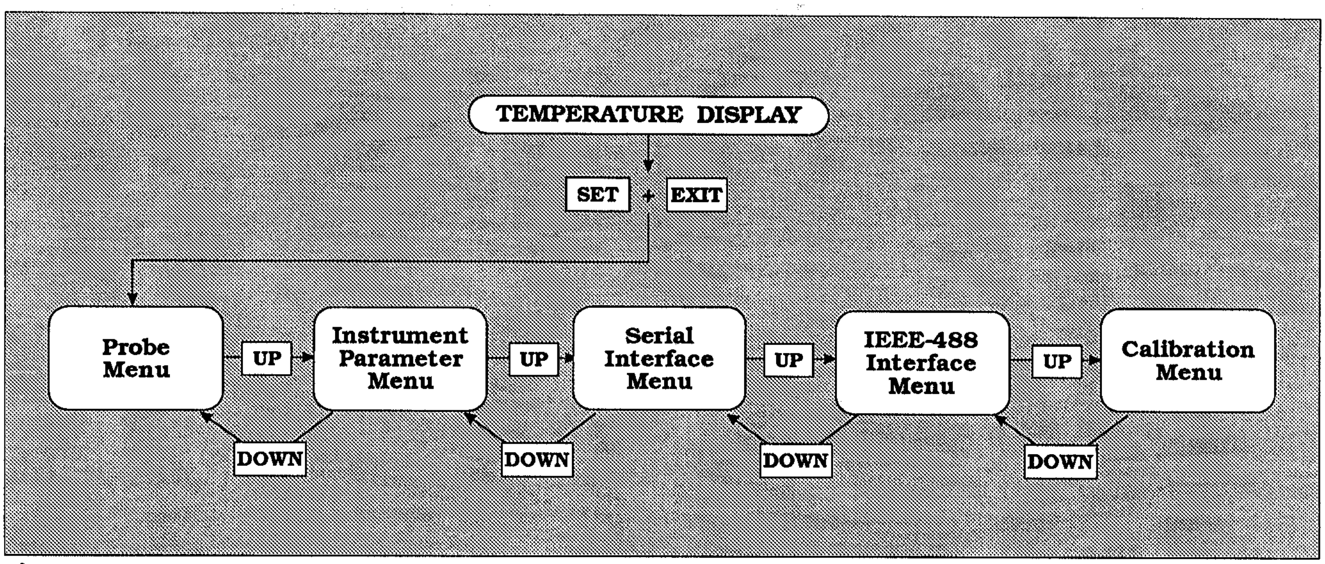

Figure 3 Parameter Menus

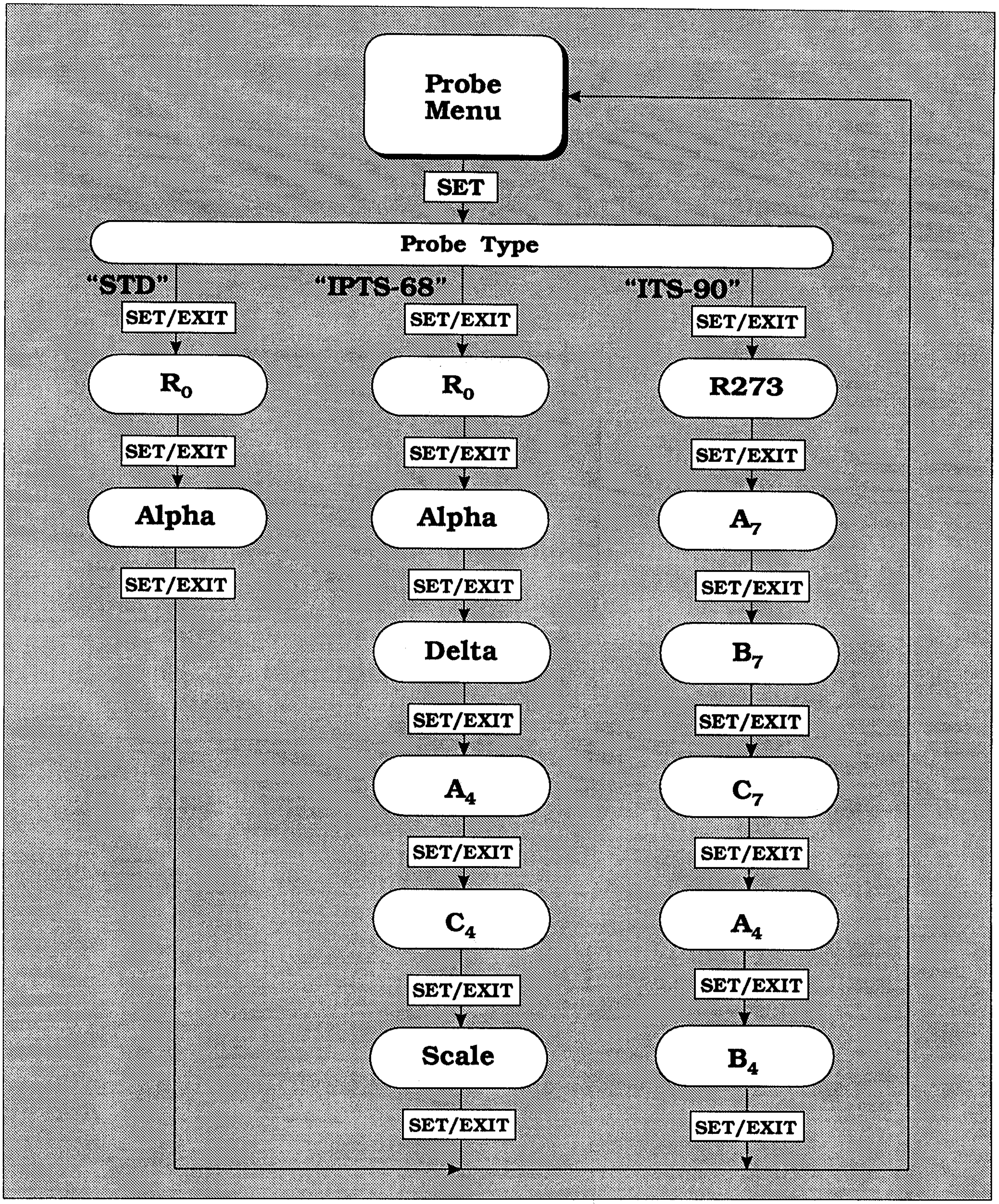

Figure 4 Probe Menu

used these may need to be configured. Also programmable are the thermometer calibration constants. Setup and programming may be done via either the front panel buttons, the serial interface, or the IEEE488 interface. The remainder of this chapter describes the programming functions in detail along with programming operations via the front panel buttons. For information on programming via either of the digital interfaces consult Chapter 5.

The programming functions are accessed within five parameter menus in the programming mode. Each of the menus contain one or more related functions and parameters. The five menus contain, 1) probe parameters, 2) instrument parameters, 3) serial interface parameters, 4) IEEE488 interface parameters (optional), and 5) calibration parameters.

The programming mode and the parameter menus are accessed by pressing the "SET" and "EXIT" buttons simultaneously and then releasing. Then choose the parameter menu desired. The default menu is the probe parameter menu indicated with " PrObE ". Press "UP" to skip this menu and move to the next menu and so on until the display indicates the desired menu. To enter the menu and view or adjust the parameters within press "SET". Figure 3 on page 5 shows the programming menu structure.

4.5 Probe parameters

The probe parameters menu contains data which describes the characterstics of the probe and it's calibration. The 1502 thermometer converts measured resistance of the probe to temperature mathematically using a specified algorithm and programmable coefficients or probe constants which characterize the temperature sensor. The user may choose one of three conversion algorithms.

The standard algorithm uses parameters R_0 and ALPHA to convert resistance to temperature with the Callendar-Van Dusen equation. The thermometer is preprogrammed with standard values of R_0=100 and ALPHA=0.00385 for a DIN 43760 type probe. The user may change these constants to better fit the characteristics of his particular probe. Callendar-Van Dusen parameters DELTA and BETA are fixed at 1.507 and 0.111 respectively and cannot be changed. For better accuracy the user may alternately choose to program the thermometer with the IPTS-68 or ITS-90 constants of the probe if they are available.

For the IPTS-68 algorithm the thermometer will allow the constants R_0, ALPHA, DELTA, A_4, and C_4 to be programmed. Normally, with the IPTS-68 program, temperatures are computed to conform to the IPTS68 temperature scale. The user may alternately wish to display temperatures according to the ITS-90 scale instead. This option may be chosen with the IPTS-68 program to have the 1502 compute temperature using the IPTS-68 constants and convert and display the temperatures according to the ITS-90 scale.

If the ITS-90 coefficients for the probe are available then the ITS-90 option should be selected and the constants entered. The user may program constants R-273, A_7, B_7, C_7, A_4, and B_4. Other subranges can also be used by setting the extra constants to 0. Set the 1502 parameters according to the table below to use different subranges. For example if the probe was calibrated with A_{10}, A_4, and B_4 then program the 1502 parameters A7 with A_{10} and set B7 and C7 to 0.

1502 PARAMETER	RANGE 83-933k	RANGE 83-692K	RANGE 83-505K	RANGE 83-429K	RANGE 83-302K
A4=	A_4	A_4	A_4	A_4	A_4
B4=	B_4	B_4	B_4	B_4	B_4
A7=	A_7	A_8	A_9	A_{10}	A_{11}
B7=	B_7	B_8	B_9	0	0
C7=	C_7	0	0	0	0

To program the probe constants and temperature scale from the front panel first enter the probe programming menu. To do this press "EXIT" while pressing "SET". The probe menu will be indicated with " PrObE " on the display. Press "SET" to choose to enter the probe programming menu. The probe parameter menu is outlined in Figure 4.

The first item in the menu is the algorithm selection. This is displayed with "Pr Std", "Pr t68", or "Pr - t90" depending on which algorithm is currently selected. Press "UP" or "DOWN" to change the selection. Press "SET" to set to the new choice. Next in the menu are the probe constants R_0 and ALPHA if the standard algorithm was chosen, R_0, ALPHA, DELTA, A_4, C_4, if the IPTS-68 algorithm was chosen, or R-273 (R0), A_7, B_7, C_7, A_4, and B_4 if the ITS90 algorithm was chosen. Press "SET" to choose to set the displayed constant or "EXIT" to skip to the next constant.

A constant is set by setting the sign, mantissa digits, and then the exponent. Use "UP" and "DOWN" to change the flashing sign or digits and "SET" to set the digit and move to the next. Pressing "EXIT" at any time will abort the operation, leave the constant unchanged, and move on to the next constant.

At the bottom of the probe menu for the IPTS-68 program is the scale selection which is shown by "Sc 68" or "Sc 90" depending on which scale is currently selected. Press "UP" or "DOWN" to change the temperature scale to IPTS68 or ITS90 and then press "SET" to change to the new scale. Press "EXIT" to return to the temperature display.

4.6 Instrument parameters

The instrument parameters menu contains the digital filter parameter. The instrument parameter menu is outlined in Figure 5.

The measured temperature of the thermometer is passed through a digital filter before it is displayed or transmitted over the digital interfaces. The filter helps to reduce fluctuations or noise in the temperature readings. It also, however, affects the thermometer response time. The filter is programmable by the user so that it may be adjusted to best suit a particular application.

The filter is programmed with a time constant in units of seconds. The time constant of the filter may be defined as the length of time required for the difference between the output and input of the filter to diminish to 37% of the initial difference. A larger time constant will produce more constant temperature readings but this will also cause the thermometer to more slowly respond to abrupt temperature changes. The thermometer is preprogrammed for a filter constant of 10.

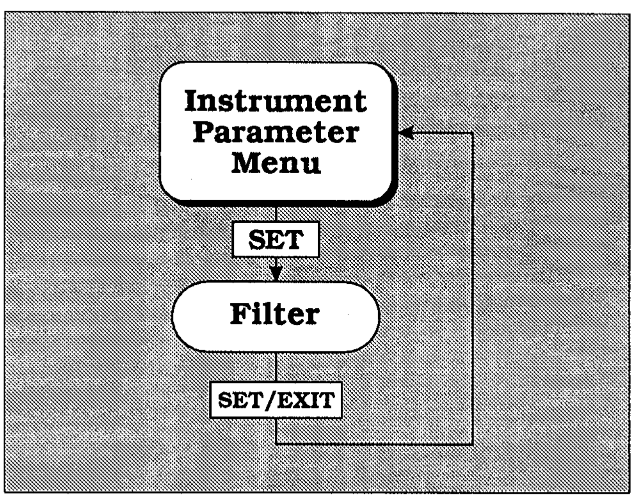

Figure 5 Instrument Parameter Menu

The user may increase this value to add more filtering or he may reduce this value if a quicker response time is desired. To disable the filter altogether set the filter constant to 0.

The filter constant is set from the front panel by entering the parameter programming mode by pressing "SET" while pressing "EXIT". The display will show " PrObE " indicating the probe parameter menu. Press "UP" to access the instrument parameter menu. The display will now ask to enter the instrument parameter menu by displaying " PAr ". Press "SET" to program the instrument parameters. The display will show " FILtEr " to indicate the filter parameter. Press "SET" to choose to set this parameter. The current filter value will be displayed. Use the "UP" and "DOWN" buttons to change the value. Press "SET" to set the filter to the new value or "EXIT" to abort the operation.

4.7 Serial interface parameters

The serial interface parameters set up the operation of the serial interface. This menu is discussed in section 5.1.2 on the serial interface.

4.8 IEEE488 interface parameters

The IEEE488 interface parameters set up the operation of the IEEE488 interface. This menu is discussed in section 5.2.1 on the IEEE488 interface. This menu is only available if the thermometer is equipped with the IEEE488 interface.

4.9 Calibration parameters

The calibration parameters menu contains the parameters which determine the accuracy of the voltage to resistance conversion operation. The 1502 is calibrated at the factory by programming into the thermometer certain calibration constants unique to the particular thermometer. Since these parameters affect the accuracy of the thermometer they should not be altered except by a knowledgeable technician. The certification sheet provided along with the thermometer lists these calibration parameters as a backup in the event that the programmed values become corrupted.

The calibration menu is accessed in a slightly more difficult manner then the other menus to prevent the parameters from being inadvertantly altered. If the calibration parameters must be altered or reset they

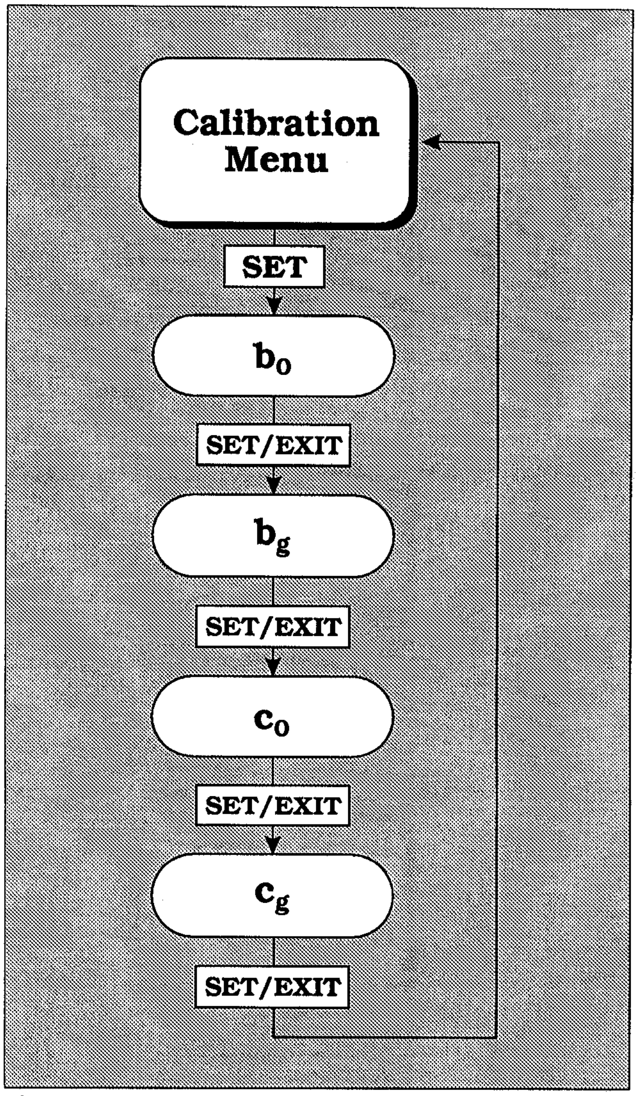

Figure 6 Calibration Menu

may be done so by first entering the programming mode as explained previously. Press "UP" repeatedly until the calibration menu is reached with " CAL " indicated on the display. Then press "SET" repeatedly five times and release. The calibration parameters menu will then be entered and the calibration parameters, b_0, b_g, c_0, and c_g may be programmed. The calibration parameters menu is outlined in Figure 6. Remember these parameters must not be altered except by a knowledgable technician.

5 Digital Communication Interface

The 1502 thermometer is capable of communicating with other equipment through the digital interface. Two types of digital interface are available. The serial interface is provided as standard on all thermometers. The IEEE488 bus interface is available as an option.

With a digital interface the thermometer may be connected to a computer or other equipment. This allows the user to display the temperature readings on the screen of a remote computer, or log the readings into a file. The temperature measurements may be used in a system to monitor and control processes or experiments. The digital interface also provides an alternate and possibly more convenient means of programming the thermometer.

5.1 Serial communication

The 1502 thermometer comes with a built in RS232 interface that allows the operator to use a computer or terminal to remotely read the temperature measured with the thermometer and also program any of the parameters and settings discussed in chapter 4.

5.1.1 Wiring

The serial communications cable attaches to the thermometer through the D9 connector at the back of the instrument. Figure 7 shows the pinout of this connector and suggested cable wiring.

5.1.2 Setup

Before operation the serial interface of the thermometer must first be set up by programming the BAUD rate and other configuration parameters. These parameters are programmed within the serial interface menu. The serial interface parameters menu is outlined in Figure 8.

To enter the parameter programming mode press "EXIT" while pressing "SET" and release, then press "UP" repeatedly until the serial interface menu is indicated with " SErIAL ". Press "SET" to enter the serial parameter menu. The parameters in the serial menu are described following.

5.1.2.1 BAUD rate

The BAUD rate is the first parameter in the menu. The display will prompt with the BAUD rate parameter by showing "BAUd". Press "SET" to choose to set the BAUD rate. The current BAUD rate value will then be displayed. The BAUD rate of the 1502 serial communications may be programmed to 300,600,1200, or 2400 BAUD. The BAUD rate is preprogrammed to 1200 BAUD. Use "UP" or "DOWN" to change the BAUD rate value. Press "SET" to set the BAUD rate to the new value or "EXIT" to abort the operation and skip to the next parameter in the menu.

5.1.2.2 Sample period

The sample period is the next parameter in the menu and prompted with " SAmPLE ". The sample period is the time period in seconds between temperature measurements transmitted from the serial inter-

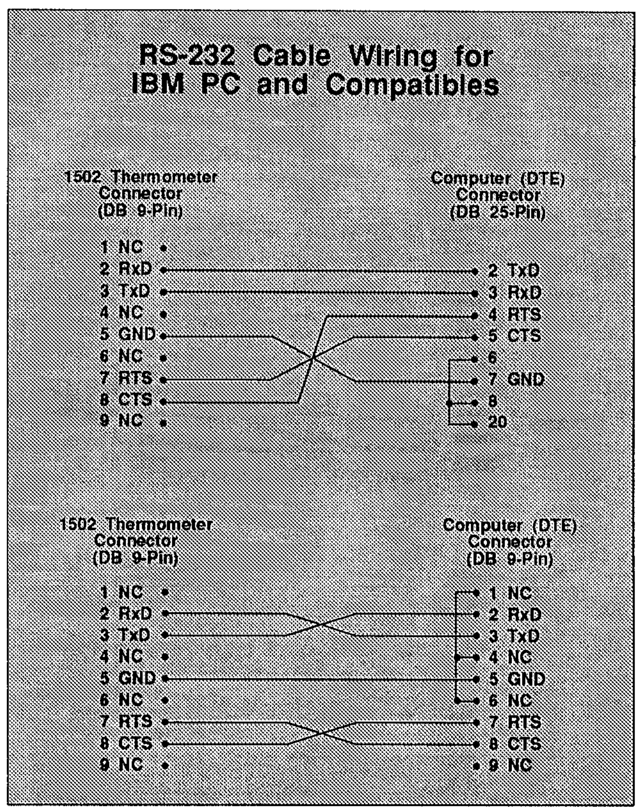

Figure 7 Serial Cable Wiring.

face. If the sample rate is set to 5 for example, then the 1502 will transmit the current measurement over the serial interface approximately every five seconds. The automatic sampling is disabled with a sample period of 0. Press "SET" to choose to set the sample period. Adjust the period with "UP" or "DOWN" and then use "SET" to set the sample rate to the displayed value.

5.1.2.3 Duplex mode

The next parameter is the duplex mode indicated with "duPL". The duplex mode may be set to half duplex ("HALF") or full duplex ("FULL"). With full duplex any commands recieved by the thermometer via the serial interface will be immediately echoed or transmitted back to the device of origin. With half duplex the commands will be executed but not echoed. The default setting is full duplex. The mode may be changed using "UP" or "DOWN" and pressing "SET".

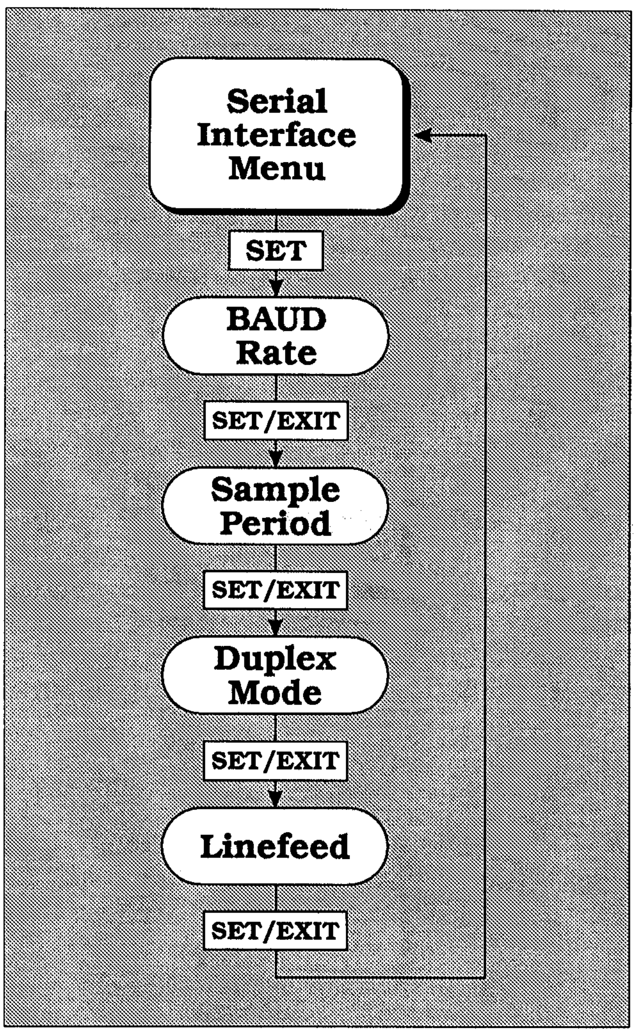

Figure 8 Serial Interface Menu

5.1.2.4 Linefeed

The final parameter in the serial interface menu is the linefeed mode. This parameter enables ("On") or disables ("OFF") transmission of a linefeed character (LF, ASCII 10) after transmission of any carriagereturn. The default setting is with linefeed on. The mode may be changed using "UP" or "DOWN" and pressing "SET".

5.1.3 Serial operation

Once the cable has been attached and the interface set up properly the thermometer will immediately begin sending temperature readings at the programmed rate. Commands may also be sent to the 1502 via the serial interface to program the various parameters. The interface commands are discussed in section 5.3. All commands are ASCII character strings terminated with a carriage return (CR, ASCII 13) or linefeed (LF, ASCII 10) character.

5.2 IEEE488 communication (optional)

The IEEE488 interface is available as an option. Thermometers supplied with this option have added circuitry installed internally and an extra connector on the back of the instrument.

5.2.1 Setup

To use the IEEE488 interface first connect an IEEE488 standard cable to the back of the thermometer. Next set the device address and if desired the talkonly mode. These parameters are programmed within the IEEE488 interface menu. The IEEE488 interface parameters menu is outlined in Figure 9.

To enter the parameter programming mode press "EXIT" while pressing "SET" and release, then press "UP" repeatedly until the IEEE488 interface menu is indicated with " IEEE ". Press "SET" to enter the IEEE488 parameter menu. The parameters in the IEEE488 menu are described following.

5.2.1.1 Device address

The device address is the first parameter in the menu. It is prompted with "AddrESS". Press "SET" to program the address. The default address is 22. Change the device address of the 1502 thermometer if necessary to match the address used by the communication equipment by pressing "UP" or "DOWN" and then "SET".

5.2.1.2 Talk-only

The second parameter in the menu is the talkonly mode parameter. This is indicated on the display with "ton". When talk-only mode is enabled ("On") the thermometer will automatically take control of the interface bus and transmit measurements as they are made. When in talk-only mode the thermometer will not accept commands via the IEEE488 interface. Use "UP" or "DOWN" and then "SET" to program the talk-only mode parameter.

5.2.1.3 Termination

The next paramater in the menu is the transmission termination character selection. The parameter is indicated on the display by "EOS". It can be set to carriage return only (Cr), linefeed only (LF), or carriage return and linefeed. Regardless of the option selected the 1502 will interpret either a carriage return or linefeed as a command termination during reception.

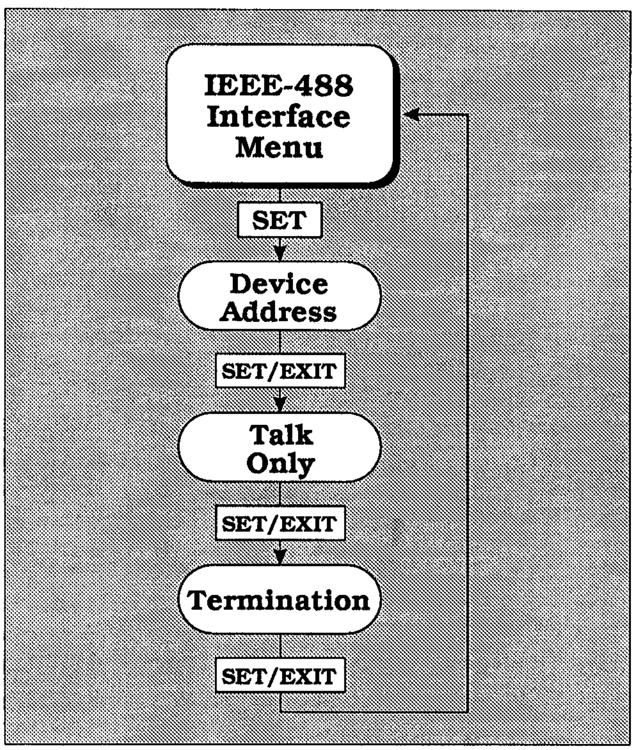

Figure 9 IEEE-488 Interface Menu

5.2.2 IEEE488 operation

Commands may now be sent via the IEEE488 interface to read the temperature or program parameters. All commands are ASCII character strings and are terminated with a carriage return (CR, ASCII 13) or linefeed (LF, ASCII 10). To read the temperature send "T"<CR>. Interface commands are listed below.

5.3 Interface commands

The various commands for reading or programming the 1502 parameters via the digital interfaces are listed in this section (see Table 2). These commands are used with both the serial interface and the IEEE488 interface. In either case the commands are terminated with a carriagereturn or linefeed character. The interface makes no distinction between upper and lower case letters, hence either may be used. Commands may be abbreviated to the minimum number of letters which determines a unique command. A command may be used to either set a parameter or display a parameter depending on whether or not a value is sent with the command following a "=" character. For example "f"<CR> will return the current setting of the filter constant and "f=5"<CR> will set the filter constant with a value of 5.

In the following list of commands, characters or data within brackets, "[" and "]", are optional for the command. A slash, "/", denotes alternate characters or data. Numeric data, denoted by "n", may be entered in decimal or exponential notation. Bold type characters are literal characters while normal type symbolizes data. Characters are shown in lower case although upper case may be used. Spaces may be added within command strings and will simply be ignored. A terminating CR is implied with all commands.

Some of the probe constant commands have different meanings depending on which probe option is selected. For example the command "a4" will set the IPTS-68 parameter A_4 if the IPTS-68 algorithm is selected or it will set the ITS-90 parameter A_4 if the ITS-90 algorithm is selected. Similarly "R0" can refer to R_0 or R-273 of any of the three algorithms. Be sure to select the appropriate conversion algorithm before programming any of the probe constants!

t[emperature]	Read current temperature measurement
u[nits]=c/f/k/o	Select temperature units C, F, K or ohms
p[robe][=s[td]/68/90]	Read or select standard, IPTS-68, or ITS-90 algorithm
s[cale][=68/90]	Read or select scale conversion, IPTS-68 or ITS-90
r[0][=n]	Read or set probe constant R0
al[pha][=n]	Read or set probe constant ALPHA
d[elta][=n]	Read or set probe constant DELTA
a4[=n]	Read or set probe constant A4
b4[=n]	Read or set probe constant B4
c4[=n]	Read or set probe constant C4
a7[=n]	Read or set probe constant A7
b7[=n]	Read or set probe constant B7
c7[=n]	Read or set probe constant C7
f[ilter][=n]	Read or set filter constant
sa[mple][=n]	Read or set serial sample period
du[plex][=f[ull]/h[alf]]	Read or set duplex mode
lf=on/of[f]	Set linefeed on or off
***b0**[=n]	Read or set calibration constant b0
***bg**[=n]	Read or set calibration constant bg
***c0**[=n]	Read or set calibration constant c0
***cg**[=n]	Read or set calibration constant cg

Legend:

[ ]	Optional command data
n	numeric data
/	alternate parameters

Table 2 Interface commands.

6 Calibration

This chapter discusses instrument calibration and measurement error issues with regard to the 1502 thermometer. Two types of calibrations are discussed. The first type of calibration discussed is instrument calibration. Instrument calibration minimizes errors in measuring resistance. Since temperature readings are derived from resistance measurements it is important that the instrument be calibrated properly. However correct instrument calibration does not guarantee accurate temperature measurements since the probe calibration also affects temperature accuracy. The second type of calibration is system calibration. When a system calibration is performed the instrument and probe are calibrated together to minimize the total of all errors. This type of calibration can also optimize accuracy over a specific temperature range of interest.

6.1 Instrument calibration

The 1502 thermometer is calibrated at the factory and certified to measure resistance at the specified accuracy. In order to guarantee accurate resistance measurement the instrument should be periodically recertified and if necessary recalibrated.

This section explains how calibration is performed. Calibration should be done by a knowlegdeable technician with access to the proper equipment. Before calibrating or altering any of the probe or calibration parameters of the thermometer be sure original values of these constants are noted for future reference.

6.1.1 Equipment

Calibration of the 1502 thermometer requires a set of three or four resistors and a computer or terminal with a serial or IEEE488 bus link to the thermometer.

The resistors provide a reference to which subsequent measurements are derived. The values of these resistors must be known with high accuracy, ±0.005Ω. The resistances may be measured using a high accuracy (20ppm) 4wire ohmmeter or bridge.

The particular values of the resistors are not critical but they must be within certain ranges for best results. The first resistor, called "R1", should be from 20 to 50 ohms. The second resistor, "R2", should be from 90 to 130 ohms. The third resistor, "R3", should be from 100 to 170 ohms, and finally the forth resistor, "R4", should be from 200 to 300 ohms. Calibration at the factory is done with resistances of R1=50Ω, R2=R3=100Ω, and R4=200Ω. Resistors R1 and R2 are used to calibrate the lower measurement range, 0Ω to approximately 150Ω. Resistors R3 and R4 are used to calibrate the upper measurement range of approximately 140Ω to 400Ω.

For best results the resistors should be connected to the thermometer through a 4wire shielded cable of approximately the same length and type as that of the probes used with the thermometer. The resistor assemblies should be terminated with 5-pin DIN plugs for easy connection to the thermometer. For resistor wiring see Appendix A.

Calibration must be done via the digital interface, either RS232 or IEEE488.

6.1.2 Instrument calibration procedure

With a set of accurately known resistors ready and digital communications established with the thermometer, the calibration procedure may begin.

The first step is to program into the 1502 the values of the calibration resistors. This is done via the digital interface using the commands,

***rcn=r**

"n" above, 1 to 4, indicates the standard resistor and "r" is the known resistance of the standard. The commands are terminated with carriage return. For example the four resistances might be programmed as,

***rc1=50.005**

***rc2=99.987**

***rc3=99.987**

***rc4=200.034**

The next step is to instruct the 1502 to begin the interactive calibration procedure. This is done by issuing the command via the digital interface,

***cal**

The thermometer will transmit back,

—CAL—

This will be followed by the values of the standard resistor values as programmed for verification.

RC1: 50.005

RC2: 99.987

RC3: 99.987

RC4: 200.034

OK? (Y)

If the values are correct then send a carriagereturn or "y" for "yes". Any other character will cause the procedure to be aborted.

The 1502 will then prompt the technician to plug in the first resistor.

plug in 50.005, press ENTER

Plug in the first resistor and press ENTER which transmits a carriagereturn. If another key is pressed instead the calibration procedure may be aborted. The thermometer will begin measuring the resistor and indicate,

sampling...

When it finishes the thermometer will display the voltage measurement made and then prompt the technician to plug in the next resistor as before with the first. Continue as instructed until all four resistors are measured. At this point the 1502 will use these four measurements to automatically calculate new values for the calibration constants, display the new values, and end the calibration procedure.

b0: 0.0012

bg: 156.316

c0: 0.0003

cg: 406.149

—ENDCAL—

Note the new calibration values for future reference. Check the calibration by measuring the resistances of the standard resistors. The resistance as measured by the thermometer should be accurate within ±0.010Ω

6.2 System calibration

In some instances the user may want to calibrate the thermomter and probe together to optimize accuracy over a certain temperature range. System calibration is done by adjusting the probe calibration constants "R_0" and "ALPHA" so that the temperature as measured with the 1502 thermometer agrees closely with a standard thermometer at two calibration temperatures. The standard thermometer used must be able to measure temperature with higher accuracy than the desired accuracy of the 1502. By using a good thermometer and carefully following this procedure the 1502 can be calibrated to an accuracy of better than 0.02°C over a range of 100 degrees.

6.2.1 Calibration Points

In calibrating the 1502 thermometer R_0 and ALPHA are adjusted to minimize the temperature measurement error at each of two different temperatures. Any two reasonably separated temperatures may be used for the calibration, however best results will be obtained when using temperatures which are just within the most useful operating range of the thermometer as determined by the user. The further apart the calibration temperatures the larger will be the calibrated temperature range but the calibration error will also be greater over the range. If for instance 50°C and 150°C are chosen as the calibration temperatures then the thermometer may achieve an accuracy of say ±0.03°C over the range 40 to 160°C. Choosing 80°C and 120°C may allow the thermometer to have a better accuracy of maybe ±0.01°C over the range 75 to 125°C but outside that range the accuracy may be only ±0.05°C.

The technician must have access to constant temperature baths or other suitable constant temperature environments at each of the two chosen calibration temperatures.

6.2.2 Measuring the error

The first step in the calibration procedure is to measure the temperature errors (including sign) at the two calibration temperatures. First measure the temperature of the lower temperature source using the standard thermometer and then the 1502 thermometer. Next measure the temperature of the higher temperature source with the thermometers. Subtract the temperatures to compute the errors.

$$err_L = t_L(\text{standard})\ t_L(1502)$$

$$err_H = t_H(\text{standard})\ t_H(1502)$$

If for example the 1502 measures 50.043°C at 50.009°C and 149.961°C at 150.014°C then the errors would be err_L = -0.034 and $err_H = 0.053$.

$R_0 = 100.000$

ALPHA = 0.0038500

$t_L(\text{standard}) = -10.087$

$t_L(1502) = -10.022$

$t_H(\text{standard}) = 209.567$

$t_H(1502) = 209.49$

Compute errors,

$err_L = -10.087 - (-10.022) = -0.065$

$err_H = 209.567 - 209.49 = 0.077$

Compute R_0,

$$R_0' = \left[\frac{(0.077)\,(-10.022) - (-0.065)\,(209.567)}{209.567 - (-10.087)}\,0.00385 + 1\right]100.000 = 100.0225$$

Compute ALPHA,

$$ALPHA' = \left[\frac{(1+(0.00385)\,(209.567))\,(-0.065) - (1+(0.00385)\,(-10.087))\,(-0.077)}{209.567 - (-10.087)} + 1\right]0.00385 = 0.00384664$$

Figure 10 Calibration Example

6.2.3 Computing R_0 and ALPHA

Before computing the new values for R_0 and ALPHA the current values must be known. The values may be found by either accessing the probe calibration menu from the 1502 front panel or by inquiring through the digital interface. The user should keep a record of these values in case they may need to be restored in the future. The new values $R_{0'}$ and ALPHA′ are computed by entering the old values for R0 and ALPHA, the calibration temperature setpoints t_L and t_H, and the temperature errors err_L and err_H into the following equations,

$$R_0' = \left[\frac{err_H \, t_L - err_L \, t_H}{t_H - t_L} ALPHA + 1 \right] R_0$$

$$ALPHA' = \left[\frac{(1 + ALPHA \, t_H) err_L (1 + ALPHA \, t_L) err_H}{t_H - t_L} + 1 \right] ALPHA$$

If for example R_0 and ALPHA were previously set for 100.000 and 0.0038500 respectively and t_L, t_H, err_L, and err_H were 50.009°C, 150.014°C, -0.034°C, and 0.053°C as given above then the new values $R_{0'}$ and ALPHA′ would be computed as 100.02985 and 0.00384550 respectively. Program the new values R0′ and ALPHA′ into the 1502 thermometer. Check the calibration by measuring the temperatures again and comparing with the standard thermometer. If desired the calibration procedure may be repeated again to further improve the accuracy.

6.2.4 Calibration example

The thermometer is to be used between 25 and 225°C and it is desired to calibrate the thermometer as accurately as possible for operation within this range. The current values for R0 and ALPHA are 100.000 and 0.0038500 respectively. The calibration points are chosen to be 10.087 and 209.567°C as measured with a standard thermometer. The measured temperatures are 10.022 and 209.49°C respectively with the 1502 thermometer. Refer to Figure 10 for applying equations to this example data and computing the new probe constants.

7 Appendix A

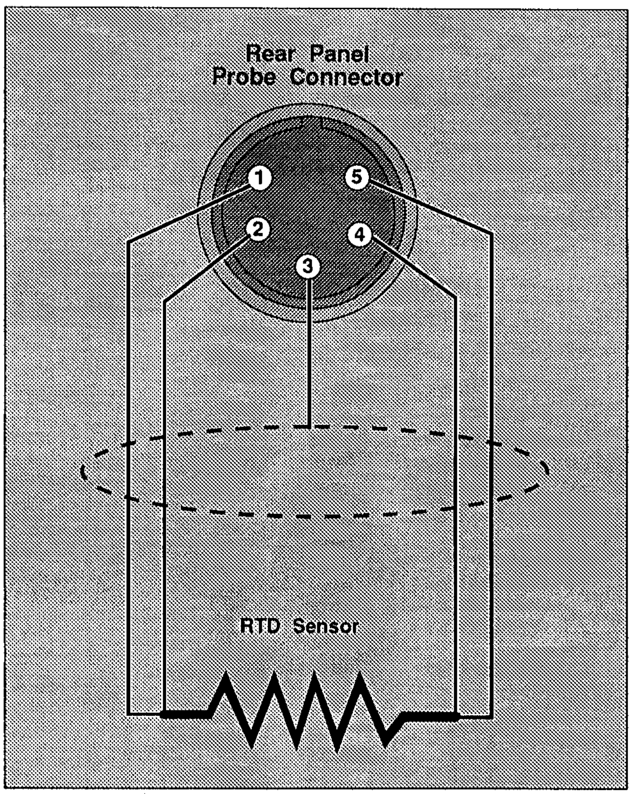

Figure 11 Probe Wiring Diagram

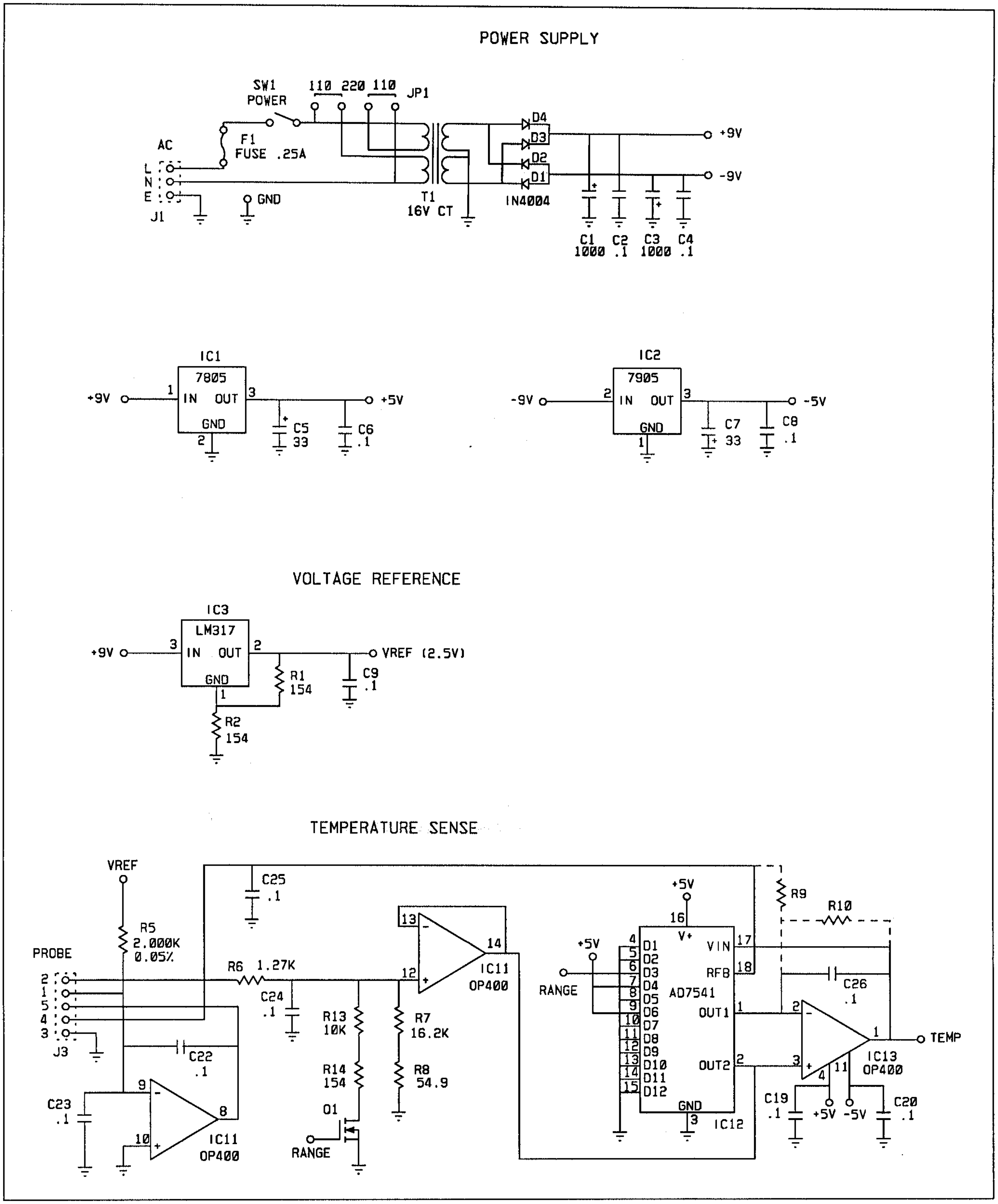

Figure 12 Schematic — Main Board, 1 of 4

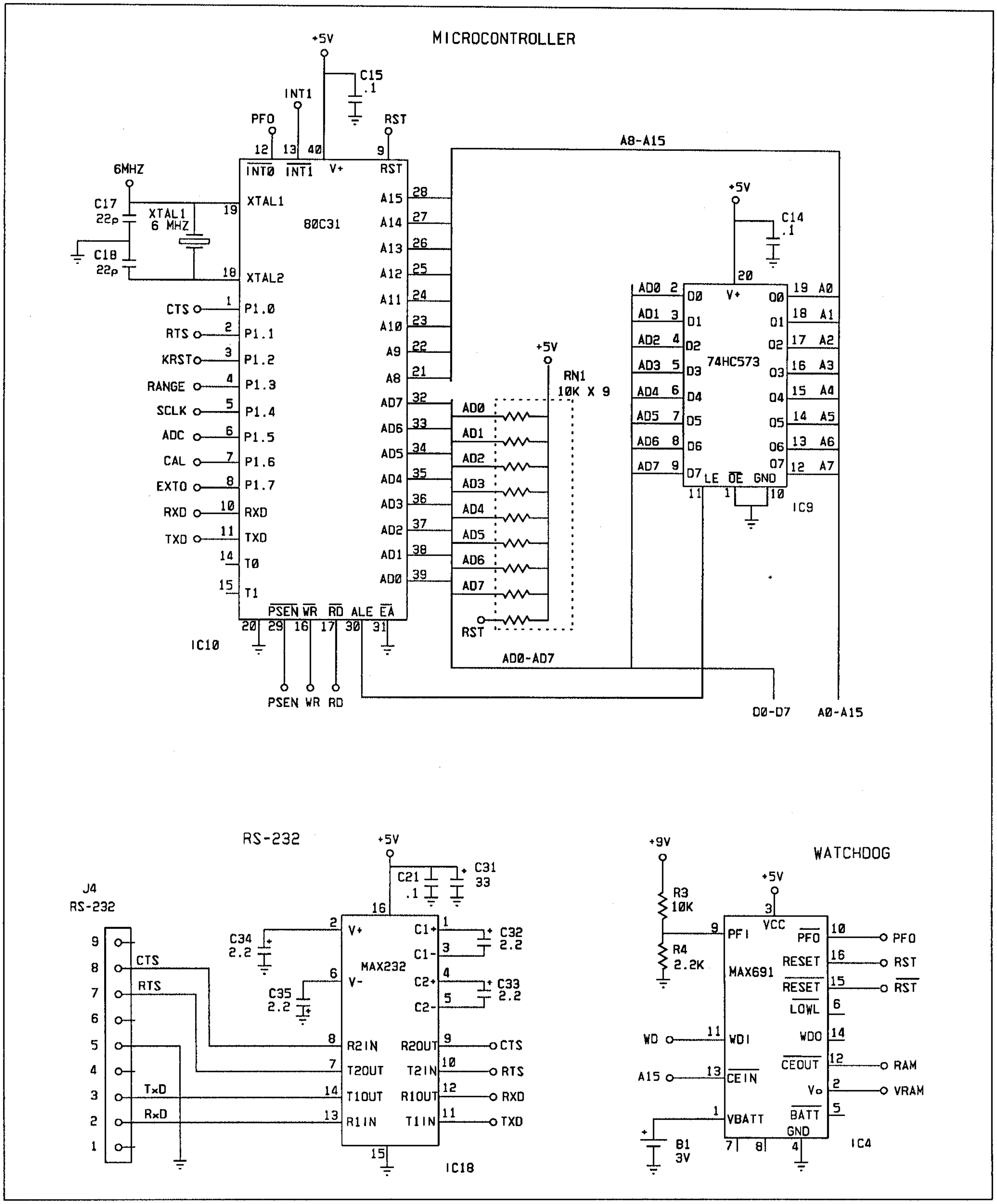

Figure 13 Schematic — Main Board, 2 of 4

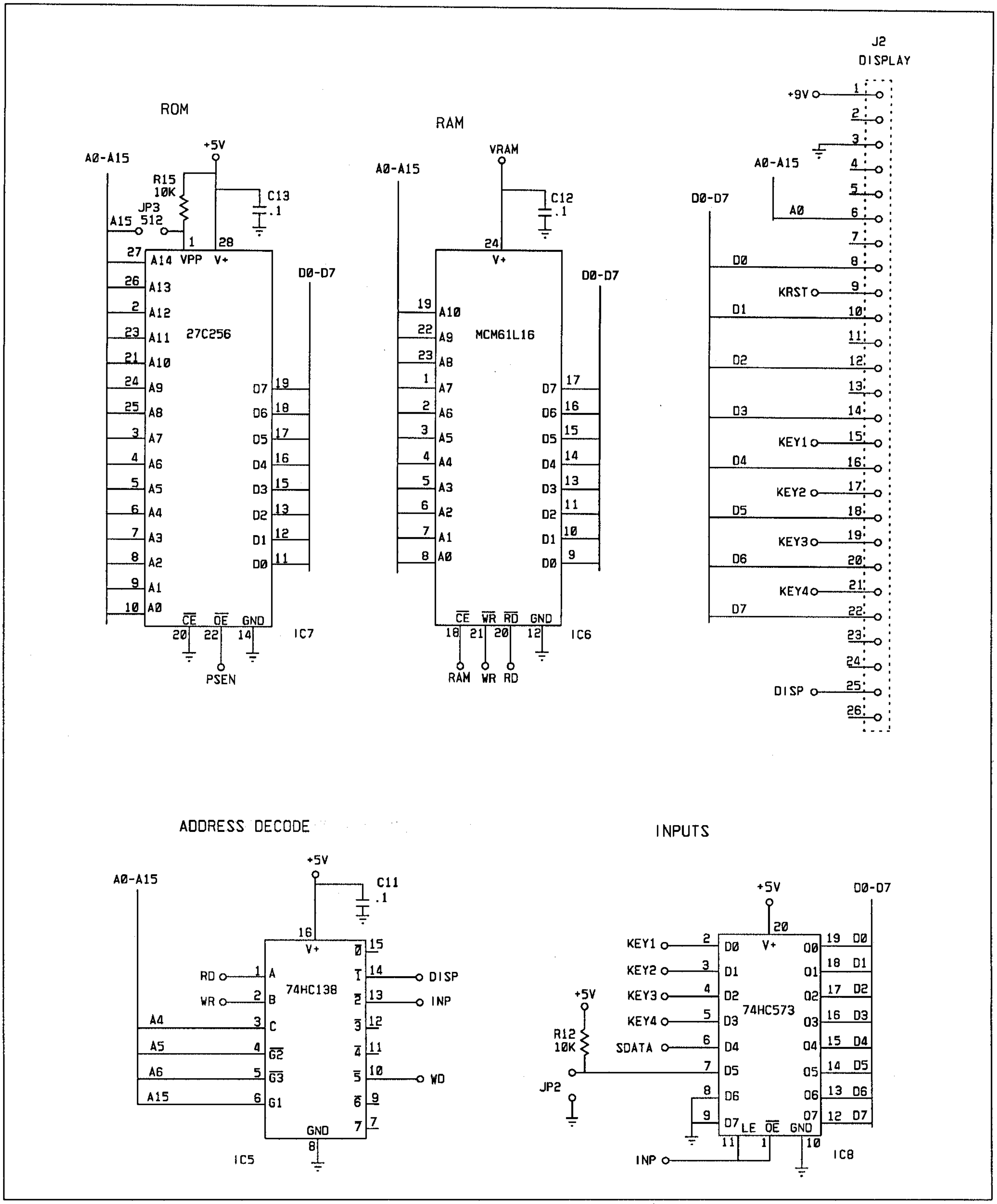

Figure 14 Schematic — Main Board, 3 of 4

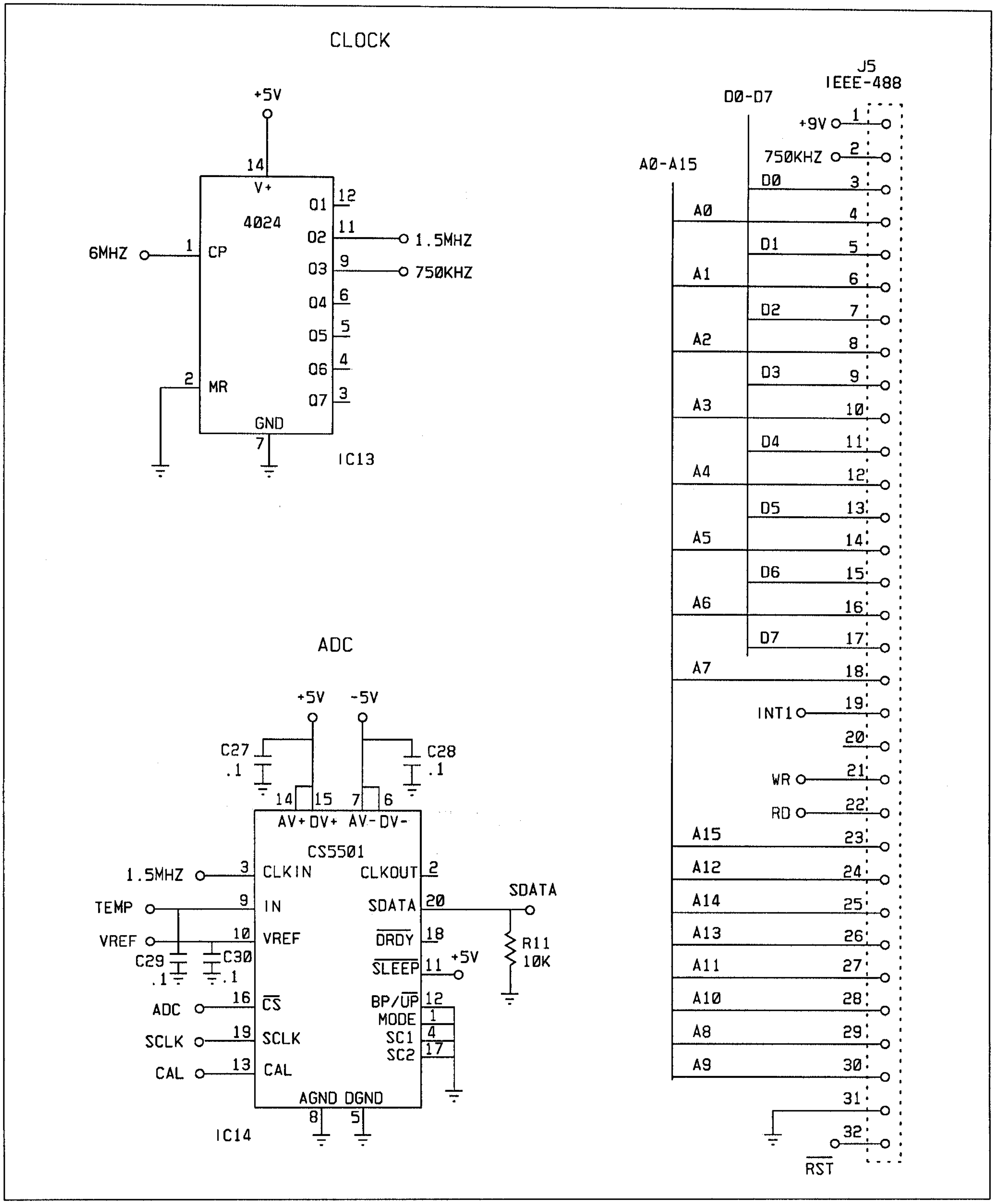

Figure 15 Schematic — Main Board, 4 of 4

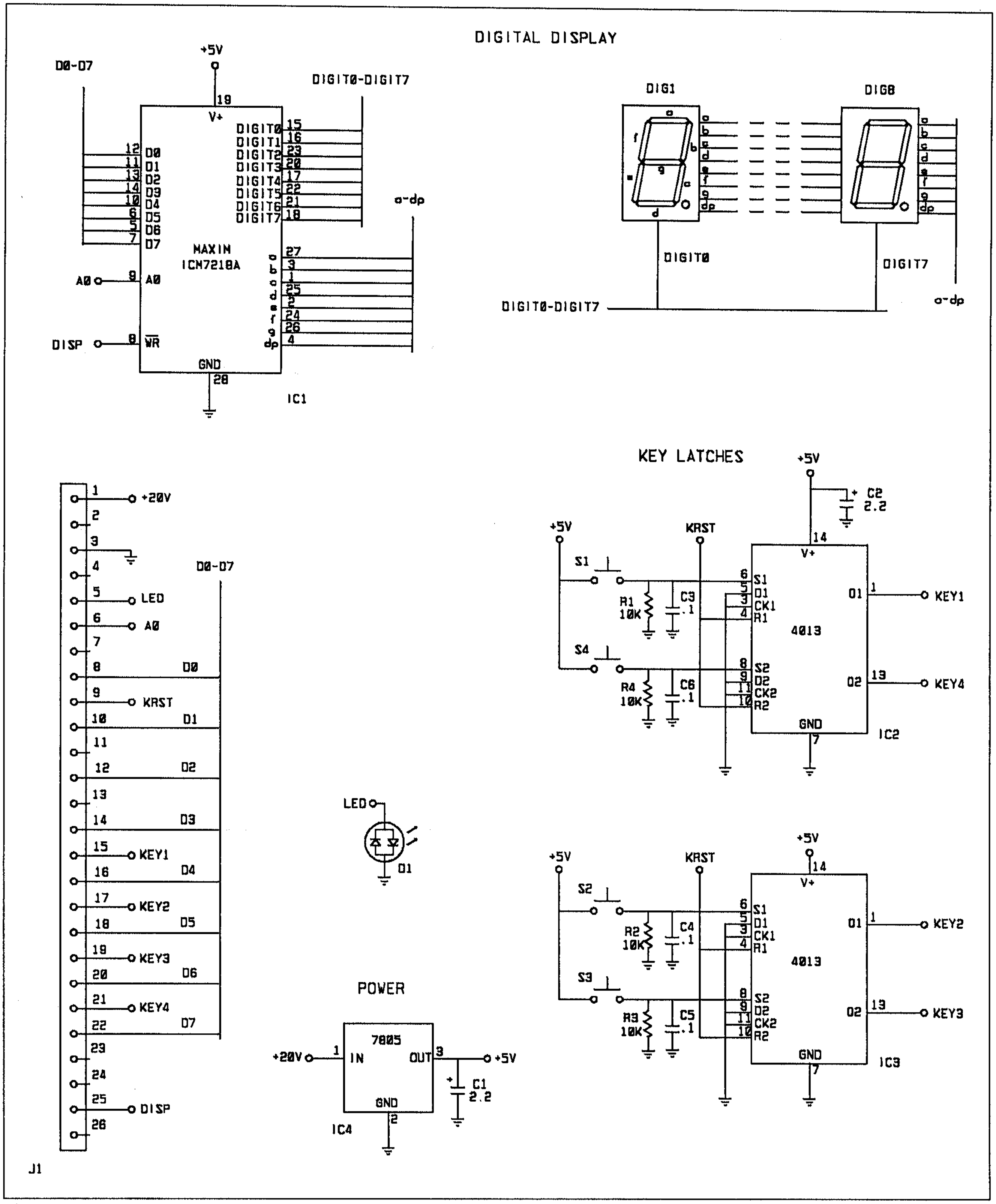

Figure 16 Schematic — Panel Board

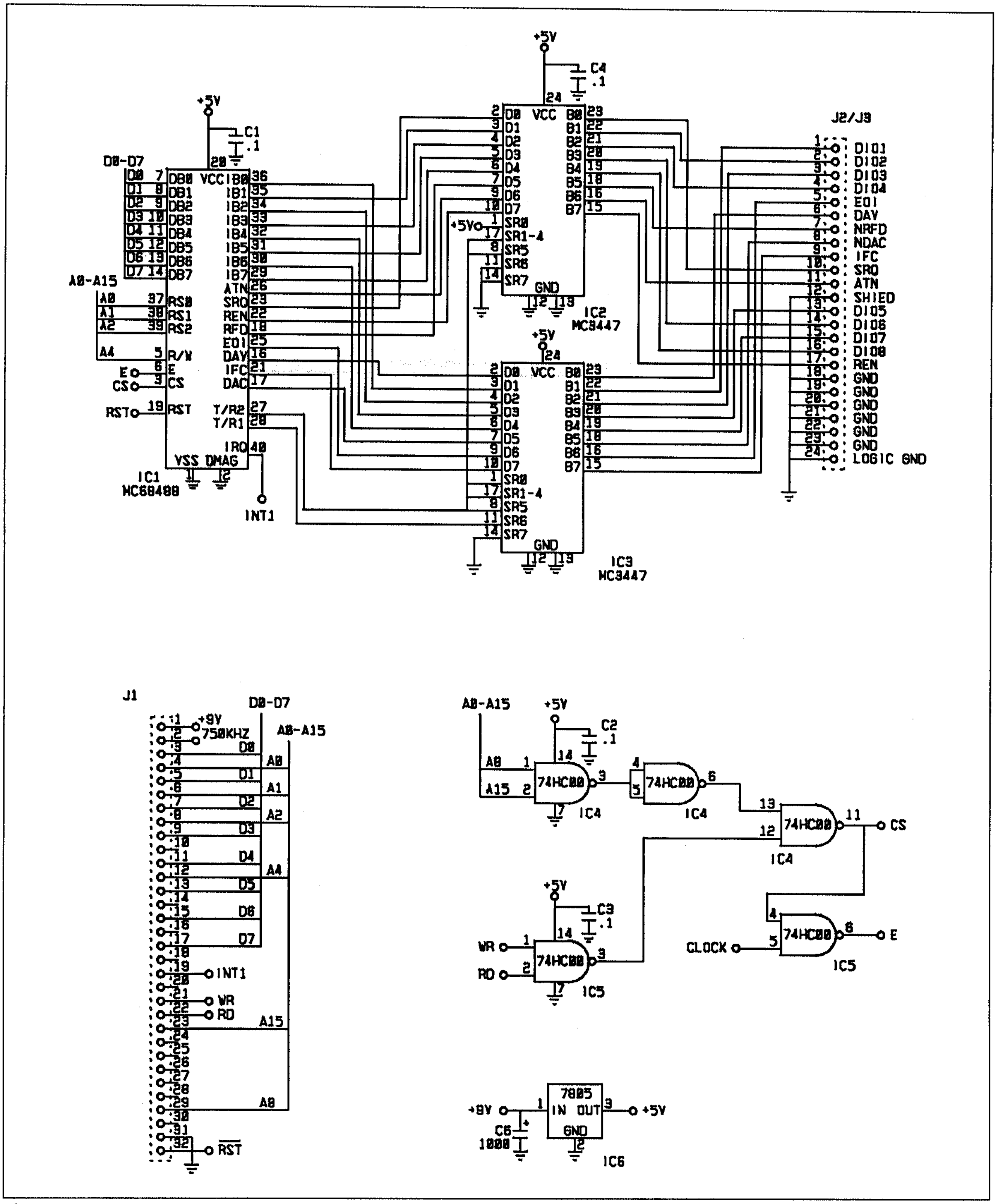

Figure 17 Schematic — IEEE-488 Interface Board

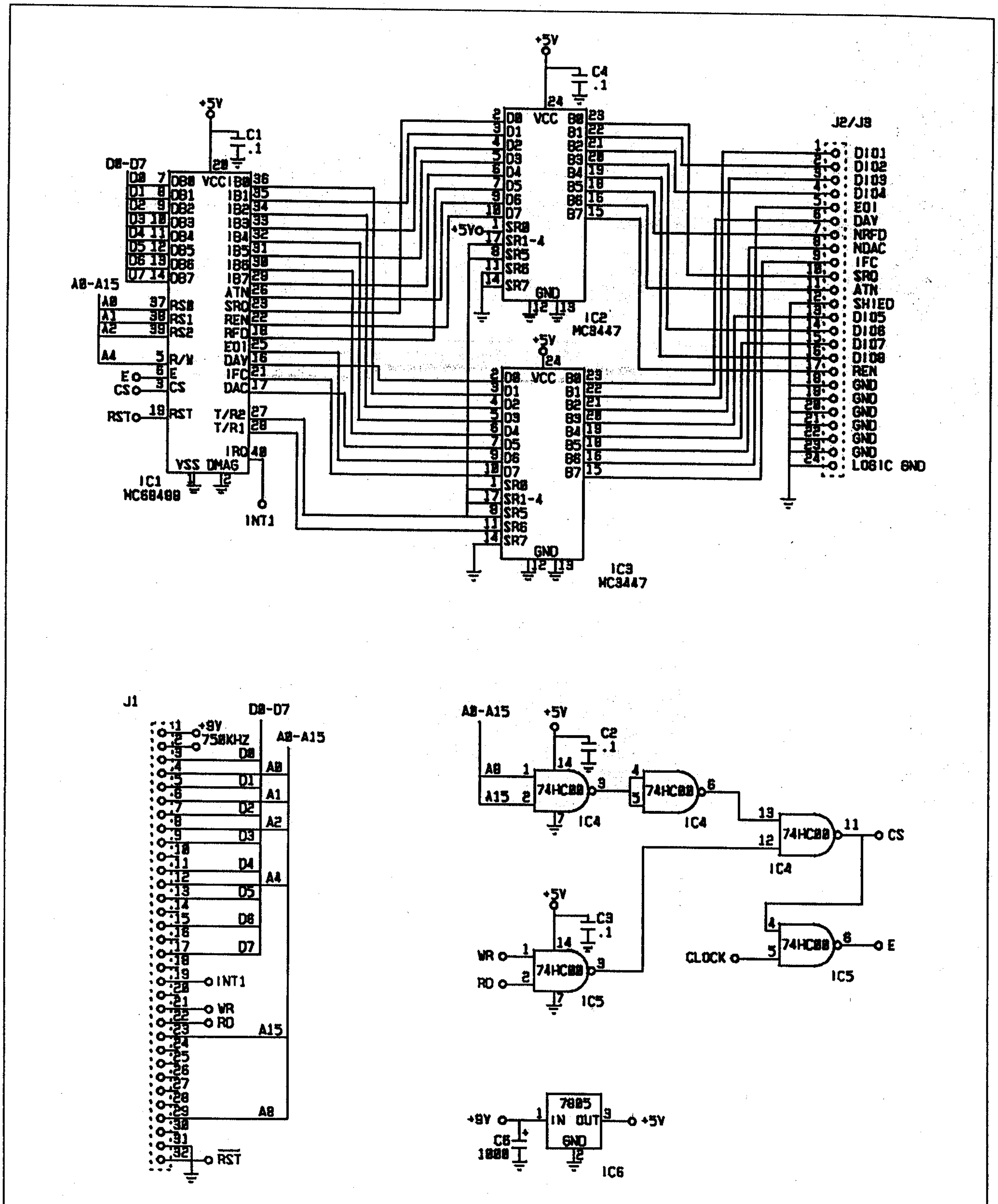

Figure 17 Schematic — IEEE-488 Interface Board

Customer Service Contact Log

Date Contacted	Contact	Phone	Date Resolved
1/8/01	DAVE PRATHER	303.541.3329	1/8/01

Method	Reason	Company / Location	Method
☑ Phone ☐ Fax ☐ E-mail	☐ Information ☐ Education ☐ Troubleshooting ☐ Return a unit ☐ Comment	Company: BAXTER (PROBE) Location:	☑ Info via Phone ☐ Info via Fax ☐ Info via E-mail ☐ Sent Info/Parts ☐ Gave RMA

Model #, Serial #, Notes

RTPW — 1502

A4 — (303. 541. 3590).

B4

~~A8~~

B8

PRATHER

```
Pr=  t68
```
IPTS-68

Select the desired probe characterization type using the ▲ and ▼ buttons and pressing the **Enter** button. After the characterization type is selected the characterization coefficients follow.

3.7.2 Setting the Characterization Coefficients

Probe characterization coefficients are set within the **Probe** menu after selecting the probe characterization type. Each coefficient appears with the name of a coefficient shown briefly followed by its value. For example,

```
A4
```

```
+4.336079
```

For some coefficients, you only need to set the digits in the number. Other coefficients also have a sign as shown above (positive sign appears as " +"). Use the ◀ and ▶ buttons to move between the digits (and the sign). The selected digit will flash. Use the ▲ and ▼ buttons to change a digit. Once the sign and digits are correct, press **Enter** to accept the number. If you decide to cancel any changes you have made, you may do so by pressing the **Ω/Exit** button. This will immediately skip to the next coefficient.

If the coefficient also requires an exponent, it will appear after setting the number as follows:

```
E     -04
```

Increase or decrease the exponent using the ▲ and ▼ buttons. Once the exponent is correct, press **Enter** to accept it.

3.7.3 ITS-90 Conversion

The ITS-90 (International Temperature Scale of 1990) characterization converts resistance to temperature using reference functions and deviation functions according to the ITS-90 specifications. The 1502 accepts deviation function coefficients for sub-range 4 (below 0.01°C) and sub-ranges 6, 7, 8, 9, 10, and 11 (above 0.01°C). The coefficients that appear in the **Probe** menu when ITS-90 is selected are "r 0.01", "A", "b", "C", "d", "A4", and "b4". The coefficient "r 0.01" sets the triple point of water resistance. Coefficients "A4" and "b4" set the a_4 and b_4 coefficients of sub-range 4. If the probe has not been calibrated for operation below 0°C these coefficients should be set to 0. Coefficients "A", "b", "C", and "d" set the a_6, b_6, c_6, and d coefficients of sub-range 6. These can also be used to set the coefficients of any other sub-range from 7 to 11. Unused coefficients must be set to 0. For example, if your probe is calibrated only with sub-range 8, set "r 0.01" to the value of R(273.16K) that appears on the calibration report, set "A" to the value of the a_8 coefficient, set "b" to the value of the b_8 coefficient, and set "C", "d", "A4", and "b4" all to 0.

3.7.4 Callendar-Van Dusen (RTD) Conversion

The RTD conversion uses the Callendar-Van Dusen equation:

$$r(t[^\circ C]) = \begin{cases} R_0\left\{1+\alpha\left[t-\delta\frac{t}{100}\left(\frac{t}{100}-1\right)\right]\right\} & t\ge 0 \\ R_0\left\{1+\alpha\left[t-\delta\frac{t}{100}\left(\frac{t}{100}-1\right)-\beta\left(\frac{t}{100}-1\right)\left(\frac{t}{100}\right)^3\right]\right\} & t<0 \end{cases}$$

The coefficients R_0, α, β, and δ can be set by the user. They are indicated as "r0", "ALPHA", "bEtA", and "dELtA" on the display. For IEC-751 or DIN-43760 sensors, the coefficients for "r0", "ALPHA", "bEtA", and "dELtA" should be 100.0, 0.00385, 1.507, and 0.111 respectively.

Some probes may be provided with A, B, and C coefficeints for the Callendar-Van Dusen equation in the following form:

$$r(t[^\circ C]) = \begin{cases} R_0\left(1+At+B^2\right) & t\ge 0 \\ R_0\left[1+At+Bt^2+C(t-100)t^3\right] & t<0 \end{cases}$$

The A, B, and C coefficients can be converted to α, δ, and β coefficients using the following formulas:

$$\alpha = A+100B \qquad \delta = -\frac{100}{\frac{A}{100B}+1} \qquad \beta = -\frac{10^8 C}{A+100B}$$

6 Calibration

This chapter discusses instrument calibration and measurement error issues with regard to the 1502 thermometer. Two types of calibrations are discussed. The first type of calibration discussed is instrument calibration. Instrument calibration minimizes errors in measuring resistance. Since temperature readings are derived from resistance measurements it is important that the instrument be calibrated properly. However correct instrument calibration does not guarantee accurate temperature measurements since the probe calibration also affects temperature accuracy. The second type of calibration is system calibration. When a system calibration is performed the instrument and probe are calibrated together to minimize the total of all errors. This type of calibration can also optimize accuracy over a specific temperature range of interest.

6.1 Instrument calibration

The 1502 thermometer is calibrated at the factory and certified to measure resistance at the specified accuracy. In order to guarantee accurate resistance measurement the instrument should be periodically recertified and if necessary recalibrated.

This section explains how calibration is performed. Calibration should be done by a knowlegdeable technician with access to the proper equipment. Before calibrating or altering any of the probe or calibration parameters of the thermometer be sure original values of these constants are noted for future reference.

6.1.1 Equipment

Calibration of the 1502 thermometer requires a set of three or four resistors and a computer or terminal with a serial or IEEE488 bus link to the thermometer.

The resistors provide a reference to which subsequent measurements are derived. The values of these resistors must be known with high accuracy, ±0.005Ω. The resistances may be measured using a high accuracy (20ppm) 4wire ohmmeter or bridge.

The particular values of the resistors are not critical but they must be within certain ranges for best results. The first resistor, called "R1", should be from 20 to 50 ohms. The second resistor, "R2", should be from 90 to 130 ohms. The third resistor, "R3", should be from 100 to 170 ohms, and finally the forth resistor, "R4", should be from 200 to 300 ohms. Calibration at the factory is done with resistances of R1=50Ω, R2=R3=100Ω, and R4=200Ω. Resistors R1 and R2 are used to calibrate the lower measurement range, 0Ω to approximately 150Ω. Resistors R3 and R4 are used to calibrate the upper measurement range of approximately 140Ω to 400Ω.

For best results the resistors should be connected to the thermometer through a 4wire shielded cable of approximately the same length and type as that of the probes used with the thermometer. The resistor assemblies should be terminated with 5-pin DIN plugs for easy connection to the thermometer. For resistor wiring see Appendix A.

Calibration must be done via the digital interface, either RS232 or IEEE488.

6.1.2 Instrument calibration procedure

With a set of accurately known resistors ready and digital communications established with the thermometer, the calibration procedure may begin.

The first step is to program into the 1502 the values of the calibration resistors. This is done via the digital interface using the commands,

***rcn=r**

"n" above, 1 to 4, indicates the standard resistor and "r" is the known resistance of the standard. The commands are terminated with carriage return. For example the four resistances might be programmed as,

***rc1=50.005**

***rc2=99.987**

***rc3=99.987**

***rc4=200.034**

The next step is to instruct the 1502 to begin the interactive calibration procedure. This is done by issuing the command via the digital interface,

***cal**

The thermometer will transmit back,

—CAL—

This will be followed by the values of the standard resistor values as programmed for verification.

RC1: 50.005

RC2: 99.987

RC3: 99.987

RC4: 200.034

OK? (Y)

If the values are correct then send a carriagereturn or "y" for "yes". Any other character will cause the procedure to be aborted.

The 1502 will then prompt the technician to plug in the first resistor.

plug in 50.005, press ENTER

Plug in the first resistor and press ENTER which transmits a carriagereturn. If another key is pressed instead the calibration procedure may be aborted. The thermometer will begin measuring the resistor and indicate,

sampling...

When it finishes the thermometer will display the voltage measurement made and then prompt the technician to plug in the next resistor as before with the first. Continue as instructed until all four resistors are measured. At this point the 1502 will use these four measurements to automatically calculate new values for the calibration constants, display the new values, and end the calibration procedure.

b0: 0.0012

bg: 156.316

c0: 0.0003

cg: 406.149

—ENDCAL—

Note the new calibration values for future reference. Check the calibration by measuring the resistances of the standard resistors. The resistance as measured by the thermometer should be accurate within ±0.010Ω

6.2 System calibration

In some instances the user may want to calibrate the thermomter and probe together to optimize accuracy over a certain temperature range. System calibration is done by adjusting the probe calibration constants "R_0" and "ALPHA" so that the temperature as measured with the 1502 thermometer agrees closely with a standard thermometer at two calibration temperatures. The standard thermometer used must be able to measure temperature with higher accuracy than the desired accuracy of the 1502. By using a good thermometer and carefully following this procedure the 1502 can be calibrated to an accuracy of better than 0.02°C over a range of 100 degrees.

6.2.1 Calibration Points

In calibrating the 1502 thermometer R_0 and ALPHA are adjusted to minimize the temperature measurement error at each of two different temperatures. Any two reasonably separated temperatures may be used for the calibration, however best results will be obtained when using temperatures which are just within the most useful operating range of the thermometer as determined by the user. The further apart the calibration temperatures the larger will be the calibrated temperature range but the calibration error will also be greater over the range. If for instance 50°C and 150°C are chosen as the calibration temperatures then the thermometer may achieve an accuracy of say ±0.03°C over the range 40 to 160°C. Choosing 80°C and 120°C may allow the thermometer to have a better accuracy of maybe ±0.01°C over the range 75 to 125°C but outside that range the accuracy may be only ±0.05°C.

The technician must have access to constant temperature baths or other suitable constant temperature environments at each of the two chosen calibration temperatures.

6.2.2 Measuring the error

The first step in the calibration procedure is to measure the temperature errors (including sign) at the two calibration temperatures. First measure the temperature of the lower temperature source using the standard thermometer and then the 1502 thermometer. Next measure the temperature of the higher temperature source with the thermometers. Subtract the temperatures to compute the errors.

$$err_L = t_L(\text{standard})\ t_L(1502)$$

$$err_H = t_H(\text{standard})\ t_H(1502)$$

If for example the 1502 measures 50.043°C at 50.009°C and 149.961°C at 150.014°C then the errors would be err_L = 0.034 and err_H = 0.053.

R_0 = 100.000

ALPHA = 0.0038500

t_L(standard) = -10.087

t_L(1502) = -10.022

t_H(standard) = 209.567

t_H(1502) = 209.49

Compute errors,

err_L = -10.087 - (-10.022) = -0.065

err_H = 209.567 - 209.49 = 0.077

Compute R_0,

$$R_0' = \left[\frac{(0.077)\,(-10.022) - (-0.065)\,(209.567)}{209.567 - (-10.087)}\,0.00385 + 1\right]100.000 = 100.0225$$

Compute ALPHA,

$$ALPHA' = \left[\frac{(1+(0.00385)\,(209.567))\,(-0.065) - (1+(0.00385)\,(-10.087))\,(-0.077)}{209.567 - (-10.087)} + 1\right]0.00385 = 0.00384664$$

Figure 10 Calibration Example

6.2.3 Computing R0 and ALPHA

Before computing the new values for R_0 and ALPHA the current values must be known. The values may be found by either accessing the probe calibration menu from the 1502 front panel or by inquiring through the digital interface. The user should keep a record of these values in case they may need to be restored in the future. The new values $R_{0'}$ and ALPHA′ are computed by entering the old values for R0 and ALPHA, the calibration temperature setpoints t_L and t_H, and the temperature errors err_L and err_H into the following equations,

$$R_0' = \left[\frac{err_H\, t_L - err_L\, t_H}{t_H - t_L} ALPHA + 1\right] R_0$$

$$ALPHA' = \left[\frac{(1+ALPHA\ t_H) err_L (1+ALPHA\ t_L) err_H}{t_H - t_L} + 1\right] ALPHA$$

If for example R_0 and ALPHA were previously set for 100.000 and 0.0038500 respectively and t_L, t_H, err_L, and err_H were 50.009°C, 150.014°C, -0.034°C, and 0.053°C as given above then the new values $R_{0'}$ and ALPHA′ would be computed as 100.0372 and 0.00384550 respectively. Program the new values R0′ and ALPHA′ into the 1502 thermometer. Check the calibration by measuring the temperatures again and comparing with the standard thermometer. If desired the calibration procedure may be repeated again to further improve the accuracy.

6.2.4 Calibration example

The thermometer is to be used between 25 and 225°C and it is desired to calibrate the thermometer as accurately as possible for operation within this range. The current values for R0 and ALPHA are 100.000 and 0.0038500 respectively. The calibration points are chosen to be 10.087 and 209.567°C as measured with a standard thermometer. The measured temperatures are 10.022 and 209.49°C respectively with the 1502 thermometer. Refer to Figure 10 for applying equations to this example data and computing the new probe constants.

[illegible] GE ANDERSON [illegible] 6.22.2000 TO [illegible]
THE EQUATIONS LISTED ON PAGES 16 17 I HAVE CIRCLED
THE ERRORS W/ CORRECTIONS. THERE [illegible] MOST [illegible]
NOT EVER BE [illegible], BUT THE
[illegible]