OPERATING INSTRUCTIONS

TYPE 1644-A

MEGOHM BRIDGE

8161

1644-A

GENERAL RADIO COMPANY

A

OPERATING INSTRUCTIONS

TYPE 1644-A

MEGOHM BRIDGE

Form 1644-0100-A
July, 1964

GENERAL RADIO COMPANY
WEST CONCORD, MASSACHUSETTS, USA

SPECIFICATIONS

Resistance Range: 1 kilohm to 1000 teraohms (10^3 to 10^{15} ohms) in ten decade ranges.

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

Test Voltage:

Fixed Voltages	10	20	50	100	volts
Minimum Resistance for Unknown	1	3	7	20	kilohms

Fixed Voltages	200	500	1000	volts
Minimum Resistance for Unknown	50	150	500	kilohms

Voltage accuracy is ± 3% ± 0.5 volt.

Short-Circuit Current: <15 milliamperes at 10 to 50 volts; <10 milliamperes at 100 to 1000 volts.

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

Minimum Test Voltage for 1% Resolution: (for approximately 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 Requirements: 105 to 125 (or 210 to 250) volts, 50 to 60 cps, 13 watts.

Cabinet: Flip-Tilt.

Dimensions: Width 12¾, height 12½, depth 7¾ inches (325 by 320 by 200 mm), over-all; with case closed and including handle.

Net Weight: 18 pounds (8.5 kg).

Shipping Weight: 22 pounds (10 kg).

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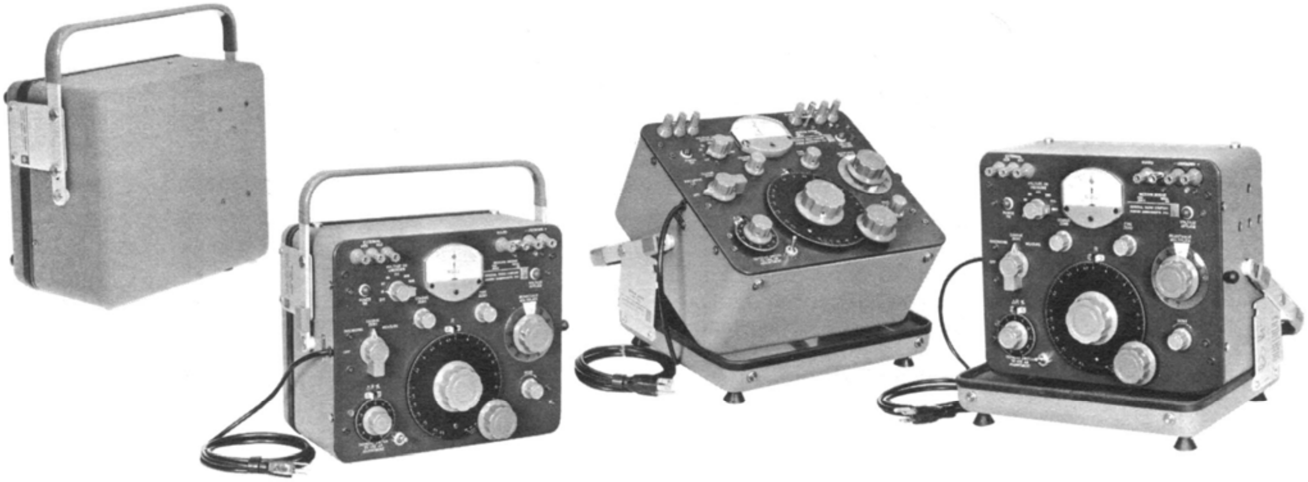
Figure 1-1. The Type 1644-A Megohm Bridge. The convenient Flip-Tilt case provides protection during transport and storage and holds open at any convenient viewing angle.



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 ($\Delta R\%$) 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:

$1\ \mathrm{k}\Omega = 10^3\ \Omega$

$1\ \mathrm{M}\Omega = 10^6\ \Omega = 10^3\ \mathrm{k}\Omega$

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

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

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.
SENS	Continous rotary control	Adjusts the sensitivity of the detector circuit. (See paragraph 2.4.)
ΔR%	Spring return, toggle 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.)
EXTERNAL GEN	Pair of insulated binding posts	For connection of an external voltage supply. (See paragraph 3.10.)
EXTERNAL 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.

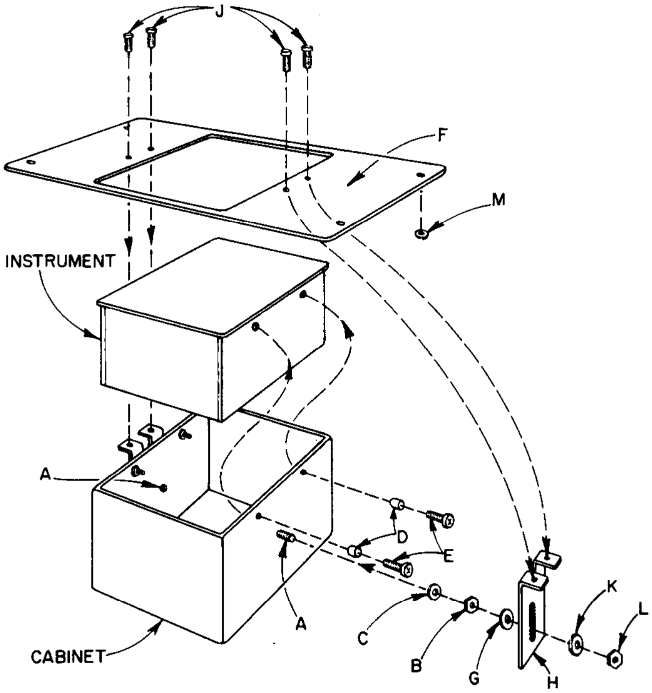


Figure 2-1. Rack mounting of the Type 1644-A.

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 230 to 115 volts, this simply means removal of the 230-v nameplate; a 115-v legend is marked beneath. For instruments changed to 230 volts, a nameplate (Type 5590-1664) may be ordered from General Radio.

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.

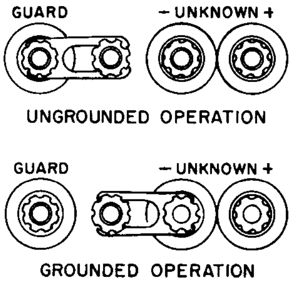


Figure 2-2. Grounding link connected to the GUARD terminal (top) and the – UNKNOWN terminal (bottom).

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	15 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 ±20% 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 high 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

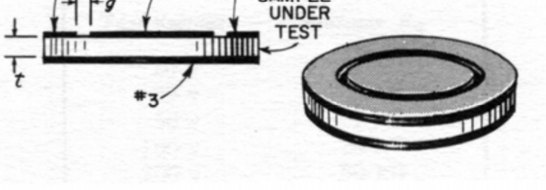


Figure 3-1. Electrode arrangement for insulation testing of solid materials.

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*	*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.

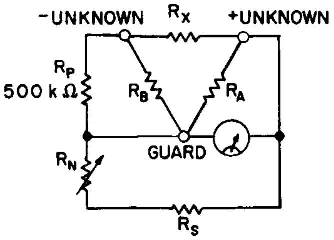


Figure 3-2. Three-terminal resistance measurement.

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.

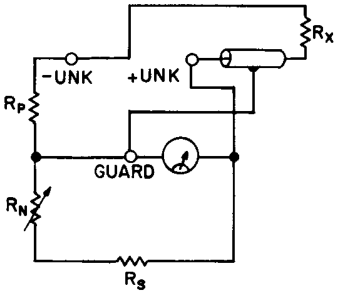


Figure 3-3. Connection for remote measurements.

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.

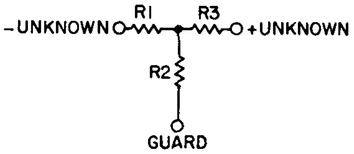


Figure 3-4a. Y configuration of a three-terminal standard.

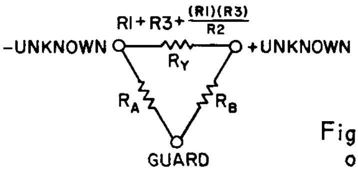


Figure 3-4b. Delta configuration of a three-terminal standard.

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

$R_O = 100\ \mathrm{M\Omega}$ (see Table 3-2).

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

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:

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

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:

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

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:

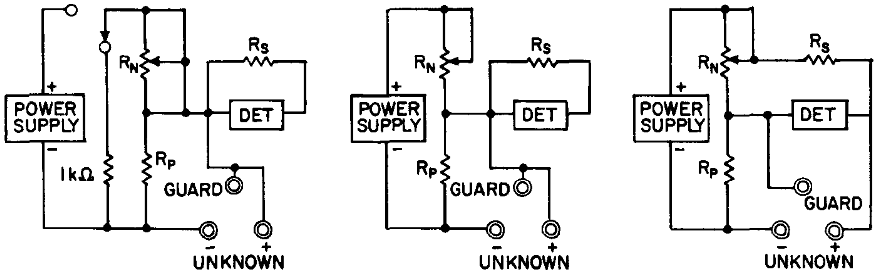
a. Clean the binding posts with a dry, clean cloth. Make sure that there is no dust or moisture between the UNKNOWN binding posts or between them and the panel.

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



DISCHARGE CHARGE MEASURE

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 meassured 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.

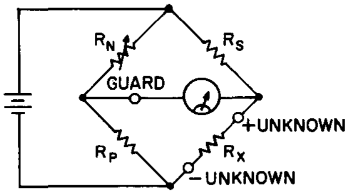


Figure 4-1. Elementary schematic diagram of the bridge circuit.

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%.

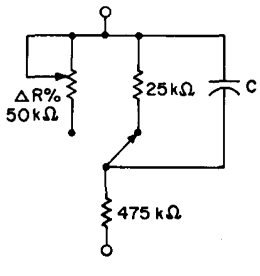


Figure 4-2. Bridge circuit with ΔR% control added.

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 five lower ranges use wire-wound ratio-arm resistors, the next two 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

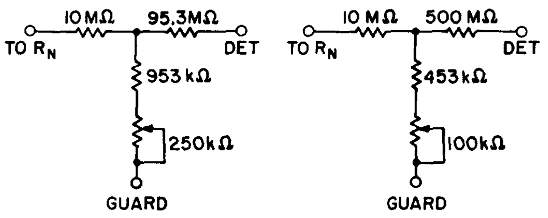


Figure 4-3. The ratio-arm T networks for the two highest ranges.

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).

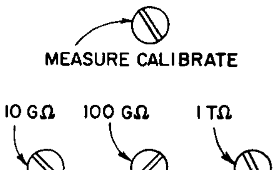


Figure 5-1. Calibration controls for the three highest ratio arms. The measure-calibrate switch is shown in the measure position. Rotate the switch clockwise to calibrate.

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

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.

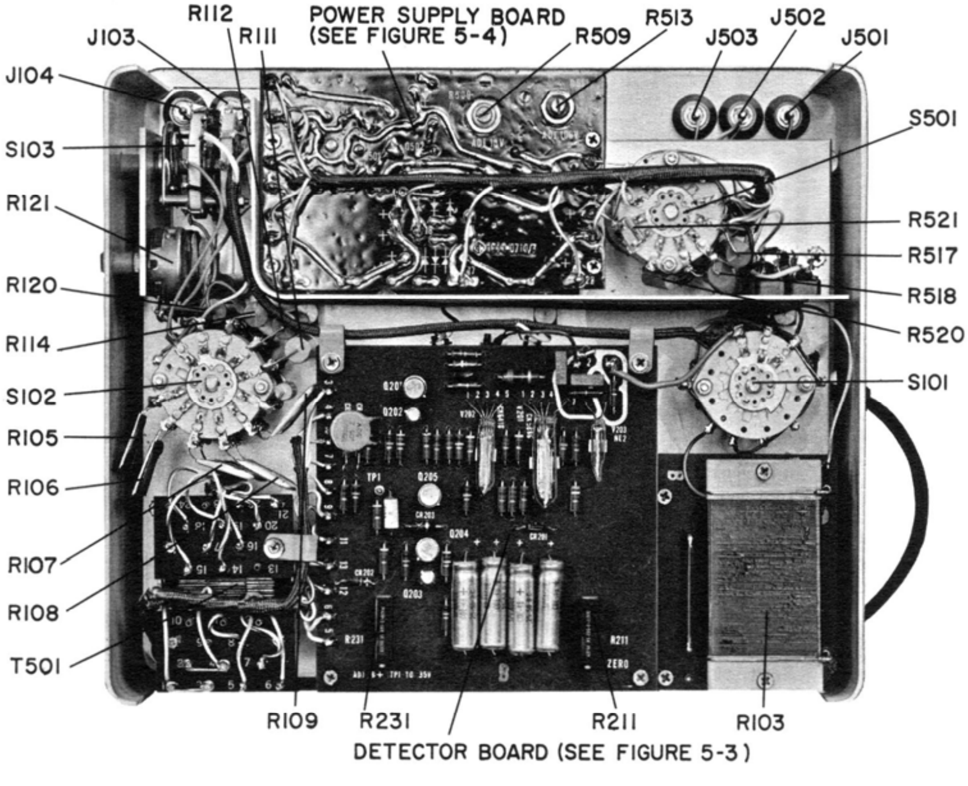


Figure 5-2. Interior view of the Type 1644-A.

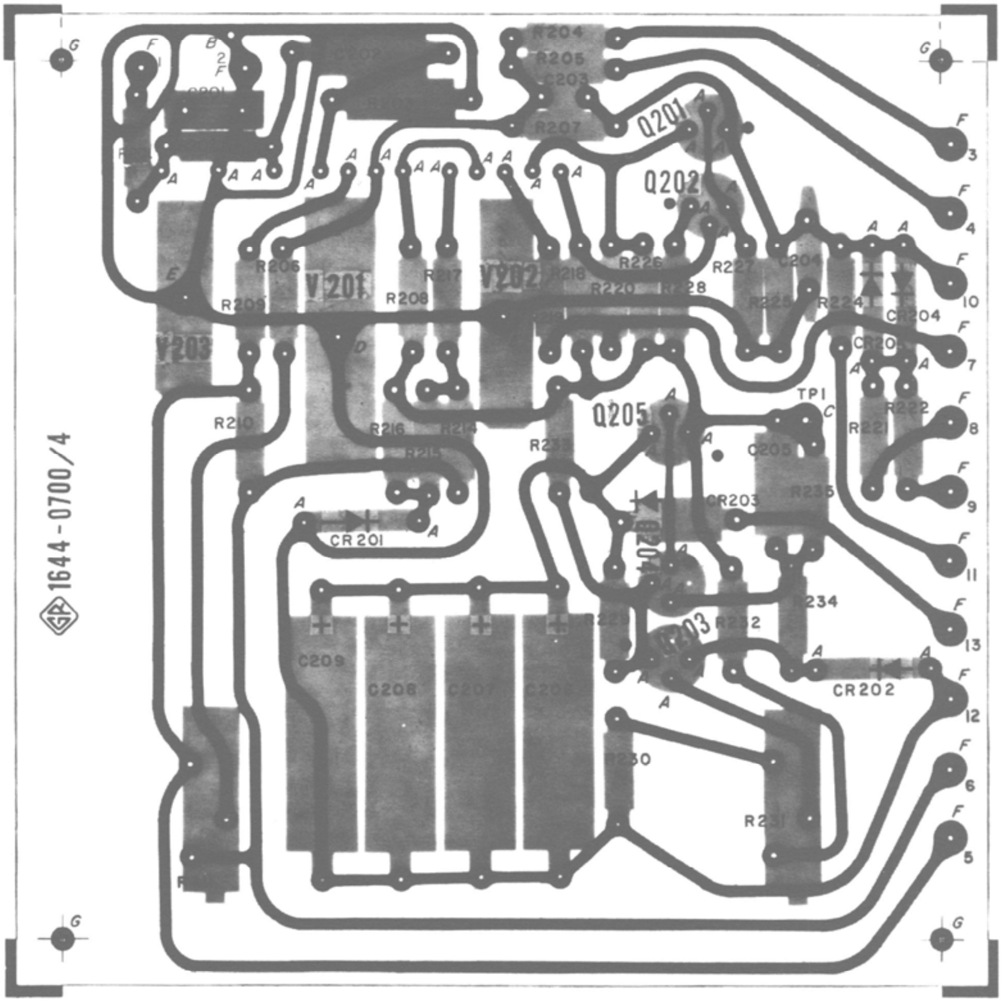


Figure 5-3. Etched-board layout for detector circuit.

PARTS LIST – DETECTOR CIRCUIT

Ref. No.	*Description*	*Part No.*
R210	RESISTOR, Composition 100 MΩ ±5% 1/2 w	1644-0420
R202	RESISTOR, Composition 100 MΩ ±5% 1/2 w	1644-0420
R203	RESISTOR, Wire-wound 200 Ω ±5% 2 w	6760-1205
R204	RESISTOR, Composition 10 MΩ ±5% 1/2 w	6100-6105
R205	RESISTOR, Composition 150 kΩ ±5% 1/2 w	6100-4155
R206	RESISTOR, Composition 22 kΩ ±5% 1/2 w	6100-3225
R207	RESISTOR, Composition 2.2 MΩ ±5% 1/2 w	6100-5225
R208	RESISTOR, Composition 4.7 MΩ ±5% 1/2 w	6100-5475
R209	RESISTOR, Composition 150 Ω ±5% 1/2 w	6100-1155
R210	RESISTOR, Composition 390 Ω ±5% 1/2 w	6100-1395
R211	POTENTIOMETER, Wire-wound 5 kΩ ±10%	6059-2509
R212	POTENTIOMETER, Wire-wound 5 kΩ ±5%	0971-3913
R213	POTENTIOMETER, Wire-wound 5 kΩ ±5%	0971-3913
R214	RESISTOR, Composition 120 Ω ±5% 1/2 w	6100-1125
R215	RESISTOR, Composition 110 Ω ±5% 1/2 w	6100-1115
R216	RESISTOR, Composition 6.2 kΩ ±5% 1/2 w	6100-2625
R217	RESISTOR, Composition 270 Ω ±5% 1/2 w	6100-1275
R218	RESISTOR, Composition 100 kΩ ±5% 1/2 w	6100-4105
R219	RESISTOR, Composition 470 Ω ±5% 1/2 w	6100-1475
R220	RESISTOR, Composition 750 Ω ±5% 1/2 w	6100-1755
R221	RESISTOR, Composition 10 kΩ ±5% 1/2 w	6100-3105
R222	RESISTOR, Composition 1 kΩ ±5% 1/2 w	6100-2105
R223	POTENTIOMETER, Composition 10 kΩ ±10%	6020-0400
R224	RESISTOR, Composition 300 Ω ±5% 1/2 w	6100-1305
R225	RESISTOR, Composition 20 kΩ ±5% 1/2 w	6100-3205
R226	RESISTOR, Composition 820 Ω ±5% 1/2 w	6100-1825
R227	RESISTOR, Composition 47 kΩ ±5% 1/2 w	6100-3475
R228	RESISTOR, Composition 4.7 kΩ ±5% 1/2 w	6100-2475
R229	RESISTOR, Composition 470-kΩ ±5% 1/2 w	6100-4475
R230	RESISTOR, Composition 20 kΩ ±5% 1/2 w	6100-3205
R231	POTENTIOMETER, Wire-wound 5 kΩ ±10%	6059-2509
R232	RESISTOR, Composition 20 kΩ ±5% 1/2 w	6100-3205
R233	RESISTOR, Composition 22 kΩ ±5% 1/2 w	6100-3225
R234	RESISTOR, Composition 4.7 kΩ ±5% 1/2 w	6100-2475
R235	RESISTOR, Composition 4.7 kΩ ±5% 1/2 w	6100-2475
C201	CAPACITOR, Mica 470 pf ±10% 500 v	4700-0600
C202	CAPACITOR, Plastic 0.001µf ±10% 200 v	4860-7309
C203	CAPACITOR, Ceramic 100 pf +80-20% 50 v	4404-1109
C204	CAPACITOR, Ceramic 0.05 pf +80-20% 50 v	4403-3500
C205	CAPACITOR, Ceramic 100 pf ±10 NM 500 v	4400-4600
C206	CAPACITOR, Electrolytic 25 µf 50 v	4450-3000
C207	CAPACITOR, Electrolytic 25 µf 50 v	4450-3000
C208	CAPACITOR, Electrolytic 25 µf 50 v	4450-3000
C209	CAPACITOR, Electrolytic 25 µf 50 v	4450-3000
CR201	DIODE, Type 1N935	6083-1026
CR202	DIODE, Type 1N967B	6083-1016
CR203	DIODE, Type 1N3253	6081-1001
CR204	DIODE, Type 1N191	6082-1008
CR205	DIODE, Type 1N191	6082-1008
M201	METER, 650 Ω ±20%	5730-1090
Q201	TRANSISTOR, Type 2N1377	8210-1377
Q202	TRANSISTOR, Type 2N910	8210-1037
Q203	TRANSISTOR, Type 2N910	8210-1037
Q204	TRANSISTOR, Type 2N1304	8210-1304
Q205	TRANSISTOR, Type 2N1131	8210-1025
V201	TUBE, Type TUE-3	8380-5886
V202	TUBE, Type CK6418	8380-6418
V203	TUBE, Type NE-2	8390-0200

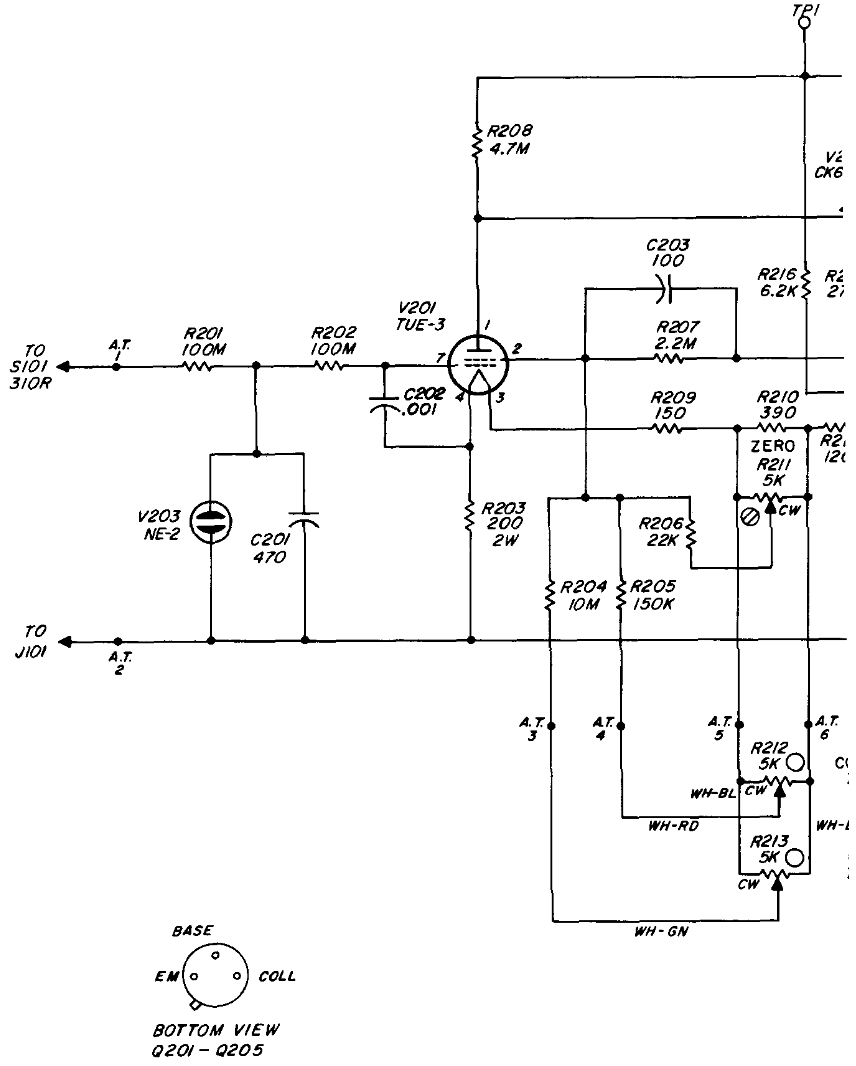
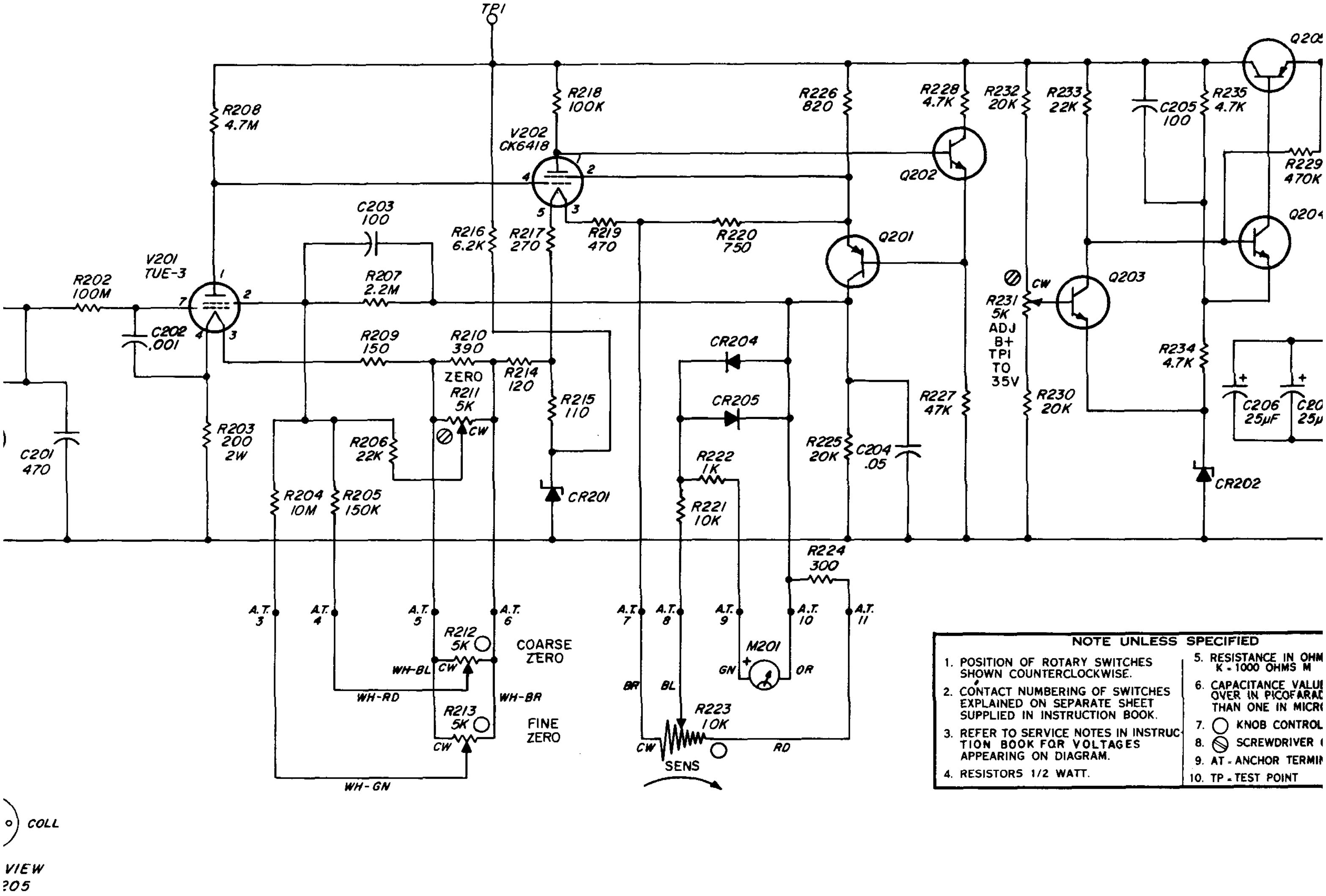

TP1
R208
4.7M
V2
CK6
C203
100
R216
6.2K
R2
2
V201
TUE-3
R207
2.2M
TO
S101
310R
A.T.
1
R201
100M
R202
100M
1
2
7
4
3
C202
.001
R209
150
R210
390
R2
12
ZERO
R211
5K
CW
V203
NE-2
C201
470
R203
200
2W
R206
22K
R204
10M
R205
150K
TO
J101
A.T.
2
A.T.
3
A.T.
4
A.T.
5
A.T.
6
R212
5K
C
WH-BL
CW
WH-RD
WH-
R213
5K
CW
WH-GN
BASE
EM
COLL
BOTTOM VIEW
Q201 – Q205

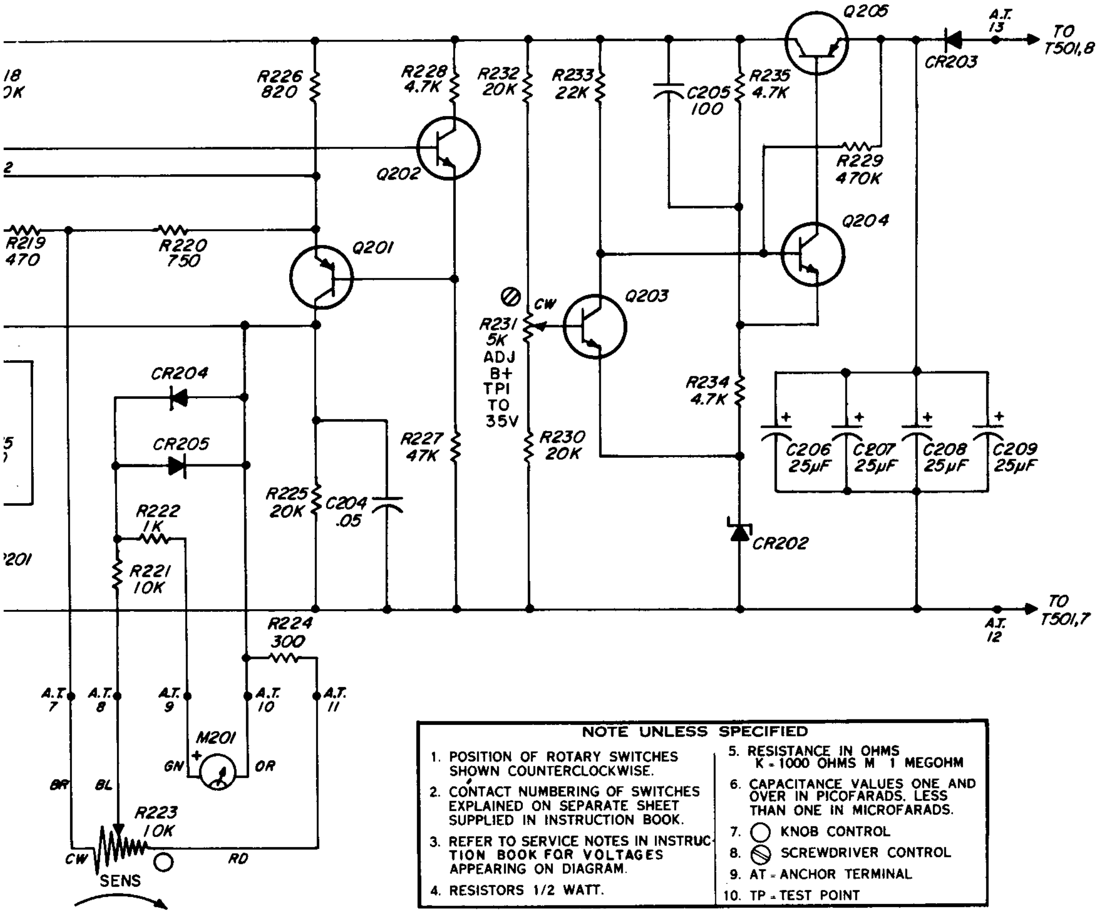
Figure 5-



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 OHM
K = 1000 OHMS M
6. CAPACITANCE VALU
OVER IN PICOFARAD
THAN ONE IN MICR
7. ○ KNOB CONTROL
8. ⊘ SCREWDRIVER
9. AT = ANCHOR TERMIN
10. TP = TEST POINT

Figure 5-4. Schematic diagram of detector circuit.



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

hematic diagram of detector circuit.

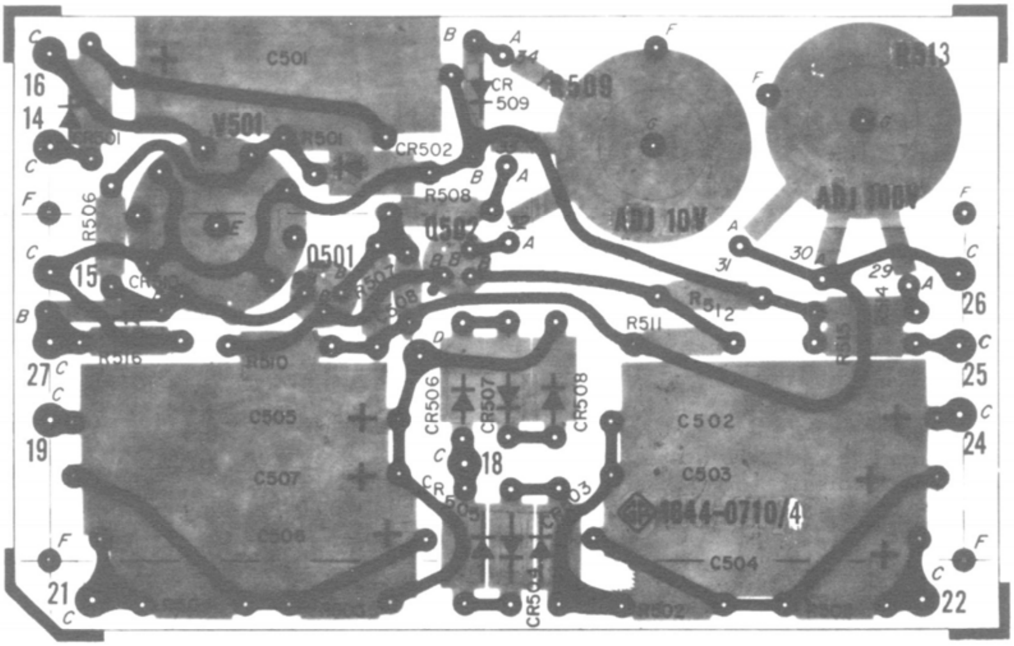


Figure 5-5. Etched-board layout for power supply.

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.

PARTS LIST – POWER SUPPLY

Ref. No.	*Description*	*Part No.*
R501	RESISTOR, Composition 4.7 kΩ ±5% 1/2 w	6100-2475
R502	RESISTOR, Composition 470 kΩ ±5% 1/2 w	6100-4475
R503	RESISTOR, Composition 470 kΩ ±5% 1/2 w	6100-4475
R504	RESISTOR, Composition 470 kΩ ±5% 1/2 w	6100-4475
R505	RESISTOR, Composition 470 kΩ ±5% 1/2 w	6100-4475
R506	RESISTOR, Composition 1 MΩ ±5% 1/2 w	6100-5105
R507	RESISTOR, Composition 2 kΩ ±5% 1/2 w	6100-2205
R508	RESISTOR, Composition 3.9 kΩ ±5% 1/2 w	6100-2395
R509	POTENTIOMETER, Composition 2.5 kΩ ±10%	6010-0700
R510	RESISTOR, Composition 10 kΩ ±5% 1/2 w	6100-3105
R511	RESISTOR, Composition 9.1 kΩ ±5% 1/2 w	6100-2195
R512	RESISTOR, Composition 11 kΩ ±5% 1/2 w	6100-3115
R513	POTENTIOMETER, Composition 100 kΩ ±10%	6010-1700
R514	RESISTOR, Composition 20 kΩ ±5% 1/2 w	6100-3205
R515	RESISTOR, Composition 47 Ω ±5% 1/2 w	6100-0475
R516	RESISTOR, Composition 300 Ω ±5% 1/2 w	6100-1305
R517	RESISTOR, Film 249 kΩ ±1% 2 w	6590-3249
R518	RESISTOR, Film 150 kΩ ±1% 1 w	6550-3150
R519	RESISTOR, Film 49.9 Ω ±1% 1/2 w	6450-9499
R520	RESISTOR, Film 24.9 kΩ ±1% 1/4 w	6350-2249
R521	RESISTOR, Film 15 kΩ ±1% 1/8 w	6250-2150
R522	RESISTOR, Film 4.99 kΩ ±1% 1/8 w	6250-1499
R523	RESISTOR, Wire-wound 6.8 Ω ±5% 2 w	6760-9685
R524	RESISTOR, Wire-wound 6.8 Ω ±5% 2 w	6760-9685
R525	RESISTOR, Power 10kΩ ±5% 5 w	6660-3105
C501	CAPACITOR, Electrolytic 25 µf 100 v	4450-5596
C502	CAPACITOR, Electrolytic 10 µf 250 v	4450-2100
C503	CAPACITOR, Electrolytic 4 µf 475 v	4450-2000
C504	CAPACITOR, Electrolytic 44 µf 475 v	4450-2000
C505	CAPACITOR, Electrolytic 10 µf 250 v	4450-2100
C506	CAPACITOR, Electrolytic 4 µf 475 v	4450-2000
C507	CAPACITOR, Electrolytic 4 µf 475 v	4450-2000
C508	CAPACITOR, Ceramic 0.0047 µf ±10% 500 v	4407-2478
CR501	DIODE, Type 1N3253	6081-1001
CR502	DIODE, Type 1N3036A	6083-1025
CR503	DIODE, Type 1N3255	6081-1003
CR504	DIODE, Type 1N3255	6081-1003
CR505	DIODE, Type 1N3255	6081-1003
CR506	DIODE, Type 1N3255	6081-1003
CR507	DIODE, Type 1N3255	6081-1003
CR508	DIODE, Type 1N3255	6081-1003
CR509	DIODE, Type 1N748A	6083-1002
CR510	DIODE, Type 1N191	6082-1008
F501	FUSE, 115 v, 0.2 a 230 v, 0.1 a	5330-0600 5330-0400
F502	FUSE, 115 v, 0.2 a 230 v, 0.1 a	5330-0600 5330-0400
J501	BINDING POST, EXTERNAL	4060-0400
J502	BINDING POST, EXTERNAL	4060-0400
J503	BINDING POST, EXTERNAL	4060-0400
P501	PILOT LIGHT, POWER ON	7510-1380
P502	PILOT LIGHT, VOLTAGE APPLIED	7510-1380
PL501	Power Cord	4200-1903
Q501	TRANSISTOR, Type 2N910	8210-1037
Q502	TRANSISTOR, Type 2N1131	8210-1025
S501	SWITCH, Rotary Wafer	7890-3300
T501	TRANSFORMER	0345-4004
V501	TUBE, Type 7239	8380-7239

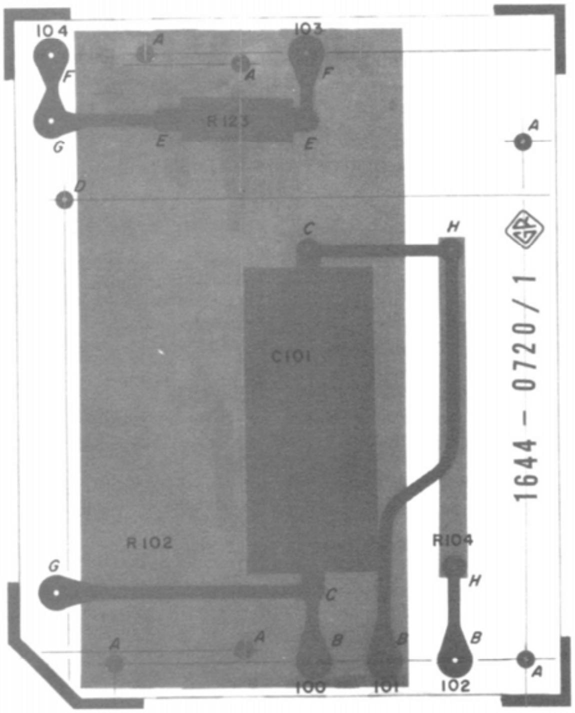


Figure 5-6. Etched-board layout for bridge circuit.

PARTS LIST – BRIDGE CIRCUIT

Ref. No.	*Description*	*Part No.*
R101	RESISTOR, 5.6-5.95 kΩ	0433-4120
R102	RESISTOR, Wire-wound 475 kΩ ±0.1%	0510-2001
R103	POTENTIOMETER, Wire-wound 50 kΩ ±5%	0975-4060
R104	RESISTOR, Precision 25 kΩ ±0.2%	6690-4267
R105	RESISTOR, Wire-wound 9.92 Ω ±1/4%	0510-3905
R106	RESISTOR, Wire-wound 100 Ω ±1/4%	0510-3924
R107	RESISTOR, Wire-wound 1 kΩ ±1/4%	0510-3928
R108	RESISTOR, Wire-wound 10 kΩ ±1/4%	0510-3933
R109	RESISTOR, Wire-wound 100 kΩ ±1/4%	0510-3931
R110	RESISTOR, Film 1 MΩ ±1/4%, 50 1/2 w	6193-4100
R111	RESISTOR, Film 10 MΩ ±1/4%, 50 2 w	6195-5100
R112	RESISTOR, Film 95.3 MΩ ±1% 2 w	6590-5953
R113	POTENTIOMETER, Composition 10 MΩ ±20%	6010-2800
R114	RESISTOR, Film 95.3* MΩ ±1% 2 w	6590-5953
R115	RESISTOR, Film 10 MΩ ±1% 1 w	6550-5100
R116	RESISTOR, Film 953 kΩ* ±1% 1 w	6250-3953
R117	POTENTIOMETER, Composition 250 kΩ ±10%	6010-2000
R118	RESISTOR 500 MΩ ±2%	6740-1500
R119	RESISTOR, Film 10 MΩ ±1% 1 w	6550-5100
R120	RESISTOR, Film 475 kΩ ±1% 1 w	6250-3475
R121	POTENTIOMETER, Composition 100 kΩ ±10%	6010-1700
R122	RESISTOR, Composition 100 kΩ ±5% 1/2 w	6110-4105
R123	RESISTOR, Wire-wound 1 kΩ ±10% 2 w	6760-2109
C101	CAPACITOR, Plastic 1μf ±10% 100 v	4860-8274
J101	BINDING POST, Insulated, GUARD	4060-0400
J102	BINDING POST, Uninsulated, Ground	4060-1800
J103	BINDING POST, Insulated, - UNKNOWN	4060-2428
J104	BINDING POST, Insulated, + UNKNOWN	4060-2428
S101	SWITCH, Rotary Wafer	7890-3270
S102	SWITCH, Rotary Wafer	7890-3280
S103	SWITCH, Rotary Wafer	7890-3290
S104	SWITCH	7910-0400

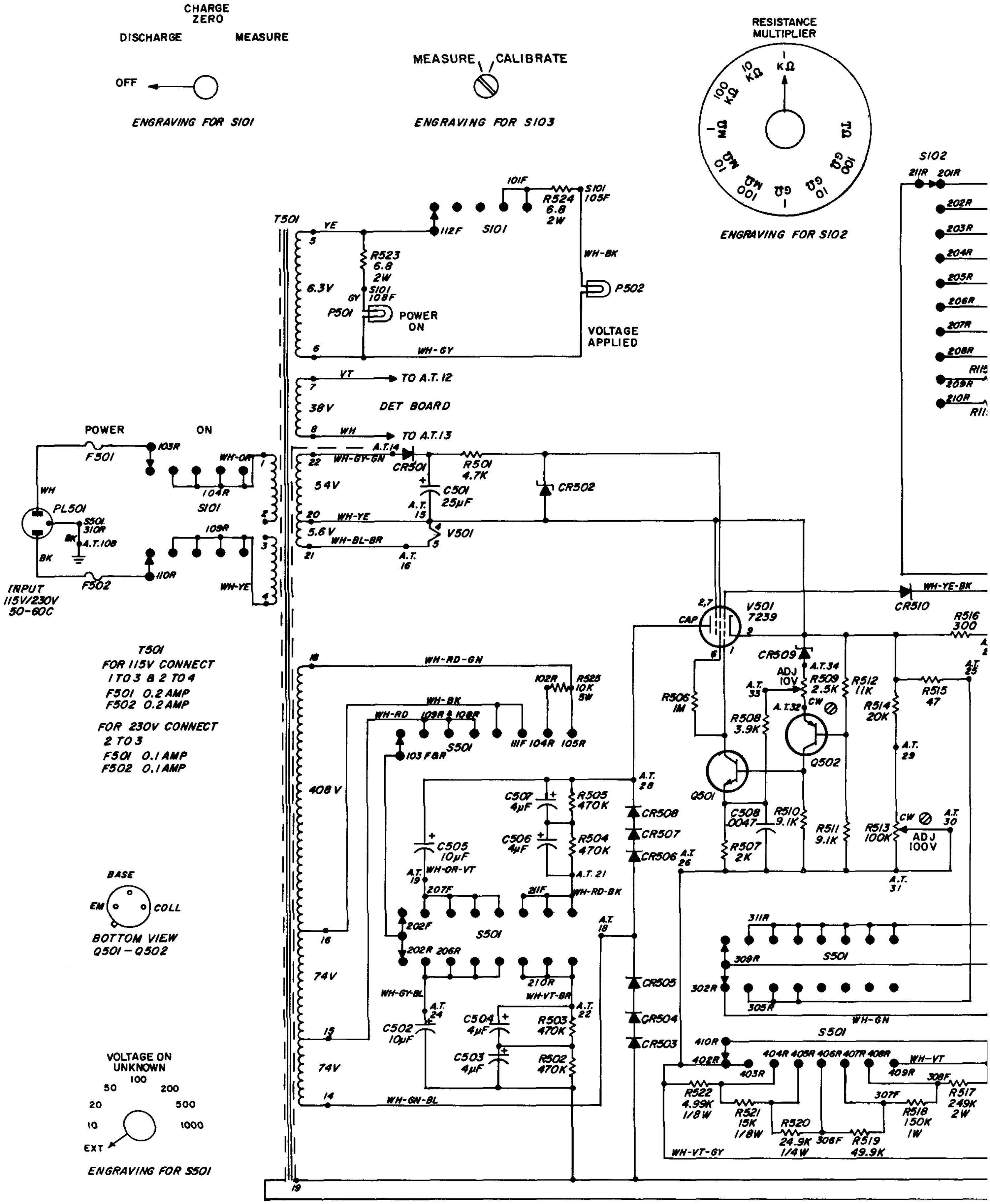
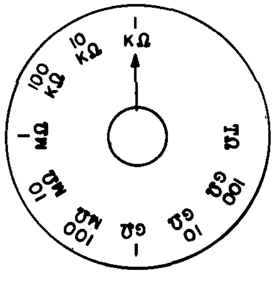


Figure 5-7. Schematic diagram of Type 1644-A Megohm Bridge.

RESISTANCE MULTIPLIER

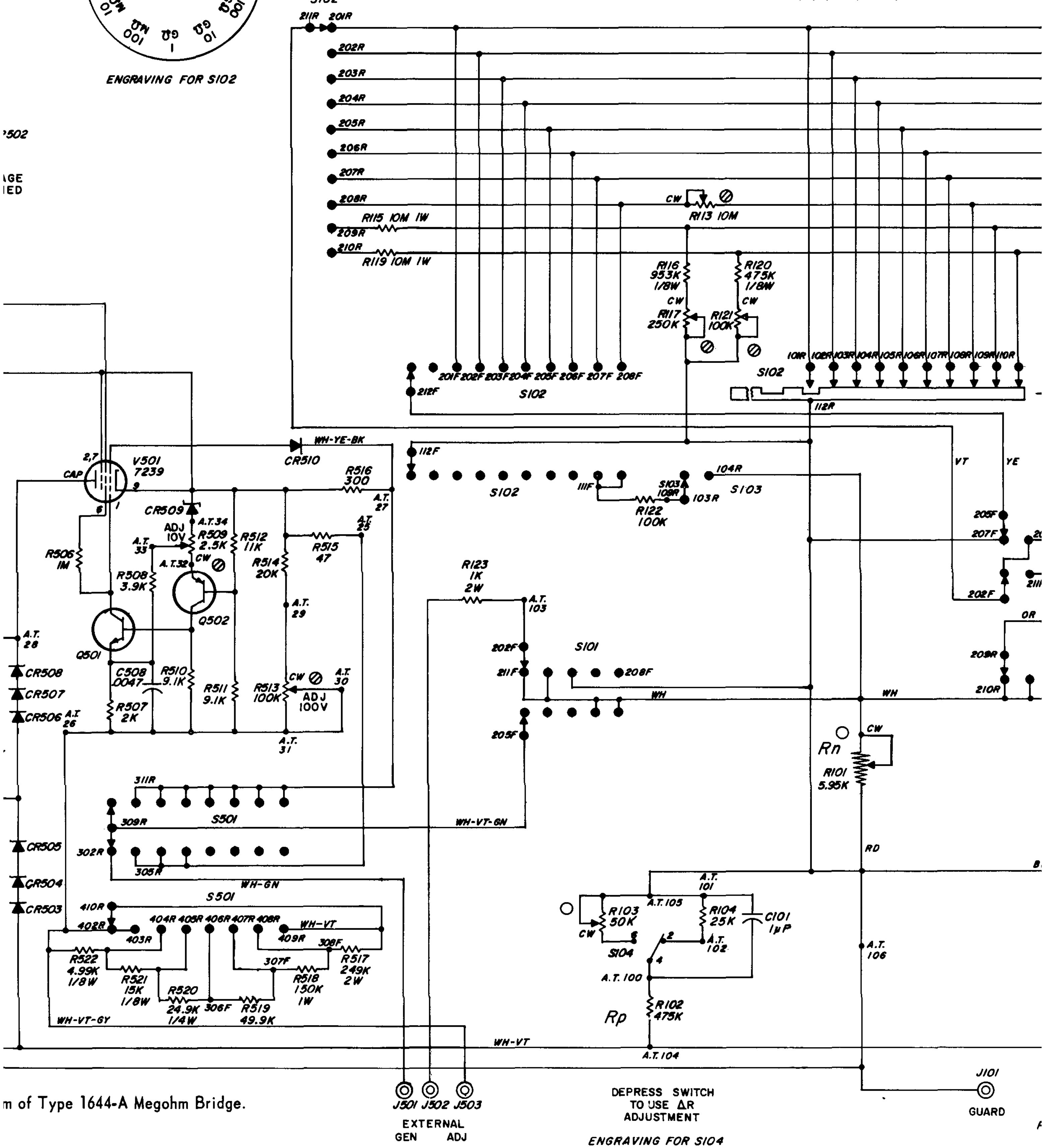


ENGRAVING FOR S102

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

ANCHOR TERMINALS USED: A.T. 14-16,18,19,21,22,24-34,100-108



m of Type 1644-A Megohm Bridge.

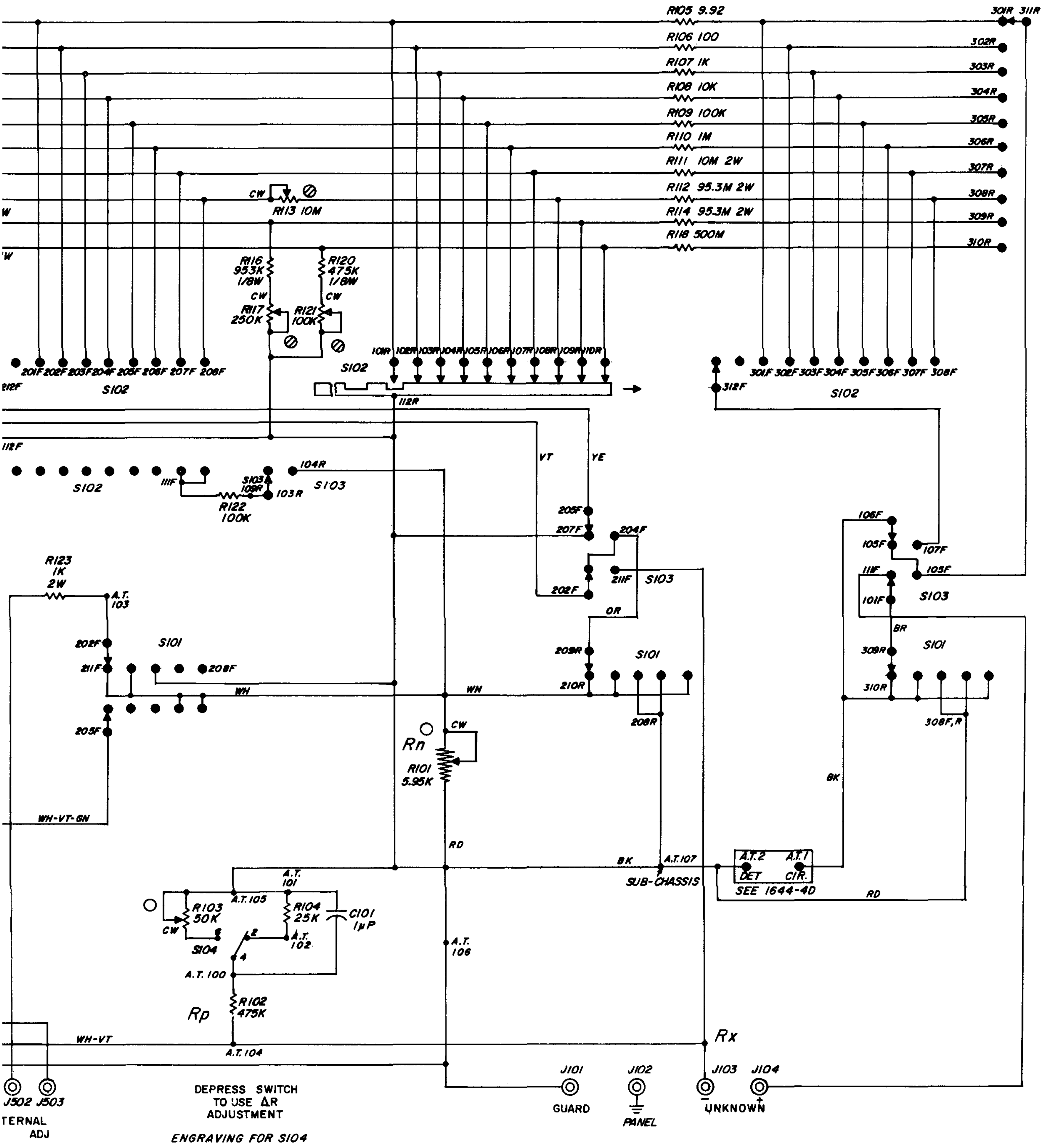
DEPRESS SWITCH
TO USE ΔR
ADJUSTMENT

ENGRAVING FOR S104

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

ANCHOR TERMINALS USED: A.T. 14-16,18,19,21,22,24-34,100-108



Appendix

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 about one megohm, such resistors have been developed to a high state of refinement through improvements in design and manufacturing techniques.

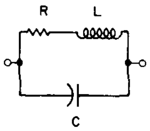


Figure 1.

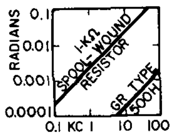


Figure 2.

Resistors designed for ac use differ from those intended for use only at direct current in that low series reactance and constancy of resistance as frequency is varied are important design objectives. Inevitably, resistors have residual capacitance and inductance associated with them, which 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. The inductance, L, is the equivalent inductance in series with the resistance, while the capacitance, 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 (Z) is:

$$Z_s = R_s + jX_s = \frac{R + j\omega\left[L\left(1 - \frac{\omega^2}{\omega_0^2}\right) - R^2C\right]}{\left(1 - \frac{\omega^2}{\omega_0^2}\right)^2 + (\omega RC)^2}$$

where $\omega_0 = \frac{1}{\sqrt{LC}}$ and $\frac{\omega^2}{\omega_0^2} = \omega^2LC.$

The effective parallel admittance is given by:

$$Y = G + jB = \frac{1}{R_p} + \frac{1}{jX_p} = \frac{\frac{1}{R} + j\omega\left[C - \frac{L}{R^2}\left(1 - \frac{\omega^2}{\omega_0^2}\right)\right]}{1 + \left(\frac{\omega L}{R}\right)^2}$$

At low frequencies where terms involving the square of frequency 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 of resistance, the series inductance invariably predominates. Generally, individual wire-wound resistors above a few kilohms are capacitive, while decades, which have increased effective capacitance, 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 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.

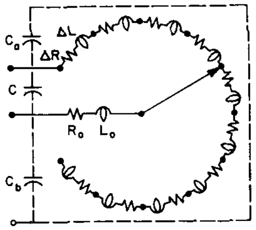


Figure 3. Equivalent circuit of a resistance decade, showing location and nature of residual impedances.

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

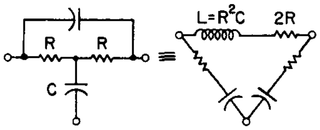
In decade boxes, the residual impedances of the switches, wiring, and cabinet are added to those of the resistors themselves. The equivalent circuit is then that of Figure 3, which represents a single Type 510 decade. For multiple-decade boxes, the series inductances are additive, but the capacitance 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 will often appear slightly inductive due to distributed capacitance along the resistor to the 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 which are easier to work with and to adjust.

Figure 4. Equivalent wye and delta networks for a resistor with capacitance to shield.



Type 1432 DECADE RESISTORS

Type 510 DECADE-RESISTANCE UNITS

USES: Decade resistors are used in circuits where a wide range of resistance values is required or where variable dummy generator and load resistances are needed. The accuracy of General Radio decade resistors easily meets the requirements of these applications and also permits them to be used as laboratory standards and as ratio arms for direct- and alternating-current bridges. Although designed primarily for direct-current and audio-frequency work, many of the models are useful well into the radio-frequency range.

These resistors are available as assemblies of 4, 5, or 6 decades in cabinets for laboratory use, or as shielded single-decade units for building into experimental equipment, production-test instruments, bridges, and other permanent assemblies.

DESCRIPTION: Each Type 510 Decade-Resistance Unit is enclosed in an aluminum shield, and a knob and etched-metal dial plate are supplied. The assembly is also available complete except for resistors, as the Type 510-P3 and -P3L 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, so that the dial values overlap. Positive detent mechanisms and bar-type knobs permit the operator to sense the position of the switches without looking at the panel. Each resistor is adjusted to be accurate within its specified tolerance at its terminals, so that resistance increments are accurate to that tolerance.

Winding methods are chosen to reduce the effects of residual reactances. The 1-ohm steps are Ayrton-Perry wound on molded phenolic forms especially shaped and heat treated to minimize aging effects. The 10- and 100-ohm steps are Ayrton-Perry wound on a form of silicone-fiberglas laminate. The 0.01- and 0.1-ohm steps are straight wire and hairpin-shaped ribbon, respectively, while the 1000-, 10,000-, 100,000-, and 1,000,000-ohm steps are unifilar wound on thin mica cards.

FEATURES:

- Low zero resistance.
- High accuracy.
- Low temperature coefficient of resistance.
- Low thermal emf to copper.
- Resistors are adjusted so that resistance increments are always correctly indicated.
- Good frequency characteristics.
- Residual reactances are small and known.
- Excellent stability.
- Unaffected by high humidity.

SPECIFICATIONS

Accuracy of Adjustment: Each of the 10 resistors in each decade is adjusted to be accurate at its terminals within the tolerances given in the table. Resistance increments are accurate to this same tolerance.

Total Resistance: The resistance at the decade terminals is the sum of the switch resistance (see below) and that indicated by the switch-setting.

Maximum Current: See table. Maximum current is engraved on panels or dial plates.

Frequency Characteristics: 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 characteristic of any of these decade resistors is 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.

Type 1432

Type 510

Type 500 RESISTOR

FEATURES:

- ♦ Convenient and accurate.
- ♦ Low thermal emf to copper.
- ♦ Low temperature coefficient of resistance.
- ♦ Excellent high-frequency characteristics.
- ♦ Standard plug-in terminals.

USES: The Type 500 Resistors are particularly recommended as resistance standards for use in impedance bridges and as secondary standards for laboratory use. The plug-type terminals make them readily interchangeable in experimental equipment. Screw terminals are also supplied for more permanent installations.

DESCRIPTION: This resistor is an accurately adjusted resistance unit wax-sealed in a phenolic case to exclude moisture and to provide protection from mechanical damage. The construction of individual units is similar to that used in the Type 510 Decade-Resistance Units (page 160).

SPECIFICATIONS

Accuracy of Adjustment: ±0.05% at the terminals, except for the 1-ohm unit, which is adjusted within ±0.15%.

Frequency Characteristics: Similar to those of the Type 510 Decade-Resistance Units for resistance values up to 600 ohms; somewhat better for higher resistances, because of the relatively small shunt capacitance of an isolated resistor.

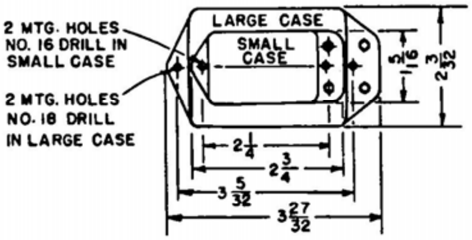
Maximum Power and Current: All units will dissipate one watt for a temperature rise of 40 degrees Centigrade. The value of current for this rise is given in the table below and is engraved on each unit.

Temperature Coefficient: Less than ±20 ppm per degree Centigrade at normal room temperature.

Type of Winding: Less than 500 ohms, Ayrton-Perry; 500 ohms and higher, unifilar on thin mica cards. Types 500-V, W, and X are made up of multiple mica cards in series.

Terminals: Both terminal screws and plugs are supplied. Each terminal stud is recessed as a jack to accommodate a plug. Standard ¾-inch spacing is used. High terminal is marked H.

Mounting: Black molded phenolic case is used for all units having a resistance of less than 1000 ohms. For units having a resistance value of 1000 ohms or higher, a low-loss mica-filled phenolic case is used.



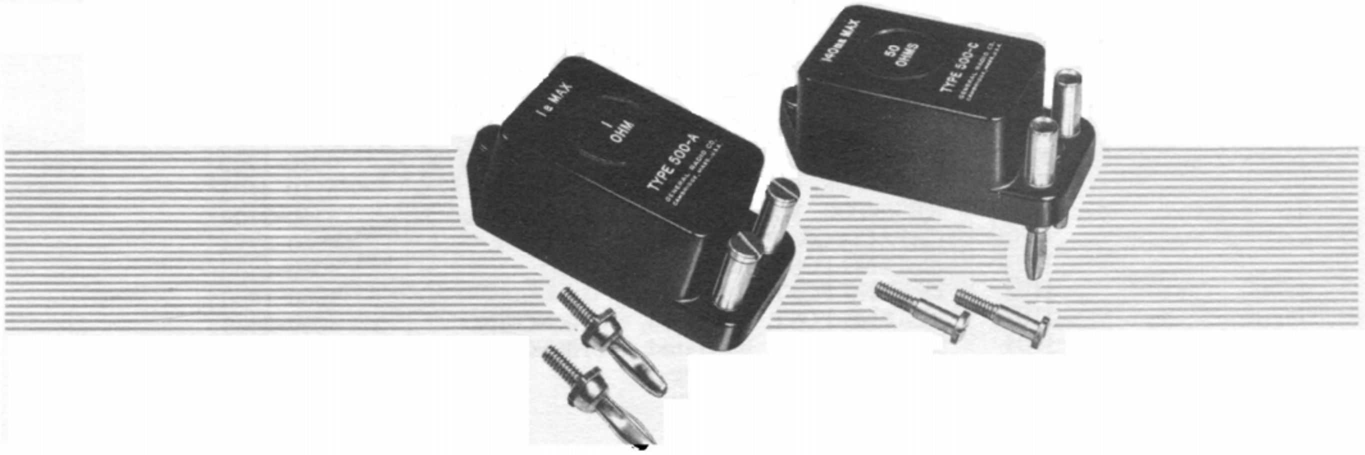
Both types are sealed with a high-melting-point wax. Types 500-A through -V are in small case; Types 500-W and -X in large case.

Dimensions: See sketch, dimensions are in inches. Over-all height, 1⅝ inches for large case, 1 inch for small case, exclusive of plugs. To convert inches to mm, multiply by 25.4.

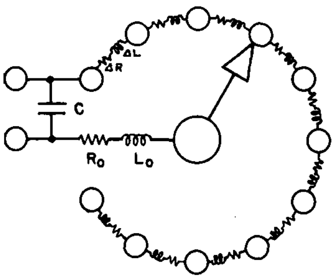
Net Weight: 2 ounces (60 g).

Shipping Weight: 8 ounces (230 g).

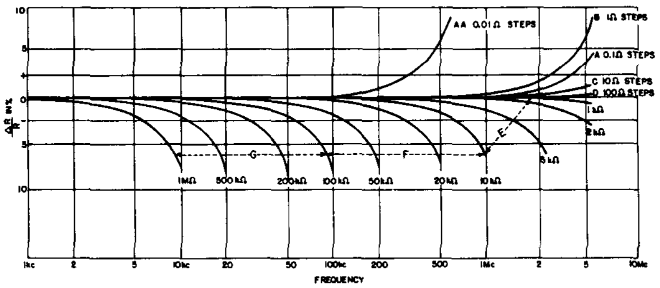
Type	*Resistance in Ohms*	*Maximum Current*	*Code Number*
500-A	1	1.0 amp	0500-9701
500-B	10	310 ma	0500-9702
500-K	20	220 ma	0500-9711
500-C	50	140 ma	0500-9703
500-D	100	100 ma	0500-9704
500-E	200	70 ma	0500-9705
500-F	500	45 ma	0500-9706
500-G	600	40 ma	0500-9707
500-H	1000	30 ma	0500-9708
500-L	2000	22 ma	0500-9712
500-M	5000	14 ma	0500-9713
500-J	10,000	10 ma	0500-9710
500-R	20,000	7 ma	0500-9718
500-T	50,000	4.5 ma	0500-9720
500-U	100,000	3 ma	0500-9721
500-V	200,000	2.2 ma	0500-9722
500-W	500,000	1.4 ma	0500-9723
500-X	1 megohm	1.0 ma	0500-9724
500-Y	2 megohms	1.1 ma	0500-9725
500-Z	5 megohms	0.7 ma	0500-9726
500-ZZ	10 megohms	0.5 ma	0500-9504



Appendix



(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 *R₀*, *L₀*, and C for the Decade Resistors:

Zero Resistance (*R₀*): 0.002 ohm or less per dial at dc (0.001-ohm switch resistance and 0.001-ohm lead resistance); 0.04 ohm per dial at 1 Mc; proportional to square root of frequency at all frequencies above 100 kc.

Zero Inductance (*L₀*): 0.10 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 ±20 ppm per degree Centigrade at room temperatures for the TYPE 510 Decade-Resistance Units and for the TYPE 1432 Decade Resistors, except for the 0.1- and 0.01-ohm decades, where the box wiring will increase the over-all temperature coefficient.

Switches: Quadruple-leaf brushes bear on lubricated contact studs ⅜ inch in diameter. Both brushes and studs are of copper alloy. These brushes are bent so as not to be tangent to the arc of travel, thus avoiding cutting and affording 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 0.001 ohm. The effective capacitance of the switch is of the order of 5 pf, with a dissipation *factor of 0.06 at 1 kc for the standard cellulose-filled molded phenolic* switch form and 0.01 for the mica-filled phenolic form used in the TYPE 510-G unit.

Terminals: For TYPE 1432, jack-top binding posts on standard ¾-inch 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.

Dimensions: TYPE 1432 — *width 4 5/16 inches (110 mm), height* 4¾ inches (120 mm); length 13 inches (330 mm) for 4-dial, 15¾ inches (400 mm) for 5-dial, and 18¼ inches (470 mm) for 6-dial box. TYPE 510 — over-all diameter 3 1/16 inches (78 mm), depth behind panel 3 5/16 inches (85 mm).

Net Weight: TYPE 1432 — 5 pounds, 4 ounces (2.4 kg) for 4-dial; 6 pounds, 5 ounces (2.9 kg) for 5-dial; and 7 pounds, 8 ounces (3.4 kg) for 6-dial box. TYPE 510 units — 11 ounces (310 grams); TYPE 510-P switches — 9½ ounces (270 grams).

Shipping Weight: TYPE 1432 — 7 pounds (3.2 kg) for 4- and 5-dial, 9 pounds (4.1 kg) for 6-dial box. TYPE 510 units and switches, 2 pounds (1.0 kg).

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

Type	*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*	*L₀ μh*	*Code Number*
510-AA	0.1	0.01	±2%	4 amp	0.16	0.01	7.7-4.5	0.023	0510-9806
510-A	1	0.1	±0.5%	1.6 amp	0.25	0.014	7.7-4.5	0.023	0510-9701
510-B	10	1	±0.15%	800 ma	0.6	0.056	7.7-4.5	0.023	0510-9702
510-C	100	10	±0.05%	250 ma	0.6	0.11	7.7-4.5	0.023	0510-9703
510-D	1000	100	±0.05%	80 ma	0.6	0.29	7.7-4.5	0.023	0510-9704
510-E	10,000	1000	±0.05%	23 ma	0.5	3.3	7.7-4.5	0.023	0510-9705
510-F	100,000	10,000	±0.05%	7 ma	0.5	9.5	7.7-4.5	0.023	0510-9706
510-G	1,000,000	100,000	±0.05%	2.3 ma	0.5	—	7.7-4.5	0.023	0510-9707
510-H	10,000,000	1,000,000	±0.025%	0.7 *ma	0.5	—	13.5-5.0	0.023	0510-9708
510-P3	Switch only	(Black Phenolic Frame)							0510-9603
510-P3L	Switch only	(Low-Loss Phenolic Frame)							0510-9833

* Or a maximum of 4000 volts, 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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