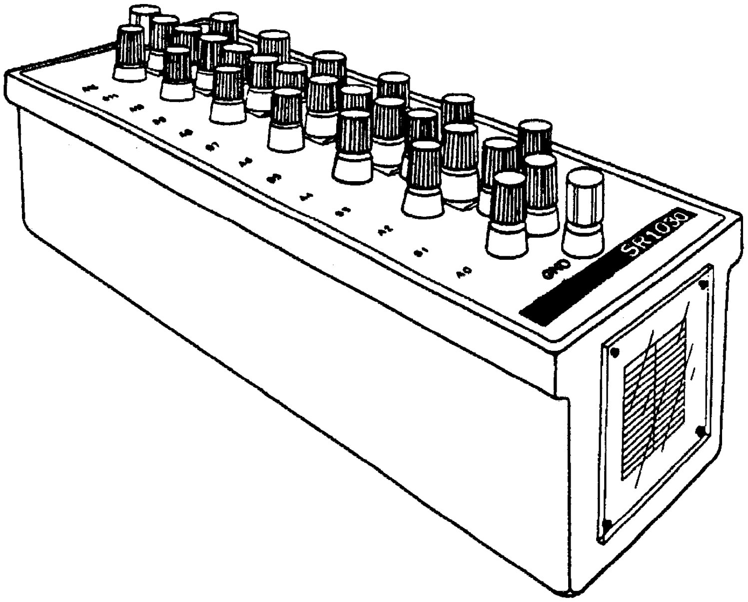
◆ PRECISION INSTRUMENTS FOR TEST AND MEASUREMENT ◆

SR-1030 SERIES

Resistance Transfer Standards

User and Service Manual



SR-1030 im/August, 2007

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◆ PRECISION INSTRUMENTS FOR TEST AND MEASUREMENT ◆

WARRANTY

We warrant that this product is free from defects in material and workmanship and, when properly used, will perform in accordance with applicable IET specifications. If within one year after original shipment, it is found not to meet this standard, it will be repaired or, at the option of IET, replaced at no charge when returned to IET. Changes in this product not approved by IET or application of voltages or currents greater than those allowed by the specifications shall void this warranty. IET shall not be liable for any indirect, special, or consequential damages, even if notice has been given to the possibility of such damages.

THIS WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED OR IMPLIED, INCLUDING BUT NOT LIMITED TO, ANY IMPLIED WARRANTY OF MERCHANTIBILITY OR FITNESS FOR ANY PARTICULAR PURPOSE.

WARNING

OBSERVE ALL SAFETY RULES
WHEN WORKING WITH HIGH VOLTAGES OR LINE VOLTAGES.

Dangerous voltages may be present inside this instrument. Do not open the case
Refer servicing to qulified personnel

HIGH VOLTAGES MAY BE PRESENT AT THE TERMINALS OF THIS INSTRUMENT

WHENEVER HAZARDOUS VOLTAGES (> 45 V) ARE USED, TAKE ALL MEASURES TO AVOID ACCIDENTAL CONTACT WITH ANY LIVE COMPONENTS.

USE MAXIMUM INSULATION AND MINIMIZE THE USE OF BARE CONDUCTORS WHEN USING THIS INSTRUMENT.

Use extreme caution when working with bare conductors or bus bars.

WHEN WORKING WITH HIGH VOLTAGES, POST WARNING SIGNS AND KEEP UNREQUIRED PERSONNEL SAFELY AWAY.

CAUTION

DO NOT APPLY ANY VOLTAGES OR CURRENTS TO THE TERMINALS OF THIS INSTRUMENT IN EXCESS OF THE MAXIMUM LIMITS INDICATED ON THE FRONT PANEL OR THE OPERATING GUIDE LABEL.

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SECTION S

SAFETY INFORMATION

S.1 INTRODUCTION

Read and follow the CAUTIONS and WARNINGS in this manual. They are designed to emphasize safety during all phases of operation and maintenance.

S.2 SAFETY TERMS AND MEANINGS

CAUTION -- Statements identify conditions or practices that could result in damage to the equipment or property.

WARNING -- Statements identify conditions or practices that could result in personal injury or loss of life. In addition, damage to the equipment or other property may result.

DANGER -- These are generally labels appearing on the equipment. They will often be reproduced in the manual.

On the equipment they indicate a hazard to personnel that could result in serious injury or loss of life is nearby.

In the manual they identify a procedure or function that exposes the user to a critically hazardous area.

S.3 WARNINGS APPEARING IN THIS MANUAL

WARNING

A POTENTIAL SHOCK HAZARD CAN EXIST ON THE SR1030 AND ITS OPTIONS (SR103 SHORTING BARS, PC101 PARALLEL NETWORK, AND SPC102 SERIES-PARALLEL COMPENSATION NETWORK) WHEN CONNECTED TO A VOLTAGE SOURCE GREATER THAN 42.4 VOLTS PEAK (30 VOLTS RMS). BE AWARE OF THIS CONDITION WHEN CONNECTING A VOLTAGE SOURCE TO THE SR1030 AND ITS OPTIONS.

WARNING

BEFORE CLEANING THE SR1030'S EXTERIOR, UNPLUG ANY POWER SOURCE CONNECTED TO THE SR1030. FAILURE TO DO SO CAN CAUSE SERIOUS INJURY FROM CONTACT WITH THE POWER SOURCE POTENTIAL.

CAUTION

DO NOT FILL 100 KILOHM-PER-STEP SR1030 WITH OIL. USE OIL IN SR1030s WITH RESISTANCE VALUES OF 1 OHM-PER-STEP THROUGH 10 KILOHM-PER-STEP ONLY.

CAUTION

DO NOT OVERFILL THE SR1030. OVERFILLING AN SR1030 COULD RESULT IN AN OIL LEAK DUE TO THERMAL EXPANSION OF OIL.

THE TEMPERATURE OF THE OIL AND SR1030 SHOULD BE STABLE AT 23° CENTEGRADE BEFORE FILLING THE SR1030. WHEN FILLING THE SR1030, BOTH TEMPERATURE EXTREMES AND TEMPERATURE DIFFERENTIALS ARE FACTORS THAT CAN CONTRIBUTE TO AN OIL LEAK DUE TO THERMAL CHARACTERISTICS OF THE OIL.

THE FUNNEL MUST BE CLEAN (INSIDE AND OUT) TO AVOID CONTAMINATING THE MINERAL OIL.

CAUTION

OIL MUST BE DRAINED FROM THE SR1030 BEFORE TRANSPORT. FAILURE TO REMOVE THE OIL WILL CAUSE UNNECESSARY STRESS ON SEALING GASKETS.

CAUTION

AVOID THE USE OF CHEMICAL CLEANING AGENTS WHICH MIGHT DAMAGE THE PLASTICS USED IN THIS UNIT. DO NOT APPLY ANY SOLVENT CONTAINING KETONES, ESTERS, OR HALOGENATED HYDROCARBONS. TO CLEAN THE SR1030, USE ONLY MILD SOAP AND WATER SOLUTIONS.

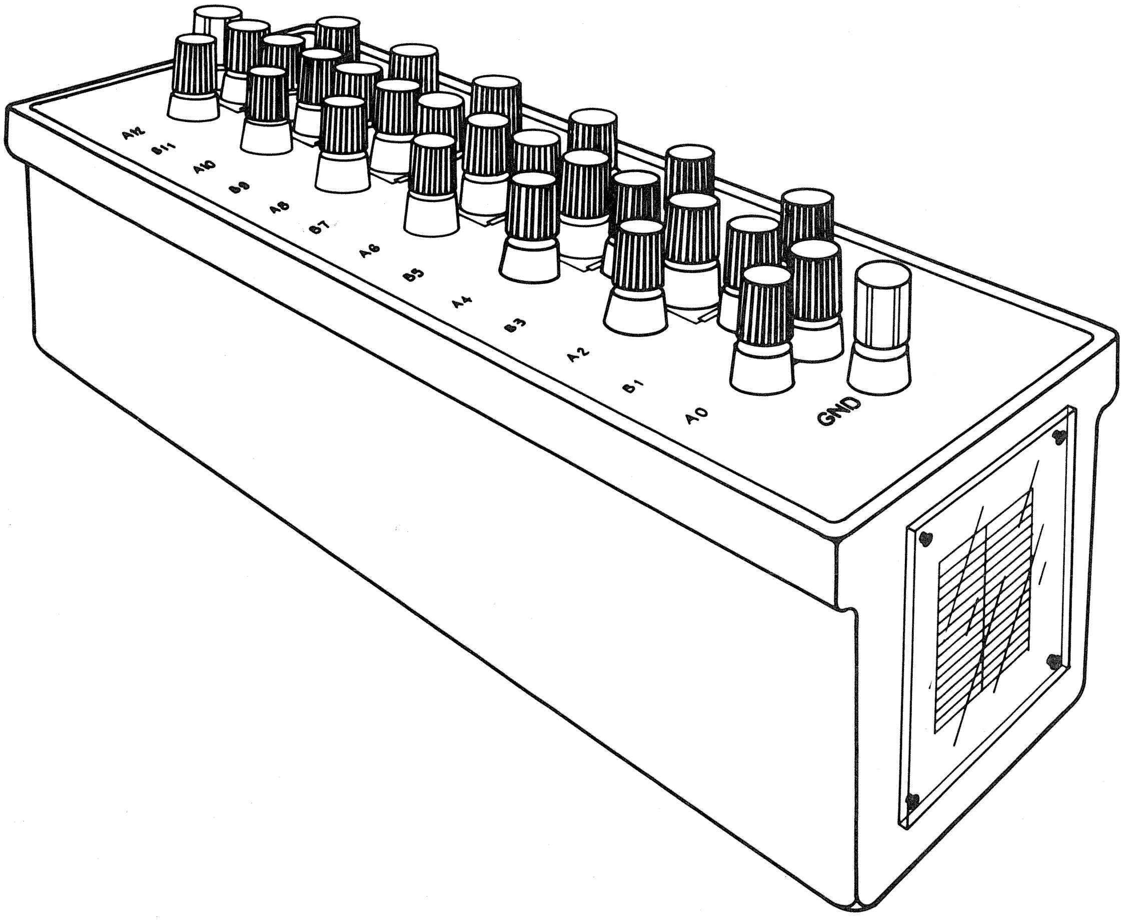


Figure 1-1. SR1030 Resistance Transfer Standards

SECTION 1
GENERAL INFORMATION

1.1 INTRODUCTION

This is the instruction manual for the Model SR1030 Resistance Transfer Standards. It provides complete information about the installation, operation, performance, and maintenance of the SR1030.

> **NOTE:** The term "SR1030" will be used in place of "Model SR1030 Resistance Transfer Standard" in this manual.

1.2 GENERAL DESCRIPTION

Each Model SR1030 Resistance Transfer Standard is a resistance box containing 12 nominally equal precision resistors. SR1030 boxes are available in decade steps from 1 ohm-per-step to 100 kilohms-per-step. A set of six SR1030s provides the calibration laboratory with accurate standards across a range of 0.1 ohm to 1.2 megohms.

There are three basic ways to use an SR1030 depending upon the required accuracy. For many applications, the resistor adjustment accuracy is high enough that the resistors can be assumed to have their nominal values. If higher accuracy is required, certified calibration data included with an SR1030 can be used to correct the values. For the highest accuracy, a resistance transfer method can be used to transfer calibration from a high-accuracy reference standard to the entire range spanned by a set of SR1030s. This method provides accuracy at the time of calibration at the parts-per-million (ppm) accuracy level.

Each SR1030 consists of 12 nominally-equal resistors that are permanently connected in series. Each resistor has two terminals at each end, allowing four-terminal connections to any individual resistor or series-connected group of resistors. The resistors are connected to the terminals using a patented (U.S. Patent No. 3,252,091) four-terminal junction to ensure that the connection to the resistors will allow accurate four-terminal measurements even when the resistors are connected in series or parallel groups.

The SR1030 owes its high accuracy and stability to the precision resistors used. The resistors are wound on specially processed mica cards. The resistors are wound with alloys that have excellent stability, extremely low temperature coefficients, and negligible thermal EMF to copper. Individual resistors with the same nominal value are wound using a technique that yields excellent temperature coefficient and long-term stability matching between resistors. With the exception of the 100 kilohm-per-step transfer standard, all of the standards are immersed in oil, providing thermal isolation to minimize the effects of variations in ambient temperature.

Each resistor is carefully built and inspected to ensure maximum control of quality, then selected for minimum temperature coefficient and given a rigorous accelerated aging treatment. Each complete resistance transfer standard is given additional stabilization treatment, followed by an extended series of tests to ensure a high standard of quality.

A calibration card is included with each SR1030 which indicates the deviation from nominal for each resistor. In addition, the card gives the cumulative deviation for use when the resistors are used in combination. The calibration data supplied on this card by is directly traceable to standards certified by the National Institute of Standards and Technology (NIST).

A set of Shorting Bars (Model SB103) are available to provide low impedance parallel and series-parallel connections of resistors within a Resistor Bank. A Parallel Compensation Network (Model PC101) and a Series-Parallel Compensation Network (Model SPC102) are available to use with the Shorting Bars to effectively eliminate connection errors when performing four-terminal measurements on resistors connected in parallel or series-parallel.

SECTION 2

SPECIFICATIONS

2.1 SR1030 SPECIFICATIONS

Nominal Values (per step)	1, 10, and 100 ohms, 1, 10, and 100 kilohms
Transfer Accuracy	
100:1	±(1 ppm + 0.1 microhm) at parallel value, using SB103, PC101, and SPC102 as necessary
10:1	±(1 ppm + 1 microhm) at series or parallel value, using SB103, PC101, and SPC102 as necessary
Initial Adjustment	±20 ppm, matched within 10 ppm
Initial Calibration Certificate	±10 ppm, NIST traceable
Calibration Conditions	23 ±1°C, low-power, four-terminal measurement, initial calibration readings are provided
Long-Term Resistance Stability	±20 ppm of nominal for 6 months ±35 ppm for 2 years ±50 ppm for 5 years
Temperature Coefficient	
1 ohm	±15 ppm/°C, matched within 5 ppm/°C
10 ohm	±1 ppm/°C, matched within 5 ppm/C°
100 ohm to 100 kilohm	±5 ppm/°C, matched within 3 ppm/°C
Power Coefficient (typical)	
1 ohm	±0.3 ppm/milliwatt/resistor
10 ohm	±0.02 ppm/milliwatt/resistor
100 ohm to 100 kilohm	±0.1 ppm/milliwatt/resistor
Maximum Power Rating	
Single step	1 watt/step
10 resistors in series	5 watts distributed

Leakage Resistance	
1 ohm to 10 kilohm	$>10^{12}$ ohm, terminal to case
100 kilohm	$>10^{13}$ ohm, terminal to case
Breakdown Voltage	1500 volts peak to case

Maximum Current and Voltage Capabilities

SR1030 Resistance Value Per Step	One Resistor Alone Maximum I, V	10 Resistors in Parallel (R/10) Maximum I, V	10 Resistors in Series (R10) Maximum I, V
1 Ohm	1.0 A, 1.0 V	7.07 A, 707 mV	707 mA, 7.07 V
10 Ohms	316 mA, 3.16 V	2.23 A, 2.23 V	223 mA, 22.3 V
100 Ohms	100 mA, 10 V	707 mA, 7.07 V	70.7 mA, 70.7 V
1 Kilohms	31.6 mA, 31.6 V	223 mA, 22.3 V	22.3 mA, 223 V
10 Kilohms	10 mA, 100 V	70.7 mA, 70.7 V	7.07 mA, 707 V
100 Kilohms	3.16 mA, 316 V	22.3 mA, 223 V	1.5 mA, 1500 V*

* Based on the breakdown voltage of 1500 volts peak to case

Oil Bath	
Type	Mineral Oil, USP Light Penco, Sontex 85, white
Insulation Resistance	Typically 10^{14} ohm
Quantity	Approximately .5 gallons
Dimensions (with oil)	
Height	120 mm (4.7 in.)
Width	117 mm (4.6 in.)
Depth	335 mm (13.2 in.)
Mass	6.35 kg (Weight 14 lb)
Operating Environment	
Temperature	22.8 ±3.3°C (73 ±6°F)
Humidity	20 to 50% relative humidity
Safe Operating Environment	
Temperature	0 to 50°C (32 to 126°F)
Humidity	15 to 80% relative humidity

2.2 OPTIONS SPECIFICATIONS

Model SB103 Shorting Bars

Function	A pair of shorting bars used to connect any number of SR1030 resistors in parallel or nine of its resistors in a series-parallel arrangement.
Effective Resistance and Accuracy	See Combined Functional Specifications
Resistance	End to end: approximately 100 microhm/bar
Maximum Current	10 ampere/bar
Dimensions (Each Bar)	
Height	36 mm (1.4 in.)
Width	241 mm (9.5 in.)
Depth	20 mm (0.8 in.)
Mass	0.23 kg (Weight 8 oz)

Model PC101 Parallel Compensation Network

Function	Used in addition to an SB103 pair for the four-terminal parallel connection of ten SR1030 resistors to yield the same resistance as the value calculated from individual four-terminal resistor measurements.
Effective Resistance and Accuracy	See Combined Functional Specifications
Resistor Matching	Matched to 0.05%.
Maximum Current	2 amperes
Breakdown Voltage	1500 volts peak-to-case
Dimensions	
Height	25 mm (1 in.)
Width	305 mm (12 in.)
Depth	81 mm (3.2 in.)
Mass	0.45 kg (Weight 1 lb)

Model SPC102 Series-Parallel Compensation Network

Function	Used in addition to an SB103 pair for the four-terminal series- parallel connection of nine SR1030 resistors to yield the same resistance as the value calculated from individual four-terminal resistor measurements.
Effective Resistance and Accuracy	See Combined Functional Specifications
Resistor Matching	Matched to 0.05%.
Maximum Current	2.0 amperes
Breakdown Voltage	1500 volts peak-to-case
Dimensions	
Height	25 mm (1 in.)
Width	305 mm (12 in.)
Depth	81 mm (3.2 in.)
Mass	0.45 kg (Weight 1 lb)

Combined Option Functional Specifications

Resistor Grouping	Ten Resistors in Parallel	Nine Resistors in Series-Parallel	Ten Resistors in Series
Nominal Value (Relative to Individual Resistor Value R)	0.1R	R	10R
Four-Terminal Measurement	Resistance Added to Value Calculated from Individual Resistor Values (Value and Tolerance in Microhms)		
With SB103 and PC 101 or SPC102	0 ±0.1	0 ±1	
With SB103 Alone	50 ±10	200 ±40	
With no Accessories			0 ±10
Two-Terminal Measurement			
With SB103	150 ±30	300 ±60	
With no Accessories			300 ±60

SECTION 3
OPERATIONS

3.1 CONNECTIONS

There are several ways in which the individual resistors can be connected within an SR1030 Resistance Transfer Standard. This section describes some of the more common connections, the equivalent circuits that are made by these connections, and the effects that each of the connections have on the accuracy of your measurement.

WARNING

A POTENTIAL SHOCK HAZARD CAN EXIST ON THE SR1030 AND ITS OPTIONS (SR103 SHORTING BARS, PC101 PARALLEL NETWORK, AND SPC102 SERIES-PARALLEL COMPENSATION NETWORK) WHEN CONNECTED TO A VOLTAGE SOURCE GREATER THAN 42.4 VOLTS PEAK (30 VOLTS RMS). BE AWARE OF THIS CONDITION WHEN CONNECTING A VOLTAGE SOURCE TO THE SR1030 AND ITS OPTIONS.

3.1.1 Series Connections

The resistors within an individual SR1030 are permanently connected in series. At the end of each resistor is a four-terminal junction that connects to two binding posts and the next resistor (except for the junctions at the two end resistors, R1 and R12, which connect to two binding posts and only one resistor). A series connection can be made to any resistor or series string of resistors by connecting to these binding posts. For example, to connect to 5 resistors in series, one set of connections can be made to the terminals labeled A0 and B0. The other set of connections should then be made to the B5 and C5 terminals. Refer to Figure 3-1 for an example of this connection.

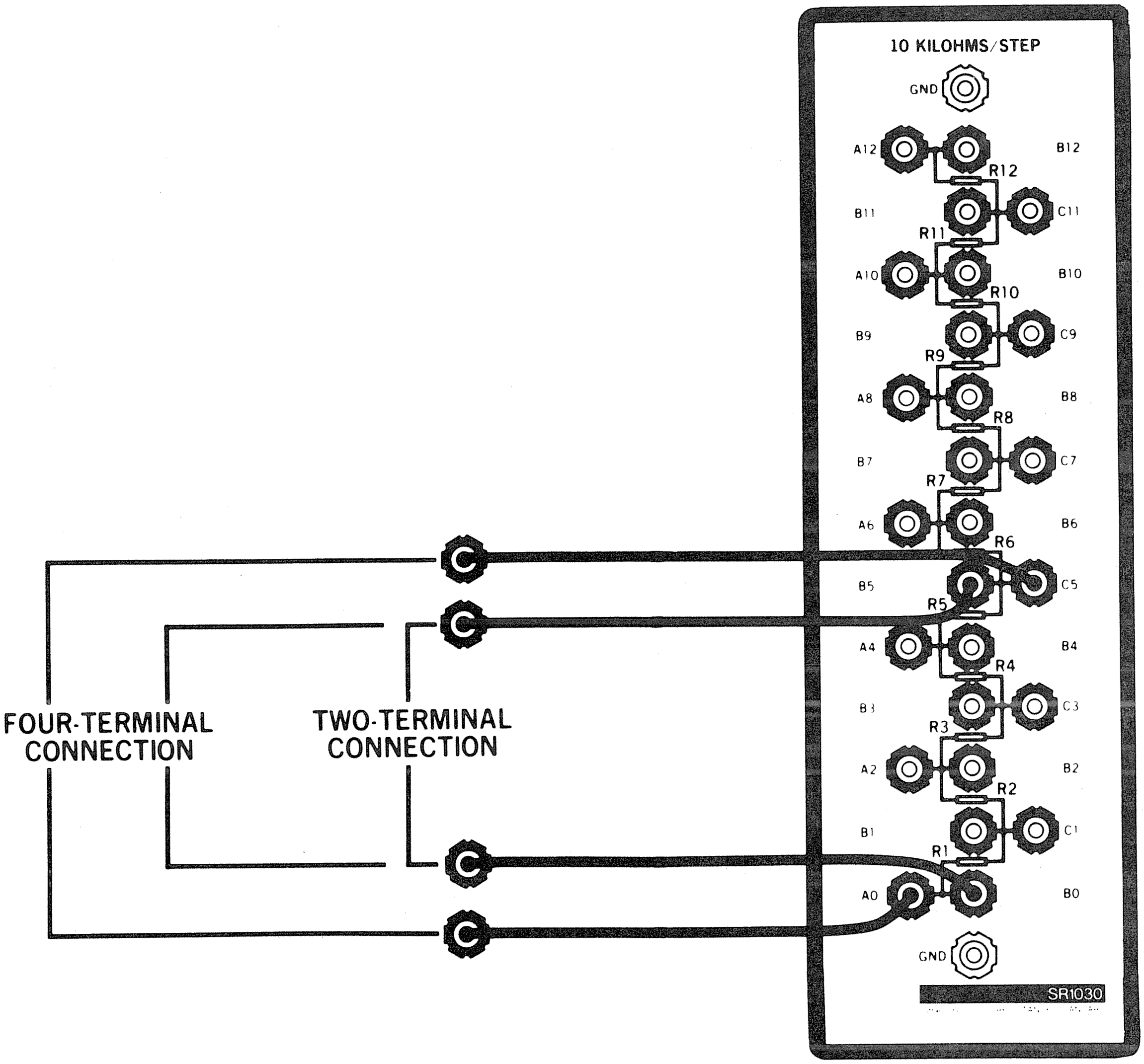


Figure 3-1. Connecting Five Resistors in Series

Besides the nominal value of the the resistors in series, there is some additional resistance internal to the SR1030 between the binding post and the resistor. This resistance is called junction resistance. When two terminal measurements are made using the SR1030, consideration must be given to how the junction resistance will affect the measurement.

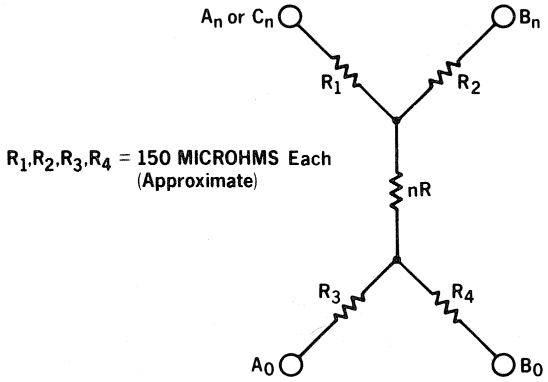


Figure 3-2. Equivalent Circuit of Series Connection

In Figure 3-2, each of the four resistances (R_1 through R_4) represent the junction resistance of the first resistor and last resistor in the series connection. When two terminal measurements are made (using Ao and An), a junction resistance of about 300 microhms is added to the total resistance of the resistors in series. However, the effect that the junction resistances have on the measurement is negligible. This is due to the large resistances (typically about 10 milliohms) that are added in series from the bridge lead connections.

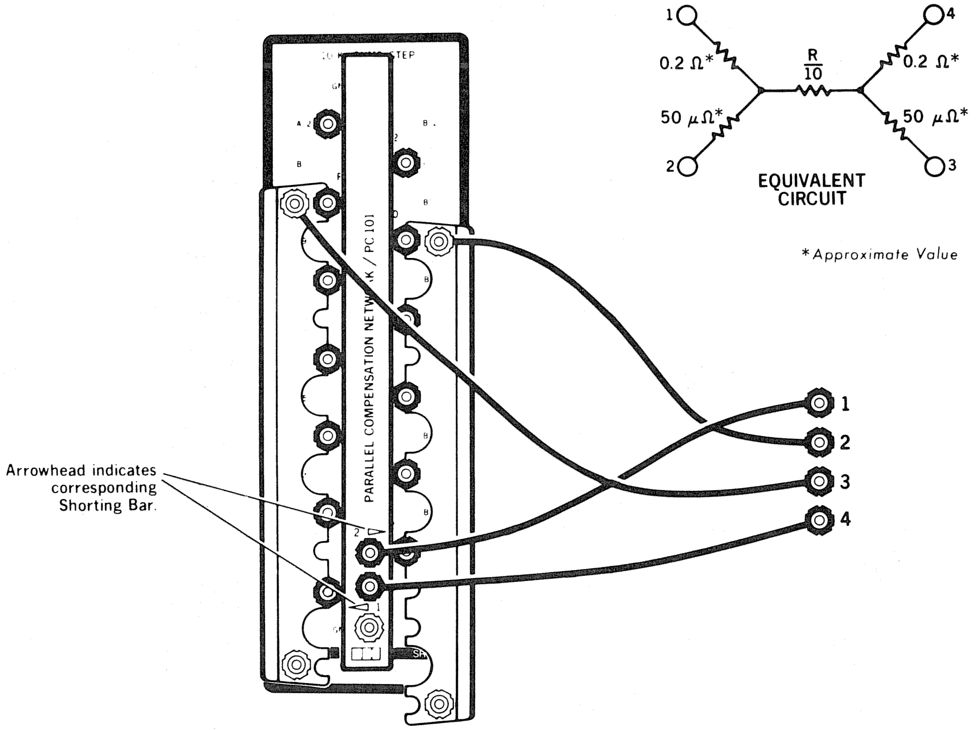
To avoid the effect of these resistances, a four-terminal measurement can be made. This will limit the junction resistance to less than one microhm.

3.1.2 Parallel Connections

Any number of the resistors in an SR1030 may be connected together in parallel by means of the SB103 shorting bars. For the 1 and 10 ohm-per-step SR1030, the paralleling leads and contact resistance may cause significant errors.

When connecting ten resistors in parallel, these errors can be essentially eliminated by the use of the PC101 Parallel Compensation Network. Refer to Figure 3-3 for an illustration of a four-terminal parallel connection using the SB103 and the PC101.

> **NOTE:** Throughout this section, the terminals on the Equivalent Circuits are labeled 1 through 4. These numbers correspond to the terminal numbers on an Model 240C Kelvin Ratio Bridge. In general terms for a lvin bridge, terminal 1 connects to the Generator, 2 connects to the Main Bridge Arms, 3 connects to the Yoke Arms, and 4 connects to the Yoke. When using an active arm bridge (such as an Model 1700 or an Model SP2522B) 1 connects to High Dr (current), 2 con s to High Sense (potential), 3 connects to Low Sense, and 4 connects to Low Drive.



*Approximate Value

Arrowhead indicates corresponding Shorting Bar.

Figure 3-3. **Four-Terminal Parallel Connection with Compensation Network**

When the Parallel Compensation Network is used, the resistance in series with it is considerably higher than the resistance in series with the shorting bars. Care should be taken when connecting this arrangement to a measuring device to ensure that the effect of this resistance is minimized. The labels in Figure 3-3 indicate the proper connection order.

A simplified four-terminal parallel connection of any number of resistors can be made using only the shorting bars as shown in Figure 3-4. This places a small connection resistance in series with the paralleled resistance. However, this value is negligible for the SR1030 with nominal values of 1 kilohm-per-step and higher.

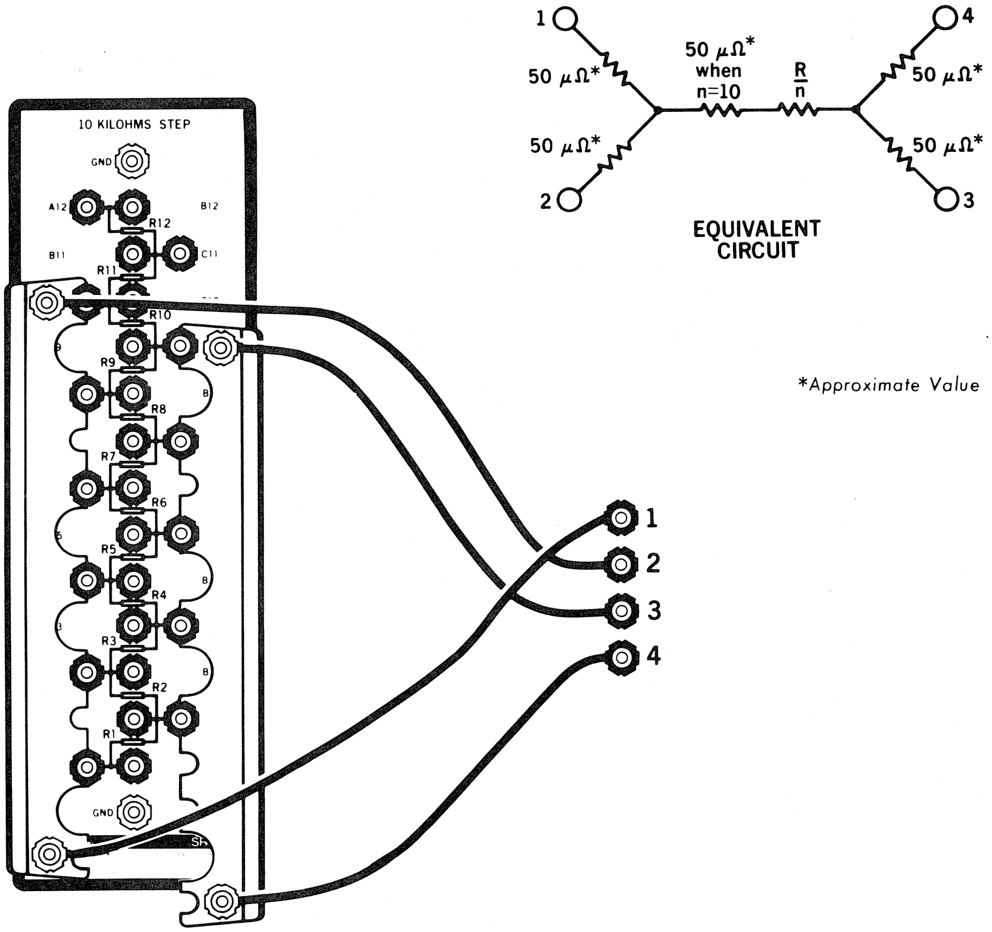
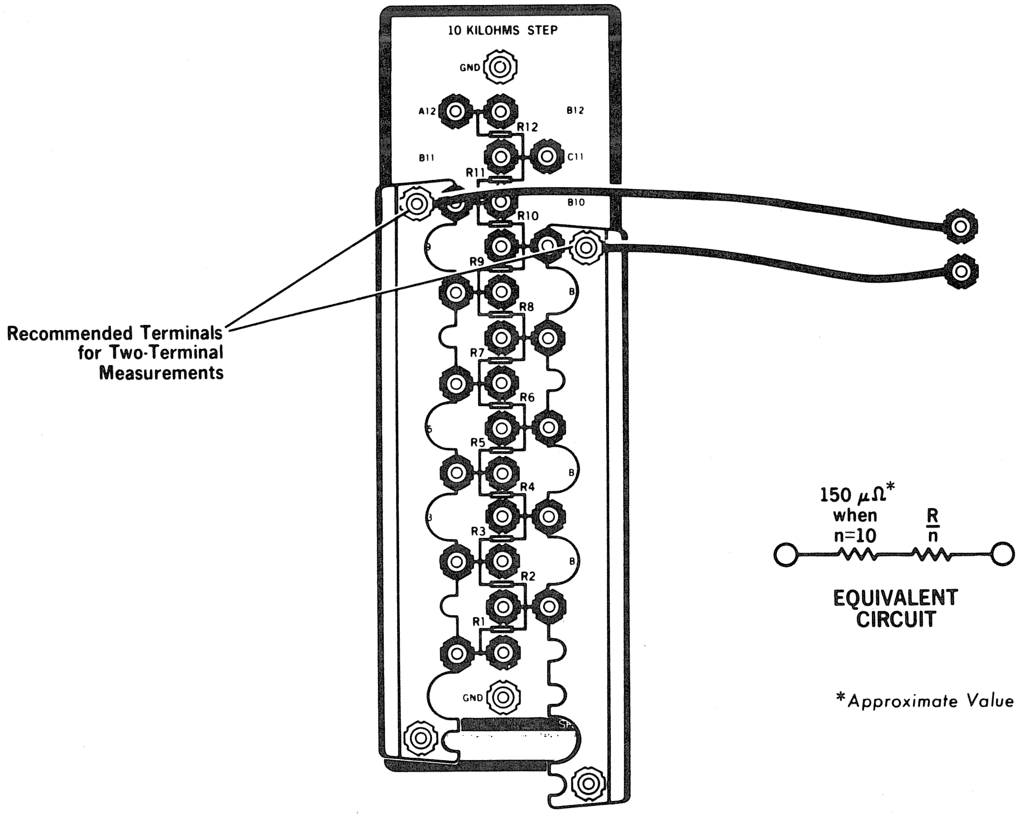


Figure 3-4. Four-Terminal Parallel Connection with Shorting Bars

A two-terminal parallel connection is made using the shorting bars shown in Figure 3-5. Be aware that this type of measuring technique introduces a series connection resistance greater than the four-terminal parallel connection. The greater series connection resistance is enounugh that it can affect the measurement.

In addition to the series connection resistance, each cable connection between the SR1030 and bridge will add about 10 milliohms. To minimize the cable connection resistance, make the two-terminal connections to the shorting bar terminals closest to the resistor terminals. See Figure 3-5.



Recommended Terminals for Two-Terminal Measurements

*Approximate Value

Figure 3-5. **Two-Terminal Parallel Connection with Shorting Bars**

3.1.3 Series-Parallel Connections

Another type of connection that can be made to the SR1030's resistors is a series-parallel connection. This is typically used to connect nine resistors in three parallel groups with the three groups in series. This connection arrangement results in a stable resistor equal in value to the nominal value of the individual resistors.

The SB103 shorting bars can be used to make this connection. The resistance added by the shorting bars (connected in series-parallel) will be insignificant for the SR1030 whose nominal value is greater than 100 ohms-per-step (about 3 ppm error on the 100 ohm-per-step bank). The added resistance will be significant when the shorting bars are used on the 1 and 10 ohm-per-step SR1030. Figure 3-6 illustrates an SR1030 with two-terminal and four-terminal connections using the shorting bars.

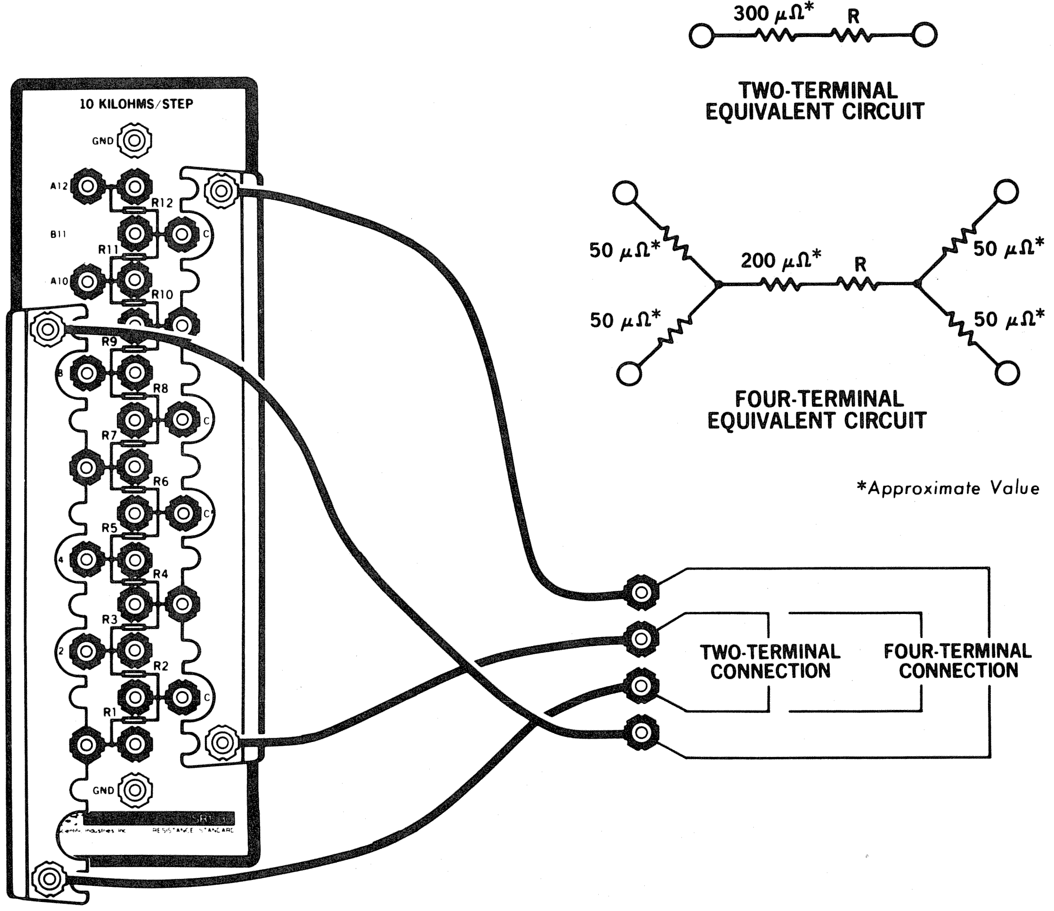


Figure 3-6. Series-Parallel Connection with Shorting Bars

As shown in Figure 3-6, additional resistance (the connection resistance of the shorting bars) appears when a series-parallel connection is made. Since there will be several contacts in parallel it will be a fairly stable and reproducible resistance and could be subtracted from the measured value.

The errors caused by the added resistance (in the four-terminal case) can be essentially eliminated by the use of a special compensation network, the SPC102 Series-Parallel Compensation Network. As indicated in Figure 3-7, more resistance is added through the Compensation Network than through the shorting bars. As with the parallel arrangement, care should be taken when connecting this arrangement to a measuring device to ensure that this resistance has a minimum effect on the measurement accuracy.

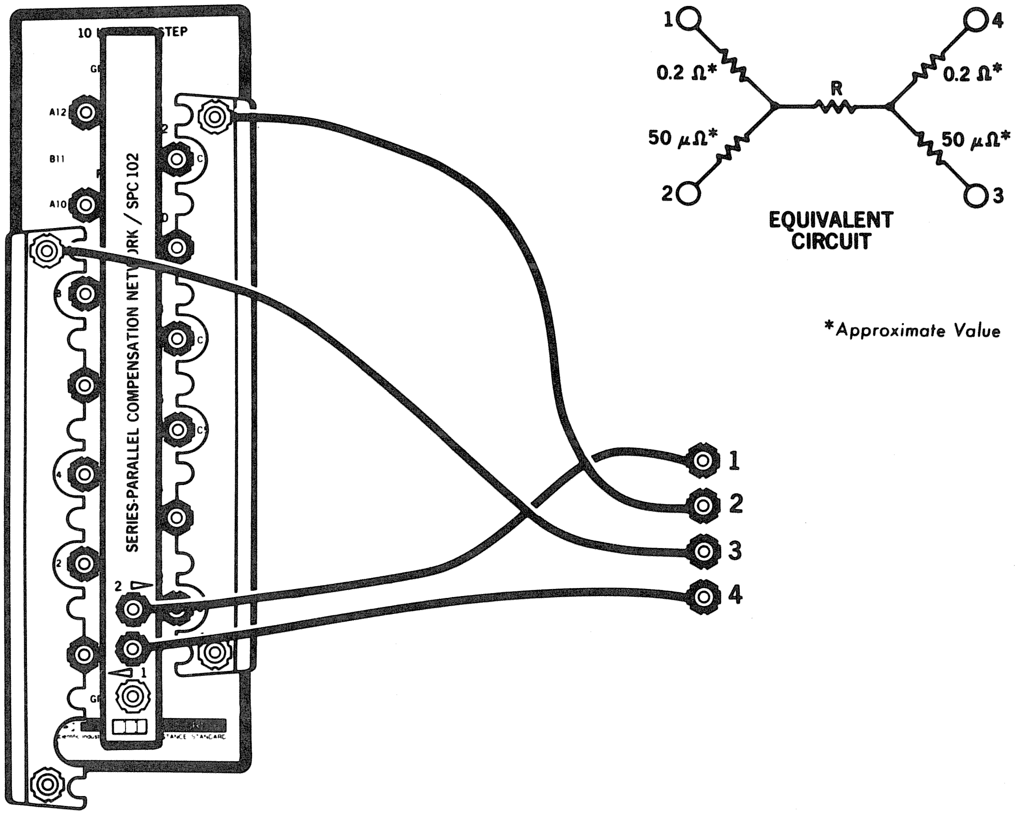


Figure 3-7. Series-Parallel Connection with Compensation Network

3.1.4 Voltage Divider Connections

Any SR1030 can be used as a calibrated voltage divider. Figure 3-8 illustrates this use. The voltage source should be connected to terminals A0 and A10 and adjusted to the desired open circuit voltage between terminals B0 and B10. The intermediate taps will then be correct in interpolating between B0 and B10.

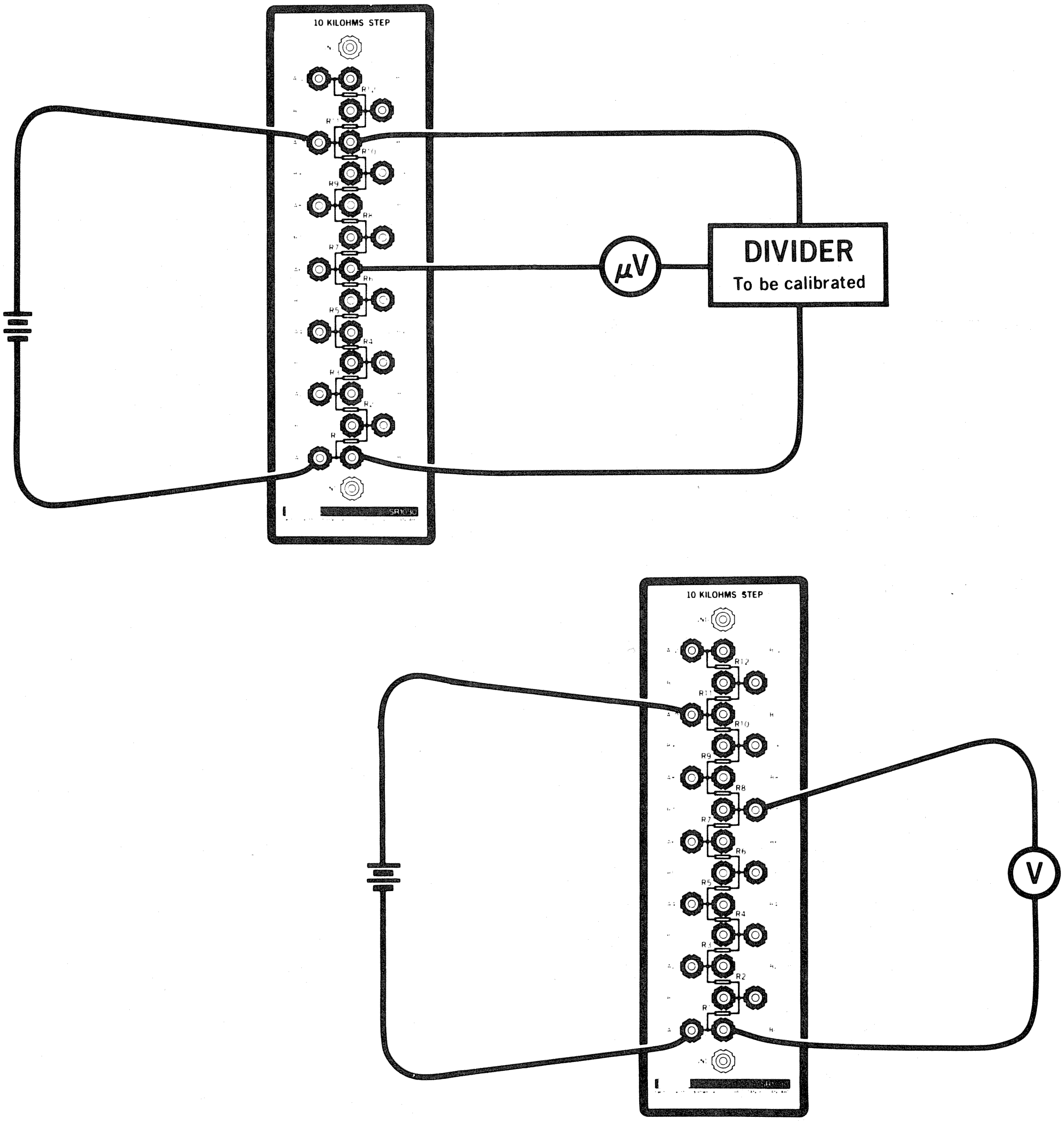


Figure 3-8. Voltage Divider Connection

For calibration of another voltage divider, an additional accessory can be used to compensate for lead and contact resistance. An Model LC875 Lead Compensator or equivalent is recommended. The Lead Compensator is connected between terminals A0, A10, and the input of the divider to be calibrated, as shown in Figure 3-9. With the detector connected between B0 and the minimum end of the divider to be calibrated, the Lead Compensator is adjusted for a detector null. With the detector connected between B10 and the maximum end of the divider, the Lead Compensator is adjusted for a detector null. The divider may then be accurately compared to the SR1030 at integral multiples of one tenth the full scale voltage.

For calibrating other than the first decade of a Kelvin-Varley voltage divider it is necessary to connect the generator to the input of the decade under calibration. This will normally require making an internal connection to the divider, as shown in Figure 3-9. This method gives a complete, high accuracy calibration of the whole Kelvin-Varley divider, including all lead and switch resistances.

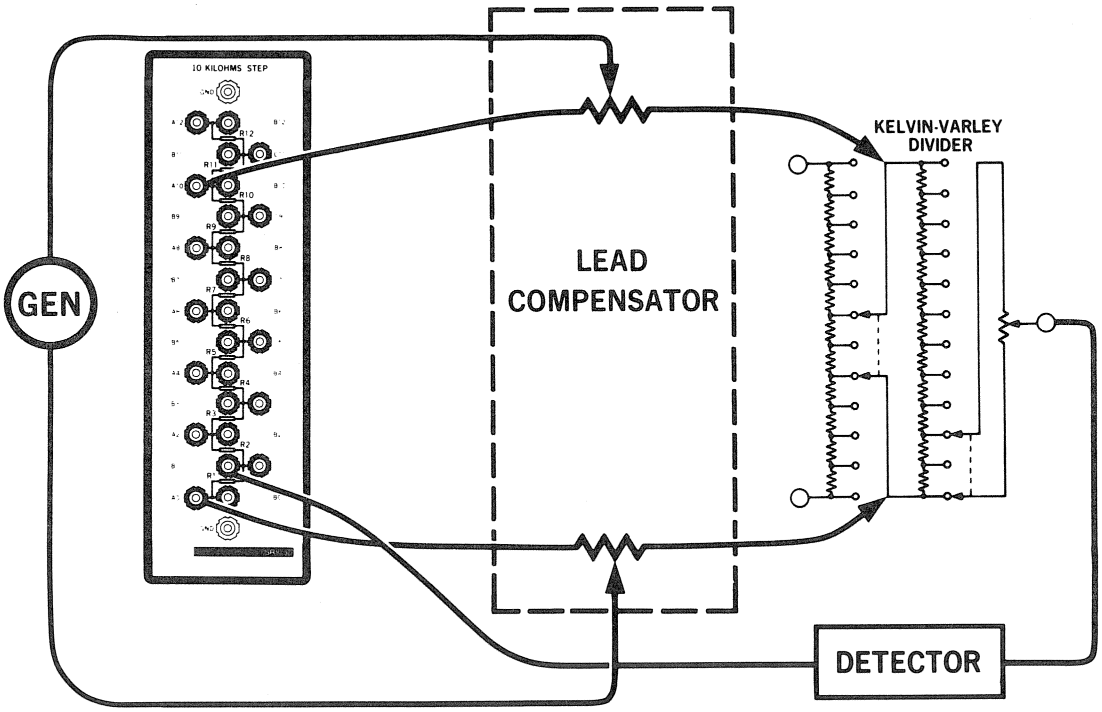


Figure 3-9. Voltage Divider Connection with Lead Compensator

3.2 HIGH ACCURACY CALIBRATION TRANSFER

The name Resistance Transfer Standard refers to the Resistors in the SR1030 that can be measured at one resistance value and used with nearly equal accuracy at a different resistance value. In a sequence of measurements using such transfers to trace calibration from a reference standard to an unknown resistor, neither the absolute value nor the long-term stability of the resistors in the SR1030 nor the bridge used for the comparisons has any significant effect on the measurement accuracy. The burden of calibration accuracy and long-term stability is placed on the reference standard alone; the concern with the rest of the system need be only with its short-term stability during the period of a few minutes required to complete the measurements. With careful operating techniques in a normal laboratory environment, each step in such a series of measurements can be accurate to one or two ppm.

In making such a chain of measurements, an advantage of using a Resistance Transfer Standard is that an accurate 100:1 transfer in resistance value can be made by only changing the connections, thus minimizing the accumulation of errors. For example, the limits of error in measuring a 1 ohm resistor might be assumed as follows:

Certified accuracy of 10 kilohm standard	1 ppm
Comparison of 10 kilohm standard with 1 kilohm-per-step SR1030 (connected for 10 kilohms)	2 ppm
Comparison of 1 kilohm-per-step SR1030 with 10 ohm-per-step SR1030 (both connected for 100 ohms)	2 ppm
Comparison of 10 ohm-per-step SR1030 (connected for 1 ohm) with unknown 1-ohm resistor	2 ppm
Sum of Error Limits	7 ppm
Square Root of the Sum of the Squares	3.6 ppm

NOTE: If the individual steps are independent and normally distributed, the square root of the sum of squares should be used as the total uncertainty.

A similar procedure can be used to transfer (in two steps) from a 1 ohm standard to 10 kilohms and (with 2 more steps) to 1 megohm, or (with 2 more steps) to 100 megohms using the SR1050 High Resistance Transfer Standard.

For highest accuracy, such a transfer procedure may be repeated each time a measurement of an unknown resistor is made. If, during such measurements, a record is kept of the calibration of an SR1030, a quantity of data will soon be accumulated with a minimum of effort. This data will indicate the stability of the SR1030 and/or the variations in calibration resulting from changes in ambient conditions, operators, or techniques. It can serve to indicate the actual accuracy of the data on the calibration chart under the laboratory conditions prevailing and it will indicate when it is time to replace the calibration chart and supply dependable data for a new chart.

3.2.1 Comparing Nominally Equal Values

The comparison of like resistance values can be made independent of the absolute accuracy and long-term stability of the comparison bridge by using either an interchange or a substitution method. A direct-reading double ratio set such as Model 240C Kelvin Ratio Bridge or Model 120 Direct Reading Double Ratio Set should be used for calibration transfer with the SR1030. These instruments can be used to make four-terminal comparison measurements with resolution and short-term stability between 0.1 ppm and 1 ppm.

3.2.1.1 Interchange Method

> **NOTE:** If the first unknown resistor used in the following example can be adjusted (as with the RS925D), the calculation can be simplified. This resistor should be adjusted to balance the bridge in the first STEP, making D_2 equal to 0. The deviation will then be $D_1/2$.

1. With the first unknown resistor connected to the unknown terminals of the bridge and the second unknown resistor connected to the standard terminals, balance the bridge, and determine the (uncalibrated) deviation of the first unknown from the second unknown. Call this reading D_2.

2. Interchange the two resistors (that is, connect the second unknown resistor to the unknown terminals and connect the first unknown resistor to the standard terminals), balance the bridge, and determine the (uncalibrated) deviation of the second unknown from the first unknown. Call this reading D_1.

3. Calculate $(D_1 - D_2)/2$, the calibrated deviation of the second resistor from the first resistor. If the deviation from nominal of the first resistor is known, add it to the deviation just calculated. This produces the deviation of the second resistor from nominal value.

3.2.1.2 Substitution Method

To measure the difference between two unknown resistors by the substitution method, connect a working standard resistor of the required nominal value to the standard terminals of the bridge and make two measurements. The first measurement is to be made with the first unknown resistor connected to the unknown terminals. The second measurement is to be made with the second unknown resistor connected to the unknown terminals. The difference between these two readings will be the difference between the values of the two resistors.

The substitution method is particularly convenient when the deviation of the first resistor is known and both the working standard and the bridge ratio can be adjusted to make the bridge deviation dial read deviation from nominal value directly. When the first resistor is connected to the unknown terminals, the deviation dial is adjusted to its known deviation from nominal value and the working standard is used to balance the bridge. When the first resistor is disconnected and the second (unknown) resistor is connected to the unknown terminals, the deviation dial at balance will indicate directly the deviation of the second (unknown) resistor from nominal value.

In a sequence of calibration transfer measurements in which the second (unknown) resistance in one comparison and the first (known) resistance in the next consist of the same group of SR1030 resistors differently connected, the deviation reading in the first comparison becomes the initial deviation setting for the next measurement. Thus the dial setting serves as a mechanical memory and indicates the actual deviation value through the whole series of measurements, including the final reading on the second (unknown) resistor.

3.2.2 Primary Resistance Standards

It is necessary to begin any chain of measurements with a primary standard resistor with a value that is accurately known and highly stable. The Model SR104 is such a resistor and is recommended for this purpose. The use of this resistor is simple and does not require a regulated-temperature oil bath, high-accuracy thermometers, or other such equipment. The SR104 has an internal oil bath, a low temperature coefficient, and a sealed-in temperature probe. The value of the SR104 is 10 kilohms ±5 ppm. The SR104 can be calibrated by the NIST to a certified accuracy of ±1 ppm.

Another commonly used primary resistance standard is the Thomas-pattern 1 ohm resistor, well known for its long-term stability. The following will aid in making accurate measurements at the 1 ohm level:

1. Operate the Thomas-pattern resistor in oil to minimize its temperature rise with power dissipation and to allow accurate measurement of the resistor temperature.

   If accurate temperature coefficient data is available for the resistor (alpha, which is about +5 ppm/°C, and beta terms), a small pot of unstirred oil at room temperature is quite adequate. Measure the oil temperature to an accuracy of ±0.2°C and calculate the value of the resistor at this temperature. Since heating by the resistor may raise the oil temperature enough to significantly affect the resistance, the temperature should be measured again when the bridge is balanced.

2. Avoid internal heating of the standard and the SR1030. Use reduced input power to the bridge for the initial balance adjustment, then increase power to approximately 1/2 watt (2/3 ampere through standard and unknown) for only a few seconds, make the final, accurate balance adjustment, and read the oil temperature. The resistance of both the Thomas-pattern resistor and the SR1030 will typically remain constant within 1 ppm for approximately 10 seconds at this power level.

3. Complete the 1 ohm-per-step SR1030 comparison with the reference standard and its use in calibrating higher value SR1030s in as short a time as possible to keep all the measurements at as nearly the same temperature as possible.

   The exact temperature of an SR1030 in calibration transfer is unimportant, but its temperature must remain sufficiently constant throughout the procedure. This is particularly important with the 1 ohm resistors, since they have higher temperature coefficient differences, about 5 ppm/°C, than the higher value resistors.

In changing the connections to the SR1030, avoid unnecessary handling to minimize temperature changes and differential thermal voltages.

3.2.3 Calibration Transfer Between SR1030 Transfer Standards

In calibration transfer measurements, the three most commonly used connection configurations for an SR1030 are: ten resistors in parallel, nine resistors in series-parallel, and ten resistors in series. These connections yield resistance values of 0.1, 1, and 10 times the individual resistor value. It is desirable to use one of these groups of resistors in preference to any single resistor, in order to minimize temperature rise with internal heating and to take advantage of averaging of temperature coefficients of the resistors.

The basic absolute resistance calibration of an SR1030 is accomplished by accurately measuring any one of these three connection configurations. Once the reference standard (or a previously calibrated SR1030) has been used to calibrate one of these three configurations for an SR1030, the values for the other configurations are obtained by a simple comparison measurement and calculation.

For 1 ppm accuracy in calibrating or using the ten resistor parallel configuration with the 1, 10, and 100 ohm-per-step SR1030, or using the nine resistor series-parallel configurations with the 1 and 10 ohm-per-step SR1030, the PC101 and SPC102 Compensation Networks should be used. The simplified four-terminal connection using the SB103 shorting bars alone is adquate for the 1 kilohm-per-step and higher value SR1030s (refer to Section 3.1.3).

The recommended sequence for calibration transfer to the various SR1030s is listed in Table 3-1.

Table 3-1. Recommended Calibration Transfer Sequence

SR1030 Resistor Value	Connection	Number of Resistors	Net Value	Compared to
100 kilohm	Parallel	10	10 kilohm	10 kilohm
10 kilohm	Series-Parallel	9	10 kilohm	Primary Standard
1 kilohm	Series	10	10 kilohm	(SR104)
100 ohm	Series	10	1 kilohm	1 kilohm-per-step SR1030 in Series-Parallel
10 ohm	Series	10	100 ohm	1 kilohm-per-step SR1030 in Parallel
1 ohm	Series	10	10 ohm	10 ohm-per-step SR1030 in Series-Parallel

3.2.4 Calibration Transfer Between Principal Resistor Configurations

The majority of calibration transfer applications require the use of only the three principal resistance configurations for an SR1030. For these measurements, the individual resistors need never be calibrated. This is the key to both the high accuracy and the extreme simplicity of this transfer technique.

Fortunately, it can be shown that nominally equal resistors connected in configurations which use the same group of resistors and distribute the power equally among them have the same deviation from the nominal values for the configurations. This deviation is equal (to one part in 10^9 for the resistor matching used in the SR1030) to the average of the deviations of the individual resistors in the group from their nominal value.

When a particular group of nominally equal resistors, all dissipating the same power, is calibrated in one configuration and exactly the same group is used in another configuration, still maintaining equal power dissipation at the new resistance value, no further measurements are necessary and no calculations are required for determining the calibrated value at the new level. Ten resistors in series will therefore have almost exactly 100 times the resistance of the same ten resistors in parallel. Similarly, nine resistors in series-parallel, giving the same nominal resistance as the individual resistors, will have almost exactly nine times their resistance in parallel, or almost exactly one ninth of their resistance in series. In each case, the deviation will be almost exactly the average of the deviations of the individual resistors. Proof of these statements can be found in Theory, Section 4 of this manual.

To transfer calibration between the ten resistor group and the nine resistor group, the difference of the unused tenth resistor from the nine-resistor series-parallel configuration must be measured*. This measured difference and the calibrated deviation of any of the three configurations can be used to calculate the deviation of the other two configurations. The difference between the two (parallel and series are equal) average deviations is given by:

$$d^{9}_{sp} - d^{10}_{cu} = 0.1\ (d^{9}_{sp} - d_{10})$$

Where:

d^{9}_{sp} is the (measured or calculated) deviation of the nine resistor series-parallel group from nominal (this deviation is equal to the average of the deviations of the nine resistors)

d^{10}_{cu} is the (measured or calculated) deviation of the ten resistor series or parallel group from nominal (this deviation is equal to the average of the deviations of the ten resistors)

$d^{9}_{sp} - d_{10}$ is the measured difference between the nine resistor series-parallel configuration and the tenth resistor (whose deviaiton is d_{10})

Notice that the resistance value of the tenth resistor need never be known, only its difference from the resistance value of the series-parallel circuit. This difference can be easily measured by the substitution method. As this difference is divided by 10 when it is used, its accuracy is somewhat less important.

---

*For transfer standard values requiring the use of the Compensation Networks, this measurement must be made by the substitution method rather than the interchange method, since the network must be removed to connect to the tenth resistor for measurement.

3.2.5 Calibration Transfer to Individual Resistors

There are two methods which can be used to calibrate the 12 resistors in one SR1030.

The first method involves making individual measurements with a bridge calibrated to the same nominal value as the individual resistors. With this method, the measured deviations are the best known deviations from nominal for each resistor. Using this method, the bridge can be calibrated to the nominal value of the resistors in either of two methods. The simpler method involves calibrating the bridge using a calibrated standard with the same nominal value as the resistors. The more complicated method involves calibrating the bridge using a calibrated standard whose nominal value is ten times or one tenth of the nominal value of the individual resistors. The appropriate SR1030 is calibrated (in series or parallel) at the same value as the standard. By performing two measurements (R10 and the resistors in series-parallel) and making a simple calculation, the bridge can be calibrated at the nominal value of the resistors. Each of the twelve resistors can then be measured directly.

The second method involves measuring the twelve resistors with a bridge that is uncalibrated. The individual deviations are recorded, noting that they are deviations from some unknown value. The series or parallel value of the resistors is then compared to a calibrated standard, with the deviation being used to correct the original twelve deviations.

Both of these procedures are listed in a step-by-step manner in Calibration Procedure, Section 3.4.1.

3.2.6 Calibration of an SR1030 as a Ten-Step Divider

Because ratio measurements do not depend upon any absolute resistance standard, no reference standard of resistance is required to calibrate an SR1030 as a divider. As is shown in Theory, Section 4, an excellent approximation of the deviation, L, of a decade divider is given by:

$$L = (n/10) * (d^{n}_{cu} - d^{10}_{av})$$

Where:

$d^{n}_{cu} = (\sum_{i=1}^{n} d_i)/n$ is the cumulative deviation of the first n resistors

d^{10}_{av} is the average deviation of the ten resistors

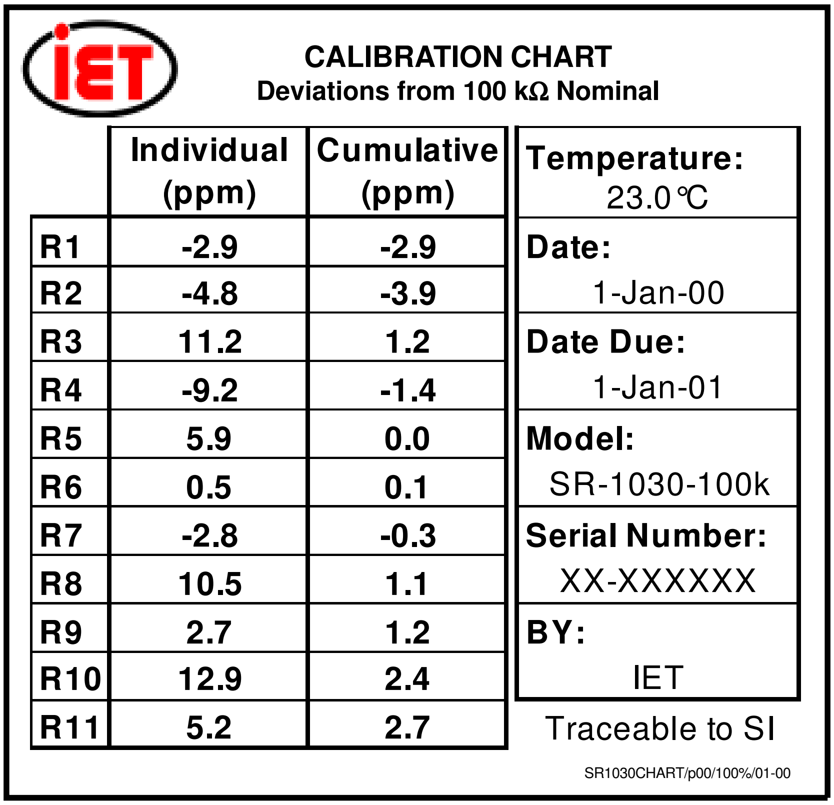
Because this equation requires the measurement (or calculation) of the difference between the cumulative deviation and the average deviation, and not the actual values of these two quantities, an uncalibrated bridge can be used. Any deviation caused by the calibration error of the bridge will be cancelled by the subtraction.

If the deviations of the individual resistors are known (as measured in the preceding section), these deviations can be used to calculate the linearity deviation directly.

Calculation of the linearity deviation by both methods is included in Calibration Procedure, Section 3.4.1.

3.3 CALIBRATION CARD

The SR1030 is supplied with a calibration card that gives resistance calibration data for each resistor, in terms of their deviation from nominal value, expressed in parts per million. These values are based on four-terminal measurements; two-terminal measurements must be corrected for the connection resistances, as discussed in CONNECTIONS, Section 3.1. An example of a calibration card is shown in Figure 3-11.



CALIBRATION CHART
Deviations from 100 kΩ Nominal

	Individual (ppm)	Cumulative (ppm)
R1	-2.9	-2.9
R2	-4.8	-3.9
R3	11.2	1.2
R4	-9.2	-1.4
R5	5.9	0.0
R6	0.5	0.1
R7	-2.8	-0.3
R8	10.5	1.1
R9	2.7	1.2
R10	12.9	2.4
R11	5.2	2.7

Temperature: 23.0℃

Date: 1-Jan-00

Date Due: 1-Jan-01

Model: SR-1030-100k

Serial Number: XX-XXXXXX

BY: IET

Traceable to SI

SR1030CHART/p00/100%/01-00

Figure 3-11. Calibration Card

The first column gives the measured deviation of each resistor from its nominal value. The second column gives the cumulative average of the deviation figures in the first column, rounded to the same number of significant figures as the first column. For example, to the right of R7, the figure in the first column is the measured deviation of R7 from nominal, while the figure in the second column is the calculated average deviation of resistors R1 through R7.

Use the cumulative average deviation figure to calibrate any series, parallel, or series-parallel connection. For an example of how to use the cumulative average deviation figure, consider the three different types of connections that can be made to the first nine resistors in a one ohm-per-step SR1030. The fist nine resistors can be connected in series for a nominal value of nine ohms, in parallel for one-ninth of an ohm, or in series-parallel for one ohm. The actual value of each of these three connections is the nominal value for that connection, summed with the cumulative deviation figure shown in column 2 opposite R9.

Information to the left of the deviation columns identifies the WARRANTY period for the SR1030 and provides a record of the environmental conditions at the time the SR1030 was calibrated. For tracking purposes a space is provided for the inspector's initials.

The part number that appears to the right of the deviation columns is the part number of the calibration card (not the SR1030).

3.3.1 Calibration Procedure

The following procedures can be used to verify the calibration readings on the Calibration Card or to supply data for a new card. These procedures should be performed only by those who have the necessary facilities. Calibration should be performed in a laboratory environment with a resistance measuring system of the required sensitivity and accuracy, and with a primary resistance standard for which the resistance is adequately known.

> **NOTE:** The signs (positive or negative) of the values used in the equations in the following procedures are significant and must not be ignored.

> **NOTE:** Both of the following procedures make reference to balancing the bridge. It is assumed that the operator will follow the appropriate procedure of zeroing the meter, reversing the generator polarity to check for thermal voltages, and performing lead and yoke adjustments whenever balancing is required.

3.3.1.1 First Method

The first method involves calibration of the bridge at the nominal value of the resistors. The deviation of each of the individual resistors is then measured directly.

> **NOTE:** If a resistance standard is available with a nominal value equal to the nominal value of the resistors to be calibrated and an ESI Model 242 Resistance Measuring System is used, several STEPs can be eliminated. Connect the standard to the UNKNOWN terminals of the bridge and set the DEVIATION dial on the bridge to the known deviation of the standard. Balance the bridge by adjusting the resistance standard connected to the STANDARD terminals of the bridge. The bridge is now calibrated. Make a copy of the Calibration Chart found in Figure 3-13 and proceed to STEP 12. An example of a completed Calibration Chart is found as Figure 3-12.

1. Make a copy of the Calibration Chart found in Figure 3-13. It will be used to keep track of the intermediate results and assist in the calculations. An example of a completed Calibration Chart and part of a Calibration Card is shown in Figure 3-12.

2. Select a calibrated standard resistor with a nominal value equal to ten times or one tenth of the nominal value of the individual resistors of the SR1030 to be calibrated. Connect this standard resistor to the UNKNOWN terminals on the bridge.

3. Set the DEVIATION dial of the bridge to the known deviation of the standard and balance the bridge by adjusting the resistance standard.

4. Connect the SR1030 in series or parallel to have the same nominal value as the standard resistor used in STEP 1. Connect this SR1030 to the UNKNOWN terminals on the bridge.

5. Balance the bridge with the DEVIATION dial. Read and record the setting as d_{av}^{10} on the Calibration Chart.

6. Set the DEVIATION dial to 0. Connect the SR1030 R10 to the UNKNOWN terminals on the bridge.

7. Balance the bridge with the resistance standard. This calibrates the bridge to the (unknown) value of R10.

8. Connect R1 through R9 of the SR1030 in series-parallel, using the shorting bars and (if the nominal resistor value is 1, 10, or 100 ohms) the SPC102 Compensation Network. Connect the SR1030 to the UNKNOWN terminals on the bridge.

9. Balance the bridge with the DEVIATION dial. Read and record the setting as d_D on the Calibration Chart. This is the difference of the value of the series-parallel network from the value of R10.

10. Calculate d_{sp} using the following:

$$d_{sp} = d_{av}^{10} + 0.1 * d_D$$

11. Set the DEVIATION dial to d_{sp}. Leaving the series-parallel network connected, balance the bridge using the resistance standard. The bridge is now calibrated at the nominal value of the individual resistors.

12. Connect each resistor (R1 through R12) in turn, to the UNKNOWN terminals of the bridge. Balance the bridge using the DEVIATION dial to measure the deviation of the resistor connected to the UNKNOWN terminals of the bridge. Record this deviation for each resistor in column B (Corrected Individual Deviations) of the Calibration Chart. Column A (Measured Individual Deviations) of the Calibration Chart is not used in this procedure.

13. Round the individual deviations to the nearest ppm and record them in the first column of the Calibration Card.

14. Sum the individual deviations from the first to each of the subsequent deviations and record these sums in column C (Cumulative Sum) of the Calibration Chart.

15. Divide each cumulative sum by the number of resistors involved in the sum and record the results in column D (Cumulative Average) of the Calibration Chart.

16. Round the cumulative averages to the nearest ppm and record them in the second column of the Calibration Card.

17. Subtract the tenth cumulative average from each of the first nine cumulative averages in turn, multiply each result by the number of resistors involved in the cumulative average, and divide by 10. Round the results to one decimal place and enter the results in column E (Linearity Deviation) of the Calibration Chart. This is the linearity deviation for each of the first nine steps when the SR1030 is used as a decade divider. For example, the fifth linearity deviation is calculated as:

$$(1.2 - 1.5) * 5/10 = -0.15$$

This would be rounded to -0.2 when entered in the Chart.

	A	B	C	D	E
	Measured Individual Deviation	Corrected Individual Deviation	Cumulative Sum	Cumulative Average	Linearity Deviation
R1	+ 3.6	+ 2.1	+ 2.1	+ 2.1	+ 0.1
R2	+ 5.7	+ 4.2	+ 6.3	+ 3.2	+ 0.3
R3	+ 0.3	- 1.2	+ 5.1	+ 1.7	+ 0.1
R4	+ 5.3	+ 3.8	+ 8.9	+ 2.2	+ 0.3
R5	- 1.6	- 3.1	+ 5.8	+ 1.2	- 0.2
R6	+ 4.9	+ 3.4	+ 9.2	+ 1.5	0.0
R7	+ 4.5	+ 3.0	+ 12.2	+ 1.7	+ 0.1
R8	- 3.2	- 4.7	+ 7.5	+ 0.9	- 0.5
R9	+ 4.0	+ 2.5	+ 10.0	+ 1.1	- 0.4
R10	+ 6.6	+ 5.1	+ 15.1	+ 1.5	
R11	+ 3.2	+ 1.7	+ 16.8	+ 1.5	
R12	- 2.7	- 4.2	+ 12.6	+ 1.0	

PART OF CALIBRATION CARD

	100 OHMS/STEP DEVIATION FROM NOMINAL	
	Individual (ppm)	Cumulative (ppm)
R1	+2	+2
R2	+4	+3
R3	−1	+2
R4	+4	+2
R5	−3	+1
R6	+3	+2
R7	+3	+2
R8	−5	+1
R9	+2	+1
R10	+5	+2
R11	+2	+2
R12	−4	+1

Figure 3-12. Completed Calibration Chart

3.3.1.2 Second Method

The second method uses an uncalibrated bridge to perform the initial measurements. The deviation between the calculated value of resistance in either the series or parallel connection is measured relative to a known standard. This deviation is applied to the original uncalibrated measurements to correct for the bridge error.

1. Make a copy of the Calibration Chart found in Figure 3-13. It will be used to keep track of the intermediate results and assist in the calculations. An example of a completed Calibration Chart is found as shown in 3-12.

2. Measure the resistance value of each of the 12 resistors in the SR1030 that is to be calibrated. The bridge does not need to be calibrated at this point. Record the deviation (in ppm) from nominal of each resistor in column A (Measured Individual Deviations) of the Calibration Chart.

3. Using the formula listed on the Calibration Chart, calculate D_{av}, the uncalibrated average of the deviation of the first ten resistors. Record this on the Calibration Chart.

4. Select a calibrated standard resistor with a nominal value equal to ten times or one tenth of the nominal value of the individual resistors of the SR1030. Connect this standard resistor to the UNKNOWN terminals on the bridge.

5. Set the DEVIATION dial of the bridge to the known deviation of the standard resistor. Balance the bridge using the resistance standard.

6. Connect the SR1030 in series or parallel to have the same nominal value as the standard resistor. Connect the SR1030 to the UNKNOWN terminals on the bridge.

7. Measure the deviation (in ppm) from nominal for the SR1030. Record this as d_{av} on the Calibration Chart.

8. Calculate the correction value by subtracting D_{av} from d_{av}. Add this correction value to each number in column A of the Calibration Chart and record the results in column B (Corrected Individual Deviations).

9. Round the individual deviations (in column B) to the nearest ppm and record them in the first column of the Calibration Card.

10. Sum the individual deviations (in column B) from the first to each of the deviations and record these sums in column C (Cumulative Sum) of the Calibration Chart.

11. Divide each cumulative sum by the number of resistors involved in the sum and record the results in column D (Cumulative Average) of the Calibration Chart.

12. Round the cumulative averages to the nearest ppm and record them in the fourth column of the Calibration Card.

13. Subtract the tenth cumulative average from each of the first nine cumulative averages, multiply each result by the number of resistors involved in the cumulative average, and divide by 10. Round the results to one decimal place and enter the results in column E (Linearity Deviation) of the Calibration Chart. This is the linearity deviation for each of the first nine steps when the SR1030 is used as a decade divider. For example, the fifth linearity deviation is calculated as:

$$(1.2 - 1.5) * 5/10 = -0.15$$

This would be rounded to -0.2 when entered in the Chart.

MODEL SR1030 Calibration Chart

d_{10}^{av} = ________ d_D = ______________

$d_{sp} = d_{10}^{av} + 0.1 \times d_D$ = ______________

	A	B	C	D	E
	Measured Individual Deviation	Corrected Individual Deviation	Cumulative Sum	Cumulative Average	Linearity Deviation
R1					
R2					
R3					
R4					
R5					
R6					
R7					
R8					
R9					
R10					
R11					
R12					

$D_{av} = 0.1\,(d_1 + d_2 + \cdots + d_{10})$ = ________

d_{av} = ______________________________

Correction Factor = $d_{av} - D_{av}$ = ________

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Figure 3-13. Calibration Chart

SECTION 4
THEORY

4.1 JUNCTION RESISTANCE

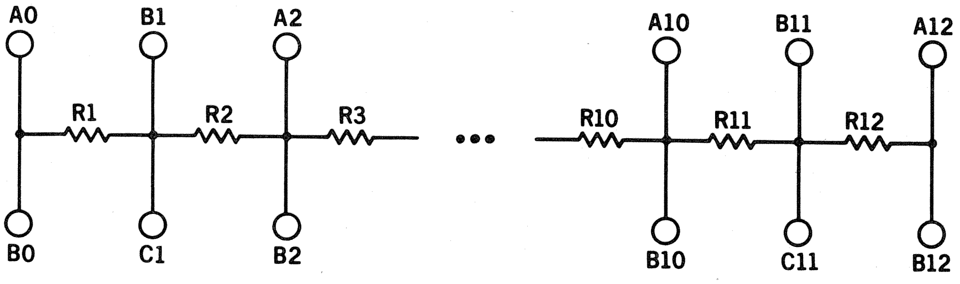
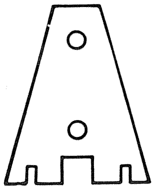


Figure 4-1. Resistor Configuration

The series configuration of a SR1030 Transfer Standard is shown in Figure 4-1. The four-terminal resistors can be measured individually or in any series combination. For the measured series resistance to be equal to the sum of the individual resistor measurements, the junctions must have zero four-terminal resistance. This junction transresistance is zero if a current source connected to each pair of the four-junction terminals produces zero voltage difference between the other two terminals.

The junction design used in the SR1030 (Figure 4-2)* has a theoretical transresistance of zero. For this to be true, if a current source is connected to any two terminals of this junction, the other two terminals will always be on an equipotential line. In practice, as a result of manufacturing tolerances, the junctions may have some transresistance. This can be measured.



*U.S. Patent No. 3 252,091

Figure 4-2. Four-Terminal Junction

The junction resistance of interest is the difference between a four-terminal measurement of two resistors in series and the sum of the four-terminal measurements of the same two resistors. The junction transresistance can be determined to find if it is negligible relative to the resistor value. Two resistance measurements must be made, as shown in Figure 4-3. These measurements can be determined to sufficient accuracy by the voltmeter-ammeter method.

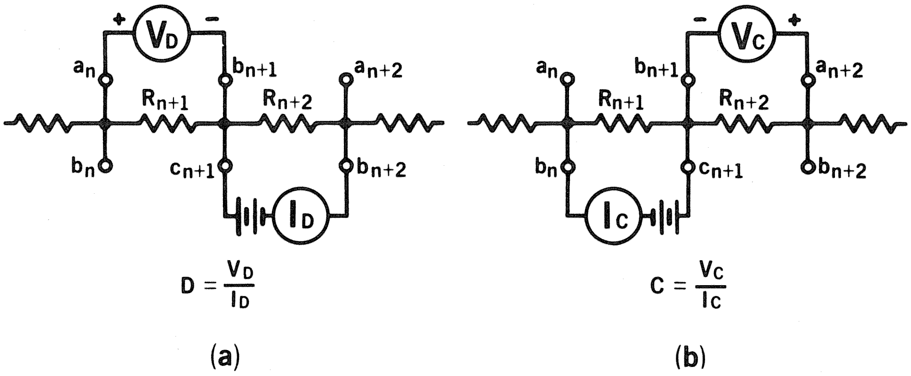


Figure 4-3. Measuring Transresistance

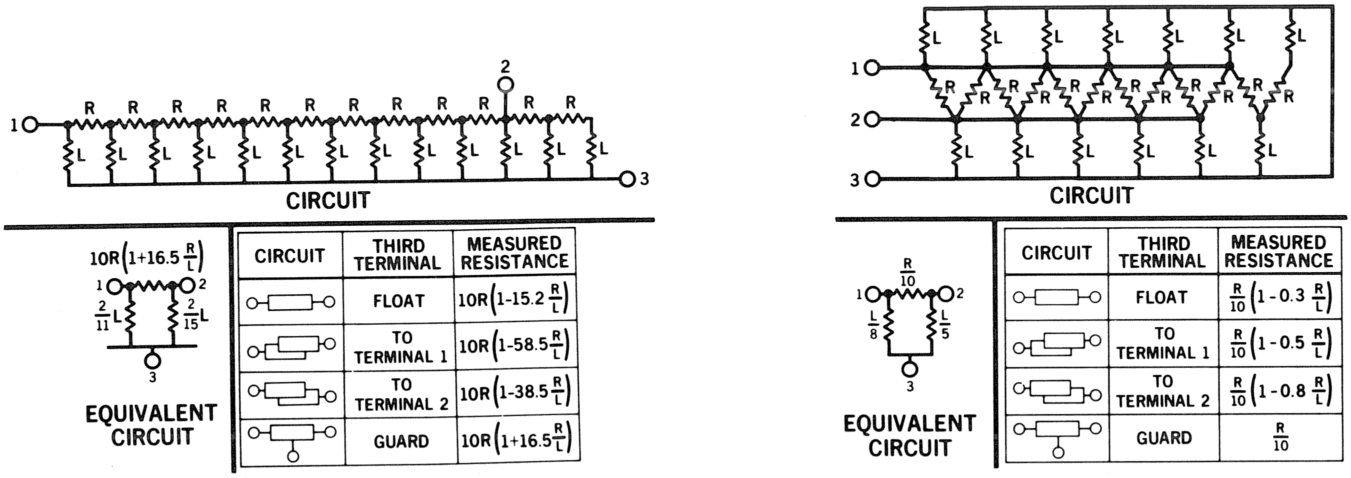
The transresistances C and D may be either positive or negative. The circuits shown will indicate the correct polarity. If a bridge is used to measure the transresistance, it may be necessary to reverse one set of leads since the bridge cannot measure negative resistance. The algebraic sum of the resistances C and D may also be either positive or negative and can either increase or decrease the series measurement relative to the sum of the individual measurements. The sum of C and D should be negligible relative to the value of the resistors involved. For example, it should be less than a microhm for the one ohm-per-step SR1030. The Model 801B Generator Detector can be used to make the transresistance measurements. With the generator RANGE set to one ohm and the POWER LIMIT set to 1000 mW, it becomes a source of one ampere current to a one ohm resistor. With the detector on the 1 microvolt range, the junctions of the one ohm-per-step SR1030 can be checked down to the 0.1 ppm level since the meter will read one ppm full sacle. Table 4-1 lists the Generator settings and the transresistance sensitivity for each SR1030 when using the Model 801B. The Generator POWER LIMIT should be set to 1000 mW in all cases.

Table 4-1. Model 801B Settings for Transresistance Measurement

SR1030 Resistance	Generator RANGE (ohm)	Measurement Current (A)	uohm/uV	ppm/uV
1	1	1	1.00	1.00
10	10	0.3	3.33	0.33
100	100	0.1	10.00	0.10
1000	1000	0.03	33.33	0.03
10000	10000	0.01	100.00	0.01
100000	100000	0.003	333.33	0.003

4.2 INSULATION RESISTANCE

Each terminal has some leakage resistance to the case. When individual resistors are measured or when groups of resistors connected in parallel are used, the leakage effects can be avoided by making three-terminal (guarded) measurements. When groups of resistors are connected in series, however, the effects cannot be avoided. Figure 4-4 shows the leakage effects for ten resistors connected in series and in parallel. The circuit was analyzed assuming that all leakage resistances were equal as shown, as this should reasonably reflect the actual leakage resistance on an SR1030.



CIRCUIT	THIRD TERMINAL	MEASURED RESISTANCE
	FLOAT	$10R\left(1-15.2\frac{R}{L}\right)$
	TO TERMINAL 1	$10R\left(1-58.5\frac{R}{L}\right)$
	TO TERMINAL 2	$10R\left(1-38.5\frac{R}{L}\right)$
	GUARD	$10R\left(1+16.5\frac{R}{L}\right)$

CIRCUIT	THIRD TERMINAL	MEASURED RESISTANCE
	FLOAT	$\frac{R}{10}\left(1-0.3\frac{R}{L}\right)$
	TO TERMINAL 1	$\frac{R}{10}\left(1-0.5\frac{R}{L}\right)$
	TO TERMINAL 2	$\frac{R}{10}\left(1-0.8\frac{R}{L}\right)$
	GUARD	$\frac{R}{10}$

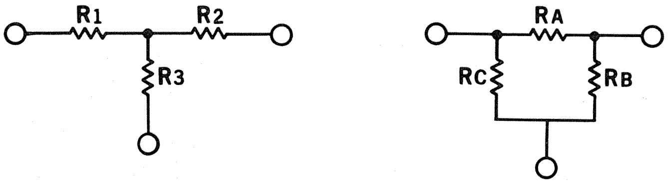
Figure 4-4. Effects of Leakage

The analysis indicates that the measured series resistance will be low if the case is not tied to guard and will be high if the resistors are guarded. The actual effect for a given measurement can be checked by making these two measurements and comparing the results. The correct value will lie somewhere between them.

4.2.1 Derivation of Series Circuit Leakage Resistance Effects

Figure 4-4 contains a series circuit equivalent circuit and three equations that relate to this circuit. The purpose of this section is to indicate how these were derived.

The process for deriving the equivalent circuit for the series connected resistors relies on the use of a "T to pi" transform. It can be shown that a three-terminal "T" resistor network (Figure 4-5a) can be transformed to a three-terminal "pi" resistor network (Figure 4-5b), or the "pi" network may be transformed to the "T" network. The equations in Figure 4-5 indicate how the values of the individual resistors transform between the two networks. Each network will have exactly the same characteristics for any measurement using only the three terminals.



$$R_1 = \frac{R_A R_C}{R_A+R_B+R_C}$$

$$R_2 = \frac{R_A R_B}{R_A+R_B+R_C}$$

$$R_3 = \frac{R_B R_C}{R_A+R_B+R_C}$$

(a)

$$R_A = R_1+R_2 + \frac{R_1 R_2}{R_3}$$

$$R_B = R_2+R_3 + \frac{R_2 R_3}{R_1}$$

$$R_C = R_1+R_3 + \frac{R_1 R_3}{R_2}$$

(b)

Figure 4-5. Transforming Between "T" and "Pi" Networks

The circuit composed of the twelve series resistors with thirteen leakage resistors to terminal 3 can be grouped into six "T" networks plus seven leakage resistors. This is shown in Figure 4-6.

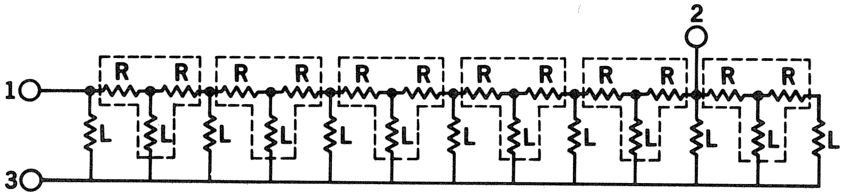


Figure 4-6. Grouping for the First Transform

Each "T" network has resistors of value R for the two horizontal arms and one resistor of value L for the vertical arm. Figure 4-7 indicates how this "T" network transforms into a "pi" network.

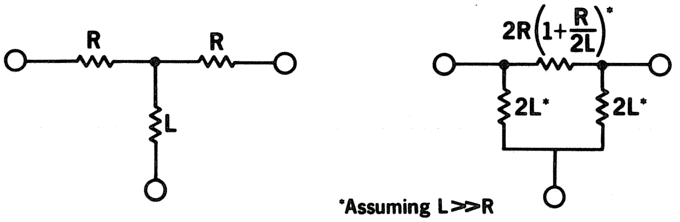


Figure 4-7. First "T" to "Pi" Transform

Replacing the original six "T" networks with the new "pi" networks results in the equivalent circuit shown in Figure 4-8a. Figure 4-8b combines the parallel resistors composed of the remaining leakage resistors and the vertical arms of the "pi" networks. The two "T" networks that will be transformed in the next step are outlined in Figure 4-8b.

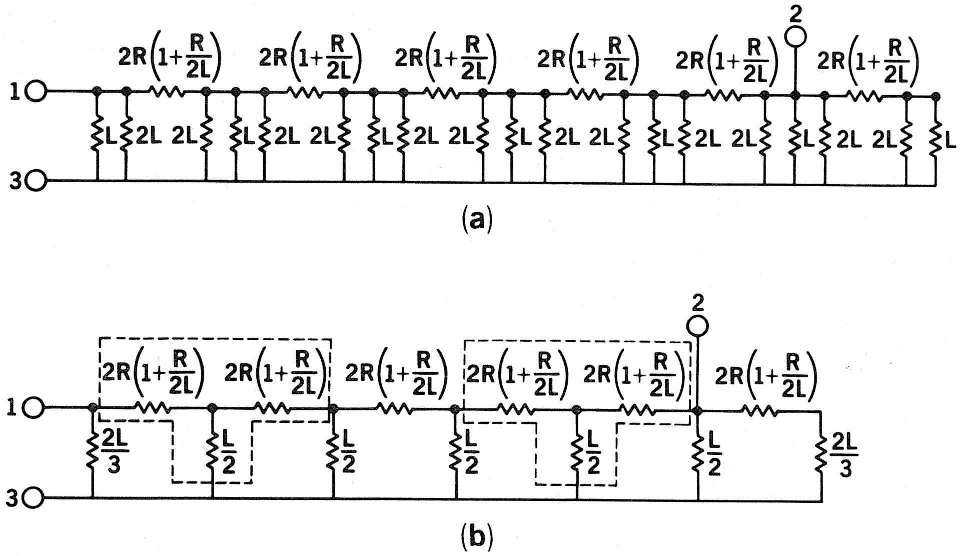


Figure 4-8. Result of First Transform

Each "T" network in Figure 4-8b has resistors of value 2R(1 + R/2L) for the two horizontal arms and one resistor of value L/2 for the vertical arm. Figure 4-9 indicates how this "T" network transforms into a "pi" network.

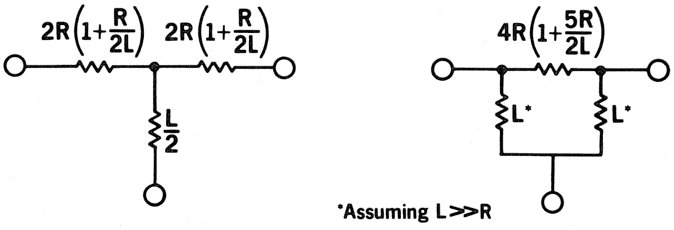


Figure 4-9. Second "T" to "Pi" Transform

Replacing the three "T" networks with the new "pi" networks results in the equivalent circuits shown in Figure 4-10. Figure 4-10b combines the parallel resistors composed of the remaining leakage resistors and the vertical arms of the "pi" networks. The vertical resistor on the far right is the parallel combination of the resistors to the right of Terminal 2 and the resistors from Terminal 2 to Terminal 3. The second series resistor from the left has been divided into two equal-value resistors for the next step. The two "T" networks that will be transformed in the next step are outlined in Figure 4-10b.

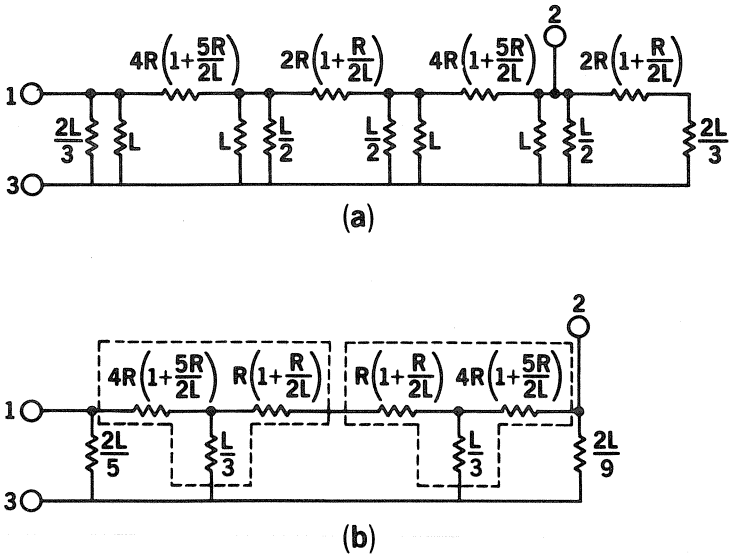


Figure 4-10. Result of Second Transform

The two "T" networks outlined in Figure 4-10b can be transformed into "pi" networks, as shown in Figure 4-11.

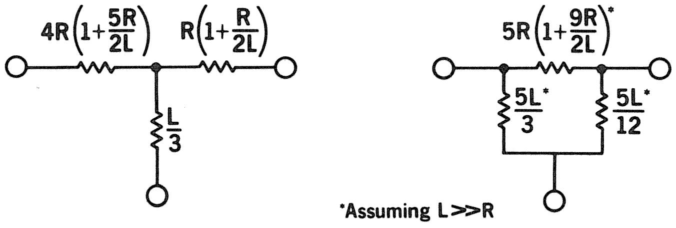


Figure 4-11. Third "T" to "Pi" Transform

The result of the third transform is shown in Figure 4-12.

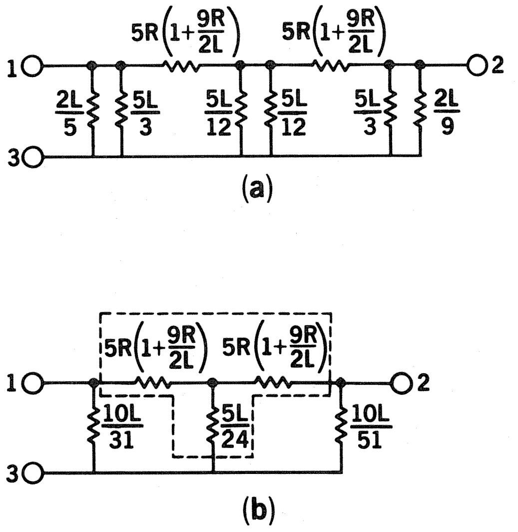


Figure 4-12. Result of Third Transform

The circuit shown in Figure 4-12b is composed of one "T" network with one extra resistor at each end. The "T" network can be transformed as shown in Figure 4-13.

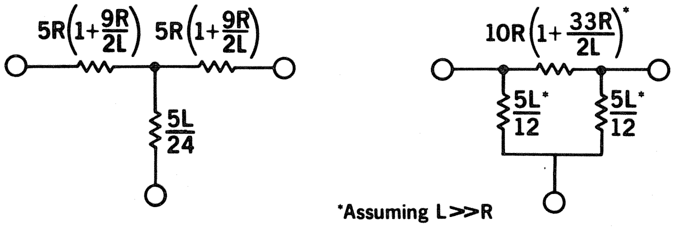


Figure 4-13. Fourth "T" to "Pi" Transform

The result of the last transform is shown in Figure 4-14. Figure 4-14b is the equivalent circuit used for the series case in Figure 4-4.

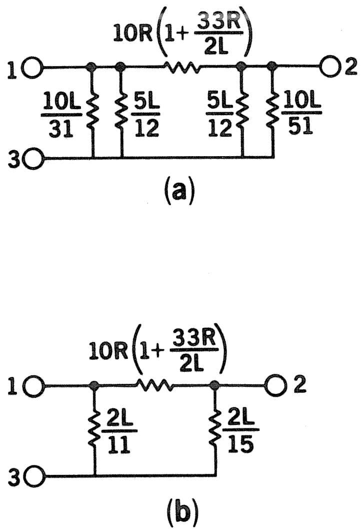


Figure 4-14. Result of Fourth Transform

4.2.1.1 Series Circuit with Floating Terminal 3

To derive the three measured resistances, the result of a measurement on the equivalent circuit should be analyzed. In the case where terminal 3 floats, the two vertical resistors are in series with one another and in parallel with the horizontal resistor. This is shown in Figure 4-15.

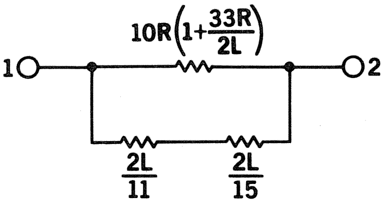


Figure 4-15. Series Equivalent Circuit with Floating Terminal 3

The measured value of this arrangement is given by:

$$R_f = \frac{10R\ (1 + 16.5\ R/L)\ (2L/11 + 2L/15)}{10R\ (1 + 16.5\ R/L) + (2L/11 + 2L/15)}$$

$$R_f = \frac{10R\ (1 + 16.5\ R/L)\ 52L/165}{52L/165 + 165\ R^2/L + 10R}$$

$$R_f = \frac{10R\ (1 + 16.5\ R/L)}{1 + (27225/52)\ (R/L)^2 + (1650/52)\ (R/L)}$$

L would typically be at least 10^7 times larger than R, so $(R/L)^2$ should be less than 10^{-14}. Compared to the 1 in the denominator, the $(R/L)^2$ term in the denominator should be insignificant and therefore can be ignored. This leaves:

$$R_f = \frac{10R\ (1 + 16.5\ R/L)}{1 + (1650/52)\ (R/L)} = \frac{10R\ (1 + 16.5\ R/L)}{1 + (825/26)\ (R/L)}$$

or

$$R_f = 10R\ (1 + 16.5\ R/L) * \frac{1}{1 + (825/26)\ (R/L)}$$

Using the relationship (which converges over the region $-1 < x < 1$):

$$\frac{1}{(1 + x)} = 1 - x + x^2 - x^3 + \ldots = 1 + \sum_{m=1}^{+\infty} (-x)^m$$

with $x = (825/26)(R/L)$:

$$R_f = 10R(1 + 16.5\ R/L)(1 - (825/26)(R/L) + (825/26)^2 (R/L)^2 - \ldots)$$

Again, the $(R/L)^2$ and higher terms can be ignored, leaving:

$$R_f = 10R(1 + 16.5\ R/L)(1 - (825/26)(R/L))$$

$$R_f = 10R(1 + R/L\ (16.5 - (825/26)) - 16.5 * (825/26)(R/L)^2)$$

Again, the $(R/L)^2$ and higher terms can be ignored, leaving:

$$R_f = 10R(1 + R/L\ (16.5 - (825/26))) = 10R(1 - R/L\ (198/13))$$

4.2.1.2 Series Circuit with Terminal 3 Connected to Terminal 1

In the case where terminal 3 is connected to terminal 1, the resistor with value 2L/11 is shorted and the resistor with value 2L/15 is in parallel with the horizontal resistor. The measured resistance in this case is given by:

$$R_{13} = \frac{10R\ (1 + 16.5\ R/L)\ (2L/15)}{10R\ (1 + 16.5\ R/L) + (2L/15)}$$

$$R_{13} = \frac{10R\ (1 + 16.5\ R/L)}{1 + 75R/L\ (1 + 16.5\ R/L)} = \frac{10R\ (1 + 16.5\ R/L)}{1 + 75R/L + 1237.5\ (R/L)^2}$$

Again, the $(R/L)^2$ term can be ignored, so:

$$R_{13} = \frac{10R\ (1 + 16.5\ R/L)}{1 + 75R/L}$$

Using the $1/(1 + x)$ relationship again ($x = 75R/L$) and ignoring terms above R/L:

$$R_{13} = 10R\ (1 + 16.5\ R/L)(1 - 75R/L)$$

$$R_{13} = 10R\ (1 + 16.5\ R/L - 75\ R/L - (16.5 * 75)(R/L)^2$$

Ignoring the $(R/L)^2$ term:

$$R_{13} = 10R\ (1 - 58.5\ R/L)$$

4.2.1.3 Series Circuit with Terminal 3 Connected to Terminal 2

In the case where terminal 3 is connected to terminal 2, the resistor with value 2L/15 is shorted and the resistor with value 2L/11 is in parallel with the horizontal resistor. The measured resistance in this case is given by:

$$R_{12} = \frac{10R\ (1 + 16.5\ R/L)\ (2L/11)}{10R\ (1 + 16.5\ R/L) + (2L/11)}$$

$$R_{12} = \frac{10R\ (1 + 16.5\ R/L)}{1 + 55R/L\ (1 + 16.5\ R/L)} = \frac{10R\ (1 + 16.5\ R/L)}{1 + 55R/L + 907.5\ (R/L)^2}$$

Again, the $(R/L)^2$ term can be ignored, so:

$$R_{12} = \frac{10R\ (1 + 16.5\ R/L)}{1 + 55R/L}$$

Using the $1/(1 + x)$ relationship again $(x = 55R/L)$ and ignoring terms above R/L:

$$R_{12} = 10R\ (1 + 16.5\ R/L)\ (1 - 55R/L)$$

$$R_{12} = 10R\ (1 + 16.5\ R/L - 55\ R/L - (16.5 * 55)\ (R/L)^2$$

Ignoring the $(R/L)^2$ term:

$$R_{12} = 10R\ (1 - 38.5\ R/L)$$

4.2.1.4 Series Circuit with Terminal 3 Guarded

If a proper three-terminal measurement is made, the effects of the vertical resistors in the equivalent circuit will be eliminated. The result will be that the measured resistance will be the value of the horizontal resistor in the equivalent circuit, $10R(1 + 16.5R/L)$. Connecting terminal 3 to a GUARD terminal on the bridge, a good approximation of a three-terminal connection can be made.

4.2.2 Derivation of Parallel Circuit Leakage Resistance Effects

The parallel resistance case is simpler than the series resistance case. Assuming equal leakage for all junctions, the circuit appears as shown in Figure 4-16.

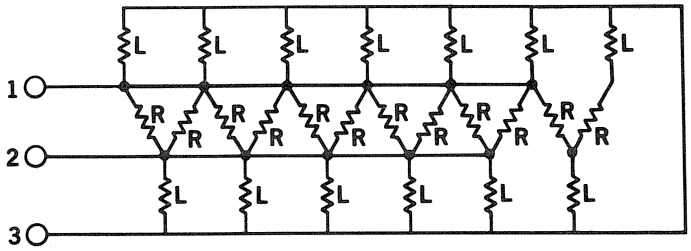


Figure 4-16. Parallel Configuration with Leakage Resistances

Combining the parallel resistors of Figure 4-16 results in the circuit shown in Figure 4-17a. The two resistors of value R (outlined in Figure 4-17a) can be replaced by short circuits as they are in series with resistors with value L and L is much greater than R. This substitution results in the equivalent circuit shown in Figure 4-17b.

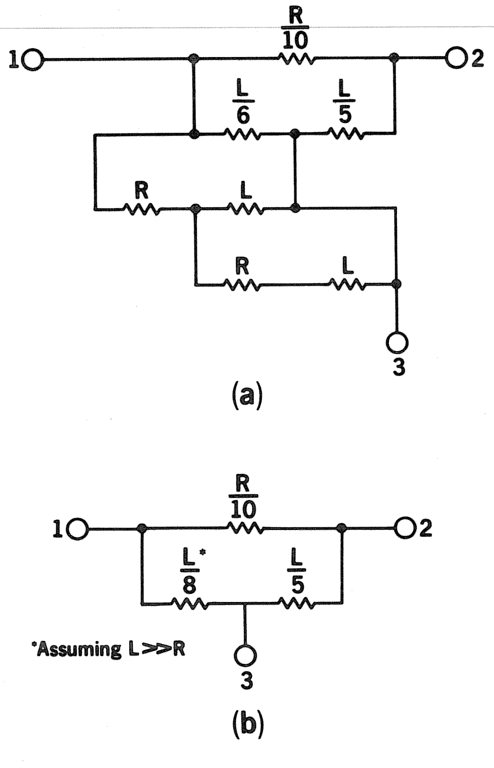


Figure 4-17. Parallel Configuration Simplified

4.2.2.1 Parallel Circuit with Floating Terminal 3

If terminal 3 of the parallel circuit is allowed to float, the two vertical resistors in the equivalent circuit are in series with one another and in parallel with the horizontal resistor. This is shown in Figure 4-18.

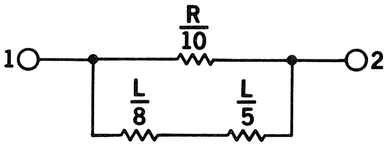


Figure 4-18. Parallel Equivalent Circuit with Floating Terminal 3

The measured value of this arrangement is given by:

$$R_f = \frac{(R/10)\ (L/8 + L/5)}{(R/10) + (L/8 + L/5)} = \frac{(R/10)\ (13L/40)}{(R/10) + (13L/40)}$$

$$R_f = \frac{R/10}{1 + (4/13)(R/L)}$$

Using the 1/(1 + x) equation (x = 4/13 R/L) and ignoring $(R/L)^2$ terms:

$$R_f = (R/10)\ (1 - (4/13)(R/L))$$

4.2.2.2 Parallel Circuit with Terminal 3 Connected to Terminal 1

In the case where terminal 3 is connected to terminal 1, the resistor with value L/8 is shorted and the resistor with value L/5 is in parallel with the horizontal resistor. The measured resistance in this case is given by:

$$R_f = \frac{(R/10)\ (L/5)}{(R/10) + (L/5)} = \frac{R/10}{1 + (1/2)\ (R/L)}$$

Using the $\frac{1}{1 + x}$ equation $(x = 1/2\ R/L)$ and ignoring $(R/L)^2$ terms:

$$R_f = (R/10)\ (1 - (1/2)\ (R/L))$$

4.2.2.3 Parallel Circuit with Terminal 3 Connected to Terminal 2

In the case where terminal 3 is connected to terminal 2, the resistor with value L/5 is shorted and the resistor with value L/8 is in parallel with the horizontal resistor. The measured resistance in this case is given by:

$$R_f = \frac{(R/10)\ (L/8)}{(R/10) + (L/8)} = \frac{R/10}{1 + (4/5)\ (R/L)}$$

Using the $\frac{1}{1 + x}$ equation $(x = 4/5\ R/L)$ and ignoring $(R/L)^2$ terms:

$$R_f = (R/10)\ (1 - (4/5)\ (R/L))$$

4.2.2.4 Parallel Circuit with Terminal 3 Guarded

If terminal 3 is connected to a Guard on the bridge, the effects of the vertical resistors in the equivalent circuit will be eliminated. The result will be that the measured resistance will be the value of the horizontal resistor in the equivalent circuit, R/10.

4.3 TRANSFER ACCURACY

To make transfer measurements which do not depend on the absolute accuracy of the transfer standard but only on its short-term stability, it is necessary to assume that ten resistors in parallel are exactly equal to one one-hundredth of the same ten resistors in series. To see how valid this assumption is, let R be the nominal value of the individual resistors and d_n the deviation from nominal of the nth resistor. The value of the nth resistor will then be: $R_n = R(1 + d_n)$. The value of the ten resistors in series will be:

$$R_s = \sum_{n=1}^{10} R(1 + d_n) = 10R\ (1 + \frac{1}{10} \sum_{n=1}^{10} d_n)$$

$$d_{av}^{10} = \frac{1}{10} \sum_{n=1}^{10} d_n$$

Where:

d_{av}^{10} is the average of the deviation d_n for ten resistors

So:

$$R_s = 10R\ (1 + d_{av}^{10})$$

The resistance of the same ten resistors in parallel will be:

$$R_p = \frac{1}{\sum_{n=1}^{10} \frac{1}{R\ (1 + d_n)}}$$

This can be calculated if the individual deviations are known. For the general case where the deviations are unknown, the equation can be solved further.

Recalling the equation (which converges over the region $-1 < x < 1$):

$$\frac{1}{(1+x)} = 1 - x + x^2 - x^3 + \ldots = 1 + \sum_{m=1}^{+\infty} (-x)^m$$

with $x = d_n$

Then:

$$R_p = \frac{R}{\sum_{n=1}^{10} \left(1 + \sum_{m=1}^{+\infty} (-d_n)^m\right)}$$

$$R_p = \frac{R}{10\left(1 + \frac{1}{10}\sum_{n=1}^{10}\sum_{m=1}^{+\infty} (-d_n)^m\right)} = \frac{R}{10}\,\frac{1}{\left(1 + \frac{1}{10}\sum_{n=1}^{10}\sum_{m=1}^{+\infty} (-d_n)^m\right)}$$

$$R_p = \frac{R}{10}\left(1 + \sum_{p=1}^{+\infty}\left(-\frac{1}{10}\sum_{n=1}^{10}\sum_{m=1}^{+\infty}(-d_n)^m\right)^p\right) = \frac{R}{10}(1 + S)$$

Where:

$$S = \sum_{p=1}^{+\infty}\left(-\frac{1}{10}\sum_{n=1}^{10}\sum_{m=1}^{+\infty}(-d_n)^m\right)^p$$

If each d_n is sufficiently less than 1, only the first and second order terms should be significant to our level of accuracy. The exponent of each d_n will be the product of m and p. If we are only interested in first and second order terms, we need to evaluate only at m=1, p=1; m=1, p=2; and m=2, p=1.

m=1, p=1:

$$S = \sum_{p=1}^{1}\left(-\frac{1}{10}\sum_{n=1}^{10}\sum_{m=1}^{1}(-d_n)^m\right)^p = \left(-\frac{1}{10}\sum_{n=1}^{10}(-d_n)^1\right)^1 = \frac{1}{10}\sum_{n=1}^{10} d_n = d_{av}^{10}$$

m=1, p=2:

$$S = \sum_{p=2}^{2}\left(-\frac{1}{10}\sum_{n=1}^{10}\sum_{m=1}^{1}(-d_n)^m\right)^p = \left(-\frac{1}{10}\sum_{n=1}^{10}(-d_n)^1\right)^2 = \left(\frac{1}{10}\sum_{n=1}^{10} d_n\right)^2 = (d_{av}^{10})^2$$

m=2, p=1:

$$S = \sum_{p=1}^{1}\left(-\frac{1}{10}\sum_{n=1}^{10}\sum_{m=2}^{2}(-d_n)^m\right)^p = \left(-\frac{1}{10}\sum_{n=1}^{10}(-d_n)^2\right)^1 = -\frac{1}{10}\sum_{n=1}^{10}(d_n)^2$$

So:

$$R_p = \frac{R}{10} (1 + d_{av}^{10} + (d_{av}^{10})^2 - \frac{1}{10} \sum_{n=1}^{10} (d_n)^2 + \text{higher order terms})$$

Since the $(d_n)^2$ terms should be insignificant, the following should be a valid approximation:

$$R_p = \frac{R}{10} (1 + d_{av}^{10})$$

Note that this has the same deviation (d_{av}^{10}) from nominal as the deviation that the series connection had from nominal.

The first-order correction to this approximation is:

$$(d_{av}^{10})^2 - 0.1 \sum_{n=1}^{10} (d_n)^2$$

which is the statistical variance of the deviations.

A similar analysis can be made for the series-parallel connection or any other configuration in which the power divides equally among the resistors.

4.4 COMPENSATION NETWORKS

To minimize the effects of the connections when using a parallel or series-parallel arrangement, Compensation Networks and shorting bars are available. Their effect on the measurement is discussed in this section.

The parallel connection of ten four-terminal resistors using the SB103 shorting bars and the PC101 Parallel Compensation Network is shown in Figure 4-19.

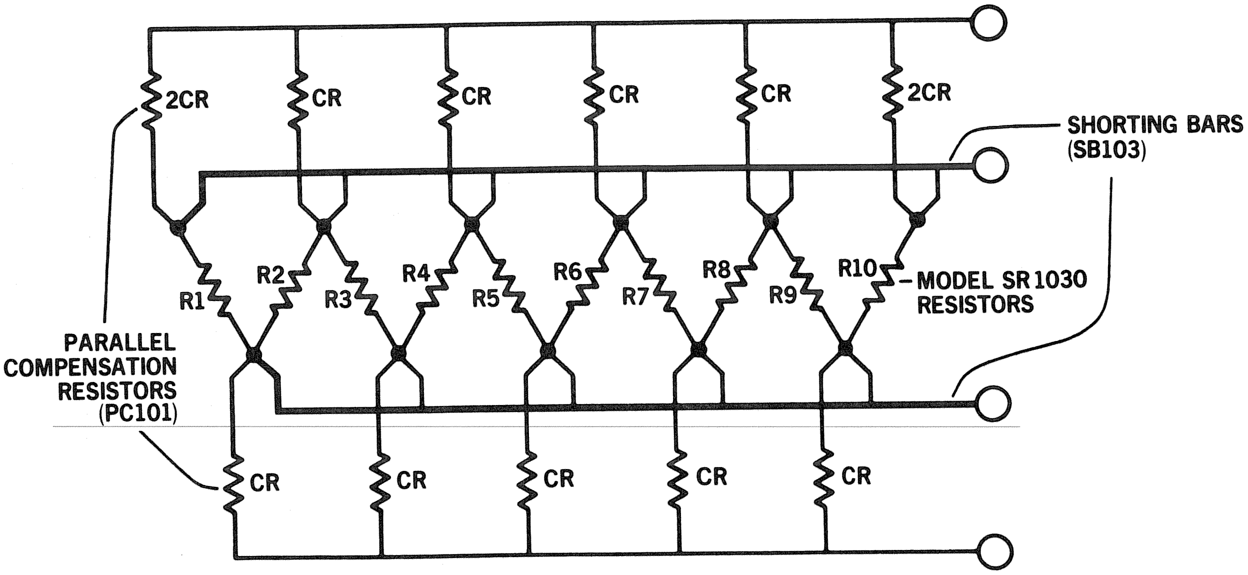


Figure 4-19. Parallel Connection with Shorting Bars and Compensation Network

The shorting bar resistance and the resistance from the junctions to the shorting bars should be small. The compensation resistors in the Compensation Network should be large compared to the uncertainty in the contact resistances when they are connected. The two compensation resistors on the ends are double the others because they connect to one SR1030 resistor instead of two in parallel.

When several nominally equal resistors are connected in parallel the connection accuracy can be analyzed by looking at the worst case. This is done by assuming that all of the compensation resistors except one are equal and that all of the shorting bar resistances except one are zero. At the same time, all of the resistors being connected are assumed to be perfect except one. The three imperfect resistors all meet at one of the junctions. Since small first-order error effects add linearly, the results of this analysis can be extended to determine the connection accuracy. The connection uncertainty is less than:

$$\pm 2 \left(\frac{r}{R}\right) (d_{CR} - d_R)$$

Where:

r is the greatest bus bar resistance
R is the nominal value of resistors being parallel connected
$(d_{CR} - d_R)$ is the greatest bridge unbalance in terms of resistance deviations of the compensation resistors and the resistors being connected

NOTE: Proof of the equation given above and those that follow can be found in Technical Article TA-6, "The Accuracy of Series and Parallel Connections of Four-Terminal Resistors," available directly from .

The values of r/R and $(d_{CR} - d_R)$ can be measured to find the expected accuracy of a particular connection.

The value of r/R can be found by measuring the voltage drops from a point on the shorting bars to the junction of adjacent resistors, shown in Figure 4-20. This is done as follows:

1. Connect the shorting bars and a DC Generator to the bank of resistors for parallel use, as shown in Figure 4-20.
2. Connect one lead of a voltmeter to one of the terminals on one of the shorting bars, as shown in Figure 4-20.
3. Measure and record the voltage to the terminal across from each terminal connected to the selected shorting bar. Calculate the largest difference between these voltages.
4. Repeat STEPs 2 and 3 for the other shorting bar.
5. Divide the higher of the two voltage differences calculated in STEPs 3 and 4 by E, the voltage of the DC Generator.

The value calculated in STEP 5 is the upper limit of (r/R), the upper limit of the error of a four-terminal measurement when the shorting bars are used without the Compensation Network, and is given by:

$$\left(\frac{r}{R}\right)_{max} = \frac{V_{max} - V_{min}}{E}$$

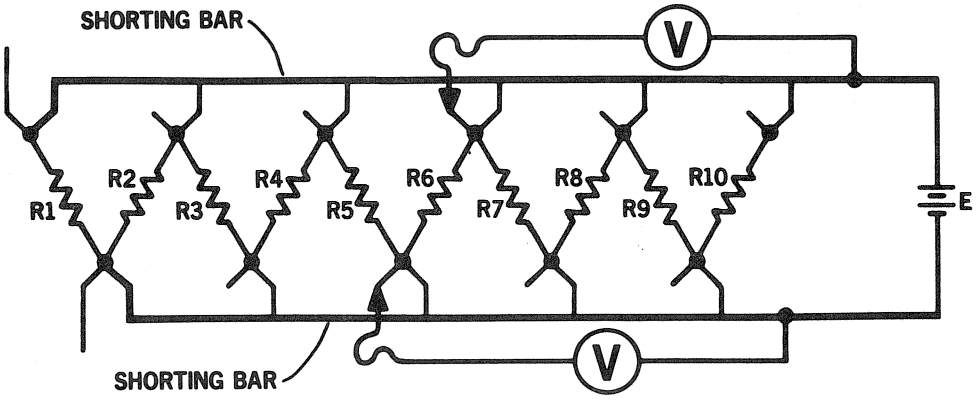


Figure 4-20. Measuring r/R

The value of $(d_{CR} - d_R)$, the bridge unbalance, is measured in the following manner. Refer to Figure 4-21.

1. Connect one shorting bar to terminals C1 through C5. Connect the PC101 Compensation Network and a DC Generator to the bank of resistors for parallel use.
2. Connect one lead of a voltmeter to terminal A10.
3. Measure and record the voltage to each of the five terminals A0 through A8. Subtract the highest voltage from the lowest voltage to calculate the largest difference.
4. Move the shorting bar to terminals A0 through A10.
5. Connect one lead of the voltmeter to terminal C5.
6. Measure and record the voltage to each of the four terminals C1 through C4. Subtract the highest voltage from the lowest voltage to calculate the largest difference.
7. Divide the higher of the two voltage differences calculated in STEPs 3 and 6 by E, the voltage of the DC Generator.

The value calculated in STEP 7 is given by:

$$(d_{CR} - d_R)_{max} = \left(\frac{V_{max} - V_{min}}{E}\right)\left(2 + \frac{2CR}{R} + \frac{R}{CR}\right)$$

The measured values of $(r/R)_{max}$ and $(d_{CR} - d_R)_{max}$ can be multiplied together and doubled to give an upper bound of the connection error. This usually includes a very substantial safety factor. The same technique can be used in the series-parallel case.

> **NOTE:** With the PC101 and SPC102 Compensation Networks, the connection uncertainty just calculated should always be negligibly small.

The bridge unbalance can be measured as shown in Figure 4-21.

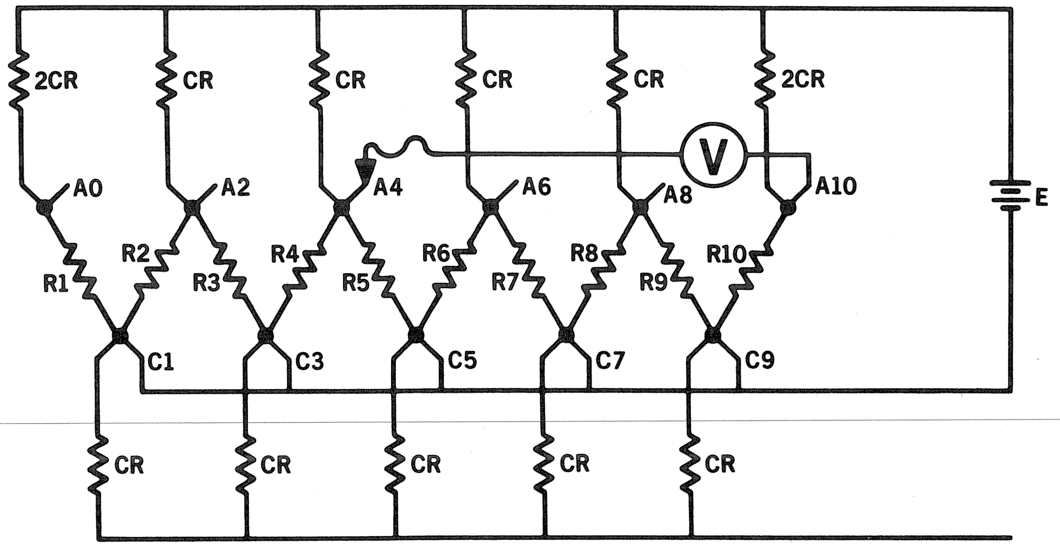


Figure 4-21. Measuring the Bridge Unbalance

4.5 LINEARITY DEVIATION

To calibrate the SR1030 as a voltage divider, the difference between the actual ratio of the output to input voltages and the setting must be determined. This difference, called linearity deviation, is given by the following.

$$L = \frac{E_{out}}{E_{in}} - S$$

Where:

L is the linearity deviation
E_{in} is the actual input voltage
E_{out} is the actual output voltage
S is the divider setting

Since the voltage and resistance divide proportionately, the linearity deviation can be found by a precision comparison of the resistors in the divider string. By using ten resistors of the SR1030 in the divider string, the output can be set to integral multiples of a tenth the input voltage. The linearity deviation for this divider can be written as:

$$L = \frac{\sum_{i=1}^{n} R_i}{\sum_{i=1}^{10} R_i} - S = \frac{\sum_{i=1}^{n} R\ (1 + d_i)}{\sum_{i=1}^{10} R\ (1 + d_i)} - S = \frac{\sum_{i=1}^{n} (1 + d_i)}{\sum_{i=1}^{10} (1 + d_i)} - S$$

Where:

L is the linearity deviation

R_i is the resistance of the ith resistor

$\sum_{i=1}^{n} R_i$ is the resistance from the Output to the COMMON terminal

$\sum_{i=1}^{10} R_i$ is the total input resistance

S is the divider setting $(0 <= S <= 1)$

n is the number of resistors between the Output and the COMMON terminal $(= 10S)$

To simplify further:

$$L = \frac{10S + \sum_{i=1}^{n} d_i}{10 + \sum_{n=1}^{10} d_i} - S$$

The cumulative deviation (at the rth resistor) is defined as:

$$d_{cu}^{r} = \frac{1}{r} \sum_{i=1}^{r} d_i$$

The following has already been defined as the average deviation:

$$d_{cu}^{10} = d_{av}^{10} = 0.1 \sum_{i=1}^{10} d_i$$

So, noting that n = 10S:

$$L = \frac{n + n\, d_{cu}^{n}}{10 + 10\, d_{av}^{10}} - \frac{n}{10} = \frac{n}{10} \left(\frac{1 + d_{cu}^{n}}{1 + d_{av}^{10}} - 1 \right)$$

$$L = \frac{n}{10} \left(\frac{1 + d_{cu}^{n} - 1 - d_{av}^{10}}{1 + d_{av}^{10}} \right) = \frac{n}{10} \left(\frac{d_{cu}^{n} - d_{av}^{10}}{1 + d_{av}^{10}} \right)$$

Assuming that $d_{av}^{10} << 1$:

$$L = \frac{n}{10} (d_{cu}^{n} - d_{av}^{10})$$

SECTION 5

APPLICATIONS

This section illustrates applications of the SR1030 by describing step-by-step resistance transfer procedures for typical instruments. The transfer techniques may be used as a method of calibrating the individual resistors in a transfer standard, to calibrate other resistors, or to calibrate the measuring instruments themselves.

The techniques shown here are intended as examples. They illustrate the way that the SR1030 can be used. A person can adapt the techniques illustrated here to other equipment.

> **NOTE:** Reference is made in this following procedures to a **tare** resistor. A tare resistor is one that is used as an external part of a measuring bridge and is left connected throughout the calibration and measuring process. Its value does not need to be accurate, but it must have good short-term stability.

5.1 ESI MODEL 123 RESISTANCE COMPARISON SYSTEM*

The examples in this section illustrates how to use the Model 123 Resistance Comparison System for determining the ratio of an SR1030 to the actiual value of a primary resistor such as an Model SR104 Resistance Standard. The ratio can then be used as a correction value when using the SR1030 Transfer Standard as a primary standard with an accuracy relative to the accuracy of the SR104 and the transfer measurement.

5.1.1 System Description

An Model 123 Resistance Comparison System consists of Models 120 Direct-Reading Double Ratio Set, 876 Lead Compensator, 830 Generator, and 900 Galvanometer. Refer to Figure 5-1.

This system uses a Wenner balance technique that eliminates errors that are due to resistance of the test leads. The resolution of the OFFSET and RATIO dials of the ratio set is 0.1 ppm. The galvanometer can be used to interpolate to 0.01 ppm throughout much of the range.

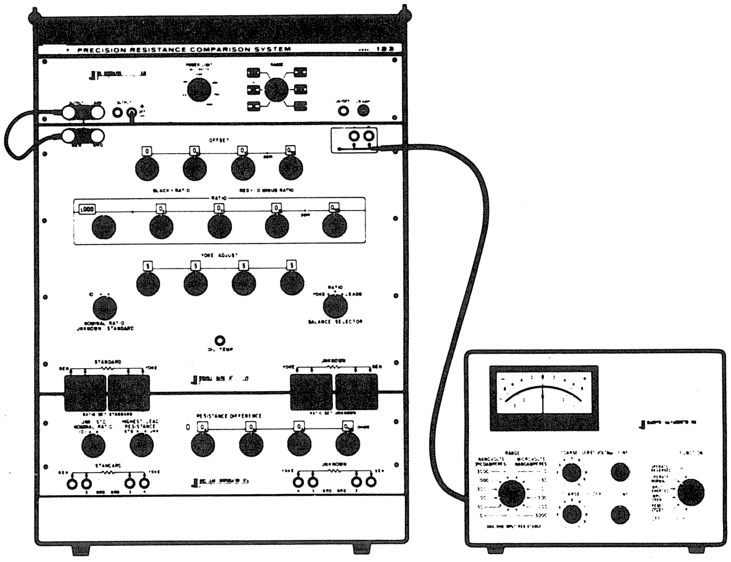


Figure 5-1. **Model 123**

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*The Model 123 is no longer being manufactured.

The accuracy of comparisons can be illustrated by the following example, in which a 10 kilohm standard value is transferred to 1 ohm. The error of each step of the transfer procedure is independent of the other steps and so the combination of errors is shown as the square root of the sum of the squares of the individual errors.

This example is taken from paragraph 5.1.5 following. The individual limits of error are those specified for the equipment used.

	Source of Error	Limit of Error (ppm)
1.	Primary standard (Model SR104 10 kilohm Resistance Standard)	1.0
2.	Comparison of resistance standard to tare resistor (using Model 123 System)	0.22
3.	Comparison of tare resistor to 1 kilohm-per-step SR1030 (series connected)	0.22
4.	100-to-1 transfer (change 1 kilohm-per-step SR1030 connection from series to parallel)	1.0
5.	Comparison of 1 kilohm-per-step (parallel connected) SR1030 to 100 ohm tare resistor	0.22
6.	Comparison of 100 ohm tare resistor to 10 ohm-per-step (series connected) SR1030	0.22
7.	100-to-1 transfer (change 10 ohm-per-step SR1030 connection from series to parallel)	1.1
8.	Comparison of 10 ohm-per-step (parallel connected) SR1030 to a 1 ohm tare resistor	0.22
9.	Comparison of 1 ohm tare resistor to an unknown 1 ohm resistor	0.22
	Sum of error limits	4.42 ppm
	Square root of the sum of the squares	1.87 ppm

NOTE: If the individual steps are independent and normally distributed, the square root of the sum of squares should be used as the total uncertainty.

NOTE: Exact details of operating the system are not covered in these procedures. The detector must be zeroed with the generator off but with the resistors to be compared connected to the UNKNOWN and STANDARD binding posts, the yoke and leads must be balanced according to the procedure in the manual for the ratio set, the generator polarity must be reversed to avoid thermal voltage errors, and the detector sensitivity must be increased after each trial balance. All of these operations are included in the single word "balance" in the following procedures.

5.1.2 Transfer from 10 kilohms to 100 kilohms and 1 kilohm

1. Connect the 10 kilohm primary standard resistor (Model SR104 is recommended) to the UNKNOWN binding posts of the Lead Compensator. Use a four-terminal connection to the resistor and connect at least one GND terminal on the standard resistor to a GND terminal on the bridge.

2. Set the RATIO controls of the ratio set to the calibrated resistance (correct for temperature) of the standard. Model SR104 contains an internal resistance temperature sensor which changes by 0.1% (1000 ppm) per degree Celsius. A calibration curve is included with the standard resistor.

3. Connect the tenth resistor (R10) of a 10 kilohm-per-step SR1030 to the STANDARD binding posts of the Lead Compensator.

4. Balance the bridge with the OFFSET dials. Do NOT adjust the RATIO dials. Record the OFFSET dial reading as d(10).

5. Connect a 10 kilohm-per-step SR1030 in series-parallel for 10 kilohms and connect the transfer standard to the STANDARD terminals of the Lead Compensator.

6. Balance the bridge with the OFFSET dials. Do NOT adjust the RATIO dials. Record the reading as d(9).

7. Set the OFFSET dials to the setting calculated by:

$$\frac{d(10) + 9d(9)}{10}$$

NOTE: Use STEPs 8 to 10 to calibrate 100 kilohm resistors. To calibrate 1 kilohm resistors, proceed to STEP 11.

8. Disconnect Shorting Bars from the 10 kilohm-per-step SR1030 and connect its first 10 resistors in series to the STANDARD terminals of the Lead Compensator.

9. Connect the 100 kilohm resistor to be calibrated to the UNKNOWN terminals of the Lead Compensator.

10. Balance the bridge with the RATIO dials. The indication of the RATIO dials is the ratio of the 100 kilohm resistor to the actual value of 100 kilohms as transferred from the primary standard. (Only the last two STEPs need be repeated for each resistor of a group of 100 kilohm resistors.)

NOTE: Use STEPs 11 to 13 to calibrate 1 kilohm resistors.

11. Connect the first ten resistors of the 10 kilohm-per-step SR1030 in parallel, using the Shorting Bars. Connect the parallel combination to the STANDARD terminals of the Lead Compensator.

12. Connect the 1 kilohm resistor to be calibrated to the UNKNOWN terminals of the Lead Compensator.

13. Balance the bridge with the RATIO dials. The indication of the RATIO dials is the ratio of the 1 kilohm resistor to the actual value of 1 kilohm as transferred from the primary standard. (Only the last two STEPs need be repeated for each resistor of a group of 1 kilohm resistors.)

5.1.3 Transfer from 10 kilohms to 100 ohms

1. Connect the 10 kilohm primary standard resistor (Model SR104 is recommended) to the UNKNOWN binding posts of the Lead Compensator. Use a four-terminal connection and connect at least one GND terminal on the standard resistor to a GND terminal on the bridge.

2. Set the RATIO controls of the ratio set to the calibrated resistance of the standard. Be sure to correct this setting for temperature. Model SR104 contains an internal resistance temperature sensor which changes by 0.1% (1000 ppm) per degree Celsius. A calibration curve is included with the standard resistor.

3. Connect the first ten resistors of a 1 kilohm-per-step SR1030 in series, 10 kilohms, to the STANDARD binding posts of the Lead Compensator.

4. Balance the bridge with the OFFSET dials. Do NOT adjust the RATIO dials.

5. Connect the first ten resistors of the 1 kilohm-per-step SR1030 in parallel, using the Shorting Bars. Connect the parallel combination to the STANDARD binding posts of the Lead Compensator.

6. Connect the 100 ohm resistor to be calibrated to the UNKNOWN binding posts of the Lead Compensator.

7. Balance the bridge with the RATIO dials. The indication of the RATIO dials is the ratio of the 100 ohm resistor to the actual value of 100 ohms as transferred from the primary standard.

5.1.4 Transfer from 10 kilohms to 10 ohms

1. Connect the 10 kilohm primary standard resistor (Model SR104 is recommended) to the UNKNOWN binding posts of the Lead Compensator. For this and the following measurements use a four-terminal connection to the resistor and connect at least one GND terminal on the standard resistor to a GND terminal on the bridge.

2. Set the RATIO dials of the Ratio Set to the calibrated resistance value of the standard. Be sure to correct this setting for temperature. The Model SR104 contains an internal resistance temperature sensor which changes by 0.1% (1000 ppm) per degree Celsius. A calibration curve is included with the standard resistor.

3. Connect ten resistors of the 1 kilohm-per-step SR1030 in series, 10 kilohms, to the STANDARD binding posts of the Lead Compensator. (This resistance is used only as a tare. Any highly stable 10 kilohm resistor can be used instead of the transfer standard.)

4. Balance the bridge with the OFFSET dials. Do NOT adjust the RATIO dials. (This calibrates the bridge for measuring 10 kilohm resistors.)

5. Connect the tenth resistor (R10) of the 10 kilohm-per-step SR1030 to the UNKNOWN binding posts of the Lead Comnpensator.

6. Balance the bridge with the RATIO dials. Do NOT adjust the OFFSET dials. Record the deviation part of the reading of the RATIO dials as d(10). (This gives the deviation of R10 from the calibrated value of 10 kilohms.)

7. Connect the 10 kilohm-per-step SR1030 in series-parallel for 10 kilohms (refer to Section 3.1.3) and connect it to the UNKNOWN binding posts of the Lead Compensator.

8. Balance the bridge with the RATIO dials. Do NOT adjust the OFFSET dials. Record the deviation part of the reading of the RATIO dials as d(9). (This is the deviation of the series-parallel connected nine resistors from the calibrated value of 10 kilohms.)

9. Set the deviation part of RATIO dials to the setting calculated by:

$$\frac{d(10) + 9d(9)}{10}$$

(This calculates the average deviation of the first ten resistors in the 10 kilohm-per-step SR1030.)

10. Connect the first ten resistors of the 10 kilohm-per-step SR1030 in parallel for 1 kilohm using the Shorting Bars. Connect this parallel combination, 1 kilohm, to the UNKNOWN binding posts of the Lead Compensator. (This provides a 1 kilohm standard which has the deviation calculated in STEP 9.)

11. Connect the first nine resistors of the 1 kilohm-per-step SR1030 in series-parallel for 1 kilohm using the Shorting Bars. Connect this 1 kilohm resistor to the STANDARD binding posts of the Lead Compensator to use as a 1 kilohm tare resistor.

12. Balance the bridge with the OFFSET dials. Do NOT adjust the RATIO dials. (This calibrates the bridge for measuring 1 kilohm resistors.)

13. Connect ten resistors of the 100 ohm-per-step SR1030 in series, 1 kilohm, to the UNKNOWN binding posts of the Lead Compensator.

14. Balance the bridge with the RATIO dials. Do NOT adjust the OFFSET dials. (This calibrates the average deviation of the first ten resistors in the 100 ohm-per-step SR1030.)

15. Connect the first nine resistors of the 10 ohm-per-step SR1030 in series-parallel for a 10 ohm tare resistor. Connect this tare resistor to the the STANDARD terminals of the Lead Compensator.

16. Connect the first ten resistors of the 100 ohm-per-step SR1030 in parallel for 10 ohms using the Shorting Bars. Plug the Model PC101 Parallel Compensation Network into the binding posts of this 100 ohm-per-step SR1030.

17. Connect the binding posts of the Compensation Network to the outer UNKNOWN binding posts of the Lead Compensator (Network terminal 1 goes to Lead Compensator terminal 1, labeled GEN, and Network terminal 2 goes to Lead Compensator terminal 4, labeled YOKE). Note the arrows on the Compensation Network showing which Shorting Bar is associated with which Compensation Network terminal. Connect the Shorting Bar pointed to by NETWORK terminal 1 to Lead Compensator terminal 2 and the Shorting Bar pointed to by Network terminal 2 to Lead Compensator terminal 3.

18. Balance the bridge with the OFFSET dials. Do NOT adjust the RATIO dials. (This calibrates the bridge for measuring 10 ohm resistors.)

19. Connect the 10 ohm resistor to be calibrated to the UNKNOWN terminals of the Lead Compensator.

20. Balance the bridge with the RATIO dials. The indication of the ratio dials is the ratio of the 10 ohm resistor to the actual value of 10 ohms as transferred from the 10 kilohm primary standard.

5.1.5 Transfer from 10 kilohms to 1 ohm

1. Connect the 10 kilohm primary standard resistor (Model SR104 is recommended) to the UNKNOWN binding posts of the Lead Compensator. For this and the following measurements use a four-terminal connection to the resistor and connect at least one GND terminal on the standard resistor to a GND terminal on the bridge.

2. Set the RATIO dials of the Ratio Set to the calibrated resistance value of the standard. Be sure to correct this setting for temperature. The Model SR104 contains an internal resistance temperature sensor which changes by 0.1% (1000 ppm) per degree Celsius. A calibration curve is included with the standard resistor.

3. Use the Shorting Bars to connect ten resistors of 10 kilohm-per-step SR1030 in series-parallel, 10 kilohms, to the STANDARD binding posts of the Lead Compensator. (This resistance is used only as a tare. Any highly stable 10 kilohm resistor can be used instead of the transfer standard.)

4. Balance the bridge with the OFFSET dials. Do NOT adjust the RATIO dials. (This calibrates the bridge for measuring 10 kilohm resistors.)

5. Connect ten resistors of the 1 kilohm-per-step SR1030 in series, 10 kilohms, to the UNKNOWN binding posts of the Lead Compensator.

6. Balance the bridge with the RATIO dials. Do NOT adjust the OFFSET dials. (This calibrates the average deviation of the first ten resistors in the 1 kilohm-per-step SR1030.)

7. Connect ten resistors of the 100 ohm-per-step SR1030 in series-parallel, 100 ohms, to the STANDARD binding posts of the Lead Compensator as a tare resistor.

8. Using the Shorting Bars, connect the 1 kilohm-per-step SR1030 that was calibrated in STEP 6 in parallel for 100 ohms and connect it to the UNKNOWN binding posts of the Lead Compensator.

9. Balance the bridge with the OFFSET dials. Do NOT adjust the RATIO dials. (This calibrates the bridge for measuring 100 ohm resistors.)

10. Connect the first ten resistors of the 10 ohm-per-step SR1030 in series for 100 ohms. Connect this 100 ohm resistor to the UNKNOWN binding posts of the Lead Compensator.

11. Balance the bridge with the RATIO dials. Do NOT adjust the OFFSET dials. (This measures the average deviation of the first ten resistors in the 10 ohm-per-step SR1030.)

12. Connect the first ten resistors of the 10 ohm-per-step SR1030 in parallel for 1 ohm using the Shorting Bars. Plug the Model PC101 Parallel Compensation Network into the binding posts of this 10 ohm-per-step SR1030.

13. Connect the binding posts of the Compensation Network to the outer UNKNOWN binding posts of the Lead Compensator (Network terminal 1 goes to Lead Compensator terminal 1, labeled GEN, and Network terminal 2 goes to Lead Compensator terminal 4, labeled YOKE). Note the arrows on the Compensation Network showing which Shorting Bar is associated with which Compensation Network terminal. Connect the Shorting Bar pointed to by NETWORK terminal 1 to Lead Compensator terminal 2 and the Shorting Bar pointed to by Network terminal 2 to Lead Compensator terminal 3.

14. Using the Shorting Bars, connect the first nine resistors of the 1 ohm-per-step SR1030 in series-parallel for a 1 ohm tare resistor. Connect this tare resistor to the the STANDARD terminals of the Lead Compensator.

15. Balance the bridge with the OFFSET dials. Do NOT adjust the RATIO dials. (This calibrates the bridge for measuring 1 ohm resistors.)

16. Connect the 1 ohm resistor to be calibrated to the UNKNOWN terminals of the Lead Compensator.

17. Balance the bridge with the RATIO dials. The indication of the ratio dials is the ratio of the 1 ohm resistor to the actual value of 1 ohm as transferred from the 10 kilohm primary standard.

5.2 MODEL 242D RESISTANCE MEASUREMENT SYSTEM

NOTE: A more accurate version of the Model 242D, the Model SP3632, is also available. Its appearance and operation are the same as for the Model 242D.

The procedure in 5.2.3 illustrates how to use a 242D measurement system to transfer the accuracy of a 10 ohm Thomas Standard Resistor to a 100 ohm per-step SR1030 for determining the deviation of an SR1 10 ohm and an SR1 1 kohm from their nominal values.

5.2.1 System Description

The Model 242D Resistance Measuring System consists of the Model 240C Kelvin Ratio Bridge, the Model RS925D Decade Resistance Standard, and the Model 801B DC Generator-Detector. The value of the resistor being measured is read as the product of the reading of the decade dials on the RS925D and the reading of the MULTIPLIER dial on the 240C (a power of 10). A DEVIATION dial is provided on the 240C for reading the difference between the actual ratio and the nominal ratio of the standard and unknown resistors.

5.2.2 Equipment Required

- Model 242D Resistance Measuring System with KELVIN KLIPS® Four-Terminal Clips
- SR1030 with SB102 Shorting Bars and PC101 Parallel and SPC102 Series-Parallel Compensation Networks
- 10 ohm Calibrated Standard Resistor (Value chosen as an example)
- 100 ohm and 1 kilohm SR1 Standard Resistors to be calibrated
- A black and a red 18-inch plug lead
- A photocopy of the data sheet from Figure 5-25, shown on the last page of Section 5

5.2.3 Detailed Procedure

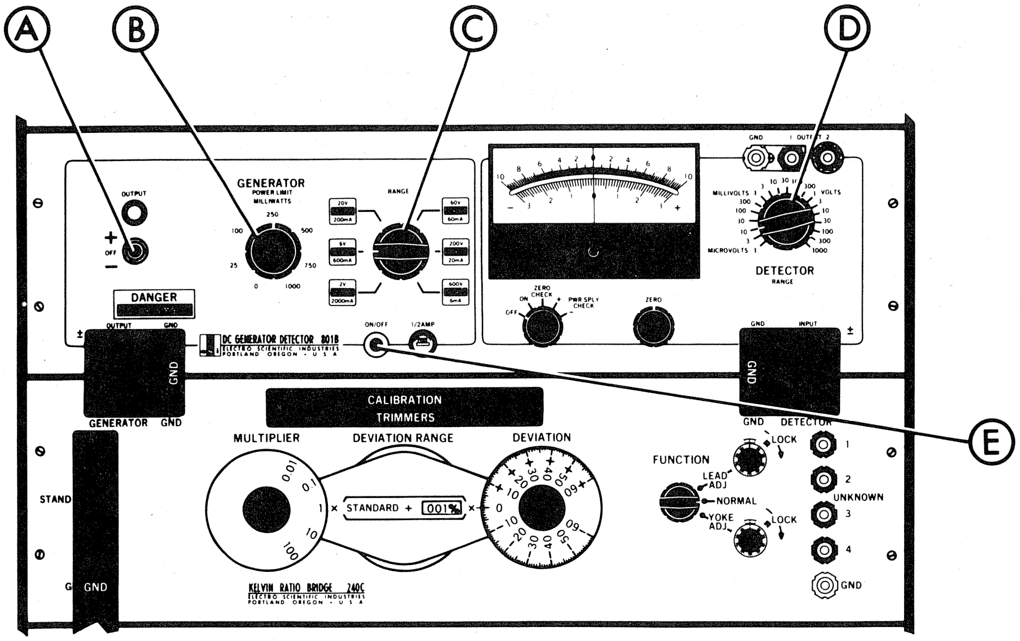


Figure 5-2. Generator-Detector Dial Settings

1. Set the Model 242D Generator Detector controls to measure a 10 ohm resistor. Reference Figure 5-2.

   A. Set the OUTPUT switch to OFF.

   B. Set the GENERATOR POWER switch to 250 MILLIWATTS.

   C. Set the GENERATOR RANGE switch to 10 ohms.

   D. Set the DETECTOR RANGE switch to 10 MICROVOLTS.

   E. Press the ON/OFF pushbutton to ON.

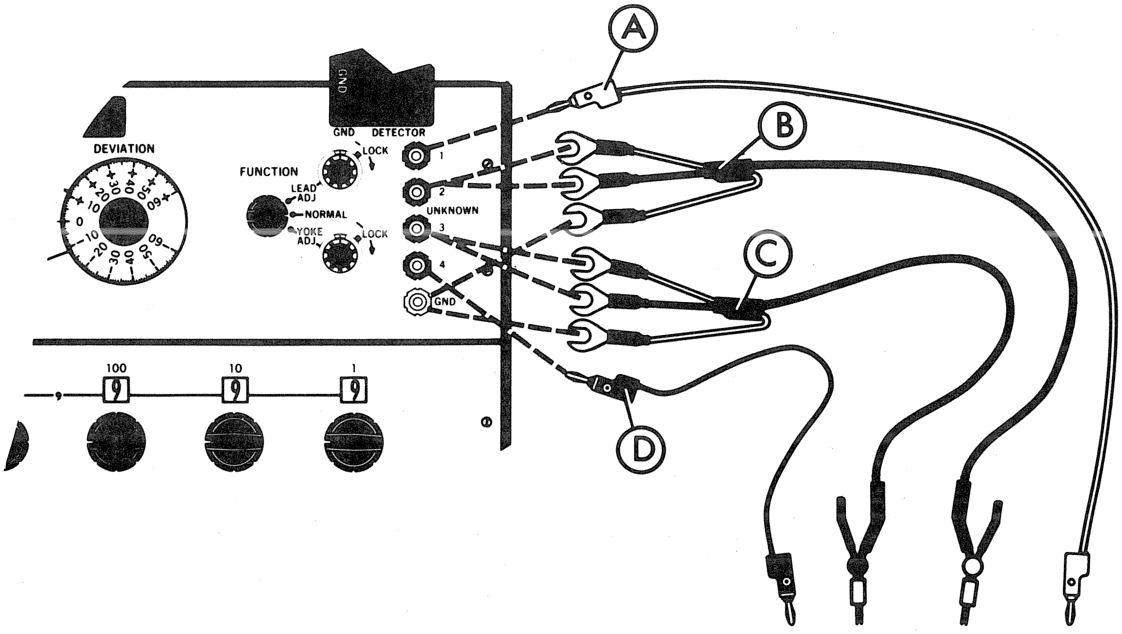


Figure 5-3. Lead Connections

2. Make the following 242D lead connections. Reference Figure 5-3.

   A. Connect the red 18-inch plug lead to the 242D Bridge UNKNOWN terminal 1.

   B. Connect the red KELVIN KLIP (with white hinge) white and black spade lugs to the 242D Bridge UNKNOWN terminal 2. Connect the Ground lead from the red KELVIN KLIP to the 242D Bridge UNKNOWN GND terminal.

   C. Connect the black KELVIN KLIP (with black hinge) white and black spade lugs to the 242D Bridge UNKNOWN terminal 3. Connect the ground lead from the black KELVIN KLIP to the 242D Bridge UNKNOWN GND terminal.

   D. Connect the black 18-inch plug lead to the 242D Bridge UNKNOWN terminal 4.

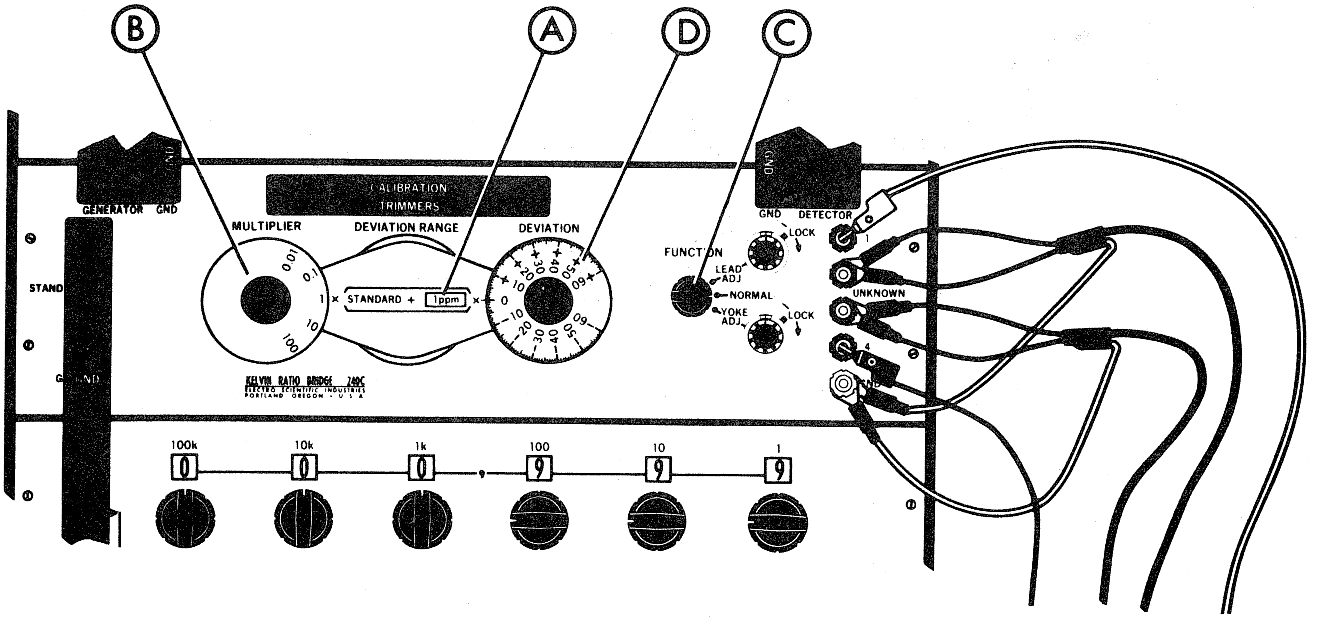


Figure 5-4. Bridge Dial Settings

3. Set the 242D Kelvin Bridge controls for measuring within a ±60 ppm range. Reference Figure 5-4.

   A. Set the DEVIATION RANGE dial to 1 ppm. The 1 ppm will appear in the small window on the right side of the dial mask.

   B. Set the MULTIPLIER dial to 1.

   C. Set the FUNCTION switch to NORMAL.

   D. Find the certified value of the 10 ohm standard resistor. Subtract the nominal value (10 ohms in this case) from the certified value. Divide the result by the nominal value (10) and multiply it by one million. This is the certified deviation in ppm, which is positive if the certified value is above the nominal value, negative if below. Set the bridge DEVIATION dial to the certified deviation. On the data sheet, record the <u>certified deviation</u> on the first (Certified Value) line.

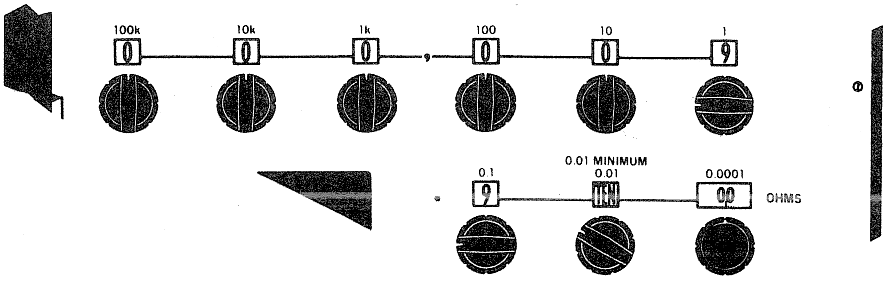


Figure 5-5. Resistance Standard Dial Setting

4. Set the 242D Resistance Standard dials to 9.9, TEN, 00 for ten ohms. Set all other dials on the resistance standard to 0. Reference Figure 5-5.

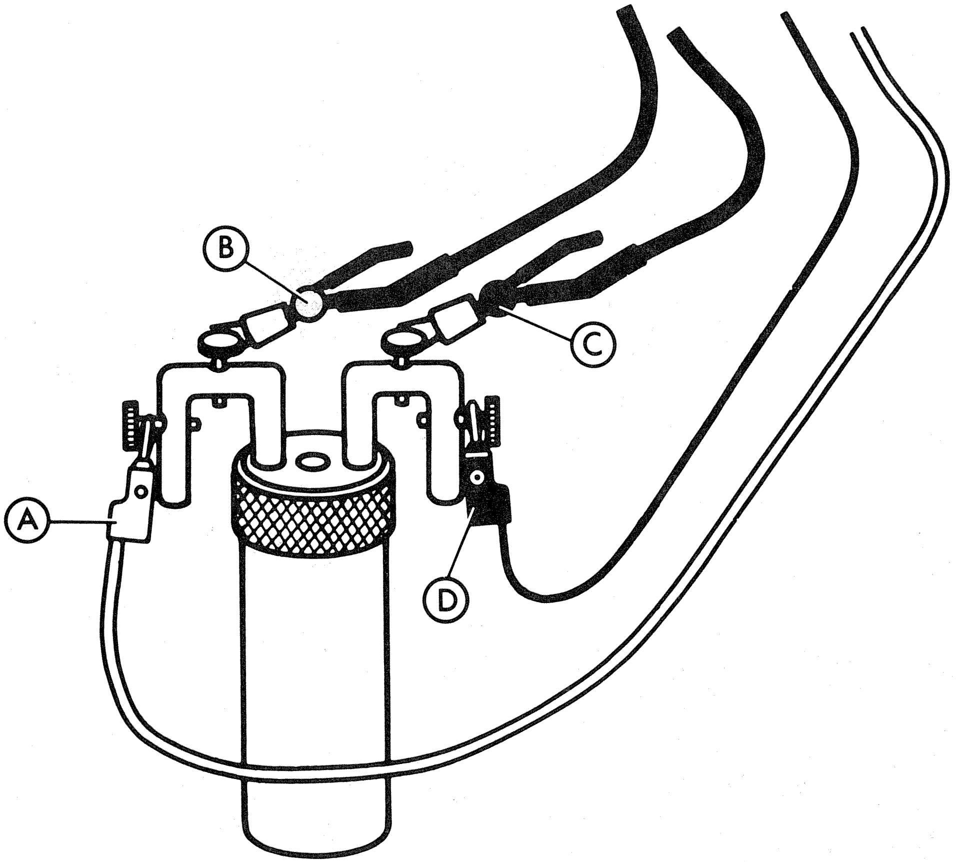


Figure 5-6. 10 ohm Standard Resistor Connections

5. Make the connections to the 10 ohm standard resistor. Reference Figure 5-6.

   A. Connect the red plug lead to the standard resistor outer screw on the first arm.

   B. Connect the red KELVIN KLIP to the standard resistor inner screw on the arm used in A.

   C. Connect the black KELVIN KLIP to the standard resistor inner screw on the other arm.

   D. Connect the black plug lead to the standard resistor outer screw on the arm used in step C.

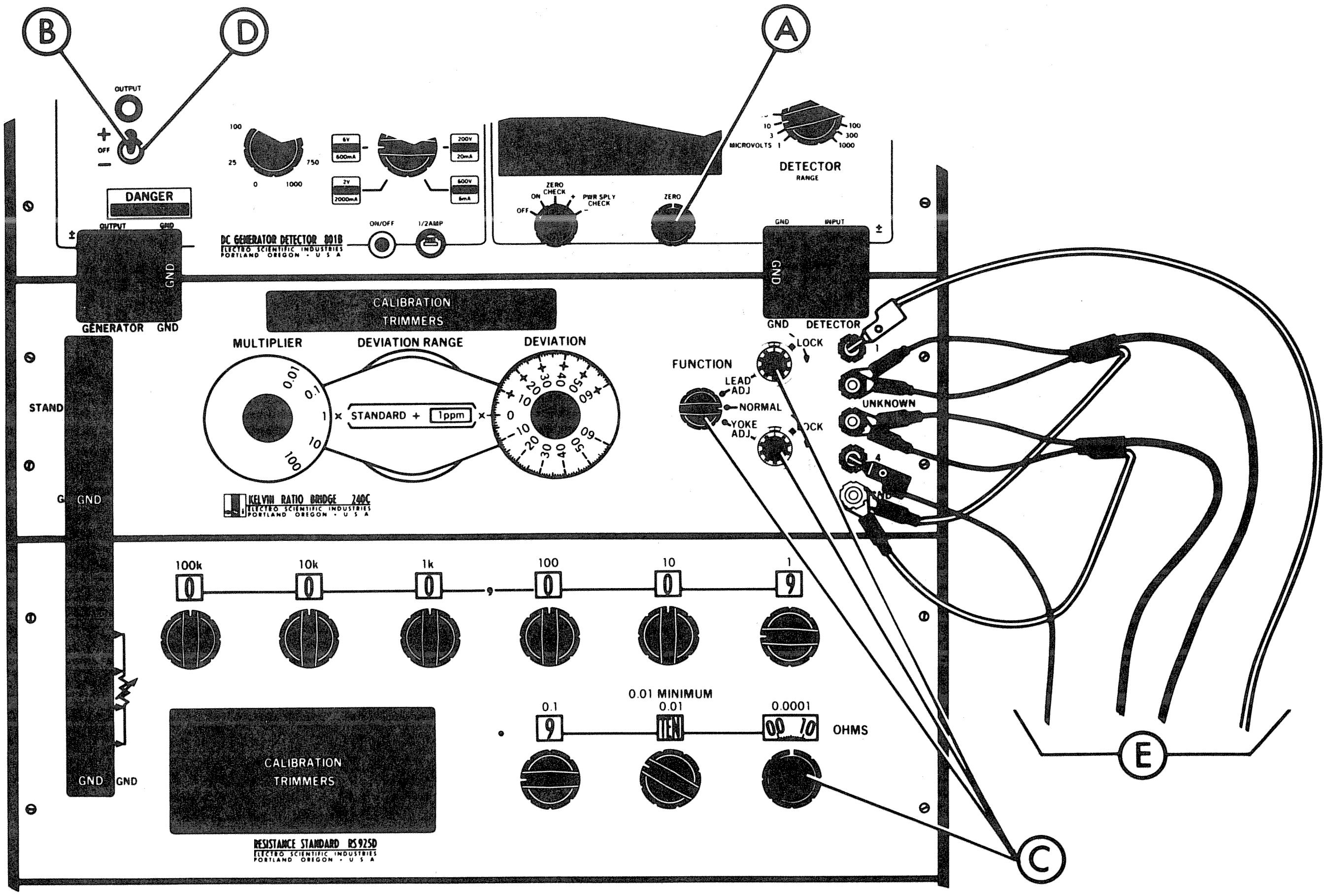


Figure 5-7. System Calibration at 10 ohms

6. Calibrate the 242D system to the 10 ohms standard resistor. Reference Figure 5-7.

   A. Adjust the 242D ZERO control for meter zero.

   B. Set the OUTPUT switch to the plus position.

C. Adjust the LEAD ADJ, YOKE ADJ, and RESISTANCE STANDARD for proper null as follows:

  C1 Set the FUNCTION switch to NORMAL. If the meter pointer is offscale, change the DETECTOR RANGE to reduce sensitivity. Return to 10 MICROVOLT position for final null balance.

  C2 Turn the FUNCTION switch to LEAD ADJ and turn the LEAD ADJ knob for a meter null.

  C3 Turn the FUNCTION switch to NORMAL and adjust the RESISTANCE STANDARD for a meter null.

  C4 Turn the FUNCTION switch to YOKE ADJ and turn the YOKE ADJ knob for a meter null.

  C5 Turn the FUNCTION switch to NORMAL and adjust the RESISTANCE STANDARD for a meter null.

  C6 Repeat steps C2 through C5 until all three FUNCTION positions give a meter null (with the DETECTOR RANGE set on 10 MICROVOLT and with both generator polarities) with no further adjustments.

D. The 242D is now calibrated at 10 ohms to the 10 ohm standard resistor. Set the OUTPUT switch to OFF.

E. Remove all leads from the 10 ohm standard resistor.

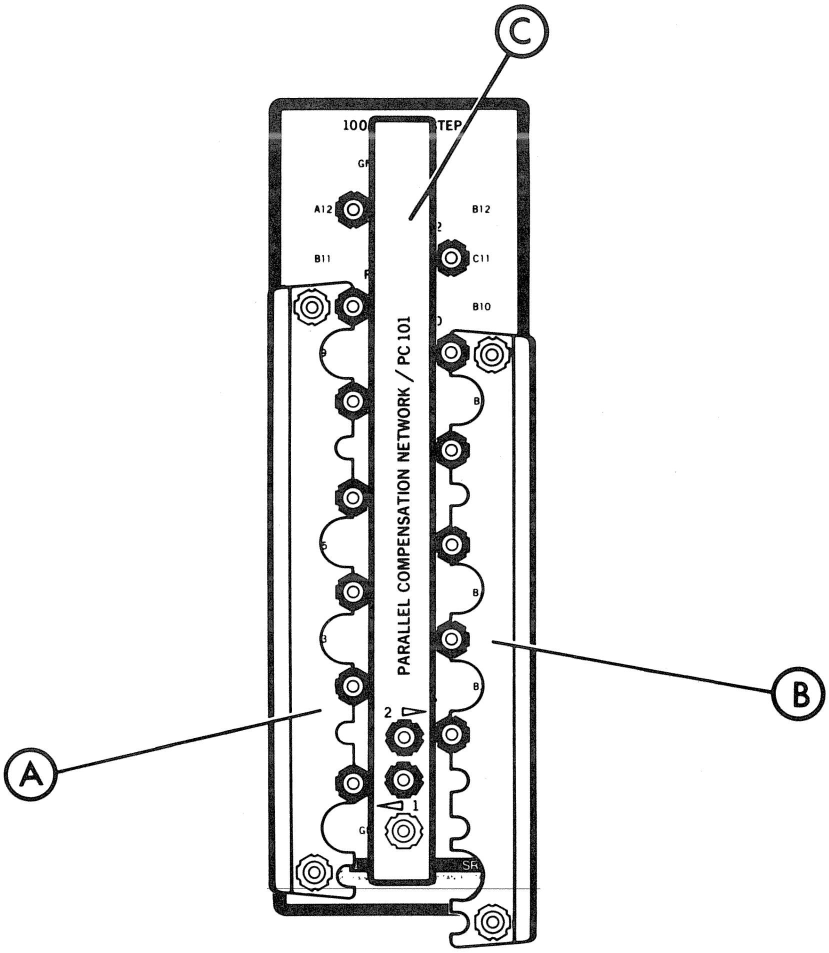


Figure 5-8. Shorting Bar and PC101 Connections for 10 ohms

7. Connect the Parrallel Compensation Network Model PC101 and the shorting bars to calibrate the 100 ohm-per-step SR1030 at 10 ohms. Reference Figure 5-8.

   A. Arrange 100 ohm-per-step so that it faces you. Connect the shorting bar at A10, A8, A6, A4, A2, and A0.

   B. Connect the other shorting bar at C9, C7, C5, C3, and C1.

   C. Connect the PC101 Network to the SR1030's center row of binding posts.

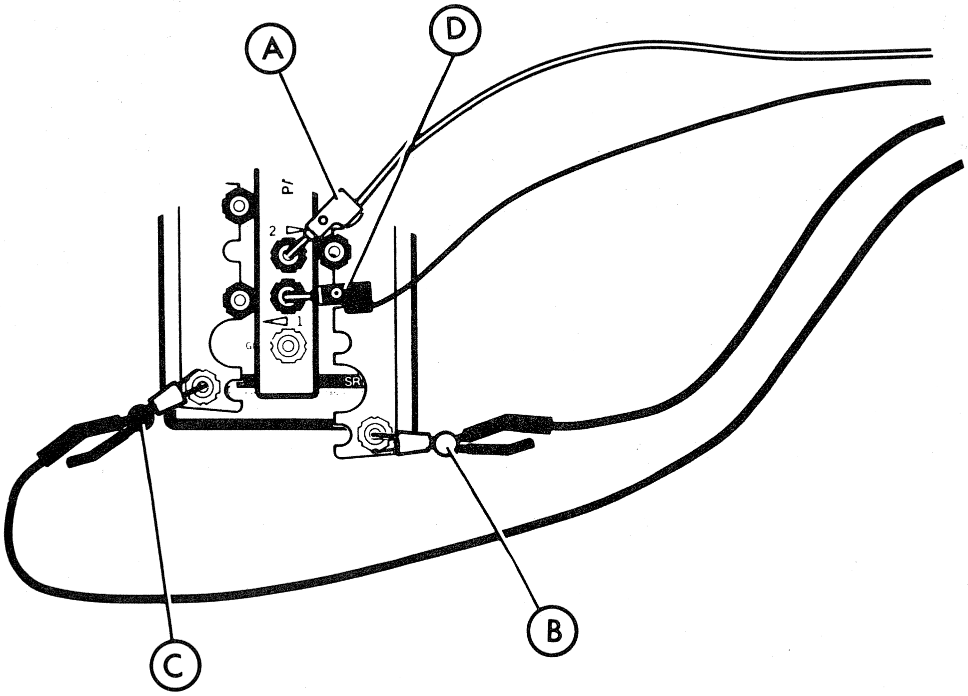


Figure 5-9. Lead Connections to the SR1030 Parllel Set Up

8. Make the 242D lead connections to the SR1030. Reference Figure 5-9.

   A. Connect the red plug lead to the PC101 terminal 2.

   B. Connect the red KELVIN KLIP to the right-hand shorting bar binding post with one jaw inside and one outside of the binding post.

   C. Connect the black KELVIN KLIP, connect to the left-hand shorting bar binding post.

   D. Connect the black plug lead to the PC101 terminal 1.

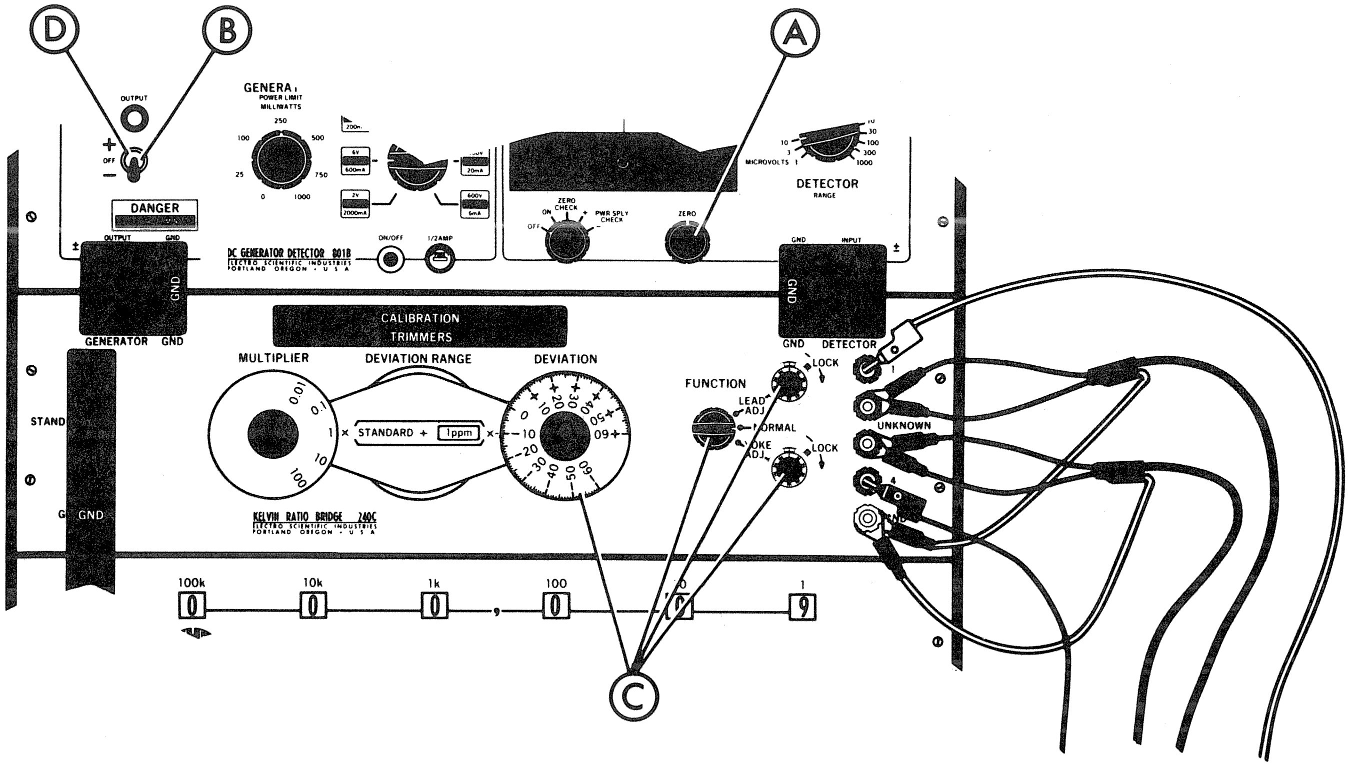


Figure 5-10. Deviation Measurement

9. Measure the SR1030s average deviation of the first 10 resistors. Reference Figure 5-10.

   A. Adjust the 242D ZERO control for meter zero.

   B. Set the OUTPUT switch to the minus position.

C. Adjust LEAD ADJ, YOKE ADJ, and DEVIATION knobs for proper null as follows:

C1 Set the FUNCTION switch to NORMAL. Adjust the DEVIATION knob to 0. If the meter pointer is offscale, change the DETECTOR RANGE to reduce sensitity. Return to 10 MICROVOLT position for final null balance.

C2 Turn the FUNCTION switch to LEAD ADJ and turn the LEAD ADJ knob for a meter null.

C3 Turn the FUNCTION switch to NORMAL and adjust the DEVIATION knob for a meter null.

C4 Turn the FUNCTION switch to YOKE ADJ and turn the YOKE ADJ knob for a meter null.

C5 Turn the FUNCTION switch to NORMAL and adjust the DEVIATION knob for a meter null.

C6 Repeat steps C2 through C5 until all three FUNCTION positions give a meter null (with the DETECTOR RANGE set on 10 MICROVOLT and with both generator polarities) with no further adjustments.

D. Set the OUTPUT switch to OFF. Record the DEVIATION dial reading on the data sheet. This is Δ_{AV}; the deviation of ten 100 ohm resistors in parallel from the calibrated 10 ohm value of the 242D System.

E. Remove all leads from the SR1030 shorting bars and network.

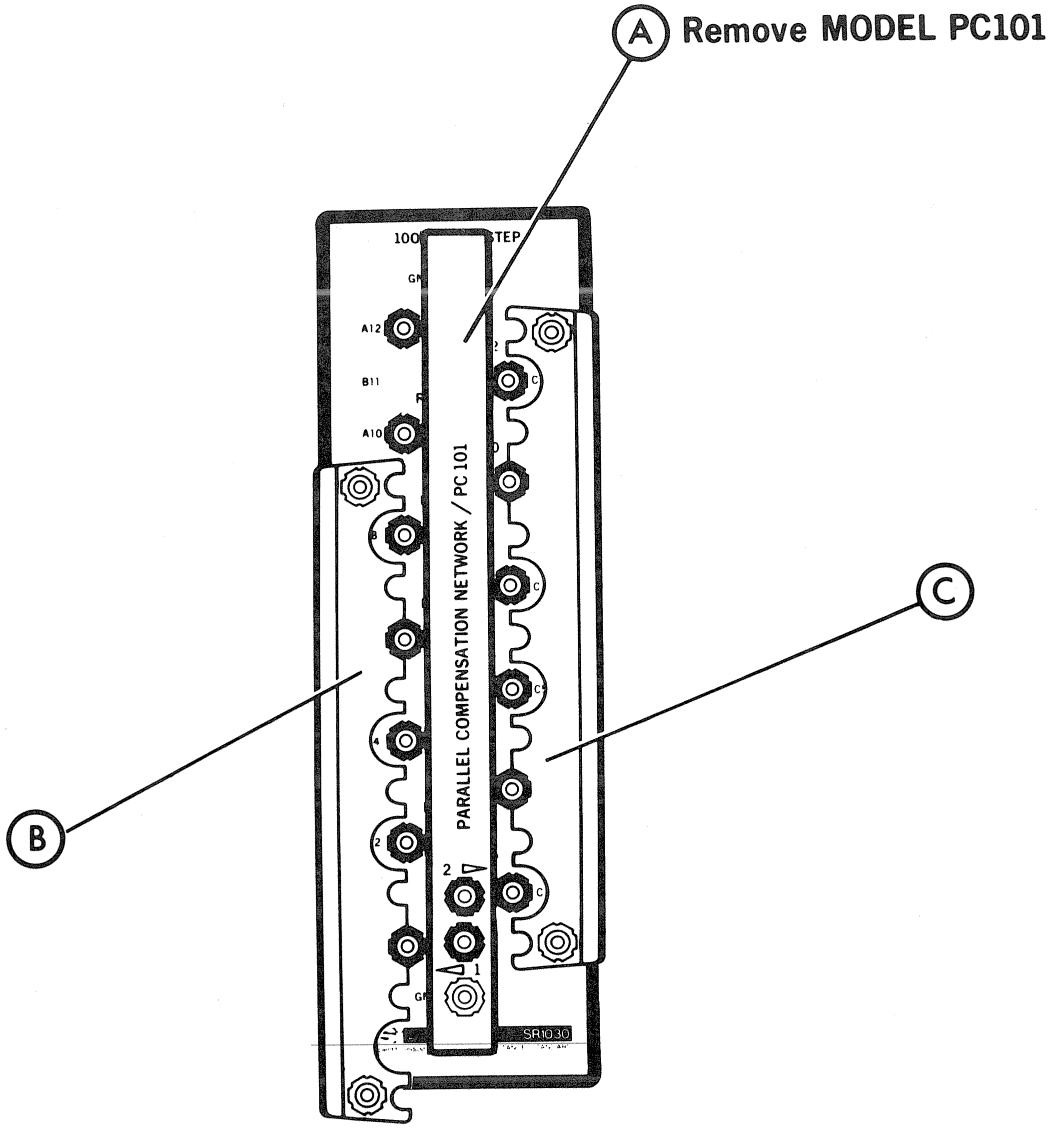


Figure 5-11. Shorting Bar Series Parallel Connection for 100 ohms

10. Connect the shorting bars for a 100 ohm series-parallel connection on the 100 ohm-per-step SR1030. Reference Figure 5-11.

    A. Remove the PC101 Network from the SR1030. Grasp both ends of the Network and pull straight up to avoid bending the banana plugs.

    B. Move the left-hand shorting bar and make connection to binding posts A0 and A6.

    C. Move the right-hand shorting bar and make connection to binding posts C3 and C9.

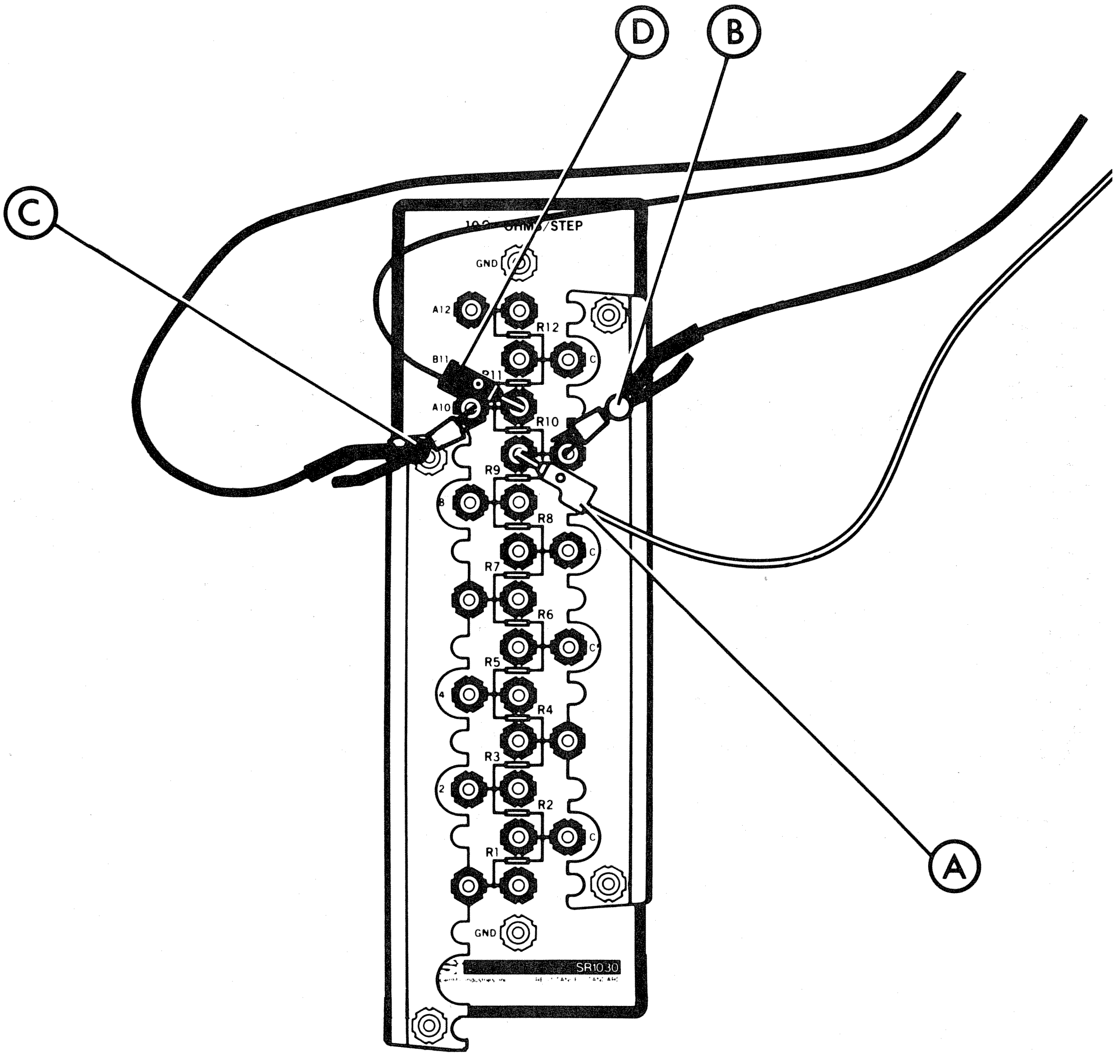


Figure 5-12. Lead Connections to Series Parallel SR1030

11. Make the 242D lead connections to measure R10 on the SR1030.

    A. Connect the red plug lead to terminal B9.

    B. Connect the red KELVIN KLIP to terminal C9.

    C. Connect the black KELVIN KLIP to the terminal A10.

    D. Connect the black plug lead to SR1030 terminal B10.

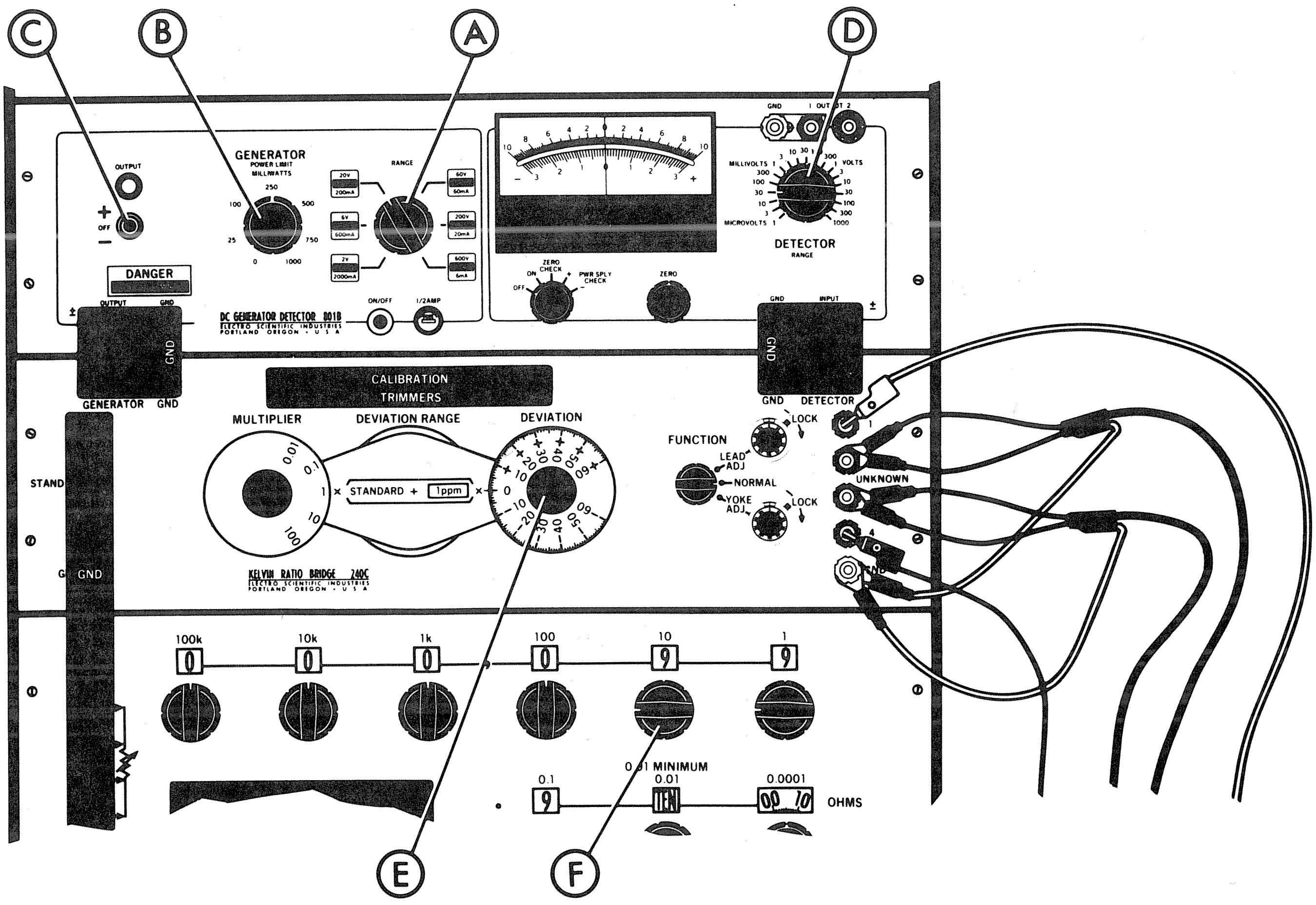


Figure 5-13. System Dial Settings

12. Set the 242D system to measure 100 ohms.

    A. Set the GENERATOR RANGE to 100 ohms.

    B. Set the GENERATOR POWER to 250 MILLIWATTS.

    C. Set the OUTPUT switch to OFF.

    D. Set the DETECTOR RANGE switch to 30 MICROVOLTS.

    E. Set the bridge DEVIATION dial to 0.

    F. Set the resistance standards 10 dial to 9.

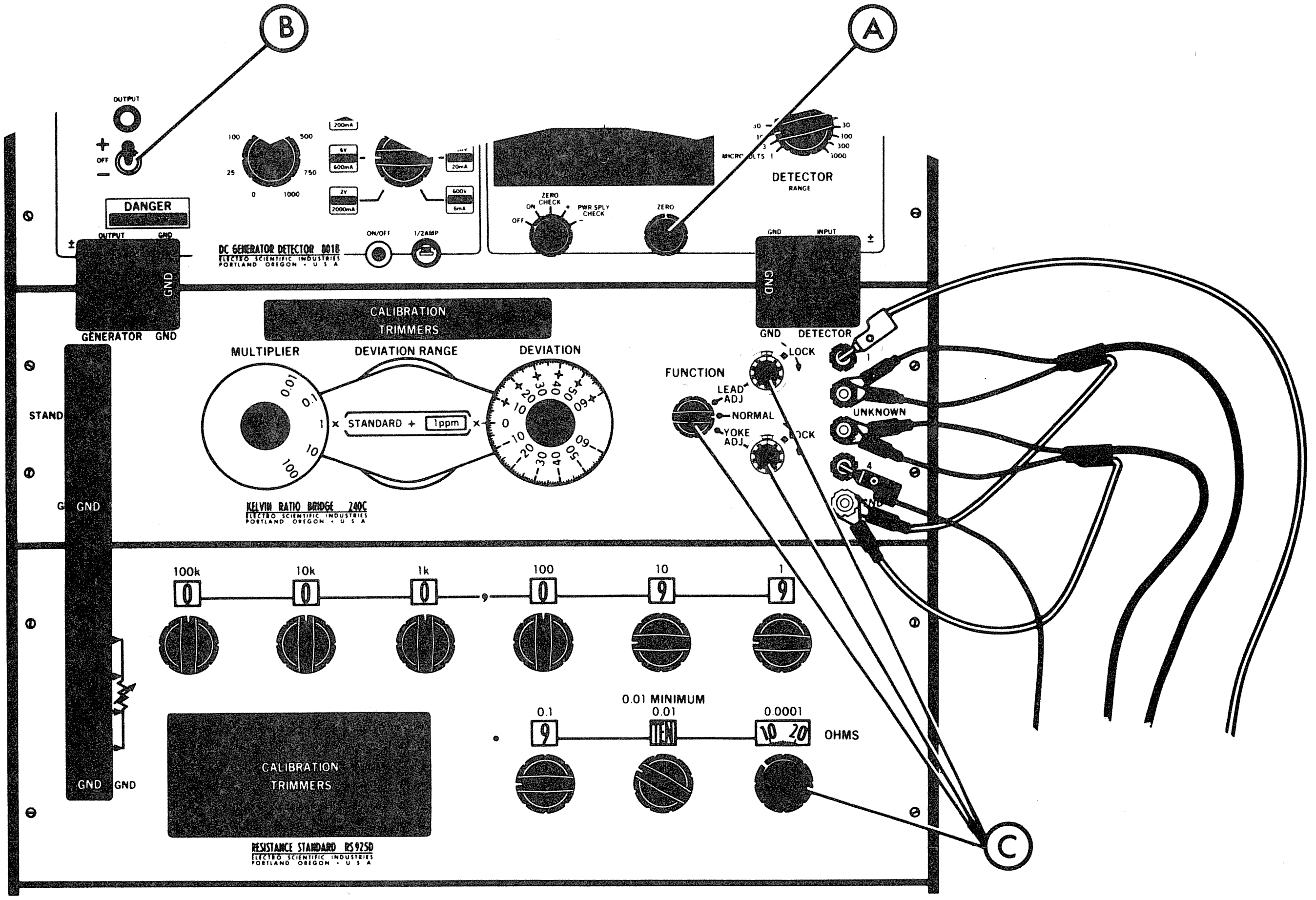


Figure 5-14. Measurement of Resistor R10

13. Measure resistor, R10. Reference Figure 5-14.

    A. Adjust the 242D ZERO control for meter zero.

    B. Set the OUTPUT switch to the plus position.

    C. Adjust the LEAD ADJ, YOKE ADJ, and RESISTANCE STANDARD for proper null as follows:

        C1 Set the FUNCTION switch to NORMAL. If the meter pointer is offscale, change the DETECTOR RANGE to reduce sensitivity. Return to 10 MICROVOLT position for final null balance.

        C2 Turn the FUNCTION switch to LEAD ADJ and turn the LEAD ADJ knob for a meter null.

        C3 Turn the FUNCTION switch to NORMAL and adjust the RESISTANCE STANDARD for a meter null.

C4 Turn the FUNCTION switch to YOKE ADJ and turn the YOKE ADJ knob for a meter null.

C5 Turn the FUNCTION switch to NORMAL and adjust the RESISTANCE STANDARD for a meter null.

C6 Repeat steps C2 through C5 until all three FUNCTION positions give a meter null (with the DETECTOR RANGE set on 10 MICROVOLT and with both generator polarities) with no further adjustments.

D. Set the OUTPUT switch to OFF.

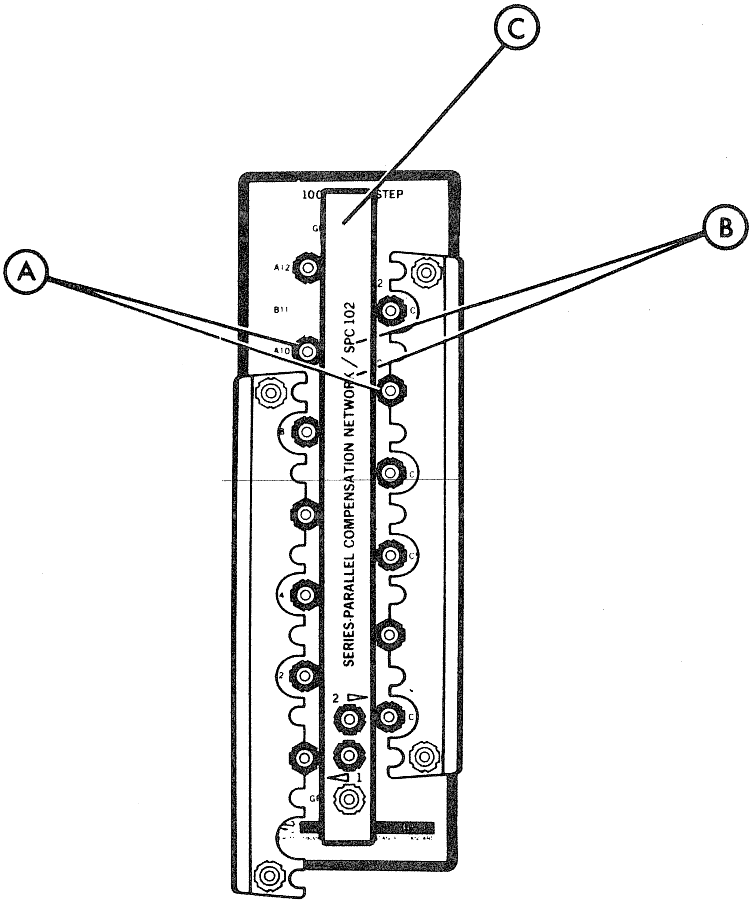


Figure 5-15. Shorting Bar and SPC102 Connections

14. Remove the KELVIN KLIPS and plug leads from the SR1030.

15. Connect the SPC102 Series-Parallel Compensation Network to the SR1030. Reference Figure 5-15.

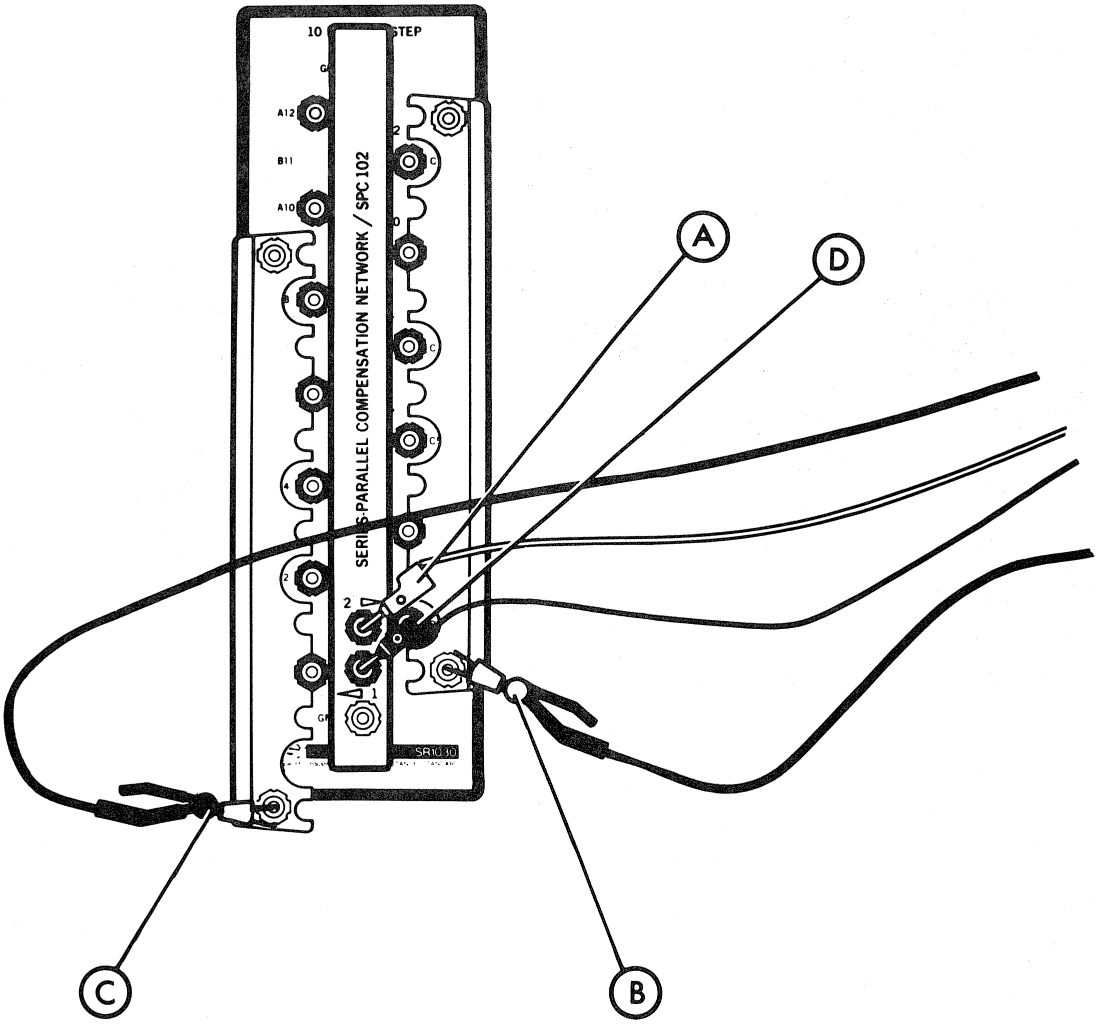


Figure 5-16. Lead Connections to SR1030 Series Parallel Set Up

16. Make the 242D lead connections to the SPC102. Reference Figure 5-16.

    A. Connect the red plug lead to the SPC102 Network terminal 2.

    B. Connect the red KELVIN KLIP to the right-hand shorting bar binding post.

    C. Connect the black KELVIN KLIP to the left-hand shorting bar binding post.

    D. Connect the black plug lead to the SPC102 Network terminal 1.

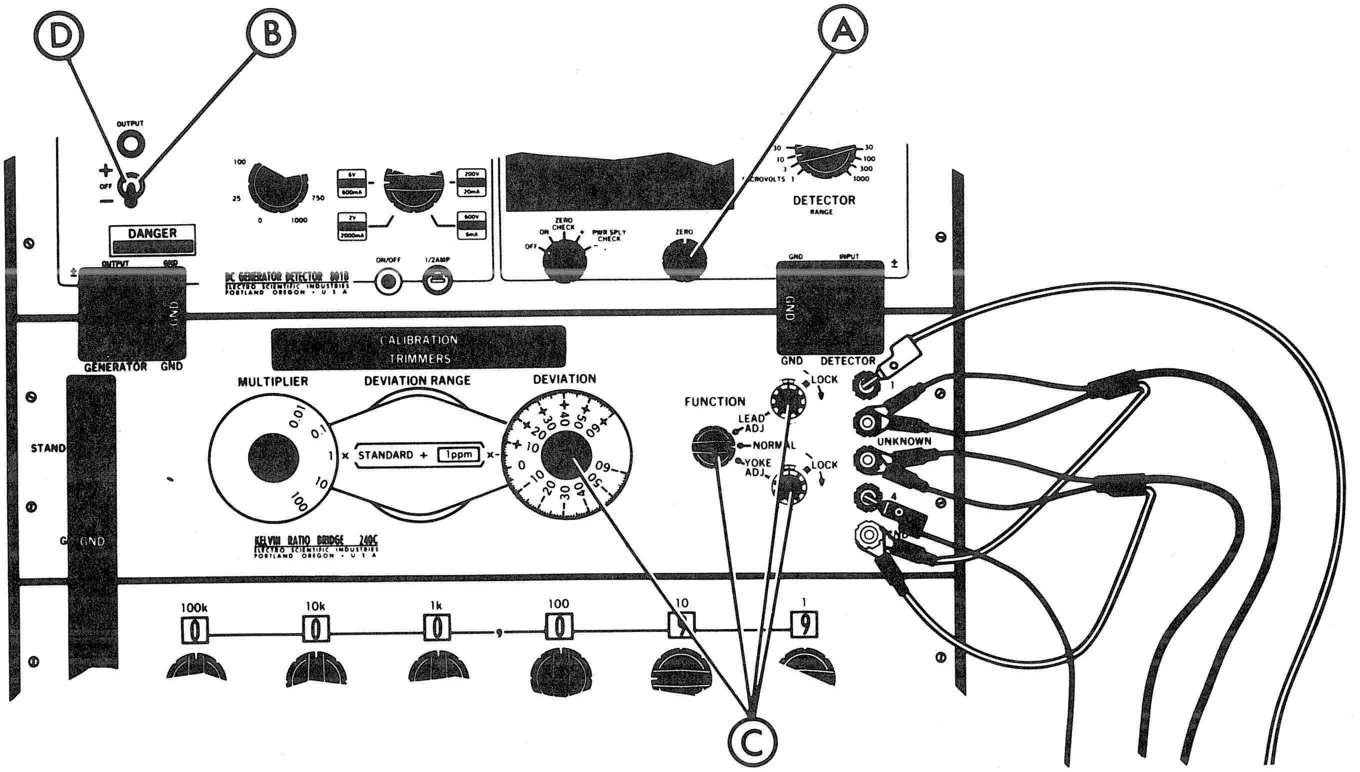


Figure 5-17. Series-Parallel Deviation from R10

17. Measure the series-parallel deviation from R10. Reference Figure 5-17.

A. Adjust the 242D ZERO control for meter zero.

B. Set the OUTPUT switch to the minus position.

C. Adjust the LEAD ADJ, YOKE ADJ, and DEVIATION dial for meter null as follows:

C1 Set the FUNCTION switch to NORMAL. Adjust the DEVIATION knob to 0. If the meter pointer is offscale, change the DETECTOR RANGE to reduce sensitity. Return to 10 MICROVOLT position for final null balance.

C2 Turn the FUNCTION switch to LEAD ADJ and turn the LEAD ADJ knob for a meter null.

C3 Turn the FUNCTION switch to NORMAL and adjust the DEVIATION knob for a meter null.

C4 Turn the FUNCTION switch to YOKE ADJ and turn the YOKE ADJ knob for a meter null.

C5 Turn the FUNCTION switch to NORMAL and adjust the DEVIATION knob for a meter null.

C6 Repeat steps C2 through C5 until all three FUNCTION positions give a meter null (with the DETECTOR RANGE set on 10 MICROVOLT and with both generator polarities) with no further adjustments.

D. Set the OUTPUT switch to OFF.

E. Record the DEVIATION reading on the Data Sheet as ΔD. This is the deviation of the series-parallel combination of the nine 100 ohm resistors from R10. Calculate Δsp on the Data Sheet, using the printed equation. Δsp is the deviation of the series-parallel connection from 10 times the nominal value of the 10 ohm standard relative to its certificate.

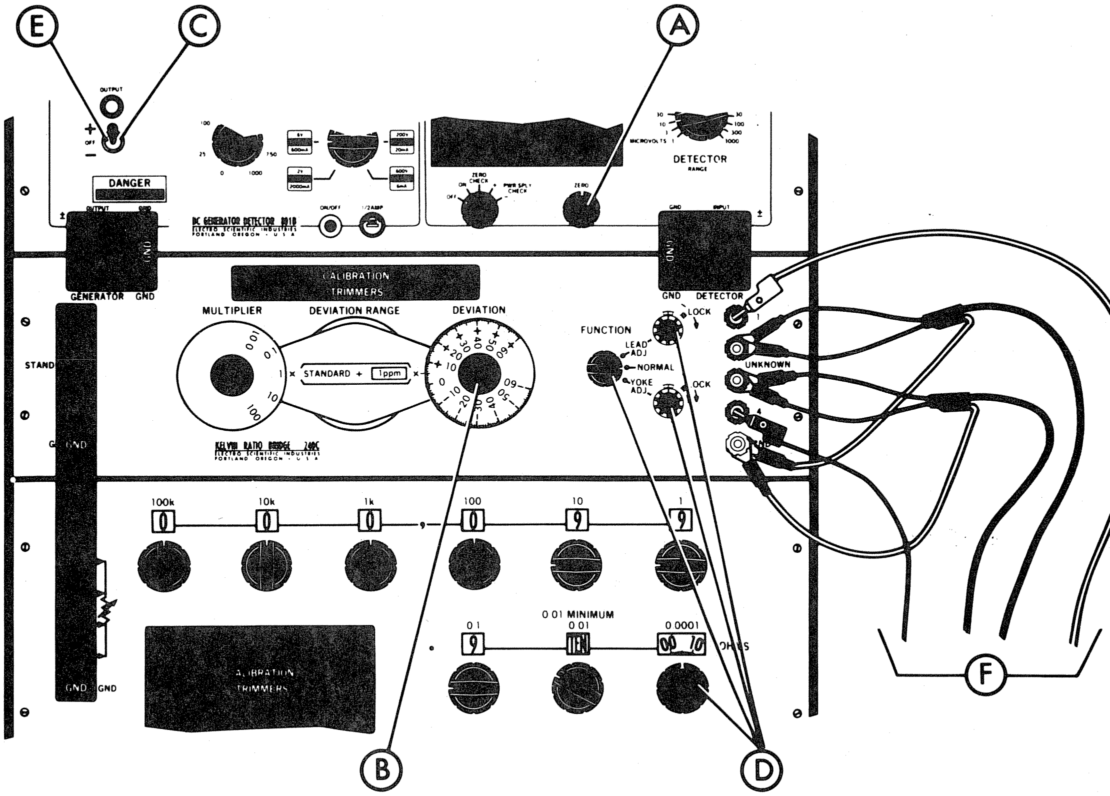


Figure 5-18. Bridge Calibration at 100 ohms

18. Calibrate the 242D bridge to the series-parallel connected 100 ohm-per-step SR1030. Reference Figure 5-18.

A. Adjust the 242D ZERO control for meter zero.

B. Set the bridge DEVIATION dial to Δsp.

C. Set the OUTPUT switch to plus position.

D. Adjust the LEAD ADJ, YOKE ADJ, and RESISTANCE STANDARD for proper null as follows:

  D1 Set the FUNCTION switch to NORMAL. If the meter pointer is offscale, change the DETECTOR RANGE to reduce sensitivity. Return to 10 MICROVOLT position for final null balance.

  D2 Turn the FUNCTION switch to LEAD ADJ and turn the LEAD ADJ knob for a meter null.

  D3 Turn the FUNCTION switch to NORMAL and adjust the RESISTANCE STANDARD for a meter null.

  D4 Turn the FUNCTION switch to YOKE ADJ and turn the YOKE ADJ knob for a meter null.

  D5 Turn the FUNCTION switch to NORMAL and adjust the RESISTANCE STANDARD for a meter null.

  D6 Repeat steps D2 through D5 until all three FUNCTION positions give a meter null (with the DETECTOR RANGE set on 10 MICROVOLT and with both generator polarities) with no further adjustments.

E. Set the OUTPUT switch to OFF. The 242D Bridge is now calibrated to read 100 ohms relative to the 10 ohm standard certified accuracy.

F. Remove all leads from the SR1030. Remove the SPC102 Compensation Network by grasping the ends of the Network and pulling straight up to avoid bending the banana plug. Remove the shorting bars.

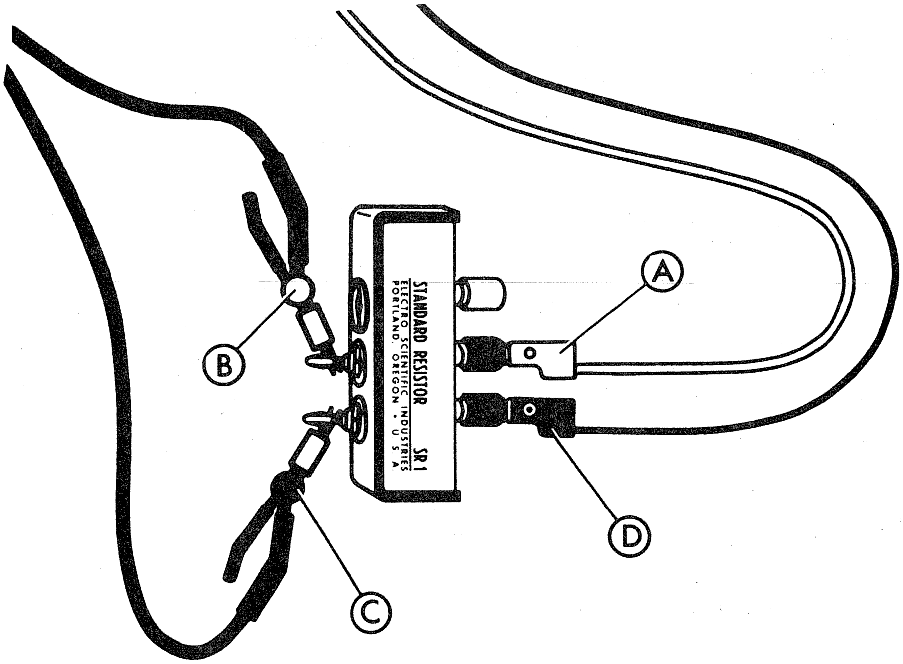


Figure 5-19. Lead Connections to SR1

19. Make the 242D lead connections to measure the 100 ohm SR1 Standard Resistor. Reference Figure 5-19.

    A. Connect the red plug lead to terminal 1 on top of the SR1.

    B. Connect the red KELVIN KLIP to terminal 1 on the bottom of the SR1.

    C. Connect the black KELVIN KLIP to terminal 2 on the bottom of the SR1.

    D. Connect the black plug lead to terminal 2 on top of the SR1.

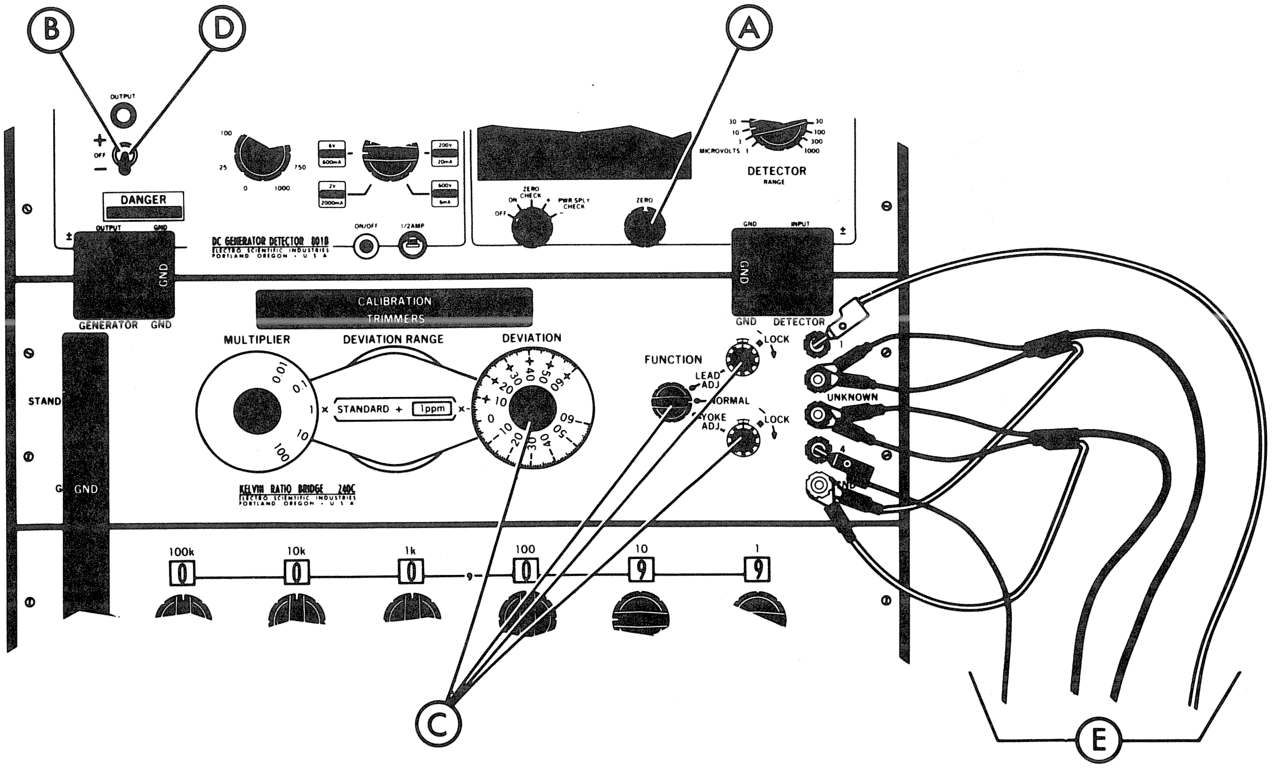


Figure 5-20. Calibration of 100 ohm SR1

20. Measure the deviation of the SR1 from the series-parallel 100 ohm transfer standard. Reference Figure 5-20.

~~A. Adjust the 242D ZERO control for meter zero.~~

B. Set the OUTPUT switch to the minus position.

C. Adjust the LEAD ADJ, YOKE ADJ, and DEVIATION for meter null as follows:

C1 Set the FUNCTION switch to NORMAL. Adjust the DEVIATION knob to 0. If the meter pointer is offscale, change the DETECTOR RANGE to reduce sensitity. Return to 10 MICROVOLT position for final null balance.

C2 Turn the FUNCTION switch to LEAD ADJ and turn the LEAD ADJ knob for a meter null.

C3 Turn the FUNCTION switch to NORMAL and adjust the DEVIATION knob for a meter null.

C4 Turn the FUNCTION switch to YOKE ADJ and turn the YOKE ADJ knob for a meter null.

C5 Turn the FUNCTION switch to NORMAL and adjust the DEVIATION knob for a meter null.

C6 Repeat steps C2 through C5 until all three FUNCTION positions give a meter null (with the DETECTOR RANGE set on 10 MICROVOLT and with both generator polarities) with no further adjustments.

D. Set the OUTPUT switch to OFF.

E. Record the DEVIATION dial reading on the Data Sheet on the fifth (100 ohm CALIBRATED VALUE) line. This is the deviation of the 100 ohm SR1 Standard Resistor from its nominal value relative to the certified deviation of the 10 ohm Standard within the accuracy of the transfer measurement.

F. Remove all leads from the 100 ohm SR1.

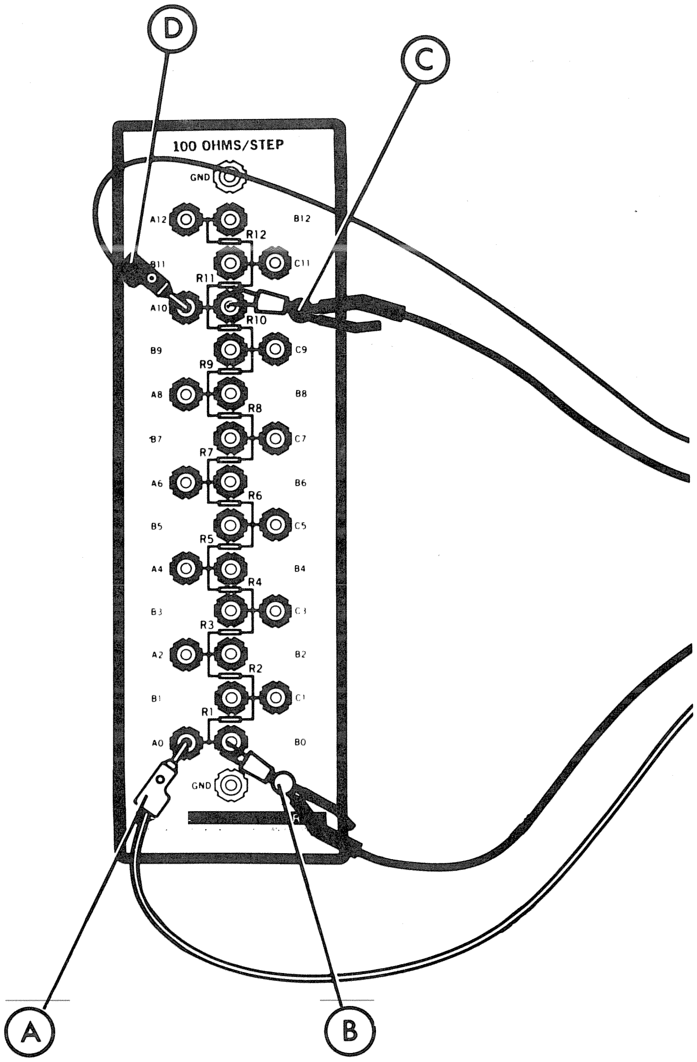


Figure 5-21. Series Connection to SR1030 for 1 kilohm

21. Make the 242D lead connections to the 100 ohms-per-step SR1030 for a series resistance of 1 kilohm. Reference Figure 5-21.

    A. Connect the red plug lead to terminal A0.

    B. Connect the red KELVIN KLIP to terminal B0.

    C. Connect the black KELVIN KLIP to terminal B10.

    D. Connect the black plug lead, connect to terminal A10.

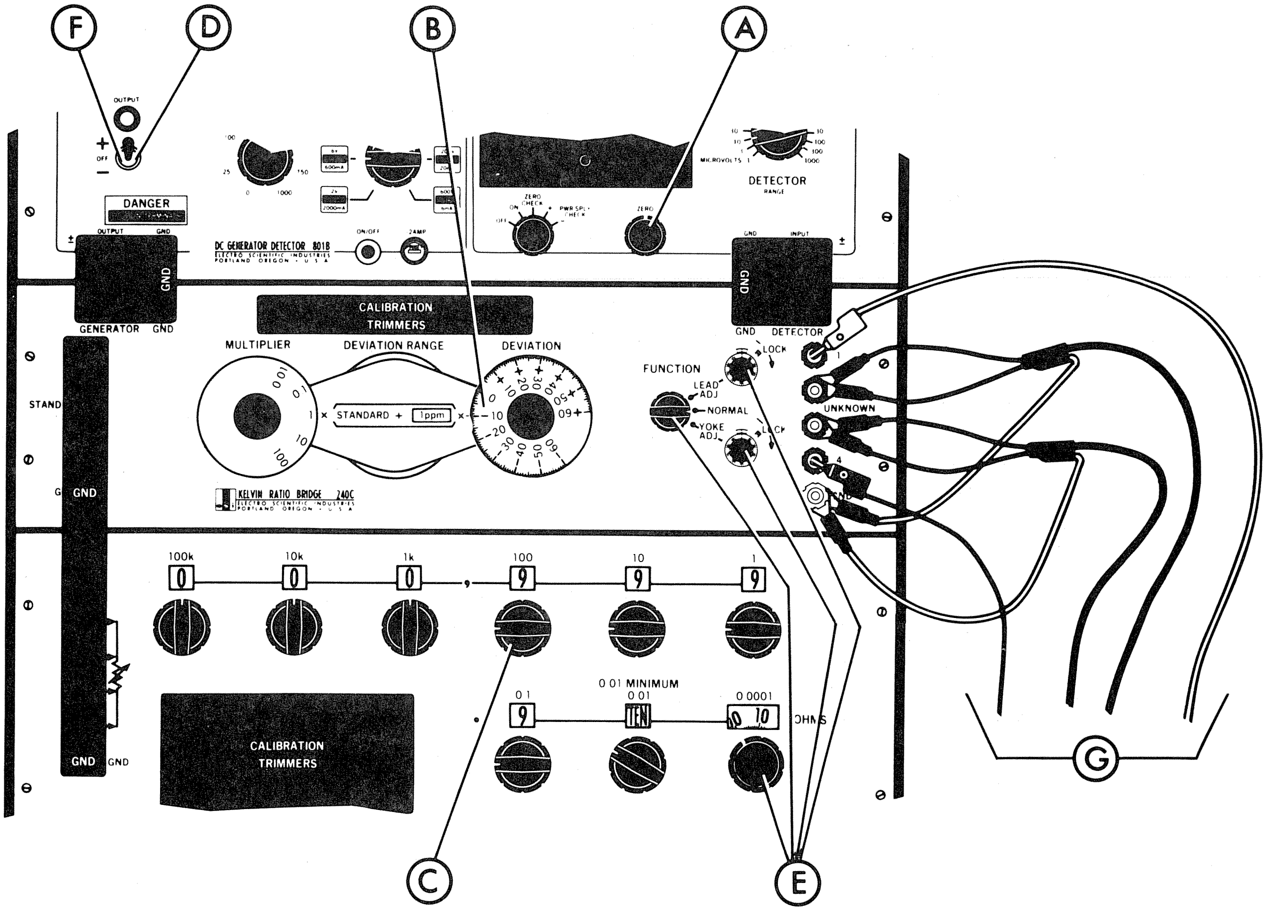


Figure 5-22. Bridge Calibration at 1 kilohm

22. Calibrate the 242D Bridge to the 1 kilohm transfer standard. Reference Figure 5-22.

    A. Adjust the 242D ZERO control for meter zero.

    B. Set the bridge DEVIATION dial to Δ_{AV}.

    C. Set the RESISTANCE STANDARD 100 dial to 9.

    D. Set the OUTPUT switch to plus position.

    E. Adjust the LEAD ADJ, YOKE ADJ, and RESISTANCE STANDARD for proper null as follows:

        E1 Set the FUNCTION switch to NORMAL. If the meter pointer is offscale, change the DETECTOR RANGE to reduce sensitivity. Return to 10 MICROVOLT position for final null balance.

E2 Turn the FUNCTION switch to LEAD ADJ and turn the LEAD ADJ knob for a meter null.

E3 Turn the FUNCTION switch to NORMAL and adjust the RESISTANCE STANDARD for a meter null.

E4 Turn the FUNCTION switch to YOKE ADJ and turn the YOKE ADJ knob for a meter null.

E5 Turn the FUNCTION switch to NORMAL and adjust the RESISTANCE STANDARD for a meter null.

E6 Repeat steps E2 through E5 until all three FUNCTION positions give a meter null (with the DETECTOR RANGE set on 10 MICROVOLT and with both generator polarities) with no further adjustments.

F. Set the OUTPUT switch to OFF. The 242D Bridge is now calibrated to measure a 1 kilohms relative to the 10 ohm standard certified accuracy.

G. Remove all leads from the SR1030.

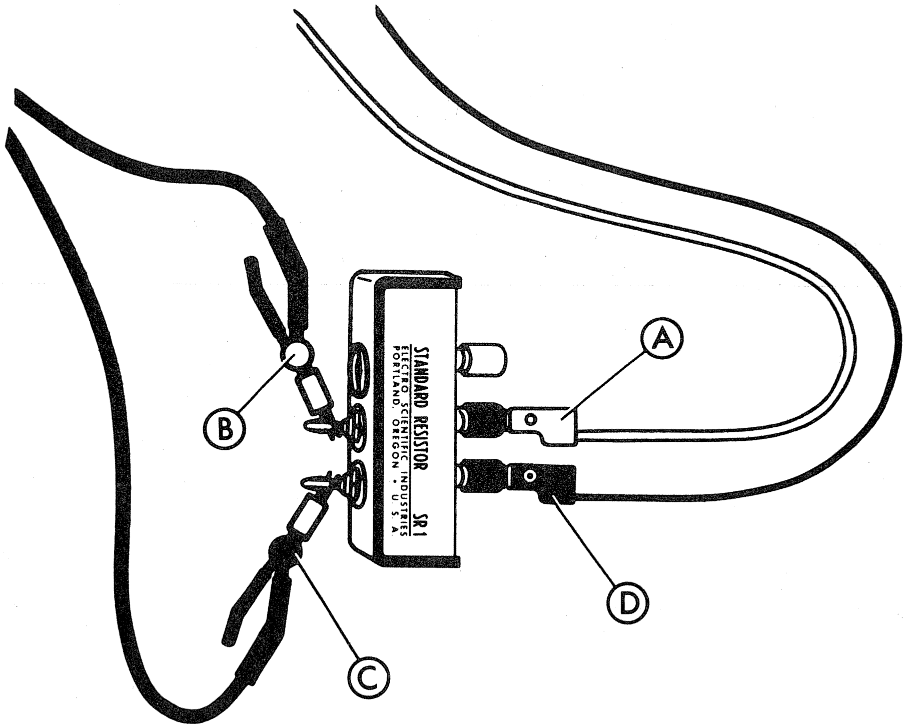


Figure 5-23. Lead Connections to 1 kilohm SR1

23. Make the 242D lead connections to measure the 1 kilohm SR1 standard resistor. Reference Figure 5-23.

    A. Connect the red plug lead to the 1 kilohm SR1, terminal 1 on top of the SR1.

    B. Connect the red KELVIN KLIP to terminal 1 on the bottom of the SR1.

    C. Connect the black KELVIN KLIP to terminal 2 on the bottom of the SR1.

    D. Connect the black plug lead to terminal 2 on top of the SR1.

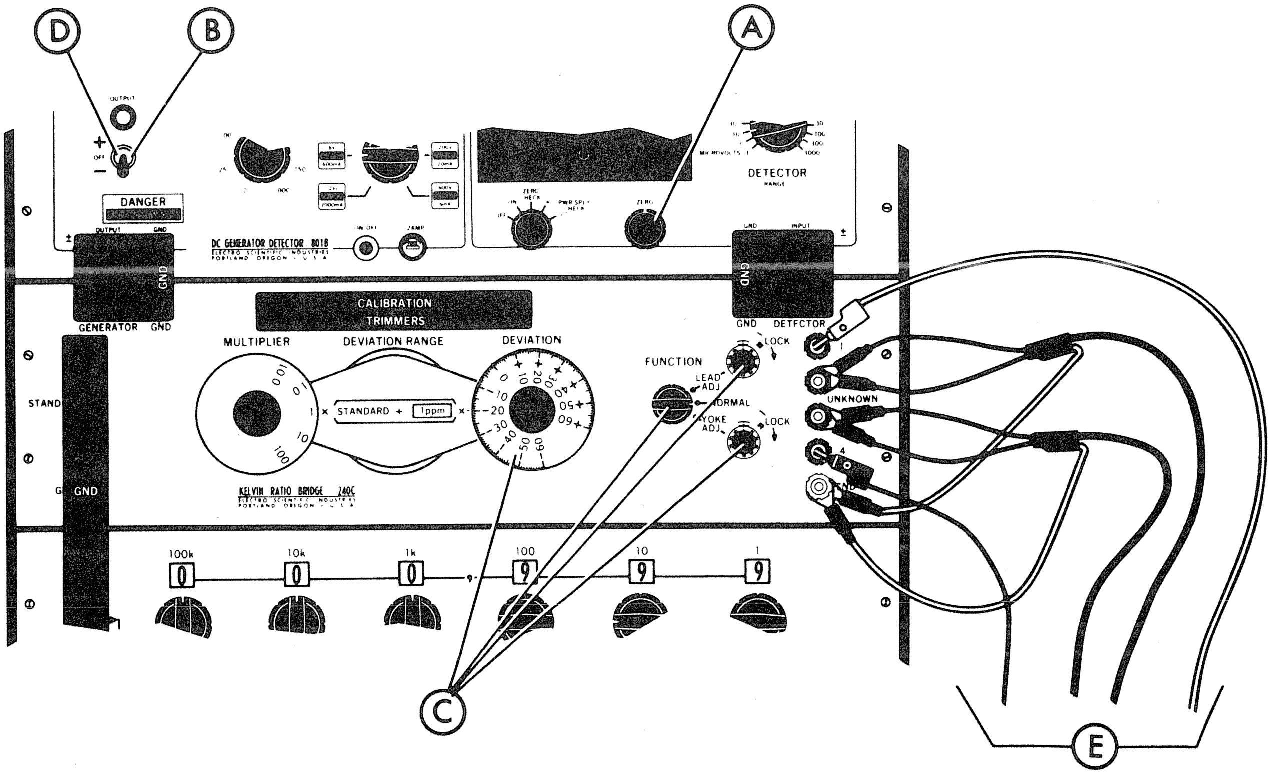


Figure 5-24. Calibration of 1 kilohm SR1

24. Measure the deviation of the SR1 from the series configured 1 kilohm transfer standard. Reference Figure 5-24.

A. Adjust the 242D ZERO control for meter zero.

B. Set the OUTPUT switch to the minus position.

C. Adjust the LEAD ADJ, YOKE ADJ, and DEVIATION for meter null as follows:

C1 Set the FUNCTION switch to NORMAL. Adjust the DEVIATION knob to 0. If the meter pointer is offscale, change the DETECTOR RANGE to reduce sensitity. Return to 10 MICROVOLT position for final null balance.

C2 Turn the FUNCTION switch to LEAD ADJ and turn the LEAD ADJ knob for a meter null.

C3 Turn the FUNCTION switch to NORMAL and adjust the DEVIATION knob for a meter null.

C4 Turn the FUNCTION switch to YOKE ADJ and turn the YOKE ADJ knob for a meter null.

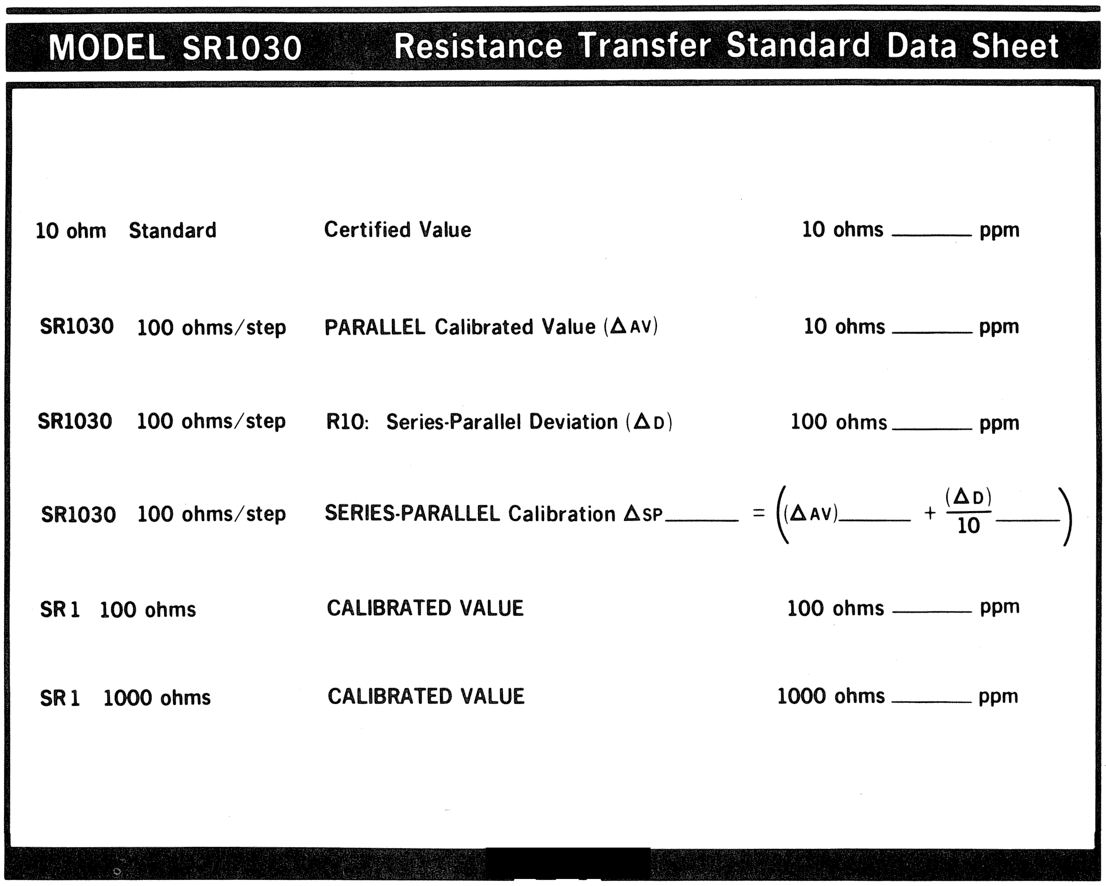
C5 Turn the FUNCTION switch to NORMAL and adjust the DEVIATION knob for a meter null.

C6 Repeat steps C2 through C5 until all three FUNCTION positions give a meter null (with the DETECTOR RANGE set on 10 MICROVOLT and with both generator polarities) with no further adjustments.

D. Set the OUTPUT switch to OFF.

E. Record the DEVIATION dial reading. This is the deviation of the 1 kilohm SR1 Standard Resistor from its nominal value relative to the Certified Deviation of the 10 ohm Standard within the accuracy of the transfer measurement.

F. Remove all leads from the 1 kilohm SR1.



MODEL SR1030 Resistance Transfer Standard Data Sheet

10 ohm	Standard	Certified Value	10 ohms ______ ppm
SR1030	100 ohms/step	PARALLEL Calibrated Value (Δ_{AV})	10 ohms ______ ppm
SR1030	100 ohms/step	R10: Series-Parallel Deviation (Δ_{D})	100 ohms ______ ppm
SR1030	100 ohms/step	SERIES-PARALLEL Calibration Δ_{SP} ______	$= \left((\Delta_{AV})\_\_\_\_\_\_ + \frac{(\Delta_{D})}{10}\_\_\_\_\_\_ \right)$
SR 1	100 ohms	CALIBRATED VALUE	100 ohms ______ ppm
SR 1	1000 ohms	CALIBRATED VALUE	1000 ohms ______ ppm

IET Labs, Inc.
534 Main Street, Westbury, NY 11590
(516) 334-5959 • (800) 899-8438 • Fax: (516) 334-5988

Figure 5-25. Resistance Transfer Data Sheet

SECTION 6

INSTALLATION, REPAIR, AND MAINTENANCE

6.1 INSTALLATION

Installation of the SR1030 consists of unpacking it from its shipping container, filling it with oil, and performing the initial checkout. The following sections describe these steps.

6.1.1 Unpacking

The SR1030 and oil should be removed from their shipping boxes. A careful inspection should be made to verify that no shipping damage has occurred. The binding posts should be given special attention as they are most likely to be damaged if shipping problems occur. If any shipping damage is apparent, **save all packaging material** and contact the shipper and promptly.

Verify that all of the appropriate items have been received as listed on the packing slip. Any discrepancies should be reported to promptly.

6.1.2 Filling the SR1030 with Oil

CAUTION

DO NOT FILL 100 KILOHM-PER-STEP SR1030 WITH OIL. USE OIL IN SR1030s WITH RESISTANCE VALUES OF 1 OHM-PER-STEP THROUGH 10 KILOHM-PER-STEP ONLY.

SR1030s with resistance values of 1 ohm-per-step through 10 kilohm-per-step must be filled with oil. The procedure requires the following:

Mineral Oil, PENRECO Sontex 85	
1 gallon (amount shipped with a single SR1030)	P/N 66701
4 gallons (amount shipped with a set of SR1030s)	P/N 64996
Funnel	P/N 66882
Allen (Hex) Wrench Driver, 5/16 inch	
Cloth Rag or Paper Towels	

1. Position the SR1030 bottom side up on a clean flat surface.

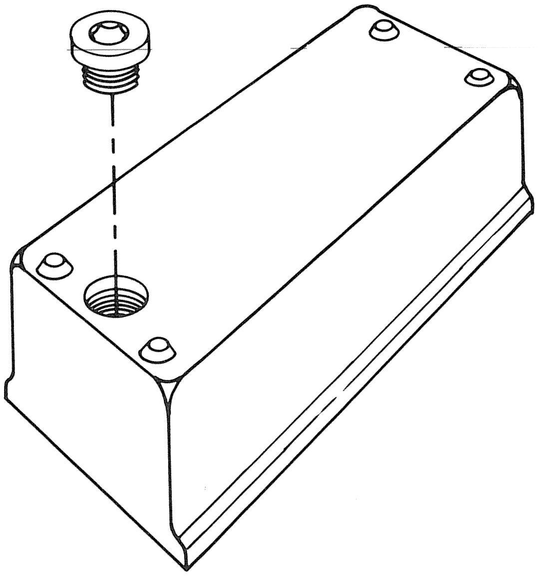


Figure 6-1. Location of the Drain/Fill Port

2. Using the 5/16 allen wrench, remove the oil plug from the bottom of the casting. Refer to Figure 6-1.

CAUTION

DO NOT OVERFILL THE SR1030. OVERFILLING AN SR1030 COULD RESULT IN AN OIL LEAK DUE TO THERMAL EXPANSION OF OIL.

THE TEMPERATURE OF THE OIL AND SR1030 SHOULD BE STABLE AT 23° CENTEGRADE BEFORE FILLING THE SR1030. WHEN FILLING THE SR1030, BOTH TEMPERATURE EXTREMES AND TEMPERATURE DIFFERENTIALS ARE FACTORS THAT CAN CONTRIBUTE TO AN OIL LEAK DUE TO THERMAL CHARACTERISTICS OF THE OIL.

THE FUNNEL MUST BE CLEAN (INSIDE AND OUT) TO AVOID CONTAMINATING THE MINERAL OIL.

3. Lay the SR1030 on a flat surface and insert the funnel in the fill port. Pour in the oil until it reaches the right angle in the fill port's opening as shown in Figure 6-2.

4. Hold the cloth rag around the funnel where it exits the SR1030. Pull the funnel from the SR1030 and wipe off the oil from the outside and inside of the funnel. Store the funnel in a plastic bag to avoid contamination.

5. Replace the plug into the drain/fill port and tighten until the plug seats against the SR1030's casting.

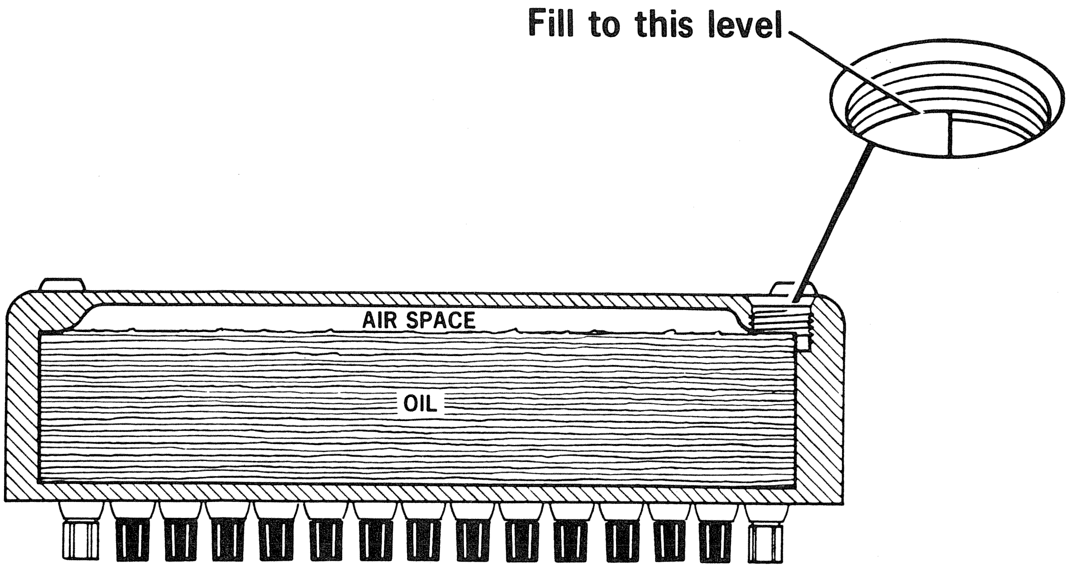


Figure 6-2. Filling the SR1030 with Oil

6.1.3 Oil Resistance Check

This measurement is made between the center conductor of any resistor binding post and the ground post. A measured resistance of less than 1 teraohm (10^{12} ohm) indicates that the oil is contaminated and should be replaced.

After the oil resistance has been checked, an initial resistance reading of the SR1030 resistors should be made. Calibration of the SR1030 is covered in Section 3.4.

6.2 REPAIR

Because of the careful matching involved, the individual resistors within a SR1030 are not field-replaceable. If a problem is identified with a resistor in the SR1030, the SR1030 should be returned to for repair.

6.2.1 Returning a SR1030 for Repair

CAUTION

OIL MUST BE DRAINED FROM THE SR1030 BEFORE TRANSPORT. FAILURE TO REMOVE THE OIL WILL CAUSE UNNECESSARY STRESS ON SEALING GASKETS.

To return a SR1030 to , you must:

1. Call TMBU Service Department and request a Return Materials Authorization (RMA) number and discuss the shipping details.
2. Drain the oil from the SR1030.
3. Ensure the SR1030s are properly packaged. A packing box must be constructed to hold the SR1030 without risk of physical damage to the resistors. An example of the SR1030's original packing box and material is shown in Figures 6-3 and 6-4. The packing material is made from 1.7 PCF Polyethylene.

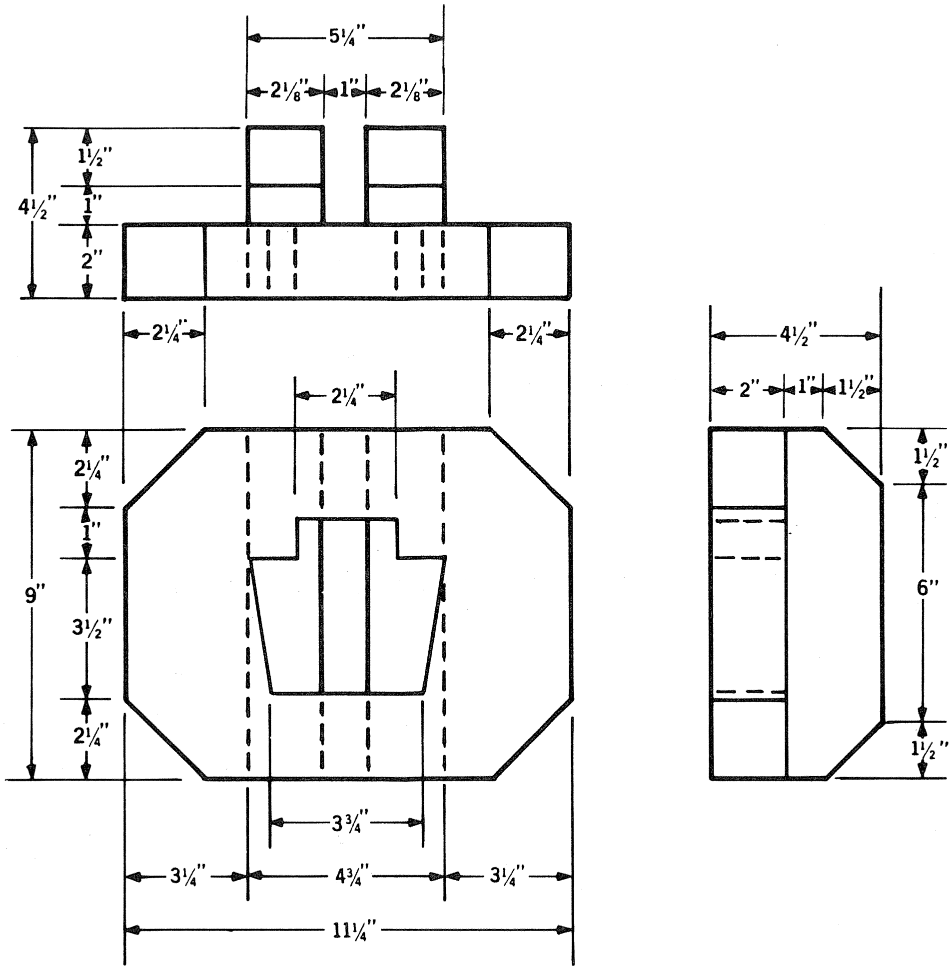


Figure 6-3. SR1030 Packing Material Dimensions

6.3.3 Maintenance of the Mineral Oil

The oil in the SR1030 should require replacement only when it has become contaminated. The following sections describe the maintenance procedures concerning the oil.

6.3.3.1 Testing the Oil for Contamination

To ensure the accuracy of the oil test, clean the top surface of the SR1030. Especially clean around the binding posts.

Test the oil for contamination by measuring the resistance between a ground post and any resistor binding post. If the resistance is less than one teraohm (10^{12} ohms), the oil is contaminated and should be replaced.

6.3.3.2 Changing the Mineral Oil

CAUTION

DO NOT FILL 100 KILOHM-PER-STEP SR1030 WITH OIL. USE OIL IN SR1030s WITH RESISTANCE VALUES OF 1 OHM-PER-STEP THROUGH 10 KILOHM-PER-STEP ONLY.

SR1030s with resistance values of 1 ohm-per-step through 10 kilohm-per-step are filled with oil. The 100 kilohm-per-step SR1030 does not use oil. The following tools and materials are required to change the oil:

Mineral Oil, PENRECO Sontex 85	
1 gallon (amount shipped with a single SR1030)	P/N 66701
4 gallons (amount shipped with a set of SR1030s)	P/N 64996
Funnel	P/N 66882
Allen (Hex) Wrench Driver, 5/16 inch	
Cloth Rag or Paper Towels	
Empty container for old oil	

1. Position the SR1030 bottom side up on a clean flat surface.

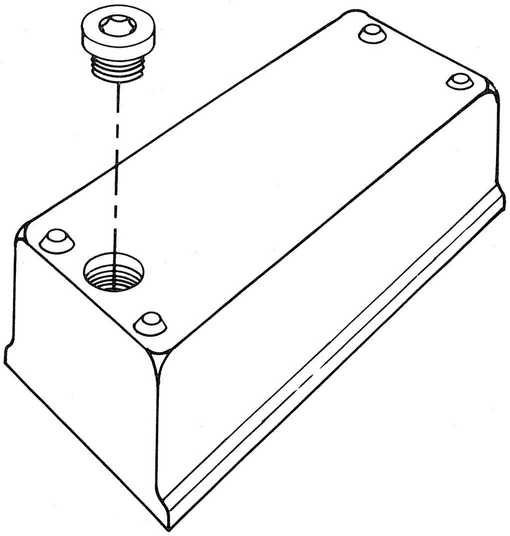


Figure 6-5. Location of the Drain/Fill Port

2. Using the 5/16 allen wrench, remove the oil plug from the bottom of the casting. Refer to Figure 6-5.

CAUTION

DO NOT OVERFILL THE SR1030. OVERFILLING AN SR1030 COULD RESULT IN AN OIL LEAK DUE TO THERMAL EXPANSION OF OIL.

THE TEMPERATURE OF THE OIL AND SR1030 SHOULD BE STABLE AT 23° CENTEGRADE BEFORE FILLING THE SR1030. WHEN FILLING THE SR1030, BOTH TEMPERATURE EXTREMES AND TEMPERATURE DIFFERENTIALS ARE FACTORS THAT CAN CONTRIBUTE TO AN OIL LEAK DUE TO THERMAL CHARACTERISTICS OF THE OIL.

THE FUNNEL MUST BE CLEAN (INSIDE AND OUT) TO AVOID CONTAMINATING THE MINERAL OIL.

3. Turn the SR1030 right side up and drain the oil into the empty container.
4. Again position the SR1030 bottom side up on a clean flat surface. Insert the funnel in the fill port and pour in the oil until it reaches the right angle in the fill port's opening as shown in Figure 6-6.

5. Hold the cloth rag around the funnel where it exits the SR1030. Pull the funnel from the SR1030 and wipe off the oil from the outside and inside of the funnel. Store the funnel in a plastic bag to avoid contamination.

6. Replace the plug into the drain/fill port and tighten until the plug seats against the SR1030's casting.

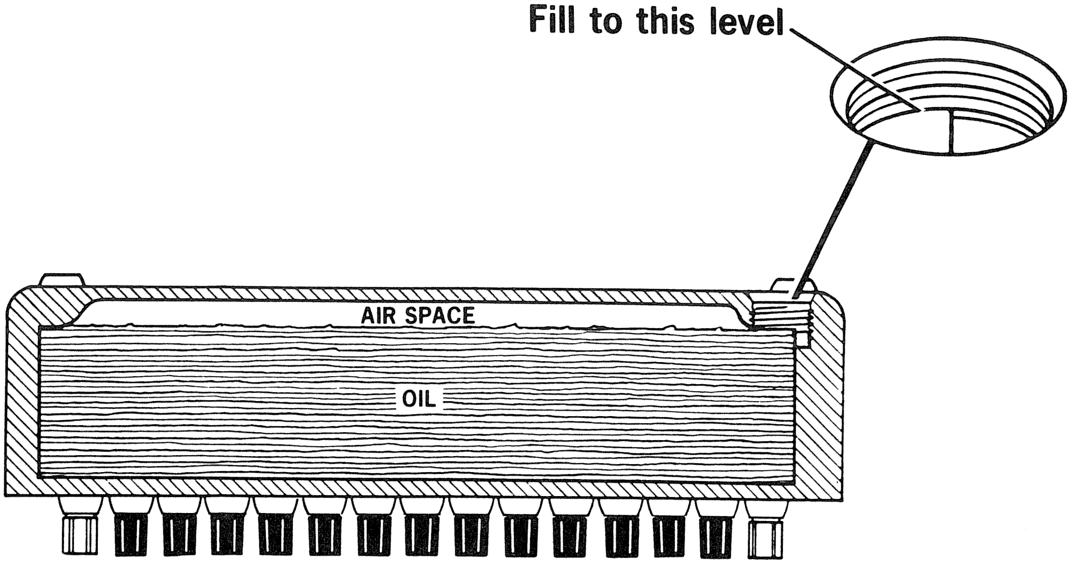


Figure 6-6. Filling the SR1030 with Oil

6.3.3.3 Disposing of Contaminated Oil

Before disposing of mineral oil, all local, state, and federal regulations as they may apply should be reviewed to determine approved disposal procedures.

6.3.3.4 Purchasing Mineral Oil

Mineral oil can be purchased from ESI in 1 gallon (P/N 66701) or 4 gallon (P/N 64966) units. Each SR1030 transfer standard requires approximately 1/2 gallon. When one SR1030 is purchased, 1 gallon of mineral oil is shipped with the unit. When a full set of SR1030s are purchased, 4 gallons of mineral oil are shipped with the set.

6.3.3.5 Cleaning Up Oil Spills

The oil tends to spread very easily if it is not cleaned up immediately. For this reason, it is suggested that great care be taken to ensure that the oil is kept in securely closed containers. In case the oil does spill, the bulk of it should be wiped up with an ordinary rag or paper towel. This should be disposed of in accordance with all local, state, and federal regulations. The remaining residue can be removed through the use of soap and water.

6.3.3.6 Material Safety Data Sheet for Mineral Oil

A Material Safety Data Sheet for the mineral oil is included with the SR1030.

SECTION 7
PARTS LISTS

7.1 SR1030 RESISTANCE TRANSFER STANDARD ORDER NUMBERS

This section lists the final assembly numbers, replacement parts, and options for each Model SR1030 Resistance Transfer Standard.

7.1.1 Final Assembly Order Numbers

Use the SR1030 final assembly number (F.A.) to order a Model SR1030 with accessories. The final assembly numbers include the manual, a funnel, and oil. To order the SR1030s without accessories, refer to Section 7.1.2.

DESCRIPTION	P/N
F.A. SR1030 1 Ohm-Per-Step	31030
Model SR1030 1 Ohm-Per-Step (includes dust cover)	66377
SR1030 Instruction Manual	67041
Funnel	66882
1 Gallon Mineral Oil	66701
F.A. SR1030 10 Ohm-Per-Step	31031
Model SR1030 10 Ohm-Per-Step (includes dust cover)	66378
SR1030 Instruction Manual	67041
Funnel	66882
1 Gallon Mineral Oil	66701
F.A. SR1030 100 Ohm-Per-Step	31032
Model SR1030 100 Ohm-Per-Step (includes dust cover)	66379
SR1030 Instruction Manual	67041
Funnel	66882
1 Gallon Mineral Oil	66701

7.1.1 Final Assembly Order Numbers (continued)

DESCRIPTION	P/N
F.A. SR1030 1 Kilohm-Per-Step	31033
Model SR1030 1 Kilohm-Per-Step (includes dust cover)	66380
SR1030 Instruction Manual	67041
Funnel	66882
1 Gallon Mineral Oil	66701
F.A. SR1030 10 Kilohm-Per-Step	31034
Model SR1030 10 Kilohm-Per-Step (includes dust cover)	66381
SR1030 Instruction Manual	67041
Funnel	66882
1 Gallon Mineral Oil	66701
F.A. SR1030 100 Kilohm-Per-Step	31035
Model SR1030 100 Kilohm-Per-Step (includes dust cover)	66382
SR1030 Instruction Manual	67041
(does not use oil)	

7.1.2 SR1030 Replacement Part Order Numbers

Because the transfer standards are not serviceable in the field, only the components that can be removed without removing the top panel, are considered to be replacement parts. Figure 7-1 shows the replacement parts of all SR1030 Resistance Transfer Standards. The list below provides the replacement part order numbers.

ITEM	DESCRIPTION	P/N
1	Dust cover	66721
2	Cap, Binding Post (Black)	01170
3	Cap, Binding Post (Gold)	01172
4	Warning Label, 1 Ohm-Per-Step SR1030	66909
5	Warning Label, 10 Ohm-Per-Step SR1030	66910
6	Warning Label, 100 Ohm-Per-Step SR1030	66911
7	Warning Label, 1 Kilohm-Per-Step SR1030	66912
8	Warning Label, 10 Kilohm-Per-Step SR1030	66913
9	Warning Label, 100 Kilohm-Per-Step SR1030	66472

ITEM	DESCRIPTION	P/N
10	Funnel	66882
11	Plug, SR1030 Drain	66171
12	Calibration Label	66471
13	Cover, Plastic Calibration Label	66430
14	Screw, 4 x 40, 0.187	03628
15	Mineral Oil, PENRECO Sontex 85, 1 Gallon	66701
16	Mineral Oil, PENRECO Sontex 85, 4 Gallons	64996
17	Model SR1030 1 Ohm-Per-Step (includes dust cover)	66377
18	Model SR1030 10 Ohm-Per-Step (includes dust cover)	66378
19	Model SR1030 100 Ohm-Per-Step (includes dust cover)	66379
20	Model SR1030 1 Kilohm-Per-Step (includes dust cover)	66380
21	Model SR1030 10 Kilohm-Per-Step (includes dust cover)	66381
22	Model SR1030 100 Kilohm-Per-Step (includes dust cover)	66382
	SR1030 Instruction Manual (not shown)	67041

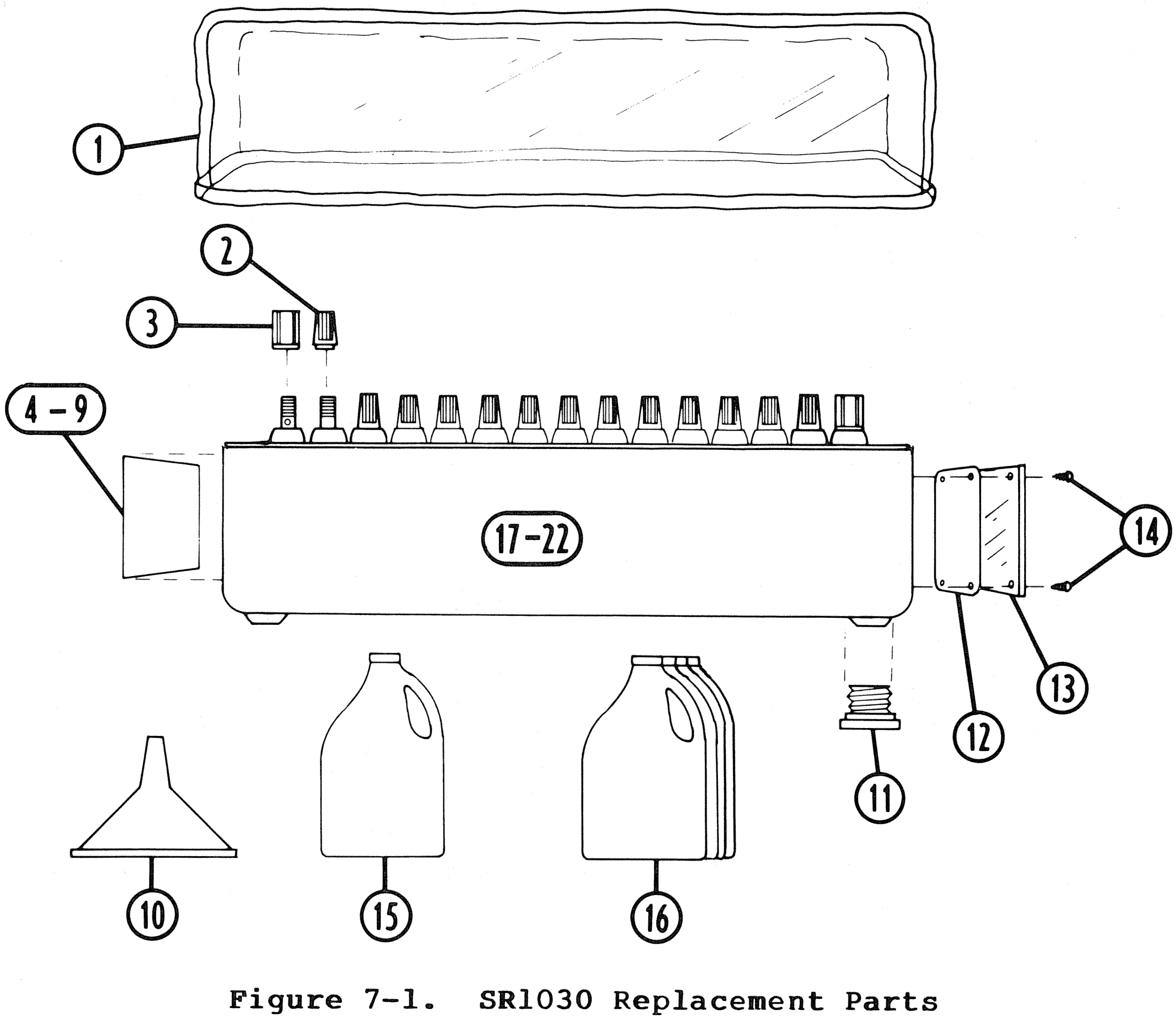


Figure 7-1. SR1030 Replacement Parts

7.2 SR1030 OPTION ORDER NUMBERS

Figure 7-2 shows options for any SR1030 Resistance Transfer Standard. The list below provides the option order numbers.

ITEM	DESCRIPTION	P/N
1	PC101 Parallel Compensation Network	08540
2	SB103 Shorting Bars	08551
3	SPC102 Series-Parallel Compensation Network	08560

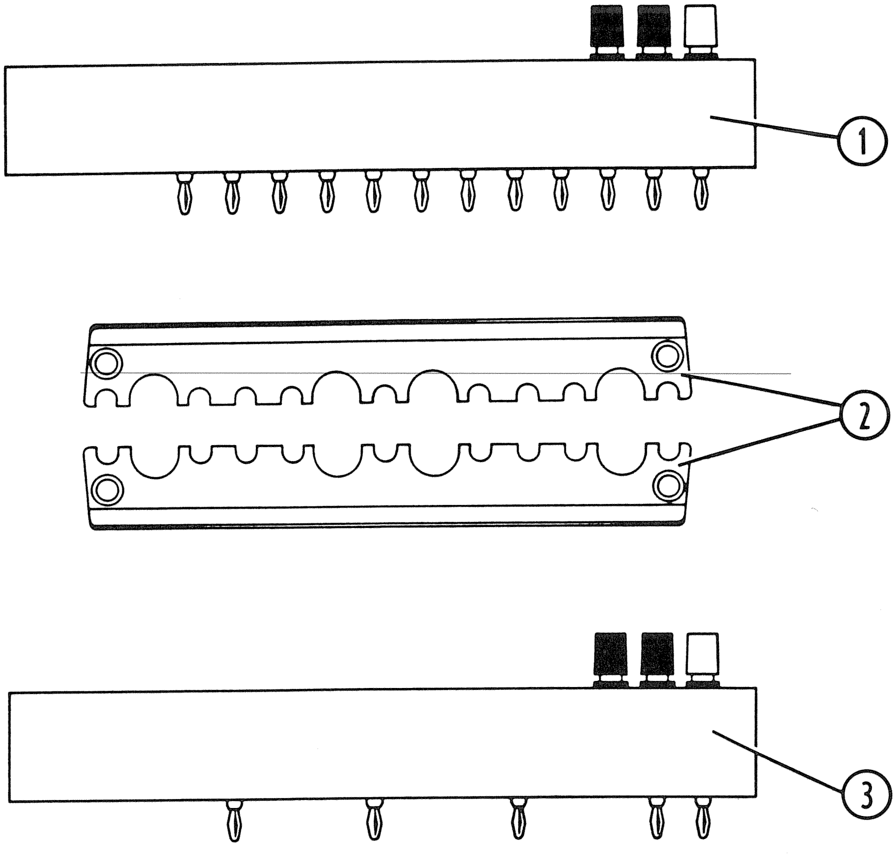


Figure 7-2. SR1030 Options