

# THE *General Radio* EXPERIMENTER

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

## THE MEGOHM BRIDGE

● IT IS BECOMING of increasing importance to be able to measure accurately and rapidly high resistances in the range from 1 megohm to 1,000,000 megohms. The volume resistivity of insulating materials is a fundamental property in predicting their electrical characteristics. It is particularly sensitive to small traces of moisture and so becomes a valuable measure of moisture content. When this property is used in conjunction with dielectric constant and power factor, a powerful means is offered of studying the molecular structure of complex dielectrics.

The bar to the successful use of the Wheatstone bridge in this high-resistance range is the relatively low resistance of the conventional galvanometer used to indicate bridge balance. The amount of power demanded by even a sensitive wall galvanometer is such as to make it difficult to measure resistances greater than 10 megohms. The use of a vacuum-tube voltmeter as the bridge detector completely resolves the difficulty. It is quite possible to obtain a tube which presents to the

FIGURE 1. TYPE 544-B Megohm Bridge



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REPAIRS vs. OBSOLESCENCE



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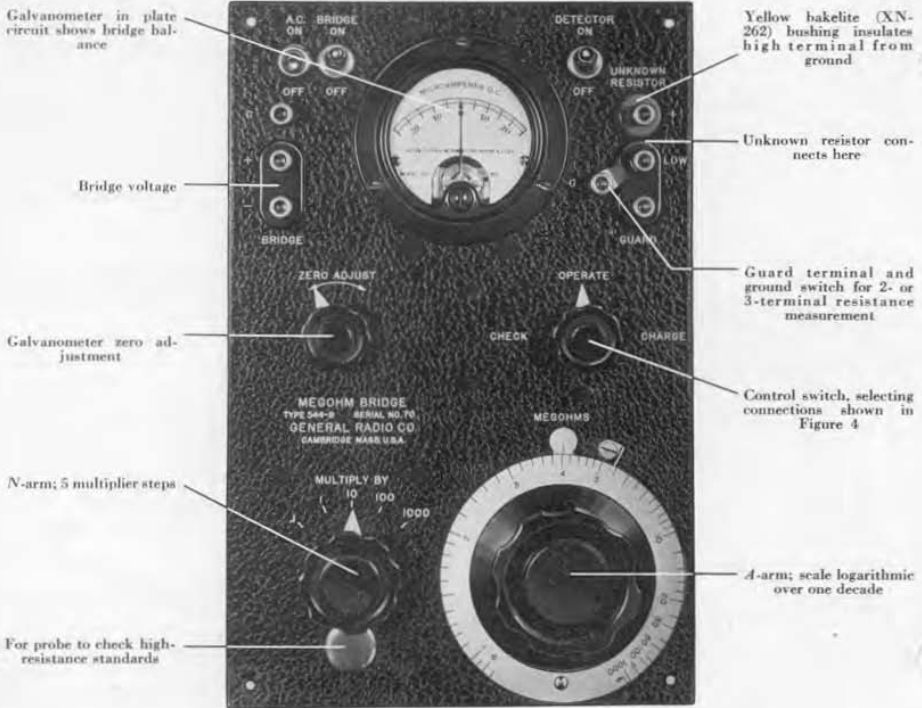


FIGURE 2. Panel view of the bridge, identifying the several controls

bridge a resistance greater than 10,000 megohms and still allows the bridge to be balanced to 0.1%, using an ordinary pointer galvanometer in its plate circuit.

### AN IMPROVED MEGOHM BRIDGE

Just such a combination of Wheatstone bridge and vacuum-tube voltmeter was designed in 1933\* and has been in use ever since. Two kinds of measurements have grown in importance since then—the leakage resistance of large condensers and the use of guard electrodes and three-terminal condensers—for which that bridge was not well adapted. In the TYPE 544-B Megohm Bridge, which is now announced, all the desirable features of the earlier model are retained (see Figure 1).

\*R. F. Field, "Bridge + Vacuum Tube = Megohm Meter," *General Radio Experimenter*, June-July, 1933, pp. 7-9.

In addition, condensers can be measured for resistance because the voltage applied to the unknown varies only slightly during balance, and all sorts of three-terminal resistors can be connected because of the flexibility of the guard terminals and grounding system.

### ACCURACY AND RANGE

The resistance reading of the bridge is taken from the settings of a five-point decade multiplier switch and a four-inch dial, having a scale which is approximately logarithmic over one decade. These appear at the bottom of the panel in Figure 2. The MEGOHMS dial is shown full size in Figure 3. The main decade is 7 inches long. Hence the scale length for the resistance range from 0.1 MΩ to 10,000 MΩ, over which the accuracy of scale reading is 2%,

is 35 inches. Taking into account the errors in the other bridge arms, the accuracies of the resistance measurements are:

Range	Error
.1 MΩ – 100 MΩ	± 3%
100 MΩ – 1,000 MΩ	± 6%
1,000 MΩ – 10,000 MΩ	± 10%

Beyond 10,000 MΩ the error is essentially that with which the scale on the MEGOHMS dial can be read. A resistance of 1,000,000 MΩ can be detected.

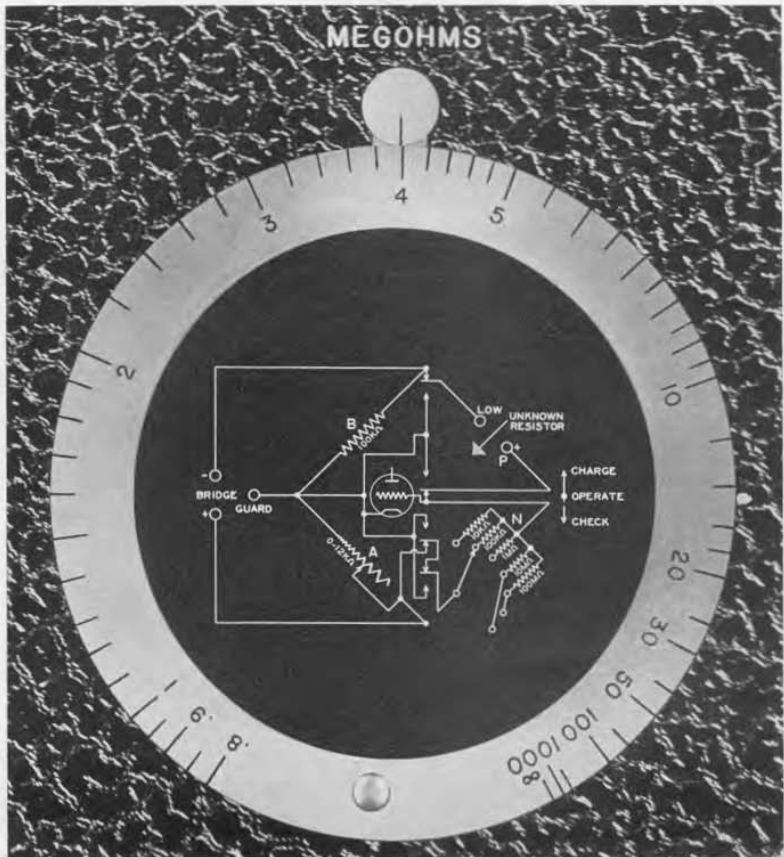
### THE BRIDGE CIRCUIT

The bridge is composed of the four arms *A*, *B*, *N*, *P* as shown for the OPERATE position in Figure 4, with the power applied across the arms *A* and *B* and the vacuum-tube voltmeter connected across the conjugate pairs *A-N* and *B-P*. For checking the galvanometer zero, the tube is isolated

from the bridge voltage as shown in the CHECK position, with the high resistors *N* and *P* connected to the grid exactly as in the OPERATE position. The effects of any voltages, alternating or direct, in the unknown resistor *P* and of any grid current of the tube will not appear in the bridge balance because they are balanced out in the zero adjustment. There is also a CHARGE position, in which the unknown resistor *P* is placed across the arm *B*. This is valuable in measuring the resistance of large condensers.

The exact connections of the various arms are shown in the schematic wiring diagram in the center of Figure 3. Not all the standard resistors which make up the *N*-arm are wire wound. The two highest

FIGURE 3. Full-size reproduction of the MEG-OHMS dial, showing also the schematic wiring diagram



are of the less stable metallized-filament type. Means are provided for connecting these resistors in the *P*-arm and measuring them in terms of the wire-wound standards.

**TERMINAL CONNECTIONS**

All the terminals of the bridge are grouped together in the upper part of the panel (Figure 2) to allow the convenient connection of all types of resistors. For measuring all grounded resistors and most two-terminal resistors, the ground post *G* is connected to the Low terminal by the spring clip provided. This group includes the insulation resistance of electrical machinery such as generators, motors, and transformers, electrical equipment such as rheostats and household appliances, single conductors, cables, and condensers. For all resistors having a third terminal, which may be brought out separately or may be ground itself, this third terminal is connected to the *GUARD* terminal as shown in Figure 6. The ground post *G* is connected to whichever of the two terminals, *Low* or *GUARD*, is grounded. The bridge then measures the direct resistance  $R_D$  and rejects the terminal resistances  $R_1$  and  $R_2$ . All multi-wire cables, multi-circuit transformers, and multiple terminal condensers and networks are included in this type of measurement. Guard electrodes are frequently added to simple two-terminal devices to eliminate both surface leakage and the effect of fringing in discs of insulating material. A good example of this using mercury electrodes is shown in Figure 5.

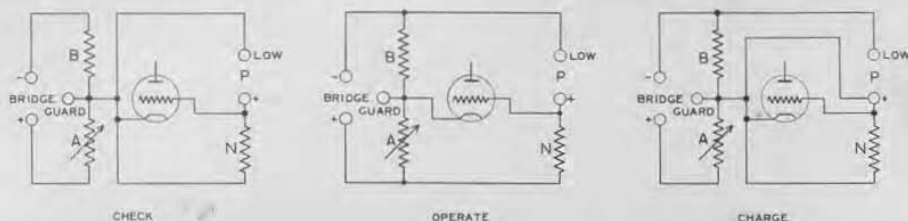
The high potential terminal and all leads connected to it are insulated with low-loss bakelite, XN-262, which even with the existing multiple paths to ground has a resistance to ground of over 1 MMΩ. The black crackle-finish on the panel is stripped from around the panel insulator so that, when the *GUARD* terminal is grounded, there will be no leakage over it to the *Low* terminal.

**RESISTANCE OF CONDENSERS**

The leakage resistance of condensers is measured in the same manner as other resistances except when the capacitance is large, a tenth microfarad or greater. Sufficient time must then be allowed to charge the condenser, through the standard resistance in the *N*-arm, to the voltage it will have when the bridge is balanced. The time constant of this circuit, which is the product of the capacitance in microfarads and the resistance in megohms, is a convenient measure of this time interval. When this is more than a few seconds, time is saved by turning the control knob to the *CHARGE* position, as shown in Figure 4. This applies to the condenser approximately the same voltage as it will have at bridge balance.

This switch position is also useful when a condenser shows considerable dielectric absorption and therefore acquires a volume charge. After the initial adjustment, the galvanometer zero can no longer be checked in the *CHECK* position because of this volume charge. In some types of insulation, such as long cables with both rubber and paper insulation and laminated materials like the pasted mica used in high voltage generators, this volume

FIGURE 4. Schematic bridge diagrams for the three positions of the control knob



charge reaches huge proportions. It may require hours and sometimes days to attain equilibrium. This effect has fostered the rule of thumb of observing the resistance one minute after the application of the voltage. Any measurement taken while this volume charge is flowing is not a measurement of leakage resistance, but of charging current. There is no definite relationship between the resistance measured at an arbitrary time and the final steady state resistance. The rate of change of the instantaneous resistance is probably of more significance\* than the resistance itself because it suggests by its magnitude how much greater the final insulation resistance will be. It is very easy to use the bridge for such measurements. Balance is maintained by adjustment of the MEGOHMS dial up to a given time and the setting then read at leisure. The current flowing can be easily calculated from the observed resistance and the voltage applied to the bridge. It is also possible to discharge the condenser through the standard resistance and calculate the discharge current.

### EXTERNAL DECADE RESISTOR

It is possible to replace the logarithmic resistor with a five-dial TYPE 602 Decade Resistance Box when the maximum possible accuracy of balance is desired. Resistances from 10 kilohms to 10 kilomegohms can then be measured with an accuracy of about  $\frac{3}{4}\%$ . Sets of high resistance standards can be compared over that same range to an accuracy of 0.1% provided such standards have negligible voltage coefficients.

### POWER SUPPLIES

The voltage normally applied to the bridge is 90 volts, obtained from one of two power supplies mounted in back of the bridge panel, one for a-c, the other for

\*R. W. Wiesman, "Insulation Resistance of Armature Windings," *Electrical Engineering*, June, 1934, pp. 1010 to 1021.

d-c operation. Either power supply will be furnished with the bridge as listed below, while the other one may be obtained as extra equipment. In the a-c supply the bridge and tube bias voltages are stabilized against line voltage fluctuations by ballast tubes. Different tubes for the bridge detector are used for a-c and d-c operation and are furnished as part of their respective power supplies. These

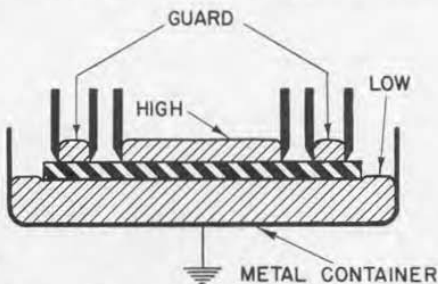
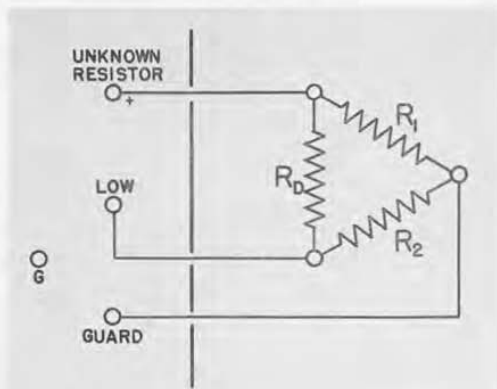


FIGURE 5. Cell for solid dielectrics, using mercury electrodes

tubes are tested for low grid current and a stock is maintained on hand. The actual voltage applied to the bridge can be measured at the BRIDGE terminals on the left of the panel. These terminals may also be used for external supply up to 500 volts. This makes it possible to study the effect of voltage on the resistance of insulation.

—R. F. FIELD

FIGURE 6. Bridge connections for the measurement of direct resistance



# TYPE 544-B MEGOHM BRIDGE

## SPECIFICATIONS

**Range and Accuracy:** See table on page 3.

**Terminals:** The terminals for connecting the unknown resistor include connections for guard electrodes so that either two- or three-terminal resistors can be measured.

**Power Supply:** Two types of power supply are available, one using batteries, the other operating from a 115-volt, 40- to 60-cycle a-c line.

**Vacuum Tubes:** With battery power

supply, a 1D5G detector tube is used; the a-c power supply uses a 6K7G detector, two 6X5G rectifiers, and an 874 ballast tube. All tubes are supplied with the instrument.

**Mounting:** Shielded oak cabinet.

**Dimensions:** Cabinet with cover closed, (width)  $8\frac{1}{2}$  x (length)  $22\frac{1}{2}$  x (height) 8 inches, over-all.

**Net Weight:** With battery power supply,  $30\frac{1}{4}$  pounds; with a-c power supply,  $25\frac{1}{4}$  pounds.

Type		Code Word	Price
544-B	Battery operated . . . . .	ALOOF	\$175.00
544-B	A-C operated . . . . .	ANNOY	225.00

## REPAIRS VS. OBSOLESCENCE

● **OUR SERVICE DEPARTMENT**, through which are handled all customer complaints, repairs, exchanges, and adjustments, is often called upon to repair and rebuild obsolete equipment. Experience has shown that misunderstandings between manufacturer and customer arise more often with obsolete instruments than with current models. The two major points of disagreement are (1) cost of repairs and (2) instrument performance after repairs are made.

### COST

Since each instrument returned for reconditioning must receive individual attention, the work must be handled in much the same way as a special manufacturing job. Consequently, the amount of supervision required per instrument is considerably more than that necessary in reg-

ularly scheduled production. An analysis of the performance characteristics must be made as well as a schedule of mechanical repairs. All badly worn or defective parts must be replaced, resistance elements re-adjusted, and the remainder of the assembly thoroughly cleaned and tightened mechanically. This involves an operating check on nearly all component parts, and when these are found defective it is often difficult to find replacements, particularly if the instrument has been obsolete for any considerable period.

Parts which are of General Radio manufacture may not be in stock. While these can be made, the operation is necessarily costly because they were originally made in large quantities. Parts and materials supplied by other manufacturers may no longer be available, which necessitates finding satisfactory substitutes or making



minor changes in the design of the instrument.

After all repair operations have been performed, a complete operating test and calibration must be made in our testing laboratory. Here again it is uneconomical to handle the instruments individually since all normal production work is done in quantity lots.

Electrical design and production methods are constantly improving. As a result, many labor operations performed on obsolete instruments are less efficiently performed than those on newer products. This is particularly true of such items as the TYPE 102 Decade-Resistance Box in which certain of the cards were wound with resistance wire having a high temperature coefficient. Readjusting resistors in these cards consumes a considerable amount of time because the wire is raised in temperature whenever a soldering iron is applied to it. The repair of these resistance boxes is often not merely a matter of readjusting a few resistors, but one of replacing most of the resistance cards in the box. Since the resistance cards represent the greater part of the original cost of the instrument, repair costs are correspondingly high.

A cost analysis of reconditioning operations on a number of obsolete instruments shows that average repair prices are approximately as follows:

<i>Original Cost of Instrument</i>	<i>Maximum Repair Charge</i>
Less than \$50.00	75% of list price
Between \$50.00 and \$100	65% of list price
Between \$100 and \$200	50% of list price
Above \$200	33% of list price

These are only approximate prices and the exact charge is, of course, dependent upon the age and the condition of the instrument. From these figures, however, it will be realized that in many instances the repair costs approach the list price of a new instrument which has replaced the model submitted for repair. Because of this it is

often less expensive, or at least very little more so, if the instrument is replaced by a newer model.

## PERFORMANCE OF RECONDITIONED INSTRUMENTS

In addition to the cost, the performance to be obtained from the repaired instrument should be carefully considered. It should be obvious that the maximum performance to be expected from a reconditioned instrument is only that obtainable when the instrument was originally sold. Usually this is considerably inferior to that obtainable from instruments of more recent design. In other words, a complete reconditioning of the TYPE 513-B Beat-Frequency Oscillator will by no means make it equal in performance to the newer TYPE 713-A Beat-Frequency Oscillator. As an element of the total cost of repairs, therefore, the performance to be expected from the repaired instrument is important.

If we offered for sale, at its original price of \$100, a brand-new TYPE 102-M Decade-Resistance Box which was manufactured between 1920 and 1931, its purchase could not be justified because a TYPE 602-M Decade-Resistance Box, which has far better characteristics and general performance, can be purchased new for \$70. Yet the cost of repairing a TYPE 102-M Box may be well in excess of \$50.

Our Service Department will be glad to advise the user of General Radio instruments regarding both the probable cost and the desirability of reconditioning old instruments. If, after an instrument is received for repair, the costs are evidently much higher than the original estimate, a formal quotation will be submitted before work is started. — H. H. DAWES





A group of TYPE 636-A Wave Analyzers under test in our calibration laboratory

## MISCELLANY

● **AMONG** recent visitors to our laboratories were Professor William R. Work, Head of the Electrical Engineering Department at Carnegie Institute of Technology, and Laurence E. Jermy, Editor of *MACHINE DESIGN*.

● **IF YOU** are going away for several

months this summer be sure to leave your forwarding address **AND POSTAGE** with your Post Office, otherwise the *Experimenters* will be returned to us with the notation "gone away — address unknown." This causes much unnecessary correspondence and delay.

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