

# OPERATING INSTRUCTIONS

for

## TYPE 544-B

# MEGOHM BRIDGE

Form 458-1  
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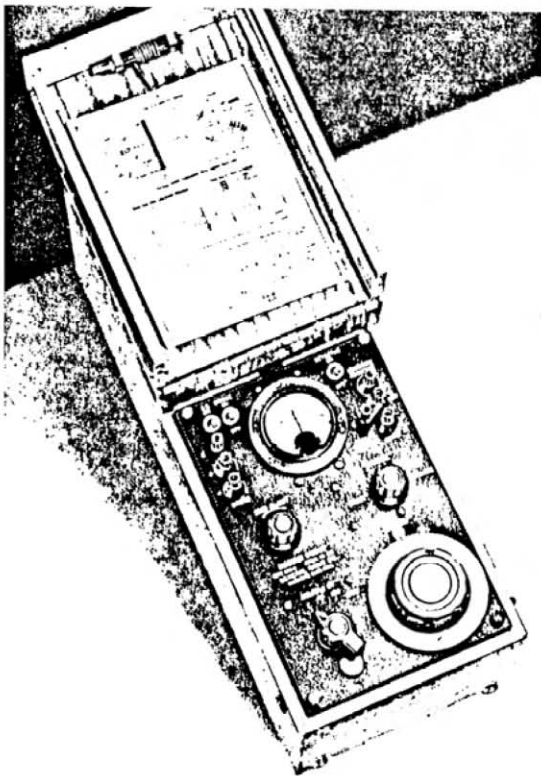
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View of the  
Type 544-B  
Megohm Bridge  
With Cover Raised  
To Show Panel

#### SPECIFICATIONS

**Range:** 0.1 megohm to 1,000,000 megohms, covered by a dial and a 5-position multiplier switch. A resistance of 1,000,000 megohms can be distinguished from infinity.

**Accuracy:**  $\pm 3\%$  on the 0.1, 1, and 10 multipliers;  $\pm 4\%$  on the 100 and 1000 multipliers. Above 10,000 megohms, the accuracy is essentially that with which the scale on the MEGOHMS dial can be read.

**Terminal:** All high-voltage terminals are insulated as a protection to the operator. A maximum of 12 ma can be drawn on short circuit.

**Power Supply:** Two types of power supply are available: (1) an a-c unit delivering d-c test voltages of 500 volts and 100 volts to the bridge, and (2) a battery power supply of 90 volts. The a-c unit operates from a 105- to 125-volt (or 210- to 250-volt), 40- to 60-cycle line. The battery power supply consists of 2 No. 6 Dry Cells and 3 Standard 45-volt batteries. This supplies 45 volts for the tube anode and 90 volts for the test voltage.

**Power Input:** 60 watts at 115 volts, 60 cycles; with battery supply, approximate current requirements are 60 ma for cathode heaters and

7.5 ma for anode.

**External Bridge Voltage:** Terminals are provided so that the bridge voltage can be obtained from an external source if desired. Up to 500 volts can be applied.

**Vacuum Tubes:** With battery power supply, a 1D5-GP detector tube is used; the 500-volt power supply uses a 6K7-G detector, a 6X4-G rectifier, a 5U4-G rectifier, and, in the voltage regulators, a 6J5-G, a 6K6-G, a 4A1 Ballast Tube, and two Type 2LAG-949 neon lamps. All tubes are supplied.

**Accessories Supplied:** With a-c power supply, a seven-foot line-connector cord and spare fuses, test probe mounted in cover and spare neon ballast tube. Batteries are supplied with the battery-operated model.

**Mounting:** Shielded oak cabinet with cover.

**Dimensions:** Cabinet with cover closed, (width) 8-1/2 x (length) 22-1/2 x (height) 8 inches, over-all.

**Net Weight:** With battery power supply, 29-1/2 pounds; with a-c power supply, 26-3/8 pounds; Type 544-P10, 14-1/4 pounds; Type 544-P3, 11-1/8 pounds.



# OPERATING INSTRUCTIONS

for

## TYPE 544-B

## MEGOHM BRIDGE

### SECTION 1.0 PURPOSE

The Type 544-B Megohm Bridge is a direct-current Wheatstone bridge for measuring high resistances. Adequate sensitivity for indicating the bridge balance is obtained from the use of a vacuum-tube voltmeter. Its controls are direct-reading in megohms.

#### 1.1 RANGE AND ACCURACY

The range of the bridge extends from 0.1 megohm to 1 megamegohm with errors varying from 3% upward. Using the main decade of the MEGOHMS dial, which is approximately logarithmic, the accuracy is 3% for the first three multiplier steps up to 100 M $\Omega$  and 4% to 10,000 M $\Omega$ . Above 10,000 M $\Omega$  the error increases rapidly, becoming 30% at 100,000 M $\Omega$ . A resistance of 1 MM $\Omega$  (1,000,000 megohms) can be detected.

### SECTION 2.0 INSTALLATION

#### 2.1 ACCESSORIES SUPPLIED

A flexible jack with lead is mounted in the cover for checking the internal standards as explained in Section 4.0, Paragraph 4.4.

#### 2.2 POWER SUPPLIES

The Type 544-B Megohm Bridge can be operated either from dry batteries or from an a-c power supply, Type 544-P3. These power supplies are interchangeable and fit into the compartment at the rear of the cabinet. One of these power supplies is normally supplied with the bridge, properly mounted in the rear compartment, except that the tubes are protected. The detector tube for the bridge is considered to be a part of the power supply, because different tubes are required for battery or a-c operation. This tube is not plugged into its socket and will be found inside the rear compartment.



## 2.3 TYPE 544-P3 500-VOLT A-C POWER SUPPLY

### 2.31 Tubes and Accessories:

- |                              |                                     |
|------------------------------|-------------------------------------|
| 1 - Type 6X5G Rectifier Tube | 2 - Type T-4-1/2 Ballast Tubes      |
| 1 - Type 5U4G Rectifier Tube | 1 - Type 4A1 Ballast Tube           |
| 1 - Type 6K6G Regulator Tube | 1 - Type 6K7G Detector Tube         |
| 1 - Type 6J5G Regulator Tube | 1 - 200 $\Omega$ Galvanometer Shunt |
|                              | 1 - Attachment Cord                 |

**2.32 Connections:** Remove the cover of the power supply compartment and also remove the bridge from its compartment. Remove the protecting cartons from the five tubes in the power supply and see that they are seated in their sockets. Check the seating of the fuses. See that the shorting links that determine the voltage applied to the bridge (500 v or 100 v) are set for the desired voltage as described in Section 5.0, Paragraph 5.4.

Plug the Type 6K7G Detector Tube into its socket below the panel. See that the 200 $\Omega$  shunt is connected across the galvanometer terminals. Reconnect the Jones plug between power supply and bridge. Replace panel and cover and connect attachment cord.

## 2.4 TYPE 544-P10 BATTERY POWER SUPPLY

### 2.41 Tubes and Accessories:

- |                             |   |
|-----------------------------|---|
| 1 - Type 1D5G Detector Tube | 1 - 2-k $\Omega$ Resistor to be used as a Battery Connector |
| 2 - No. 6 Dry Cells         |   |
| 3 - 45 v Dry Batteries      | 1 - Wooden Battery-Separator                                |
| 1 - Battery Connector       | 1 - Battery Cable with Jones Socket                         |

**2.42 Connections:** Remove the cover of the power supply compartment and also remove the bridge from its compartment. Check the arrangement and wiring of the batteries as shown in the battery diagram and cable color code of Figures 1 and 9. This figure also appears on the instruction sheet fastened in the cover. The 2-k $\Omega$  battery connector furnishes protection against a short circuit of the UNKNOWN terminals.

Plug the Type 1D5G Detector Tube into its socket below the panel. See that the galvanometer is not shunted. Reconnect the Jones plug between power supply and bridge. Replace panel and cover.

## 2.5 EXCHANGE OF POWER SUPPLIES

The two power supplies are interchangeable. The a-c power supply is held down by three machine screws.

When the change is made between battery and a-c power supply, the galvanometer shunt and the detector tube must be changed. The 200- $\Omega$  galvanometer shunt is used with the a-c tube, Type 6K7G, in order to reduce its

sensitivity to that of the battery tube, Type 1D5G, which is sufficiently sensitive for most uses. If greater sensitivity is desired, the shunt can be omitted. The battery tube, Type 1D5G, must NEVER be used with an a-c power supply. Its filament will be burned out instantly.

## SECTION 3.0 MEASUREMENTS

### 3.1 ADJUSTMENT

Ground the bridge at the terminal marked "G" in the upper left corner of the panel and swing the spring connector pivoted on the G terminal on the right side of the bridge to the LOW terminal.

With the control knob (CHECK-OPERATE-CHARGE) set at CHECK, throw all three switches at the rear of the panel to ON. (For battery operation it is unnecessary to throw the A.C. switch.) After about 10 seconds (immediately for battery operation), the galvanometer will deflect off scale to the left and then return toward zero. Bring the galvanometer to zero by turning the ZERO ADJUST knob in the direction in which the pointer of the galvanometer should move. At least 2 minutes (1 minute for battery operation) are required for all filaments to attain equilibrium.

### 3.2 CHECKS

Swing the MULTIPLY BY switch over its range. The galvanometer may deflect a half division to the right with this switch set at 1000 because of positive ion grid current. A deflection exceeding one division generally indicates excessive grid current and the detector tube should be replaced. Occasionally the grid current is high just after the tube is turned on and decreases to a normal value after 10 or 20 minutes. Large electrostatic fields near the bridge will also cause the galvanometer to deflect to the right with the MULTIPLY BY switch set at 1000. This effect will be accentuated when a long unshielded lead is connected to the + UNKNOWN terminal. (See Section 4.0, Paragraph 4.1, EXTRANEIOUS POTENTIALS.)

### 3.3 GROUNDED RESISTOR

**3.31 Procedure:** Swing the spring connector pivoted on the G terminal to the LOW terminal. Connect the resistor to be measured to the UNKNOWN RESISTOR terminals with its ground side connected to the LOW terminal. After these connections are made the ground connection mentioned under ADJUSTMENT becomes unnecessary.

With the control knob set at CHECK bring the galvanometer to zero by means of the ZERO ADJUST knob. Throw the control knob to OPERATE and return the galvanometer to zero by adjustment of the MULTIPLY BY switch and the MEGOHMS dial. A low resistance deflects the galvanometer to the left, a high resistance to the right. Hence the MEGOHMS dial should be turned in



the direction in which the pointer of the galvanometer should move. The **MULTIPLY BY** switch, on the other hand, should be turned in the opposite direction. In general, that setting of the **MULTIPLY BY** switch should be chosen which leaves the **MEGOHMS** dial set in its main decade from 1 to 10.

The resistance of the unknown resistor in megohms is the product of the setting of the **MULTIPLY BY** switch and the reading of the **MEGOHMS** dial.

**3.32 Accuracy:** The accuracy of this resistance reading is 3% between 0.1 and 100 megohms and 4% between 1000 and 10,000 megohms, provided the **MEGOHMS** dial is set on its main decade between 1 and 10. The accuracy of the two shorter decades above 10 is determined by the spacing of the graduations.

The errors involved in these measurements come mainly from the errors of calibration or adjustment of the resistors in the arms of the bridge. Numerical values for these errors are given in Section 5.0, Paragraph 5.1. Methods for checking the errors of the standard resistors **N** used with the **MULTIPLY BY** switch set at 100 and 1000 and reducing the errors of the **MEGOHMS** dial are given in Section 4.0, Paragraphs 4.4 and 4.5.

**3.33 Precautions:** Since all high resistances have imperfect insulation, they will have capacitance and dielectric absorption. They may also have d-c and a-c voltages induced in them by external electrostatic fields. These various conditions indicate their presence by their effect on the initial zero adjustment or on the bridge balance. If the galvanometer zero drifts in either direction, in either its initial adjustment or in the final bridge balance, or if this zero is different with the control knob in **CHECK** and **CHARGE** positions, one or more of the above conditions exist. The proper procedure to follow is discussed in Section 4.0, Paragraph 4.1.

### 3.4 UNGROUNDED RESISTOR

If the resistor to be measured has neither terminal grounded, its resistance may be measured by the method of Paragraph 3.3 provided it can be entirely supported on the **UNKNOWN RESISTOR** terminal.

When the unknown resistor has its own insulating supports, it is no longer a two-terminal resistor, but is a three-terminal resistor, ground being the third terminal. It has three resistances, as shown in Figure 4, its direct resistance  $R_D$  and its two terminal resistances  $R_1$  and  $R_2$ . When such a resistor is connected to the **UNKNOWN RESISTOR** terminals, that terminal resistance which is associated with the terminal connected to the **LOW** terminal is shorted and the resistance measured by the bridge is that of the direct resistance and the other terminal resistance in parallel.

The direct resistance  $R_D$  can be measured by swinging the ground connector to the **GUARD** terminal and balancing the bridge as described in Paragraph 3.3. A more complete discussion of the measurement of direct resistance is given in Section 4.0, Paragraph 4.2.



## SECTION 4.0 OTHER USES

### 4.1 RESISTANCE OF CAPACITORS

While the resistance of a capacitor is measured in the same manner as a pure resistance, as described in Section 3.0, Paragraph 3.1, certain extra precautions must be taken because of the large capacitance which is in parallel with the resistance.

Functional wiring diagrams of the bridge are shown in Figure 3. With the control knob set in the CHECK position, the unknown capacitor connected to the UNKNOWN RESISTOR terminals is placed in parallel with the standard resistor N in the grid circuit of the detector tube. If there is no residual charge in the capacitor, the setting of the ZERO ADJUST knob will be the same as if the parallel capacitor were not present. Any residual charge will cause the zero of the galvanometer to drift until this charge is completely dissipated.

When the control knob is turned to the OPERATE position, the bridge voltage is applied to the capacitor through the standard resistor N. If the time constant RC of capacitor and resistor is only a few seconds, steady state conditions will be set up in the time necessary to operate the various controls. For the largest standard, 100 M $\Omega$ , used when the MULTIPLY BY switch is set at 1000, the capacitor may have a capacitance of 0.01  $\mu$ f for a time constant of 1 second and 0.1  $\mu$ f for a time constant of 10 seconds.

When the time constant is greater than 5 seconds, time will be saved by turning the control knob to the CHARGE position. This removes the standard resistor N from the charging circuit and applies directly to the capacitor a voltage within 10% of that which it will finally have with the control knob set at OPERATE. This process may be repeated as often as desired, rebalancing the bridge each time that the control knob is set at OPERATE.

A time constant of 100 seconds is about as large as it is convenient to use. After each adjustment of the bridge, sufficient time must elapse to show in which direction the galvanometer is moving and this time is proportional to the time constant. This consideration sets an upper limit of perhaps 10  $\mu$ f with the MULTIPLY BY switch set at 100, and 1  $\mu$ f with this switch set at 1000.

Since it is impossible to check the zero of the galvanometer in the CHECK position without completely discharging the capacitor, the CHARGE position can be used for this purpose, whenever it has been shown that there are no extraneous potentials induced in the capacitor, as explained below.

**4.11 Dielectric Absorption:** All solid dielectric capacitors have dielectric absorption. It is particularly noticeable in those capacitors having a laminated structure. In addition to the normal charge, there is a volume charge which slowly diffuses into the material, requiring minutes, hours and even days to attain equilibrium. The charging current which flows is added to the steady leakage current and gives an instantaneous resistance which is lower than the true leakage resistance.



This phenomenon may be studied by maintaining the bridge balance by continual adjustment of the MEGOHMS dial. The resistance at any time may be observed by ceasing to maintain the bridge balance after that instant and noting the reading. The necessity of reading a continually moving pointer at a specified time is thus avoided. The bridge may then be brought into balance for the next reading. The initial zero adjustment of the bridge must be made with the control knob in the CHECK position so that all resistance values may start from the uncharged condition of the specimen.

When dielectric absorption exists, it has been customary to observe the instantaneous resistance one minute after the application of the charging voltages and call that the insulation resistance. Such a resistance value is, however, merely a measure of dielectric absorption and may have little relation to true insulation resistance. The rate of change of resistance with time is a better measure of insulation resistance, because it suggests by its magnitude a possible upper limit of resistance.\*

If the time constant of the unknown capacitor and the standard resistor is greater than a few seconds, the initial charging current will not have ceased before observations on the dielectric absorption are begun. The actual values of resistance as observed will then depend somewhat on the setting of the MULTIPLY BY switch. It is usually advisable to use as small a multiplying factor as possible and allow the setting of the MEGOHMS dial to pass up into the second decade. It is sometimes preferable to throw the control knob to the CHARGE position for a definite time interval, say one minute, before passing to the OPERATE position. This procedure eliminates the initial charging current, but leaves the first part of the curve dependent on the setting of the MEGOHMS dial while the charging took place.

The time required to dissipate a volume charge, when the terminals of a capacitor are shorted, is approximately the same as the charging time. The presence of a volume charge is shown by a shift in the zero balance of the bridge for the CHECK position from its normal value which is essentially that for the control knob in the CHARGE position. The gradual disappearance of this charge may be observed as a drift in the galvanometer zero for the CHECK position.

**4.12 Charge and Discharge Current:** The charging current flowing into the capacitor at any instant may be calculated from the observed resistance  $P$ , the standard resistance  $N$ , and the voltage  $E$  applied to the bridge.

$$I = \frac{E}{N + P} = \frac{10E}{M(1 + 10D)} \quad \mu a \quad (1)$$

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\*R. W. Wiesman, "Insulation Resistance of Armature Windings", Electrical Engineering, June, 1934.

Murphy and Morgan, "The Dielectric Properties of Insulating Materials", Bell System Technical Journal, July, 1939.



where  $M$  is the setting of the **MULTIPLY BY** switch and  $D$  the reading of the **MEGOHMS** dial. The voltage  $E$  applied to the bridge may be measured by a high resistance voltmeter connected across the **BRIDGE** terminals. The voltmeter resistance must be sufficiently high (at least  $1\text{ M}\Omega$ ) so that its application does not affect the bridge voltage.

The discharge current flowing out of a capacitor which has been previously charged may be measured in the following manner. A piece of mica or other thin but high-resistance insulator is slipped in between contacts 2 and 4 of the control switch when set in the **OPERATE** position. These contacts are shown in Figure 8 and are the two nearest the panel in the outside row. The **LOW** terminal is then connected to the + **BRIDGE** terminal. The charged capacitor is connected to the **UNKNOWN RESISTOR** terminals in a direction reversed from its connection during charge. The bridge will balance in the same manner as during the charging cycle. The resistance read in the normal way is the resistance which the capacitor would have if the voltage across it were normal. The discharge current is given by Equation (1).

**4.13 Extraneous Potentials:** Unshielded resistors and capacitors, especially those having large physical dimensions, may have a voltage induced in them by an external electrostatic field. This is usually an alternating potential, because alternating electric fields at the power supply frequency are usually present in laboratories, factories and power houses. An appreciable voltage may also be induced in the lead from the high **UNKNOWN** terminal to the resistor if this lead is long and unshielded, particularly if it is allowed to lie next to the attachment cord. The effect of this induced voltage is to change the effective bias of the detector tube and hence the galvanometer deflection. As shown in Figure 3, the unknown and standard resistors are connected in parallel in the grid circuit of the detector tube in exactly the same way in both the **CHECK** and **OPERATE** positions. If then the zero adjustments are made with the control knob in the **CHECK** position, the effect of the induced voltage will be eliminated. Even a large induced voltage will not cause a direct error in the bridge balance, provided the zero adjustment can still be made.

The existence of induced voltage is disclosed by a difference in the zero balance for the **CHECK** and **CHARGE** positions. Alternating voltages affect the balance as well as direct voltages, because the tube rectifies as well as amplifies.

## 4.2 DIRECT RESISTANCE

The direct resistance of a three-terminal resistor may be measured by connecting the third terminal to the **GUARD** terminal, as shown in Figure 5. There are three cases dependent on the method of grounding of the three-terminal resistor. For each of these the bridge must be grounded at a different junction.

**4.21 One Main Terminal Grounded:** The grounded terminal is connected to the **LOW** terminal and the spring connector pivoted on the **G** terminal swung to **LOW**. This connection is used for grounded insulators and cables when the

direct resistance to ground of some terminal or lead is wanted. All other terminals and leads are connected to the GUARD terminal. The third terminal may also be a guard electrode provided to remove the effect of leakage over the surface of the insulation or to prevent fringing at the edges of the electrodes. When the bridge is balanced the GUARD and high terminals are at the same potential. The electrodes may be mercury confined in rings as shown in Figure 6, lead foil pressed closely to the surface of the insulator, or solid metal shaped to fit. Intimate contact is essential for obtaining correct results. Air pockets or voids are almost perfect insulators. Petrolatum may be used to make the lead foil adhere, provided most of it is squeezed out by heavy rolling.

**4.22 Third Terminal Grounded:** The larger or outside main terminal is connected to the LOW terminal and the spring connector pivoted on the G terminal swung to GUARD. This connection is used for insulators mounted on grounded metal and cables with grounded sheaths when the direct resistance between two terminals or leads held in the insulation is wanted. All other terminals and leads are connected to the grounded GUARD terminal.

**4.23 No Terminal Grounded:** The network is strictly no longer a three-terminal resistor, but a four-terminal resistor with ground as the fourth terminal. The three terminals are connected to +, LOW and GUARD terminals in the order desired for the measurements. The spring connector pivoted on the G terminal is swung free and the + BRIDGE terminal grounded. This connection is rarely needed because it is almost always possible to ground one of the three terminals of a network without altering a given direct resistance.

**PRECAUTIONS:** The terminal resistances  $R_1$  and  $R_2$  of Figure 4 become a part of the bridge,  $R_2$  shunting the B arm having 100 k $\Omega$  resistance, and  $R_1$  shunting the vacuum-tube voltmeter. They must not be of such low value as to introduce errors into the bridge balance.  $R_2$  should be at least 100 times B and preferably 1000 times, 10 M $\Omega$  for the former and 100 M $\Omega$  for the latter case.  $R_1$  does not affect the bridge balance directly but decreases the sensitivity of this balance. It should not be much lower than the input resistance of the tube, which is about 10 kM $\Omega$ . The effect of 100 M $\Omega$  is very noticeable.

#### 4.3 TERMINAL RESISTANCE

The terminal resistances of a three-terminal resistor can be measured by considering them as direct resistances and measuring them by the methods of Paragraph 4.2. The same three types of grounding as are described in that section may occur. Care must be taken that those resistances which become terminal resistances for this measurement are sufficiently large, as defined under PRECAUTIONS in Paragraph 4.2.

#### 4.4 INTERNAL STANDARDS

The internal standards used in the N arm of the bridge when the MULTIPLY BY switch is set at 100 and 1000 can be measured in terms of the lower resistance standards of the N arm by using the flexible jack stored in the cover. These two resistors are provided with plug terminals mounted on the switch,

which can be reached by the flexible jack through a hole in the panel. The two plug terminals are arranged in the same order from left to right as the switch positions. The other end of the jack is connected to the LOW terminal.

With the jack on the left terminal and the MULTIPLY BY switch set at 10, the standard resistor for the 100 position is measured in terms of the standard for the 10 position with the MEGOHMS dial at approximately 1. With the jack on the right terminal the standard resistor for the 1000 position is measured in terms of the 10-position standard when the MULTIPLY BY switch is set at 10. The standard resistor for the 10 position is adjusted to 0.25% and the MEGOHMS dial is calibrated to 2%. These measurements are thus accurate to 3% and can serve only as a check on the internal standards. Greater accuracy can be attained by the use of an external decade resistor as explained in Paragraph 4.5.

#### 4.5 EXTERNAL DECADE RESISTOR

The logarithmic resistor, A, controlled by the MEGOHMS dial may be replaced by a suitable decade resistor by opening the A arm at some point (by placing a piece of paper or other thin insulator under the contact arm of the logarithmic resistor) and connecting the decade resistor to the GUARD and + BRIDGE terminals. The case of the decade resistor should be grounded. The bridge is then balanced by means of this decade resistor and the MULTIPLY BY switch.

$$R_x (\text{megohms}) = \frac{10,000}{R (\text{decade})} \times M$$

where M is the setting of the MULTIPLY BY switch.

The Type 1432-J Decade Resistor\* covers the same range as the logarithmic resistor with an accuracy of 0.05%.

The three lower standards in the N arm and the resistor in the B arm are adjusted to an accuracy of 0.25%. Hence, readings can be made with the MULTIPLY BY switch set at 0.1, 1, 10 to an accuracy of 0.6%. The two higher standards in the N arm can be measured by the method of Paragraph 4.4, using a suitable decade resistor, to an accuracy of 0.6%. Hence, readings with the MULTIPLY BY switch set at 100 and 1000 will have an accuracy of 1% when the proper correction for the standard is applied.

#### 4.6 SUBSTITUTION METHODS

Two resistors having resistance values in the same decade may be compared with one another with an error which is the same as that of a direct measurement. The entire error is that of reading the MEGOHMS dial, 2% for each setting. The maximum error of the comparison is 4%, which is the same as that of a direct reading with the MULTIPLY BY switch set at 100 and 1000.

When the two resistors are nearly equal, the settings of the MEGOHMS

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\*See General Radio Catalog for data.

dial are nearly the same and the error is reduced to that of reading the difference of the two settings.

When an external decade resistor is used, as suggested in Paragraph 4.5, the maximum error of the comparison is 0.2%, provided that this is not limited by the sensitivity of the bridge balance. For nearly equal resistors the error is determined entirely by the precision of balance.

**4.61 Intercomparison of Standards:** Sets of standards may be compared by means of an external decade resistor to an accuracy of about 0.1% over the range from 10 k $\Omega$  to 10 kM $\Omega$ . For this comparison it is desirable to have pairs of standards of values 1, 2, 5 per decade. Any other combination will suffice which allows each standard to be compared directly with a number of those of lower value connected in series. The two 1's are first compared, then the 2's with the 1's in series. Next the 5's are compared with the 2's and a 1 in series and finally the 10's, 1's of the next decade, are measured in terms of the two 5's in series.

**4.611 Voltage Coefficient:** An important source of error will occur if the resistors have an appreciable voltage coefficient of resistance. Each resistor is first measured so as to have across it nearly the full voltage of the bridge. Then it is placed in series with other resistors so that it has across it one-half its former voltage or less. The voltage coefficient may be measured by varying the bridge voltage as indicated in Paragraphs 4.8 and 5.4. Corrections may then be applied in order to correct the measured resistance to a constant voltage.

#### 4.7 SENSITIVITY

The sensitivity of the bridge balance varies by almost 10 to 1 over the main decade of the MEGOHMS dial as arm A decreases from 10 k $\Omega$  to 1 k $\Omega$ . The 200  $\Omega$  shunt placed across the galvanometer decreases its sensitivity by a factor of 4.3. This figure is approximately the ratio of sensitivities of the a-c and battery detector tubes Types 6K7G and 1D5G. The sensitivity of bridge balance with battery tube or with a-c tube and galvanometer shunted is 1.3% at the 10 end of the main decade with 100 volts applied to the bridge. The sensitivity is improved to about 0.3% with 500 volts applied to the bridge or with 100 volts, a-c tube and shunt removed. A maximum sensitivity of 0.06% holds for the latter case with 500 volts. For resistances in the A arm less than 1 k $\Omega$ , the sensitivity expressed in percent increases to 0.6% for 100  $\Omega$ , 6% for 10  $\Omega$ , 60% for 1  $\Omega$ .

#### 4.8 BRIDGE VOLTAGE

The input terminals of the bridge appear on the left side of the panel marked + - BRIDGE. The voltage across the bridge can be measured by connecting a high resistance voltmeter to these terminals. The resistance of this voltmeter should be high (at least 1 M $\Omega$ ) compared to the bridge resistance. The minimum allowable depends also on the regulation of the power supply.

When a grounded resistor is to be measured, its ungrounded terminal will be positive. This terminal can be made negative by transposing the leads from power supply to bridge. This change is most easily made at the BRIDGE ON - OFF switch. The connections to the galvanometer should also be reversed



in order to maintain the proper relation between galvanometer deflection and rotation of the MEGOHMS dial.

An upper limit of 500 volts across the bridge is set by the power dissipation of the B arm. None of the other arms of the bridge can be overloaded except when the control switch is set in the CHARGE position. For this position the unknown resistor is connected directly across the B arm. If this resistor happens to have a low resistance or is shorted, the full voltage of the power supply is placed across the logarithmic resistor, which forms the A arm, whose maximum current is 40 ma. Under these conditions this current will be exceeded for 100 volts across the bridge if the MEGOHMS dial reads more than 0.8, which is the minimum reading. It is, therefore, desirable that the power supply have considerable regulation. The short circuit current of the Type 544-P3 500-volt a-c Power Supply is 12 ma at 500 volts and 6 ma at 100 volts. When dry batteries are used a protective resistance should be placed in series, 2 k $\Omega$  for 90 volts, 5 k $\Omega$  for 200 volts, 12 k $\Omega$  for 500 volts. A 2-k $\Omega$  resistor is supplied with the Type 544-P10 Battery Power Supply for this purpose.

The voltage applied to the bridge is affected slightly by the setting of the MEGOHMS dial, because of the regulation inherent in all power supplies as just described. The decrease in voltage as the dial is turned from 1 to 10 amounts to 0.3% for Type 544-P10; and 2% at 100 volts and 5% at 500 volts for Type 544-P3. With the MULTIPLY BY switch set at .1, the resistance of the N and P arms become comparable with that of the A and B arms. In the extreme case, when the unknown resistor is 100 k $\Omega$ , the resistance of the bridge is halved to 55 k $\Omega$ . For this condition the voltage across the bridge is reduced by 2% for the Type 544-P10; and 12% at 100 volts and 29% at 500 volts for the Type 544-P3. The changes for the Type 544-P3 Power Supply are smaller than might be expected in view of its small short-circuit current because the series triode regulator tube tends to maintain constant current.

The voltage across the unknown resistor P varies with the setting of the MEGOHMS dial from 90% to 100% of the bridge voltage according to the expression

$$E_P = \frac{B}{A + B} E = \frac{10D}{1 + 10D} E = \frac{E}{1 + \frac{1}{10D}} \quad (2)$$

where D is the reading of the MEGOHMS dial.

## SECTION 5.0 CONSTRUCTION

### 5.1 RESISTANCE ARMS

The schematic wiring diagram of the bridge is shown in Figure 2 (also on the instruction sheet mounted in the cover). The complete wiring diagram is shown in Figure 9. It is a simple d-c Wheatstone bridge with unequal arms controlled by the MULTIPLY BY switch for the N arm and by the MEGOHMS

dial for the A arm. All of the resistors are wire wound except the two highest resistances in the N arm, which are deposited carbon. Their resistance values, error of adjustment, temperature coefficient and voltage coefficient are given in Table I. The error given for the A arm is for the main decade of the dial over which the logarithmic shape of the resistor keeps the fractional accuracy essentially constant. Its resistance in kilohms at any setting is ten times the reciprocal of the dial reading.

TABLE I

Arm	Switch	R	Type	Error in %		Coefficients in %	
				Arm	Bridge	Temp.	Volt.
B		100 k $\Omega$	Wire	.25		.01	.00
A		0-1.25 k $\Omega$	Wire	2.0		.01	.00
N	0.1	10 k $\Omega$	Wire	.25	3	.01	.00
	1	100 k $\Omega$	Wire	.25	3	.01	.00
	10	1 M $\Omega$	Wire	.25	3	.01	.00
	100	10 M $\Omega$	Deposited	1.0	4	-.04	.0001
	1000	100 M $\Omega$	Carbon	1.0	4	-.06	.0002

## 5.2 VACUUM-TUBE VOLTMETER

Bridge balance is indicated by means of a vacuum-tube voltmeter whose connections are shown schematically in Figure 7 and completely in Figure 9. Supercontrol pentodes, Type 1D5G and Type 6K7G, are used in order to obtain sufficient mutual conductance at the low plate voltage necessary to keep the grid current less than 100  $\mu\text{a}$ . Grid, screen and plate voltages are obtained from a voltage divider having a total resistance of 6 k $\Omega$  and carrying a current of 7.5 ma when used with Type 544-P3 and Type 544-P10 Power Supplies. Plate voltage is 29 volts. The effective mutual conductances of the two tubes are 60 micromhos for Type 1D5G and 250 micromhos for Type 6K7G. The 200  $\Omega$  galvanometer shunt used with the a-c tube equalizes these mutual conductances. It may be removed in order to obtain maximum sensitivity for such measurements as those described in Section 4.0, Paragraph 4.6.

The galvanometer has a center zero with a current sensitivity of 100  $\mu\text{a}$  full deflection and a resistance of 660  $\Omega$ . A scale division corresponds to 4  $\mu\text{a}$ . Increasing the plate current produces a positive deflection of the galvanometer. The rheostat controlled by the ZERO ADJUST knob balances out the plate current from the galvanometer, counter-clockwise motion corresponding to increased plate current. The pointer of this knob should be approximately within the span of the arrow engraved on the panel for the battery tube and within 15° of a left horizontal position for the a-c tube.

A resistance of 10 M $\Omega$  is placed in the grid circuit to prevent an excessive voltage being placed on the grid of the tube when the bridge is unbalanced. A 0.001  $\mu\text{f}$  capacitor connected from grid to cathode acts with the 10 M $\Omega$  resistor as a resistance-capacitance filter to attenuate by a factor of 4 any alternating voltage induced in the unknown resistor and its leads.

### 5.3 SWITCHES

Parts of the CHECK-OPERATE-CHARGE control switch, the MULTIPLY BY switch and the whole of the bushing of the + UNKNOWN terminal are connected directly across the unknown resistor. They are, therefore, made of a mica-filled phenolic or polystyrene which has a very high insulation resistance usually greater than  $10\text{ MM}\Omega$ . Any leakage over these switches or the bushing will show as a measurable resistance when the bridge is balanced with the unknown resistor disconnected.

### 5.4 POWER SUPPLY - A-C OPERATION

Type 544-P3 500-Volt A-C Power Supply: The connections of this power supply are shown schematically in Figure 8 and completely in Figure 10. Its component parts are listed in Section 2.0. The two series triodes maintain constant current in their respective circuits by varying their plate resistances inversely with the line voltage. Their cathodes are connected to voltage dividers placed across neon tubes, which maintain a constant voltage of about 55 v.

The bridge current is 5 ma and the detector plate current 7.5 ma. These currents are stabilized against line voltage changes by adjusting the cathode voltage dividers R-2 and R-1 so that no change in current occurs when line voltage changes from 130 volts to 100 volts. The change in line voltage is most easily made by means of a Type 200-B or V-5 Variac. If a Variac is not available, the voltage applied to the bridge can be decreased by 10% by inserting a resistance of  $30\ \Omega$ . The currents are then brought to their correct values by adjusting the grid voltage dividers R-4 and R-3. All of these voltage dividers are so wired that turning them clockwise causes the output currents to increase. The output currents are measured by opening the shorting links on the terminal board which is mounted over the transformer, those for the bridge being marked 500 V and those for the detector being marked DET, and inserting a suitable milliammeter. These adjustments have all been made for the tubes supplied.

For the nominal bridge current of 5 ma the voltage across the bridge is 500 volts with the MEGOHMS dial set at  $\infty$ . As the setting of the dial is decreased to 1 the bridge resistance increases from  $100\ \text{k}\Omega$  to  $110\ \text{k}\Omega$ . The bridge current decreases but only by 4%, since the power supply is stabilized only for changes in line voltage and not for changes in load. The voltage across the bridge increases by 5%, while the voltage across the unknown resistor decreases by the same amount as the current, 4%.

Shunt and series resistors controlled by shorting links on the terminal board are provided for obtaining voltages other than 500 v for the bridge supply. The condition to be satisfied is that the load presented to the power supply shall be  $100\ \text{k}\Omega$  regardless of the resistance or voltage of the bridge. The resistors used are shown in Figure 10. For a  $100\ \text{k}\Omega$  bridge the links should cover the label "500 V" in order to obtain 500 volts across the bridge. Placing the links over the labels "100 V" gives 100 volts across the bridge. Intermediate voltages between 500 v and 300 v can be obtained by adjusting voltage

divider R-4 in a counterclockwise direction. Further reduction to 200 v can be obtained by adjusting voltage divider R-2 counterclockwise. Although this last adjustment disregards the amplification constant condition, the stability is not noticeably impaired at this low voltage level. Provision is also made for supplying a bridge having a resistance of  $1\text{ M}\Omega$ .\*

The a-c ripple appearing across the output terminals of the power supplies is not greater than 0.6 volt for the bridge supply and 2.8 volts for the detector tube. The power drawn from the line is 55 watts at 115 volts, increasing to 64 watts at 125 volts. There is no large change with frequency down to 40 cycles. Frequencies lower than 40 cycles must not be used.

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\* Note for special bridges having  $1\text{ M}\Omega$  ratio arm B added: When using this ratio arm (toggle switch in the X10 position), short circuit the terminals marked  $1\text{ M}\Omega$  to maintain the normal bridge voltages.



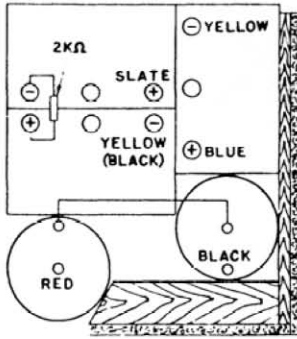


Figure 1. Arrangement of batteries in rear compartment with color code of cable.

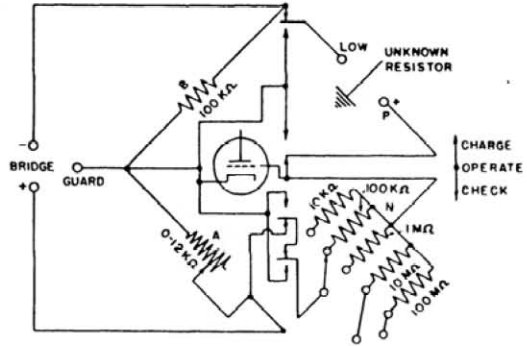


Figure 2. Schematic Wiring Diagram for Type 544-B Megohm Bridge.

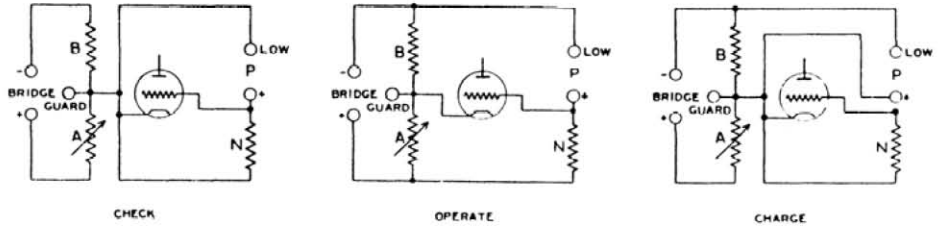


Figure 3. Connections of Type 544-B Megohm Bridge for three positions of control knob.

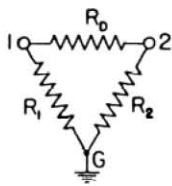


Figure 4. Direct resistance with two terminal resistances to ground.

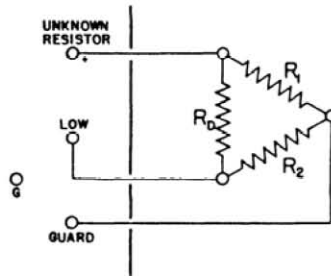


Figure 5. Bridge connections for measurement of direct resistance.

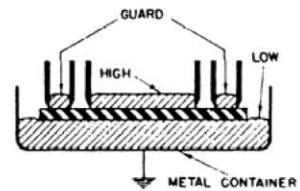


Figure 6. Mercury Electrodes.

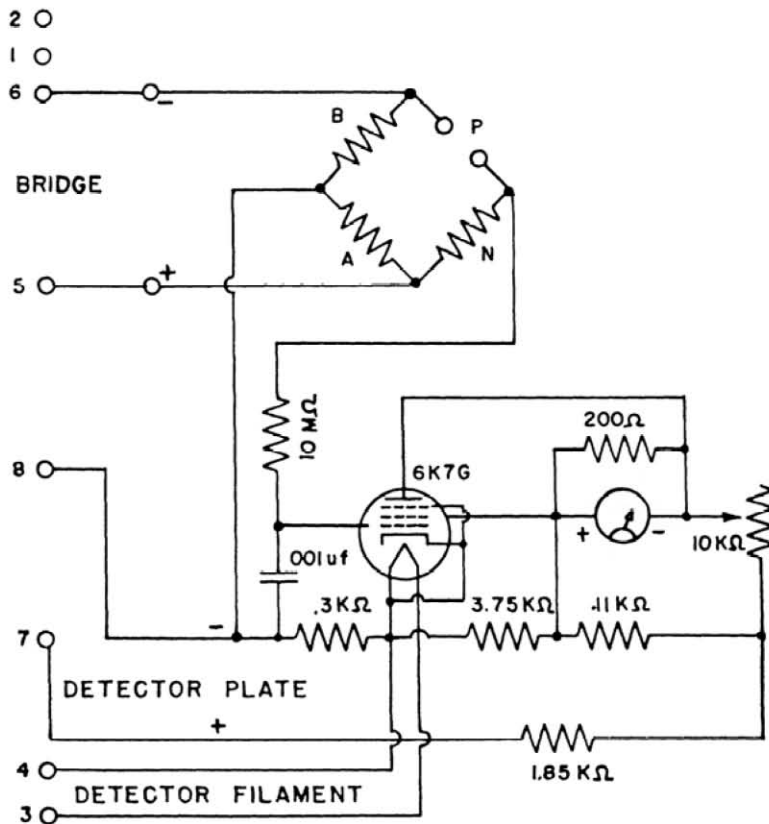


Figure 7. Schematic Wiring Diagram of Vacuum-Tube Voltmeter and Bridge.

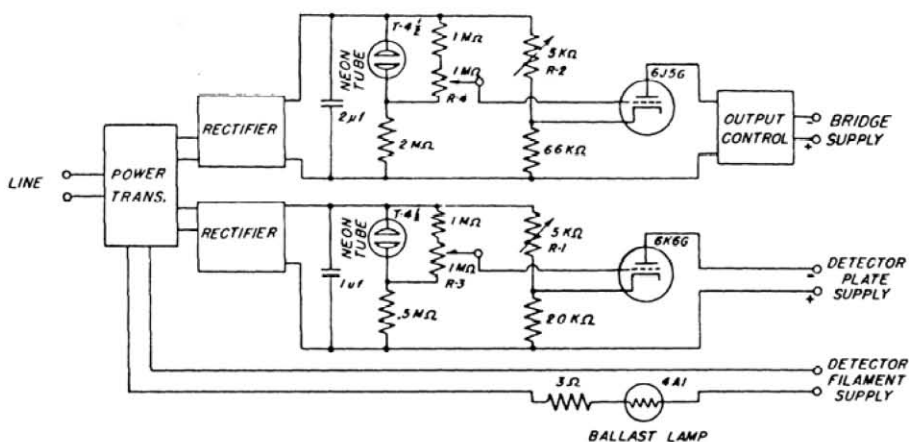


Figure 8. Schematic Wiring Diagram of Type 544-P3 Power Supply.

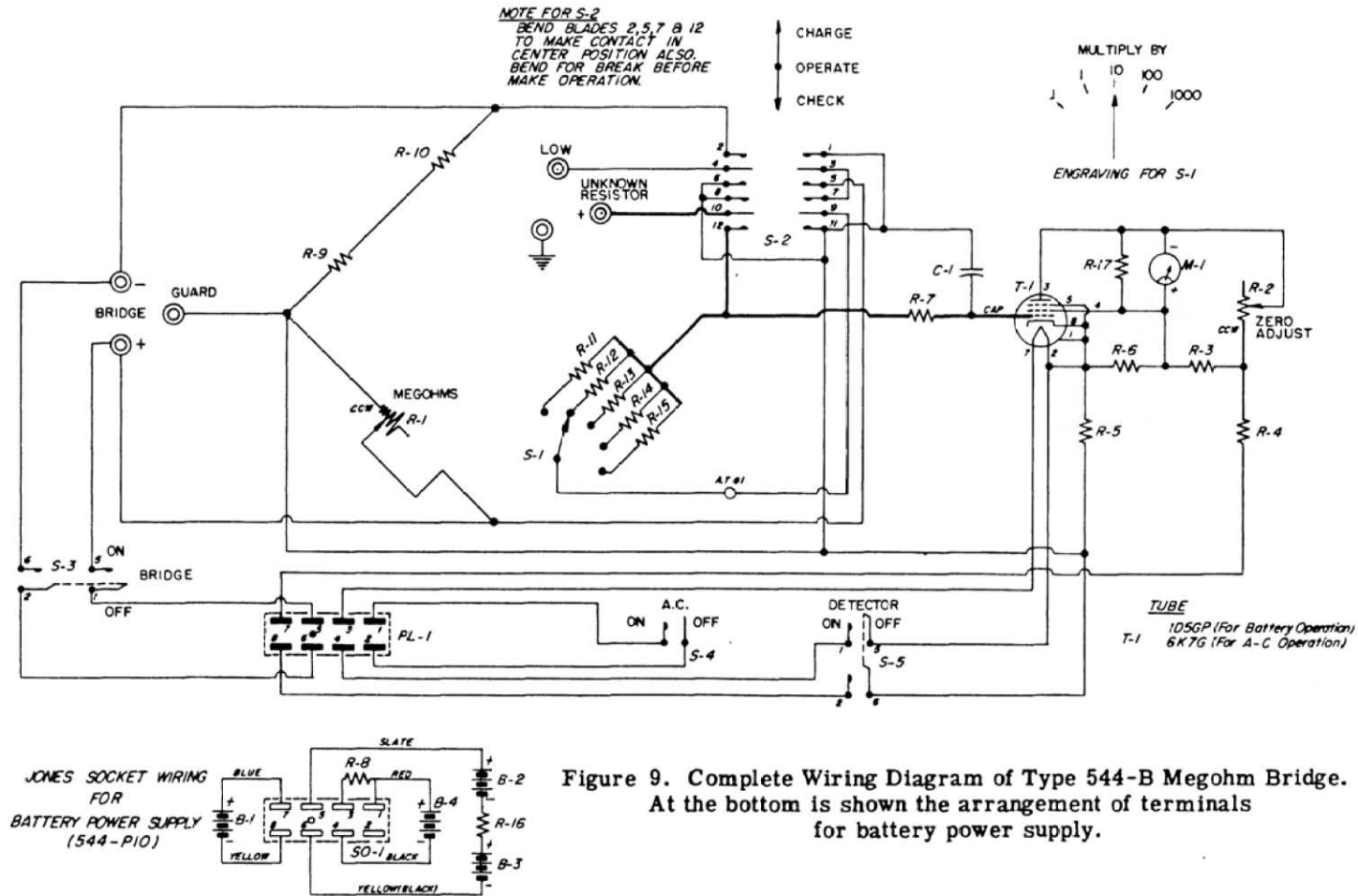


Figure 9. Complete Wiring Diagram of Type 544-B Megohm Bridge. At the bottom is shown the arrangement of terminals for battery power supply.

## Parts List for Type 544-B

### RESISTORS

R-1 = 12.2 - 12.7 k Ohms	
R-2 = 10 k Ohms	± 5%
R-3 = 110 Ohms	544-314
R-4 = 1.85 k Ohms	
R-5 = 300 Ohms	
R-6 = 3.75 k Ohms	544-313
R-7 = 10 Megohms	±10% IRC
R-8 = 15 Ohms	±10% IRC
R-9 = 50 k Ohms	±1/4% IRC
R-10 = 50 k Ohms	±1/4% IRC
R-11 = 10 k Ohms	±1/4% IRC
R-12 = 100 k Ohms	±1/4% IRC
R-13 = 1 Megohm	±1/4% IRC
R-14 = 10 Megohms	± 1% Wilkor
R-15 = 100 Megohms	± 1% Wilkor
R-16 = 2.2 k Ohms	± 10%
R-17 = 220 Ohms	± 10%

### TYPE

544-332
301
544-311
BT1
BW-1/2
WW-4
WW-4
WW-3
WW-5
CP-1
CP-2
544-324 *
BW-1**

### SWITCHES

S-1 = 5 Position
S-2 = 4PDT
S-3 = DPST
S-4 = SPST
S-5 = DPST

544-342
339-AL
SWT-333
SWT-323
SWT-333

### BATTERIES

B-1 = 45 Volt Burgess (B)	5308
B-2 = 45 Volt Burgess (B)	5308
B-3 = 45 Volt Burgess (B)	5308
B-4 = 3 Volt (2 1-1/2 Volt) Eveready	#6

### MISCELLANEOUS

C-1 = Capacitor 0.001 μf ±10% Dubilier 1MS

PL-1 = Plug CDMP-461-8

SO-1 = Socket CDMS-464-8

M-1 = Meter 588-321

\* For Battery operation only.

\*\* For A-C operation only.

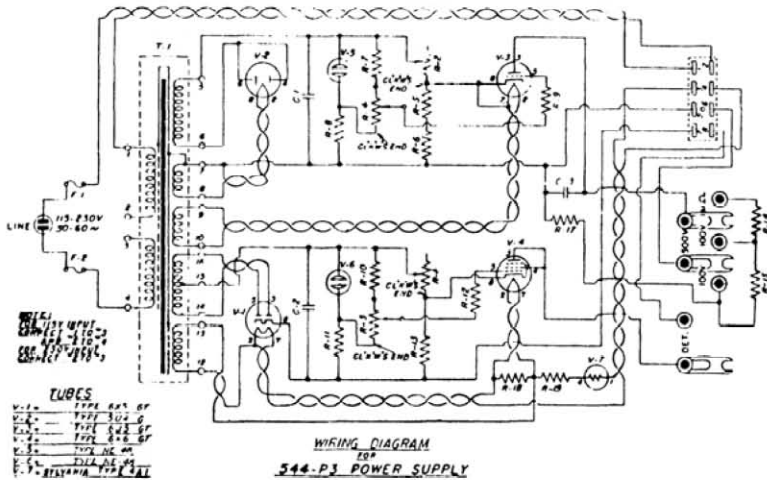


Figure 10. Complete Wiring Diagram of Type 544-P3 Power Supply.

### Resistors

R-1 = 5 kΩ	R-10 = 1 MΩ
R-2 = 5 kΩ	R-11 = 470 kΩ
R-3 = 1 MΩ	R-12 = 1.8 MΩ
R-4 = 1 MΩ	R-13 = 20 kΩ
R-5 = 33 kΩ	R-14 = 5.6 kΩ
R-6 = 33 kΩ	R-15 = 80 kΩ ± 2%
R-7 = 1 MΩ	R-17 = 25 kΩ ± 2%
R-8 = 1.8 MΩ	R-18 = 27 Ω
R-9 = 1.8 MΩ	R-19 = 6.8 Ω

### Capacitors

C-1 = 2.0 μf
C-2 = 1.0 μf
C-3 = 1.0 μf

### Fuses

For 115 volt operation:  
 F-1 = 0.8 amp. Slow Blow 3AG  
 F-2 = 0.8 amp. Slow Blow 3AG  
 For 250 volt operation:  
 F-1 = 0.4 amp. Slow Blow 3AG  
 F-2 = 0.4 amp. Slow Blow 3AG

### Tubes

V-1 = Type 6X5-GT
V-2 = Type 5U4-G
V-3 = Type 6J5-GT
V-4 = Type 6K6-GT
V-5 = Type NE-48
V-6 = Type NE-48
V-7 = Sylvania Type 4A1

### Transformer

T-1 = GR 365-410-2

## CHANGE NOTICE

### Type 544-B Operating Instructions

For battery operation, the vacuum tube now used and supplied is the Type 1L4 miniature rather than the Type 1D5-G octal indicated in the operating instructions. A miniature-to-octal socket adapter is supplied. A single 1.5-volt #6 battery is now used and is supplied.

The resistor shown in the multi-point connector for the battery supply (R-3 on pp. 17 and 18) is replaced by a short-circuit and a new resistor R-8 of 220 ohms, BW-1/2 5%, is connected between the octal-socket terminal #6 and one side of R-5. For battery operation, the 1L4 is triode connected and the miniature-to-octal adapter automatically connects the 220-ohm resistor, R-8, in parallel with R-5 (page 17) for proper bias connection.

GENERAL RADIO COMPANY  
Cambridge 39, Massachusetts

Form 453-11

July, 1954

