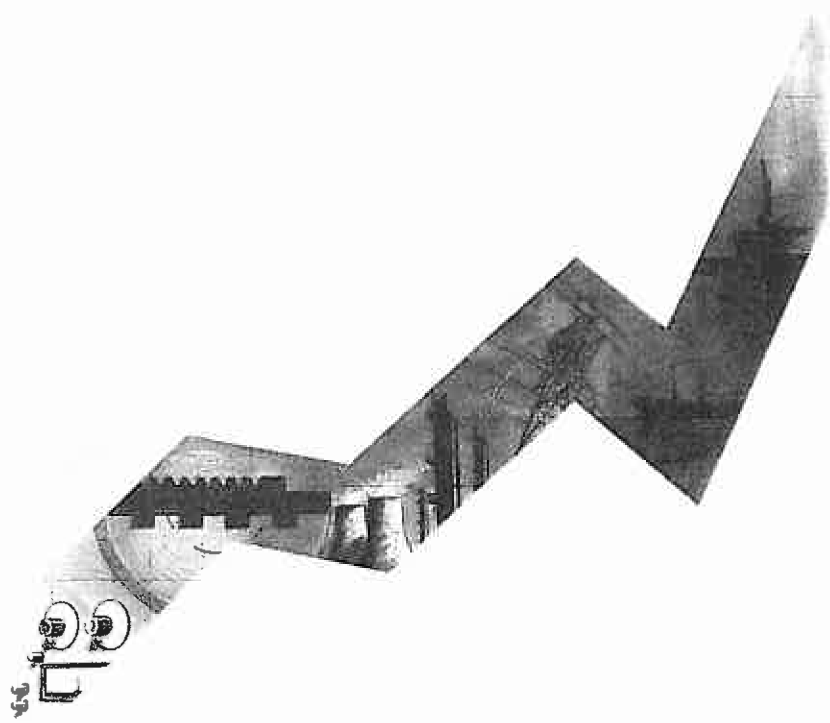
Guildline

TECHNICAL MANUAL FOR

MODEL 9975

DIRECT CURRENT COMPARATOR

RESISTANCE BRIDGE



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TM9975-C-01

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SECTION 1

INTRODUCTION

1.1 SCOPE

This manual contains operating and service information about the Guildline Instruments Model 9975 DIRECT CURRENT COMPARATOR RESISTANCE BRIDGE. The reader should have some familiarity with electronic circuitry and electronic service techniques.

1.2 GENERAL DESCRIPTION

A. FUNCTIONAL DESCRIPTION

The Guildline Instruments Direct Current Comparator Resistance Bridge, Model 9975 is an eight decade bridge, with a built in photocell amplifier, galvanometer and power supply to make precision resistance measurements.

The instrument is designed to measure resistance over the range 0.01 Ω to 10 MΩ; 0.01 Ω to 10 kΩ as a four-terminal measurement, 10 kΩ to 10 MΩ as a two-terminal measurement. Measurement accuracy to ±(0.2 ppm of reading + 1 step of dial 8), with a resolution of 1 part in 10^8 of full scale is obtainable. In addition to its obvious application to standards laboratory resistance measurements, the Model 9975 offers unparalleled versatility in resistance thermometry; its wide range enables the use of sensors with "ice-point" resistances from the 0.25 Ω "gold point" platinum sensors to germanium and carbon sensors at 10 kΩ or more. A "double-power" feature readily checks sensor self-heating and the recorder output is a great convenience in monitoring the plateau of a freezing point.

The principle of operation of the bridge is based on a technique of direct current comparison developed at the National Research Council of Canada under the direction of N. L. Kusters. The Model 9975 represents the latest application of this technique for the most accurate and precise resistance measurement commercially available. The current comparator employs transformer turns ratio at zero frequency (dc) to achieve a permanent linearity of better than a few parts in 10^8.

1.2 B. PHYSICAL DESCRIPTION

The Model 9975 is a completely self-contained instrument, housed in a "Formica" cabinet intended for bench mounting. Front panel mounted are individual meters for thermometer current, ampere-turn balance and bridge balance and the more frequently used controls. The left side-panel contains two groups of four terminals for connection of the unknown and the standard resistor plus less frequently used controls. The controls of the photocell amplifier are accessible through the door on the right side-panel.

1.3 SPECIFICATIONS

Range: 0.01 Ω to 10 MΩ:

0.01 Ω to 10 kΩ as a four-terminal measurement
10 kΩ to 10 MΩ as a two-terminal measurement

Dial Linearity: ±0.02 ppm of full scale

Dial Resolution: ±0.01 ppm of full scale

Accuracy: ±(0.2 ppm of reading + 1 step of dial 8) within noise limitations. See relative humidity specification and Note 1.

NOTE 1: The accuracy of this instrument depends in some measure on its environment. For optimum results, the recommendations contained in the Instrument Society of America paper ISA RP52.1 (Recommended Environments for Standards Laboratories for Echelon II laboratories should be observed.

Noise: Voltage (1) and Current (2)

1. Voltage: < 1 nV or

$$\frac{10^{-9}}{\text{Current in the standard resistor (A)} \times \text{the value of the standard resistor (ohms)}}$$

2. Current:	$< 0.3\ \mu A$.turns or $\dfrac{0.3 \times 10^{-3}}{\text{Current in the standard resistor (amperes)}}$
Test Currents:	From internal supply, 30 V compliance: 0.001, 0.003, 0.01, 0.03, 0.1, 0.3, 1, 3, 10, 30 and 100 mA. All currents may be multiplied by $\sqrt{2}$ (double power), to 100 mA maximum. Accuracy: ±1.5% Stability: ±0.5% Terminals with compliance to 20 V are provided for programming an external power supply.
Current Reversal:	Manual/Automatic, switch selectable at periods of 4 s, 8 s, or 16 s. Terminals are provided to supply a current reversing signal to a programmable external supply.
Detector Time Constant:	0.3 s, 1 s or 3 s, switch selectable.
Recorder Output:	0-10 V at 1 mA maximum.
Dimensions:	410 mm wide, 380 mm high, 500 mm deep (20" x 15" x 19½").
Weight:	43 kg (95 lbs.)
Line Power:	115 V/60 Hz or 230 V/ 50 Hz, 100 W maximum.
Fuse:	2 A, located below line plug on rear of cabinet.
Relative Humidity:	35% to 55%. These limits must be observed to maintain specified accuracy.

Options:

01 BCD output connections (factory installed) includes 99754 Interface Module.

Accessories:

Series 9330 Standard Four-Terminal Resistors
Special standard resistor for potentiometer calibration (specify potentiometer to be calibrated).

Model 9923, Range Extender, automatic reversing switch and 100 A programmable power supply.

External power supply, range 0 V to 1000 V, reversible.

Series 9730 Constant Temperature Oil Baths.

1.4 OPERATING PARAMETER SELECTION

Use Table 1-1 to select the voltage, current and power dissipated in the standard and unknown resistors, and to determine the accuracy of a measurement. Note that the absolute accuracy of the instrument is always ±(0.2 ppm of reading + 1 step of dial 8) although the noise, voltage and current, may be large enough to cause more uncertainty than this. Use the equations given below to calculate the apparent accuracy for unknown resistances not given in the table.

$$\text{Resolution limit of voltage noise in ppm} = \frac{1 \times 10^{-9}}{I_s \times R_s} \qquad (1)$$

where I_s is the current in the standard resistor in amperes.

R_s is the standard resistor value in ohms.

$$\text{Resolution limit of current noise in ppm} = \frac{3 \times 10^{-7}}{I \times 10^{3}} \qquad (2)$$

$$\text{Apparent accuracy} = (1) + (2) \qquad (3)$$

TAB 1-1

MODEL 9975 DCC RESISTANCE BRIDGE OPERATING PARAMETERS

FOUR TERMINAL MEASUREMENTS (1)

UNKNOWN RESISTOR				STANDARD RESISTOR				NOISE LIMITS (2) (ppm)		ACCURACY (ppm)	STANDARD AMPERE TURNS
Rx (Ω)	Wx (mW)	Ex (mV)	Ix (mA)	Rs (Ω)	Ws (mW)	Es (mV)	Is (mA)	Voltage	Current		
0.001	10×10^3	100	100×10^3	1	10	100	100	0.01	0.003	±1.2	100
0.001	100	10	10×10^3	1	0.1	10	10	0.1	0.03	±1.2	10
0.01	1×10^3	100	10×10^3	1	10	100	100	0.01	0.003	±0.7	100
0.01	10	10	1×10^3	1	0.1	10	10	0.1	0.03	±0.7	10
0.1	100	100	1×10^3	1	10	100	100	0.01	0.003	±0.7	100
0.1	1	10	100	1	0.1	10	10	0.1	0.03	±0.7	10
1	10	100	100	1	10	100	100	0.01	0.003	±0.2	100
10	1	100	10	1	10	100	100	0.01	0.003	±0.2	100
10	10	300	30	10	9	300	30	0.003	0.01	±0.2	31
100	1	300	3	10	9	300	30	0.003	0.01	±0.2	31
100	10	1×10^3	10	100	10	1×10^3	10	N/A(3)	0.03	±0.2	10
1×10^3	1	1×10^3	1	100	10	1×10^3	10	N/A	0.03	±0.2	10
1×10^3	10	3×10^3	3	1×10^3	9	3×10^3	3	N/A	0.1	±0.2	3
1×10^4	1	3×10^3	0.3	1×10^3	9	3×10^3	3	N/A	0.1	±0.2	3

TWO TERMINAL MEASUREMENTS

UNKNOWN RESISTOR				STANDARD RESISTOR				NOISE LIMITS (2)		ACCURACY (ppm)	STANDARD AMPERE TURNS
Rx (Ω)	Wx (mW)	Ex (V)	Ix (μA)	Rs (Ω)	Ws (mW)	Es (V)	Is (μA)	Voltage (ppm)	Current (ppm)		
1×10^4	10	10	1000	1×10^4	10	10	1000	N/A (3)	0.3	±0.2	1
1×10^5	1	10	100	1×10^4	10	10	1000	N/A	0.3	±0.2	1
1×10^5	4	20	200	1×10^5	4	20	200	N/A	1.5	±0.7	0.2
1×10^6	0.4	20	20	1×10^5	4	20	200	N/A	1.5	±0.7	0.2
1×10^6	0.4	20	20	1×10^6	0.4	20	20	N/A	15	±7	0.02
1×10^7	0.04	20	2	1×10^6	0.4	20	20	N/A	15	±7	0.02

NOTES: 1) The parameters detailed in the first five rows require the use of a Model 9923 Range Extender.

2) The resolution limit of voltage noise is 1×10^{-9} V and of current noise is 3×10^{-7} ampere-turns.

3) Not applicable.

4) The parameters detailed in the first five rows do not include Model 9923 Accuracy Limitation

SECTION 2

INITIAL OPERATING INSTRUCTIONS

2.1 INTRODUCTION

This section contains information regarding the installation and initial operation of the Model 9975. It also contains a front panel and side panel layout of all controls and indicators and a detailed description of their function. The contents of this section should be read before operating the Model 9975.

2.2 INSTALLATION

The instrument is thoroughly tested and inspected before shipment and should be free from electrical or mechanical damage when received. The customer should inspect it carefully, verify that all items on the packing list are present and check the instrument operation as soon as possible. Refer to the warranty card at the front of this manual if any damage or deficiencies are found. The installation procedure is as follows:

1) Unpack the instrument carefully and place it on a level, firm bench where it will not be subjected to excessive vibration. There must be easy access to the left side-panel controls and terminals and to the zero control on the photocell amplifier on the right side of the bridge.

2) Connect the line cord to the rear panel ensuring that the 120/240 V switch is in its proper position, and connect to power line. For 240 V operation a suitable connector must be installed by the user.

3) It is recommended that the photocell amplifier be removed from the bridge and placed under the bench on a solid block directly on the floor. The wiring to the amplifier has been left long enough for this purpose, as the amplifier is sensitive to vibration.

2.3 INITIAL OPERATION

1) Connect two 1 Ω resistors (Model 9330 or equivalent) to the R_x and R_s terminals on the side-panel using short lengths of wire as shown in Fig. 3-1, page 3-24. Set the PCA OUT switch on the side-panel to the OUT position. Set the REV RATE switch on the side-panel to "4", and the R_sΩ switch on the side-panel to "1". Also, on the side-panel set the MAN/AUTO switch to its MAN position. Insert the RANGE PLUG in its $R_s \leq 1$ kΩ mode.

2) On the front-panel set the R_x/R_s dial x1 to "1", and all the rest of the R_x/R_s dials to "0". Also, on the front-panel, insure that the CURRENT I_xmA switch is at zero, the x1 x$\sqrt{2}$ switch is at x1, the GALVANOMETER SENSITIVITY switch is at x1, and the GALVANOMETER D1/D2 switch is on D1. Switch the power OFF/ON switch to ON. Observe that the Power ON and OSCILLATOR LIGHTS come ON.

> CAUTION: IF THE OSCILLATOR LIGHT SHOULD BECOME EXTINGUISHED AT ANY TIME WHEN THE BRIDGE POWER IS ON, THE POWER SHOULD BE IMMEDIATELY TURNED OFF. REFER TO SECTION 5. (OSCILLATOR OFF TROUBLESHOOTING GUIDE), FIG. 5-3, PAGE 5-16.

3) Physically adjust the PHOTOCELL AMPLIFIER such that the ROUND PORT is clearly visible to you. This puts the black knob of the photocell amplifier to your right. Look through the amplifier port at an approximate angle of 30° to your left and observe the light pattern on the photocell sensors as shown in Fig. 2-3, page 2-9. If the light pattern is off centre then adjust the ZERO CONTROL (black knob) to centre the light pattern. Observing the light pattern and adjusting the photocell amplifier mechanical zero will provide a rough setting. To set the light pattern more accurately, observe the GALVANOMETER METER on the front-panel of the bridge, and adjust the mechanical zero such that the galvanometer meter needle swings through zero, to the opposite side of the meter. Reverse your adjustment of the mechanical zero to bring the galvanometer meter needle back to zero. Switch the PCA OUT switch on the side-panel to PCA. The galvanometer meter needle should lock on near zero. Adjust the GALVANOMETER BALANCE CONTROL on the front-panel to centre the galvanometer meter needle.

4) Set the CURRENT I_xmA control to 3.0 and observe unidirectional I_x current on the I_x METER (Indicates 30). Operate the CURRENT REVERSING switch on the front-panel and observe manual reversal of I_x current as indicated by the I_x meter.

5) Set the MAN/AUTO switch on the side-panel to AUTO and observe reversal of I_x current as indicated by I_x meter every two seconds as the CURRENT REVERSING RATE is set to 4 s per cycle.

6) Adjust the HIGH TRACK control on the front-panel until no change of deflection is observed on the AMPERE TURN BALANCE meter during current reversals.

7) Adjust the COMPARATOR BALANCE control on the side-panel to re-centre the AMPERE TURN BALANCE meter. Turn the control fully clockwise and then counterclockwise and observe full scale deflection of the AMPERE TURN BALANCE meter. Re-centre the meter.

8) On the front-panel reset the CURRENT I_xmA switch to zero and set the GALVANOMETER D1/D2 switch to D2. Observe that the GALVANOMETER meter needle settles around its zero position. On the side-panel adjust the REC ZERO control such that the GALVANOMETER meter needle swings through zero and back again.

9) This completes the initial operation of the Model 9975. Before any precise measurements are taken, a warm up time of approximately one to two minutes should be allowed.

2.4 CONTROLS AND INDICATORS FRONT-PANEL (Fig. 2-1, page 2-7)

The controls and indicators are shown on Fig. 2-1, page 2-7 and are labelled from 1 through 16.

ITEM	DESCRIPTION	FUNCTION
1.	CURRENT I_xmA switch	Selects current in milliamperes through R_x.

ITEM	DESCRIPTION	FUNCTION
2.	x1 x$\sqrt{2}$ switch	Multiplies current through R_x as set by item 1.
3.	I_x meter	Indicates current through R_x.
4.	GALVANOMETER	Detector indicator.
5.	AMPERE TURN BALANCE (ATB) meter	Indicates the signal from the ampere-turn detector circuit.
6.	GALVANOMETER SENSITIVITY switch	Adjusts the sensitivity of the galvanometer.
7.	GALVANOMETER D1/D2	Used with the MAN/AUTO switch, item 1, para. 2-5 to connect the detector indicator, item 4, either as a galvanometer or in parallel with the recorder output.
8.	R_x/R_s dials	Measure dials (8).
9.	OSC indicator	When lit, indicates correct operation.
10.	POWER indicator	When lit, indicates "POWER ON".
11.	POWER OFF/ON switch	Enables instrument to be turned on and off.
12.	TIME CONSTANT SEC switch	Selects the RC circuits at the input of the detector-modulator, for noise deflection.
13.	HIGH TRACK control	Allows adjustment for Ampere Turn Balance, as indicated on item 5 by zero deflection.
14.	TRANSIENT SUPPRESSION control	Allows adjustment to minimize the effect of reversal transients upon the galvanometer.

ITEM	DESCRIPTION	FUNCTION
15.	GALV BALANCE control	Centres the galvanometer reading (item 4).
16.	CURRENT REVERSING switch	Enables manual reversal of current through R_x and R_s, in conjunction with item 1 of section 2-4.

2.5 CONTROLS AND INDICATORS, SIDE-PANEL (Fig. 2-2, Page 2-8)

ITEM	DESCRIPTION	FUNCTION
1.	MAN/AUTO switch	Enables manual reversal of current through R_x and R_s, together with item 16 of section 2-4 when in MAN position. Item 6 determines the time interval between automatic reversals when in the AUTO position.
2.	INT/EXT switch	Normally in the INT position. When used in the "EXT" position the range plug must be in the $R_s \geq$ 10 kΩ position. When in the EXT position it disconnects the internal power supply and presents a programming voltage for an external power supply at item 13 for 2 terminal high resistance measurement.
3.	REC ZERO control	Enables zero adjusting of the external recorder.
4.	R_sΩ switch	When set to the value of R_s, which functions as the feedback resistor for the galvanometer, it adjusts the gain of the galvanometer for a constant loop gain.

ITEM	DESCRIPTION	FUNCTION
5.	COMP BAL control	Allows centering of item 5 (Section 2-4) after balancing by means of item 13 (Section 2-4).
6.	REV RATE SEC switch	Selects the time between automatic reversals.
7.	REC SENS control	Determines the output of the detector-demodulator circuit.
8.	OUT/PCA switch	Disconnects the photocell amplifier from R_x and R_s.
9.	REC Terminals	Allows connection of an external chart recorder.
10.	CCT COM and ground Terminals	Normally linked, connecting the common line of the bridge electronics and the low side of R_x and R_s to the ground wire of the line cord.
11.	R_x Terminals (4)	Allows connection of the unknown resistor or thermometer under test.
12.	R_s Terminals (4)	Allows connection of the standard resistor.
13.	EXT PS Terminals	For programming the reversal of an external power supply.
14.	Range Plug, $R_s \leq 1$ kΩ $R_s \leq 10$ kΩ	For low value measurements $R_s \leq 1$ kΩ faces up, for high value measurements $R_s \leq 10$ kΩ.

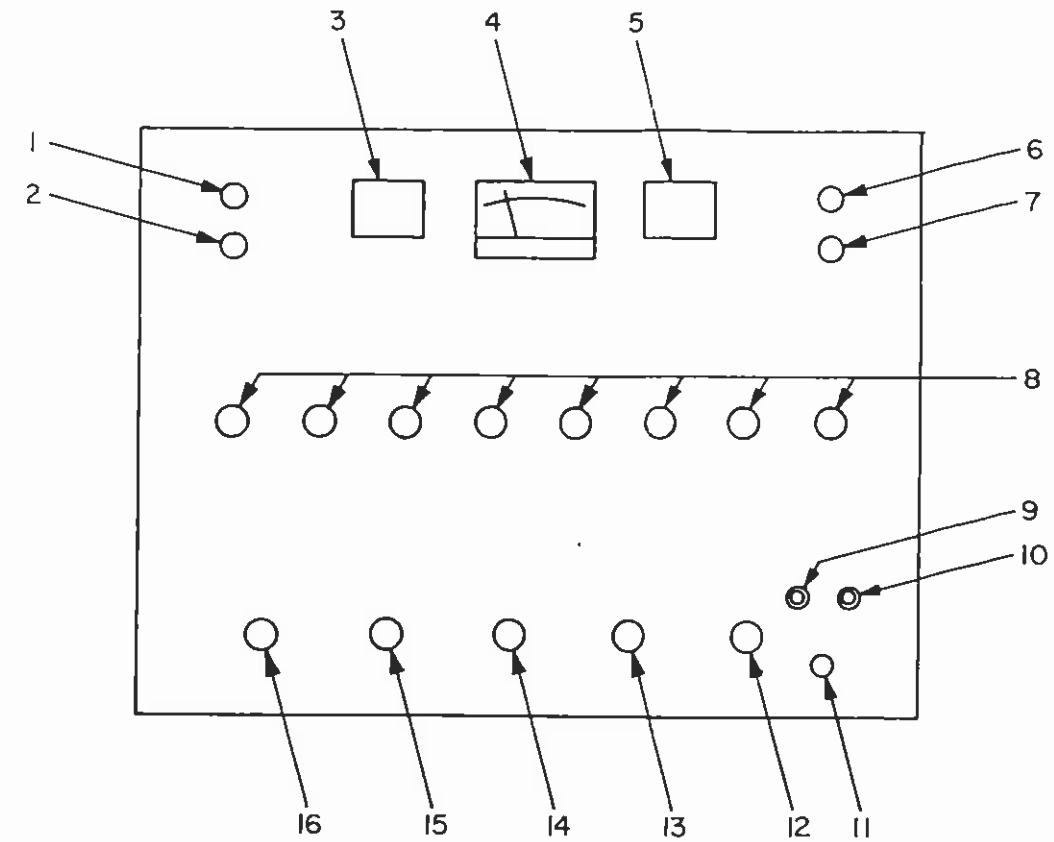


FIG. 2-1
MODEL 9975
FRONT PANEL CONTROLS

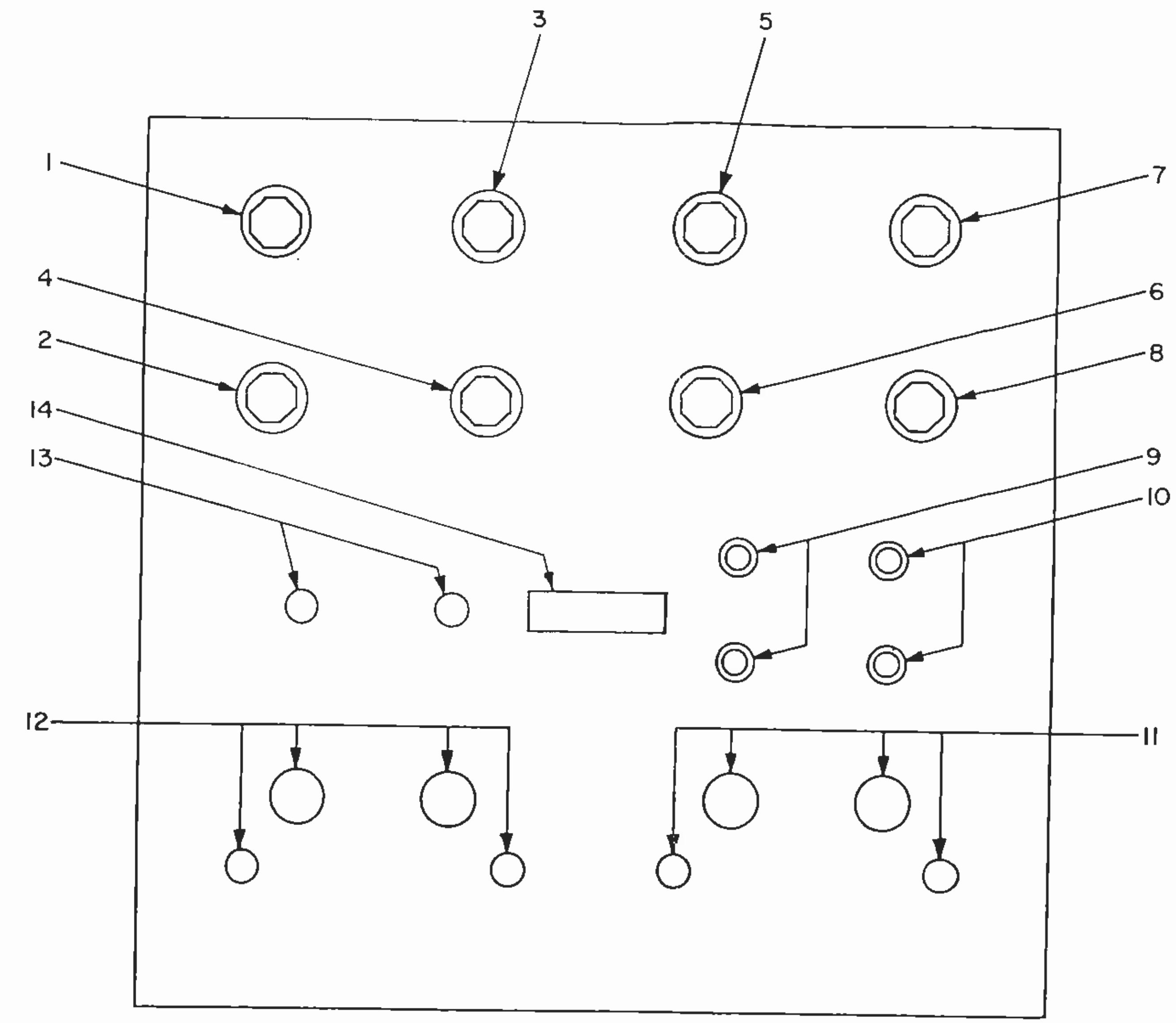


FIG. 2-2
MODEL 9975
SIDE PANEL TERMINALS

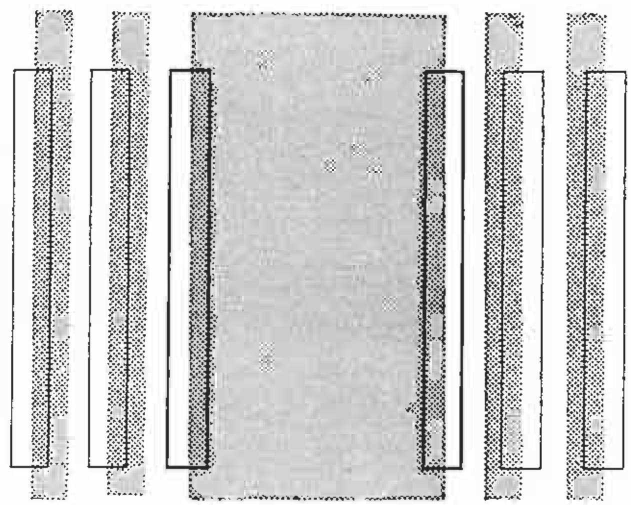


Fig. 2-3

MODEL 9460B

LIGHT PATTERN

SECTION 3

MEASUREMENT OPERATION

3.1 INTRODUCTION

This section contains information regarding the measurement of low value resistors and low value resistance thermometers in the range of R_s equal to 1 Ω to R_s equal to 1 kΩ as four-terminal measuring devices, low value resistors in the range of R_s equal to 10 mΩ to R_s equal to 100 mΩ. It contains information on high resistance values in the range of R_s equal to 10 kΩ to R_s equal to 1 MΩ. Included also is a section on specific procedure for different types of thermometers and a section on potentiometer calibration.

3.2 RESISTANCE MEASUREMENT - LOW VALUE (and low resistance thermometry)

$1\ \Omega \leq R_s \leq 1\ \mathrm{k}\Omega$

The Model 9975 bridge in its low resistance mode, $R_s \leq 1$ kΩ on the side-panel range plug-up, enables measurement of resistance of values up to 1 kΩ: 10 kΩ (R_s: R_x). Several types of resistance thermometers, each involving a different resistance range, reference resistor and thermometer current can also be measured in this mode. In all these cases the general operational procedures of the bridge are the same and these will be outlined first. The procedure for the measurement of resistors and thermometers (up to 10 kΩ) is identical.

NOTE:

> In this, as in all measurements, optimum results will be obtained if the environment is controlled. The recommendations in ISA RE52.1 (see NOTE on page 1-2), especially in regards to relative humidity, should be observed.

A) GENERAL PROCEDURES

1. Connect the thermometer leads or the resistor (e.g. Model 9330 10 Ω) to be measured to the four terminals labelled R_x, on the side-panel, where C_1P_1 identifies one current - potential pair and C_2P_2 the other pair. Refer to Figure 3-1, Page 3-24.

2. Select a reference resistor (e.g. 10 Ω Model 9330) and connect it to the four terminals labelled R_s, also on the side-panel. Provision is made for R_s values of 1 Ω, 10 Ω, 100 Ω and 1 kΩ. Normally a value is chosen that will make the maximum expected thermometer ratio lie between 1 : 1 and 10 : 1 as this will bring all ratio dials into play and ensure the best available measuring precision.

3. Set the R_sΩ switch (left side-panel) to the value of the standard resistor (e.g. - 10 Ω).

4. Set the MAN/AUTO switch (left side-panel) to the current reversal mode desired. Normally the automatic mode is used for its obvious convenience. However, in the event that the galvanometer will not stabilize sufficiently well at the slowest automatic reversing rate the manual mode can be used to obtain still slower rates. Such an event might occur, for example, if there are spurious polarization effects in the thermometer insulation, or if measurements of ratios near 10 : 1 are desired to the optimum precision of parts in 10^8 in which case the inherent bridge time constant must be taken into account.

5. Set the REV RATE switch to the desired frequency. Normally a setting of 4 seconds per cycle is used in order to obtain the fastest possible response time. However, before the final balance is taken slower rates should be tried so as to avoid errors of the type mentioned in step 4 above.

6. Turn the OUT/PCA switch to OUT to open circuit the input to the photo-cell amplifier.

7. Set the GALVANOMETER SENSITIVITY switch to x1, i.e. the lowest sensitivity.

8. Set the GALVANOMETER switch to its D1 position in order to observe any offset on the galvanometer due to thermal emf's.

9. Switch bridge power ON. Note that the OSC indicator is illuminated.

CAUTION

IF THE OSCILLATOR LIGHT SHOULD BECOME EXTINGUISHED AT ANY TIME WHEN THE BRIDGE POWER IS ON, THE POWER SHOULD BE IMMEDIATELY TURNED OFF (SEE OSCILLATOR OFF TROUBLESHOOTING GUIDE SECTION).

10. Null the galvanometer approximately by adjusting the ZERO control on the photocell amplifier itself. (Right side-panel).

11. Set the ratio dials as close as possible to the anticipated value of R_x/R_s and the GALVANOMETER SENSITIVITY switch to x1.

12. With the CURRENT I_xmA switch set to zero turn the PCA/OUT switch to PCA to complete the feedback circuitry of the galvanometer.

13. Set the GALVANOMETER switch to the D2 position and null either the galvanometer, or the external recorder, using the REC ZERO control on side-panel. (NOTE: if both the galvanometer and recorder are to be used simultaneously then the recorder must be positioned independently by its own zero control).

14. Turn the GALVANOMETER D1/D2 switch to D1 and set the resistor (or thermometer) current (I_x) to the desired value by means of the CURRENT I_xmA switch (e.g. 1 mA). In general the thermometer current should be made as large as possible to minimize circuit noise effects, but within the constraint that it must not produce excessive self heating in the thermometer itself. A certain amount of self heating can be tolerated and accurately corrected for by measuring the resistance at two (or more) different currents and then extrapolating a graph of resistance versus $(I_x)^2$ to the zero current resistance.

A special feature of this bridge is the $\sqrt{2}$ current multiplier which permits the zero current extrapolation to be carried out quickly and accurately by subtracting the difference between the readings at switch position x$\sqrt{2}$ and x1 from the reading at position x1. (Note the galvanometer and external recorder sensitivity is maintained the same on both x1 and x$\sqrt{2}$ positions so that the difference in readings may also be determined directly from the deflection on the galvanometer or the recorder. Since the accuracy of the $\sqrt{2}$ current multiplier is factory set to within 0.5%, the self heating correction will have a corresponding accuracy of at least 1%.

15. Adjust the HIGH TRACK control until the pointer of the AMPERE TURN BALANCE meter gives no deflection when the I_x current is reversed. Note that the rest position of the pointer need not be on zero in order to get a true ratio, but if desired it can be set on zero by adjusting the COMPARATOR BALANCE control.

16. Compensate for thermal emf's by adjusting the GALV BALANCE control until the galvanometer deflects equally on each side of centre scale.

17. Adjust the eight R_x/R_s dials until there is no change in galvanometer deflection upon current reversals.

18. Increase the GALVANOMETER SENSITIVITY and re-adjust the R_x/R_s dials and GALV BALANCE as necessary.

19. Repeat the adjustment at higher settings of the GALVANOMETER SENSITIVITY switch up to the setting that will yield the required measuring sensitivity.

20. Adjust the TRANSIENT SUPPRESSION control to minimize the transient "kick" on the galvanometer.

21. If the recorder output is not in use then set the GALVANOMETER switch to its D2 position and proceed with the final balance of the measuring dials using the galvanometer as a null indicator. If the recorder output is to be used as the null indicator, then it is sometimes useful to leave the GALVANOMETER switch in the D1 position and make simultaneous observations of the thermal emf's with the secondary galvo. The thermal emf's do not affect the deflection of the recorder.

22. If the above balance was carried out with the REV RATE switch on its fastest setting, it is recommended that the balance be repeated at slower reversing rates unless previous experience makes this precautionary test unnecessary. Note earlier comments in steps 4 and 5.

3.3 MEASUREMENT OF LOW RESISTANCE ($0.01\ \Omega \leq R_s \leq 0.1\ \Omega$)

The Model 9975 will measure resistances as low as 10 mΩ. However, two factors should be recognized when operating the instrument at this level:

1) The photocell amplifier is looking at very low input resistance, and becomes heavily overdamped and sluggish. The current reversal should be set at 16 s, or manual reversal used.

2) The range of the GALV BALANCE control is reduced when the measured resistors are of low value and becomes ineffective at $R_s = 0.01\ \Omega$. Further, with the lower values of resistors, the effects of thermal emf's become more noticeable. To bring the detector meter to centre scale, centre the GALV BALANCE control and make the adjustment by means of the ZERO control of the photocell amplifier.

3.4 HIGH RESISTANCE MEASUREMENT ($10\ k\Omega \leq R_s \leq 10\ M\Omega$)

For measurements from 10 kΩ to 10 MΩ the programmed range plug on the side-panel must be inserted with the marking $R_s \geq 10\ k\Omega$ facing up. This electricall inverts the bridge to keep the input resistance to the detector low. For all measurements in this mode, the $R_s\,\Omega$ switch on the side-panel must be in position 1000.

When the Model 9975 is used for high resistance measurement, the internal master power supply is operated in a constant voltage mode rather than a constant current mode.

The output voltage is determined by the setting of the CURRENT I_xmA switch and the output voltage is 100 times the setting of this switch times the output of the internal master power supply (approx. 22 Vdc). Therefore, this switch should only be on the lowest three settings giving an output of approx. 2.2 V, 6.6 V and 20 V on positions 0.001, 0.003 and 0.01 respectively.

The x1 $x\sqrt{2}$ switch will increase all the output voltages by a factor of $\sqrt{2}$ which doubles the power in the tested resistors.

a) Two-Terminal Measurement

Two-terminal measurements of a resistance of 10 kΩ or greater can now be made by connecting the bridge as shown in Fig. 3-2, page 3-25. The operation of all bridge controls are in the same sequence and are performed in the same manner as described in Para. 3-2. Two-terminal measurements are satisfactory at a resistance of 10 kΩ or greater because the lead resistance is insignificant relative to the measured resistance. Lead resistance becomes more significant however, when the measured resistance is below 10 kΩ and four-terminal resistance measurements should be used. If the required precision for values greater than 10 kΩ is such that there is a significant difference between two-terminal and four-terminal configurations the bridge may be used in the inverted (high resistance) mode for four-terminal measurement as described in (b) below.

b) Four-Terminal Measurement

Four-terminal measurement in the high resistance mode can be accomplished by utilizing the connections shown in Fig. 3-3, page 3-26. To minimize the stability and resolution requirement of R_T (ideally a decade resistance box) R_T must be one hundredth or less of the value of R_s, and R_T is derived from the ratio $R_x/R_s = R_T/R_T$. The balancing resistor, R_B can be any type resistor with a nominal resistance of 1Ω . The bridge is operated in the normal manner as described in Para. 3-2 with the exception that an extra balancing step is required at the higher settings of galvanometer sensitivity. This is accomplished by means of opening and closing S1 while adjusting R_T until no change of balance is observed. This operation ensures the potential at P_1 of R_s is identical to the potential at P_1 of R_x, thereby eliminating the effects of lead resistance on the resultant readings.

3.5 EXT POWER SUPPLY (PS) TERMINALS

Terminals are provided on the side-panel to program an external reversible power supply (not supplied) if desired. The programming voltage appearing at these terminals is the internal master power supply voltage which is set by the CURRENT I_xmA switch on the front-panel. (See Section 3-4).

3.6 SPECIFIC PROCEDURES FOR DIFFERENT TYPES OF THERMOMETERS

In this section the appropriate R_s value and thermometer currents for each type of thermometer are presented, along with estimates of the temperature discrimination levels that may be achieved with this bridge. In certain cases the allowable power that can be generated in the thermometer sensor by the measuring current has been specified, rather than the thermometer current itself, in order to permit a more generalized treatment. The value of measuring power or current that is recommended here will normally cause between 0.5 mk and 5 mk self heating, for which a correction may be applied using the procedures outlined in Section 3-2. The estimated temperature discrimination levels specified here correspond to a 3 s bridge time constant, a galvanometer noise of 1.0 nV, a magnetic core noise of 0.3 μA.turns and a thermometer power or current as recommended.

1. Standard Platinum Resistance Thermometers with 25   Ice Point Resistance

a) Temperature Range -183°C (90 K) to +630°C (903 K).
Thermometer Resistance Range is from 6 Ω at -183°C to 84 Ω at 630°C.
R_s of 10 Ω will cover the range adequately.
Smallest Dial Step is equivalent to about 0.01 mK over the specified temperature range.
Thermometer current of 1 mA is recommended.
Temperature discrimination level is equal to or less than 0.04 mK over the specified temperature range.

b) Temperature Range 14 K to 90 K.
Thermometer Resistance Range is from 0.03 Ω at 14 K to 6 Ω at 90 K.
R_s of 1 Ω will cover the range adequately.
Smallest Dial Step is equivalent to 0.02 mK at 14 mK decreasing to about 0.001 mK at 90 K. (See Noise Level Limitation para. 4-8, Page 4-10).
Thermometer Power is 10 μW is recommended.
Temperature discrimination level is equal to about 0.005 mK over the specified temperature range.

c) For Temperature Range 2 K to 14 K

Thermometer Resistance Range is typically from 0.01 Ω at 2 K to 0.03 Ω at 14 K.

R_s of 1 Ω is the best available choice at present and gives reasonably good coverage.

Smallest Dial Step is equivalent to 1 mK at 2 K decreasing to 0.02 mK at 14 K.

Thermometer Power of 10 μW is recommended.

Temperature discrimination level varies from 0.16 mK at 2 K to 0.005 mK at 14 K.

2. <u>High Temperature Platinum Resistance Thermometer with 0.2 Ω Ice Point Resistance</u>

Temperature Range 0 to 1064°C (gold point).

Thermometer Resistance Range is from 0.2 Ω at 0°C to 1.0 Ω at 1064°C.

R_s of 1 Ω covers the range perfectly.

Smallest Dial Step is equivalent to about 0.1 mK at 0°C increasing to about 0.2 mK at 1064°C.

Thermometer Current of 10 mA is recommended.

Temperature discrimination level is about 0.1 mK over the specified temperature range.

3. <u>Germanium Resistance Thermometers</u>

Temperature Range: There are a wide variety of germanium thermometers marketed for different temperature intervals in the 0.1 K to 90 K region. As a prime example consider the 2 K to 20 K range where there instruments are usually considered superior to other thermometers.

Thermometer Resistance Range: The various commercial thermometers cover a variety of resistance ranges lying mostly in the 10 Ω to 10 kΩ range. A typical example would be 5 kΩ at 20 K, decreasing to 200 Ω at 10 K and to 50 Ω at 2 K. R_s of 1 kΩ will cover the range 1 kΩ to 11 kΩ adequately, while an R_s of 100 Ω will cover the range below 1 kΩ adequately.

Thermometer power of 0.1 μW is recommended.

Temperature discrimination level will be approximately 0.1 mK over the 2 K to 20 K range using the recommended power and R_s values.

3.7 POTENTIOMETER CALIBRATION (or Kelvin-Varley dividers with input $\leq$ 10 Ω)

Connect the potentiometer (or Kelvin-Varley divider) to be calibrated as shown in Fig. 3-4, page 3-27, ensuring the side-panel controls are set as shown. The calibration can be performed using either a potentiometric method or a four-terminal resistor method. The method to be used depends on the preference of the operator and the particular circuit of the potentiometer to be calibrated. Table 3-1 is provided as an example calibration sheet.

As most potentiometers have a high capacitive effect on the bridge the REV RATE SEC switch on the side-panel (shown in position 8 on Fig. 3-4) may have to be moved up to position 16 to reduce this effect (and the noise on the galvanometer) to an acceptable level.

The Guildline Model 9144 Potentiometer has been used as an example, the method being identical for most other potentiometers.

a) Potentiometric Method

1. Set the Model 9975 R_x/R_s dial 10^{-1} to 1 and the GALVANOMETER D1/D2 switch to D1.

2. Set the Model 9144 dial x0.1 to 10 (1 V) on the x1 range and lock down key H+ on the TEST keys.

3. With all other Model 9144 measuring dials set to zero increase the CURRENT I_xmA control on the Model 9975 to 0.001 mA.

4. Obtain a balance of the Model 9975 as indicated by its galvanometer by adjusting the resistance box or the current controls of the Model 9144, until no change of deflection is observed on the Model 9975 galvanometer upon current reversal.

5. Inrease the CURRENT I_xmA switch in steps up to position 10 mA while adjusting the resistance box or the Model 9144 current controls to maintain balance (with the GALVANOMETER SENSITIVITY switch at position x100).

6. Obtain a final balance by adjusting the fine current control on the Model 9144.

7. Turn the Model 9975 CURRENT I_xmA switch to zero and turn the GALVANOMETER D1/D2 switch to D2. Adjust the RECORDER ZERO control on the side-panel for zero indication on the chart recorder.

8. Increase the CURRENT I_xmA control to 10 mA and readjust the Model 9144 fine current controls for zero indication on the chart recorder. To set the sensitivity of the chart recorder increase the Model 9144 x 10^{-5} dial by one step (corresponding to 10 ppm error) and adjust the RECORDER SENS control on the side-panel for required sensitivity. Turn the Model 9144 10^{-5} dial back to zero.

There may be a small offset in the Model 9975 tracking, as indicated on the ATB meter, which can not be balanced out by means of the Model 9975 HIGH TRACK control. This does not affect the accuracy of the measurement.

The 1.00000 V setting of any potentiometer is assumed to be without error because this is the setting at which the potentiometer is standardized. The above procedure balances the potentiometer against the Model 9975 so that direct comparisons can now be made between the potentiometer dial settings and the turns ratio of the Model 9975. Turn CURRENT I_xmA switch to zero.

9. Set all measure dials of both the Model 9144 and Model 9975 to zero and increase the CURRENT I_xmA to 10 mA. The zero error of the Model 9144 can now be measured on the Model 9975 by adjusting its measure dials for zero indication on the chart recorder. Record the error and return the CURRENT I_xmA back to zero.

10. Increase the Model 9144 0.1 V dial by 1 step and increase the third measure dial (x10^{-2}) by one step. Increase the CURRENT I_xmA to 10 mA. Adjust the Model 9975 measure dials for zero indication on the chart recorder. Record the error and return the CURRENT I_xmA back to zero.

11. All remaining steps of 9144 can be checked against the 9975 turns ratio in the same manner as described in step 10 for 1st step of the 0.1 V dial.

12. Upon completion of the x1 RANGE calibration measure the error of the x0.1 RANGE by balancing the 9975 with the 9144 set at x1 RANGE and dial x0.1 set to 10 with all other dials to zero. Switch the 9144 range switch to x0.1 RANGE and re-balance the 9975. The error of the 9144 x0.1 RANGE is indicated by the 9975 measure dials as in step 10.

b) <u>Four-Terminal Resistor Method</u>

A potentiometer such as the Guildline Instruments Model 9144 can be considered to be a variable four-terminal resistor. The circuit resistance of the 9144 is 50 Ω/V nominal. Therefore a 10 Ω standard resistor is chosen for the reference standard (R_s). The measurement technique is basically the same as described in Section 3-2, Resistance Measurement - Low Value. A synopsis of the procedure to be followed is given below.

1. Connect a 10 Ω four-terminal standard resistor to the R_s terminals of the 9975 side-panel, ensuring the CURRENT I_xmA control is at zero.

2. Connect the 9144 EMF+ terminal to the P_2 terminal of R_x on the 9975 side-panel.

3. Connect the 9144 EMF- terminal to the P_1 terminal of R_x on the 9975 side-panel.

4. Connect the BATTERY+ terminal of the 9144 to the C_2 terminal of R_x on the 9975 side-panel.

5. Connect the C_0 terminal of the 9144 to the C_1 terminal of R_x on the 9975 side-panel. Ensure the 9144 is in the x1 RANGE mode and that its sensitivity key 4 is locked down.

6. Set the 9144 dial x0.1 to 10 and the 9975 measure dial x1 to 5 (50 Ω).

7. Set the CURRENT I_xmA control to 10 mA and balance the 9975 by adjusting the measure dials.

8. If the Model 9975 balances at a measure dial reading of greater than 5 000 000 0 then a high value (10 MΩ) variable resistor should be placed so that it shunts the current terminals of the Model 9144. This variable resistor is then adjusted so that the Model 9975 balances exactly at a measure dial reading of 5 000 000 0.

9. If in step 7, the Model 9975 balances at a measure dial reading of less than 5 000 000 0 the high value variable resistor should be placed so that it shunts the current terminals of R_s and consequently adjusted so that the Model 9975 balances at a measure dial reading of 5 000 000 0.

10. Steps 7, 8 and 9 correct the nominal resistance value of the potentiometer, which is accurate only in terms of ratio and not in terms of absolute resistance.

11. Increase the Model 9975 measure dials to read 5 000 005 0 and adjust its GALVANOMETER SENSITIVITY control so that the GALVANOMETER deflection is at least one major division. These 5 steps of the second last measure dial ($x10^{-6}$) correspond to 1 ppm deviation of the potentiometer under test. Therefore, note the amount the GALVANOMETER deflects.

Each step of the Model 9144 dial x0.1 now corresponds to 5 steps of the corresponding measure dial of the Model 9975 (dial x 10^{-1}), similarly for the other Model 9144 dials.

12. Reduce the CURRENT I_x mA to zero and set the Model 9144 dial x0.1 to zero and the Model 9975 measure dials to zero. Increase the CURRENT I_x mA. Rather than balancing the Model 9975 by means of its measure dials it is more convenient to balance it by means of the Model 9144 measure dials. The error can then be read directly in volts as indicated on the Model 9144 dials, but in the opposite sign. That is, if the Model 9144 measure dials give a negative reading the error must be positive. Compare all dial settings of the Model 9144 in the same manner, noting the error at each step.

13. After completing the calibration of the Model 9144 x1 RANGE, reset dial x0.1 of the Model 9144 to 10 with all other dials to zero and re-balance the Model 9975. Switch to the Model 9144 x0.1 RANGE and obtain the error of this range as in (12) above.

3.8 CLASSICAL METHOD OF POTENTIOMETER CALIBRATION

The classical method is described so that the operator can check the results obtained using either of the methods in Para. 3-7.

a) Linearity of the measuring dials

1. Linearity of Dial 1

Connect a second, external potentiometer to the EMF terminals and link the CK terminals. Turn the check switch to the READ position, Dial 1 to position 1 and Dials 2, 3, 4 to zero. Turn the dials of the external potentiometer to approximately 0.1 V and with increasing sensitivity on the TEST sensitivity keys 1 to 4 adjust the current in either or both potentiometers for zero deflection on the measuring galvanometer. Adjust the galvanometer amplifier gain to give a deflection of 100 mm for the addition of one step of Dial 4 of the potentiometer under test (1 μV nominal).

Release the galvanometer key 4, restore Dial 1 to zero and turn Dial 2 to 100. Press TEST key 4 and record the galvanometer deflection due to the difference between the first step of Dial 1 and the total of Dial 2.

To establish correct polarity for the difference add one step of Dial 4 to the total of Dial 2. The resulting deflection indicates an increase in Dial 2 over the balance obtained for one step of Dial 1, which is the direction of the deflection which would be produced by a small Dial 1 step. Designate deflections in this direction as negative indicating that the Dial 1 step is small when compared to Dial 2 total.

Balance two steps of Dial 1 against the external potentiometer with Dial 2 at zero. Reduce the setting of Dial 1 to 1 and increase Dial 2 to 100. Record the deflection due to the difference between the second step of Dial 1 and the total of Dial 2.

Repeat the same procedure for each step of Dial 1 up to 20. Check the sensitivity of the galvanometer before each comparison. It is easily possible to obtain a comparison between steps to ±0.1 μV, equivalent to ±1 ppm, throughout the dial, provided that the current in both potentiometers is stable. In the upper half of the dial it will be found that care is necessary to avoid errors due to differing rates of current drift in the two potentiometers.

<u>Tabulation of Results</u>: A typical arrangement of the results of the Dial 1 linearity check is given in Table 3-2, page 3-22.

If ΔG is the difference between one coil of Dial 1 and the total coils of Dial 2 the average difference between each of the coils of Dial 1 and the total of Dial 2 is given by:

$$\overline{\Delta G_1} = \frac{1}{10} \sum_{x=1}^{10} \Delta G_{x1}$$

The difference between each individual difference and the average difference is:

$$\Delta G_{x1} - \overline{\Delta G_1} = \Delta G_{x1} - \frac{\sum_{x=1}^{10} \Delta G_{x1}}{10}$$

and the deviation D_{n_1} from perfect linearity at the nth step of Dial 1 is given by the algebraic sum of the deviations from the average between zero and the nth step:

$$D_{n_1} \quad \sum_{x=1}^{n} \left[\Delta G_{x1} - \overline{\Delta G_1} \right]$$

In the Table 2 computation of typical results the dial is assumed to have zero error at zero and the 1 V point. It is preferable to assume zero error at 1 V rather than at 2 V because it is at this point that the potentiometer is made to read correctly (in terms of the standard cell voltage) during the standardization procedure.

The mean of the difference between the total of Dial 2 and each of the first ten steps of Dial 1 is obtained as shown above and as listed in Col. 3 of Table 2. The algebraic sum of the entries in Col. 4 gives the deviation from true linearity D_{n1} in terms of galvanometer deflection. Voltage deviation is obtained in Col. 5.

If the arithmetic is correct the figures in Cols. 4 and 5 for step 10 should always be zero. A plot of Col. 5 gives a graphic representation of dial linearity to which may be added limit lines defining ±1 ppm of reading, ±10 ppm of reading, etc.

The corrections C_1 for each step of Dial 1 are the figures in Col. 5. For example, if a measurement of an emf's results in a balance at 3 steps of Dial 1, the actual voltage measured would be:

$$D_1 + C_1 = 0.3 \text{ V} + 0.6 \ \mu\text{V}$$

2. Linearity of Dials 2 and 3

The procedure for obtaining the linearity of Dials 2 and 3 is the same as for Dial 1. Each step of Dial 2 is compared with the total of Dial 3 and each step of Dial 3 is compared with the total of Dial 4. The differences ΔG_2 for Dial 2 are tabulated, the mean difference ΔG_2 is obtained and the deviation from linearity D_{n2} for each step of the dial is derived. D_{n3}, the deviation for each step of Dial 3 is obtained similarly.

In checking the linearity of the 100 step dials care should be taken to ensure that the accumulation of small errors is not excessive. A lineartiy check in groups of 10 against the CK2 and CK3 check resistors should produce a linearity curve with approximately the same shape as that obtained for the 100 step check.

3. Linearity of Dial 4

The linearity of Dial 4 in which a resistor error of 1% is equivalent to only 0.01 V on the x1 range can be checked to sufficient accuracy by galvanometer deflection. An external potentiometer is not required.

Short circuit the EMF terminals and the CK terminals. Turn all four measuring dials to zero. Reduce the galvanometer amplifier gain so that the full 10 steps of Dial 4 produce a deflection of 100 mm.

Decrease the setting of Dial 4 step by step observing that galvanometer deflection increments are approximately equal.

b) Intercomparison of Dials

The overall linearity of the four measuring dials of the potentiometer is a combination of the individual linearity of each dial and the agreement of the total of each dial with the average step of the next higher dial.

The amount by which Dial 2 deviates from the average step of Dial 1 has already been obtained as ΔG_1. In the example shown in Table 2, $\overline{\Delta G_1}$ = -20 mm, which indicates that the total of Dial 2 is 0.2 μV larger than the average step of Dial 1. Each of the steps of Dial 2 are thus in error by $\Delta G_1/100$.

The total error of the nth step of Dial 2 is the sum of the error due to deviation from linearity (D_{n2}) and the error due to lack of agreement between Dials 1 and 2,

$$E_{n2} = D_{n2} - n.\ \frac{\overline{\Delta G_1}}{100}$$

This is the same as the correction to be used in the EMF equation on Page 3-20 to obtain the true EMF which appears at the EMF terminals when Dial 2 is set to the nth step.

Similarly the total error the nth step of Dial 3 is:

$$E_{n3} = D_{n3} - n\left[\frac{\overline{\Delta G_2}}{100} + \frac{\overline{\Delta G_1}}{10\ 000}\right]$$

and it can be seen that the second term inside the brackets is insignificant.

The total error of the nth step of Dial 4 is:

$$E_{n4} = D_{n4} - n\left[\frac{\overline{\Delta G_3}}{10} + \begin{array}{l}\text{very small corrections}\\ \text{from Dials 1 and 2}\end{array}\right]$$

c) Standard Cell Dial

If the Model 9144 internal standard cells SC1 and SC2 are used as working standards there is no requirement for corrections to the standard cell dial. The engraving of the standard cell dial has no meaning other than to identify a particular switch position that is appropriate for one or other of the internal standard cells.

If an external cell is used to standardize the potentiometer through the reference circuit it is necessary to know the corresponding settings of standard cell dials and the measuring dials, or in other words, the corrections for the standard cell dial in terms of the 1 V setting of the measuring dials. Table 3-3 is provided as an example calibration sheet.

Use the circuit arrangement shown in Fig. 3-4. Set the standard cell dial to 1.017500 and the measuring dials to the same voltage with corrections for the second and third dials, (Dial 1 is assumed to have zero error at the 10th step). Turn the standard cell selector switch to SCX and the dials of the external potentiometer to approximately 1.0175 V. Obtain a balance between the external potentiometer and the standard cell circuit by adjustment of the dials of the external potentiometer or by adjustment of the current in either potentiometer with the REF key 4 depressed.

Release the REF key 4, press the TEST key 4 and adjust the measuring dials for balance. The amount by which the dials must be moved or the amount of the galvanometer deflection (converted to voltage by comparison with one step of Dial 4) gives the error in agreement between the 1.0175 setting of the SC dial and the measuring dials.

For inclusion in the EMF equation in Para. 6 of this section, this microvolt error should strictly be converted to proportional parts by dividing by 1.0175. This produces a change of less than 2% in the error voltage and is unlikely to have any significance whatever. For a disagreement as large as 10 μV between the SC dial and the measuring dials the change in the correction would be 2 parts in 10^7.

Repeat the procedure for dial settings 76, 77, 78, etc. to 1.019x (which corresponds to 1.0200) to obtain corrections C_{s2} for each position of the outer standard cell dial. Make a similar comparison for settings of the fine standard cell dial to obtain corrections C_{s1} at 10 intervals of 10 μV. The sign of the corrections C_{s1} and C_{s2} to be included in $C_{s1} + C_{s2} = C_s$ for the EMF equation is positive if, when equal voltages are appearing at the EMF and SCX terminals the numerical reading of the SC dial is greater than that of the four measuring dials.

d) Range Factor F

When the range of the measuring dials is reduced ten times it is necessary to know the error in the 10:1 ratio between the currents in the measuring dials on the two ranges.

> It is important that the comparison be made between 10 steps of Dial 1 on the x0.1 range and the corrected value for 1 step of Dial 1 on the x1 range.

With the range switch in the x1 position balance the voltage due to one step of Dial 1 against an external potentiometer connected to the EMF terminals. When a suitable balance has been obtained switch to the x0.1 range and turn the measuring dials to 10 times the actual value of the first step of Dial 1. Note the galvanometer deflection or the change in Dial 4 setting required to obtain the second balance. This gives the range factor correction C_f applicable to the x0.1 range.

EXAMPLE:

External potentiometer balanced against dial setting 0.100 000 on x1 range.

Error of 0.1 setting (from Table 2) +4 ppm.

Switch to x0.1 range and dial setting 1.000 004 which gives an accurate 10:1 ratio.

If to obatin the second balance Dial 4 must be changed to give a dial reading of 1.000 007, it has been necessary to increase the dial resistance by 3 ppm to compensate for the fact that the current is low by 3 ppm.

All measurements taken on the x0.1 range will be high by 3 pppm and the range factor correction C_f is therefore -3×10^{-6}. Note that if the error is negative so that a setting less than 1.0 is required on the x0.1 range, it should be obtained with Dial 3 in the -1 position so that Dial 1 may remain at 1.0.

e) Zero Correction

Link the EMF terminals and CK terminals. Turn the four measuring dials to zero and the check switch to READ. Lock down the high sensitivity TEST galvanometer key 4 and adjust the galvanometer amplifier sensitivity so that 1 μV gives a deflection of 100 mm. In this low resistance circuit the galvanometer sensitivity will be so high that it may be necessary to switch to the 1/10 range on the secondary galvanometer.

Any residual emf which may be present in the measuring circuit with the dials set to zero may be due to thermal emf's which vary with temperature or due to an actual error in the potentiometer zero which may be expected to be constant. Additionally, there may be thermal emf's in the galvanometer. These three sources of emf can be separated and evaluated by disconnection of the 6 V battery and reversal of the galvanometer but in the use of the potentiometer it is necessary only to know the sum of the true zero error and internal thermal emf's.

Having obtained a steady deflection with the measuring dials set to zero and the correct galvanometer sensitivity, reverse the galvanometer by pressing TEST key 5. The change in deflection on reversal represents twice the potentiometer zero error. Compare the polarity of the original deflection with the polarity of the deflection due to one step of Dial 4. The zero correction C_0^1 or $C_0^{0.1}$ (for the x1 and x0.1 ranges) has the same sign as the zero error.

f) EMF Equation

The voltage E at the EMF terminals may be expressed by the equation:

$$E = F\ (1 + C_s + C_f)\ \ (D_1 + D_2 + D_3 + D_4 + C_1 + C_2 + C_3 + C_4) + C_0^F$$

where,

F is the range factor x1 or x01,

C_s is the standard cell dial correction consisting of C_{s1} and C_{s2} and is in proportional parts. This correction is zero if the potentiometer is standardized by connecting the standard cell to the EMF terminals and balancing the known standard cell voltage against the corrected setting of the four measuring dials.

C_f is the range factor correction for the x0.1 range in proportional parts and is zero on the x1 range.

D_1, D_2, D_3 and D_4 are the dial readings for the four measuring dials and C_1, C_2, C_3 and C_4 are the corrections for these settings on the four dials in microvolts.

C_0^f is the zero correction for the x1 or x0.1 range in volts.

TABLE 3-1

EXAMPLE POTENTIOMETER CALIBRATION SHEET

Model No. ______________ Serial No. ________________

Temperature ___________°C Date ______________________

Setting	9975 Bridge Dial Setting	Correction in μV
Dial I		
0.0000	0000000	0 μV
0.1000	0010000	0
0.2000	0020001	-10 μV
0.3		
0.4		
0.5		
0.6		
0.7		
0.8		
0.9		
1.0	0100000	0 μV
1.1		
1.2	0120002	-20 μV
1.3		
1.4		
1.5		
Dial 2		
0.00	0000000	0 μV
0.01	0001000	
0.02	0002001	-10 μV
0.03		
0.04		
0.05		
0.06		
0.07		
0.08		
0.09		
0.10	0010001	-10 μV
Dial 3		
0.000		
0.001		
0.002		
0.003		
0.004		
0.005		
0.006		
0.007		
0.008		
0.009		
0.010		

Table 3-2

Example of linearity computation for Dial I

Coil No. (x)	Galvanometer deflection in mm due to difference between coil and reference (Dial II total) (ΔG_{x1}) (+when Dial I coil is greater than Dial II total)	Difference between each individual difference and the average difference ($G_{x1} - \overline{\Delta G_1}$)	Deviation from linearity (Algebraic sum) in mm deflection (D_{n1})	Deviation in μV ($\frac{mm}{100}$)
1	+20	+40	+40	+0.40
2	+30	+50	+90	+0.90
3	-50	-30	+60	+0.60
4	-70	-50	+10	+0.10
5	-90	-70	-60	-0.60
6	-35	-15	-75	-0.75
7	+25	+45	-30	-0.30
8	-60	-40	-70	-0.70
9	-10	+10	-60	-0.60
10	+40	+60	0	0
Total	-200			
Average difference	$\overline{\Delta G_1} = -20$			
11	+35	+55	+55	+0.55
12	+15	+35	+90	+0.90
13	-40	-20	+70	+0.70
14	+10	+30	+100	+1.00
15	-20	0	+100	+1.00
16	-35	-15	+85	+0.85
17	-25	-5	+80	+8.80
18	+25	+45	+125	+1.25
19	-70	-50	+75	+0.75
20	-40	-20	+55	+0.55

Galvanometer sensitivity = 100 mm/μV

TABLE 3-3

EXAMPLE STANDARD CELL DIAL CALIBRATION SHEET

Measure Dial Setting	Standard Cell Dial Setting	9975	Correction in μV
1.01800	1.01800	01018001	
1.01900	1.01900	01019002	
1.0200	1.02000	0102000	

RANGE

Range	Measure Dial Setting	9975 Bridge Dial Setting	Range Correction
X1	0.10000	0010000	0
X0.1	1.0000	0010000	0
	OR		
X1	1.00000	010000	0
X0.1	1.00000	0010000	0

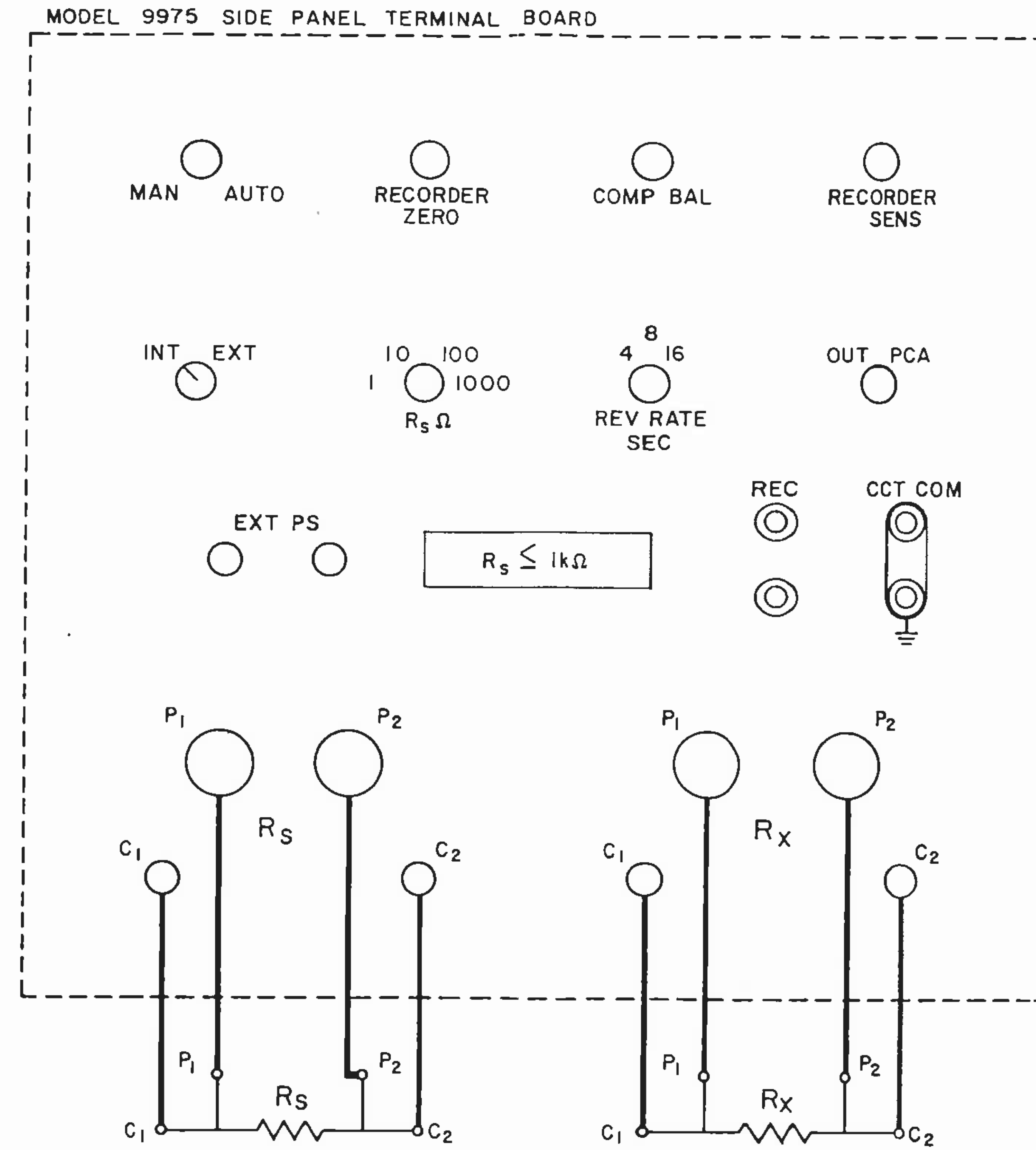


FIG. 3-1
MODEL 9975
FOUR-TERMINAL MEASUREMENT
CONNECTIONS

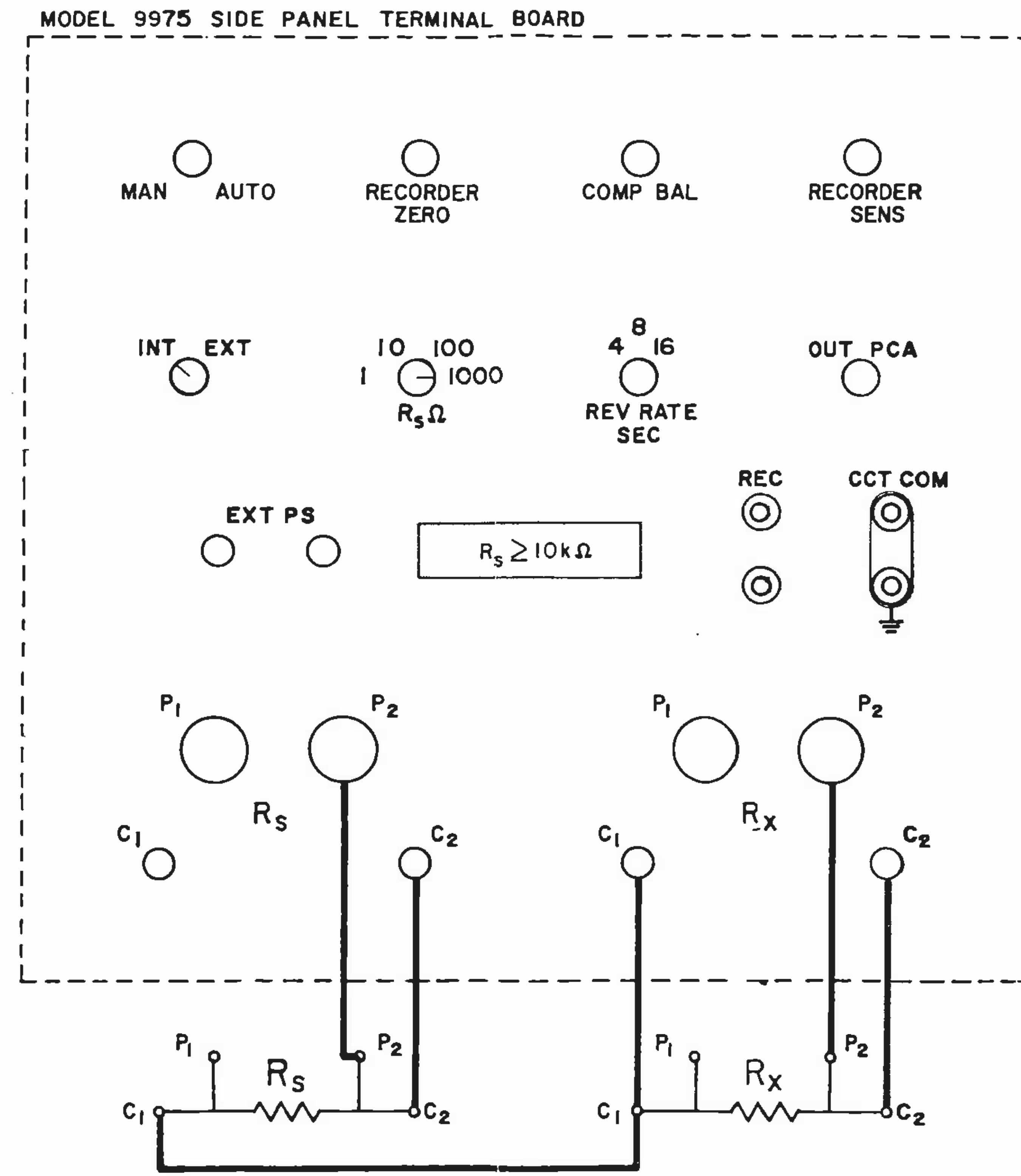
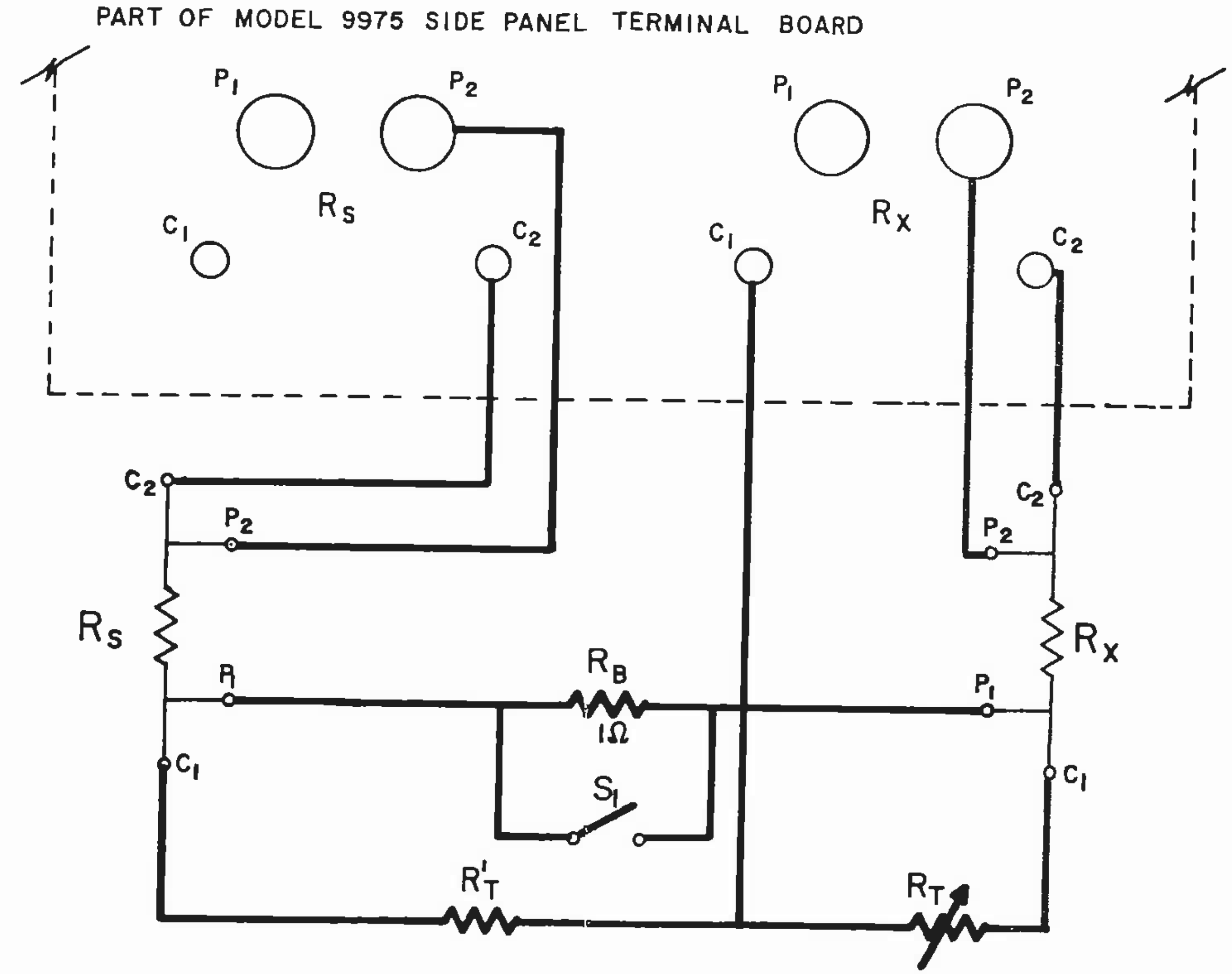


FIG. 3-2
MODEL 9975
TWO TERMINAL MEASUREMENT
CONNECTIONS



NOTES: 1) $R'_T = 0{\cdot}01\ R_S$ OR LESS, R_T IS DERIVED FROM THE RATIO $\frac{R_X}{R_S} = \frac{R_T}{R'_T}$

2) MODE PLUG IS INSERTED WITH RANGE $R_S \geq 10\,k\Omega$ FACING UP

FIG. 3-3
MODEL 9975
FOUR TERMINAL MEASUREMENT FOR
VALUES OF 10K OHMS OR GREATER

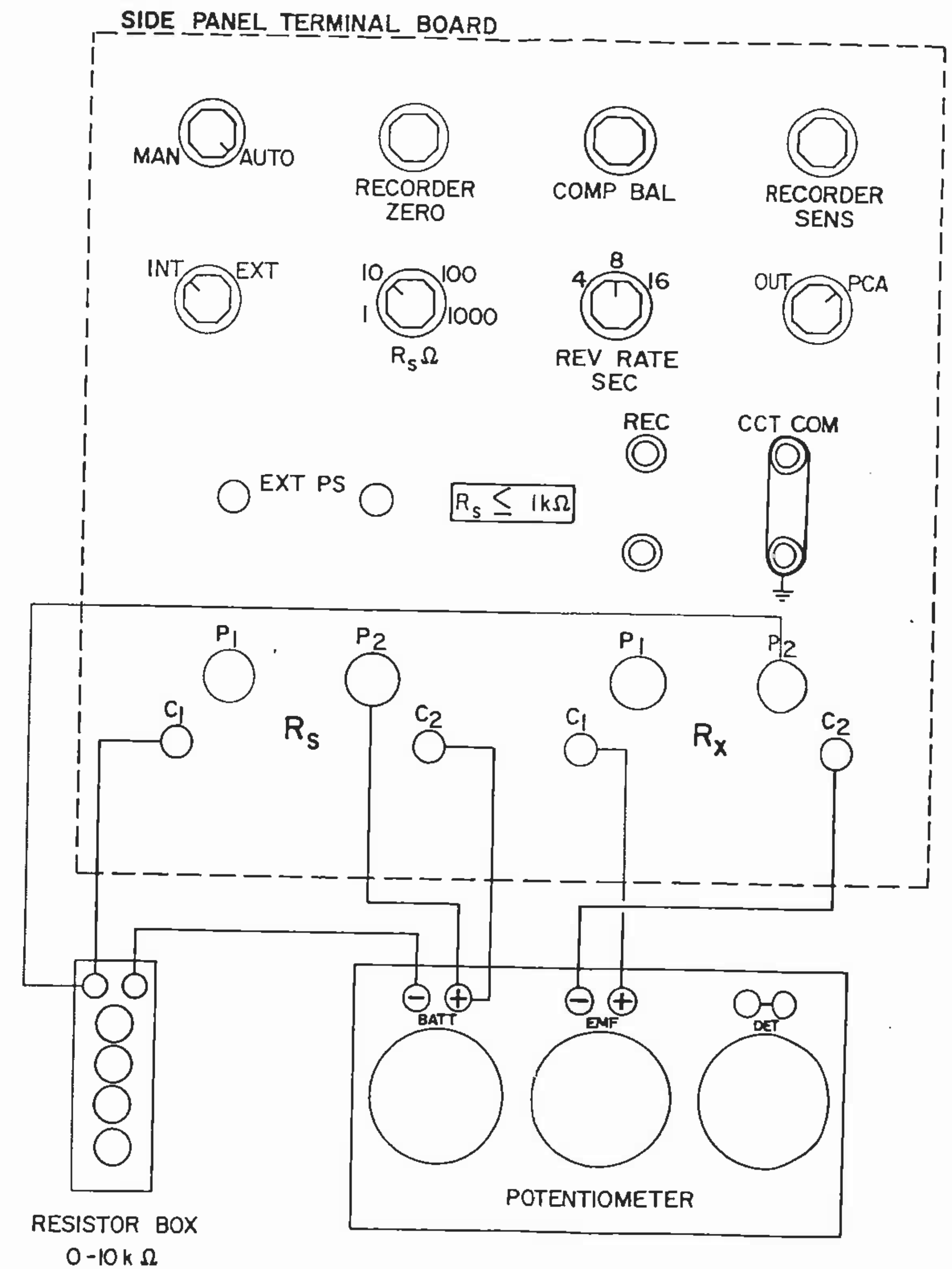


FIG. 3-4
MODEL 9975
POTENTIOMETER CALIBRATION
CONNECTIONS