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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also

IN THIS ISSUE

ROUTINE FREQUENCY MEASUREMENTS TO 0.005%

● **THE TYPE 620-A HETERODYNE FREQUENCY METER AND CALIBRATOR,*** which is widely used for routine frequency measurements by transmitter manufacturers, communication companies, inspection services, and laboratories, is now being supplied with a slow-motion drive and auxiliary dial by means of which the precision and facility of setting and reading the scale are greatly increased. The friction drive formerly used has been replaced by a gear drive that has a reduction ratio of about 15:1. To insure smooth action and accurate repetition of settings, the pinion and driving shaft are integral, and the internal drive gear is spring-pressed to remove backlash.

As shown in Figure 1, the driving shaft carries an auxiliary dial, which effectively subdivides each full main scale division into ten parts. Since each main scale division corresponds to 10 kc, each auxiliary scale division is 1 kc. At the low-frequency end (10 Mc) of the main dial, there-

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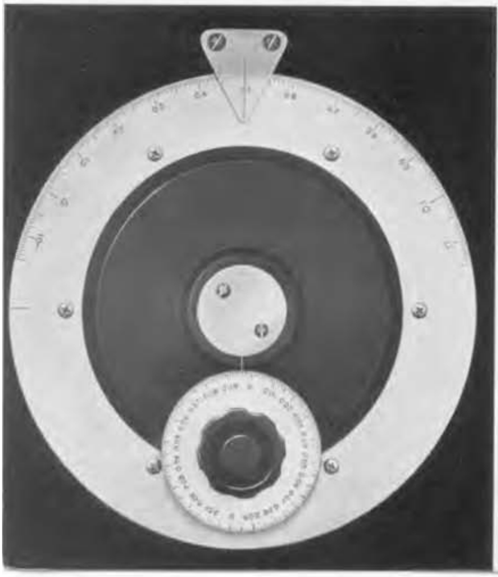
* J. K. Clapp, "A Direct-Reading Frequency Meter with Built-In Calibrator," General Radio *Experimenter*, September-October, 1936.

Figure 1. Panel view of the Type 620-A Heterodyne Frequency Meter and Calibrator.

fore, the smallest auxiliary scale division is 0.01%; at the high-frequency end (20 Mc), it is 0.005%.

The TYPE 620-A Heterodyne Frequency Meter and Calibrator consists of an oscillator whose frequency can be varied between 10 Mc and 20 Mc, and a 1-Mc crystal oscillator against which the frequency of the variable oscillator can be standardized. An unknown frequency is measured by matching the frequency of the variable oscillator to that of the unknown (as indicated by zero beat in a receiver). The calibration of the variable oscillator is then checked against the crystal calibrator and allowance made for any drift. For measurements above 20 Mc, harmonics of the variable oscillator are used. Below 10 Mc, the fundamental of the oscillator is matched to a harmonic of the unknown. By using harmonics in this way, frequencies between about 300 kc and 300 Mc can be measured, although the fundamental range of the variable oscillator is from 10 to 20 Mc.

FIGURE 2. View of the dial of the heterodyne frequency meter showing scale calibration. Each division on the auxiliary dial is 0.001 Mc.



The frequency of the variable oscillator is read directly from a switch and dial on the panel. The crystal calibrator is used solely to determine the error in the indicated oscillator frequency. This error is then added to or subtracted from the oscillator dial reading in order to obtain the correct value of the unknown frequency under measurement.

The over-all accuracy of measurement depends upon the accuracy of the crystal calibrator and the accuracy of *frequency intervals* on the scale of the variable oscillator. Errors in the absolute calibration of the variable oscillator are kept low in order to make the dial as *nearly* direct reading as possible, to avoid ambiguity in identifying the crystal calibrating points, and for convenience in operation. In checking transmitter adjustments and in laboratory investigations, the results as read directly from the dial, without correction, are many times sufficiently accurate (about 0.1% or better). Beyond that, the absolute calibration of the dial is of little consequence, because errors can be determined and allowed for in terms of the crystal calibrator.

The variable condenser in the variable oscillator covers a frequency span of 1 Mc. A 10-point switch changes the frequency in steps of 1 Mc from 10 Mc to 19 Mc. The frequency of the oscillator is, therefore, the sum of the switch and dial readings, corrected for the dial error in terms of the crystal oscillator.

In Figure 1 and Figure 2, the indicated oscillator frequency is 14.496 Mc. Suppose, for example, that, when the calibrator is switched on, the zero-beat setting for the 14.5 Mc calibration point is found to be 14.513 Mc, an error of + .013 Mc. This indicates that the oscillator dial indication is .013 Mc higher than the actual oscillator frequency in the vicinity of 14.5 Mc, and the true frequency for a dial setting of 14.496 Mc is 14.496 − .013 or 14.483 Mc.

Ten or more usable calibrating frequencies are available on *each* dial range. These result not only from harmonics of the crystal oscillator frequency beating with the fundamental of the frequency meter, but also from beats between harmonics of both oscillators.

Variations in the frequency of the crystal oscillator are usually negligible, and the accuracy of measurement is mainly dependent on the precision with which the dial is set when matching the unknown frequency and when checking against the calibrator. An accuracy of better than 0.01% is easily obtainable.

— J. K. CLAPP

SPECIAL MEGOHM BRIDGES

● **THE NEW FIELD** of d-c resistance measurements opened up by the TYPE 544-B Megohm Bridge[*] and the TYPE 544-P3 500-volt Power Supply[*] is widening rapidly. The ease with which measurements in the thousands of megohms can be made permits detailed studies of the effect on insulation resistance of time, temperature, and humidity; measurements which have heretofore not been considered feasible. While the stock model of the bridge meets the needs of most users, there appear to be many occasions when greater resistance range, greater sensitivity, and greater accuracy are needed. Several modifications of the stock bridge to meet these requirements are described below.

INCREASED RANGE

The normal resistance range of the TYPE 544-B Megohm Bridge is 0.1 to 10,000 megohms with an accuracy of measurement varying from 3 to 10%. The error increases to 30% at 100,000 megohms and a resistance of 1 megamegohm[†] can be detected. The bridge circuit used, together with the necessary switching connections, is shown in Figure 1. The expression for the unknown resistance P in terms of the other arms of the bridge is:

$$P = \frac{B}{A} N \qquad (1)$$

The resistance range as a whole can be raised by increasing B or N. The upper limit alone can be raised by decreasing A. Of these three methods only the first and last are possible. A standard resistance of 1000 megohms is relatively unstable and inaccurate, and in any case is too near in value to the input resistance of the detector tube to be safe. The choice between increasing B or decreasing A depends both on convenience and on the range desired. Resistor B can be increased to 1 megohm without changing its accuracy. For a greater change in range, a TYPE 602 Decade Resistance Box is connected externally in place of the 10 kΩ logarithmic resistor. For some uses it may be more convenient to substitute a logarithmic resistor of lower value. By raising B to 1 MΩ and dropping A to 1 Ω, the upper resistance limit of the bridge becomes 100 MMΩ.

The connections needed for these changes are shown in Figure 2. The

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[*] R. F. Field, "A 500-Volt Megohm Bridge," General Radio *Experimenter*, Volume XIV, No. 1, June, 1939.

[†] The prefixes kilo- and mega-, abbreviated to k and M, will be used to indicate a thousand- and a million-fold. 1 kMMΩ, a kilomegamegohm, 10^9 megohms, or 10^{15} ohms.

positions of the switches on the panel are shown in Figure 3. Other changes and switches shown in these figures will be described later. Choice of resistor *B* is made by the toggle switch marked MULTIPLY BY 1 – 10 at the center of the panel. An external Type 602 Decade Resistance Box is used by connecting it between the terminals marked GUARD and + BRIDGE and throwing the toggle switch at the bottom of the panel marked STD. EXT–INT to EXT.

INCREASED SENSITIVITY

The sensitivity of balance of a d-c resistance bridge depends on the voltage sensitivity of the detector, the voltage applied to the bridge, and the ratio of the resistance of the arms (here *A* and *B*) across which the bridge supply is connected.‡ Expressed in terms of 1/5 of a galvanometer division, the sensitivity of the standard Type 544-B Megohm Bridge varies from 0.15% at 1 on the MEGOHMS dial to 1.3% at 10 and 12% at 100, with 100 volts across the bridge. Raising the bridge voltage to 500 volts decreases these percentages by a factor of 5 and allows a resistance of 100 kMΩ to be balanced to 2.5%.

For a-c operation of the bridge there is a 200 Ω shunt across the galvanometer. Removing this shunt increases the bridge sensitivity by a factor of 4.3. A resistance of 100 kMΩ can then be balanced to 0.6%. The position of this shunt in the circuit is shown in Figure 4 which gives the complete connections of the a-c detector tube. This shunt is controlled by a toggle switch mounted on the panel just below the galvanometer (see Figure 3). With the shunt removed the current sensitivity of the galvanometer is .8 μa for 1/5 division.

EXTERNAL GALVANOMETER

In order to measure resistances of 1 MMΩ or greater, a sensitive wall galvanometer or portable galvanometer with light-beam and scale must be connected externally. The insulated, closed-circuit jack (see Figures 3 and 4) used for introducing this galvanometer in series with the internal pointer galvanometer is mounted in the lower left corner of the panel and marked EXT. GALV. A galvanometer having a sensitivity of 0.1 μa per mm. will allow a resistance of 1 MMΩ to be balanced to 0.7%. Improving the galvanometer sensitivity to 0.01 μa per mm. allows 10 MMΩ to be balanced to 0.7% and 100 MMΩ to 7%. It will then be possible to detect 1 kMMΩ.

The resistance across the UNKNOWN terminals through the insula-

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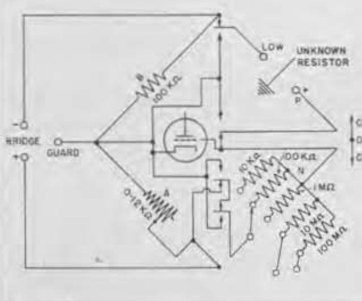
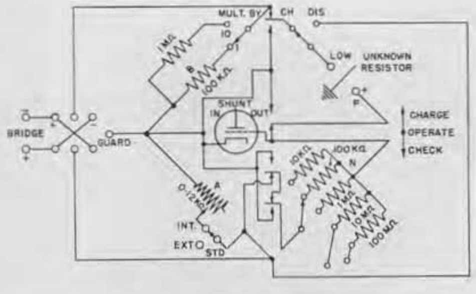
‡ Sensitivity $d = \frac{E_{OUT}}{E_{IN}} \cdot \frac{(1 + A/B)^2}{A/B}$ when galvanometer resistance is large compared to any arm. See page 68, Catalog K.

Figure 1. (*Left*) Schematic diagram of the stock model of Type 544-B Megohm Bridge. Figure 2. (*Right*) Schematic diagram of the megohm bridge, including all the modifications discussed in this article. With the exception of the charge-discharge and polarity reversing switches, these are shown in the panel view of Figure 3.





tion of terminals, switches, and detector tube is between 10 and 100 MMΩ, depending considerably on relative humidity. When measuring resistances of this order, either an initial reading must be made with the unknown disconnected or the bridge must be grounded to the GUARD terminal.

A number of difficulties will arise when using a high sensitivity galvanometer. Foremost among these is the adjustment of the galvanometer to zero when the selector switch is set on CHECK or CHARGE. The plate current of the detector tube is normally balanced out of the galvanometer circuit by turning the 10 kΩ rheostat controlled by the ZERO ADJUST knob (see Figures 3 and 4). The fineness of adjustment of this rheostat, as determined by its wire turns per inch, is only sufficient for the shunted internal galvanometer. Since an external galvanometer with a sensitivity of 0.01 μa per mm. is 340 times more sensitive than the internal shunted galvanometer, the fineness of zero adjustment must be increased in this same ratio. This can be done by adding a second 10 kΩ rheostat shunted by 250 Ω, as shown in Figure 4. A fixed resistance of 1 kΩ is placed in series with the rheostat to limit this control to its useful range. The two rheostats are mounted coaxially and are engaged by clutches to the shaft extending through the panel to the ZERO ADJUST knob. The knob and shaft are held in engagement with the shunted rheostat which provides the fine adjustment. Whenever the range of this control is exceeded, pressure on the knob releases this clutch and engages the other rheostat for a coarse control. Directions engraved on the panel below the ZERO ADJUST knob are shown in Figure 3. The needed improvement of 340 in zero adjustment is equaled or exceeded over 0.6 of the complete motion of the shunted rheostat. The maximum rotation of this rheostat is equivalent to two wires on the coarse adjustment rheostat.

When the selector switch is turned from CHECK to OPERATE, there is a momentary change in galvanometer current, even when the bridge is exactly balanced. The resultant deflection of the galvanometer, while of no consequence when the internal galvanometer is used, is so large in the case of a sensitive external galvanometer that it is desirable to short it, whenever the selector switch is turned.

With the LOW terminal grounded (the ordinary use of the bridge), the detector tube, and hence the galvanometer, is above ground by approxi-

FIGURE 3. Panel view of a TYPE 544-BS4 Megohm Bridge. In addition to the switches shown, two others can be installed: a charge-discharge switch and a polarity reversing switch.

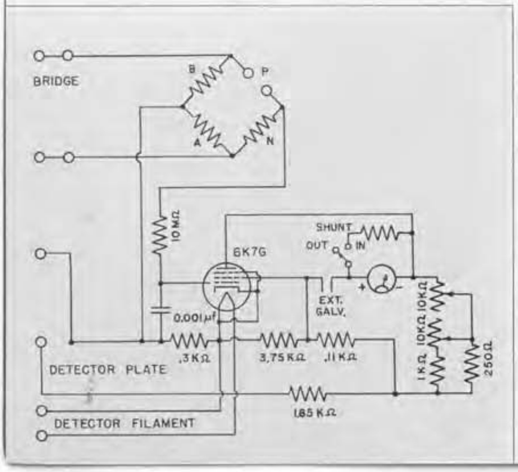
mately the bridge voltage. An external galvanometer must therefore be insulated from ground and protected from electrostatic fields.

The voltages supplied to the detector by the Type 544-P3 Power Supply are sufficiently well regulated so that the zero of the shunted galvanometer does not shift by more than 1.5 divisions for a line voltage change from 105 to 125 volts. Satisfactory operation with an external sensitive galvanometer can be obtained by operating the instrument from a magnetic type voltage regulator.* In extreme cases it may be necessary to operate the detector tube from dry and storage batteries. The bridge voltage can always be taken from the a-c supply.

CHARGE AND DISCHARGE CURRENT

Much commercial insulation shows the phenomenon of dielectric absorption, now frequently referred to as interfacial polarization.† Common examples are cables, generators, transformers, and paper condensers. On the application of voltage and after the flow of charging current to the condenser, there is a slow decrease in current and an increase in apparent resistance. From a knowledge of the voltage applied to the bridge and the resistance reading, the charging current can be calculated. It is sometimes also desirable to obtain the discharge current. This can be done by means of the CHARGE-DISCHarge switch shown in Figure 2, which allows the already charged condenser to discharge into the standard resistor *N*, while leaving the detector tube connected between the *N* and *A* arms. Adjustment of the *A* arm will bring the galvanometer reading to zero, provided that the bridge voltage has been reversed by means of the reversing switch marked + − in Figure 2. From the resistance readings of the bridge the discharge current can be calculated. The two switches just described do not appear in Figure 3, but will be placed, the CHARGE-DISCHarge switch near the right side of the panel above the MEGOHMS dial, and the + − reversing switch to the right of the BRIDGE terminals.

Figure 4. Diagram of connections for the a-c detector tube, including the galvanometer shunt.



RECENT IMPROVEMENTS

All Type 544-B Megohm Bridges are now supplied with five insulated binding posts, those marked BRIDGE, UNKNOWN, LOW, GUARD. This precaution leaves no high voltage terminals exposed. Even though the maximum current that can be drawn from the Type 544-P3 500-volt Power Supply on short circuit is only 12 ma, it is felt that some danger exists unless all high voltage terminals are protected.

It has become possible to obtain a mica condenser of .001 µf capacitance having a leakage resistance of at least

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* Regulators of this type are made by the Raytheon Manufacturing Company, Waltham, Mass., and the Solar Electric Company, Chicago, Ill.

† General Radio *Experimenter*, June, 1939.

100 kMΩ. Such a condenser is now placed between grid and filament of the detector tube to form with the 10 MΩ series resistor a resistance-capacitance filter which reduces the effect of a-c voltage on the galvanometer reading by a factor of four. An alternating voltage of 2 volts can then be placed across the UNKNOWN terminals without changing the galvanometer zero by more than 0.3 division, even with the MULTIPLY BY switch set at 1000.

SUMMARY AND PRICES

Seven modifications of the Type 544-B Megohm Bridge have been described. The cost of making each change is listed below. Type numbers have been assigned to the more common combinations. While in general the cost of any combination is the sum of these separate charges, a reduction is made for the two most commonly demanded.

—R. F. Field

Prices for Separate Changes and Numbered Combinations

*Change**	*Price*	S4†	S5	S6	S7	S8
MULTIPLY BY 1–10	$12.50	——	——	——		——
SHUNT	6.00	——	——	——		——
STD. EXT – INT	6.00	——	——			——
EXT. GALV.	7.50	——				——
ZERO ADJUST	21.00	——				——
CHARGE	6.00				——	——
+ –	6.00				——	——
NET PRICES	——	$50.00	$24.50	$18.50	$12.00	$60.00

* Designations in this column correspond to panel engraving in Figure 3.
† The combination Type 544-BS4 covers the more common uses of the bridge and has been in greatest demand.

MODERNIZATION OF BROADCAST FREQUENCY MONITORS

● **IN ACCORDANCE WITH A RULE** of the Federal Communications Commission, all new broadcast transmitters installed after January 1, 1940, whether for new stations or for old stations, will be required to use a broadcast frequency monitor suitable for monitoring over the range 20–0–20 cycles. The Type 475-C Frequency Monitor and the Type 681-B Frequency-Deviation Meter described in the *Experimenter* for January, 1940, are approved by the FCC for this service.

On or before January 1, 1942, all standard broadcast stations will be required to comply with the same rule. Users of older equipment will, of course, wish to have it modified to comply with the new specifications. The stringent requirements placed on the performance of the monitor by the new specifications can only be met by using modern tubes, circuits, and construction methods. Consequently, the old Type 575 Piezo-Electric Oscillator and the Type 581 Frequency-Deviation Meter are not suitable for this service, and will have to be replaced by new equipment as they cannot be modified.

The Type 475-A or -B Frequency Monitors and the Type 681-A Frequency-Deviation Meters can, however, be rebuilt to be equivalent to the new Type 475-C Frequency Monitor and Type 681-B Frequency-Deviation Meter. The modification includes all of the necessary changes to make the electrical circuit and performance of the old instrument equal to the new, and also involves mechanical changes which make them practically identical in appearance. The modified units carry a full new-instrument guarantee.

New thermostats and thermometers for 60° C. will be installed in any monitors now operating at 50°, permitting operation at higher ambient temperatures. The thermostat circuit will be changed to that used in the new meter, which prolongs thermostat life.

The price of the modification is $310 if the customer already has the low-temperature-coefficient Type 376-L Quartz Plate. If the customer has the old Type 376-J Quartz Plate the cost of the modification including a new low-temperature-coefficient Type 376-L Quartz Plate is $375. Special colors as listed for the new monitors can be supplied at an additional price of $10.00.

In order that the modification of these instruments be carried out with a minimum of delay to each station, it is necessary that a production schedule be set up and rigidly adhered to. This schedule is now being planned and, as soon as final arrangements are made, the Service Department will send complete details to each station using the old equipment. Please do not return monitors for modification without first writing to the Service Department. — H. H. Dawes

DON'T FORGET THE EXHIBIT OF GENERAL RADIO INSTRUMENTS TO BE HELD AT THE STEVENS HOTEL, CHICAGO, FEBRUARY 12 TO 17

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BRANCH ENGINEERING OFFICES
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