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Low Thermal Scanner Applications

INTRODUCTION

Working together with leading laboratories around the world, we have identified a variety of automated systems that optimize results for low level DC measurements. It is our goal to see the best methods implemented in as many laboratories as possible. This paper presents various methods for measuring voltage, resistance and temperature with uncertainties below 1 ppm. In each case the goal of automation is not simply to save labor, but also to improve accuracy as well.

Substantial progress has been made in automating test systems over the past half century. However, they have not been useful for maintaining reference standards due to the lack of suitable switches. Most computer controllable switches generate thermal offsets of about a microvolt. A scanner with very low thermal offsets is now available that makes possible many exceptional improvements in automating precision measurements. The scanner used to achieve these results has thermal offsets typically below 20 nanovolts. It has a high leakage resistance of only 1.5×10^{12} ohms, or as high as 1.5×10^{14} ohms for the guarded version of the scanner.

The scanner is presently being used together with a commercial software package, to maintain the volt in hundreds of standards laboratories around the world including the national laboratories of most industrialized nations. Although the scanner was designed for making voltage comparisons, more recently it is being used for other types of precision measurements as well. Over the last few years, much innovative work has been done to automate precision temperature and resistance measurements. Several methods are achieving errors as low as 0.1 ppm. This paper reviews some recent innovations with the goal of enabling more laboratories to improve measurements and reduce uncertainties.

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Data Proof is committed to seeing the best available methods spread throughout the worlds measurement community.

LOW THERMAL SCANNER

The device that makes this scanner possible is a sensitive latching relay. The main problem with using conventional relays is the thermal voltage caused by the heat generated by the current in the relay coil. With our latching relays a short pulse of only 10 milliseconds is all that is required to toggle the contacts from one side to the other. Thus the heat generated is negligible.

Data Proof scanners us a customized sealed relay that offers very low thermal offsets. The relay circuit makes a connection by shorting together adjacent contacts. Because the contacts are in pairs and are very close together on the board, any emfs generated by the relay contacts are canceled out.

Separate relays are used to connect the high and low input circuits so that devices that are not being compared are completely removed from the circuit and left floating. There are two lines, A-Line and B-Line for each channel. Separate relays are used to make the connections to either the A-Line or the B-Line.

ISOTHERMAL BOX: Switching assemblies are housed in a heavy machined aluminum box. This isothermal enclosure helps to maintain a uniform temperature at each of the relay contacts. The PC board edge connectors carry only the relay coil circuits. All the input and output lines are soldered directly to the board to prevent thermal voltage offsets caused by connectors.

TWO-TERMINAL: The diagram below shows the connections for comparing two-terminal devices such as voltage standards. Any two units can be compared by closing one of the A-Line relay and one of the B-Line relay. When comparing voltage standards, the small difference voltage is measured by a meter across the high A and B Lines. In this example the negative terminals are connected together on the low output Lines. All other devices connected to the scanner are left floating. The two units under test can then be switched to the opposite A or B Lines and the small difference is measured again. The meter offset can be eliminated by using the "forward" measurements and "reverse" measurements.

DUAL DESIGN: The instrument is a dual scanner; with each input channel switched independently of one of the two output lines. True four-terminal measurements are possible because both the positive and negative side of each channel can be switched. This makes the scanner ideal for a very broad number of applications.

The Guarded Low Thermal Scanner provides four input lines for each channel. So instead of requiring two channels to make a four-terminal connection, each channel can make four-terminal connections with this scanner. Additional relays are also used to switch the guard shield for the high and low guards. The Data Proof Low Thermal Quad Scanner offers eight output lines for making direct four-terminal comparisons. This scanner is designed to support Current-Comparator-Bridges so similar measurement instruments.

STANDARD CELL PROTECTION: These scanners have been carefully designed to protect standard cells from being damaged by scanner or operator error. A contact on each relay is tied to a series protection circuit. All relays must be open before power can be applied to close any relay. This protection circuit is available at the rear panel so that multiple scanners can be cascaded and all cells in a large system will have this protection feature.

CONVENIENT OPERATION: The relay circuits are activated either by front panel push buttons or by means of an IEEE-488 bus. A simple three-character bus command sets the interface to remote, opens any previously closed relay, and then closes the specified relay. Because of the dual output arrangement and low thermal design the scanner is very versatile. It can be used for many applications to automate low level measurements while avoiding errors caused by the switching.

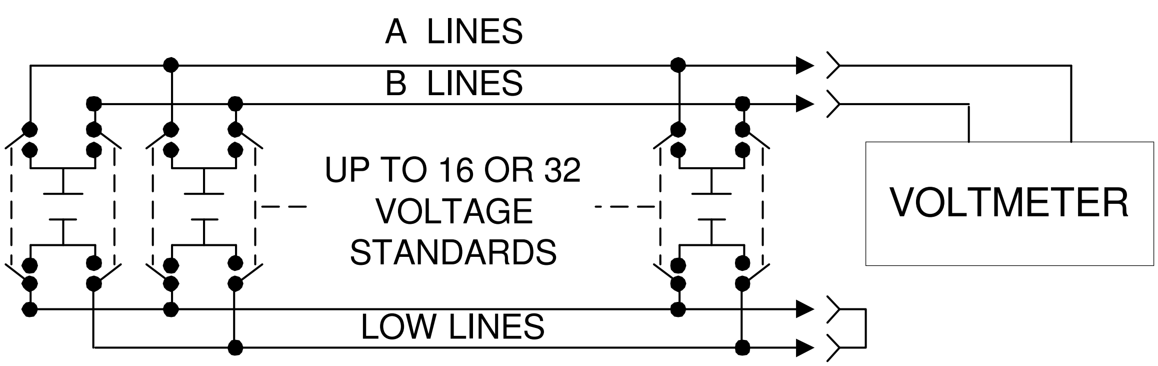


Diagram for Opt.1, 2 ,4 Low Thermal Scanners

Dual Scanner Design

MAINTAINING THE LABORATORY VOLT

A variety of voltage standards are used around the world to maintain a local or national volt. The volt in this case is usually not the output of a particular device; rather it is the statistically derived value from a group of artifact standards. All of the standards in the group have a known offset from the statistical volt and thus any one of them can be used to calibrate other standards.

The following pages describe examples of how to intercompare voltage standard such as saturated cells, solid-state devices or a Josephson Array. Laboratories using artifact standards (saturated cells or solid-state) should make periodic comparisons with units traceable to their national standard. For a laboratory to have confidence in its own internal volt requires having more than one voltage standard. We recommend a minimum of four standards to maintain a good statistical average at the 1 ppm level. If requirements exceed 1 ppm, then more than four standards will be needed in the group. Alternatively a Josephson array may be used. The process recommended for laboratories to maintain their internal volt with three or more voltage standards follows.

Recommended process

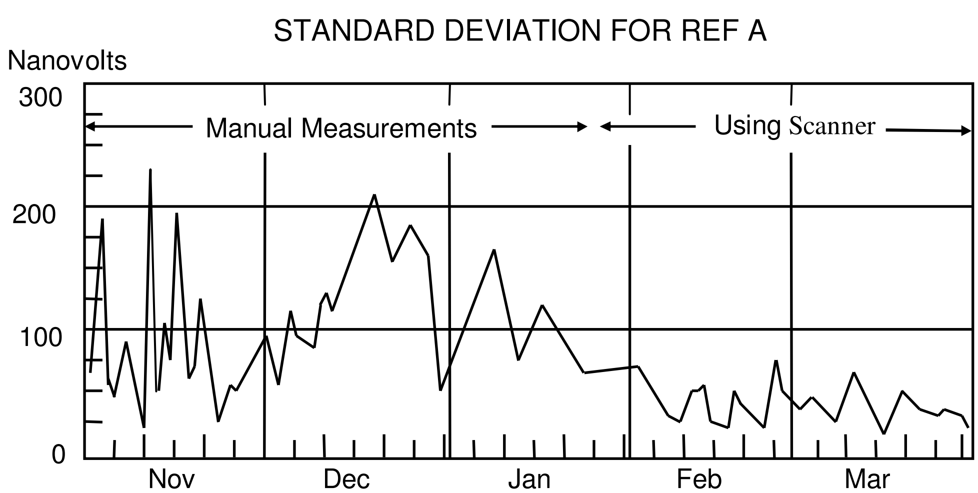
Voltage standards, whether they are saturated cells or solid-state are compared in pairs. The low terminals of the two standards being compared are connected together. The small difference between the two high terminals are then measured by means of a suitable meter. Measurements should be taken both in the forward and reverse directions to effectively eliminate the zero offset of the meter circuit. Only the negative terminals of the pair being measured should be connected together; all other devices are left floating.

All of the standards in a group are compared in pairs in an appropriate order or "measurement design". The design used should follow the procedure recommended by your national laboratory. Most national laboratories recommend one of three designs: ***ring***, ***favored cell*** or ***statistically-balanced***. Ring designs are used in some Asian countries and favored cell designs are used in some European countries. In The United States, NIST recommends the use of statistically-balanced designs. Procedures will be described in more detail in the next section (For more information, refer to NBS Technical Note 430).

Improving measurement results

Voltage measurements are extremely sensitive. Handling the leads will increase measurement errors because of the thermal emfs caused by friction and body heat. Saturated cells are also sensitive to changes caused by stray capacitance from your body presence and other electrical noises in the laboratory. The best way to reduce these errors is through the use of a Low Thermal Scanner. A switching system eliminates the need to handle the measurement leads during the measurement process. With automation, data runs can be taken when disturbances are a minimum, usually at night.

Below is a graph showing the readings taken over a five month period. For the first three months the measurements were taken manually with the leads moved by hand. During the last two months, the graph shows the significant improvement in standard deviations when a Low thermal Scanner had been installed and the leads were no longer handled.



PLOT SHOWING MEASUREMENT IMPROVEMENT WITH SCANNER

VRMP: VOLTAGE COMPARISON SOFTWARE

The Voltage Reference Maintenance Program(VRMP) completely automates the process for maintaining statistical control of the laboratory volt. It controls the scanner and voltmeter to take measurements, computes statistical information, prints reports, and stores the results in a data file. A graphics routine is included to create statistical control charts from the stored data.

The system can make measurement runs on groups as large as 32 units. Also, the system can be easily set up to run measurements at night, avoiding disturbances.

Special ten-to-one and one-to-ten scaling routines are included to allow comparisons between 1, 1.018 and 10-volt standards. Scaling accuracies of 0.2 ppm can be realized using certain 8½ digit multimeters. These procedures are described in the next section.

The program creates an appropriate test design that compares each of the units with other selected units. Comparisons are made for pairs of standards. For each comparison the voltmeter takes ten readings in the forward direction. Relays are then reversed and ten additional reading are taken in the reverse direction. This process effectively reduces errors caused by zero offset in the meter circuit.

When all intercomparisons are complete, the program computes a least-squares-fit of the data. Values for each unit are assigned based on this calculation and the values of the reference units included in the test.

The procedures used in the VRMP are accepted by most organizations running Measurements Assurance Programs (MAPs) such as NIST and Fluke. In this way laboratories undertaking MAPs need only send in the printouts provided by the software.

SYSTEM DESCRIPTION

This system uses the procedure of measuring the differences between pairs of voltage standards in a measurement design. The program was designed to follow the procedure recommended by NIST to measure pairs of devices in a ***statistically balanced*** design. However, other methods such as the ***favored cell*** and ***ring*** designs can also be used.

The scanner is a dual scanner that allows any two devices connected to the inputs to be compared against each other. All other devices connected to the scanner are left floating to reduce errors due to ground loops. The software provides a measurement design for any number of devices between 3 and 32. A delayed start feature will allow up to four different designs to be run unattended at any time.

A scanner setup screen in the program makes it easy to change the arrangement and to add or remove units from the system. Once a unit's name and channel number are entered, the program keeps track of its connection and switches it automatically in the test design. Values for the reference units are stored on a setup screen and are the values traceable to your national laboratory reference unit.

DATA PROOF
2562 Lafayette Street
Santa Clare, CA 95050

VOLTAGE REFERENCE REPORT

STANDARD DEVIATION: 0.08 **DATE: 8 July 1995**
A - B COMPONENT: 0.02 **TIME: 12:22:46**

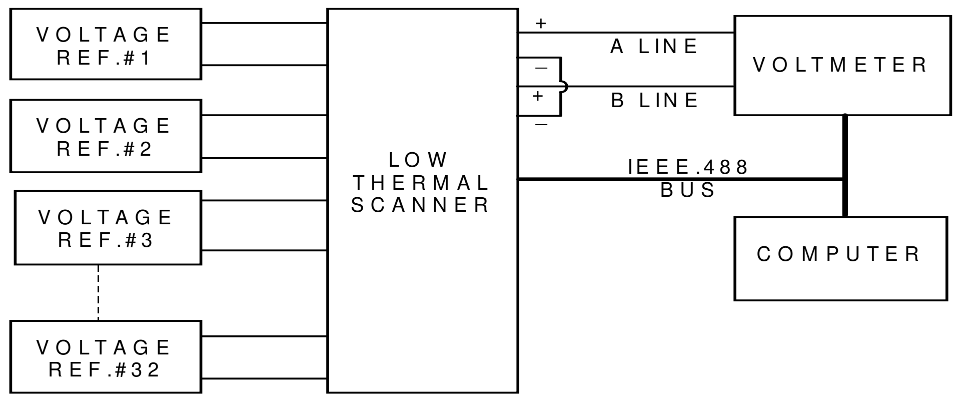
EMF DIFFERENCE BETWEEN PAIRS - MICROVOLTS

OBS	A-LINE	B-LINE	READING	DEV
1	10REF 1	10REF 2	-31.06	-0.04
2	10REF 1	10REF 3	-47.47	0.05
3	10REF 2	10REF 3	-16.59	-0.06
4	10REF 2	10REF 1	31.02	0.07
5	10REF 3	10REF 1	47.38	-0.07
6	10REF 3	10REF 2	16.52	0.06

LEAST SQUARES ANALYSIS OF EMF STANDARD DATA

GROUP	NOMINAL MICROVOLTS	GROUP MEAN	TEMP INDICATION
10REF	10 000 000.00	10 000 033.87	

NO	SCANNER POSITION	UNIT NAME	REFERENCE MICROVOLTS	DEVIATION MICROVOLTS	CORRECTED MICROVOLTS
1	1	10REF 1	10 000 004.74	2.97	10 000 007.71
2	2	10REF 2	10 000 044.22	-5.53	10 000 038.69
3	3	10REF 3	10 000 052.63	2.56	10 000 055.19



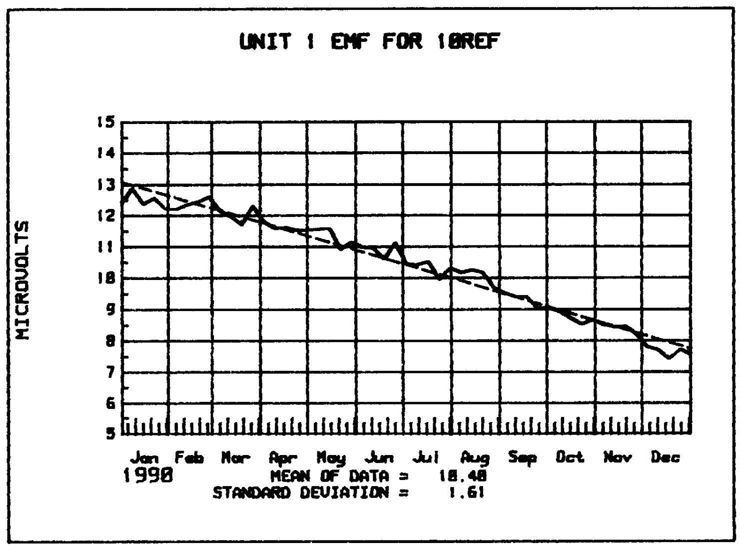
VOLTAGE COMPARISON SYSTEM

VOLTAGE SYSTEM RESULTS

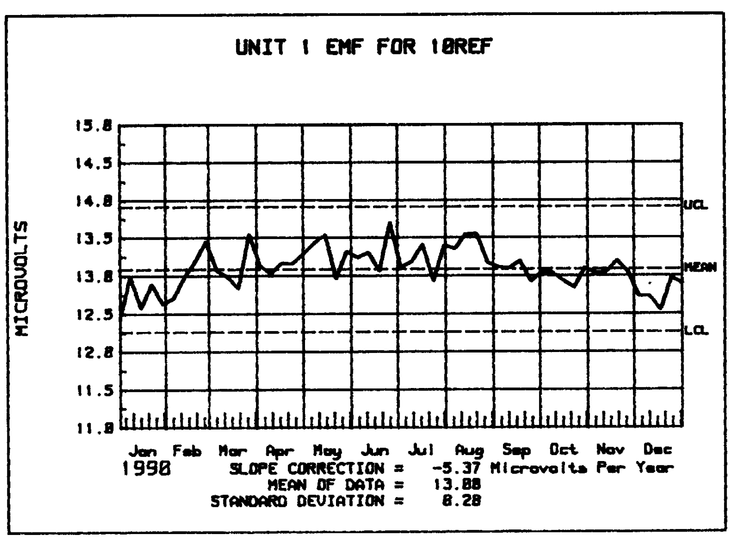
Standard deviations for a measurement design are typically less than 20 nanovolts at 1 volt, and 200 nanovolts for 10 volt units. This corresponds to 0.02 ppm. Thus, the laboratory volt can be improved through automation that renders the measuring system errors negligible.

STATISTICAL ANALYSIS

When the measurements are complete the program computes a best-fit voltage for each unit in the test. A report may be printed such as the example shown on the previous page. This report shows the six readings for the three 10-volt units, the deviations from the least-squares-fit and the best-fit value for each standard. These values may also be stored in a data file.



EMF PLOT FOR 10-VOLT STANDARD



EMF PLOT WITH SLOPE REMOVED

A plotting routine that creates several different control charts is included in the software. The figure above shows the voltage for a 10-volt standard over the period of one year. The vertical axis is 10 microvolts full scale or 1 ppm of 10 volts. The plot shows that the standard is drifting downward about 0.5 ppm per year with a fairly constant slope.

The software can also plot the data with the slope removed. The figure at the left shows the same standard without the slope. Note that the vertical scale has been reduced to 0.4 ppm of full scale. If slope values for the reference units are entered on the setup screen, corrected values will be computed for each test.

VRMP VOLTAGE SCALING SYSTEM

The following simplified method compares the different outputs of voltage standards. It enables users to make comparisons between different outputs up to 50 volts. Comparisons can be made between 1, 1.018 and 10 volts to better than 0.5 ppm.

This system is included in the VRMP software described in the previous section. The only equipment needed besides the software is a Low Thermal Scanner and a voltmeter with sufficient resolution and linearity.

TEN-TO-ONE PROCEDURE

The first step measures each traceable reference unit included in the test design. This set of measurements, along with a repeat set of measurements taken at the end of the procedure, is used to calibrate the voltmeter. Difference measurements are then taken between pairs of devices as described in the previous section except in this case the 9 volt difference between 1-volt and 10-volt outputs is measured.

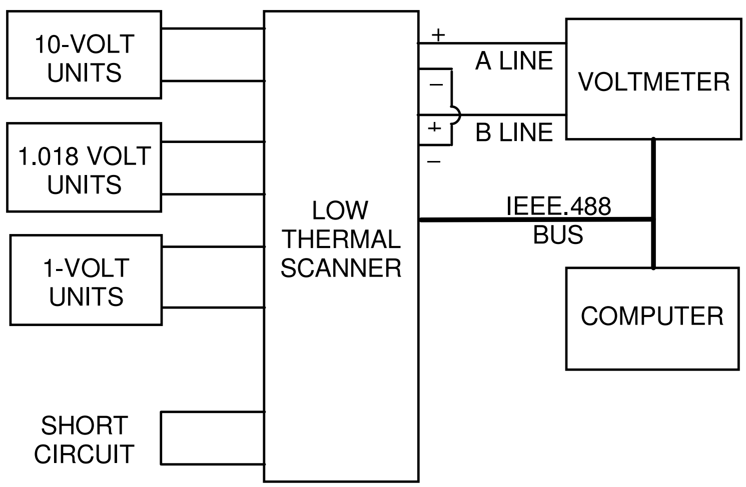
A calibration ratio for the meter is calculated by dividing the actual readings by the known value of each of the traceable reference units. This calibration factor is then applied to each of the difference measurements. The corrected measurements are used in the least-squares-fit calculation to determine the unknown values.

When using 10-volt traceable reference units this procedure works very well. Since the readings between pairs will be approximately 9 volts, and the calibration is done at 10 volts, the voltmeter need have good linearity only over the range of 9 to 10 volts. The values for the 1-volt units are computed from the least-squares-fit calculation.

ONE-TO-TEN PROCEDURE

A more complicated procedure must be used to ensure good results when scaling from 1 or 1.018-volt units. Rather than simply calibrating the meter at 1 volt and depending on it to be linear from 1 to 9 volts, an alternative method is used that only requires the meter to have good linearity over the range from 9 to 10 volts.

In this procedure the measured value for each 10-volt device in the test is taken along with the traceable 1 or 1.018-volt reference devices. A preliminary meter correction is found. The difference measurements are then taken as before. These readings are adjusted using the preliminary meter correction. Computed values are found for the 10-volt units from the least-squares-fit calculation that are biased on the known 1-volt values. The final meter correction is found by adjusting the correction so that the adjusted computed values for the 10-volt devices are equal to their adjusted measured values. By using the method described only the meter readings at 9 and 10 volts are significant in determining the final values for the 10-volt units.



VOLTAGE SCALING SYSTEM

RESULTS

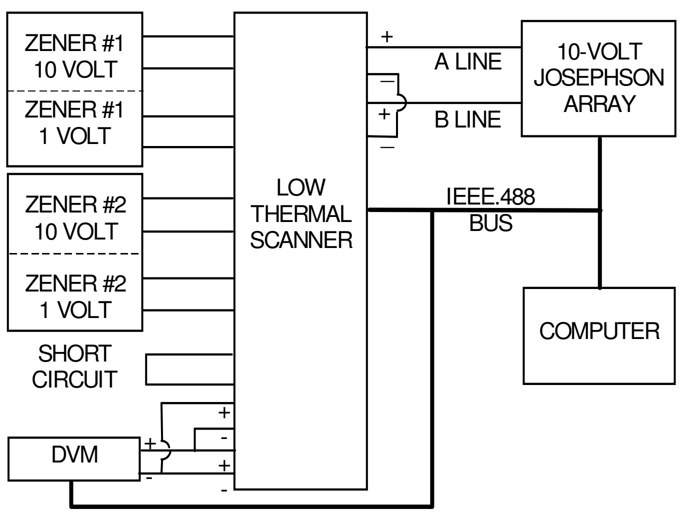
The accuracy of the scaling procedure is primarily dependent on the meter linearity and on the resolution available on the 10-volt range. Tests using the procedure with two commercially available voltmeters have been done at laboratories that have 10-volt Josephson arrays. Many test runs show that values obtained with the scaling procedure lie within 0.5 ppm of measurements made directly against the Josephson arrays. Typical measurement differences were about 0.2 ppm. The two meters tested were the Agilent 3458A and the Datron 1281. Several of each of these two models were used.

Laboratories can now take advantage of the superior long-term stability of saturated cells to maintain their volt, while using the more rugged solid-state devices as working standards and for volt transfers between laboratories.

10-VOLT JOSEPHSON JUNCTION ARRAY SYSTEM

Three novel improvements enable automation of a voltage standard system based on a 10-volt Josephson array: (1) A low thermal scanner controls switching for calibrating both Zener references and digital voltmeters (DVM), (2) A programmable attenuator is used to obtain voltage steps, and (3) Measurements of DVM noise are used to verify array stability.

This work was done by Richard Steiner and Robert Astalos at NIST, and was presented at the CPEM'90 in Ottawa (IEEE Trans. IM vol. 40, April 1991). The system is being used at NIST to calibrate and evaluate Zener standards, and to evaluate the stability of DVMs.



10 VOLT JOSEPHSON JUNCTION ARRAY SYSTEM

10-VOLT JOSEPHSON ARRAY SYSTEM DESCRIPTION

A Josephson array with 19,900 junctions can provide many precise voltages over the range from 0 to +10 volts. NIST has developed a completely automatic system that engages a programmable millimeter wave attenuator to generate known voltage steps. It also controls the DVM and low thermal scanner to perform the comparisons. This system operates completely unattended. A technician, who may be unfamiliar with Josephson physics, needs only to perform a basic setup sequence for operation.

The NIST system uses a novel connection arrangement to provide the required switching. Unlike voltage references, a Josephson array need not be physically reversed within the circuit since it can be electrically reversed. The array is connected to the scanner output terminals and the DVM is connected to two of the input channels as shown in the diagram. The DVM is connected directly to Channel 15 and is reverse connected to Channel 16. This allows the array to be compared directly against any of the Zener inputs using the DVM to read the small voltage difference. The complete circuit is reversed by interchanging the A/B Channel for the Zener, using the other DVM channel, and reversing the array polarity. This eliminates the effects of the thermal emfs from the cryogenic wiring.

The same connection scheme works as well for DVM calibrations. For this case, one scanner input channel is shorted to let the DVM be linked directly to the array. No further switching is needed.

GENERATING AND VERIFYING STEPS

Generating array steps is an integral process requiring sensitive adjustments of the voltage bias and millimeter wave power. Mr. Steiner has found a reliable method of automating step selection using a programmable attenuator. This method is general enough for use with any array and any voltage.

Verifying array steps is of major importance. Since multiple DVM readings are always involved, the standard deviation of each series is used as the vital parameter to monitor step quality. If the standard deviation is more that about 1.5 times greater than the background noise, the computer repeats the measurement or a new step is generated.

10-VOLT JOSEPHSON ARRAY SYSTEM RESULTS

The Zener reference calibration is an average of four independent points, derived from sixteen DVM readings and four array polarity changes. This procedure provides a straightforward calculation of the standard deviation of the mean. The Type-A random uncertainty is about 0.004 ppm at 10 volts, and about 0.008 ppm at 1.018 volts.

For DVM calibrations the array provides voltages at various calibration points. The NIST system calculates a proportionality constant (gain error) for each polarity and deviations from this linear fit at each measured value (linearity errors). System resolution is 0.02 ppm.

OhmRef: RESISTANCE MAINTENANCE PROGRAM

A variety of methods are available for making automated resistance measurements. There are three methods available in the OhmRef software. Each method is capable of achieving parts-per-million results, and some can do better than one ppm depending upon the resistance level. The method chosen will depend upon the equipment available, resistance level and accuracy required. Each method can be used to scale resistors over a range of 10 to 1.

OhmRef provides very good results with a low cost system using equipment already available in most laboratories. The program is easy to setup and use. It accommodates any value of resistor between 0.1 milliohm and 100 megohms. The following describes the three methods used in OhmRef with recommended ranges and typical results that can be achieved by each method.

GENERAL MEASUREMENT PROCEDURE

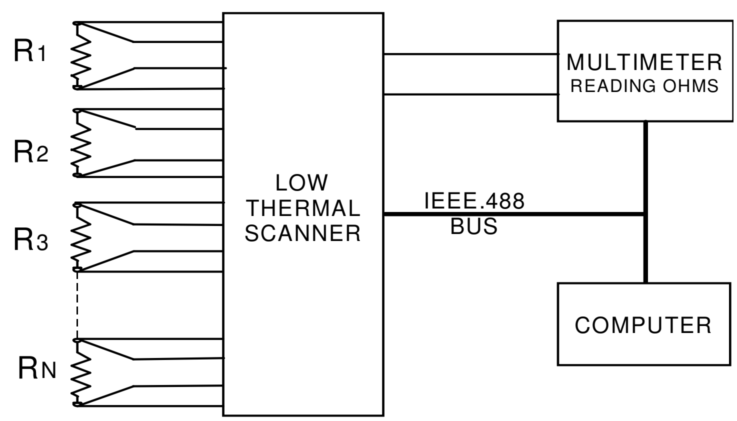
For all three methods the program creates a statistically balanced design for the resistors being compared. Any number of resistors can be compared with OhmRef between two and eight. The resistors are measured in pairs, and the difference between each pair is recorded. The software will control the scanner and source, and get readings from the multimeter. The voltage or current to be applied is determined from the current limit entered on the OhmRef setup screen for each resistor. When all the intercomparisons are complete the program computes a least-squares-fit of the data. Values for each of the resistors are assigned based on the least-squares-fit results and the average of the values of the reference resistors in the test.

Readings are taken as rapidly as possible for each pair of resistors in the design to reduce errors caused by instabilities in the current source. Only the average of the difference readings from both forward and reverse measurements is recorded. In this way, the source needs to be stable only for the duration of a pair measurement rather than for the entire measurement. Statistical monitoring of the meter readings reduces measurement time by avoiding taking more samples than are necessary. Readings are taken rapidly until five successive readings fall within a preset deviation.

THREE METHODS FOR MEASURING RESISTORS

Method 1: Direct four-terminal DMM connection

For this method the DMM is set to the ohms function and makes four-terminal connections through the scanner to measure the resistors directly. This method does not require an external source; and thus, is simplest method, requiring only a Low Thermal Scanner and an 8½ digit digital multimeter. The method is useful for measuring higher values of resistance (above 100 kilohms) where the DMM loading reduces the accuracy for methods 2 and 3.

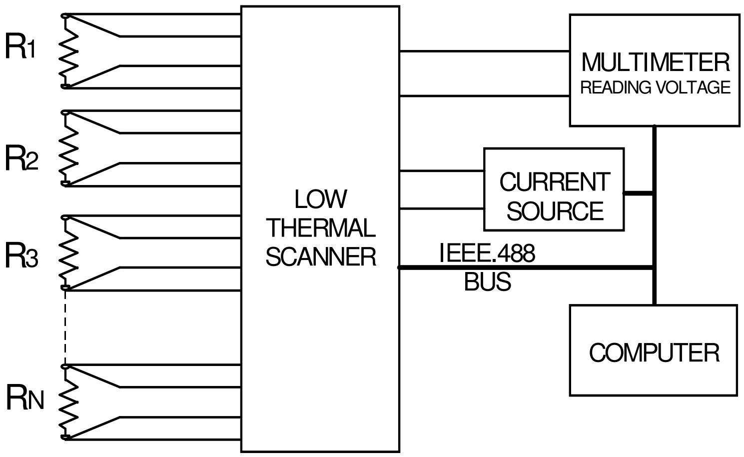


METHOD 1: DIRECT FOUR-TERMINAL CONNECTION TO DMM

Method 2: Direct connection using external source

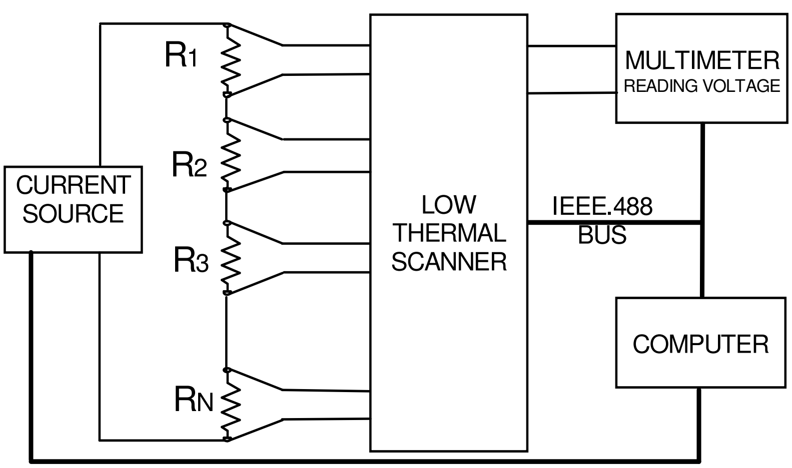
This method uses an external current source that provides several advantages over the first method. First, the source polarity can be reversed which reduces errors caused by circuit thermals and meter zero offset. Also a higher current can be used which allows greater resolution. With this method the multimeter is set to measure voltage rather than resistance. In the voltage mode scaling between different values of resistors can be done with greater accuracy. Be sure to consider the loading effect of the multimeter input impedance when measuring resistors above 100 kilohms.

OhmRef limits the maximum current to 100 milliamps when Data Proof scanners are used. Although the relay manufacturer specifies a maximum current limit of 0.5 amps, life tests run at that level have shown contact discoloration which could lead to increased thermal offsets. No such effect was noted at 100 milliamps. For higher current operation method 3 is recommended.



METHOD 2: DIRECT CONNECTION WITH CURRENT SOURCE

Method 3: Series connection using external source
In this method all the resistors in the test are hard-wired together with the current source. The current path is not switched through the scanner. This has the advantage that any current level can be used limited only by the source. Also the current is not interrupted by the switching process. The meter reads the voltage drop across the resistors through the scanner. During the measurement process the current source is electrically reversed to reduce the effects of circuit thermals. This method is useful for lower value resistors where higher currents are required. However it has the disadvantage that the resistors to be tested must be wired together for each test. Whereas with methods 1 and 2 any resistors connected to the scanner can be compared simply by choosing them from the program startup screen .



METHOD 3: SERIES CONNECTION WITH EXTERNAL SOURCE

STATISTICAL ANALYSIS

For all three methods OhmRef measures pairs of resistors and records the differences. When all readings are completed OhmRef does a least-squares-fit calculation to find best-fit values for all the resistors in the test. The best-fit values are based on the least-squares-fit and the reference values of the traceable units in the test. A report can be printed that shows the difference readings along with the best-fit resistor values. The report is similar to the report shown in an earlier section of this paper titled *VRMP: Voltage Maintenance Program.* Also as in the VRMP the data can be stored in a data file so that control charts and plots can be made at a later time. The stored data can also be exported to a DOS file for analysis using a spread sheet program.

Results

Standard resistors can be compared in an automated statistically controlled process. By using the scanner to make many measurements rapidly, and by reversing the source and resistance connections, system errors are greatly reduced. Typical uncertainties for each method are as follows.

Method 1 can be used to compare nominally equal resistors over the range of 1 ohm to 100 megohm with uncertainties in the range of 1 to 10 ppm. The uncertainty increases near 1 ohm due to the meter resolution, and above 1 megohm due to leakages in the meter circuit.

Method 2 is recommended over the range of 1 ohm to 1 megohm. This method usually gives better results than method 1 up to 1 megohm because higher currents can be used. Uncertainties in the midrange can be about 0.5 ppm. Uncertainties when scaling 10 to 1 will be in the range of 1 ppm to 7 ppm.

Method 3 works well from 1 milliohm to 1 megohm. It achieves similar results over the midrange and better results at the lower values because more power can be applied to the resistors. Uncertainties of about 0.5 ppm can be obtained when measuring nominally equal values, and about 1 ppm when scaling 10 to 1.

RING METHOD FOR MEASURING STANDARD RESISTORS

Expanding on the concept of the unbalanced-bridge technique, a new system for measuring standard resistors has been developed. This system is capable of comparing any even number (six or more) of nominally equal resistors from 10 ohms to 1 megohm. The precision ranges from about 0.07 ppm at 10 kilohm to about 1 ppm at 1 megohm. This automated measuring system was developed at NIST, and was presented by Ron Dziuba at the CPEM'88.

RING SYSTEM DESCRIPTION

This system is currently being using at NIST to measure differences between nominally equal four-terminal Rosa and other types of resistors from 1 kilohm to 1 megohm. Six nominally equal resisters, R1 through R6 (as shown in the figure below), are mounted on a mercury-wetted ring stand located in a temperature controlled oil bath. A precision source of known output voltage is connected to opposite corners of the ring at nodes `AA', dividing the ring into two parallel strings of three resistors. Six measurements are then taken of the small differences in potential between the opposing terminal taps, i.e., Val, Vbk, Vcj, Vdi, Veh and Vfg. The value used for each measurement is the average of the readings with the voltage source in the forward and reverse directions. The voltage source is then moved to `BB' and six more measurements are taken between opposing terminal taps. Finally six more measurements can be taken after the voltage source is moved to `CC'. A matrix is formed from the three sets of measurements. From this matrix the values of the unknown resistors are determined based on their comparisons to the known resistor values.

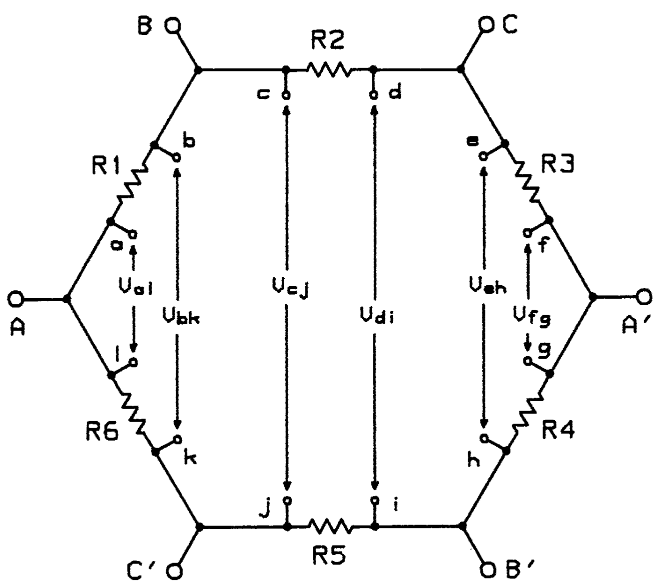
A program developed at NIST, written in Basic, runs the entire measurement process. The program controls two low thermal scanners, one that rotates the voltage source and another one that makes the connections between the resistor potential terminals and the DVM. The computer program records the readings and calculates the results.

A guarding system is used to reduce errors due to leakage resistance in the DVM and voltage source circuits. The system can be run at night when the environmental disturbances are at a minimum.

At NIST the system is usually set up to operate four six-arm mercury ring stands at the decade values between 1 kilohm and 1 megohm. Also the system has the flexibility to accommodate lower resistance values down to 10 ohms, as well as other types of standard resistors.

RING SYSTEM RESULTS

The NIST system compares six resistors at a time including three unknowns, two reference units and one check standard. Uncertainties vary depending on the resistance level. Best results are achieved when comparing 10 kilohm resistors, with a random uncertainty of about 0.07 ppm. At 100 ohms the random uncertainty is about 0.26 ppm.



RING RESISTANCE SYSTEM

GUARDED HIGH-OHM RESISTANCE SYSTEM

By using a guarded scanner and two sources to form a guarded resistance bridge, measurements from 100KΩ to 10GΩ can be made with excellent accuracy. This system provides a simple yet effective way to activate both the high and low guard circuits. Adjusting the source outputs to set the high impedance side of the bridge circuit to zero volts reduces errors caused by meter circuit loading. The system described here is similar to one to the one used by NIST for measuring resistors in the GΩ range.

HIGH-OHM DESCRIPTION

This circuit is a wheatstone bridge where two legs of the bridge are voltage sources. A DVM measures the voltage across the bridge and a low thermal scanner is used to switch the resistors in the test.

The standard low thermal scanner has leakages of about $10^{12}\Omega$. In a normal arrangement the leakage currents would cause errors of about 1 ppm at the 1 MΩ and 100 ppm at 100 MΩ. By using a fully guarded scanner, leakages can be significantly reduced.

Because the sources have low impedances, the high guards can be connected directly to the source outputs. The low guard can be connected directly to ground because the sources are always adjusted so that the DMV reads zero.

Keeping both sides of the bridge at zero volts reduces leakage errors. This is done by using two voltage sources for two arms of the bridge as shown in the diagram below. Voltage source #1 is adjusted so that the DVM always reads zero, which sets the center point of the two resistors being compared to zero volts. The tare standard is always in the circuit, and the low thermal scanner is used to switch the standard and test resistors into the circuit one at a time.

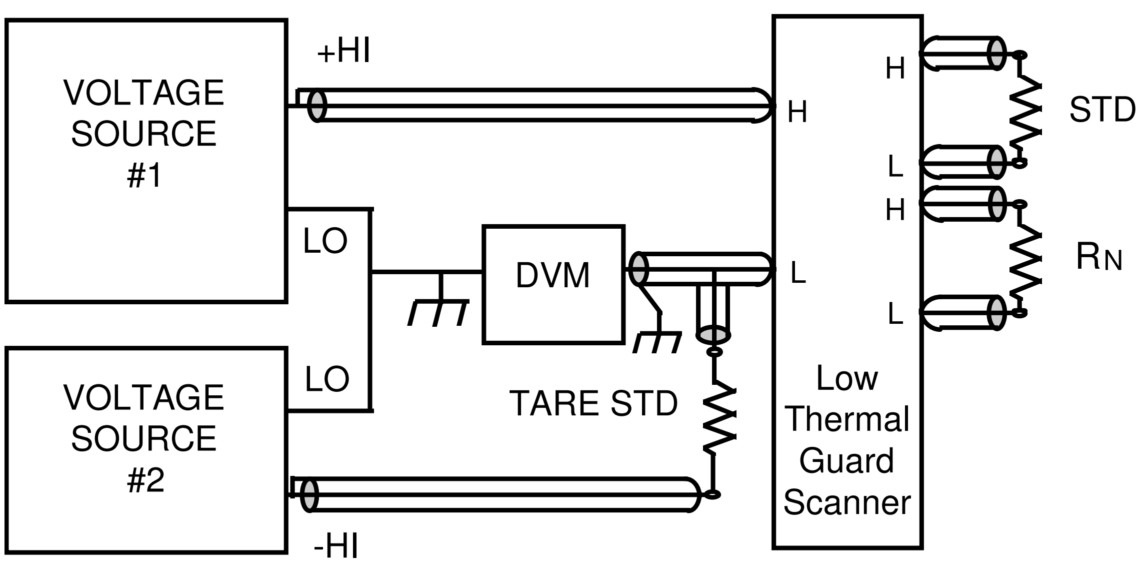
OHMREF SOFTWARE

The High-Ohm Resistance method is now included in the Data Proof OhmRef software. This provides a convenient means to set up an make high resistance measurements. OhmRef will allow up to 8 resistors to be compared at a time.

HIGH-OHM RESULTS

A non-guarded scanner can be used to compare resistors to 10MΩ with an uncertainty of about 1ppm. With a guarded scanner good results can be obtained comparing 1GΩ resistors with an uncertainty of about 10 ppm.

Different values of resistors can be compared over a wide range with the uncertainty is primarily dependant upon the scaling accuracy of the voltage source used.



GUARDED HIGH-OHM CONNECTION

THERMOCOUPLE CALIBRATION SYSTEM

The measurement of temperature is a basic parameter in the control of many processes in both research and industry. Thermocouples are used extensively for many higher temperature measurements. Manual calibration of thermocouples is a tedious and time consuming process. With the aid of a low thermal switching system, with thermal emfs in the nanovolt region, automation with high accuracy is possible.

The following system is being used by Brad Mellons and Will Schneider of Lockheed Missiles and Space Company in Sunnyvale, California for the calibration of thermocouples in their Standards Laboratory. They are using this system to calibrate all types of base metal junctions as well as platinum-rhodium types. The most critical are the type S units, which have an output sensitivity of only 8 to 12 microvolts per degree Celsius.

SYSTEM DESCRIPTION

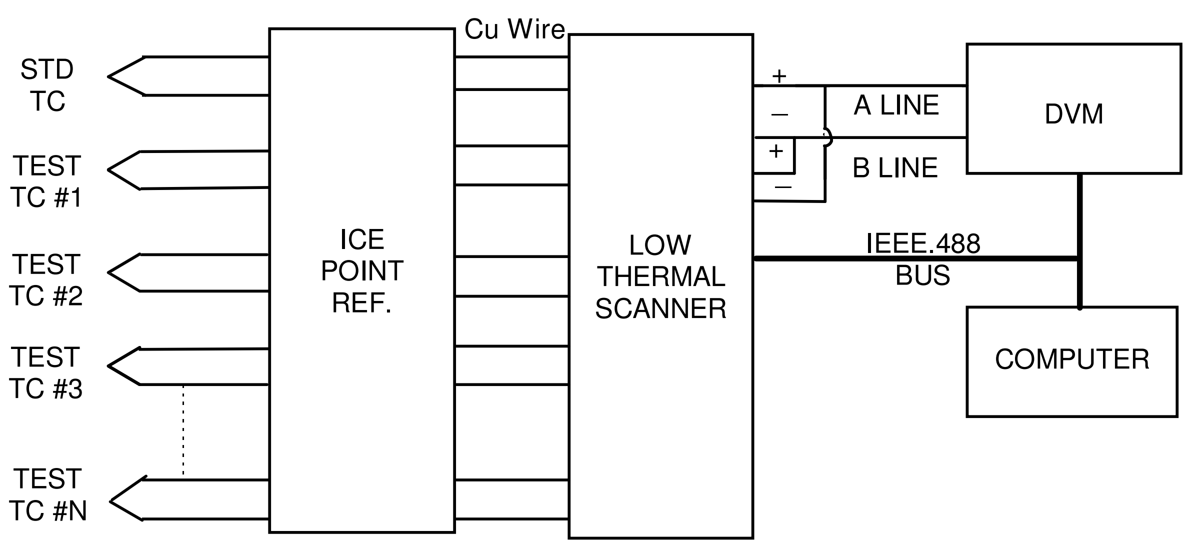
At Lockheed-Martin, the thermocouple leads are connected to ice point references that are connected to scanner input channels (see figure below). The appropriate ice point references are selected for the type of thermocouple under test.

An alternative configuration would be to connect the thermocouples directly to the scanner input channels and connect the ice points between the scanner output terminals and the DVM. With this method only two pairs of ice points are required. A small additional error is created by the temperature difference between the input and output terminals. With insulation this error can be reduced to less than 0.2 degrees Celsius.

Once the connections are made the measurement process is completely automated. At Lockheed the computer controls the oven and waits until the oven reaches equilibrium as measured by the standard thermocouple. The scanner is then switched to take a series of readings to compare the test thermocouples to the standard, with half the readings taken in the reversed direction. When all test units have been checked the computer will set the oven controller to the next temperature.

THERMOCOUPLE SYSTEM RESULTS

The major source of error in a temperature calibration is caused by gradients in the oven. At Lockheed the stability of a measurement for a type S thermocouple is about 1.5 microvolts. The day-to-day repeatability of the same thermocouples in the same holes in the oven is about 2.5 microvolts. This corresponds to about 0.2 to 0.3 degrees Celsius. For other types of thermocouples with higher outputs, the errors caused by the measuring system are negligible.



THERMOCOUPLE MEASUREMENT SYSTEM

SIMPLIFIED THERMOCOUPLE COMPARISON SYSTEM

A system for comparing thermocouples was developed that eliminates the need for stable furnace temperatures and ice point references. This simplified system can be used without sacrificing accuracy if all units under test are the same type and have similar construction to the reference unit.

This system was used at Agilent to calibrate platinum vs. platinum-rhodium type R thermocouples used to calibrate silicon defusion furnaces. The range of calibration was from 600 to 1100 degrees Celsius.

SYSTEM DESCRIPTION

By using a reference standard with identical construction and materials to the thermocouples being calibrated, all time constants will be the same. Because all units in the test have the same time constant, accurate measurements can be made in a slowly moving furnace. A reference standard and several units under test are placed in the calibration furnace. The furnace is heated to a temperature slightly above the highest calibration point, and then turned off and allowed to slowly cool. At HP the furnace used was a well-insulated fluidized bed that took about 6 hours to cool from 1150 to 600 degrees Celsius.

Readings are taken at calibration points as the furnace is cooling down, usually every 50 degrees. The furnace temperature does not need to be stable or to be known closer than a few degrees because only difference measurements are being made. The units in the test must have the same time constant and all must be at the same temperature.

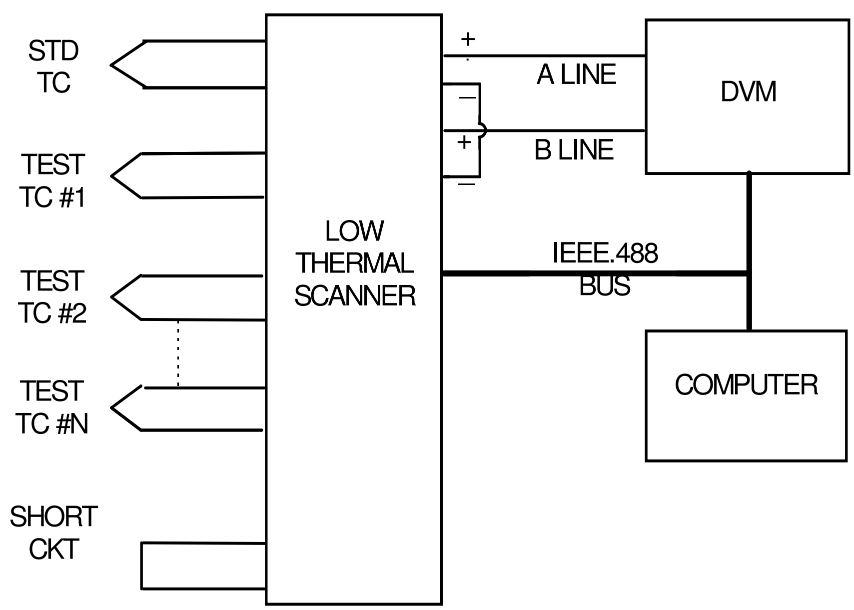
A low thermal scanner is used to measure differences between each unit under test and the reference standard. A short circuit is placed across one of the scanner inputs enabling the reference unit to monitor the furnace temperature directly. When the temperature falls two or three degrees above the test point, a set of measurements is taken. Each unit under test is compared several times to the reference standard.

Ice point cold junction references are not used because it is not necessary to know the absolute temperature, closer than a few degrees. The approximate cold junction correction required for the furnace temperature is made by measuring the temperature at the DVM terminals. When doing the calculations for the difference measurements the cold junction corrections cancel.

COMPARISON RESULTS

This system was tested by making repeated measurements with the thermocouples in the same furnace wells. Agreement was about 0.3 deg. at 1100 deg. C. and 0.1 deg. at 600 deg. C. When the reference unit was interchanged with a test unit the agreement was about 0.5 deg. at 1100 deg. C. and 0.2 at 600 deg. C.

Similar results were obtained using the conventional procedure with stabilized furnace temperatures and ice points. Thus no additional errors are introduced using the simplified procedure.

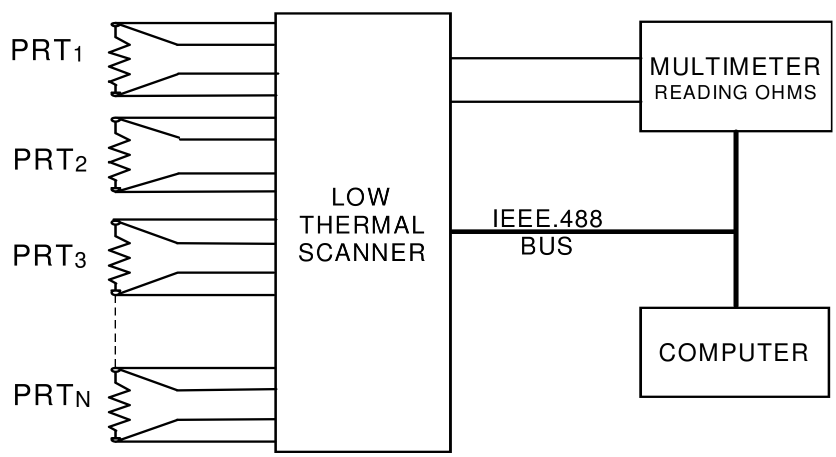


SIMPLIFIED THERMOCOUPLE COMPARISON SYSTEM

PRT Comparison System

The low thermal scanner is an excellent tool for comparing platinum resistance thermometers (PRTs). Accurate measurements require the ability to detect differences of a fraction of a milliohm. For example, a 25 ohm laboratory reference PRT operating at 1 milliamp has a sensitivity of about 0.1 ohm per degree Celsius. Thus in order to observe a 1 millidegree temperature change the system must be able to resolve 0.1 milliohm. This corresponds to a voltage change of only 100 nanovolts across the PRT. Since the low thermal scanner has typical thermal offsets of only 10 or 20 nanovolts so it will allow sub-millidegree accuracy with out introducing significant switching errors. Through automation many readings can be taken rapidly for improved results.

Two setups that work well for measuring PRTs are described. Both take advantage of automation to improve measurement results. Several reference PRTs or a number of production PRTs may be compared at one time.



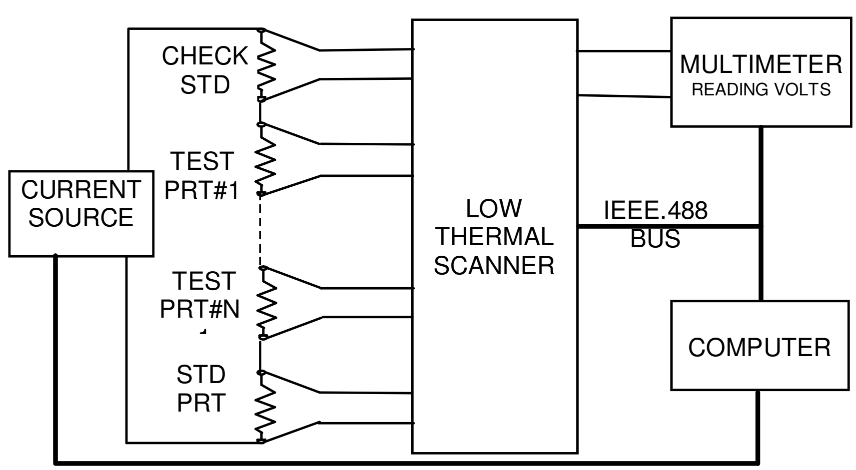
PRT FOUR-TERMINAL CONNECTION

FOUR-TERMINAL CONNECTION

Because a PRT is essentially a resistor, the normal resistor connections can be used. The four-terminal connection diagram at the upper right shows how PRTs can be connected to be compared using a high resolution multimeter. Some meters have a math module built in that accepts entry of PRT calibration coefficients and displays corrected temperature directly.

SERIES CONNECTION

The diagram shown on the lower right shows the connection using an external current source. In this case the multimeter is set to read volts. This method has several advantages. The most important advantage is that you can control the PRT. Also the current source and the scanner output can be reversed separately so that four different measurements can be made on each unit to reduce errors in the meter circuit.



PRT SERIES CONNECTION

PRT SYSTEM RESULTS

Both systems enable the performance of PRTs to be automatically verified in a systematically controlled process. The Series Connection system has been used to measure R-zero of 100 ohm test probes to approximately 0.3 milliohm at a confidence level of one standard deviation.