TYPE 544-B

MEGOHM BRIDGE

OPERATING INSTRUCTIONS

TYPE 544-B

MEGOHM BRIDGE

GENERAL RADIO COMPANY

WEST CONCORD, MASSACHUSETTS, USA

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: ±3% on the 0.1, 1, and 10 multipliers; ±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 a No. 6 Dry Cell 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 50 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 1L4 detector tube is used; the 500-volt power supply uses a 6K7-G detector, a 6X5-G rectifier, a 5U4-G rectifier, and, in the voltage regulators, a 6J5-GT, a 6K6-GT, a 4A1 Ballast Tube, and two Type NE-48 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

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 MΩ and 4% to 10,000 MΩ. Above 10,000 MΩ the error increases rapidly, becoming 30% at 100,000 MΩ. A resistance of 1 MMΩ (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-Ω 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 200Ω 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 1L4 Detector Tube   1 - 8.2-kΩ Resistor to be used as
1 - No. 6 Dry Cell   a Battery Connector
3 - 45-v Dry Batteries   1 - Wooden Battery-Separator
1 - Socket Adaptor   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 8.2-kΩ battery connector furnishes protection against a short circuit of the UNKNOWN terminals, and also minimizes shock hazard.

Plug the Type 1L4 Detector Tube into the adaptor and plug the adaptor into the socket below the panel. See that the galvanometer is not shunted. Reconnect the Jones plug between power supply and bridge. Replace bridge 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-Ω galva-

nometer shunt is used with the a-c tube, Type 6K7G, in order to reduce its sensitivity to that of the battery tube, Type 1L4, which is sufficiently sensitive for most uses. If greater sensitivity is desired, the shunt can be ommited. The battery tube, Type 1L4, 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 ground (uninsulated) terminal in the upper left corner of the panel and swing the connector pivoted on the ground 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 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 4.13, EXTRANEOUS POTENTIALS.)

3.3 GROUNDED RESISTOR

3.31 Procedure: Swing the connector pivoted on the ground 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.

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 MUL-
TIPLY 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 gradua-
tions.

The errors involved in these measurements come mainly from the errors
of calibration or adjustment of the resistors in the arms of the bridge. Numeri-
cal 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 vari-
ous conditions indicate their presence by their effect on the initial zero adjust-
ment or on the bridge balance. If the galvanometer zero drifts in either direc-
tion, 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 dis-
cussed in Section 4.0, Paragraph 4.1.

3.4 UNGROUNDED RESISTOR

If the resistor to be measured has neither terminal grounded, its resist-
ance may be measured by the method of Paragraph 3.3 provided it can be en-
tirely 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 re-
sistance 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 con-
nector to the GUARD terminal and balancing the bridge as described in Para-
graph 3.3. A more complete discussion of the measurement of direct resist-
ance is given in Section 4.0, Paragraph 4.2.

4

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, Paragraphs 3.3 and 3.4, certain extra precautions must be taken because of the time constant associated with the capacitor and the resistance of the standard arm, N, of the bridge.

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.

The use of the CHARGE position for checking the zero of the galvanometer as well as for charging the capacitor is recommended.* This connection removes the standard resistor, N, and applies directly to the capacitor a voltage equal to the voltage across the B arm. (See Paragraph 4.8.)

When the control knob is thrown to the OPERATE position, the potential across the capacitor is instantaneously equal to the B arm potential and the bridge is momentarily in balance, <u>for whatever setting of the MEGOHMS dial was chosen for the CHARGE setting</u>. If the resistance of the capacitor is such that some other setting of R_A is required for balance, the voltage across the capacitor differs from the required voltage for balance. The difference between the initial value and the ultimately required value must equalize through the standard resistor. As the potential readjusts, R_A can be adjusted to balance the bridge and apparent resistance can be observed at any instant. Note that this apparent resistance may be larger or smaller than the true leakage resistance. The variation with time of the apparent resistance is governed by the time constant $C_X R_N$; (The time constant may be greater if dielectric absorption is significant. See Paragraph 4.11.)

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 μf with the MULTIPLY BY switch set at 100, and 1 μf with this switch set at 1000.

To obtain the true resistance of capacitors having very high values of resistance, the following specific procedure is suggested:
1) Adjust zero with the switch in the CHARGE position and the MEGOHMS dial set at infinity and the MULTIPLY BY switch set at 1000.
2) Set the control knob in the OPERATE position and wait until equilibrium

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*Except for the condition of extraneous potentials induced in the capacitor (see Paragraph 4.13).

is reached as seen on the bridge galvanometer.
  3) Adjust the MEGOHMS dial to balance.

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 volt-
ages and call that the insulation resistance. Such a resistance value is, how-
ever, 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 magni-
tude a possible upper limit of resistance.* The ratio of the 10-minute value to
the one-minute value is frequently referred to as the Polarization Index.

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 MUL-
TIPLY 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 cur-
rent, but leaves the first part of the curve dependent on the setting of the MEG-
OHMS 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

*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.

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.

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

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 MΩ) 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 <u>One Main Terminal Grounded</u>: The grounded terminal is connected to the LOW terminal and the spring connector pivoted on the ground 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 <u>Third Terminal Grounded</u>: The larger or outside main terminal is connected to the LOW terminal and the spring connector pivoted on the ground 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 <u>No Terminal Grounded</u>: 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-kΩ 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 MΩ for the former and 100 MΩ 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 kMΩ. The effect of 100 MΩ 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 MUL-TIPLY 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

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*See General Radio Catalog for data.

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 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 0.1%, 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.

4.6.1 Intercomparison of Standards: Sets of standards may be compared by means of an external decade resistor to an accuracy of better than 0.1% over the range from 10 kΩ to 10 kMΩ. 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. For best accuracy these should be 1% resistors so that the top decade may be kept fixed at each level, and balances should be made to 0.01%.

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 kΩ to 1 kΩ. The 200-Ω shunt placed across the galvanometer decreases its sensitivity by a factor of 4.3. The sensitivity of bridge balance 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 with 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 kΩ, the sensitivity expressed in percent increases to 0.6% for 100 Ω, 6% for 10 Ω, 60% for 1 Ω. When using the battery tube, the 200-Ω galvanometer shunt is removed.

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 MΩ) 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 22 ma. Under these conditions, this current will be exceeded for 100 volts across the bridge if the MEGOHMS dial reads more than 2.2. 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, protective resistance of about 90 ohms per volt should be placed in series: 8.2 kΩ for 90 volts, 18 kΩ for 200 volts, 47 kΩ for 500 volts, etc. A 8.2-kΩ resistor is supplied with the Type 544-P10 Battery Power Supply. These values reduce the maximum current to 12 ma. (See paragraph 4.9.)

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 kΩ, the resistance of the bridge is halved to 55 kΩ. 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

$$E_P = \frac{B}{A + B} E = \frac{10D}{1 + 10D} E = \frac{E}{1 + \frac{1}{10D}} \tag{2}$$
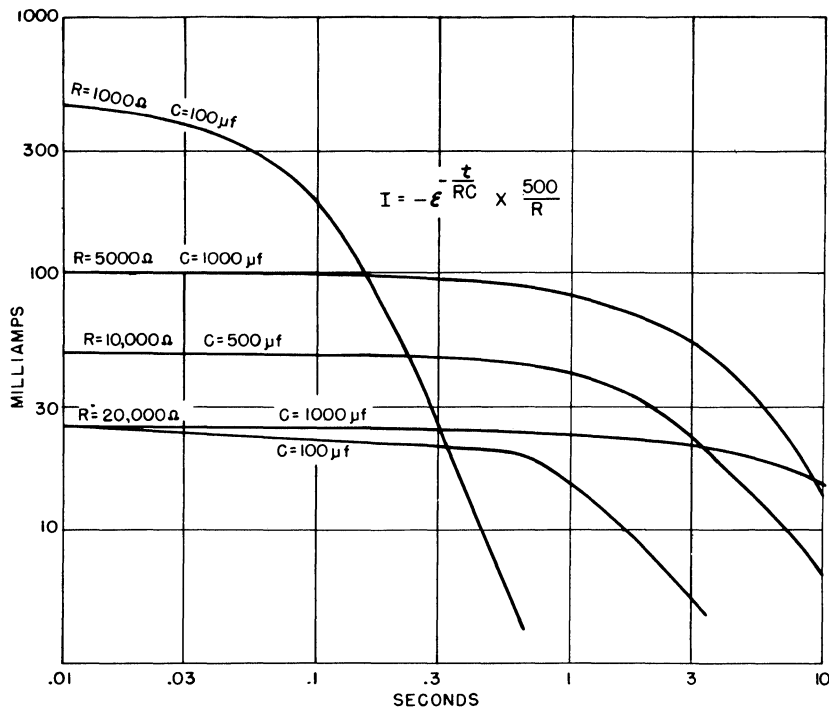
where D is the reading of the MEGOHMS dial.

CAUTION: Remember that there can be 500 volts at the BRIDGE and UNKNOWN binding posts.

4.9 SHOCK HAZARD

Every precaution has been taken in the design of the Type 544-B Megohm Bridge to reduce the possibility of shock. However, the operator should be aware of the dangers involved because of the high voltages present. The resistance to current depends, of course, on humidity conditions. From arm to arm, leg to arm, leg to leg, it can be as low as 300 ohms but under some circumstances it can be as high as one megohm. At low voltages, the skin offers a fair protection but at higher voltages, the skin is burned, its resistance is lowered and the low internal body resistance is controlling.

When the control switch of the bridge is in the OPERATE or CHARGE position, touching the two UNKNOWN terminals with one finger is painful and can cause a slight burn. The maximum direct current that can flow for any value of "body" resistance connected across the UNKNOWN or BRIDGE binding posts is 12 ma for 500-volt operation. Since the lethal value depends on the individual and on humidity conditions, extreme caution must be observed at all times. In fact one authority maintains that danger to life exists where potential exceeds 22.5 volts for wet-hand contact.*

*Wills Maclachlan, "Electric Shock," Electrical Engineering, October, 1951.

Plot of milliamps versus seconds with the equation:

$$I = -\varepsilon^{-\frac{t}{RC}} \times \frac{500}{R}$$

Curves labeled: R=1000 Ω, C=100 μf; R=5000 Ω, C=1000 μf; R=10,000 Ω, C=500 μf; R=20,000 Ω, C=1000 μf; C=100 μf.

When a large capacitor is connected to the UNKNOWN terminals, it should be treated with great caution because there can be 500 volts at its terminals and it may have no appreciable inherent current-limiting series resistances. The current that will flow through the body upon connecting the "body resistance" to its terminals will at first be very great and the speed with which the current is damped depends on the capacitance as well as the resistance. A current-limiting resistor of one megohm should be connected as near to the capacitor as possible. Current decay curves for various values of capacitance and of "body resistance" are shown in the figure on page 12.

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 % Arm	Bridge	Coefficients in % Temp.	Volt.
B		100 kΩ	Wire	.25		.01	.00
A		0-12.5 kΩ	Wire	2.0		.01	.00
N	0.1	10 kΩ	Wire	.25	3	.01	.00
	1	100 kΩ	Wire	.25	3	.01	.00
	10	1 MΩ	Wire	.25	3	.01	.00
	100	10 MΩ	Deposited	1.0	4	-.04	.0001
	1000	100 MΩ	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. Type 1L4 and Type 6K7G are used at low plate voltage to keep the grid current at about 100 $\mu\mu$a or less. Electrode voltages are obtained from a voltage divider having a total resistance of 6 kΩ 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 200-Ω galvanometer shunt used with the a-c tube 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-μa full deflection and a resistance of 660 Ω. A scale division corresponds to 5 μa. 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.

A resistance of 10 MΩ 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-μf capacitor connected from grid to cathode acts with the 10 MΩ 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 MMΩ. 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 W5 or W5MT Variac®. If a Variac is not available, the voltage applied to the bridge can be decreased by 10% by inserting a resistance of 30 Ω. 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 ∞. As the setting of the dial is decreased to 1 the bridge resistance increases from 100 kΩ to 110 kΩ. 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 increases by 4%.

Erratic fluctuations of the bridge meter with the operation switch in the CHARGE and OPERATE positions may be caused by a defective capacitor, C1, in the Type 544-P3 A-C Power Supply, a defective unknown capacitor, or line-voltage transients.

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 kΩ regardless of the resistance or voltage of the bridge. The resistors used are shown in Figure 10. For a 100 kΩ 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 MΩ.*

The Type 544-404 Adaptor Board, available on special order, plugs into the terminal board on the Type 544-P3 Power Supply to provide 125-volt output. In the accompanying illustration (Figure 11), the Adaptor plugs into the terminals shown in black.
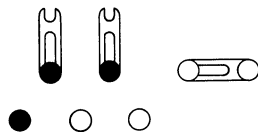

Figure 11. Terminal Board of Power Supply, showing connections to Type 544-404 Adaptor.

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.

---

*Note for special bridges having 1-MΩ ratio arm B added: When using this ratio arm (toggle switch in the X10 position), short circuit the terminals marked 1 MΩ to maintain the normal bridge voltages. When these terminals are left open, the bridge voltage is approximately 790, for the 500-volt connection. This may be increased to about 900 volts by adjusting R-2 and R-4 at the sacrifice of regulation. With the BRIDGE switch in the OFF position, an external bridge voltage of any value up to 1000 volts may be connected at the BRIDGE + and - binding posts. See paragraph 4.8 for current limits, protective resistors, etc.
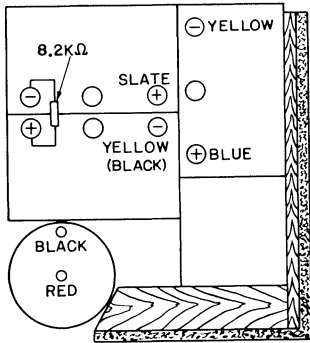
Figure 1. Arrangement
of batteries in rear com-
partment with color code
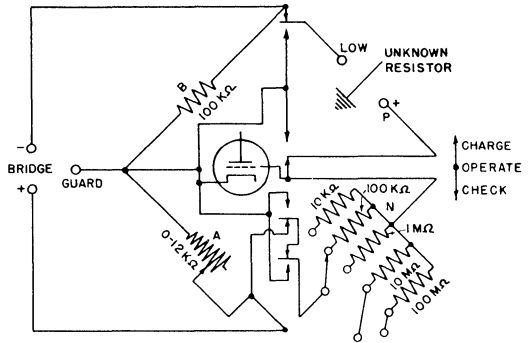of cable.

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

CHECK   OPERATE   CHARGE

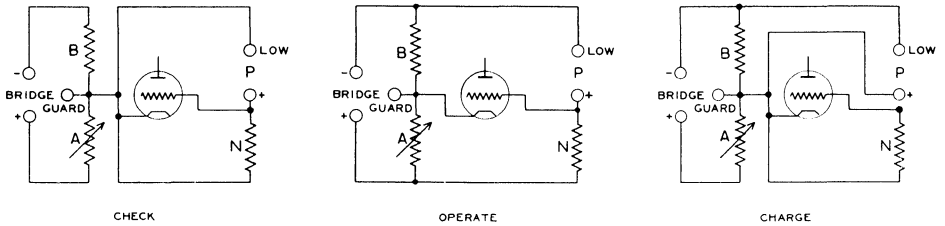Figure 3. Connections of Type 544-B Megohm Bridge for three
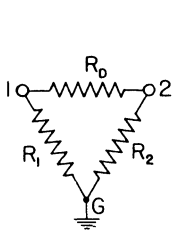positions of control knob.

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

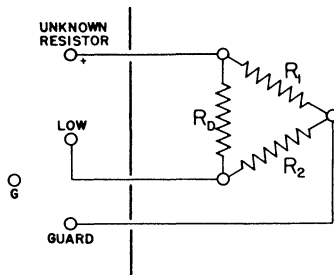Figure 5. Bridge connec-
tions for measurement of
direct resistance.
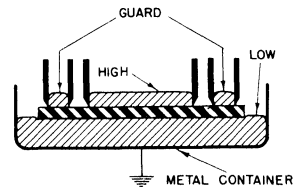
Figure 6. Mercury
Electrodes.

16
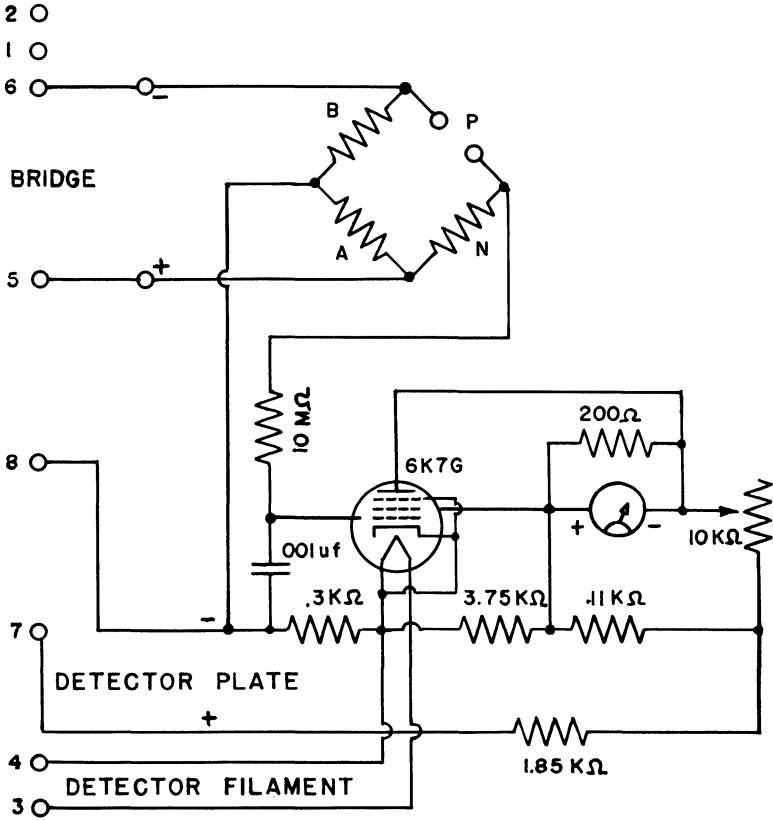
Figure 7. Schematic Wiring Diagram of Vacuum-Tube Voltmeter and Bridge.
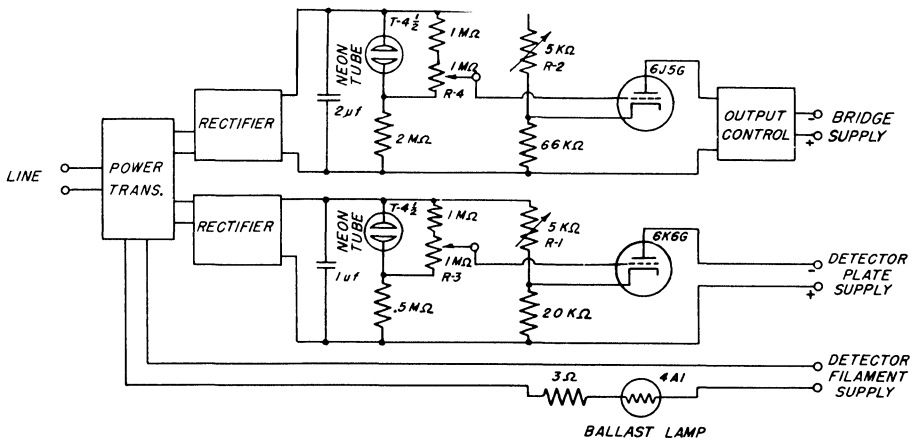
Figure 8. Schematic Wiring Diagram of Type 544-P3 Power Supply.

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NOTE FOR S-2
BEND BLADES 2,5,7 & 12
TO MAKE CONTACT IN
CENTER POSITION ALSO.
BEND FOR BREAK BEFORE
MAKE OPERATION.

CHARGE

OPERATE

CHECK

MULTIPLY BY

10   100

1000

ENGRAVING FOR S-1

LOW

UNKNOWN
RESISTOR

BRIDGE

GUARD

MEGOHMS

CCW

BRIDGE

ON

OFF
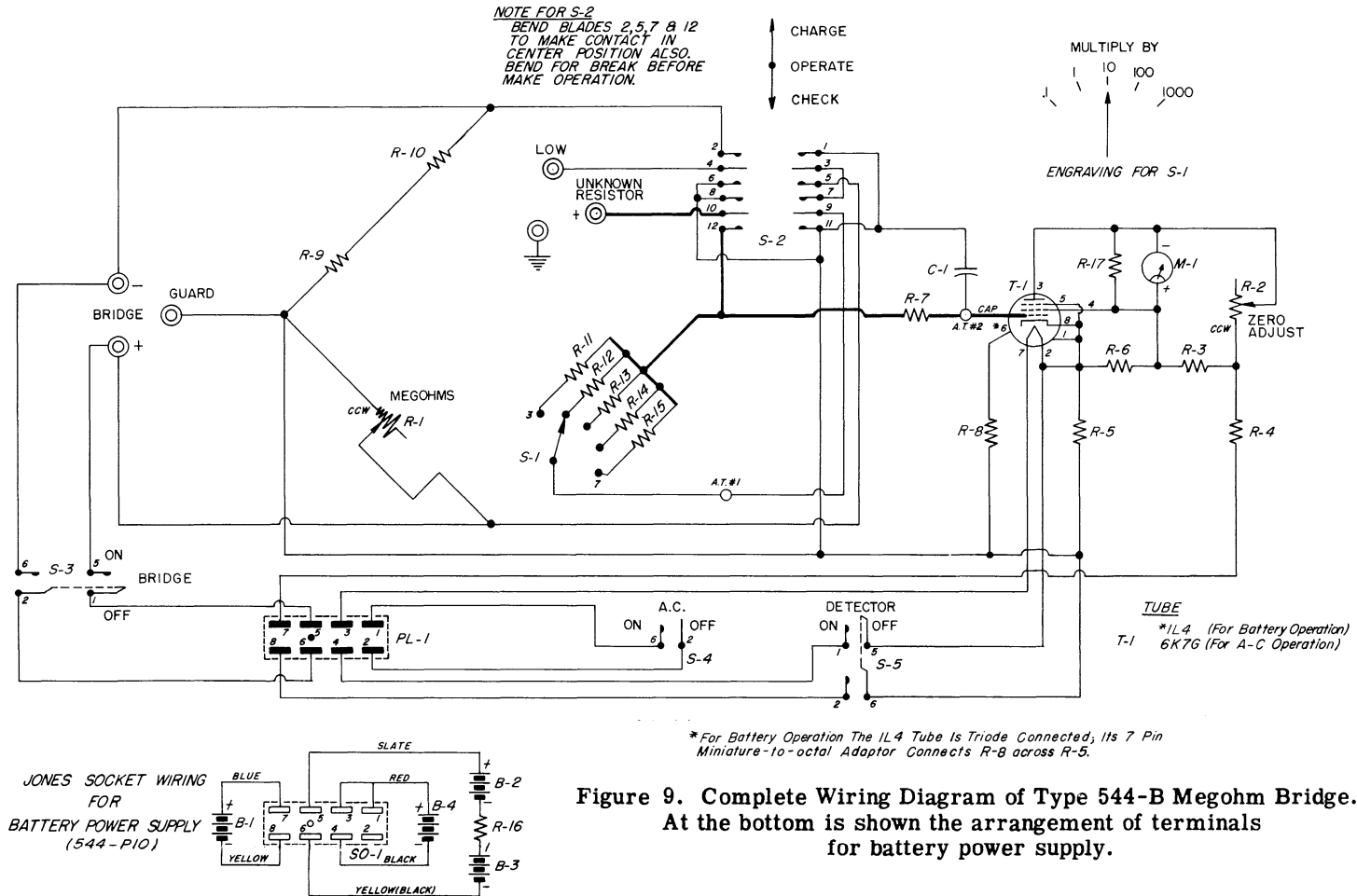
JONES SOCKET WIRING
FOR
BATTERY POWER SUPPLY
(544-PIO)

SLATE

BLUE

RED

YELLOW

YELLOW(BLACK)

A.C.

ON   OFF

DETECTOR

ON   OFF

TUBE

*IL4 (For Battery Operation)
T-1   6K7G (For A-C Operation)

* For Battery Operation The IL4 Tube Is Triode Connected; Its 7 Pin
Miniature-to-octal Adaptor Connects R-8 across R-5.

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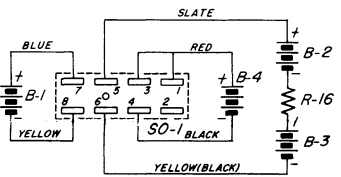
Parts List for Type 544-B Megohm Bridge

RESISTORS		TYPE
R-1	= 12.2 - 12.7 k Ohms	544-332
R-2	= 25 k Ohms ±10%	POSC-7
R-3	= 110 Ohms	
R-4	= 1.85 k Ohms } 544-314 }	544-311
R-5	= 300 Ohms	
R-6	= 3.75 k Ohms } 544-313 }	
R-7	= 10 Megohms ±10%	REC-30BF
R-8	= 220 Ohms ±10%	REW-3C
R-9	= 50 k Ohms ±1/4%	REPR-17
R-10	= 50 k Ohms ±1/4%	REPR-17
R-11	= 10 k Ohms ±1/4%	REPR-16
R-12	= 100 k Ohms ±1/4%	REPR-10
R-13	= 1 Megohm ±1/4%	REPR-18
R-14	= 10 Megohms ± 1%	REF-75
R-15	= 100 Megohms ± 1%	REF-3-3
R-16	= 8.2 k Ohms ± 10%	544-324*
R-17	= 220 Ohms ± 10%	REW-4C **

SWITCHES

S-1	=	5 Position	544-342
S-2	=	4PDT	339-AL
S-3	=	DPST	SWT-333
S-4	=	SPST	SWT-323
S-5	=	DPST	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	=	1.5 Volt Eveready	#6

MISCELLANEOUS

C-1	=	Capacitor 0.001 μf ±10%	COM-30B
PL-1	=	Plug	CDMP-461-8
SO-1	=	Socket	CDMS-464-8
M-1	=	Meter	588-321

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LINE 115-230V. 50-60 ~

F-1
F-2

T-1

NOTE:
FOR 115V. INPUT
CONNECT #1 TO #3
AND #2 TO #4
FOR 230V. INPUT
CONNECT #2 TO #3

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

V-2
V-5
R-7
R-2
R-9
V-3
CL'KW'S END
R-5
R-4
R-8
C-1
CL'KW'S END
R-6
C-4
T-1,#11

R20
C-3
R-17
R-16
V-3,#6
WM.
1500V
100V
100V
R-14
R-15
DET.
V-3,#6

V-6
R-10
R-1
C-5
V-4
CL'K'WS END
R-12
R-3
R-11
C-2
V-1
R-13
CL'K'WS END
R-18
R-19
V-7

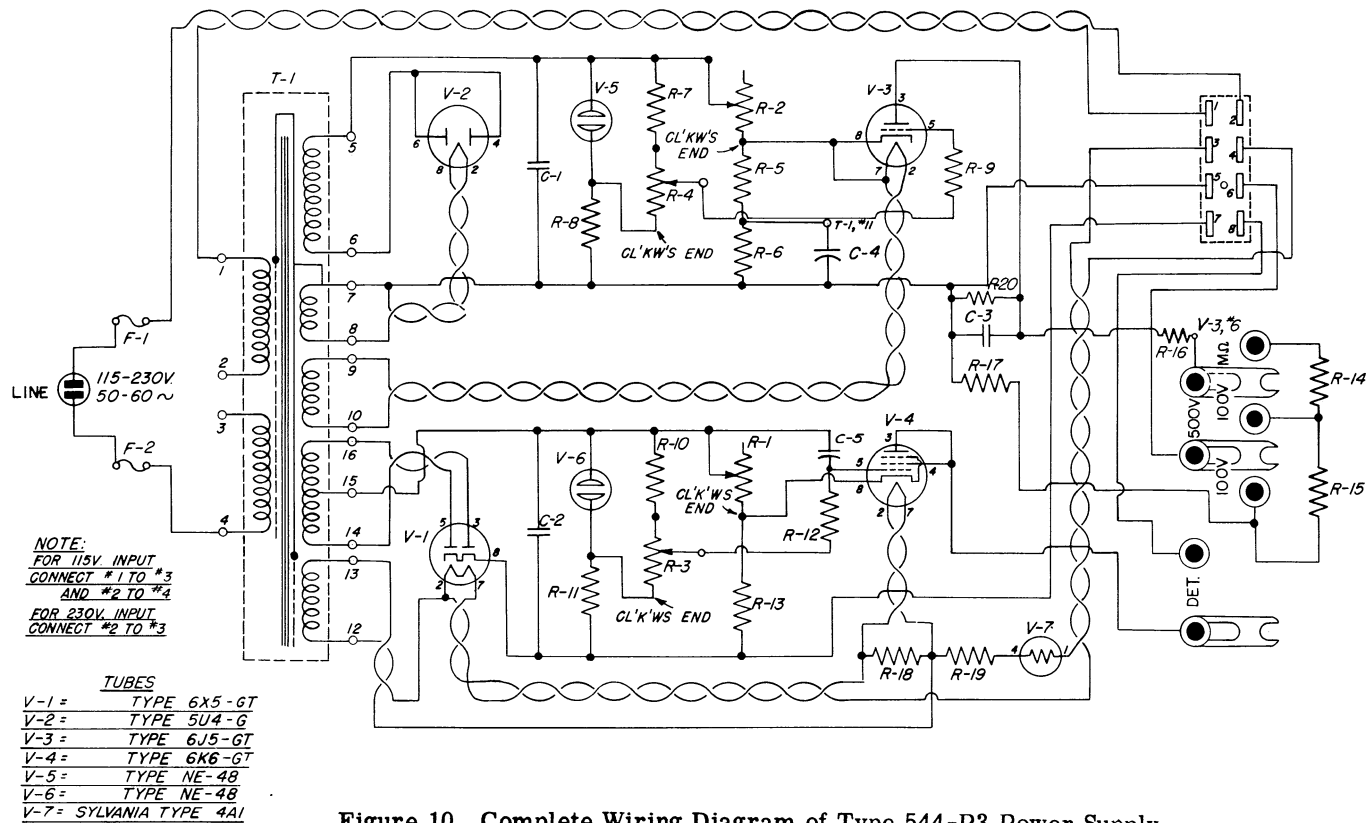**Figure 10. Complete Wiring Diagram of Type 544-P3 Power Supply.**

Parts List for Type 544-P3 Power Supply

RESISTORS:

R-1	=	5 kilohms	±10%		POSW-3
R-2	=	5 kilohms	±10%		POSW-3
R-3	=	1 Megohm	±20%		POSC-11
R-4	=	1 Megohm	±20%		POSC-11
R-5	=	33 kilohms	±5%	12W	REPO-1009
R-6	=	33 kilohms	±5%	12W	REPO-1009
R-7	=	1 Megohm	±5%	1/2W	REC-20BF
R-8	=	1.8 Megohms	±10%	1W	REC-30BF
R-9	=	1.8 Megohms	±5%	1/2W	REC-20BF
R-10	=	1 Megohm	±5%	1/2W	REC-20BF
R-11	=	470 kilohms	±5%	1/2W	REC-20BF
R-12	=	1.8 Megohms	±5%	1/2W	REC-20BF
R-13	=	20 kilohms	±5%	8W	REPO-1045
R-14	=	5.6 kilohms	±10%	1W	REC-30BF
R-15	=	80 kilohms	±2%	5W	REF-1-4
R-16	=	100 Ohms	±10%	2W	REW-6C
R-17	=	25 kilohms	±2%	1W	REF-1-2
R-18	=	27 Ohms	±10%	2W	REW-6C
R-19	=	6.8 Ohms	±10%	1W	REW-4C
R-20	=	2.7 Megohms	±10%	1W	REC-30BF

CONDENSERS:

C-1	=	2.0 µf	±10%	1000VDC	COL-23
C-2	=	1.0 µf		600VDC	COL-5
C-3	=	1.0 µf		600VDC	COL-5
C-4	=	0.022 µf	±10%	600VDC	COL-71
C-5	=	0.01 µf	±10%	600VDC	COL-71

TRANSFORMER:

T-1 = G.R.Co. 365-410-2

FUSES:

F-1	=	0.8 amp	3AG	Slo-Blo	(GR FUF-1)	For 115 v.
F-2	=	0.8 amp	3AG	Slo-Blo	(GR FUF-1)	
F-1	=	0.4 amp	3AG	Slo-Blo	(GR FUF-1)	For 230 v.
F-2	=	0.4 amp	3AG	Slo-Blo	(GR FUF-1)	

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