INSTRUCTION MANUAL

TYPE 1644-A

MEGOHM BRIDGE

1644-A

GENERAL RADIO COMPANY

C

INSTRUCTION MANUAL

TYPE 1644-A

MEGOHM BRIDGE

Form 1644-0100-C
November, 1967

GENERAL RADIO COMPANY
WEST CONCORD, MASSACHUSETTS, USA

SPECIFICATIONS

Resistance Range: 1 kΩ to 1000 TΩ (10^3 to 10^{15} Ω) in ten ranges.

Accuracy: 10^3 Ω to 10^{10} Ω, ±1%. After self-calibration: 10^{10} to 10^{12} Ω, ±1%*; 10^{13} Ω, ±2%; 10^{14} Ω, ±10%; 10^{15} Ω, ± one scale division.

Test Voltage: Voltage accuracy is ±3% ± 0.5 V.

Fixed Voltages	10	20	50	100	200	500	1000	V
Minimum Unknown R	1	3	7	20	50	150	500	kΩ

Short-Circuit Current: <15 mA, 10–50 V; <10 mA, 100–1000 V.

ΔR% Dial: ±5% range; accurate to ±0.2% or, for small changes, to ±0.1%.

* At high voltages; 1% accuracy is obtainable at 10 V up to 10^{11} Ω; see above.

Minimum Test Voltage for 1% Resolution: for approx 1-mm meter deflection

Multiplier Setting	*Max R_x*	*Volts*
100 G or less	10^{11}	10
100 G	10^{12}	100
1 T	10^{13}	200

Power Required: 105 to 125 or 210 to 250 V, 50 to 60 c/s, 13 W.

Mechanical Data: Flip-Tilt Case

Model	*Width*		*Height*		*Depth*		*Net Wt*		*Ship Wt*	
	in	*mm*	*in*	*mm*	*in*	*mm*	*lb*	*kg*	*lb*	*kg*
*Portable**	12¾	325	12½	320	7¾	200	18	8.5	29	13.5
Rack	19	485	12¼	315	5†	130	19	9.0	31	14.5

* Dimensions with case closed and including handle. † Behind panel.

See also *General Radio Experimenter*, July 1964.

US Patent Numbers D 187,740 and 2,966,257.

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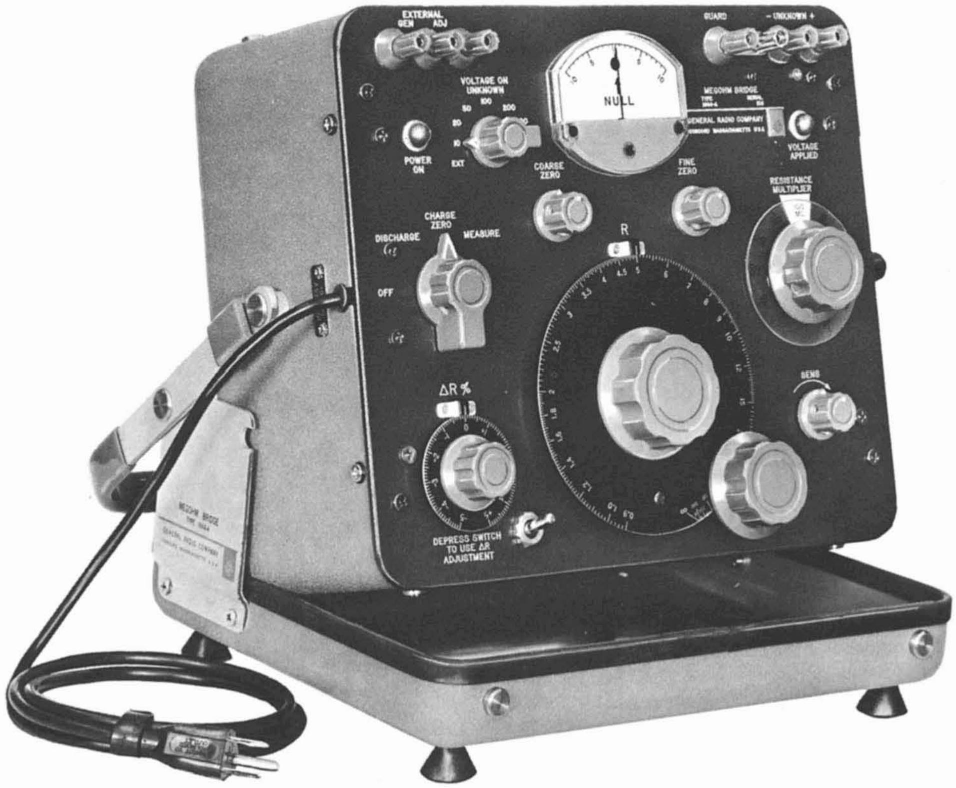


Figure 1-1. The Type 1644-A Megohm Bridge. The convenient Flip-Tilt case provides protection during transport and storage and holds open at any convenient viewing angle.

SECTION 1

INTRODUCTION

WARNING

High voltage may be present at any of the red binding posts, depending on the switch settings. Although the current available from the instrument itself is not dangerous under most conditions, lethal energy may be stored in a capacitance connected to the instrument. ALWAYS SET THE FUNCTION SWITCH TO DISCHARGE BEFORE CONNECTING OR DISCONNECTING THE UNKNOWN COMPONENTS.

1.1 PURPOSE.

The Type 1644-A Megohm Bridge (Figure 1-1) measures resistance from 10^3 to 10^{15} ohms. It is useful for measurements of resistors, of insulation resistance on components and machinery, for resistivity tests on samples of insulating material, and for leakage-resistance measurements on capacitors. The vernier (ΔR%) dial permits accurate measurements of voltage and temperature coefficient of resistance. The voltage applied to the unknown may be set from 10 volts to 1000 volts.

1.2 CONTROLS AND CONNECTORS.

Table 1-1 (on page 2) lists the controls and connectors on the panel and sides of the Type 1644-A Megohm Bridge.

Low-thermal-emf binding posts are used for the GUARD, ground, and UNKNOWN terminals. The critical parts of these binding posts are made of gold-plated copper, designed to minimize spurious dc signals caused by thermal disturbances. They are particularly useful in the presence of low-level signals such as those encountered when a bridge is at or near balance.

1.3 SYMBOLS.

The following abbreviations are on the RESISTANCE MULTIPLIER dial of the Type 1644-A Megohm Bridge:

$1\ k\Omega = 10^3\ \Omega$

$1\ M\Omega = 10^6\ \Omega = 10^3\ k\Omega$

$1\ G\Omega = 10^9\ \Omega = 10^6\ k\Omega = 10^3\ M\Omega$

$1\ T\Omega = 10^{12}\ \Omega = 10^9\ k\Omega = 10^6\ M\Omega = 10^3\ G\Omega$

TABLE 1-1
CONTROLS AND CONNECTORS

Name	*Type*	*Function*
Function	5-position rotary control	Turns instrument on, selects DISCHARGE, CHARGE-ZERO, or MEASURE function. (See paragraph 2.2.)
COARSE ZERO	Continous rotary control	For coarse zero adjustment of detector.
FINE ZERO	Continous rotary control	For sensitive zero adjustment of detector.
VOLTAGE ON UNKNOWN	8-position rotary control	Selects magnitude of internal voltage applied to the unknown or connects an external voltage source. (See paragraph 2.2.)
RESISTANCE MULTIPLIER	10-position rotary control	Selects the measurement range.
R	Continous rotary control with dial	Balances bridge.
SENSITIVITY	Continous rotary control	Adjusts the sensitivity of the detector circuit. (See paragraph 2.4.)
ΔR%	Spring return switch	Inserts ΔR% adjustment in the measurement circuit. (See paragraph 2.4.)
	Continous rotary control with dial	Balances bridge over ±5% range. (See paragraphs 3.6, 3.7, and 3.8.)
- UNKNOWN +	Pair of insulated binding posts	For connection of component to be measured.
Ground	Uninsulated binding post	Ground connection to instrument chassis. (See paragraph 2.1.4.)
GUARD	Insulated binding post	For connection to points to be guarded, such as shields of leads. (See paragraph 3.4.)
EXT GEN	Pair of insulated binding posts	For connection of an external voltage supply. (See paragraph 3.10.)
EXT ADJ	Pair of insulated binding posts	For connection of a resistor to adjust the voltage applied to the unknown to values between those supplied. (See paragraph 3.9.)

SECTION 2

OPERATING PROCEDURE

2.1 INSTALLATION.

2.1.1 OPENING AND TILTING THE CABINET.

The directions for opening the Type 1644-A are given on the handle support of the instrument. Once open, the instrument can be tilted to any convenient angle, as shown in Figure 1-1. The angle should be chosen to give the most comfortable access to the knobs and the best view of the meter and dials.

The instrument may be locked fully open by the same slide pins that are used to lock the instrument closed. Thus, the instrument can be carried in the open position with the cover firmly in place.

The cover forms a convenient storage place for the instruction manual and for any test data that should be kept with the instrument.

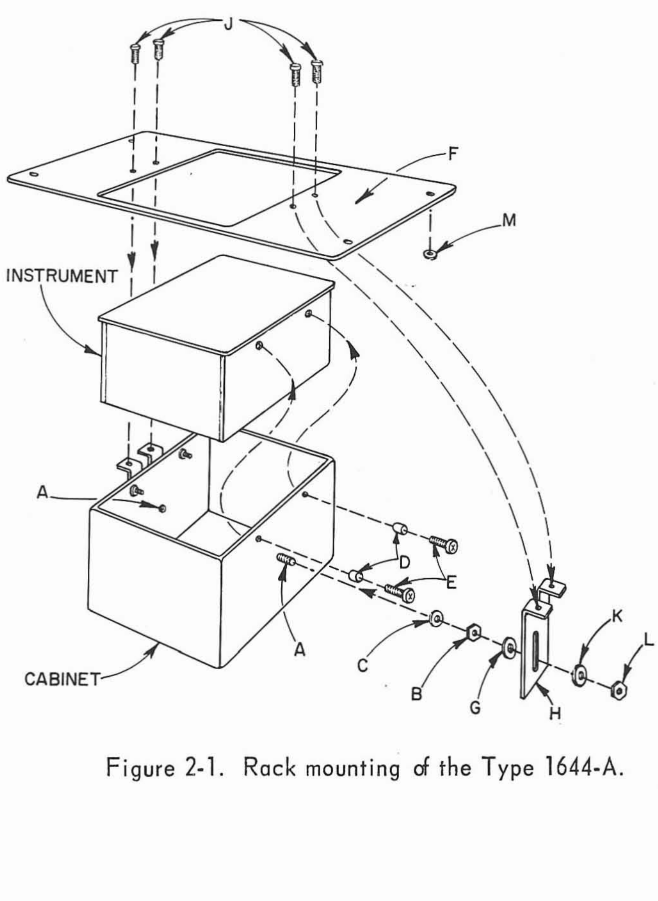


Figure 2-1. Rack mounting of the Type 1644-A.

2.1.2 RACK MOUNTING.

The Type 1644-A can be mounted in a relay rack by means of a Type 0480-9756 Adaptor Set. The procedure is as follows (see Figure 2-1):

a. Open the instrument to its horizontal position (fully open).
b. Remove the No. 10-32 screws with resilient washers that hold the instrument in the cabinet. These screws are on the sides of the instrument near the panel edge.
c. Lift the instrument out of the cabinet.
d. From the inside of the cabinet, remove the two pivot screws.
e. Lift the cabinet off the handle and cover assembly.
f. In place of the pivot screws, insert the two 3/4-inch screws (A) supplied in the hardware set with the adaptor panel. Place a nut (B) and lockwasher (C) on each screw and secure.
g. Replace the instrument in the cabinet. Put a 3/16-inch metal spacer (D) on each of the 5/8-inch screws (E) supplied with the hardware set and secure these through the cabinet into the instrument in place of the screws removed in step b.
h. Place the adaptor panel (F) over the instrument and let it rest on the spacers.
i. Put a large flat washer (G) over the projecting screws on each side of the instrument.
j. Put the slot in the bracket (H) over the projecting screws so that the holes in the ell of the bracket line up with the holes in the adaptor panel.
k. Secure each bracket to the panel with 1/2-inch screws (J).
l. Put another flat washer (K) and nut (L) on the projecting side screw and tighten. This secures the bracket to the cabinet.
m. The instrument can now be mounted in a standard 19-inch relay rack. For mounting instruments with 3/16-inch panels, a washer is provided to place between the adaptor panel and the rack at each panel screw, so that the panel will be flush with the panels of heavier units.

2.1.3 CONNECTION TO POWER SUPPLY.

Connect the Type 1644-A to a source of power as indicated by the legend at the input socket at the rear of the instrument, using the power cord provided. While instruments are normally supplied for 115-volt operation, the power transformer can be reconnected for 230-volt service (see schematic diagram, Figure 5-7). When changing connections, be sure to replace line fuses with those of current rating for the new input voltage (refer to Parts List). Appropriate measures should be taken so that the legend indicates the new input voltage. On instruments changed from 250 to 115 volts, order a 115-volt nameplate (5540-0500). For instrument changes to 230 volts, order a 230-volt nameplate (5540-1164).

2.1.4 GROUNDING THE INSTRUMENT.

If the power cord does not have a ground wire (third wire), it is wise to connect the chassis ground terminal (J4) to a good ground. This is particularly important for very high resistance measurements where lack of a ground can cause difficulty. It is also advisable to ground the panels of nearby instruments to avoid electrostatic coupling to the detector.

2.1.5 CONNECTION OF GROUNDING LINK.

The grounding link, captive to the uninsulated (chassis) binding post, may be connected either to the GUARD terminal or to the - UNKNOWN terminal as shown in Figure 2-2. The ground-to-GUARD connection is preferable if the unknown is a small, separate component, or if it is mounted in an enclosure that should be guarded. (Refer to paragraph 3.4). However, if one terminal of the unknown must be grounded or is a large exposed surface, this terminal should be connected to the - UNKNOWN binding post and the grounding link connected between the - UNKNOWN post and the chassis ground post.

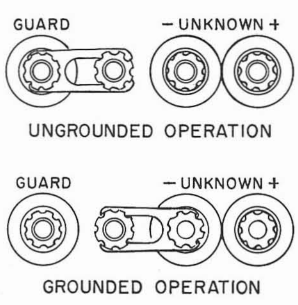


Figure 2-2. Grounding link connected to the GUARD terminal (top) and the – UNKNOWN terminal (bottom).

2.2 BASIC MEASUREMENT PROCEDURE.

Many types of measurements under various conditions can be made with this instrument. The following is the basic measurement procedure. References are given to paragraphs that discuss each step more fully or consider alternate procedures or special measurements.

WARNING

This instrument provides a high test voltage. The current is limited to a value that is safe for most persons, but it can be dangerous to those with poor hearts and is painful to all. Particular care should be used in the measurement of capacitor leakage, because LETHAL ENERGY may be stored in the unknown capacitor. ALWAYS SET THE FUNCTION SWITCH TO DISCHARGE BEFORE CONNECTING OR DISCONNECTING THE UNKNOWN COMPONENT.

Proceed as follows:

a. Turn the function switch from OFF to DISCHARGE. Allow a minute or two for warmup.
b. Select the desired test voltage with the VOLTAGE ON UNKNOWN switch. (Refer to paragraph 3.9 for external adjustment of the voltage supply and to paragraph 3.10 for use of an external supply.) The minimum resistance that can be measured at each test voltage is given in Table 2-1. Avoid changing the test voltage when the function switch is in the MEASURE position as this will severely overload the detector amplifier which will then require several minutes to recover.
c. Connect the component to the UNKNOWN terminals. Note polarity. (For grounding-link connection, refer to paragraph 2.1.5; for remote measurements, refer to paragraph 3.5.)
d. Set the RESISTANCE MULTIPLIER switch to the desired range (if it is known).
e. Set the SENSITIVITY control fully clockwise for measurements either on the highest ranges or at low voltages. Set it halfway (arrow up) for other measurements. (Refer to paragraph 2.4.)
f. Set the function switch to CHARGE-ZERO and adjust the COARSE ZERO and then the FINE ZERO controls for a meter zero (null).

TABLE 2-1

MINIMUM MEASUREMENT RANGES

Test Voltage	*Minimum R_X*
10 v	1 kΩ
20 v	3 kΩ
50 v	7 kΩ
100 v	20 kΩ
200 v	50 kΩ
500 v	150 kΩ
1000 v	500 kΩ

g. Set the function switch to MEASURE and adjust the main R dial (and the RESISTANCE MULTIPLIER switch, if necessary) to give a null (meter zero). A deflection to the right indicates that the dial setting should be increased. For maximum accuracy on the highest ranges, rezero the meter (step f) when the RESISTANCE MULTIPLIER switch is reset.

h. The value of the unknown resistance is the dial reading at null indication multiplied by the quantity indicated on the RESISTANCE MULTIPLIER dial. (For accuracy of measurement, refer to paragraph 2.3.)

i. Return the function switch to DISCHARGE and then remove the component measured.

2.3 ACCURACY.

The bridge accuracy is ±1% between readings of 0.9 and 10 on the main R dial. Above a reading of 10, the accuracy tolerance increases proportionally so that it is ±2% at 20 and ±10% at 100. An indication of 1000 can be distinguished from 500 or ∞. There are three exceptions to this:

a. the three highest ranges will not necessarily be 1% accurate if they have not been recently calibrated or if the ambient temperature has changed appreciably (refer to paragraph 5.4.1);

b. reduced sensitivity reduces the accuracy on the two highest ranges if less than 100 volts is applied to the unknown;

c. on the 1-TΩ multiplier range, the accuracy is 2%.

For greatest accuracy, particularly at high resistance values, be sure that the component to be measured is not shunted by insulating materials with resistance low enough to introduce error. (See also paragraphs 3.11 and 3.12.)

2.4 SENSITIVITY.

The high sensitivity of the internal dc null detector (approximately 300 μvolts/division near zero) permits accurate measurements with low applied voltages, for measurement on the high ranges, and for measurements of small differences with the ΔR% dial. For other measurements less sensitivity keeps the pointer on scale over a greater adjustment range and does not show the amplifier drift and the discontinuous meter jumps due to finite resolution of the main R dial. Balances to a precision well beyond the bridge accuracy offer no advantage, and take more time.

For maximum sensitivity, the measurement should be made on the highest range possible. The expression for the bridge output voltage is:

$$E_O = \frac{E_{IN}\,(\delta\%)\,M}{(\text{Dial Reading})\,(10^4)}$$

where δ is the unbalance in percent
M is unity except on the 100-GΩ and 1-TΩ ranges where it is 0.1 and 0.05, respectively.

Thus, a low dial reading increases sensitivity. With careful zeroing, voltages as low as 50 μvolts can be detected. Therefore, with 10 volts applied and a dial indication of 1, resolution is 0.05% on all but the two highest ranges.

Note that the meter scale is nonlinear. This allows a wide dynamic range without adjustment of the SENSITIVITY control and still gives high sensitivity near null (zero). Full meter deflection is not possible when the SENSITIVITY control is fully counterclockwise. This low sensitivity is useful for limit measurements on the linear portion of the scale (refer to paragraph 3.13).

SECTION 3

APPLICATIONS

3.1 RESISTOR MEASUREMENT.

The EIA standard test voltage for fixed composition resistors, film resistors, and wire-wound resistors is 100 volts for values above 100 kΩ, 10 volts between 1 kΩ and 9.9 kΩ, and 30 volts between 10 kΩ and 99 kΩ. (To obtain a 30-volt test voltage with the internal supply of the Type 1644-A, connect a 20-kΩ resistor between the EXTERNAL ADJ terminals and set the VOLTAGE ON UNKNOWN switch to 50, as described in paragraph 3.9.)

For many types of resistors, the value measured at some other voltage may be considerably different from that at the standard test voltage, due to a large voltage coefficient (refer to paragraph 3.7). In many cases, measurements at the voltage at which the resistor will be used are helpful.

Resistors as low as 1 kΩ may be measured easily to 1% on the Type 1644-A Megohm Bridge. More accurate substitution measurements are possible using the ΔR% dial if an external standard is available (refer to paragraph 3.6).

If the resistors to be measured are small, separate units, they should be measured ungrounded with the grounding link connected between the GUARD and ground terminals. Resistors may be measured rapidly in a production-line setup using the procedure described in paragraph 3.13.

3.2 INSULATION TESTING.

3.2.1 COMPONENT, MACHINERY, AND SWITCHGEAR INSULATION.

Insulation testing on a wide variety of apparatus is possible with the Megohm Bridge, but different types of devices require different precautions. When one terminal is the case of the apparatus, or is a large, exposed surface, this terminal should be grounded, for both accuracy and safety, by connection to the - UNKNOWN terminal with the link connected between this terminal and the chassis ground terminal (refer to paragraph 2.1.5). When the device to be measured includes polarized rectifiers or capacitors, the sign of the applied voltage must be correct. Note that the +UNKNOWN terminal may be grounded with an external lead if necessary (disconnect the link from both adjacent terminals), but errors may occur when this connection is used to measure resistances above approximately 100 MΩ.

The connection of leads to large equipment also requires some care, and the problems of a large capacitive time constant and dielectric absorption may also be present (refer to paragraphs 3.3.3 and 3.2.3, respectively).

3.2.2 TEST SAMPLES.

This bridge is well suited for resistance measurements on samples of insulating material as described by ASTM Standard D257. This standard describes in detail the techniques of both surface- and volume-resistivity measurements. Diagrams of several electrode configurations, applicable formulas, and suggested precautions are given.

The most commonly used electrode arrangement for solid materials is that shown in Figure 3-1. This configuration may be used for either surface- or volume-resistivity measurements, but for surface

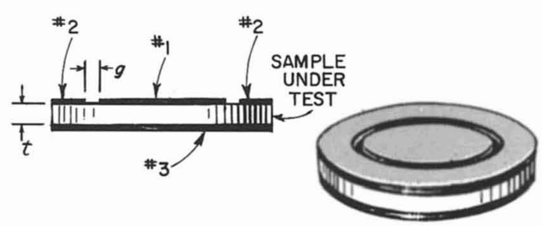


Figure 3-1. Electrode arrangement for insulation testing of solid materials.

measurements the gap, g, should be approximately twice the sample thickness, t. The connection of the electrodes to the bridge depend on the quantity to be measured as shown in Table 3-1. The ASTM Standard also describes other sample holders for both liquid and solid materials.

Standard voltages for this test are 100, 250, 500, 1000, 2500, 5000, 10,000, and 15,000 volts, of which the most common are 100 and 500 volts. The Type 1644-A Megohm Bridge will supply 100, 500, and 1000 volts directly, and 250 volts when an external resistor is used (235 kilohms when the VOLTAGE ON UNKNOWN switch set to 500; refer to paragraph 3.9).

3.2.3 DIELECTRIC ABSORPTION.

The apparent resistance of an insulator is the ratio of voltage applied to the current flowing through it. Unfortunately, the current is time-dependent and the true insulation resistance is the limiting, steady-state value.

The time-dependent currents are the simple charging current that depends on the capacitance of the sample and on the resistance of the voltage source, and the current due to dielectric absorption. The simple charging current is negligible after the function switch has been in the CHARGE-ZERO position for a very short time (except when large capacitors are tested; refer to paragraph 3.3.2). However, the absorption current may be appreciable for minutes, hours, or in rare cases, even days. This dielectric absorption is the result of dipole and interfacial polarization and ion mobility and is particularly large for laminated materials.

A measure of the dielectric absorption is the polarization index, which is defined as the ratio of the resistance measured after 10 minutes to that measured after one minute of electrification. Often, a single measurement after one minute is called the insulation resistance. Although this value may be far from the true resistance for some insulators, it is useful for comparison of measurements on materials with relatively low absorption.

3.2.4 MEASUREMENT PROCEDURE.

The procedure for measurement of insulation resistance is the same as the basic measurement procedure described in paragraph 2.2 except for charging and dielectric-absorption considerations.

The function switch should be left in the CHARGE position long enough to charge the sample. The time required for simple charging is usually well under one second except for capacitors or extremely large samples (refer to paragraph 3.3.2).

When dielectric absorption is present, the main R dial must be continually adjusted to maintain a balance. To measure resistance at any given moment, simply stop adjusting the dial at the desired time. Thus, it is not necessary to make a reading on a moving dial (see paragraph 3.3.4).

3.3 LEAKAGE RESISTANCE OF CAPACITORS.

3.3.1 GENERAL.

WARNING

The energy stored in a capacitor may be LETHAL. The function switch should be set to discharge before you connect or disconnect the capacitor to be measured. DO NOT TOUCH THE CAPACITOR TERMINALS WHILE THE "VOLTAGE APPLIED" LIGHT IS ON.

The procedure for measurements of the leakage resistance on capacitors is basically the same as that for resistors except that the several effects described in the following paragraphs become more important as the capacitance and leakage resistance become greater.

3.3.2 CHARGING TIME.

The function switch should be left in the CHARGE position long enough to ensure that the capacitor is completely charged. If it is not fully charged, the charging current will reduce the measured value of leakage resistance, and the charging time constant in the MEASURE position can become quite large (refer to paragraph 3.3.3).

The charging time is limited mainly by the maximum current of about 8 ma that can be drawn from the power supply. Charging time is, therefore:

$$t = \frac{CV}{I} = \frac{CV}{8\ \text{ma}}$$

$$t = \frac{(C\ \text{in}\ \mu f)\ (V\ \text{in volts})}{8} \times 10^{-3}\ \text{sec}$$

This time is usually less than 1 second except for large electrolytic capacitance units. The current is somewhat greater than 8 ma at 50 volts or less.

TABLE 3-1

ELECTRODE CONNECTIONS FOR INSULATION TESTING

	For Volume Resistivity		*For Surface Resistivity*	
Electrode	*Function*	*Connect to*	*Function*	*Connect to*
#1	Guarded Electrode	+ UNKNOWN	Guarded Electrode	+ UNKNOWN
#2	Guard Electrode	GUARD	Unguarded Electrode	- UNKNOWN
#3	Unguarded Electrode	- UNKNOWN	Guard Electrode	GUARD

3.3.3 TIME-CONSTANT EFFECTS.

The time constant of the bridge-capacitor system for the MEASURE function is the product of the capacitance measured and the effective bridge output resistance, R_O, given in Table 3-2. If this product is greater than about 0.1 second, the bridge will appear to be sluggish and the user may adjust the bridge beyond balance before the null-detector deflection reverses sign. Adjustment will be easier, although the total balance time will not be less, if you wait for a period of several time constants between balances.

When the function switch is set to CHARGE, the capacitor being tested is charged to a voltage that is dependent upon the position of the R dial. This voltage may differ from the final capacitor voltage by as much as 1% of the applied voltage. The final charging or discharging must be done with the function switch set to MEASURE so the time required is independent of further adjustment of the R dial.

In extreme cases, this time constant may be so long that it is impractical to wait. An alternate procedure described below makes use of the fact that the bridge is initially at balance when the function switch is rotated from CHARGE-ZERO to MEASURE, and then drifts slowly off null. The direction of the null-detector drift indicates the direction that the main R dial should be rotated to obtain the final balance.

The alternate balance procedure for measurement of capacitors with long time constants is given below:

a. Set the function switch to CHARGE and allow time for full charging (refer to paragraph 3.3.2).
b. Rotate the function switch to MEASURE and note the direction of the drift from zero (discount the small, fast deflection caused switching phenomena).
c. Make a large adjustment in the main R dial in the direction indicated by the null detector (i.e., a right-hand meter deflection indicates that the dial reading should be increased).
d. Return the function switch to CHARGE and repeat the above steps until a balance is reached.

Note that the time constant is reduced if the measurement is made on a lower range (i.e. with a dial reading above 10) so that a lower-valued standard is used. This, of course, gives reduced accuracy, but high accuracy is rarely required for this type of measurement. Also, use reduced detector sensitivity, at least to get a rough balance.

3.3.4 DIELECTRIC ABSORPTION.

Dielectric absorption is present to some degree in all capacitors, but is particularly pronounced in some impregnated paper types and is lowest in unimpregnated polystyrene, polyethylene, and Teflon® units. The effect of dielectric absorption is discussed in paragraph 3.2.3. For measurements on most types of capacitors, electrification for two minutes is common practice.

TABLE 3-2
BRIDGE OUTPUT RESISTANCE

Range	R_S *Value*	R_S *Type*	R_O
1 kΩ	10 Ω	Wire-wound	5 kΩ†
10 kΩ	100 Ω	Wire-wound	5 kΩ†
100 kΩ	1 kΩ	Wire-wound	5 kΩ†
1 MΩ	10 kΩ	Wire-wound	15 kΩ†
10 MΩ	100 kΩ	Wire-wound	100 kΩ
100 MΩ	1 MΩ	Metal-film	1 MΩ
1 GΩ	10 MΩ	Metal-film	10 MΩ
10 GΩ	100 MΩ	Carbon-film**	100 MΩ
100 GΩ	1000 MΩ*	Carbon-film**	100 MΩ
1 TΩ	10,000 MΩ*	Carbon-film**	500 MΩ

* T network, effective value given, refer to paragraph 3.6.3.
** Adjustable, refer to paragraph 5.4.1.
† Depends on setting of R dial.

When both appreciable dielectric absorption and a long time constant are present, measurements become quite difficult because it is hard to tell which effect causes the meter drift. In such cases, it is often useful to make limit measurements. Set the main R dial and the RESISTANCE MULTIPLIER switch to the acceptance limit and wait to see if the meter deflects to the left, which indicates that the resistance is below the limit. A time limit should be included in the specifications for such a limit measurement.

3.3.5 ERRATIC DEFLECTIONS CAUSED BY LINE TRANSIENTS.

When leakage resistance of capacitors is measured on the higher resistance ranges, the test-voltage supply must be extremely well regulated to avoid erratic meter deflections due to power-line transients. The capacitor being measured couples the high voltage supply to the detector so that rapid variations of less than 1 millivolt on the high voltage supply are easily seen. The regulation of the internal supply of the Type 1644-A is very good, but in extreme cases, when the power-line voltage is very noisy, an external battery should be used as the test-voltage supply (refer to paragraph 3.10).

3.3.6 SMALL VOLTAGE CHANGES DURING CAPACITANCE MEASUREMENTS.

In the measurement of high-capacitance, very-low-leakage capacitors (particularly polystyrene units), a small drift in the bridge voltage supply will cause an error in leakage measurements. This is particularly noticeable when the bridge indication is greater than infinity. This condition occurs when the voltage rate-of-change multiplied by the time constant ($C_{unknown}$ x R_O; see Table 3-2 for values of R_O) is in the order of a few millivolts. It is, therefore, most noticeable for measurements at high voltage and on the high RESISTANCE MULTIPLIER ranges.

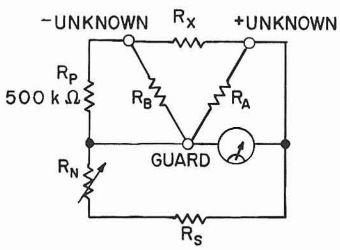


Figure 3-2. Three-terminal resistance measurement.

One source of this difficulty is the drift in the internal supply during warm-up. A warm-up period of one hour is recommended. In extreme cases, an external supply of high stability must be used (refer to paragraph 3.10). Another cause of this difficulty is ambient temperature change which changes both the internal supply voltage and the temperature of the capacitor being measured. If the capacitor has an appreciable temperature coefficient, a capacitor voltage change will result.

3.4 GUARDED (DIRECT) THREE-TERMINAL MEASUREMENTS.

In many cases it is necessary to measure the resistance between two points in the presence of resistance from one or both of these points to a third point (usually ground). This third point can often be guarded to avoid error due to shunting the unknown with the extraneous resistances.

This is shown diagrammatically as a three-terminal resistor in Figure 3-2. Here, R_X is the quantity to be measured (the direct resistance) despite the presence of R_A and R_B. If the junction of R_A and R_B is tied to guard, R_A is across the detector and causes no error, but reduces the sensitivity by the factor $\frac{R_A}{R_O + R_A}$ (see Table 3-2 for values of R_O). The other extraneous resistance, R_B, is across the 500-kΩ resistor, R_P, where it causes an error of more than 1% if R_B is below 50 MΩ. The error due to R_B is approximately $-\frac{R_P}{R_B} \times 100\%$.

The guard may be used whether the GUARD or the - UNKNOWN terminal is grounded. Note however, that if the - UNKNOWN terminal is grounded, the GUARD terminal will be at high potential. Often the terminal to be guarded is a large chassis or case and it is safer to ground the GUARD terminal.

3.5 REMOTE MEASUREMENTS.

Measurements can be made on components that are some distance from the instrument if care is used to prevent leakage between the connecting leads and to avoid shock. A convenient way to do this is to use a shielded cable as shown in Figure 3-3.

The + UNKNOWN terminal should be connected to the center conductor and the shield tied to the GUARD terminal. The lead to the - UNKNOWN terminal need not be shielded, but if it is, its shield should also be tied to GUARD.

The - UNKNOWN lead should be insulated unless this terminal is grounded. All shields tied to GUARD should be insulated if the GUARD terminal is not grounded.

3.6 SUBSTITUTION MEASUREMENTS.

3.6.1 GENERAL.

Substitution (or comparison) measurements can be made with accuracy up to 0.1% by means of the ΔR% dial. Substitution measurements require an external standard that is known to an accuracy substantially better than the desired measurement accuracy. Resistors of high accuracy are not available in the high megohm range but the three-terminal standard described below can be used. If only the differences between resistors are to be determined, and not absolute values, the value of the standard need not be accurately known.

3.6.2 PROCEDURE.

The procedure for a substitution measurement is simply to measure the unknown and then the standard and determine the difference between them. The value for R_x is then:

$$R_x = R_s + R_{xm} - R_{sm}$$

where R_x and R_s are the true values of the unknown and the standard

R_{xm} and R_{sm} are the measured values of the unknown and the standard.

The difference between R_{xm} and R_{sm} can be most accurately determined if this difference is small enough to be within the range of the ΔR% dial. The first balance should be made with the main R dial and then the ΔR% dial. The second balance should be made using only the ΔR% dial (leave the R dial as set). The value of the unknown is then:

$$R_x = R_s \left(1 + \frac{\Delta R\%}{100}\right)$$

Here, ΔR% is the ΔR% dial reading for the unknown minus that for the standard.

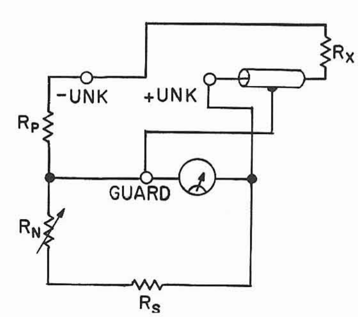


Figure 3-3. Connection for remote measurements.

An alternate scheme may be used if a T network with an adjustable resistor (refer to paragraph 3.6.3) is used as a standard. In this case, the T is used to make the second balance and is adjusted for a null without moving either dial of the bridge. The value of the unknown is calculated from:

$$R_x = R1 + R3 + \frac{(R1)(R3)}{R2} + (0.5\ M\Omega)\frac{R3}{R2}$$

3.6.3 THREE-TERMINAL RESISTANCE STANDARDS.

The T or Y connection of resistors shown in Figure 3-4a is electrically identical to the Δ configuration of Figure 3-4b. This is the familiar Y-Δ transformation. If R2 is small and R1 and R3 are large, the resistance R_Y can be very large. R_Y can be used as a standard and will be very stable and accurate if wire-wound resistors are used for the resistors of the T.

Such a T network should be connected to the bridge as shown in Figure 3-2. Unfortunately, the resistances R_A and R_B shunt the bridge resistor R_P, which causes an error (refer to paragraph 3.4), and shunt the detector, which decreases sensitivity. The loss of sensitivity limits the attainable accuracy at low test voltages (refer to paragraph 3.6.4).

The error caused by the shunt on R_P can be compensated for in the calculation of the resistors of the T. For any desired value of R_Y, the value of R2 should be:

$$R2 = \left(\frac{500\ k\Omega + R1}{R_Y - R1 - R3}\right) R3$$

The lowest value R_Y can have is R1 + R3.

For the most precise measurements, R1 and R3 should be the largest wire-wound units available, and R2 should be a multi-dial decade box. If R1 and R3 are 1-MΩ units, such as General Radio Type 500-X (accuracy of ±0.05%), then the equation for R2 becomes:

$$R2 = \frac{1.5}{R_Y - 2}\ M\Omega$$

where R_Y is in megohms.

If R1 = R3 = 10 MΩ, then:

$$R2 = \frac{105}{R_Y - 20}\ M\Omega$$

Table 3-3 lists the values of R2 for decade values of R1 and R3 from 10 MΩ to 1 TΩ.

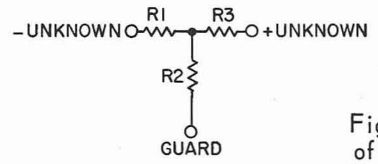


Figure 3-4a. Y configuration of a three-terminal standard.

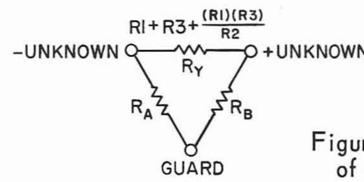


Figure 3-4b. Delta configuration of a three-terminal standard.

3.6.4 ACCURACY AND SENSITIVITY.

The bridge accuracy for substitution measurements using the ΔR% dial is ±0.1% as long as the sensitivity is adequate (refer to paragraph 2.4). However, if the two balances are well within 1 percent of each other, the bridge accuracy can be as good as ±0.02%. Measurements on the main R dial can be made to ±1/4% if the difference is small and the scale is carefully interpolated.

The accuracy of the standard must also be considered in the over-all accuracy determination. To determine the accuracy for the worst case, the tolerance of the standard must be added to the bridge tolerance. When a T network is used, the worst possible tolerance of the T is the sum of the tolerances of the separate resistors if

$$\frac{(R1)(R3)}{R2} \gg R1 + R3$$

When a T standard is used to measure very high values, the sensitivity is generally the limiting factor. The approximate output voltage is:

$$E_O = \frac{(E_{IN})(\delta\%)(M)}{(\text{Dial Reading})(10^4)} \times \frac{R1}{R_O + R1}$$

where δ% is the unbalance in percent

M is unity except on the 100-GΩ and 1-TΩ ranges where it is 0.1 and 0.05, respectively

R_O is given in Table 3-2.

Example:

A 10-GΩ component is measured on the 10-GΩ range.

A T network with 1-MΩ resistors is used.

E_{IN} = 1000 volts.

δ% = 0.1%.

TABLE 3-3

RESISTANCE VALUES FOR T NETWORKS

R_Y, Equivalent Resistance	10 MΩ	100 MΩ	1 GΩ	10 GΩ	100 GΩ	1 TΩ
R2, when R1 = R3 = 1 MΩ	187.5 kΩ	15.306 kΩ	1.5022 kΩ	150.02 Ω	15.000 Ω*	1.5000 Ω*
R2, when R1 = R3 = 10 MΩ		1.3125 MΩ	107.14 kΩ	10.521 kΩ	1.0502 kΩ	105.0 Ω*

* Poor sensitivity

R_O = 100 MΩ (see Table 3-2).

$$E_O = \frac{(1000)\,(0.1)}{(1)\,(10^4)} \times \frac{1\ \text{M}\Omega}{101\ \text{M}\Omega} = 100\ \mu\text{volts.}$$

This would give meter deflections of about 1 mm.

If the arms of the T network were increased to 10 MΩ, the sensitivity would be increased by a factor of 10.

3.7 MEASUREMENT OF VOLTAGE COEFFICIENT.

3.7.1 GENERAL.

The Type 1644-A Megohm Bridge is well suited for the measurement of voltage coefficient because of the high resolution of its ΔR% dial and the wide range of applied voltage.

The voltage coefficient of a resistor is generally defined as:

$$VC = \frac{R1 - R2}{R2\,(V1 - V2)} \times 100\%$$

where V1 > V2
R1 is the resistance at V1
R2 is the resistance at V2
VC is in % per volt.

Any two voltages may be used, but, because the voltage coefficient is not necessarily a constant (i.e., the resistance is not always a linear function of voltage), the voltages used should be specified.

A common practice is to use two voltages differing by a factor of ten to one, in which case the formula reduces to:

$$VC = \frac{\Delta R}{R} \times \frac{1}{0.9\ V} \times 100\%$$

where ΔR is the resistance difference
R is the resistance at the lower voltage
V is the higher voltage.

The EIA Standard RS172 (Fixed Composition Resistors) specifies the use of the rated voltage for V in the above formula.

If the applied voltage is high enough to cause appreciable power dissipation, the measurement should be made quickly to determine the true voltage coefficient and to avoid temperature effects. The EIA specification suggests that the time for measurement (at the higher voltage) be less than 5 seconds.

Most resistors have a negative voltage coefficient (a lower resistance value at higher voltage), except for semiconductor back resistance which has a positive voltage coefficient as long as the voltage is well below the break-down value.

3.7.2 PROCEDURE.

The procedure for voltage-coefficient measurement is as follows:

a. Measure the resistance of the unknown at the lower voltage. For best accuracy use the ΔR% dial as the final balance adjustment, and note the ΔR% dial indication.

b. Change the position of the VOLTAGE ON UNKNOWN switch to the higher voltage and re-zero the bridge with the function switch set to CHARGE-ZERO, if necessary.

c. Balance the bridge with the ΔR% dial only (do not change the setting of the main R dial).

d. The voltage coefficient is:

1) Initial balance made only with R dial:

$$VC = \frac{\Delta R\%\ \text{Dial Reading}}{\text{Voltage Change}}$$

2) Initial balance made using ΔR% dial:

$$VC = \frac{\text{Change in }\Delta R\%\ \text{Dial Reading}}{\text{Voltage Change}}$$

3.8 MEASUREMENT OF TEMPERATURE COEFFICIENT.

3.8.1 GENERAL.

The ΔR% dial allows the precise measurement of temperature coefficient, which is defined as:

$$TC\%/°C = \frac{\Delta R}{R} \times \frac{100\%}{\Delta t}$$

where ΔR is the resistance change between the test temperature and the reference temperature
R is the resistance at the reference temperature
Δt is the temperature change in °C from the reference temperature.

The EIA Standards RS196 (Fixed Film Resistors) and RS172 (Fixed Compensation Resistors) specify that measurements be made at -15°C. The EIA Standard RS229 (Wire-Wound Resistors) specifies measurements at -55°C, +105°C, and +145°C, and a reference temperature of +25°C.

Shielded leads should be used to connect the sample in the temperature chamber to the bridge to avoid pickup and leakage (refer to paragraph 3.5).

3.8.2 PROCEDURE.

The procedure for the measurement of temperature coefficient is as follows:

a. With the resistor in an environment held at 25°C, measure the resistance. For best accuracy use the ΔR% dial as a final balance adjustment. (Standard voltages should be used, refer to paragraph 3.1.) Note the ΔR% dial reading.

b. Change the temperature of the resistor environment to the test temperature and, after stabilization, measure the resistance again, using only the ΔR% dial. (Leave the main R dial set as is.)

c. The temperature coefficient is:

$$TC = \frac{\text{Change in }\Delta R\%\ \text{Dial Reading}}{\text{Temperature Difference in °C}}$$

3.9 EXTERNAL ADJUSTMENT OF THE INTERNAL TEST VOLTAGE.

Any test voltage between 10 volts and 1000 volts may be obtained by connection of the proper resistor between the EXTERNAL ADJ terminals.

WARNING

Voltage is present on the EXTERNAL ADJ terminals unless the VOLTAGE ON UNKNOWN switch is set to EXT or the instrument is turned off.

To adjust the internal test voltage proceed as follows:

a. Set the VOLTAGE ON UNKNOWN switch to EXT and connect a resistor of value R between the EXTERNAL ADJ terminals:

$$R = \frac{500\,(V_S - 10)\,(V_D - 10)}{V_S - V_D} \text{ ohms}$$

where V_S is the VOLTAGE ON UNKNOWN switch setting

V_D is the desired voltage.

It is generally preferable to set V_S to the closest value above the desired voltage, V_D. Table 3-4 gives the values of resistance to obtain many common voltages. The external resistor should be rated for $(V_D - 10)$ volts.

b. Set the VOLTAGE ON UNKNOWN switch to V_S and proceed with the measurement.

If a resistor of the required value is not available, a rheostat larger than this value may be used. With the VOLTAGE ON UNKNOWN switch set to EXT, attach the rheostat between the EXTERNAL ADJ terminals, then set the VOLTAGE ON UNKNOWN switch to V_S. Set the function switch to CHARGE-ZERO and adjust to the desired voltage using a voltmeter connected between the UNKNOWN terminals. Note that the - UNKNOWN terminal will be negative by an amount equal to V_D if the GUARD terminal is grounded, or the + UNKNOWN terminal will be positive by an amount equal to V_D if the - UNKNOWN terminal is grounded.

TABLE 3-4

RESISTANCE VALUES FOR EXTERNAL VOLTAGE ADJUSTMENT

V_D	V_S	R
12 v	20 v	1.25 kΩ
15 v	20 v	5 kΩ
25 v	50 v	12 kΩ
30 v	50 v	20 kΩ
40 v	50 v	60 kΩ
60 v	100 v	56.25 kΩ
70 v	100 v	90 kΩ
80 v	100 v	157.5 kΩ
90 v	100 v	360 kΩ
125 v	200 v	145.7 kΩ
150 v	200 v	266 kΩ
175 v	200 v	627 kΩ
250 v	500 v	235.2 kΩ
300 v	500 v	355.3 kΩ
350 v	500 v	555.3 kΩ
400 v	500 v	955.5 kΩ
475 v	500 v	4.557 MΩ
600 v	1000 v	730.1 kΩ
700 v	1000 v	1.139 MΩ
750 v	1000 v	1.465 MΩ
800 v	1000 v	1.955 MΩ
900 v	1000 v	4.406 MΩ

3.10 EXTERNAL TEST-VOLTAGE SUPPLY.

An external supply for the test voltage is useful for voltages below 10 volts, for continuous voltage adjustment, or for extreme stability for measurements on capacitors (refer to paragraph 3.3.5). For best stability, a battery is recommended. The maximum voltage that may be applied to the bridge is 1000 volts.

Set the VOLTAGE ON UNKNOWN switch to EXT, and connect the external supply to the EXTERNAL GEN terminals. To keep the same polarity as the internal supply, the negative terminal should be connected to the right-hand GEN terminal (that is, the middle of the three EXTERNAL terminals). The external supply should be current-limited to protect it from short circuits. It is also advisable to limit the current to a safe value to avoid shock.

WARNING

With the external supply connected as described above and the GUARD terminal of the bridge grounded, the negative side of this supply is at a negative potential when the function switch is set to CHARGE-ZERO or MEASURE, and the positive terminal is at high potential when the function switch is set to discharge. With the – UNKNOWN terminal grounded, the negative supply of the external supply is also grounded, and the positive side will be at a positive voltage for all positions of the function switch.

With the external generator connected as described above, the function switch will perform its operations. Note that the external supply is disconnected but not shorted in the DISCHARGE position. The circuit diagram for each position of the function switch is shown in Figure 3-5.

3.11 MEASUREMENTS ON VERY HIGH-VALUED RESISTORS.

3.11.1 GENERAL.

Extra precautions and careful technique are required for precise measurements on very high-valued resistors for several reasons.

The ratio-arm resistors used for the three highest ranges are carbon-film types and are not as stable as those used on the lower ranges. For accurate measurements on the highest ranges, the ratio arms may be adjusted by the procedure given in paragraph 5.4.1.

On the two highest ranges the sensitivity is reduced by a factor of 1/10 and 1/20, respectively, because T networks are used as standards (refer to paragraph 4.1). Measurements made at test voltages below 100 volts are difficult.

Other difficulties in measuring high valued resistors are discussed in the following paragraphs.

3.11.2 ELECTROSTATIC COUPLING.

On the three highest ranges the + UNKNOWN terminal is at a very high impedance and, as a result, a very small capacitive coupling to this terminal can cause a large voltage on the detector input. Two separate phenomena are present:

a. Variable capacitance to a point at a fixed voltage will induce a transient voltage on the detector. To observe this, set the main R dial to ∞, the function switch to MEASURE, and move your hands above the +UNKNOWN terminal.

b. Fixed capacitance to a variable voltage will also induce a voltage on the + UNKNOWN terminal, but it should have no dc component and will not cause a detector deflection unless it overdrives the detector, or is low enough in frequency (refer to paragraph 3.12.4).

3.11.3 SWITCH TRANSIENTS.

The movement of the function switch and the RESISTANCE MULTIPLIER switch will also cause transient detector voltages because of the changing capacitance of these switches (refer to paragraph 3.11.2) and more subtle contact phenomena. These fluctuations should be ignored.

3.11.4 SHUNT LEAKAGE BETWEEN LEADS.

At high resistance levels one must be sure that the component being measured forms the only path between the + UNKNOWN and - UNKNOWN terminals. Leads should not touch each other, even if they are insulated with high-quality material. Shielding is the best way to avoid leakage between leads (refer to paragraph 3.5). If the - UNKNOWN terminal is grounded, leakage between the +UNKNOWN terminal and ground shunts the unknown. Therefore, ungrounded measurements should be used wherever possible.

3.11.5 MOISTURE ON THE UNKNOWN.

The device measured should be clean and dry. High-valued resistors should be handled only by their leads to avoid surface dirt. Surface moisture will reduce the resistance value considerably. For example, breathing on a glass-enclosed resistor of only 1 GΩ will cause a momentary change of several percent.

3.12 MEASUREMENTS UNDER ADVERSE CONDITIONS.

3.12.1 HIGH HUMIDITY.

The Type 1644-A Megohm Bridge has been designed to operate under conditions of rather high humidity but, nevertheless, errors will occur on the highest ranges when the relative humidity is over approximately 90%. However, the most serious errors generally result from the effects of humidity in the external unknown connections. A few simple precautions should be taken:

a. Clean the binding posts with a dry, clean cloth. Make sure that there is no dust or moisture between the UNKNOWN binding posts or between them and the panel.

b. Use ungrounded measurements if possible. That is, connect the GUARD terminal to the adjacent chassis ground terminal with the connecting link.

c. Be particularly careful to keep the leads that connect the bridge to the unknown separate from each other.

To determine possible errors due to humidity, balance the bridge with no connections to the UNKNOWN terminals; it should balance at ∞.

The most important precaution necessary under humid conditions is to avoid leakage on the surface of

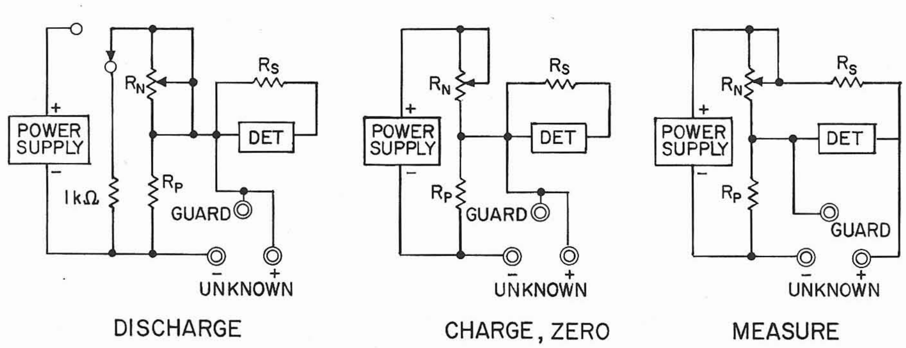


Figure 3-5. Circuit diagrams for the Type 1644-A Megohm Bridge for each position of function switch.

the component being measured. In almost all cases, the error due to this leakage will be many times larger than errors due to improper operation of the bridge itself. Many high resistances simply cannot be measured in a humid environment. Often, a simple solution is to place the component in a box with a light bulb or other source of heat. Shielded leads should be used to connect to the bridge (refer to paragraph 3.5).

3.12.2 TEMPERATURE EXTREMES.

The Type 1644-A Megohm Bridge should operate satisfactorily over a range from -30 to +50°C. The instrument may be exposed to temperatures from -40 to +85°C without damage.

For accurate measurements on the three highest resistance ranges, the ratio arms used should be adjusted at the temperature of use to take into account their temperature coefficients (refer to paragraph 5.4.1).

The temperature coefficient of the component being measured is often high enough so that it cannot be neglected and the bridge should not be expected to give the room-temperature value of the unknown when the component is not at room temperature.

3.12.3 VIBRATION AND SHOCK.

The vacuum-tube electrometer used in the detector is somewhat subject to mechanical shock and will give a transient deflection under these conditions. The detector mounting reduces this effect. However, if the bridge is set on a vibrating platform it should be mechanically isolated from the platform by a thick layer of some spongy material, such as foam rubber.

Vibration or other movement of the leads connecting the unknown can also cause transient detector deflection (refer to paragraph 3.11.2).

3.12.4 HIGH AC FIELDS.

Unshielded components and any unshielded leads that connect the component to the + UNKNOWN terminal may have a voltage induced on them because of capacitance coupling to objects which carry an ac voltage. The bridge is more sensitive to this capacitance pickup on the higher resistance ranges. The detector input circuit contains a low-pass filter that gives 50-db rejection at 60 cps, but large pickup can cause enough signal to overdrive the amplifier, shift its effective dc voltage, and yield an erroneous indication.

Such pickup can be easily detected by a change in meter deflection when the function switch is rotated counterclockwise from DISCHARGE to the adjacent, detented, unlabeled position. In this switch position, the bridge is connected just as in the MEASURE position except that the test voltage is not applied. (When the switch is in the DISCHARGE and CHARGE-ZERO positions, the + UNKNOWN terminal is not connected to the detector, see Figure 3-5.)

If ac pickup is a problem, the best solution is to shield the + UNKNOWN connecting lead and corresponding terminal of the unknown component, to ground the bridge and all nearby equipment, and to keep power cables as far from the bridge, the component measured, and the leads, as possible. If the effect of pickup cannot be completely removed, improved accuracy will result if this unlabeled switch position is used when the meter is zeroed.

3.12.5 SAMPLES WITH SOURCES OF EMF.

Some samples may contain either known or unsuspected sources of voltage due to chemical action, thermal emf, contact potential, or the presence of electrets. If such voltages are additive to the applied voltage, they will cause a bridge error.

If these voltages appear between the + UNKNOWN terminal and the GUARD terminal in a guarded system, they are particularly troublesome because they are applied directly across the detector. If the polarity is the same, this may result in a balance beyond ∞. Such a difficulty is apt to occur during guarded measurements on heterogeneous mechanical assemblies under high humidity.

3.13 PRODUCTION LIMIT TESTING.

Resistors, or the leakage resistance of all types of components, can be rapidly checked without repeated adjustment of the main R dial by using the meter as a limit indicator. Two types of operation are possible:

a. Simple, single-limit testing. To check rapidly that components are above or below some resistance level, set the RESISTANCE MULTIPLIER switch and the main R dial to the limit value, and connect the components to be measured, one at a time, to the UNKNOWN terminals. A deflection to the right indicates the resistance is higher than the limit and a deflection to the left indicates that it is lower. The function switch should be set to DISCHARGE between measurements to avoid shock, to avoid repeated meter banging, to check the zero between measurements, and to start each measurement at zero.

b. Lo-go-hi measurements. The meter deflection may be used to separate the components tested into three groups: those below the tolerance range, those in the tolerance range, and those above the tolerance range. The main R dial and the SENSITIVITY control (or VOLTAGE ON UNKNOWN switch) can be adjusted so that a meter deflection to the left of a certain value represents the lower limit, and a meter deflection to the right of a certain value represents the upper limit. A deflection of 5 divisions is recommended, since beyond that the meter is quite nonlinear. Once the controls are set, the components may be tested without adjustment of the dials. It is, however, preferable to zero the bridge between measurements.

The Type 1650-P1 Test Jig (see Figure 3-6) is a convenient fixture for testing small axial-lead components. The fixture is at ground potential and uses grounded, shielded leads; therefore, the GUARD terminal of the bridge should be grounded. The unpainted panel screw beneath the UNKNOWN terminals should be used to hold the shield on the leads of the Test Jig to the panel and to form the guard connection.

In permanent test setups using the Type 1650-P1 or another fixture, a warning light should be located near the jig to indicate when voltage is applied to the terminals.

Figure 3-6. The Type 1650-P1 Test Jig for production test setups.

3.14 BATTERY OPERATION.

The bridge may be battery-operated if a power line is not available. Two batteries are required: one battery to supply the test voltage should be connected to the EXTERNAL GEN terminals and may supply any voltage up to 1000 volts (refer to paragraph 3.10). The second battery to power the detector should supply 45 volts at about 20 ma. It should be connected with its positive terminal to AT13 and its negative terminal to AT12 on the detector board (see Figure 5-3). The cable connections to these terminals should be removed.

SECTION 4

THEORY OF OPERATION

4.1 BRIDGE.

The bridge circuit in the Type 1644-A Megohm Bridge is a conventional Wheatstone bridge (see Figure 4-1). The equation of balance for this bridge is:

$$R_X = \frac{R_P R_S}{R_N}$$

When the balance condition is met, there will be no voltage across the detector.

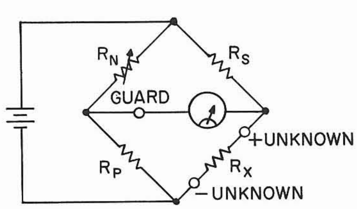


Figure 4-1. Elementary schematic diagram of the bridge circuit.

In the Type 1644-A Megohm Bridge, the resistor R_N is the main R adjustment which is a precision wire-wound rheostat of 5.5 kΩ. The value of R_N is inversely proportional to R_X, so that, when R_N is set to zero, the corresponding dial reading is infinity. The winding mandrel of this rheostat is exponentially shaped in the region between dial readings of 0.9 and 10 so that the scale in this region is logarithmic. This results in a constant angular displacement for a given percent unbalance. From 10 to ∞, the rheostat is linear which yields a simple inverse scale. The rheostat has a mechanical compensating mechanism which can be set to give a tracking accuracy far better than 1%.

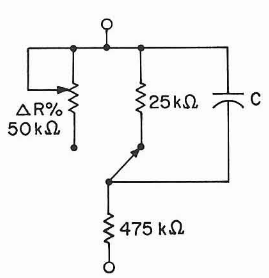


Figure 4-2. Bridge circuit with ΔR% control added.

The resistor R_P represents a fixed 500-kΩ resistor unless the ΔR% switch is depressed to put the ΔR% adjustment in the circuit (see Figure 4-2). When R2 is in the circuit, R_P may be adjusted ±5% which gives a ±5% change in the balance adjustment. This small adjustment is used for precise substitution measurements of small changes of resistance. The ΔR% switch, S104, has a spring return so that this adjustment will not be left in the circuit accidentally and thereby cause an error in the main R dial indication. The capacitor C is added to avoid a switching transient when R2 is added to, or removed from, the circuit.

The ratio-arm resistors, R_S, are selected by the RESISTANCE MULTIPLIER switch. The lowest range uses a wire-wound ratio-arm resistor, the next six ranges use metal film-type resistors, and the three highest ranges use high-valued carbon-film types. Because the carbon-film resistors are less stable, the three highest ranges are adjustable and may be set precisely using the calibration procedure described in paragraph 5.4.1.

Both ends of the ratio-arm resistors are switched and the unused resistors are guarded to avoid leakage resistance between terminals of switch wafers (see Figure 5-7). The two highest ratio-arm resistors actually consist of two T networks, as shown in Figure 4-3. This is done so that more stable, lower-valued resistors may be used, trimming adjustments can be made with rheostats of reasonable values, and the bridge output impedance is small enough to minimize time-constant problems (refer to paragraph 3.3.3). These T networks are equivalent to Δ networks as explained in paragraph 3.6.3. The loading on the adjustment R_N is always greater than 10 MΩ, which causes negligible error. The use of the T's does reduce the bridge sensitivity, however. The ratio between

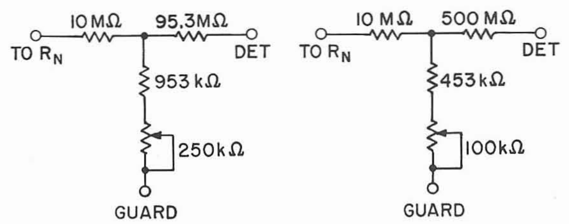


Figure 4-3. The ratio-arm T networks for the two highest ranges.

the voltage on R_N and R_S is always 1/100th or less of the voltage on R_P and R_X. This large "bridge ratio" results in less sensitivity than would be available if it were smaller, but has the following advantages:

a. The standard is 1/100th or less of the unknown resistor and, therefore, on many ranges it is a much more stable resistor than any unknown resistor would be. For example, resistors up to 100 MΩ are measured using wire-wound standards, and resistors to 10 GΩ are measured using 1/4% metal-film types.

b. The voltage applied to the unknown varies by only 1% over the entire range of R_N. (This would be 10% on a bridge with a 10-to-1 ratio.)

c. Because R_S is smaller, several effects resulting from high bridge output impedance, such as time-constant problems in capacitance measurement, and capacitance pickup and zero shift resulting from grid current on the highest ranges, are reduced.

d. Because a much lower voltage is applied to R_S than to R_X, changes in R_S due to its voltage coefficient are negligible. This is particularly important when voltage coefficients are measured with the ΔR% dial.

The use of the T networks on the highest ranges can be considered as a further increase of this bridge ratio.

The bridge is mounted on a subpanel which is tied to the GUARD point which is the low side of the detector. Both UNKNOWN terminals are mounted on a plate connected to this GUARD point to avoid any leakage resistance across the UNKNOWN terminals. Leakage resistance from any point on the bridge to GUARD causes negligible effect if it is over 200 MΩ or so. This value is easily obtained with good insulating materials.

In use, either the GUARD point or the - UNKNOWN terminal can be tied to the panel ground. In the latter case, there may be a high voltage between the subpanel and the outside panel.

When the switch on the side of the instrument is set in the CAL position, the ratio-arm resistor normally used for the range selected is connected instead across the UNKNOWN terminals, and the ratio-arm resistor normally used two ranges lower is used as the standard. Thus, each resistor is checked against one that is 1/100th of its value. (Refer to paragraph 5.4.1.)

4.2 DETECTOR.

The detector circuit consists of a multistage, dc-feedback amplifier, with an electrometer-tube input stage, that drives the panel meter. The over-all sensitivity of the circuit is about 100 μv/mm.

The electrometer tube provides the high input resistance necessary to prevent loading the bridge and, thus, decreasing sensitivity. It also has a very low grid current to avoid appreciable zero shifts when the bridge output resistance is changed as the range is changed. Preceding the input tube is a two-stage RC filter to reduce the effects of pickup. This grid circuit also includes a neon tube, which, with a series resistor, limits the grid current drawn to less than 1 microampere, whatever voltage is applied.

The second stage in the amplifier is also a vacuum tube because of the high plate resistance of the first stage. Following the second stage are a common-collector and then a common-emitter transistor stage. The output voltage is fed back through a divider to the second grid of the input stage. This grid is also used for the ZERO adjustments.

The amplifier output drives the zero-center panel meter. This meter has shaped pole pieces to give high sensitivity near a bridge null and decreased sensitivity up scale. This nonlinearity facilitates balance by eliminating the need for readjustment of the SENSITIVITY control during balance.

The supply voltage for this detector is very well regulated. The heater current in the vacuum tubes is taken from the plate supply and is, thus, also well regulated. The critical voltages on the first stage are further regulated by a low-temperature-coefficient Zener diode.

4.3 TEST-VOLTAGE SUPPLY.

The internal test voltage is regulated by a series regulator using a high-voltage vacuum tube as the series element. The reference for this regulator is a Zener diode and the amplifier consists of cascaded transistor stages. The control circuit is connected to the output and has a maximum of only 10 volts across it while the remaining output voltage is dropped across a resistor.

The current through this dropping resistor is adjusted to be precisely 2 ma by the internal ADJ 100 V adjustment and the voltage across the amplifier is adjusted to 10 volts with the ADJ 10 V adjustment. The output voltage is the sum of 10 volts plus 2 ma times the dropping resistor. This resistor is used to change the test voltage. The EXTERNAL ADJ terminals shunt this resistor so that its value may be modified to get intermediate values (refer to paragraph 3.9).

This supply is current-limited to about 8 ma for ranges over 50 volts and to about 15 ma at 50 volts and lower. Shorting the supply will not damage it.

SECTION 5

SERVICE AND MAINTENANCE

5.1 WARRANTY.

We warrant that each new instrument sold by us is free from defects in material and workmanship, and that, properly used, it will perform in full accordance with applicable specifications for a period of two years after original shipment. Any instrument or component that is found within the two-year period not to meet these standards after examination by our factory, district office, or authorized repair agency personnel, will be repaired or, at our option, replaced without charge, except for tubes or batteries that have given normal service.

5.2 SERVICE.

The two-year warranty stated above attests the quality of materials and workmanship in our products. When difficulties do occur, our service engineers will assist in any way possible. If the difficulty cannot be eliminated by use of the following service instructions, please write or telephone our Service Department (see rear cover), giving full information of the trouble and of steps taken to remedy it. Be sure to mention the serial and type numbers of the instrument.

Before returning an instrument to General Radio for service, please write to our Service Department or nearest district office, requesting a Returned Material Tag. Use of this tag will ensure proper handling and identification. For instruments not covered by the warranty, a purchase order should be forwarded to avoid unnecessary delay.

5.3 REMOVAL FROM CABINET.

To remove the instrument from the cabinet, remove the four screws near the panel on the sides of the instrument and pull the instrument up out of the cabinet.

WARNING

Use care in trouble-shooting the instrument when it is out of its case and connected to the power line. Dangerous voltages are present, particularly at the transformer terminals. Connect the ground strap between the GUARD and ground terminals to keep the subpanel (GUARD) at ground potential.

5.4 BRIDGE CALIBRATION.

5.4.1 RATIO ARMS.

The ratio arms (and the R_p-arm resistor) may be checked easily without external standards or test equipment. Resistance between the UNKNOWN terminals will not interfere with the calibration, but impedance between the - UNKNOWN and GUARD terminals will cause calibration error. The eight lower-valued arms should maintain their values accurately for many years, but the three highest-valued units are less stable. They can be adjusted to value as follows:

a. Set the function switch to DISCHARGE.
b. Set the VOLTAGE ON UNKNOWN switch to 10 v.
c. Connect the captive link between the GUARD terminal and the panel ground terminal.
d. Rotate the measure-calibrate screw-driver control on the right-hand side of the instrument (see Figure 5-1) fully clockwise.
e. Set the RESISTANCE MULTIPLIER switch to 100 kΩ.
f. Set the function switch to CHARGE-ZERO and zero the bridge with the COARSE ZERO and FINE ZERO controls.

TABLE 5-1 – RATIO-ARM RESISTORS

RESISTANCE MULTIPLIER Setting	100 kΩ	1 MΩ	10 MΩ	100 MΩ	1 GΩ
Resistor Used as Standard	R105 (10 Ω)	R106 (100 Ω)	R107 (1 KΩ)	R108 (10 kΩ)	R109 (100 kΩ)
Resistor Used as Unknown	R107 (1 kΩ)	R108 (10 kΩ)	R109 (100 kΩ)	R110 (1 MΩ)	R111 (10 MΩ)

g. Set the function switch to MEASURE and balance the bridge. It should balance near a reading of 1. Make note if the balance point differs from 1 by more than 1/2% (1/4 dial division.
h. Set the RESISTANCE MULTIPLIER switch to each range up to 1 GΩ, in turn. For each range, rezero the meter and then balance the bridge. Note any ranges that do not balance within 1/2%.
i. If any measurements are off, the resistor in error can be identified by the chart of Table 5-1. Note that the 10-Ω, 100-Ω, 1-MΩ, and 10-MΩ resistors appear only once in this table. An error in any one of these would cause only one inaccurate balance. Values in between would cause two inaccurate balances that would be off in opposite directions. If all the values are off in the same direction, R_p is in error.
j. Set the RESISTANCE MULTIPLIER switch to 10 GΩ and set the main R dial to 1. Balance the bridge by means of the adjustment on the side of the instrument in the left-hand hole (see Figure 5-1).
k. Repeat step i. for the 100-GΩ and 1-TΩ ranges, making the balance with the middle and right-hand adjustments, respectively (see Figure 5-1).

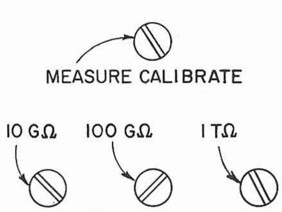


Figure 5-1. Calibration controls for the three highest ratio arms. The measure-calibrate switch is shown in the measure position. Rotate the switch clockwise to calibrate.

5.4.2 MAIN DIAL.

To check the accuracy of the main dial, connect a decade resistance box to the UNKNOWN terminals and measure at various points over the dial range. A Type 1432-Q Decade Resistor (1 MΩ in 10-Ω steps) that permits readings up to 1000 (1 k) on the 1-kΩ range is recommended.

The main dial should give readings to approximately 1/2% over the range from 0.9 to 10 and to an equivalent scale distance (approximately 1/2 mm) over the rest of the range. If the readings differ by substantially more than this, the main rheostat should be readjusted.

To readjust the main rheostat, use a dc bridge with an accuracy of ±0.1%. Remove the Type 1644-A from its cabinet and swing the detector board out on its cable. (Unsolder leads to terminals 1 and 2 on the board and remove the screws at the corners of the board.) Disconnect one of the internal leads that is connected to the rheostat and connect the dc bridge across the rheostat.

The main rheostat has a mechanism that permits accurate adjustment at eight points with adjustment screws. Table 5-2 lists the dial readings and resistance values for these eight points and for intermediate points that should also be within ±1/2% or 2-1/2 ohms, whichever is larger. These adjustments are numbered clockwise starting at the slot in the cam plate. After any adjustments are made, rotate the dial over its entire range and recheck all points.

TABLE 5-2
MAIN DIAL CALIBRATION

Dial Reading	*Resistance*	*Screw Adjustment*
0.9	5556 Ω	-
1.0	5000 Ω	1
1.3	3846 Ω	-
1.5	3333 Ω	2
1.9	2632 Ω	-
2.5	2000 Ω	3
3.2	1563 Ω	-
4.0	1250 Ω	4
5.0	1000 Ω	-
6.3	793.7 Ω	5
8.0	625.0 Ω	-
10.0	500.0 Ω	6
13.0	384.6 Ω	-
20.0	250.0 Ω	7
32.0	156.3 Ω	-
100.0	50.0 Ω	8
200.0	25.0 Ω	-
∞	0.0 Ω	-

5.5 TEST-VOLTAGE ADJUSTMENTS.

To check the test voltages connect an accurate, high-impedance voltmeter between the UNKNOWN terminals and set the function switch to CHARGE-ZERO. Connect the link between the - UNKNOWN terminal and the chassis ground terminal to keep the negative terminal of the voltmeter near ground potential. The test voltages should be within ±3%. They will vary 1% over the range of the R dial so that, if they are readjusted, the R dial should be set to 2 to obtain center values.

TABLE 5-3
DETECTOR VOLTAGES

Connect the captive link between the ground and GUARD terminals.
Adjust R231 for 35.0 volts dc between TP1 and ground.

Tube or Transistor (Type)	*Pin*	*DC Volts to Ground*	*Tube or Transistor (Type)*	*Pin*	*DC Volts to Ground*
V201 (CK5886)	1	10.8	Q202 (2N910)	C	32.5
	2	6.65		B	26.0
	3	3.20		E	25.5
	4	2.0	Q203 (2N910)	C	27.5
	7	0.0		B	18.0
V202 (CK6418)	1	26.0		E	17.5
	2	25.7	Q204 (2N1304)	C	45.7
	3	13.1		B	27.5
	4	10.8		E	27.4
	5	11.8	Q205 (2N1131)	C	35.0
Q201 (2N1377)	C	17.9		B	45.7
	B	25.5		E	46.5
	E	25.7			

The test voltages may be readjusted by means of the internal adjustments R509 and R513 (see Figure 5-2). R509 should be set to give 10 volts and R513 to give 100 volts (with the corresponding settings of the VOLTAGE ON UNKNOWN switch). If these voltages are correct, but others are in error, the fault is with one of the dropping resistors, R517 through R527. If the voltages are way off, check the circuit voltages against those of Tables 5-3 and 5-4 to help determine the faulty component.

The voltages in Tables 5-3 and 5-4 are measured with a vacuum-tube voltmeter under the following conditions:

Function switch set to CHARGE-ZERO
RESISTANCE MULTIPLIER switch set to 1 k
Measure-calibrate switch set to measure
VOLTAGE ON UNKNOWN switch set to 10 v
Power-line voltage of 115 volts.

5.6 DETECTOR ADJUSTMENTS.

5.6.1 METER-ZERO ADJUSTMENT.

If the COARSE ZERO adjustment on the panel is near the end of its range, or off range, it can be reset to mid range, and the detector zeroed using R211 which is located on the detector board (see Figure 5-2). THIS ADJUSTMENT SHOULD BE MADE WITH THE CONNECTING LINK BETWEEN THE GUARD TERMINAL AND THE GROUND TERMINAL TO AVOID SHOCK.

5.6.2 DETECTOR SUPPLY VOLTAGE.

The detector supply voltage from TP1 to AT12 should be 35 volts. This is set using R231 (see Figure 5-2).

TABLE 5-4
POWER-SUPPLY VOLTAGES

Connect the captive link between the ground and - UNKNOWN terminals.
Adjust R509 for 10.0 volts dc across the UNKNOWN terminals.

Tube or Transistor (Type)	*Pin*	*DC Volts to Ground*
V501 (7239)	1	6.7
	2	10.0
	4	10.0
	6	60.0
	7	10.0
	9	10.0
	Cap	200.0
	Between 4 and 5	5.6 ac
Q501 (2N910)	C	6.6
	B	2.7
	E	2.1
Q502 (2N1131)	C	2.7
	B	4.7
	E	5.5

5.7 TROUBLE-SHOOTING.

5.7.1 NOISY OR ERRATIC BALANCE.

If the bridge has not been used in some time, surface contamination in the wire-wound R or ΔR% adjustment may cause erratic behavior of the null indicator. To remedy this situation, rotate these controls over their ranges several times.

5.7.2 LOW BRIDGE SENSITIVITY.

To check the bridge sensitivity proceed as follows:

a. Set the VOLTAGE ON UNKNOWN switch to 10 v, the measure-calibrate switch (on the side panel) to calibrate (fully clockwise), the SENSITIVITY control fully clockwise, and the RESISTANCE MULTIPLIER to 100 kΩ.
b. Balance the bridge. It should balance near 1.

A 1% change in the ΔR% dial is 1 millivolt and should give a 2-1/2-division deflection. If the gain is insufficient, check the voltage in the detector board and compare them with those of Table 5-3. This should help locate a faulty component.

5.7.3 INABILITY TO BALANCE OR LARGE ERROR.

If the bridge does not balance, several things should be considered before the bridge is returned for service:

a. Make sure that the measure-calibrate switch (side panel) is in the measure position (counterclockwise), see Figure 5-1. The bridge will always balance near 1 when this switch is in the calibrate position.
b. Make sure that the component is correctly connected.
c. Check all panel switch settings.
d. Try measuring a known resistor.
e. Refer to paragraph 3.11 for measurement of high-valued resistors and to paragraph 3.12 for measurements under adverse conditions.

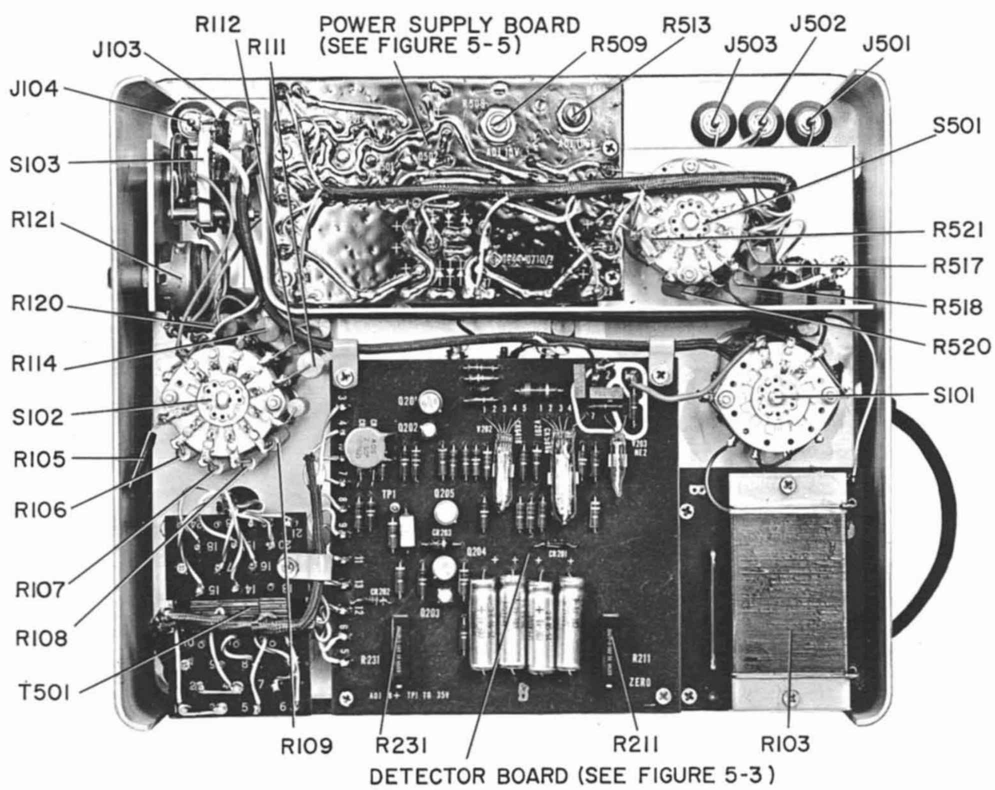


Figure 5-2. Interior view of the Type 1644-A.

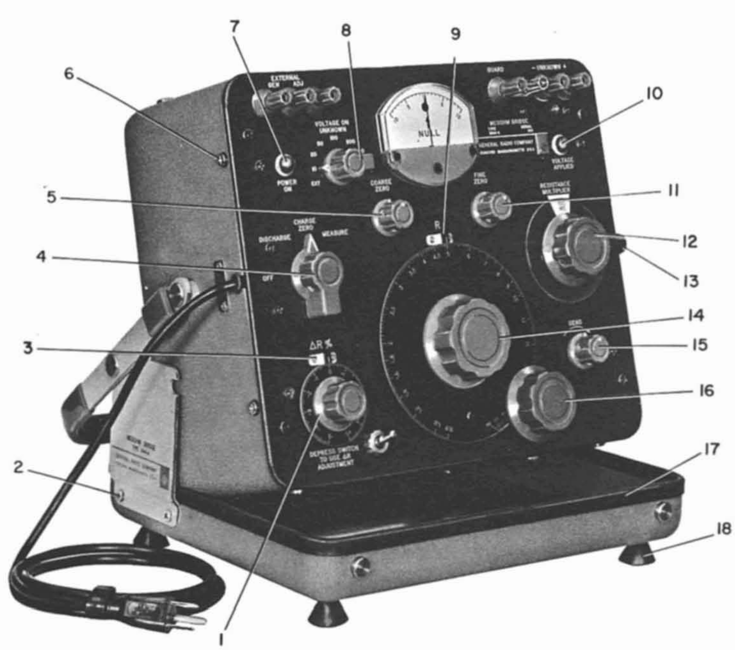
FEDERAL MANUFACTURERS CODE

From Federal Supply Code for Manufacturers Cataloging Handbooks H4-1 (Name to Code) and H4-2 (Code to Name) as supplemented through June, 1967.

Code	Manufacturers Name and Address
00192	Jones Mfg. Co., Chicago, Illinois
00194	Walsco Electronics Corp., Los Angeles, Calif.
00656	Aerovox Corp., New Bedford, Mass.
01009	Alden Products Co., Brockton, Mass.
01121	Allen-Bradley, Co., Milwaukee, Wisc.
01295	Texas Instruments, Inc., Dallas, Texas
02114	Ferroxcube Corp. of America, Saugerties, N. Y. 12477
02606	Fenwal Lab. Inc., Morton Grove, Ill.
02660	Amphenol Electronics Corp., Broadview, Ill.
02768	Fastex Division of Ill. Tool Works, Des Plaines, Ill. 60016
03508	G. E. Semiconductor Products Dept., Syracuse, N. Y. 13201
03636	Grayburne, Yonkers, N. Y. 10701
03888	Pyrofilm Resistor Co., Cedar Knolls, N. J.
03911	Clairex Corp., New York, N. Y. 10001
04009	Arrow, Hart and Hegeman Electric Co., Hartford, Conn. 06106
04713	Motorola Semi-Conduct Product, Phoenix, Ariz. 85008
05170	Engineered Electronics Co., Inc., Santa Ana, Calif. 92702
05624	Barber-Colman Co., Rockford, Ill. 61101
05820	Wakefield Eng., Inc., Wakefield, Mass. 01880
07127	Eagle Signal Div. of E. W. Bliss Co., Baraboo, Wisc.
07261	Avnet Corp., Culver City, Calif. 90230
07263	Fairchild Camera and Instrument Corp., Mountain View, Calif.
07387	Birtcher Corp., No. Los Angeles, Calif.
07595	American Semiconductor Corp., Arlington Heights, Ill. 60004
07828	Bodine Corp., Bridgeport, Conn. 06605
07829	Bodine Electric Co., Chicago, Ill. 60618
07910	Continental Device Corp., Hawthorne, Calif.
07983	State Labs Inc., N. Y., N. Y. 10003
07999	Amphenol Corp., Borg Inst. Div., Delavan, Wisc. 53115
08730	Vemaline Prod. Co., Franklin Lakes, N. J.
09213	General Electric Semiconductor, Buffalo, N. Y.
09823	Burgess Battery Co., Freeport, Ill.
09922	Burndy Corp., Norwalk, Conn. 06852
11599	Chandler Evans Corp., W. Hartford, Conn.
12498	Teledyn Inc., Crystalonics Div., Cambridge, Mass. 02140
12672	RCA Commercial Receiving Tube and Semiconductor Div., Woodridge, N.J.
12697	Clarostat Mfg. Co. Inc., Dover, N. H. 03820
12954	Dickson Electronics Corp., Scottsdale, Ariz.
13327	Solitrone Devices, Tappan, N. Y. 10983
14433	ITT Semiconductors, W. Palm Beach, Florida
14655	Cornell Dubilier Electric Co., Newark N. J.
14674	Corning Glass Works, Corning, N. Y.
14936	General Instrument Corp., Hicksville, N. Y.
15238	ITT, Semiconductor Div. of Int. T. and T, Lawrence, Mass.
15605	Cutler-Hammer Inc., Milwaukee, Wisc. 53233
16037	Spruce Pine Mica Co., Spruce Pine, N. C.
19701	Electra Mfg. Co., Independence, Kansas 67301
21335	Fafnir Bearing Co., New Briton, Conn.
24446	G. E. Schenectady, N. Y. 12305
24454	G. E., Electronic Comp., Syracuse, N. Y.
24455	G. E. (Lamp Div), Nela Park, Cleveland, Ohio
24655	General Radio Co., W. Concord, Mass 01781
26806	American Zettler Inc., Costa Mesa, Calif.
28520	Hayman Mfg. Co., Kenilworth, N. J.
28959	Hoffman Electronics Corp., El Monte, Calif.
30874	International Business Machines, Armonk, N.Y.
32001	Jensen Mfg. Co., Chicago, Ill. 60638
35929	Constanta Co. of Canada Limited, Montreal 19, Quebec
37942	P. R. Mallory and Co. Inc., Indianapolis, Ind.
38443	Marlin-Rockwell Corp., Jamestown, N. Y.
40931	Honeywell Inc., Minneapolis, Minn. 55408
42190	Muter Co., Chicago, Ill. 60638
42498	National Co. Inc., Melrose, Mass. 02176
43991	Norma-Hoffman Bearings Corp., Stanford, Conn. 06904
49671	RCA, New York, N. Y.
49956	Raytheon Mfg. Co., Waltham, Mass. 02154
53021	Sangamo Electric Co., Springfield, Ill. 62705
54294	Shallcross Mfg. Co., Selma, N. C.
54715	Shure Brothers, Inc., Evanston, Ill.
56289	Sprague Electric Co., N. Adams, Mass.
59730	Thomas and Betts Co., Elizabeth, N. J. 07207
59875	TRW Inc. (Accessories Div), Cleveland, Ohio
60399	Torrington Mfg. Co., Torrington, Conn.
61637	Union Carbide Corp., New York, N. Y. 10017
61864	United-Carr Fastener Corp., Boston, Mass.
63060	Victoreen Instrument Co., Inc., Cleveland, Ohio
63743	Ward Leonard Electric Co., Mt. Vernon, N. Y.
65083	Westinghouse (Lamp Div), Bloomfield, N. J.
65092	Weston Instruments, Weston-Newark, Newark, N. J.
70485	Atlantic-India Rubber Works, Inc., Chicago, Ill. 60607
70563	Amperite Co., Union City, N. J. 07087
70903	Belden Mfg. Co., Chicago, Ill. 60644
71126	Bronson, Homer D., Co., Beacon Falls, Conn.
71294	Canfield, H. O. Co., Clifton Forge, Va. 24422
71400	Bussman Mfg. Div. of McGraw Edison Co., St. Louis, Mo.
71590	Centralab, Inc., Milwaukee, Wisc. 53212
71666	Continental Carbon Co., Inc., New York, N. Y.
71707	Coto Coil Co. Inc., Providence, R. I.
71744	Chicago Miniature Lamp Works, Chicago, Ill.
71785	Cinch Mfg. Co. and Howard B. Jones Div., Chicago, Ill. 60624
71823	Darnell Corp., Ltd., Downey, Calif. 90241
72136	Electro Motive Mfg. Co., Willmington, Conn.
72259	Nytronics Inc., Berkeley Heights, N. J. 07922
72619	Dialight Co., Brooklyn, N. Y. 11237
72699	General Instrument Corp., Capacitor Div., Newark, N. J. 07104
72765	Drake Mfg. Co., Chicago, Ill. 60656
72825	Hugh H. Eby, Inc., Philadelphia, Penn. 19144
72962	Elastic Stop Nut Corp., Union, N. J. 07083
72982	Erie Technological Products Inc., Erie, Penn.
73445	Amperex Electronics Co., Hicksville, N. Y.
73559	Carling Electric Co., W. Hartford, Conn.
73690	Elco Resistor Co., New York, N. Y.
73899	J. F. D. Electronics Corp., Brooklyn, N. Y.
74193	Heinemann Electric Co., Trenton, N. J.
74861	Industrial Condenser Corp., Chicago, Ill.
74970	E. F. Johnson Co., Waseca, Minn. 56093
75042	IRC Inc., Philadelphia, Penn. 19108
75382	Kulka Electric Corp., Mt. Vernon, N. Y.
75608	Linden and Co., Providence, R. I.
75915	Littelfuse, Inc., Des Plaines, Ill. 60016
76005	Lord Mfg. Co., Erie, Penn. 16512
76487	James Millen Mfg. Co., Malden, Mass. 02148
76545	Mueller Electric Co., Cleveland, Ohio 44114
76684	National Tube Co., Pittsburg, Penn.
76854	Oak Mfg. Co., Crystal Lake, Ill.
77147	Patton MacGuyer Co., Providence, R. I.
77166	Pass-Seymour, Syracuse, N. Y.
77263	Pierce Roberts Rubber Co., Trenton, N. J.
77339	Positive Lockwasher Co., Newark , N. J.
77542	Ray-O-Vac Co., Madison, Wisc.
77630	TRW, Electronic Component Div., Camden, N. J. 08103
77638	General Instruments Corp., Brooklyn, N. Y.
78189	Shakeproof Div. of Ill. Tool Works, Elgin, Ill. 60120
78277	Sigma Instruments Inc., S. Braintree, Mass.
78488	Stackpole Carbon Co., St. Marys, Penn.
78553	Tinnerman Products, Inc., Cleveland, Ohio
79089	RCA, Commercial Receiving Tube and Semiconductor Div., Harrison, N. J.
79725	Wiremold Co., Hartford, Conn. 06110
79963	Zierick Mfg. Co., New Rochelle, N. Y.
80030	Prestole Fastener Div. Bishop and Babcock Corp., Toledo, Ohio
80048	Vickers Inc. Electric Prod. Div., St. Louis, Mo.
80131	Electronic Industries Assoc., Washington, D.C.
80183	Sprague Products Co., North Adams, Mass.
80211	Motorola Inc., Franklin Park, Ill. 60131
80258	Standard Oil Co., Lafeyette, Ind.
80294	Bourns Inc., Riverside, Calif. 92506
80431	Air Filter Corp., Milwaukee, Wisc. 53218
80583	Hammarlund Co. Inc., New York, N. Y.
80740	Beckman Instruments, Inc., Fullerton, Calif.
81073	Grayhill Inc., LaGrange, Ill. 60525
81143	Isolantite Mfg. Corp., Stirling, N. J. 07980
81349	Military Specifications
81350	Joint Army-Navy Specifications
81751	Columbus Electronics Corp., Yonkers, N. Y.
81831	Filton Co., Flushing, L. I., N. Y
81860	Barry Controls Div. of Barry Wright Corp., Watertown, Mass.
82219	Sylvania Electric Products, Inc., (Electronic Tube Div.), Emporium, Penn.
82273	Indiana Pattern and Model Works, LaPort, Ind
82389	Switchcraft Inc., Chicago, Ill. 60630
82647	Metals and Controls Inc., Attleboro, Mass.
82807	Milwaukee Resistor Co., Milwaukee, Wisc.
83058	Carr Fastener Co., Cambridge, Mass.
83186	Victory Engineering Corp (IVECO), Springfield, N. J. 07081
83361	Bearing Specialty Co., San Francisco, Calif.
83587	Solar Electric Corp., Warren, Penn.
83740	Union Carbide Corp., New York, N. Y. 10017
84411	TRW Capacitor Div., Ogallala, Nebr.
84835	Lehigh Metal Products Corp., Cambridge, Mass. 02140
84971	TA Mfg. Corp., Los Angeles, Calif.
86577	Precision Metal Products of Malden Inc., Stoneham, Mass. 02180
86684	RCA (Electrical Component and Devices) Harrison, N. J.
88140	Cutler-Hammer Inc., Lincoln, Ill.
88219	Gould Nat. Batteries Inc., Trenton, N. J.
88419	Cornell Dubilier Electric Corp., Fuquay-Varina, N. C.
88627	K and G Mfg. Co., New York, N. Y.
89482	Holtzer Cabot Corp., Boston, Mass.
89665	United Transformer Co., Chicago, Ill.
90201	Mallory Capacitor Co., Indianapolis, Ind.
90750	Westinghouse Electric Corp., Boston, Mass.
90952	Hardware Products Co., Reading, Penn. 19602
91032	Continental Wire Corp., York, Penn. 17405
91146	ITT Cannon Electric Inc., Salem, Mass.
91293	Johanson Mfg. Co., Boonton, N. J. 07005
91598	Chandler Co., Wethersfield, Conn. 06109
91637	Dale Electronics Inc., Columbus, Nebr.
91662	Elco Corp., Willow Grove, Penn.
91719	General Instruments, Inc., Dallas, Texas
91929	Honeywell Inc., Freeport, Ill.
92519	Electra Insulation Corp., Woodside, Long Island, N. Y.
92678	Edgerton, Germeshausen and Grier, Boston, Mass.
93332	Sylvania Electric Products, Inc., Woburn, Mass.
93916	Cramer Products Co., New York, N. Y. 10013
94144	Raytheon Co. Components Div., Quincy, Mass.
94154	Tung Sol Electric Inc., Newark, N. J.
95076	Garde Mfg. Co., Cumberland, R. I.
95146	Alco Electronics Mfg. Co., Lawrence, Mass.
95238	Continental Connector Corp., Woodside, N. Y.
95275	Vitramon, Inc., Bridgeport, Conn.
95354	Methode Mfg. Co., Chicago, Ill.
95412	General Electric Co., Schenectady, N. Y.
95794	Ansconda American Brass Co., Torrington, Conn.
96095	Hi-Q Div. of Aerovox Corp., Orlean, N. Y.
96214	Texas Instruments Inc., Dallas, Texas 75209
96256	Thordarson-Meissner Div. of McGuire, Mt. Carmel, Ill.
96341	Microwave Associates Inc., Burlington, Mass.
96906	Military Standards
97966	CBS Electronics Div. of Columbia Broadcasting Systems, Danvers, Mass.
98291	Sealectro Corp., Mamaroneck, N. Y. 10544
98821	North Hills Electronics Inc., Glen Cove, N. Y.
99180	Transitron Electronics Corp., Melrose, Mass.
99378	Atlee Corp., Winchester, Mass. 01890
99800	Delevan Electronics Corp., E. Aurora, N. Y.

PARTS LIST – MECHANICAL

Fig. Ref.	Description	Part No.	Fed. Mfg. Code	Mfg. Part No.	Fed. Stock No.
1	Dial Assembly, ΔR%	1644-3100	24655	1644-3100	
2	Screw, No. 10-32, 3/8 in. Washer, Split, No. 10	7080-1000 8040-2400	24655 96906	7080-1000 MS35337-81	5305-974-0373 5310-058-2951
3	Indicator	5460-1301	24655	5460-1301	
4	Knob, POWER OFF - MEASURE	5500-1100	24655	5500-1100	5355-912-0009
5	Knob, COARSE ZERO	5530-0400	24655	5530-0400	5355-985-6850
6	Panel Screw and Washer, No. 10-32, 1/2 in.	7098-0160	24655	7098-0160	5305-993-0650
7	Socket Assembly, POWER ON	7510-1380	72765	121-7-204 (red)	
8	Knob, VOLTAGE ON UNKNOWN	5500-0400	24655	5500-0400	5355-051-6594
9	Indicator, R dial	5460-1301	24655	5500-1100	5355-912-0009
10	Socket Assembly, VOLTAGE APPLIED	7510-1380	72765	121-7-204 (red)	
11	Knob, FINE ZERO	5530-0400	24655	5530-0400	5355-985-6850
12	Dial and Knob Assembly, RESISTANCE MULTIPLIER	1644-1040	24655	1644-1040	
13	Stop, rubber bumper to check instrument rotation.	5260-0700	24655	5260-0700	5340-738-6329
14	Dial Assembly, R dial	1644-3090	24655	1644-3090	
15	Knob, SENS	5530-0400	24655	5530-0400	5355-985-6850
16	Knob, vernier drive for R dial	5520-2100	24655	5520-2100	5355-954-7040
17	Gasket, rubber gasket for cabinet edge.	5167-5429	24655	5167-5429	
18	Foot, rubber	5250-1902	24655	5250-1902	



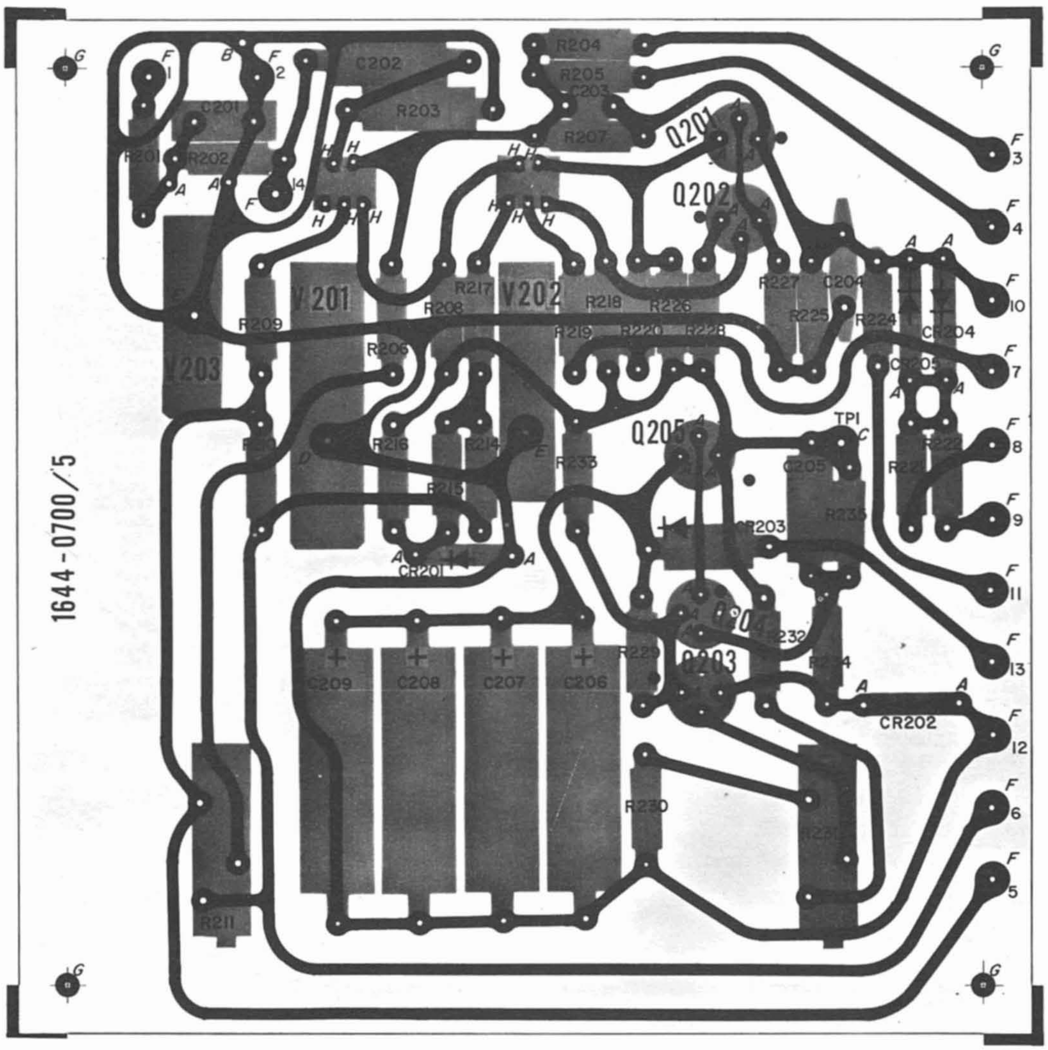
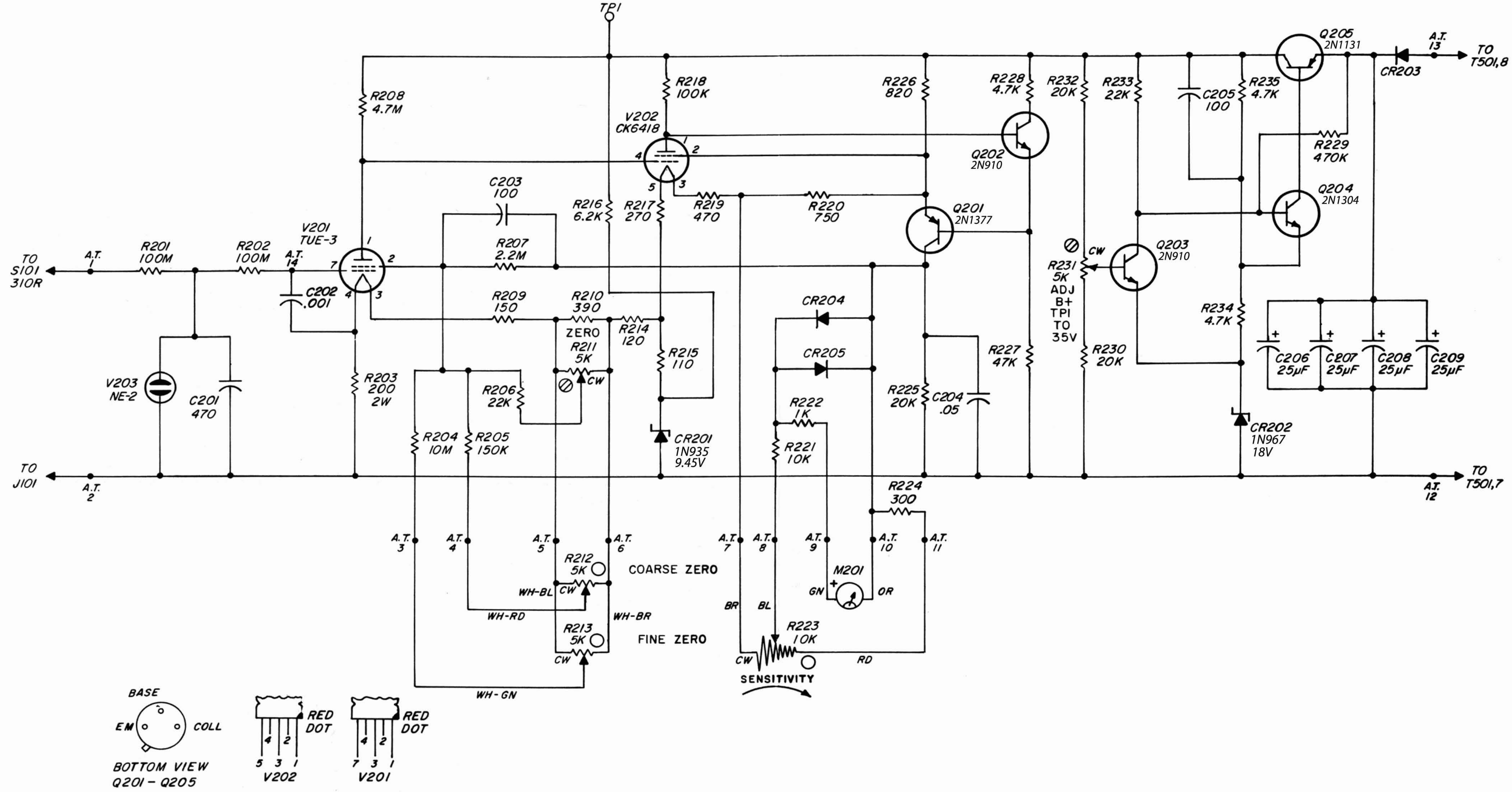


Figure 5-3. Etched-board layout for detector circuit (P/N 1644-2710).

NOTE: The number appearing on the foil side is not the part number. The dot on the foil at the transistor socket indicates the collector lead.

PARTS LIST – DETECTOR CIRCUIT

Ref No.	Description	Part No.	Fed. Mfg. Code	Mfg. Part No.	Fed. Stock No.
RESISTORS					
R201	Composition, 100MΩ ±5% 1/2W	1644-0420	24655	1644-0420	
R202	Composition, 100MΩ ±5% 1/2W	1644-0420	24655	1644-0420	
R203	Wire-wound, 200Ω ±5% 2W	6760-1205	75042	BWH, 200Ω ±5%	
R204	Composition, 10MΩ ±5% 1/2W	6100-6105	01121	RC20GF106J	5905-279-1865
R205	Composition, 150kΩ ±5% 1/2W	6100-4155	01121	RC20GF154J	5905-279-2522
R206	Composition, 22kΩ ±5% 1/2W	6100-3225	01121	RC20GF223J	5905-171-2004
R207	Composition, 2.2MΩ ±5% 1/2W	6100-5225	01121	RC20GF225J	5905-190-8885
R208	Composition, 4.7MΩ ±5% 1/2W	6100-5475	01121	RC20GF475J	5905-185-8490
R209	Composition, 150Ω ±5% 1/2W	6100-1155	01121	RC20GF151J	5905-299-1541
R210	Composition, 390Ω ±5% 1/2W	6100-1395	01121	RC20GF391J	5905-279-1890
R211	Potentiometer, Wire-wound 5kΩ ±10%	6059-2509	80294	3067P-1-502	
R212	Potentiometer, Wire-wound 5kΩ ±5%	0971-3913	24655	0971-3913	
R213	Potentiometer, Wire-wound 5kΩ ±5%	0971-3913	24655	0971-3913	
R214	Composition, 120Ω ±5% 1/2W	6100-1125	01121	RC20GF121J	5905-252-5434
R215	Composition, 110Ω ±5% 1/2W	6100-1115	01121	RC20GF111J	5905-279-3515
R216	Composition, 6.2kΩ ±5% 1/2W	6100-2625	01121	RC20GF622J	5905-279-2673
R217	Composition, 270Ω ±5% 1/2W	6100-1275	01121	RC20GF271J	5905-171-2006
R218	Composition, 100kΩ ±5% 1/2W	6100-4105	01121	RC20GF104J	5905-195-6761
R219	Composition, 470Ω ±5% 1/2W	6100-1475	01121	RC20GF471J	5905-192-3973
R220	Composition, 750Ω ±5% 1/2W	6100-1755	01121	RC20GF751J	5905-195-9481
R221	Composition, 10kΩ ±5% 1/2W	6100-3105	01121	RC20GF103J	5905-185-8510
R222	Composition, 1kΩ ±5% 1/2W	6100-2105	01121	RC20GF102J	5905-195-6806
R223	Potentiometer, Composition, 10kΩ ±10%	6020-0400	01121	JA, 10kΩ ±10%	5905-829-3323
R224	Composition, 300Ω ±5% 1/2W	6100-1305	01121	RC20GF301J	5905-279-5481
R225	Composition, 20kΩ ±5% 1/2W	6100-3205	01121	RC20GF203J	5905-192-0649
R226	Composition, 820Ω ±5% 1/2W	6100-1825	01121	RC20GF821J	5905-171-1999
R227	Composition, 47kΩ ±5% 1/2W	6100-3475	01121	RC20GF473J	5905-254-9201
R228	Composition, 4.7kΩ ±5% 1/2W	6100-2475	01121	RC20GF472J	5905-279-3504
R229	Composition, 470kΩ ±5% 1/2W	6100-4475	01121	RC20GF474J	5905-279-2515
R230	Composition, 20kΩ ±5% 1/2W	6100-3205	01121	RC20GF203J	5905-192-0649
R231	Potentiometer, Wire-wound, 5kΩ ±10%	6059-2509	80294	3067P-1-502	
R232	Composition, 20kΩ ±5% 1/2W	6100-3205	01121	RC20GF203J	5905-192-0649
R233	Composition, 22kΩ ±5% 1/2W	6100-3225	01121	RC20GF223J	5905-171-2004
R234	Composition, 4.7kΩ ±5% 1/2W	6100-2475	01121	RC20GF472J	5905-279-3504
R235	Composition, 4.7kΩ ±5% 1/2W	6100-2475	01121	RC20GF472J	5905-279-3504
CAPACITORS					
C201	Mica, 470pF ±10% 500V	4700-0600	14655	22A5T47	
C202	Plastic, 0.001μF ±10% 200V	4860-7309	84411	663UW, 0.001μF ±10%	
C203	Ceramic, 100pF, +80-20% 50V	4404-1109	72982	831, 100pF +80-20%	
C204	Ceramic, 0.05pF +80-20% 50V	4403-3500	01121	40-503W	5910-883-7321
C205	Ceramic, 100pF ±10 NM 500V	4400-4600	72982	315GP6, 100pF ±10%	5910-668-3463
C206	Electrolytic, 25μF 50V	4450-3000	56289	D33883	5910-799-9285
C207	Electrolytic, 25μF 50V	4450-3000	56289	D33883	5910-799-9285
C208	Electrolytic, 25μF 50V	4450-3000	56289	D33883	5910-799-9285
C209	Electrolytic, 25μF 50V	4450-3000	56289	D33883	5910-799-9285
MISCELLANEOUS					
CR201	DIODE, Type 1N935	6083-1026	07910	1N935	5960-760-9599
CR202	DIODE, Type 1N967B	6083-1016	28959	1N967B	
CR203	DIODE, Type 1N3253	6081-1001	79089	1N3253	5961-814-4251
CR204	DIODE, Type 1N191	6082-1008	93916	1N191	5961-296-3360
CR205	DIODE, Type 1N191	6082-1008	93916	1N191	5961-296-3360
M201	METER, 650Ω ±20%	5730-1090	40931	MEDS 109	
	METER COVER, Honeywell	ME-3-701			
Q201	TRANSISTOR, Type 2N1377	8210-1377	96214	2N1377	5960-950-3449
Q202	TRANSISTOR, Type 2N910	8210-1037	24454	2N910	
Q203	TRANSISTOR, Type 2N910	8210-1037	24454	2N910	
Q204	TRANSISTOR, Type 2N1304	8210-1304	01295	2N1304	5961-892-0800
Q205	TRANSISTOR, Type 2N1131	8210-1025	96214	2N1131	5960-788-8644
V201	TUBE, Type TUE-3	8380-5887	24655	TUE-3	
V202	TUBE, Type CK6418	8380-6418	94144	CK6418	5960-537-3967
V203	TUBE, Type NE-2	8390-0200	24446	NE-2	6240-179-1811



NOTE UNLESS SPECIFIED

1. POSITION OF ROTARY SWITCHES SHOWN COUNTERCLOCKWISE.
2. CONTACT NUMBERING OF SWITCHES EXPLAINED ON SEPARATE SHEET SUPPLIED IN INSTRUCTION BOOK.
3. REFER TO SERVICE NOTES IN INSTRUCTION BOOK FOR VOLTAGES APPEARING ON DIAGRAM.
4. RESISTORS 1/2 WATT.
5. RESISTANCE IN OHMS K = 1000 OHMS M = 1 MEGOHM
6. CAPACITANCE VALUES ONE AND OVER IN PICOFARADS. LESS THAN ONE IN MICROFARADS.
7. ○ KNOB CONTROL
8. ⊘ SCREWDRIVER CONTROL
9. AT ANCHOR TERMINAL
10. TP = TEST POINT

Figure 5-4. Schematic diagram of detector circuit.

PARTS LIST – POWER SUPPLY

Ref. No.	Description	Part No.	Fed. Mfg. Code	Mfg. Part No.	Fed. Stock No.
RESISTORS					
R501	Composition, 4.7kΩ ±5% 1/2W	6100-2475	01121	RC20GF472J	5905-279-3504
R502	Composition, 470kΩ ±5% 1/2W	6100-4475	01121	RC20GF474J	5905-279-2515
R503	Composition, 470kΩ ±5% 1/2W	6100-4475	01121	RC20GF474J	5905-279-2515
R504	Composition, 470kΩ ±5% 1/2W	6100-4475	01121	RC20GF474J	5905-279-2515
R505	Composition, 470kΩ ±5% 1/2W	6100-4475	01121	RC20GF474J	5905-279-2515
R506	Composition, 1MΩ ±5% 1/2W	6100-5105	01121	RC20GF105J	5905-192-0390
R507	Composition, 2kΩ ±5% 1/2W	6100-2205	01121	RC20GF202J	5905-190-8887
R508	Composition, 3.9kΩ ±5% 1/2W	6100-2395	01121	RC20GF392J	5905-279-3505
R509	Potentiometer, Composition, 2.5kΩ ±10%	6010-0700	01121	JU, 2.5kΩ ±10%	5905-910-5671
R510	Composition, 10kΩ ±5% 1/2W	6100-3105	01121	RC20GF103J	5905-185-8510
R511	Composition, 9.1kΩ ±5% 1/2W	6100-2915	01121	RC20GF912J	5905-249-4200
R512	Composition, 11kΩ ±5% 1/2W	6100-3115	01121	RC20GF113J	5905-279-2667
R513	Potentiometer, Composition, 100kΩ ±10%	6010-1700	01121	JU, 100kΩ ±10%	5905-797-1054
R514	Composition, 20kΩ ±5% 1/2W	6100-3205	01121	RC20GF203J	5905-192-0649
R515	Composition, 47Ω ±5% 1/2W	6100-0475	01121	RC20GF470J	5905-252-4018
R516	Composition, 300Ω ±5% 1/2W	6100-1305	01121	RC20GF301J	5905-279-5481
R517	Film, 249kΩ ±1% 2W	6590-3249	75042	MDH, 249kΩ ±1%	5905-727-0286
R518	Film, 150kΩ ±1% 1W	6550-3150	75042	MEF, 150kΩ ±1%	5905-553-2392
R519	Film, 49.9kΩ ±1% 1/2W	6450-2499	75042	CEC, 49.9kΩ ±1%	5905-553-2201
R520	Film, 24.9kΩ ±1% 1/4W	6350-2249	75042	CEB, 24.9kΩ ±1%	5905-577-6741
R521	Film, 15kΩ ±1% 1/8W	6250-2150	75042	CEA, 15kΩ ±1%	5905-581-7626
R522	Film, 4.99kΩ ±1% 1/8W	6250-1499	75042	CEA, 4.99kΩ	
R523	Wire-wound, 6.8Ω ±5% 2W	6760-9685	75042	BWH, 6.8Ω ±5%	5905-965-8779
R524	Wire-wound, 6.8Ω ±5% 2W	6760-9685	75042	BWH, 6.8Ω ±5%	5905-965-8779
R525	Power, 10kΩ ±5% 5W	6660-3105	80183	246E, 10kΩ ±5%	5905-840-2578
MISCELLANEOUS					
C501	Electrolytic, 25μF 100V	4450-5596	80183	DEE, 25μF, 100V	
C502	Electrolytic, 10μF 250V	4450-2100	37942	97681	5910-318-6508
C503	Electrolytic, 4μF 475V	4450-2000	80183	D32845	5910-893-0879
C504	Electrolytic, 44μF 475V	4450-2000	80183	D32845	5910-893-0879
C505	Electrolytic, 10μF 250V	4450-2100	37942	97681	5910-318-6508
C506	Electrolytic, 4μF 475V	4450-2000	80183	D32845	5910-893-0879
C507	Electrolytic, 4μF 475V	4450-2000	80183	D32845	5910-893-0879
C508	Ceramic, 0.0047μF ±10% 500V	4407-2478	72982	841, 0.0047μF ±10%	5910-842-9584
CR501	DIODE, Type 1N3253	6081-1001	79089	1N3253	5961-814-4251
CR502	DIODE, Type 1N3036A	6083-1025	79089	LMZ-12-0A	5961-933-7412
CR503	DIODE, Type 1N3255	6081-1003	79089	1N3255	5961-964-5242
CR504	DIODE, Type 1N3255	6081-1003	79089	1N3255	5961-964-5242
CR505	DIODE, Type 1N3255	6081-1003	79089	1N3255	5961-964-5242
CR506	DIODE, Type 1N3255	6081-1003	79089	1N3255	5961-964-5242
CR507	DIODE, Type 1N3255	6081-1003	79089	1N3255	5961-964-5242
CR508	DIODE, Type 1N3255	6081-1003	79089	1N3255	5961-964-5242
CR509	DIODE, Type 1N748A	6083-1002	07910	1N748A	5960-800-3973
CR510	DIODE, Type 1N3255	6081-1003	79089	1N3255	5961-964-5242
F501	FUSE, 115V, 0.2A	5330-0600	71400	MDL, 0.2A	
	FUSE, 230V, 0.1A	5330-0400	71400	MDL, 0.1A	5920-356-2185
F502	FUSE, 115V, 0.2A	5330-0600	71400	MDL, 0.2A	
	FUSE, 230V, 0.1A	5330-0400	71400	MDL, 0.1A	5920-356-2185
J501	BINDING POST, EXTERNAL	0938-3002	24655	0938-3002	
J502	BINDING POST, EXTERNAL	0938-3002	24655	0938-3002	
J503	BINDING POST, EXTERNAL	0938-3002	24655	0938-3002	
P501	PILOT LIGHT, POWER ON	7510-1380	72765	121-7-204 (red)	
P502	PILOT LIGHT, VOLTAGE APPLIED	7510-1380	72765	121-7-204 (red)	
PL501	Power Cord	4200-1903	24655	4200-1903	
Q501	TRANSISTOR, Type 2N910	8210-1037	24454	2N910	
Q502	TRANSISTOR, Type 2N1131	8210-1025	96214	2N1131	5960-788-8644
S501	SWITCH, Rotary Wafer	7890-3300	76854	Type HC	
T501	TRANSFORMER	0345-4004	24655	0345-4004	
V501	TUBE, Type 7239	8380-7239	24446	7239	5960-060-7592

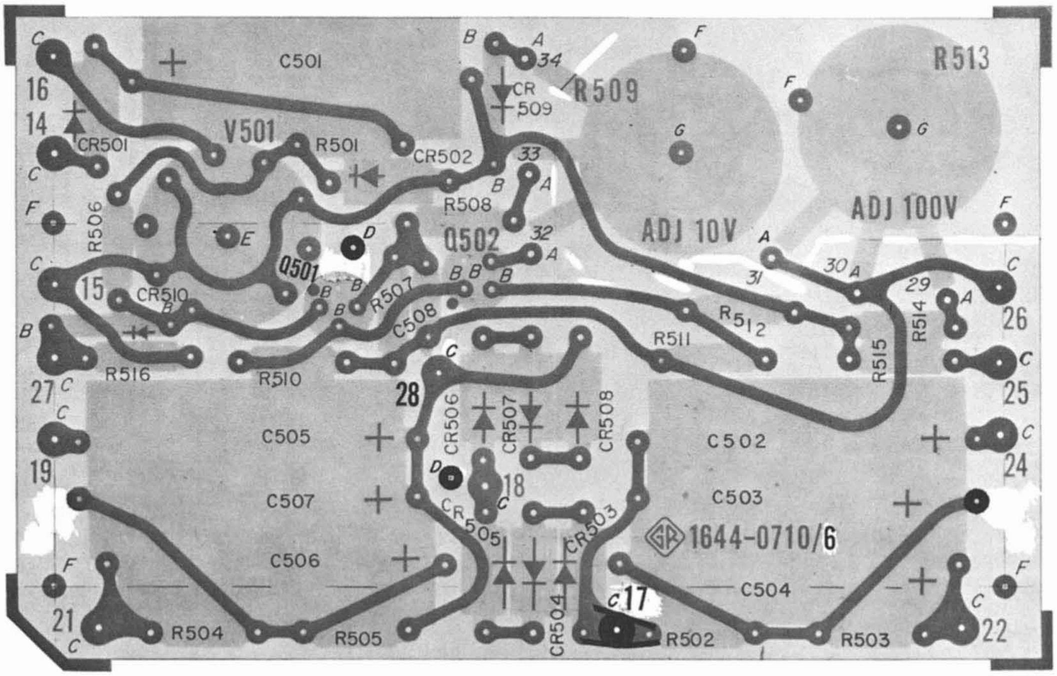
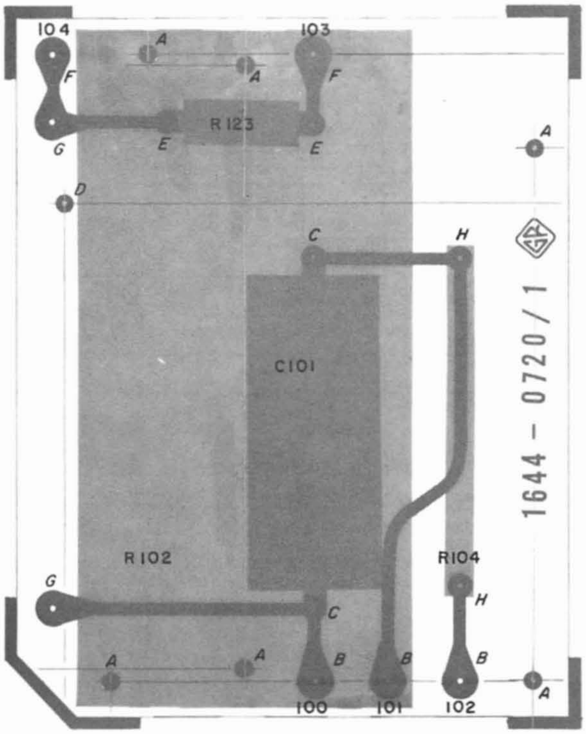


Figure 5-5. Etched-board layout for power supply (P/N 1644-2700).

NOTE: The number appearing on the foil side is not the part number.
The dot on the foil at the transistor socket indicates the collector lead.



NOTE: The number appearing on the foil side is not the part number. The dot on the foil at the transistor socket indicates the collector lead.

Figure 5-6. Etched-board layout for bridge circuit (P/N 1644-2721).

PARTS LIST – BRIDGE CIRCUIT

Ref No.	Description	Part No.	Fed. Mfg. Code	Mfg. Part No.	Fed. Stock No.
RESISTORS					
R101	5.6-5.95kΩ	0433-4120	24655	0433-4120	
R102	Wire-wound, 475kΩ ±0.1%	0510-2001	24655	0510-2001	
R103	Potentiometer, Wire-wound, 50kΩ ±5%	0975-4060	24655	0975-4060	
R104	Precision, 25kΩ ±0.2%	6690-4267	24655	6690-4267	
R105	Wire-wound, 9.92Ω ±1/4%	0510-3905	24655	0510-3905	
R106	Wire-wound, 100Ω ±1/4%	6188-0100	75042	MEC-T2, 100Ω ±1/4%	
R107	Wire-wound, 1kΩ ±1/4%	6188-1100	75042	MEC-T2, 1kΩ, ±1/4%	
R108	Wire-wound, 10kΩ ±1/4%	6188-2100	75042	MEC-T2, 10kΩ ±1/4%	
R109	Wire-wound, 100kΩ ±1/4%	6188-3100	75042	MEC-T2, 100kΩ ±1/4%	
R110	Film, 1MΩ, ±1/4% 50 1/2W	6193-4100	75042	MEC, 1MΩ ±1/4%	
R111	Film, 10MΩ ±1/4% 50 2W	6195-5100	75042	MEH, 10MΩ ±1/4%	
R112	Film, 95.3MΩ ±1% 2W	6592-5953	75042	MDH, 95.3MΩ ±1%	
R113	Potentiometer, Composition, 10MΩ ±20%	6010-2800	01121	JU, 10MΩ ±20%	5905-065-0705
R114	Film, 95.3* MΩ ±1% 2W	6592-5953	75042	MDH, 95.3MΩ, ±1%	
R115	Film, 10MΩ ±1% 1W	6188-5100	75042	MEC-T2, 10MΩ ±1%	
R116	Film, 953kΩ* ±1% 1W	6250-3953	75042	CEA, 953kΩ ±1%	
R117	Potentiometer, Composition, 250kΩ ±10%	6010-2000	24655	6010-2000	5905-055-5061
R118	500MΩ ±2%	6740-1500	63060	RX-1, 500MΩ ±2%	
R119	Film, 10MΩ ±1% 1W	6188-5100	75042	MEC-T2, 10MΩ ±1%	
R120	Film, 475kΩ ±1% 1W	6250-3475	75042	CEA, 475kΩ ±1%	5905-646-5681
R121	Potentiometer, Composition, 100kΩ ±10%	6010-1700	01121	JU, 100kΩ ±10%	5905-797-1054
R122	Composition, 100kΩ ±5% 1/2W	6450-3110	75042	CEC-TO, 100kΩ ±5%	
R123	Wire-wound, 1kΩ ±10% 2W	6760-2109	75042	BWH, 1kΩ ±10%	
MISCELLANEOUS					
C101	Plastic, 1μF ±10% 100V	4860-8274	84411	663UW, 1μF ±10%	
J101	BINDING POST, Insulated, GUARD	0938-3002	24655	0938-3002	
J102	BINDING POST, Uninsulated, Ground	0938-3022	24655	0938-3022	
J103	BINDING POST, Insulated, - UNKNOWN	0938-4158	24655	0938-4158	
J104	BINDING POST, Insulated, + UNKNOWN	0938-4158	24655	0938-4158	
S101	SWITCH, Rotary Wafer	7890-3270	76854	Type HC	
S102	SWITCH, Rotary Wafer	7890-3280	76854	Type HC	
S103	SWITCH, Rotary Wafer	7890-3290	76854	Type HC	
S104	SWITCH	7910-0400	04009	83072-S	

Rotary switch sections are shown as viewed from the panel end of the shaft. The first digit of the contact number refers to the section. The section nearest the panel is 1, the next section back is 2, etc. The next two digits refer to the contact. Contact 01 is the first position clockwise from a strut screw (usually the screw above the locating key), and the other contacts are numbered sequentially (02, 03, 04, etc), proceeding clockwise around the section. A suffix F or R indicates that the contact is on the front or rear of the section, respectively.

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4. RESISTORS 1/2 WATT.
5. RESISTANCE IN OHMS K - 1000 OHMS M - 1 MEGOHM
6. CAPACITANCE VALUES ONE AND OVER IN PICOFARADS, LESS THAN ONE IN MICROFARADS.
7. ◯ KNOB CONTROL
8. ⊘ SCREWDRIVER CONTROL
9. AT ANCHOR TERMINAL
10. TP - TEST POINT

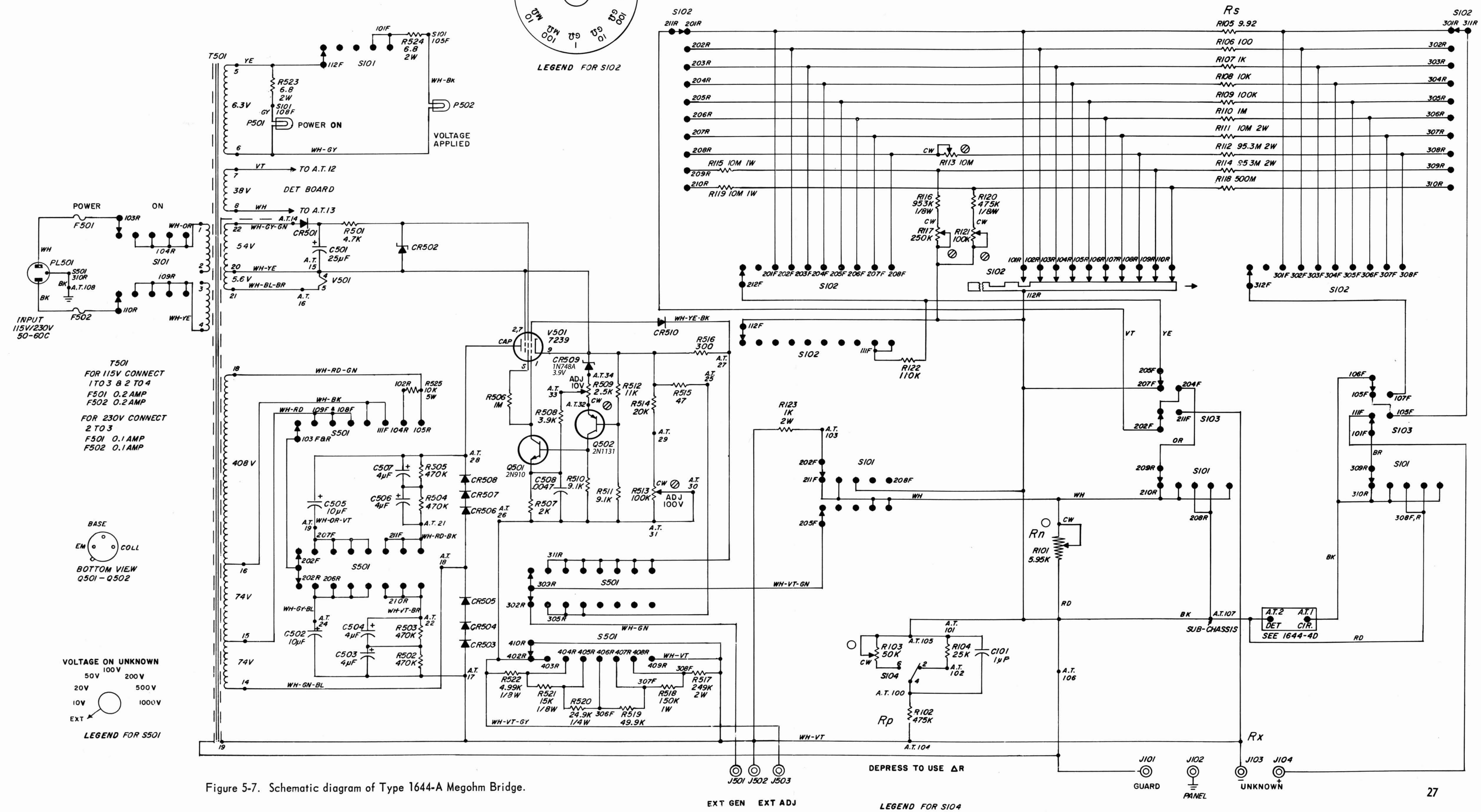


Figure 5-7. Schematic diagram of Type 1644-A Megohm Bridge.

RESISTORS

Detailed specifications on General Radio resistors available for use with this bridge.

Because of its accuracy of adjustment, long-term stability, low- and uniform-temperature coefficient, and relative immunity to ambient humidity conditions, the wire-wound resistor is the most suitable type for use as a laboratory standard at audio and low radio frequencies, as well as at dc. In the resistance range from a fraction of an ohm to over one megohm, such resistors have been developed to a high state of refinement through improvements in design and manufacturing techniques.

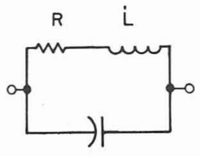


Figure 1.

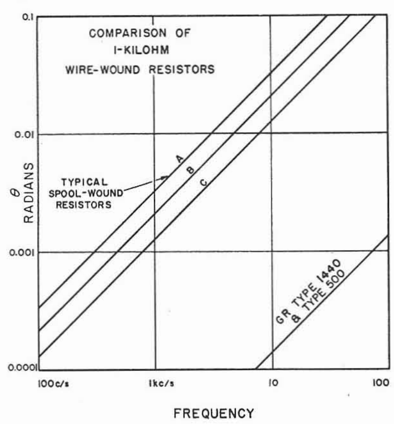


Figure 2.

Resistors designed for ac use differ from those intended for use only at dc in that low series reactance and constancy of resistance as frequency is varied are important design objectives. The residual capacitance and inductance become increasingly important as the frequency is raised, acting to change the terminal resistance from its low-frequency value.

For frequencies where the resistance and its associated residual reactances behave as lumped parameters, the equivalent circuit of a resistor can be represented as shown in Figure 1. L is the equivalent inductance in series with the resistance, and C is the equivalent capacitance across the terminals of the resistor.

It is necessary to differentiate clearly between the concepts of equivalent series and equivalent parallel circuits. The two-terminal circuit of Figure 1 can be described as an impedance $R_s + jX_s$ or as an admittance $G + jB = \frac{1}{R_p} + \frac{1}{jX_p}$, wherein the parameters are a function of frequency. This distinction between series and parallel components is more than a mathematical exercise — the use to which the resistor is to be put will frequently determine which component is of principal interest.

The expression for the effective series impedance is:

$$Z_s = R_s + jX_s = \frac{R + j\omega\left[L\left(1 - \frac{\omega^2}{\omega_r^2}\right) - R^2C\right]}{\left(1 - \frac{\omega^2}{\omega_r^2}\right)^2 + (\omega RC)^2}$$

where $\omega_r = \frac{1}{\sqrt{LC}}$ and $\frac{\omega^2}{\omega_r^2} = \omega^2 LC$.

The effective parallel admittance is given by:

$$Y = G + jB = \frac{1}{R_p} + \frac{1}{jX_p} = \frac{\frac{1}{R} + j\omega\left[C - \frac{L}{R^2}\left(1 - \frac{\omega^2}{\omega_r^2}\right)\right]}{1 + \left(\frac{\omega L}{R}\right)^2}$$

At low frequencies where terms in ω^2 are negligible, the resistor may be represented by a two-element network consisting of the dc resistance, R, in series with an inductance equal to $L - R^2C$ or in parallel with a capacitance equal to $C - L/R^2$. Because of the presence of the R^2 term in the equivalent reactive parameters, shunt capacitance is the dominating residual for high values of resistance, while for low values the series inductance invariably predominates. Generally, individual wire-wound resistors above a few kilohms are capacitive, while decades are capacitive at somewhat lower values.

In the simplified circuit above, the effective parallel resistance of a high-valued resistor in which shunt capacitance dominates would be independent of frequency. Actually, other effects may cause the parallel resistance to decrease with frequency. For example, dielectric losses in the shunt capacitance, C, of Figure 1 are equivalent to a resistance

$$R_d = \frac{1}{D\omega C}$$

(where D is the dissipation factor of the distributed capacitance), which decreases with frequency and causes the effective parallel resistance to decrease rapidly beyond a certain frequency. In addition, distributed capacitance along the winding causes a similar rapid decrease in resistance even if its dielectric loss is negligible. The equations above indicate that the effective series resistance of low-valued resistors would be independent of frequency up to quite high frequencies. In practice, if the residual inductance and capacitance are kept small, skin effect becomes the main cause for departure from the low-frequency value of these resistors.

General Radio wire-wound resistance elements are designed to minimize inductance in low-resistance values and to minimize capacitance for high values of resistance. All units up through 200 ohms utilize an Ayrton-Perry winding, in which each resistor consists of two windings in opposite directions, such that their magnetic fields are opposed and largely

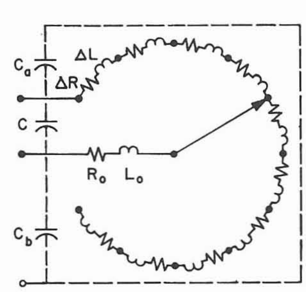


Figure 3. Equivalent circuit of a resistance decade, showing location and nature of residual impedances.

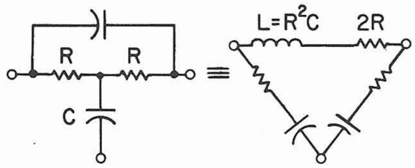


Figure 4. Equivalent wye and delta networks for a resistor with capacitance to shield. The presence of the capacitance, C, gives the resistor an apparent inductive component, $L = R^2C$.

cancel. For very low-valued units, the residual inductance of such a winding is of the order of 1% of that of a corresponding single winding.

Elements having 500-ohm resistance or higher are unifilar-wound on flat rectangular "cards," and have inherently less inductance than so-called "noninductive" spool-wound types because of the low cross-sectional area of the winding (refer to Figure 2). The capacitance of a card-type resistor is also much lower than that of a spool type because the turns of wire are not piled up but are evenly wound in one layer.

These wire-wound resistors exhibit a negligible frequency error in resistance up to about 500 kc/s for values up to 500 ohms, and only moderate errors at 1Mc/s.

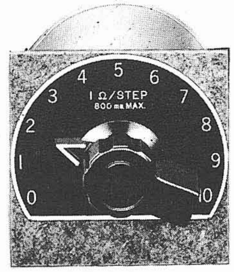
In decade boxes, the residual impedances of the switches, wiring, and cabinet are added to those of the resistors themselves. The equivalent circuit is then that of Figure 3, which represents a single Type 510 decade. For multiple-decade boxes, the series inductances are additive, but the capacitance is approximately that across the highest valued decade used (see specifications for each type).

The effect of the residual reactance depends greatly upon the way the resistor is connected in the circuit. For example, parallel capacitance can often be compensated for when the resistor is connected in parallel with a capacitor. For high-valued resistors, the upper frequency limit for a given error is some ten times higher in the effective parallel resistance than it is for the series connection.

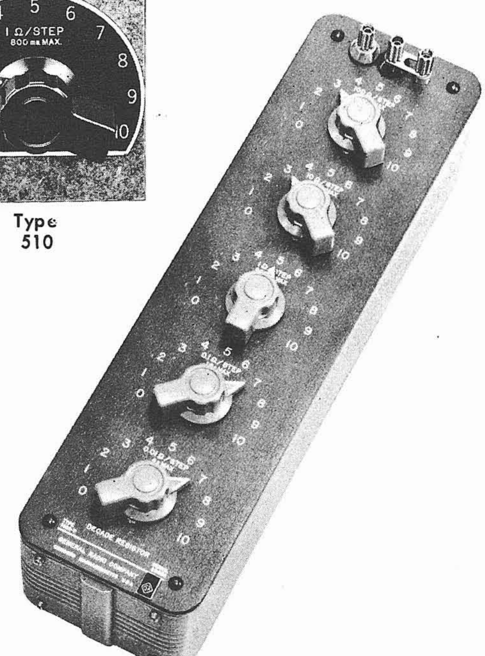
General Radio decade boxes have a separate terminal for the case. With a three-terminal connection, the capacitance is reduced because capacitance from the resistor terminals to the case (C_a and C_b in Figure 3) are guarded and do not shunt the resistance. Moreover, this direct impedance can appear slightly inductive due to distributed capacitance from resistor to case, as explained by the wye-delta transformation of Figure 4.

The resistance material used for most General Radio units is Evanohm,* an alloy with excellent stability, very low and constant temperature coefficient, low thermal emf with copper, and high tensile strength. It is relatively insensitive to humidity and strain. For resistance units of less than 5 ohms, the older, well-known manganin alloy is used because its lower resistivity allows wire dimensions that are easier to work with and to adjust.

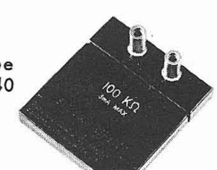
* Registered trademark of the Wilbur B. Driver Company.



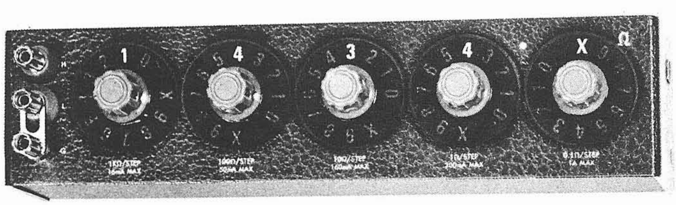
Type 510



Type 1432



Type 1440



Type 1434

Type	*Name*	*Use*
1440	Standard Resistor	Laboratory standard
1434	Decade Resistor	Resistance box, small, compact
1432	Decade Resistor	Resistance box, highest accuracy
510	Decade-Resistance Unit	Circuit component

Type 1432 DECADE RESISTORS

Type 510 DECADE-RESISTANCE UNITS

FEATURES:
±0.025% accuracy. ■ Low thermal emf to copper.
Low zero resistance. ■ Low temperature coefficient of resistance.
Resistance increments, as well as total value, are always correctly indicated.
Good frequency characteristics. ■ Residual reactances are small and known.
Excellent stability. ■ Unaffected by high humidity.

USES: The Type 1432 Decade Resistors are primarily intended for precision measurement applications where their excellent accuracy, stability, and low zero resistance are important. They are convenient resistance standards for checking the accuracy of resistance measuring devices and are used as components in dc and audio-frequency impedance bridges. Many of the models can be used up into the radio frequency range. While they are also useful as substitution boxes for optimizing electronic circuitry, the less expensive Type 1434 Decade Resistors are recommended for such less exacting applications.

The individual decades (Type 510 Decade-Resistance Units) are available for applications requiring only one decade or as components to be built into experimental equipment, production test equipment, or commercial instruments.

DESCRIPTION: Each Type 510 Decade-Resistance Unit is enclosed in an aluminum shield, and a knob and etched-metal dial plate are supplied. The switch assemblies, less resistors, are also available as the Type 510-P4 and -P4L Switches.

The Type 1432 Decade Resistor is an assembly of Type 510 Decade-Resistance Units in a single cabinet. Mechanical as well as electrical shielding of the units and switch contacts is provided by the attractive aluminum cabinet and panel. The resistance elements have no electrical connection to the cabinet and panel, for which a separate shield terminal is provided.

Each decade has eleven contact studs and ten resistors in series. All the contact studs in the lower-valued decades have a silver overlay to ensure stability of resistance, and all the decades have a silver contact on the zero setting to give low and constant zero resistance.

Winding methods are chosen to reduce the effects of residual reactances. The 1-, 10-, and 100-ohm steps use winding techniques that minimize inductance. The 0.01- and 0.1-ohm steps are straight wire and hairpin-shaped ribbon respectively, and the high valued units are straight wound on mica forms.

SPECIFICATIONS

Long-Term Accuracy: ±0.025% for resistance settings on decades above 100 Ω per step. For lower resistance settings, see table. Our general two-year warranty applies to these tolerances unless the unit is damaged by excessive current. Tolerance shown applies to both resistance increments and total resistance after correction for zero resistance.

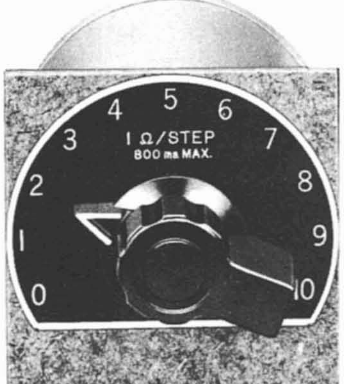
Maximum Current: The maximum current for each decade is given in the table below and also appears on the panel of each decade box and on the dial plate of each decade resistance unit.

Frequency Characteristic: The accompanying plot shows the maximum percentage change in effective series resistance, as a function of frequency for the individual decade units. For low-resistance decades the error is due almost entirely to skin effect and is independent of switch setting, while for the high-resistance units the error is due almost entirely to the shunt capacitance and its losses and is approximately proportional to the square of the resistance setting.

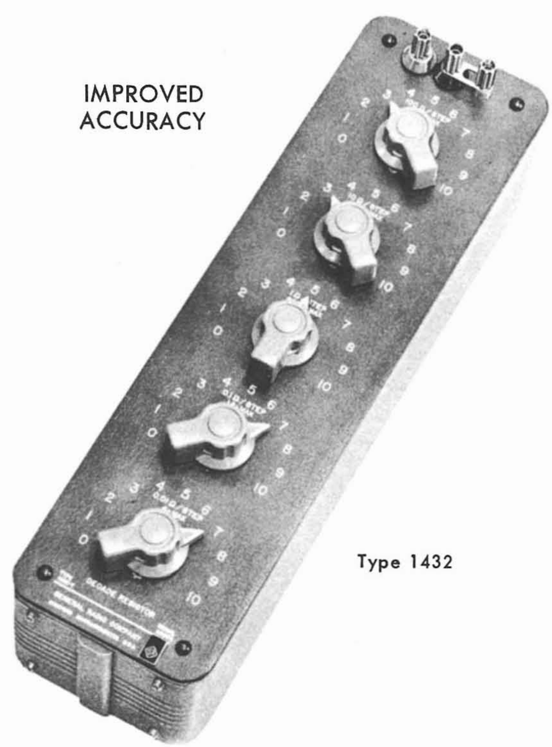
The high-resistance decades (Types 510-E, -F, -G, and -H) are very commonly used as parallel resistance elements in resonant circuits, in which the shunt capacitance of the decades becomes part of the tuning capacitance. The parallel resistance changes by only a fraction (between a tenth and a hundredth) of the series-resistance change, depending on frequency and the insulating material in the switch.

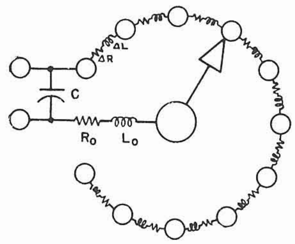
Characteristics of the Type 1432 Decade Resistors are similar to those of the individual Type 510 units, modified by the increased series inductance, L_o, and shunt capacitance, C, due to the wiring and the presence of more than one decade in the assembly. At total resistance settings of approximately 1000 ohms or less, the frequency characteristics of any of these decade resistors are substantially the same as those shown for the Type 510 units. At higher settings, shunt capacitance becomes the controlling factor, and the effective value of this capacitance depends upon the settings of the individual decades.

IMPROVED ACCURACY

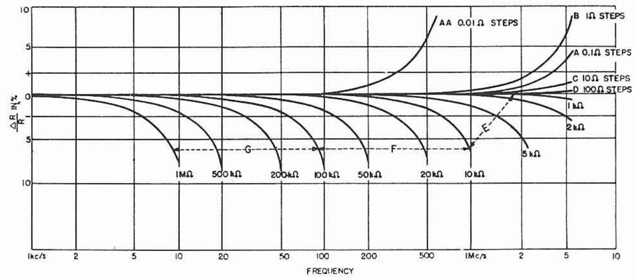


Type 510


Type 1432



(Left). Equivalent circuit of a resistance decade, showing location and nature of residual impedances.



(Right) Maximum percentage change in series resistance as a function of frequency for Type 510 Decade-Resistance Units.

Typical Values of R_o, L_o, and C for the Decade Resistors:

Zero Resistance (R_o): 0.001 Ω per dial at dc; 0.04 Ω per dial at 1 Mc/s; proportional to square root of frequency at all frequencies above 100 kc/s.

Zero Inductance (L_o): 0.1 μH per dial.

Effective Shunt Capacitance (C): This value is determined largely by the highest decade in use. With the low terminal connected to shield, a value of 15 to 10 pF per decade may be assumed, counting decades down from the highest. Thus, if the third decade from the top is the highest resistance decade in circuit (i.e., not set at zero), the shunting terminal capacitance is 45 to 30 pF. If the highest decade in the assembly is in use, the effective capacitance is 15 to 10 pF, regardless of the settings of the lower-resistance decades.

Temperature Coefficient of Resistance: Less than ±10 ppm per degree C for values above 100 Ω and ±20 ppm per degree C for 100 Ω and below, at room temperatures. For the Type 1432 Decade Resistors, the box wiring will increase the over-all temperature coefficient of the 0.1- and 0.01-Ω decades.

Switches: Quadruple-leaf brushes bear on lubricated contact studs of ⅜-in diameter in such a manner as to avoid cutting but yet give a good wiping action. A cam-type detent is provided. There are eleven contact points (0 to 10 inclusive). The switch resistance is less than 0.0005 Ω. The effective capacitance is of the order of 5 pF, with a dissipation factor of 0.06 at 1 kc/s for the standard cellulose-filled molded phenolic switch form and 0.01 on the mica-filled phenolic form used in the Type 510-G and 510-H units.

Maximum Voltage to Case: 2000 V peak.

Terminals: For Type 1432, low-thermal-emf jack-top binding posts on standard ¾-in spacing. Shield terminal is provided. Type 510 units have soldering lugs.

Mounting: Type 1432, lab-bench cabinet Type 510, complete with dial plate, knob, template, and mounting screws.

Mechanical Data:

Type 1432	*Width*		*Height*		*Length*		*Net Wt*		*Ship Wt*	
	in	*mm*	*in*	*mm*	*in*	*mm*	*lb*	*kg*	*lb*	*kg*
4-Dial	4⁵⁄₁₆	110	4¾	125	13	330	5¼	2.4	6	2.8
5-Dial	4⁵⁄₁₆	110	4¾	125	15¾	400	6¼	2.9	7	3.2
6-Dial	4⁵⁄₁₆	110	4¾	125	18¼	465	7½	3.5	9	4.1
Type 510	*Diameter*		*Depth Behind Panel*				*oz*	*kg*	*lb*	*kg*
	3¹⁄₁₆	78	3⁵⁄₁₆	85			11	0.4	2	1

DECADE RESISTORS

Catalog Number		*Total Ohms*	*Multiple of*	*No. of Dials*	*Type 510 Decades Used*
1432-9721	**Type 1432-U**	111.1	0.01 ohm	4	AA, A, B, C
1432-9711	**Type 1432-K**	1111	0.1	4	A, B, C, D
1432-9710	**Type 1432-J**	11,110	1	4	B, C, D, E
1432-9712	**Type 1432-L**	111,100	10	4	C, D, E, F
1432-9717	**Type 1432-Q**	1,111,000	100	4	D, E, F, G
1432-9720	**Type 1432-T**	1111.1	0.01	5	AA, A, B, C, D
1432-9714	**Type 1432-N**	11,111	0.1	5	A, B, C, D, E
1423-9713	**Type 1432-M**	111,110	1	5	B, C, D, E, F
1432-9716	**Type 1432-P**	1,111,100	10	5	C, D, E, F, G
1432-9725	**Type 1432-Y**	11,111,000	100	5	D, E, F, G, H
1432-9724	**Type 1432-X**	111,111	0.1	6	A, B, C, D, E, F
1432-9726	**Type 1432-Z**	11,111,100	10	6	C, D, E, F, G, H
1432-9702	**Type 1432-B**	1,111,110	1	6	B, C, D, E, F, G
1432-9723	**Type 1432-W**	11,111.1	0.01	6	AA, A, B, C, D, E

DECADE-RESISTANCE UNITS

Catalog Number		*Total Resistance Ohms*	*Resistance Per Step (ΔR) Ohms*	*Accuracy of Resistance Increments*	*Maximum Current 40° C Rise*	*Power Per Step Watts*	*ΔL μH*	*C** pF*	*L_o μH*
0510-9806	**Type 510-AA**	0.1	0.01	±2%	4 A	0.16	0.01	7.7–4.5	0.023
0510-9701	**Type 510-A**	1	0.1	±0.5%	1.6 A	0.25	0.014	7.7–4.5	0.023
0510-9702	**Type 510-B**	10	1	±0.15%	800 mA	0.6	0.056	7.7–4.5	0.023
0510-9703	**Type 510-C**	100	10	±0.05%	250 mA	0.6	0.11	7.7–4.5	0.023
0510-9704	**Type 510-D**	1000	100	±0.025%	80 mA	0.6	0.29	7.7–4.5	0.023
0510-9705	**Type 510-E**	10,000	1000	±0.025%	23 mA	0.5	3.3	7.7–4.5	0.023
0510-9706	**Type 510-F**	100,000	10,000	±0.025%	7 mA	0.5	9.5	7.7–4.5	0.023
0510-9707	**Type 510-G**	1,000,000	100,000	±0.025%	2.3 mA	0.5	—	7.7–4.5	0.023
0510-9708	**Type 510-H**	10,000,000	1,000,000	±0.025%	0.7* mA	0.5	—	13.5–5.0	0.023
0510-9604	**Type 510-P4**	Switch only	(Black Phenolic Frame)						
0510-9511	**Type 510-P4L**	Switch only	(Low-Loss Phenolic Frame)						

* Or a maximum of 4000 V, peak.
** The larger capacitance occurs at the lowest setting of the decade. The values given are for units without the shield cans in place. With the shield cans in place, the shunt capacitance is from 10 to 20 pF greater than indicated here, depending on whether the shield is tied to the switch or to the zero end of the decade.

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