the GENERAL RADIO Experimenter

INDEX

TO

GENERAL RADIO
EXPERIMENTER

VOLUMES XIV AND XV

June, 1939 to May, 1941

GENERAL RADIO COMPANY
CAMBRIDGE MASSACHUSETTS
U. S. A.

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VOLUME XIV NO. 8 JANUARY, 1940

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

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A BROADCAST FREQUENCY MONITOR FOR THE 20-CYCLE RULE

● ACCORDING TO RULE 3.59* of the Federal Communications Commission, on and after January 1, 1940, the frequency of each new broadcast station, and of each existing station where a new transmitter is installed, must be maintained within 20 cycles of the assigned frequency. After January 1, 1942, the frequencies of all standard broadcast stations must be held to this tolerance.

The FCC specifications for frequency monitors have necessarily changed as a result of the new tolerance specifications and, to meet these new specifications, the General Radio Company has designed a new visual-type frequency monitor. Although functionally the same as previous models, which have had a greater customer acceptance than any other make, this new monitor has a better

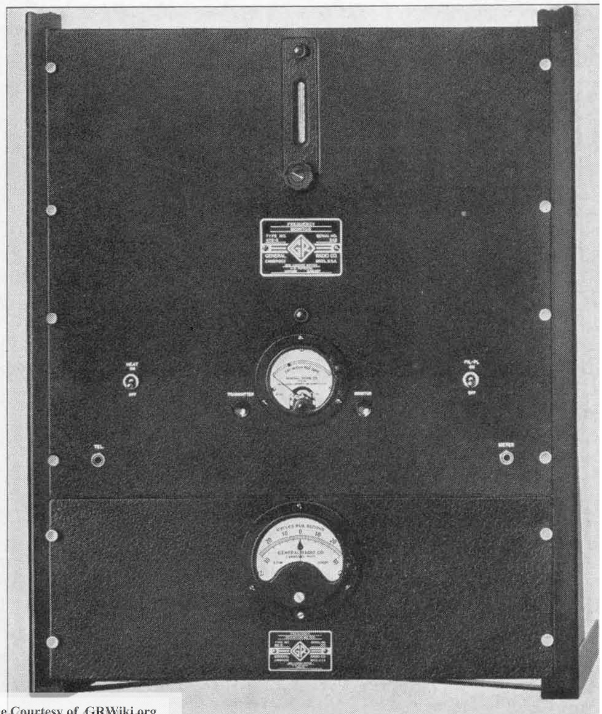

FIGURE 1. Panel view of the broadcast frequency monitor.

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* Rules governing Standard Broadcast Stations.

precision of reading, better accuracy, and better stability. In addition, it includes a number of improvements which contribute to increased ease of operation and decreased maintenance. It is designed for easy installation and simple, trouble-free operation. Provision has been made for stocking a number of standard panel finishes, and special finishes to match other equipment can also be obtained.

The complete visual-type frequency monitor consists of (1) Type 475-C Frequency Monitor, with a Type 376-L Quartz Plate and (2) Type 681-B Frequency Deviation Meter. The function of the frequency monitor unit is to produce an audio-frequency beat between a standard frequency oscillator and the transmitter. The frequency deviation meter indicates the deviation of the frequency of this beat from a standard 1000-cycle value. The process is shown functionally in Figure 2.

TYPE 475-B FREQUENCY MONITOR

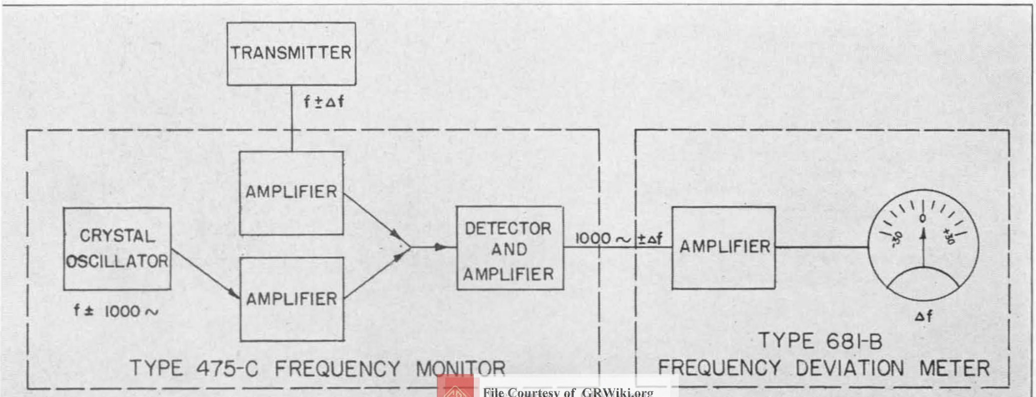
The schematic circuit diagram of Figure 3 shows the several elements of the frequency monitor unit: a piezoelectric oscillator, a buffer amplifier, an amplifier for the transmitter voltage, and a detector for producing the audio-frequency beat.

The circuit of the crystal oscillator has several interesting features which contribute to a high degree of frequency stability. The frequency depends on circuit and tube parameters to a far less degree than in most circuits. No tuning inductance is used, and the tuning condensers, C_1 and C_2, have only a minor effect on the frequency, which depends almost completely upon the quartz crystal. For instance, a change of 25% in the capacitance of C_1 and C_2 produces a change of only 6 parts in one million in the oscillator frequency. Condensers C_1 and C_2 are locked at the factory and no panel tuning controls are necessary. This oscillator circuit was developed in the General Radio laboratories and is used in General Radio primary and secondary frequency standards for monitoring the frequencies of radio stations by the United States and foreign governments.

The quartz plate, Type 376-L, is cut to have a low temperature coefficient and is mounted in a dust-proof, air-gap-type holder. The temperature coefficient is less than 2 parts per million per degree Centigrade, as is shown by the plot of Figure 5.

The temperature of the plate is held to ±0.1 degree Centigrade by a tem-

Figure 2. Functional block diagram of the monitoring system. The frequency of the monitoring crystal can be either above or below that of the transmitter, since reversing the leads of the indicating meter reverses the direction of the deviation indication.



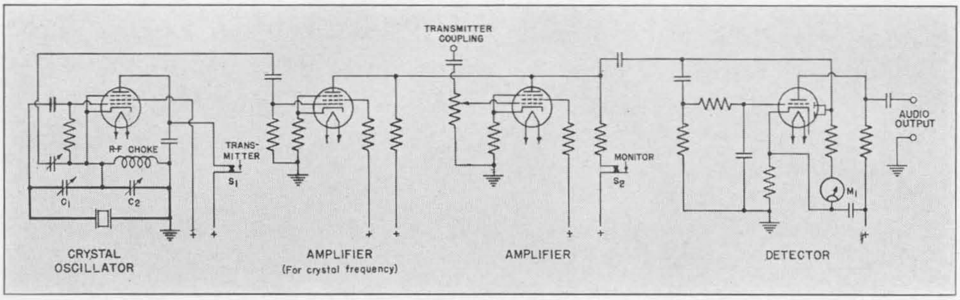


FIGURE 3. Schematic circuit diagram of the TYPE 475-C Frequency Monitor. The meter M_1 in the diode circuit indicates the levels of the signals from the crystal oscillator and the transmitter. Additional contacts (not shown in the diagram) on the push buttons short circuit the meter when neither button is depressed.

perature-control system, so that no appreciable variation in frequency with temperature can occur. Very little restraint on the vibration of the plate is introduced by the holder, so that the plate vibrates freely. The heat-control circuit is arranged so that the mercury thermostat breaks only a very small current, thus prolonging the life of the thermostat.

The crystal amplifier reduces the load which would otherwise be imposed on the oscillator and, by isolating the oscillator from the load, prevents the coupling to the transmitter from affecting the amplitude and frequency of the oscillator. The amplifier for the transmitter frequency prevents any voltage of the crystal frequency from getting into the transmitter circuits and producing modulation at 1000 cycles. Looser coupling to the transmitter can be used, and the monitoring voltage can be taken directly from the transmitter crystal control unit. For transmitters using low-level modulation, this is essential. A meter on the panel furnishes a positive indication of correct signal level from the transmitter and from the crystal oscillator. The level from the transmitter is read by pressing the button labeled TRANSMITTER. When the reading falls within the red range on the scale, the level is correct. Similarly, pressing the MONITOR button gives an indication of crystal oscillator level. The same red range on the scale is used. Means for adjusting the input to both amplifiers are provided behind the panel. These insure correct coupling when the monitor is installed, prevent false readings due to overloading, and greatly facilitate maintenance, without unnecessarily complicating the operation.

TYPE 681-B FREQUENCY DEVIATION METER

Like the frequency monitor unit, the frequency deviation meter is func-

FIGURE 4. The signal-level indicator on the frequency monitor unit. When the input level is correct, the meter reading is within the red (shown black in the photograph) range on the scale.

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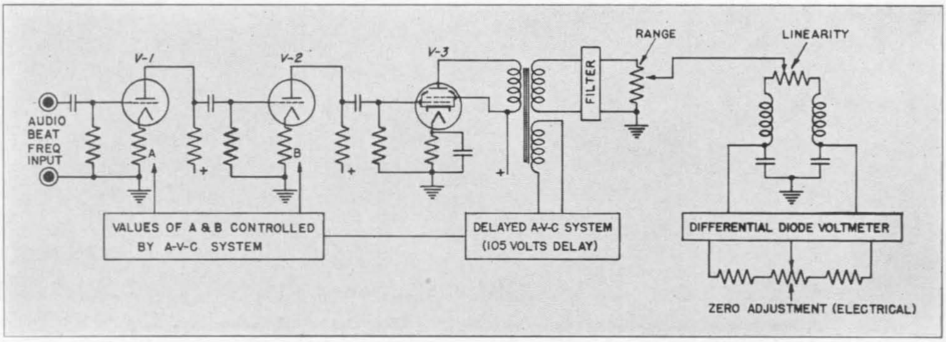
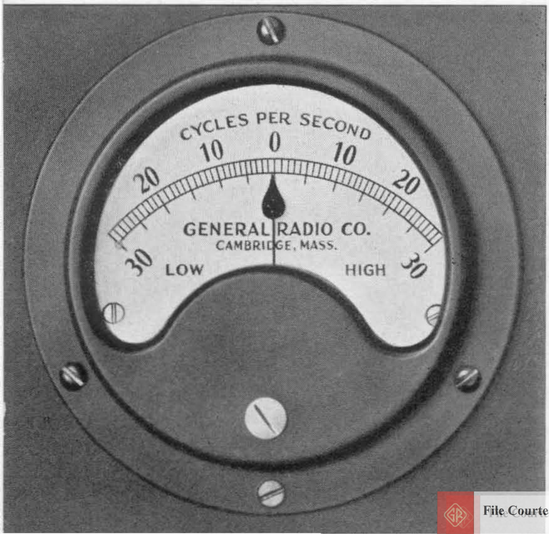


FIGURE 5. Schematic circuit diagram of the TYPE 681-B Frequency Deviation Meter. The automatic volume control eliminates the need for a manual input control.

tionally the same as previous models (see Figure 5), but has been completely redesigned in those details which produce greater accuracy and ease of operation.

Owing to the requirements of a narrower deviation range and increased precision of reading, errors of indication have necessarily been made very small. This has been achieved by making the response more nearly linear and the circuits more stable, and by reducing harmonics of the beat frequency. The linearity of the frequency meter has been improved by using a dual sharpness-of-resonance control (marked LINEARITY in Figure 5) which operates on both tuned circuits simultaneously but in opposite senses. Better stability is obtained through improved construction of the tuned circuit inductors and capacitors. Lower distortion in the amplifier tube and the inclusion of a low-pass filter greatly reduce errors caused by waveform.

FIGURE 6. Frequency deviations are indicated on this meter, which can be read to better than one-half cycle.



The A-V-C system replaces the manual level adjustment provided on older models. By using a large delay voltage, satisfactory operation is obtained over the same limits formerly attainable by manual adjustment. Constant input voltage to the frequency deviation meter is held over a beat-frequency amplitude range of 0.5 volt to 8 volts. This means that, after the monitor has been installed, such factors as changes in line voltage, changes in the adjustment of the transmitter, and aging of tubes and circuit elements will not affect the accuracy of the meter indication, and no corrective adjustments are required.

Only two controls are necessary, the mechanical and electrical zero settings. Both of these are screwdriver adjustments accessible from the panel. The electrical zero adjustment covers a range of ± 40 cycles. The indicating meter has a range of −30 to +30 cycles.

MODERNIZATION OF OLDER MONITORS

Between now and January, 1942, many users of the older models of frequency monitors will wish to have them modified to comply with the new rules. No models of the old Type 575 Frequency Monitors or Type 581 Deviation Meters can be modernized. The Type 681 Deviation Meters also cannot be brought into compliance with the new rule. However, a program is now being worked out for modernizing the Type 475 Frequency Monitors, and a trade-in allowance arrangement will be made, if practicable, on old Type 681 Deviation Meters turned in for new ones. Details of these plans will be announced later.

— J. K. Clapp

SPECIFICATIONS

Frequency Range: ±30 cycles.

Accuracy: When received, ±13 parts in one million; an adjustment is provided to bring the reading into agreement with monitoring station measurements.

Vacuum Tubes: The following tubes are required and are supplied with the instrument:

1 — 6J7G
2 — 6AC7
1 — 6R7G
1 — 5V4G
2 — 6F8G
1 — 6V6G
2 — 6H6G
1 — VR-105-30

Stability: ±5 parts in one million.

Coupling to Transmitter: The monitor must be coupled to the transmitter at a point where the carrier is *unmodulated*. Only a small degree of capacitive coupling is required. A coupling wire is provided in the connecting cable supplied with the monitor.

Accessories Supplied: Connecting cables, pilot lights, and fuses (with spares).

Power Supply: 105- to 125-volt, 50- to 60-cycle, a-c line.

Power Input: 175 watts with heat on.

Mounting: Standard 19-inch relay-rack panels.

Dimensions: Panel, (length) 19 x (height) 22½ inches; behind panel, (length) 17¼ x (height) 22¼ x (depth) 11¾ inches.

Net Weight: 95 pounds.

Description	*Code Word*	*Price*
Visual-Type Frequency Monitor	DEVOR	**$560.00**

This instrument is manufactured and sold under the following U. S. Patents and license agreements:

1. Patents of the American Telephone and Telegraph Company, solely for utilization in research, investigation, measurement, testing, instruction and development work in pure and applied science.
2. Patents and patent applications of Dr. G. W. Pierce pertaining to piezo-electric crystals and their associated circuits.
3. Patent No. 1,944,315.
4. Patent No. 1,967,184.
5. Patent No. 2,012,497.

ONE CYCLE PER SECOND FROM THE INVERSE FEEDBACK OSCILLATOR

● **IN THE RESEARCH LABORATORY** there is frequently a need for a generator of frequencies well below the 15 or 20 cycles per second that is the usable low-frequency limit of most audio-frequency oscillators.

Good power output and good waveform at these very low frequencies can be obtained from the Type 608-A Oscillator* by using an external range-extension unit. Extension of the operating range to low frequencies is made possible by the unique inverse-feedback circuit† used in this instrument.

The oscillator is normally operated by means of a series of push buttons, which provide oscillation at any one of

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*H. H. Scott, "A Low-Distortion Oscillator," *General Radio Experimenter*, Volume XIII, No. 11, April, 1939.

†H. H. Scott, "A New Type of Selective Circuit and Some Applications," *Proceedings of the Institute of Radio Engineers*, Volume 26, No. 2, pp. 226–235, February, 1938.

27 frequencies throughout the audible range. The unit is also equipped with jacks, allowing operation of the circuit at various other frequencies, and this has proved to be a most advantageous feature since not only are other frequencies within the normal range available, but satisfactory operation can be attained at frequencies falling considerably outside of this normal range, provided some slight sacrifice in purity of waveform can be tolerated.

A good example of the usefulness of the oscillator at very low frequencies occurred recently in the General Radio laboratories, during work on the design of a vibration meter which will have a flat response down to 2 or 3 cycles per second. Such response is not difficult to secure in cases where only a moderate amount of amplification is required, but in this application the high degree of sensitivity required a high-gain multistage amplifier, and, obviously, some satisfactory means were required for making exact measurements of its gain-frequency characteristics.

An auxiliary unit containing the necessary high resistances for operation of the oscillator at lower frequencies was, therefore, constructed and arranged to plug into the standard Type 608-A Oscillator.

In several applications where customers have required special low-frequency oscillators, attachments have been built for the Type 608-A. One of these is shown in Figure 1. This particular model, Type 608-400, operates at 7, 8, 10, and 15 cycles and can be attached to any Type 608-A Oscillator with no changes in the unit excepting to cut a slot in the dust cover to allow passage of the cable.

The difficulties of accurate harmonic measurements at such low frequencies have made it impractical thus far to determine quantitatively the actual harmonic content of the oscillator waveform when operating at such low frequencies. There is no reason to believe, however, that it should be seriously worse than at higher frequencies, so long as the 5000-ohm output circuit is used, which does not involve the transformer. Certainly, for most laboratory uses at these frequencies the purity of waveform is entirely satisfactory. Figure 2 shows oscillograms of the output of the oscillator at several frequencies between one and 10 cycles per second.

Thus far the requirements of customers for equipment of this type have been so varied that no standard designs

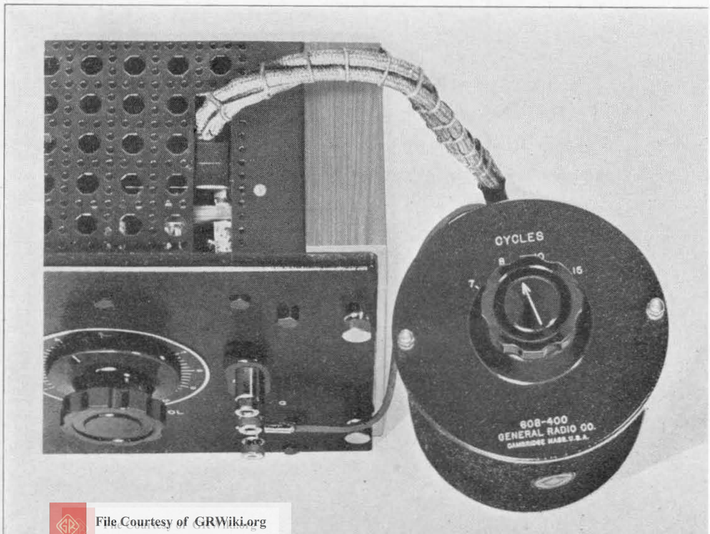

Figure 1. Showing a range-extension unit connected to the Type 608-A Oscillator. A jack plate is provided in the oscillator, and the only necessary modification is the hole in the cover to admit the plug.

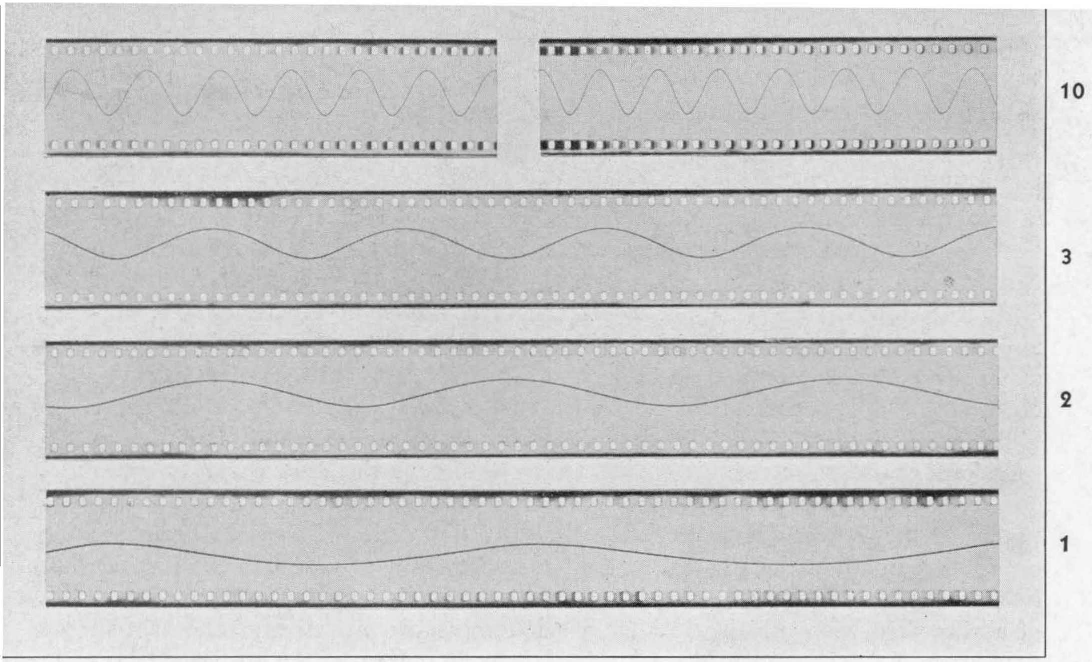

FIGURE 2. Oscillograms of the output voltage of TYPE 608-A Oscillator at low frequencies. Reading from top to bottom the frequencies are 10, 3, 2, and 1 cycle per second. These waveforms were photographed with a TYPE 651-A Camera.

are being carried in stock. Special range-extension units of this type can, however, be built to order to customers' specifications. The cost is dependent upon the number of frequencies required and the value of the frequencies. The price of the unit increases as the frequency decreases, due to the higher values of the precision resistances required. Correspondence regarding your particular requirements is invited.

— H. H. SCOTT

MISCELLANY

● **THE NEW** Broadcast Frequency Monitor described in this issue was designed by J. K. Clapp, H. H. Hollis, and P. K. McElroy.

● **AN EXHIBIT** of General Radio apparatus will be held at the Stevens Hotel, Chicago, from February 12 to 17, 1940. This is to be a working display of equipment as it is used in typical applications and will include many new instruments. *Experimenter* readers are cordially invited to attend.

● **AT THE DECEMBER 15** meeting of the Boston Section of the Institute of Radio Engineers, Dr. W. N. Tuttle and Dr. D. B. Sinclair of the General Radio Company presented a symposium on Twin-T Null Circuits.

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THE General Radio EXPERIMENTER

VOLUME XIV NO. 9 FEBRUARY, 1940

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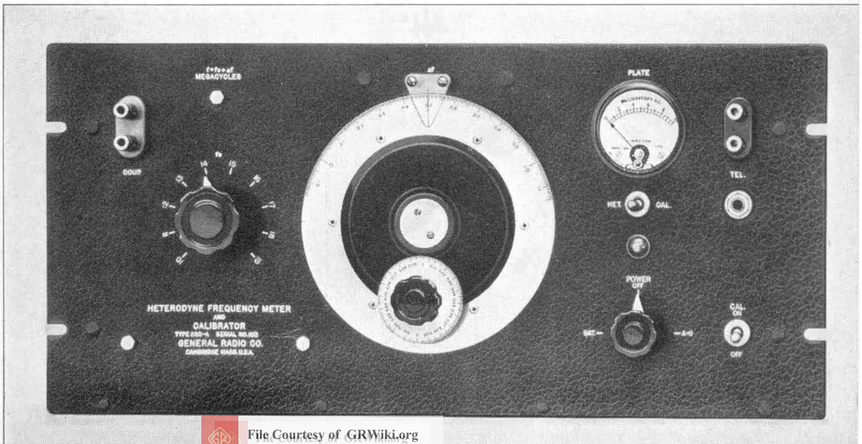
[*] J. K. Clapp, "A Direct-Reading Frequency Meter with Built-In Calibrator," General Radio *Experimenter*, September-October, 1936.

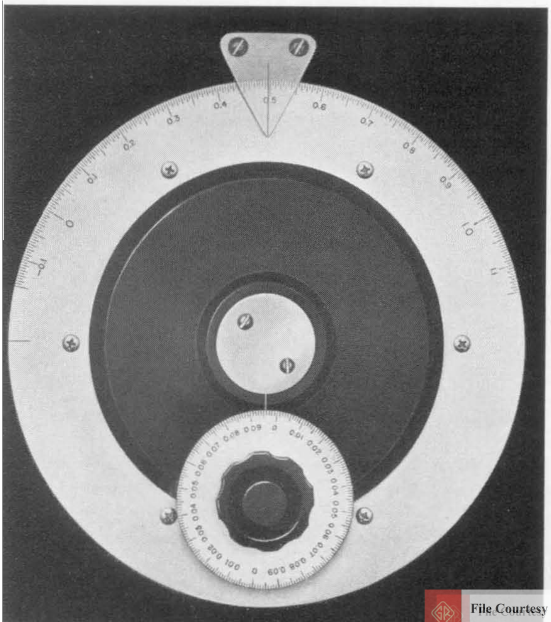
Figure 1. Panel view of the Type 620-A Heterodyne Frequency Meter and Calibrator.



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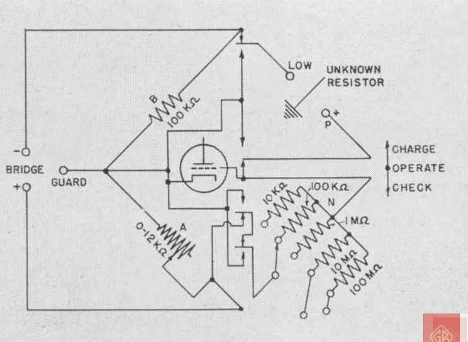
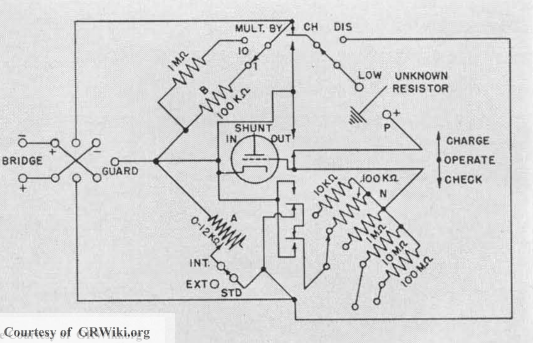
‡ Sensitivity $d = \frac{E_{\text{OUT}}}{E_{\text{IN}}} \cdot \frac{(1 + A/B)^2}{A/B}$ when galvanometer resistance is large compared to any arm. See page 68, Catalog K.

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.





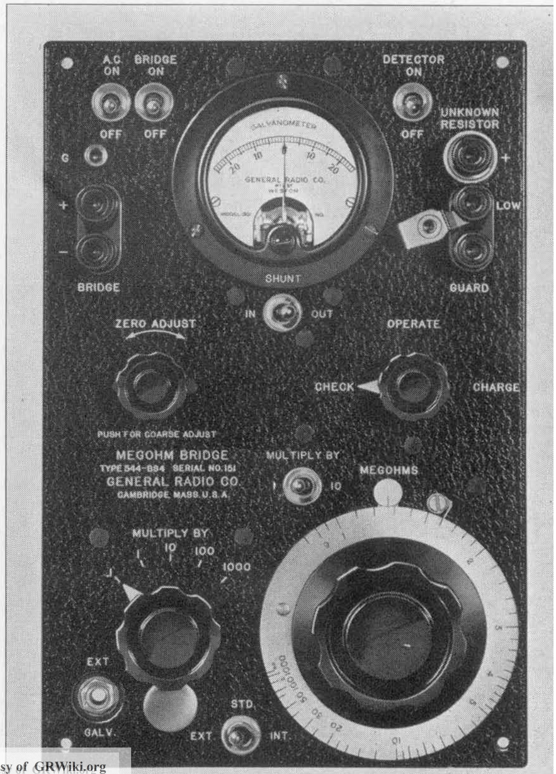
tion of terminals, switches, and detector tube is between 10 and 100 MMΩ, depending considerably on relative humidity. When measuring resistances of this order, either an initial reading must be made with the unknown disconnected or the bridge must be grounded to the GUARD terminal.

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.



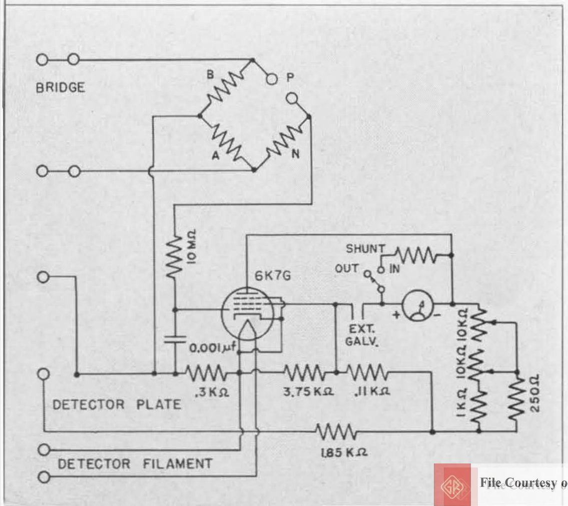
mately the bridge voltage. An external galvanometer must therefore be insulated from ground and protected from electrostatic fields.

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

File Courtesy of GRWiki.org

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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30 STATE STREET · CAMBRIDGE A, MASSACHUSETTS
BRANCH ENGINEERING OFFICES
90 WEST STREET, NEW YORK CITY
1000 NORTH SEWARD STREET, LOS ANGELES, CALIFORNIA

THE General Radio EXPERIMENTER

VOLUME XIV NO. 10 MARCH, 1940

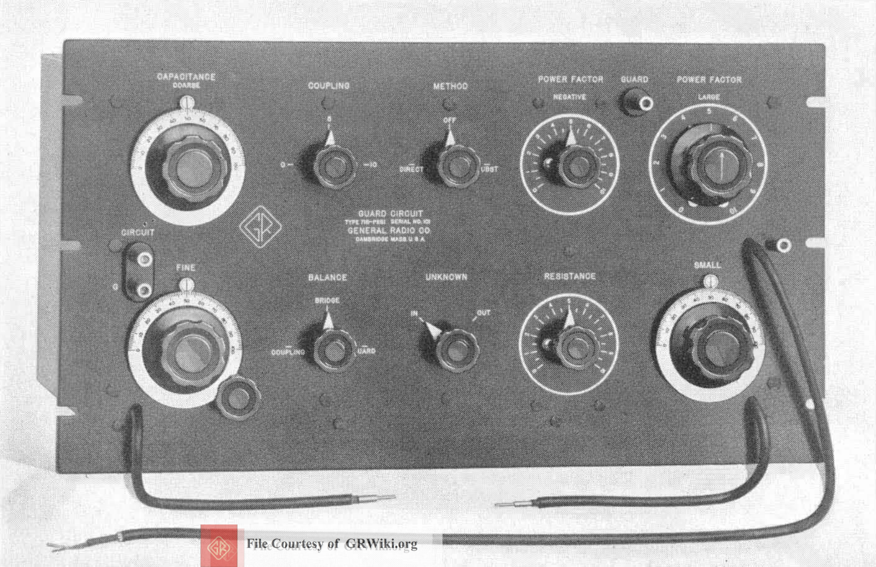
ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also IN THIS ISSUE

A GUARD CIRCUIT FOR CAPACITANCE BRIDGE MEASUREMENTS

● **THE FUNCTION OF A GUARD CIRCUIT** is to provide a point to which the third terminal of a three-terminal impedance can be connected, so that the direct impedance between the other two terminals can be measured correctly by means of a suitable bridge circuit. A typical combination of capacitance bridge, guard circuit, and three-terminal capacitance is shown in Figure 2. The direct capacitance *C* is measured by the bridge because the terminal capacitances are carried to the guard circuit, C_1 providing coupling to the guard circuit, and C_2 becoming a part of guard arm *H*. If the third terminal were not connected to the guard circuit, the bridge would measure the direct capacitance *C* in parallel with the two terminal

Figure 1. Panel view of the Type 716–P2 Guard Circuit.



capacitances C_1 and C_2 in series. Examples of three-terminal capacitances are multiple-wire cables and multiple-winding transformers. The direct capacitance of any pair of terminals can be measured by connecting all the other terminals to the middle point of the guard circuit.

GUARD ELECTRODES

A second class of three-terminal impedances is that in which a guard electrode is added so that a particular property of the impedance may be measured correctly. One of the earliest forms of guard electrode is the guard ring shown in Figure 3, which is used in measuring the insulation resistance of cables. It serves to prevent the leakage current over the surface of the insulation from being included with that flowing through the volume of the insulation. The guard ring, inner conductor, and outer sheath taken together form a three-terminal resistance such as is shown diagrammatically in Figure 4. The guard ring is usually connected to one of the other corners of the bridge as shown in Figure 3. No error results as long as the terminal resistance R_2 is large compared with the resistance of the bridge arm N. If this condition is not fulfilled, the guard ring must be connected to a guard circuit *FH* shown connected to the bridge by dotted lines. The same sort of direct connection to the bridge is sometimes used in lieu of a guard circuit on capacitance bridges, the junction of the ratio arms being the corner of the bridge to which the guard electrode is connected. This places the terminal capacitance C_1 of Figure 2 across ratio arm B. The capacitance reading of the bridge will be essentially correct, but the dissipation factor will be in error by an amount $B\omega C_1$.

In capacitance measurements the most important use of a guard electrode is in defining exactly the measured capacitance, so that the air capacitance can be calculated and the dielectric constant obtained therefrom. A sectional view of guard and measuring electrodes applied to a disk of insulation is given in Figure 5. The gap between the guard and guarded electrodes is kept as small as possible. The effective diameter of the guarded measuring electrode is taken as that of the middle of the gap. It is usual to connect the electrodes to the bridge and guard circuit in such a way as to bring the guard and guarded electrodes to the same potential. The lettering of the three capacitances in Figure 5 is in accordance with this condition when applied to the bridge of Figure 2. The danger arising from connecting the electrodes in any other order is that the volt-

FIGURE 2. Schematic diagram showing how a guard circuit is connected to a bridge for measuring a three-terminal capacitance.

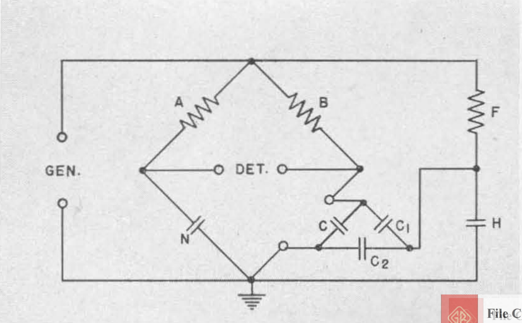
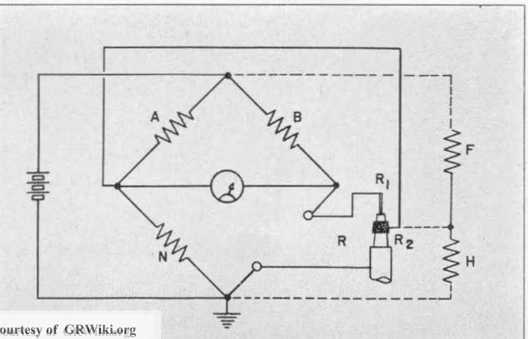


FIGURE 3. Diagram showing how a guard ring is connected to a bridge when measuring the insulation resistance of cables.



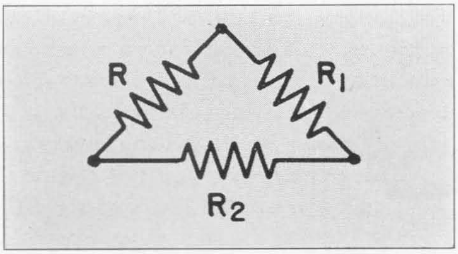


FIGURE 4. Equivalent circuit of the cable of Figure 3, showing how the resistance paths make up a three-terminal network.

age between guard and guarded electrodes may be sufficiently high to break down the short gap between them, or at least to produce an error in both capacitance and dissipation factor because of non-linear characteristics of the insulation. For low voltages the order of connection is immaterial, because capacitance and resistance depend only on geometrical configuration and the properties of the material.

GUARD CIRCUIT BALANCE

Because a coupling impedance always exists between at least one of the corners of the bridge to which the guard circuit is not connected and the middle point of the guard circuit, as C_1 in Figure 2, the guard circuit becomes a part of the bridge arms to which it is coupled. The reading of the bridge will be incorrect unless the guard circuit is also balanced. The vector conditions of balance are

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

where the guard circuit impedances F and H include any terminal impedances added from the impedance under measurement. The guard circuit can be balanced against either pair of bridge arms A and N or B and P. The bridge must then be rebalanced. Successive balances of bridge and guard circuit must follow until the conditions of Equation (1) are satisfied.

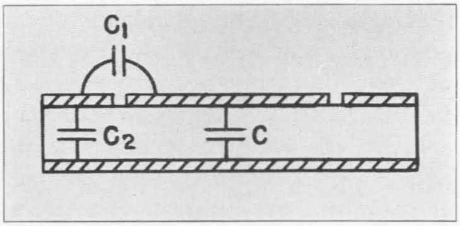


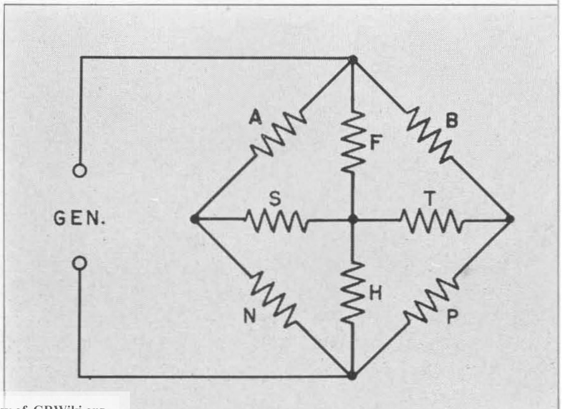
FIGURE 5. Sectional view of guard and measuring electrodes as used in determining the dielectric constant of a disk of insulating material.

The usual method of testing for balance of the guard circuit consists in transferring one terminal of the detector from bridge circuit to guard circuit by means of suitable shielded switching. This necessarily implies that the guard circuit is connected across the generator. An alternative method, which has several points of superiority, is to connect the middle point of the guard circuit to one of the corners of the bridge to which it is not otherwise directly connected. The guard circuit is thus placed in parallel with a similar pair of bridge arms. Successive balancing of bridge alone and bridge and guard circuit in parallel, carried out in exactly the same manner as before, will satisfy the conditions of Equation (1).

COUPLING CIRCUIT

The error introduced into the bridge

FIGURE 6. Diagram of a bridge with both guard and coupling circuits.



readings by a lack of balance of the guard circuit depends on the magnitude of the impedances coupling it to the bridge. These are shown diagrammatically in Figure 6. The two impedances S and T together form a coupling circuit. It is obvious that, if both of these impedances were infinite, the balance of the guard circuit would not matter and this circuit would be merely a load on the generator. But this is, of course, an impossible condition, because in the use of the guard circuit one of the terminal impedances is connected to it. A second way in which unbalance of the guard circuit will not affect the bridge readings is that the coupling circuit is balanced so that

$$\frac{A}{B}=\frac{N}{P}=\frac{S}{T} \qquad (2)$$

From the symmetry displayed in Figure 6, there is really no difference between guard circuit and coupling circuit. Equation (2) must follow from Equation (1) since the positions of generator and detector are interchangeable. These conditions have been studied recently in considerable detail by Balsbaugh[1] and Astin[2]. Any approach toward balance of the coupling circuit will decrease the dependence of the bridge on guard circuit balance. It is, therefore, quite usual to provide a partial balance of the coupling circuit by balancing only the dominant component. In the circuit of Figure 2 a variable air condenser C_S connected between the junction of the guard arms F and H and the junction of the bridge arms A and N would be adjusted until

$$\frac{A}{B}=\frac{C_1}{C_S} \qquad (3)$$

The only convenient method for determining balance of the coupling circuit is by connecting its middle point, the junction of guard and coupling circuits, to whichever corner of the bridge places it across a similar pair of bridge arms. In the circuit of Figure 2, the middle point would be carried to ground.

The earliest type of guard circuit was suggested by Wagner for the purpose of removing from the bridge circuit the capacitances to ground of the bridge arms, generator, and detector. Since the

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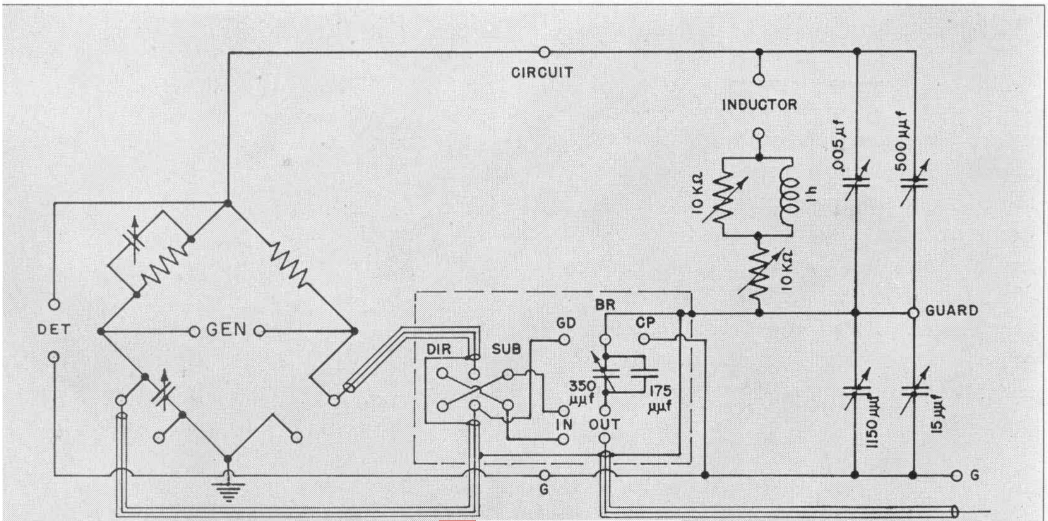
[1] Balsbaugh & Moon, "Bridge for Precision Power Factor Measurements," AIEE Trans., Vol. 52, p. 528, 1933.
Balsbaugh & Herzenberg, "Comprehensive Theory of a Power Factor Bridge," Journal of the Franklin Institute, Vol. 218, p. 49, 1934.

[2] A. V. Astin, "Measurement of Relative and True Power Factors of Air Capacitors," Journal of Research of National Bureau of Standards, Vol. 21, p. 425, 1938.

FIGURE 7. Wiring diagram of the TYPE 716–P2 Guard Circuit.



generator was usually connected across the ratio arms, *A* and *B* of Figure 1, the Wagner Ground was composed of similar impedances, like the coupling circuit just described for Figure 2. Frequently it consisted merely of a rheostat used as a voltage divider with the sliding contact grounded. Balsbaugh[3] has suggested that the circuit connected across the generator be called the guard circuit, and the circuit connected across the detector, the coupling circuit.

TYPE 716-P2 GUARD CIRCUIT

The Type 716-P2 Guard Circuit embodies most of the features contained in the above discussion. Its wiring diagram is given in Figure 7 in connection with that of the Type 716-A Capacitance Bridge, with which it is designed to be used. It consists of guard arms *F* and *H* and a coupling capacitance C_S, together with the switching necessary to connect the junction of guard and coupling circuits to the bridge for balancing, and to connect and disconnect the three-terminal capacitance being measured. The arms *F* and *H* are made as flexible as possible so that the guard circuit may cover the same capacitance and dissipation factor ranges as the bridge. The exact numerical values of these arms are shown in Figure 7. The resistance arm *F* is made variable because the total capacitance of arm *H*, being the sum of C_H and one of the terminal capacitances, may be greater than C_N. Arm *F* also has a parallel capacitance C_F and a series inductance L_F so that it may be balanced for dissipation factor under all conditions. The decade condenser is necessary when resistance *F* is small. The inductance, which provides a negative dissipation factor, is needed when the losses in the terminal capacitances added to the arm *H* are excessive. The conditions to be met are seen by expressing Equation (1) in terms of the storage factors of the resistance arms and the dissipation factors of the capacitance arms.

$$Q_A + D_N = Q_B + D_P = Q_F + D_H \qquad (4)$$

where $Q_F = F\omega C_F$, $D_H = H\omega C_H$, etc. When D_H is very large, Q_F must be negative to make a balance possible.

The Type 716-P2 Guard Circuit is made of relay-rack width like the Type 716-A Capacitance Bridge and is intended to be mounted above the bridge in a relay rack or in back for table mounting. The appearance of the panel is seen in Figure 1. The guard circuit proper is connected to the bridge by a shielded cable. The other corners of the bridge (the high sides of the capacitance arms) are carried to the switches in the guard circuit in shielded cables with the shields connected to the middle of the guard circuit. This procedure minimizes the capacitance added across the capacitance arms of the bridge and makes it possible to use the bridge for either direct-reading or substitution measurements. The three leads to the unknown three-terminal condenser are carried from the guard circuit panel, two in a shielded cable and one as a ground lead. The coupling condenser is made up of a fixed part, which equals the capacitance introduced by the shielded cable, and a variable air condenser, which balances the terminal capacitance C_1.

While the Type 715-P6 Guard Circuit is arranged for operation with the Type 716-A Capacitance Bridge, it can be used with any capacitance bridge having comparable resistance and capacitance arms, provided suitable connections can be made to the bridge. It can be used

---

[3] Balsbaugh, Howell & Dotson, "Generalized Bridge Network for Dielectric Measurements" to be published in AIEE. Presented at the Winter Convention of the American Institute of Electrical Engineers, New York, January 22–26, 1940.

File Courtesy of GRWiki.org

over the same frequency range as the bridge. This frequency range can be extended by changing the values of the resistance arm and its series inductance. A wide-frequency-range guard circuit can be constructed by ganging together three sets of resistance arms and providing three different inductors, the various sets being selected by a three-point switch. Prices for these special arrangements will be quoted on request.

— R. F. FIELD

SPECIFICATIONS

Range and Accuracy: The range and accuracy of the TYPE 716-A Capacitance Bridge are not altered by the use of the guard circuit. The addition of the guard circuit causes an error in the reading of the capacitance dial of 1 μμf but a correction can be easily made for this.

Resistance Arm: 0 to 20 kΩ in series with 0 to 1 h and in parallel with 20 to 5000 μμf.

Capacitance Arm: 40 to 1150 μμf with a fine adjustment.

Coupling Circuit: 180 to 525 μμf.

Shielding: The three transfer and disconnecting switches are mounted in an insulated shield kept at guard potential. A metal dust cover and the aluminum panel form a complete grounded shield.

Frequency Range: The guard circuit is intended to be used at a frequency of 1 kc. It can be used, however, over the same range as the TYPE 716-A Capacitance Bridge, provided the power factors of the terminal capacitances are not excessive at the lower frequencies.

Mounting: Relay-rack or cabinet mounting.

Dimensions: Panel, 19 x 7½ inches; depth behind panel, 9 inches.

Net Weight: 30 pounds.

Type	*Description*	*Code Word*	*Price*
716-P2M	Cabinet	BOSOMGUARD	$190.00
716-P2R	Relay Rack	BONUSGUARD	170.00

CHECKING THE ACCURACY OF NEW YORK CITY TELEPHONE TIME SERVICE

● **"WHEN YOU HEAR THE SIGNAL,** the time will be one thirty-eight and one-quarter." Four times each minute, an operator sitting before a microphone in a soundproof room at a New York Telephone Company building in mid-Manhattan tells the correct time to the inquiring city — and someone in the New York area wants to know the time almost continuously during the day and night.

The Telephone Company's time-telling service carries the high polish of good engineering. The operator, selected for her voice appeal, faces a panel fitted with switch knobs, lamps, and a double clock — double in case of emergency. Beside the numbers registering the time in hours and minutes, quartered seconds roll under an index for their revolving disk. A green light gives the operator the cue to announce the time just before the signal tone. If her voice is too loud, a yellow pilot light glows on the panel; a blue one admonishes her if she speaks too low. Since the operators shift every half hour these signals are particularly helpful to the new operator in adjusting her voice.

Miss Time Service does not hear the "Thank you" of her listeners because of a one-way connection to their lines. A pilot light indicates that her number, Meridian 7-1212, is being called. If the light should go out, the operator could rest her voice. But it seldom goes out.

The Telephone Company arranged to check the accuracy of the clocks by a binaural comparison with the Arlington radio time signals, listening to the clock

File Courtesy of GRWiki.org

pulse with one ear and to the radio signal with the other. By this method a quarter-second is a good accuracy.

To benefit jewelers, astronomers, and others who asked for highly precise time, it became desirable to provide a means for making a closer check. To meet this need, a visual stroboscopic checking device was worked out with the General Radio Company, which, while comparatively inexpensive, permits checking the Time Bureau signals to five-thousandths of a second.

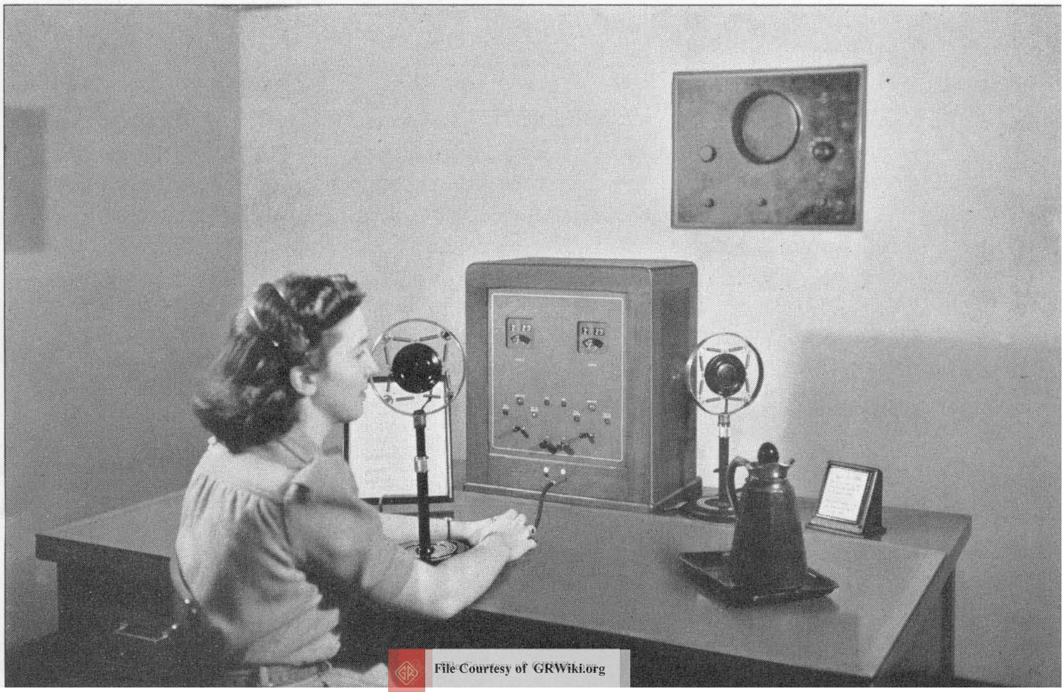
This unit, the P-489 Time Comparator, is essentially a 113-kilocycle amplifier which flashes a Strobotron lamp at the beginning of each Arlington signal and at the beginning of the time tone sent to the telephone subscribers. The flash shows through a slit in a disk turning once a second, and any variation in the time as compared to the Arlington signal is measured by the space between the flashes. The one-hundredth second scale graduations surrounding the rotating disk are three-sixteenths of an inch apart. The narrow slit permits reading to half-divisions — five thousandths of a second.

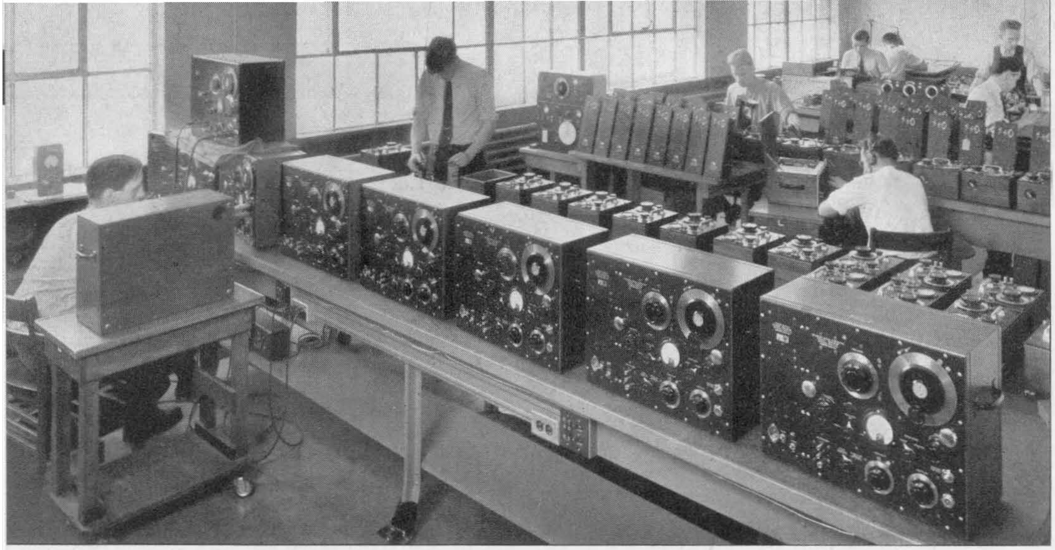
Today the equipment is installed at the Time Bureau, where, each hour that the Arlington time signals are transmitted, a check may be made on the accuracy of the Bureau's tone. Since the Bureau's time source is the crystal clock of the Bell Telephone Laboratories, the stability and accuracy of the time transmitted to the Bureau are unquestioned. The Time Comparator is the final absolute check on the functioning of the several miles of cable, the clocks, and the ingenious pulse-control relays.

The usefulness of the P-489 Time Comparator is not limited to time bureaus. Astronomical observatories and public utilities, whose customers depend on electric clocks, will find in it a distinct advantage in the stroboscopic rather than the aural method of checking their time against the Arlington time signals.

—F. Ireland

The time service operator seated at her desk with the double clock. The rectangular panel on the wall above the desk is the Time Comparator. Photograph courtesy New York Telephone Company.





A portion of the standardizing laboratory at the General Radio Company. In the foreground are several TYPE 605-B Standard-Signal Generators undergoing calibration.

MISCELLANY

● **THE TYPE 631-B STROBOTAC** is now equipped with a slow-motion drive which greatly facilitates setting the speed control dial. This drive has a reduction ratio of 5 to 1. Precise settings of flashing speed can be made while the Strobotac is held in the hand.

● **"THE NON-DESTRUCTIVE TESTING** of Insulation" was the title of a paper delivered by R. F. Field before the February 8 meeting of The Electrical Equipment Committee of New England, an organization composed of engineers from New England public utility companies.

● **"SQUARE-WAVE TESTING"** was discussed by Mr. L. B. Arguimbau at the January 26 meeting of the Boston Section, I.R.E., and also at the recent Broadcast Engineering Conference at Ohio State University.

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also IN THIS ISSUE

TRANSIENT RESPONSE OF A BROADCAST SYSTEM

● AS STATED IN A PREVIOUS ARTICLE,* a knowledge of the response of a linear network to a suddenly applied voltage is sufficient to determine the behavior of the network when any other voltage is applied and, similarly, tests of the operation of a linear amplifier with square waves applied are sufficient to determine its response to the complex waveforms of speech or music.

The advantages of square-wave testing on audio-frequency amplifiers suggest the desirability of extending the test method to radio broadcasting systems. Although broadcast transmitters and receivers operate

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*L. B. Arguimbau, "Network Testing with Square Waves," General Radio *Experimenter*, December, 1939.

Figure 1. The author with the equipment used for making the tests. In the background is the frequency-modulated relay transmitter of the Yankee Network.

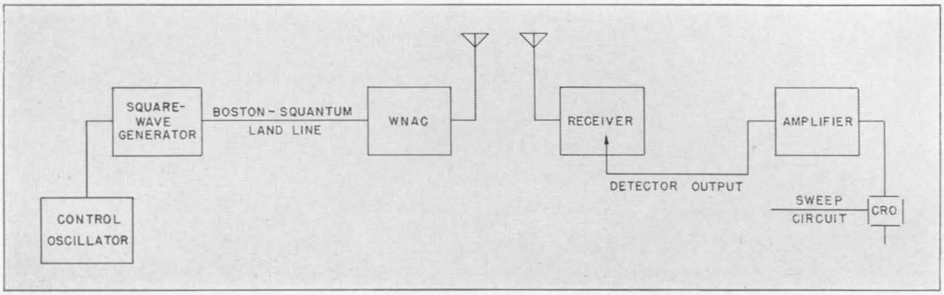


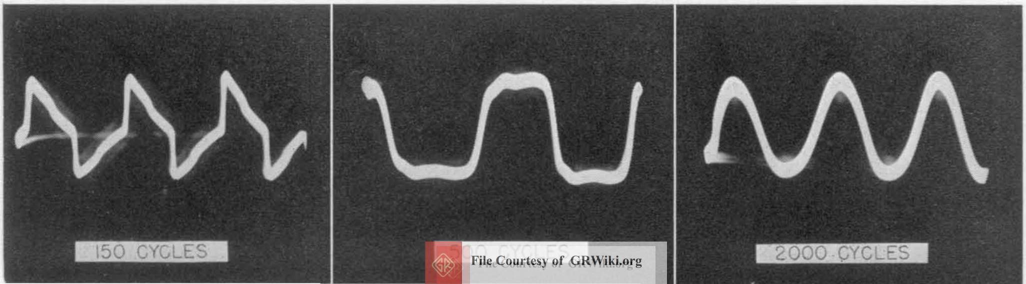
FIGURE 2. Diagram of the test method used for the amplitude-modulated system.

by virtue of non-linear elements, the carrier envelope in an amplitude-modulated transmitter output varies in a linear fashion with the audio-frequency input, and the audio output of a diode detector varies linearly with the carrier envelope. The envelope can be treated as a simple signal except when high percentage of modulation and unsymmetrical side-band clipping are present simultaneously. Under normal conditions, therefore, the same test methods that are used on linear networks should be valid for the broadcast system.

Through the courtesy of Mr. Paul de Mars of the Yankee Network, we were able to make a series of tests on the over-all transient response of two typical broadcast systems, one using an amplitude-modulated transmitter (WNAC of Boston), the second using an Armstrong frequency-modulated transmitter. It should be emphasized that in these tests no attempt has been made to localize the elements limiting the frequency range. As will be seen from Figure 2, the amplitude-modulated system included the program line and a receiver in addition to the transmitter. It is likely that the receiver was more important than the transmitter in limiting the fidelity. This arrangement was intentional as the tests were made to determine whether or not square-wave methods were applicable to such a complicated system and not for the purpose of making a technical investigation of the details of the system. As a matter of fact, this arrangement made it possible to get a direct comparison of the fidelity of an amplitude system as used at present under favorable conditions with the fidelity of the Armstrong system. The results of the tests on WNAC are shown in Figure 3. Several points may be noticed. With a 150-cycle square wave, the response has a very sharp slope, indicating phase shifts at the low frequencies.

The response to a 500-cycle square wave is somewhat similar to the high-frequency response of a single-stage

FIGURE 3. Oscillograms showing the shape of square waves after passing through the complete amplitude-modulation system.



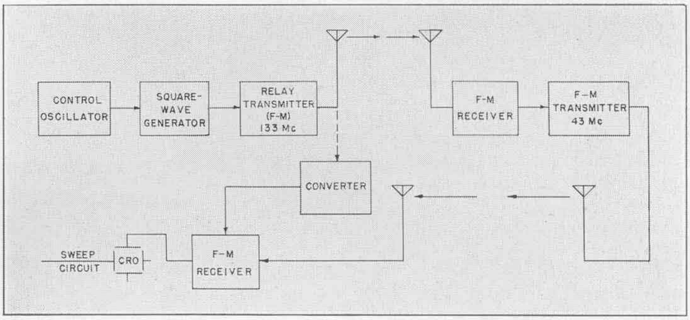


FIGURE 4. Diagram of the arrangement used for testing the frequency-modulation system.

amplifier and indicates appreciable attenuation at frequencies as low as 1500 cycles.

As is well known, a square wave contains only odd harmonics of its fundamental period. Thus, a square wave having a repetition frequency of 2000 cycles will have a 2000-cycle component and no other components below 6000 cycles. The fact that the response to a 2000-cycle square wave is essentially sinusoidal indicates that the system does not pass 6000 cycles or higher frequencies.

Figure 4 shows the arrangement used in testing the frequency modulation system. Two connections were tested. In one case the relay transmitter in Boston was modulated by a square wave and received in Paxton, Massachusetts, about 40 miles distant. The receiver output was then used to modulate the Paxton transmitter, which was then received in Boston. This chain of two transmitters and receivers is the arrangement normally used by the Yankee Network in Boston. In a second test, the output of the relay transmitter was passed through a converter and received directly.

The response for the complete two-link system is shown in Figure 5. The 60-cycle response bears a close resemblance to that of a multi-stage resistance-capacitance-coupled amplifier.* In spite of the severe phase shift shown by this curve, a careful analysis of it indicates that the attenuation at 60 cycles is less than 2 db.

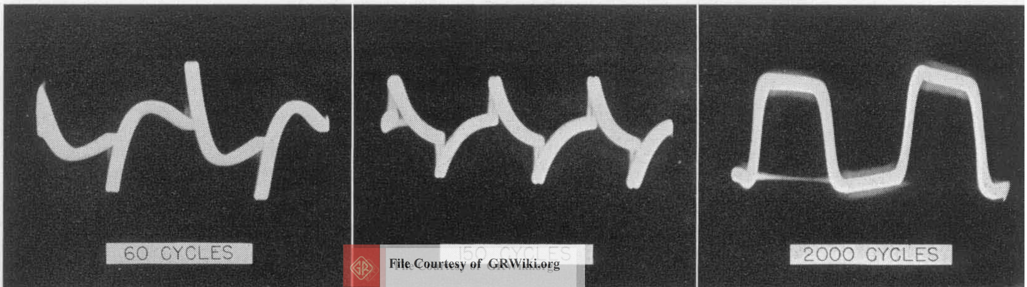
At 150 cycles the phase shift is obviously less. There is no measurable attenuation at this frequency. The high-frequency response as indicated by the 2000-cycle square-wave pattern is excellent.

Corresponding patterns for the relay transmitter are shown in Figure 6. The 150-cycle pattern is similar to that for the amplitude-modulated system. The difference in appearance of the vertical trace is caused by the limited high-

---

*A method for computing such curves is given in an article by H. M. Lane, "Resistance-Coupled Amplifier in Television," *Proc. I. R. E.*, April, 1932.

FIGURE 5. Square-wave patterns obtained for the complete frequency-modulation system. The oscillograms at the center and the right compare respectively with those at the left and right in Figure 3.



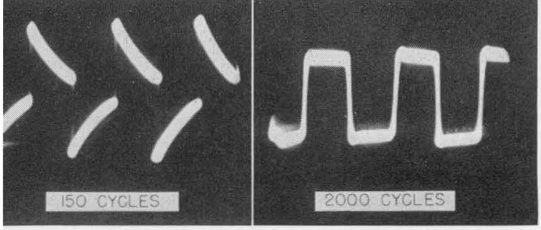


FIGURE 6. Oscillograms for the f-m relay transmitter and receiver only. Compare these with the results for the same frequencies on the amplitude modulation system (Figure 4).

frequency response of the amplitude-modulated system. The 2000-cycle pattern indicates that the cut-off frequency is around 30 kilocycles.

The writer is not in a position to comment upon the theoretical questions concerning the fidelity of frequency-modulation systems, but can say without hesitation that the experimental results indicate a very high fidelity.

These square-wave tests do not include the microphone and loudspeaker. While it is impossible to test these elements by purely electrical methods, the combination of speaker and microphone can be so tested by applying square waves to the speaker, picking up the sound wave with the microphone, and observing its waveform on a cathode-ray oscillograph. Tests were made in this way on a variety of loudspeakers and microphones. With none of these combinations was it possible to get recognizable square-wave patterns on the oscillograph.

This is not true of a phonograph recording and reproducer. In recent work done at M. I. T. by Mr. L. P. Reitz, a square-wave generator was applied to a record cutter and the pickup was later connected to an amplifier and cathode-ray tube. The results were by no means as good as those shown for the broadcast systems but the patterns were definitely recognizable as due to simple flaws such as insufficient low-frequency response and high-frequency resonance. The effect of equalizers on the high-frequency resonance could be followed clearly.

There has been much discussion about the applicability of square-wave technique to acoustics, about whether or not phase is of importance and, if so, under what circumstances. Comments of a large number of people would indicate that there is a considerable difference of opinion on the point. In any case, we can say that the response of a high-fidelity radio system is almost perfect in comparison to that of any available acoustic systems. The difference between these two is so glaring that it would seem that much more emphasis should be put on acoustic work.

The results show that square waves are useful in testing electrical networks and mechanical reproducers, but are not applicable to any of the acoustic systems tested. At least the results indicate that the method has considerable promise in design and maintenance work on electrical networks.

— L. B. Arguimbau

TYPE 50 VARIACS FOR MULTIPLE AND 3-PHASE OPERATION

● **THE NEW TYPE 50 VARIAC***, because of its ability to handle comparatively large amounts of power, has a considerably greater field of application than the smaller types. Ganged assemblies for use in 3-phase circuits and for parallel operation extend this field still further.

---

*S. A. Buckingham, "New Models of the Variac," General Radio *Experimenter*, Volume XIV, No. 2, July, 1939.

THREE-PHASE OPERATION

As pointed out in a previous article,† the maximum amount of power which can be handled by an assembly of Variacs in a three-phase system is

$$(E_{in})\ (I_{max})\ (\sqrt{3})$$

where

E_{in} = input line voltage

I_{max} = maximum allowable output current.

This holds regardless of the type of circuit used, i.e., whether the Variacs are connected in a wye, a closed delta, or an open delta. This power can be handled in the vicinity of line voltage. When the over-voltage feature is used, rated current instead of maximum current must be used in calculating the output rating. It should also be noted that, when the power rating, so calculated, exceeds the combined ratings of the individual Variacs in the assembly, a greater-than-normal temperature rise may be expected because of greater losses produced by the higher flux density in the core. For a 50° Centigrade rise, the maximum power drawn should not exceed the sum of the individual ratings.

The connections most commonly used in three-phase Variac assemblies are the wye and the open delta. The closed delta, while sometimes useful for specialized applications, does not give the type of voltage variation usually desired. Circuits for the wye and open delta connections are given in Figures 1 to 4. Corresponding ratings are listed in Table I, page 6. Only circuits operating at 230 volts and higher are listed because there are comparatively few applications for lower-voltage three-phase systems.

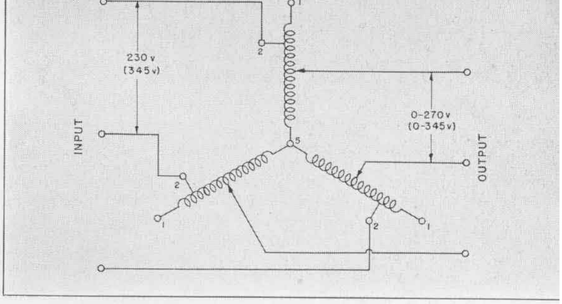


FIGURE 1. Three TYPE 50-A Variacs, wye-connected as shown here, can be used on a 230-volt circuit to give a maximum output voltage of 270 volts. If the over-voltage connection is not used, i.e., if the line input is connected to terminal 1 instead of terminal 2, a maximum of 345 volts can be handled.

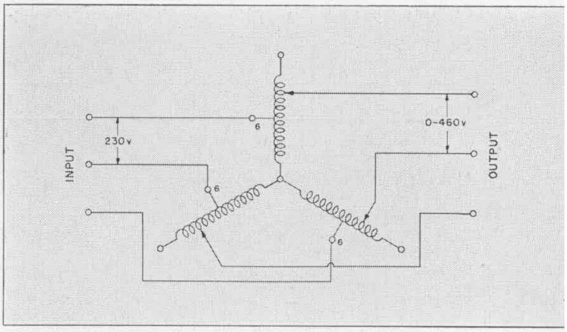


FIGURE 2. TYPE 50-B Variacs, wye-connected on a 230-volt circuit, will give a maximum output voltage of 460, open circuit. Regulation, however, is poor.

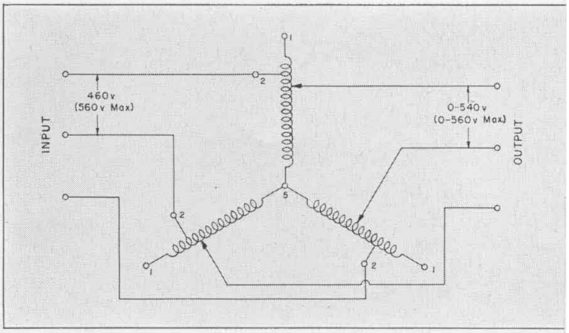


FIGURE 3. TYPE 50-B Variacs in a wye connection can be used on a 460-volt circuit to give a maximum output voltage of 540. If the input line is connected to terminal 1 instead of terminal 2, the maximum input and output voltage can be 560.

PARALLEL OPERATION

When Variacs are operated in parallel a current equalizing choke must be used

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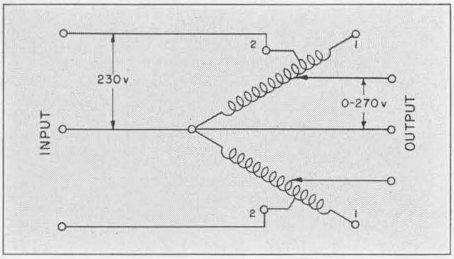
†L. E. Packard, "Three-Phase Voltage Control with the Variac," General Radio *Experimenter*, Volume XI, No. 10, March, 1937.



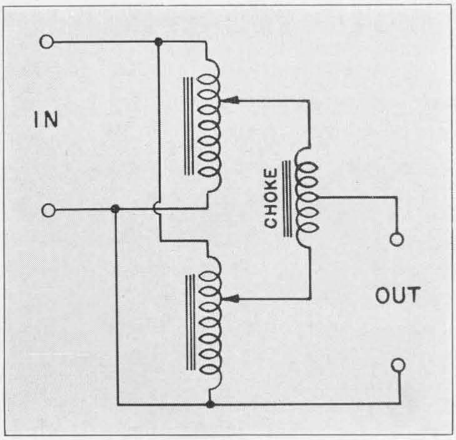


Figure 4. The open-delta connection uses one less Variac than the wye. This diagram shows two Type 50-B Variacs in an open delta.

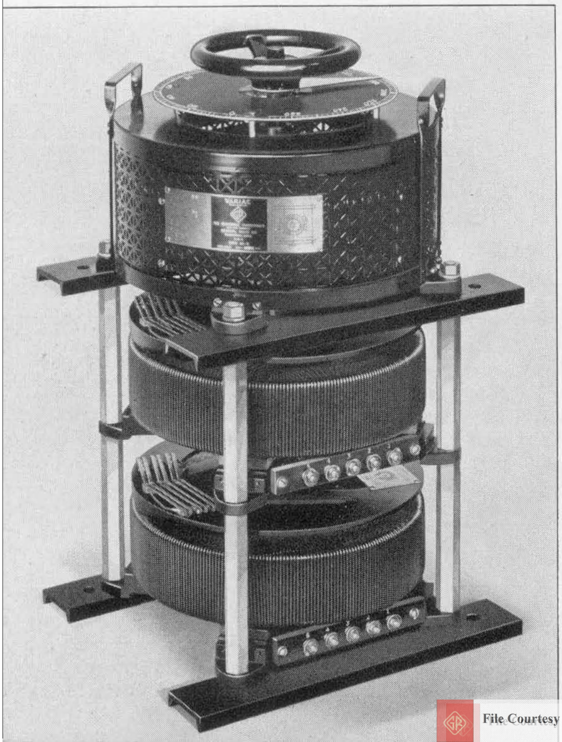
Figure 5. (*Right*) Connections for current-equalizing choke when Variacs are in parallel.

TABLE I

OUTPUT					*INPUT*				
KVA		*Line Current in Amperes*		*3-Phase Line Voltage*	*3-Phase Line Voltage*	*Cir-cuit*	*Type*	*No. Req'd.*	*See Figure*
At Input Volt.	*At Max. Volt.*	*Max.*	*Rated*						
18	16	45	40	0–270	230	Y	50-A	3	(1)
26	26†	45	40	0–345	345	Y	50-A	3	(1)
		31	20	0–460*	230	Y	50-B	3	(2)
25†	16	31	20	0–540	460	Y	50-B	3	(3)
30†	19	31	20	0–560	560	Y	50-B	3	(3)
12.5	8	31	20	0–270	230	Open Δ	50-B	2	(4)

*Open-circuit voltage — regulation is poor for this connection.

†For outputs as great as this, the flux density is higher than normal, resulting in larger losses and a higher-than-normal temperature rise. The maximum output for 50° rise is 22.5 kva. The output listed can, however, be safely handled by the Variac for short periods.



to limit the flow of circulating current. Connections for such a choke are shown in Figure 6. For parallel operation of two Type 50 Variacs, Type 50-P1 Choke is available. This unit is mounted in a cast metal frame which can be fastened by the user in any convenient location in a two-gang assembly of Type 50 Variacs.

The power-handling capacity of two Variacs in parallel is, of course, double that of a single unit.

Type 50 Variacs are now available in two- and three-gang assemblies. Delivery can usually be made within two weeks after the order is received. Prices are listed below. — S. A. Buckingham

Figure 6. A three-gang assembly of Type 50-B Variacs.

SPECIFICATIONS

Mounting: Unless the order specifies otherwise, ganged assemblies will be supplied for table mounting. This can be changed to panel mounting by loosening the shaft and sliding it through the assembly.

The standard shaft length will accommodate a 1½-inch panel. If the assembly is to be used on a thicker panel, this must be specified in the order, and a special long shaft will be furnished without extra charge.

The ganged assemblies cannot be used on a vertical panel without auxiliary bracing.

Dimensions: 2-gang, 15½ x 15½ x 17½ inches over-all; 3-gang, 15½ x 15½ x 25½ inches over-all.

Net Weight: 2-gang, 175 pounds; 3-gang, 250 pounds.

Type	*Description*	*Code Word*	*Price*
50-AG2	2-gang, Type 50-A	TOKENGANDU	$225.00
50-BG2	2-gang, Type 50-B	TOPAZGANDU	225.00
50-AG3	3-gang, Type 50-A	TOKENGANTY	335.00
50-BG3	3-gang, Type 50-B	TOPAZGANTY	335.00
50-P1	Choke	PARALLCHOK	7.50

Variacs are manufactured under U. S. Patent No. 2,009,013.
The trade name VARIAC is registered at the U. S. Patent Office.

A NEW SOUND-LEVEL METER

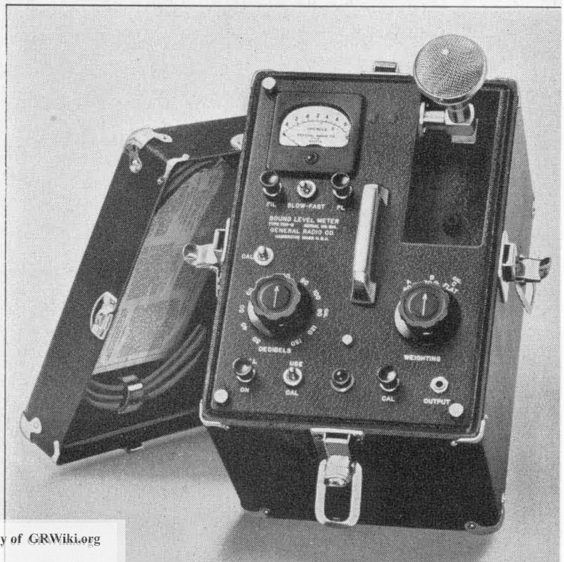
● **THE THREE YEARS** which have elapsed since the original announcement of the Type 759-A Sound-Level Meter have seen the transformation of sound-level measurements from a little-used and little-known laboratory procedure into a valuable and widespread commercial operation. The General Radio sound-level meter has been accepted in countless laboratories and industries as an accurate, convenient, and economical means for making the various noise measurements required by modern conditions and markets.

The experience gained in building many hundreds of these instruments has enabled the General Radio Company to produce an improved model known as the Type 759-B based upon the same principles as the previous type, but incorporating advancements and simplifications which provide even higher degrees of convenience and accuracy.

Of first importance is the microphone. An exhaustive study of the various types available on the market has led to the development of this special type. Throughout the A.S.A.* range of 60 to 8000 cycles its performance is substantially the same as the earlier model so far as frequency characteristic is concerned. The new unit, however, is more sensitive and rugged and is substantially unaffected by all ordinary changes in temperature and humidity. Use of this more sensitive microphone has allowed the designers to make other changes in the sound-level meter which improve its dependability and ability to withstand hard usage in the field.

For the convenience of the user the two attenuators have been combined,

Figure 1. View of the Type 759-B Sound-Level Meter with cover removed.



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* "American Tentative Standards for Sound-Level Meters for Measurement of Noise and Other Sounds," Bulletin Z24.3, American Standards Association.

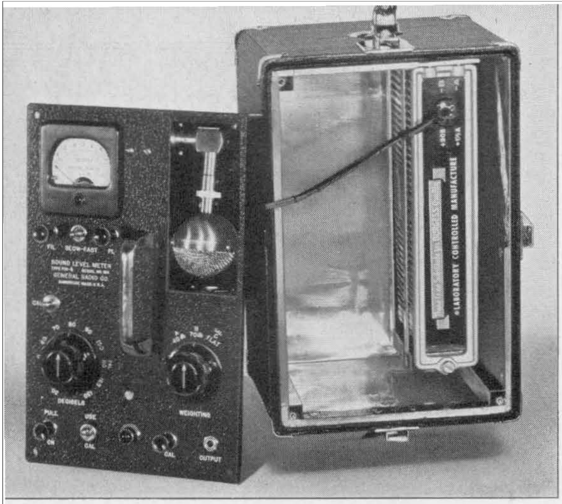

FIGURE 2. The power supply for the sound-level meter is a single block battery which mounts inside the cabinet. Connections are made with a plug as shown.

so that the main attenuator knob covers the complete decibel range. The range itself has been extended, so that the maximum level is now +140 db.

A further improvement is the provision of a slow-fast meter. With the control switch in the fast position the meter movement is the same as in the TYPE 759-A and corresponds to the A.S.A. specifications. Many users, however, have expressed a desire for a more heavily damped meter. Merely throwing the control switch to the slow position produces this result, thus simplifying the measurement of the average level of fluctuating sound.

Since the previous model sound-level meter was designed, many improvements have been made in vacuum tubes, and tubes of the latest 1.4-volt series are used in the new model. The additional gain available from these tubes, together with the more sensitive microphone, allows considerable simplification of the circuit. An important feature of the new circuit is the double output stage, one-half of which drives the indicating meter and the other connects to the output jack for use with an analyzer, external meter, or phones. There is no connection between the internal indicating meter circuit and this extra output circuit. This eliminates all rectifier distortion from the output and also makes the meter readings quite independent of what is connected to the output. The added convenience of these features will be readily appreciated by customers who use the sound meter with an analyzer.

Last but not least, the new sound-level meter uses a single block battery of the type used in portable radio receivers. Positive connection to the battery is made by means of a single plug. The battery both weighs and costs less than a set of batteries for the earlier model meter.

In spite of the improved design, the price of the new sound-level meter remains the same as that of the earlier model — $195.00. For most practical purposes the two meters are interchangeable, but the new meter is even more convenient and serviceable than the older one.

—H. H. SCOTT

The Type 759-A Sound-Level Meter is manufactured and sold under the following United States Letters Patent:

1. Patents of the American Telephone and Telegraph Company solely for utilization in research, investigation, measurement, testing, instruction and development work in pure and applied science.
2. Patent No. 1,871,886.

GENERAL RADIO COMPANY
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BRANCH ENGINEERING OFFICES
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1000 NORTH SEWARD STREET, LOS ANGELES, CALIFORNIA

THE General Radio EXPERIMENTER

VOLUME XIV NO. 12 MAY, 1940

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also IN THIS ISSUE

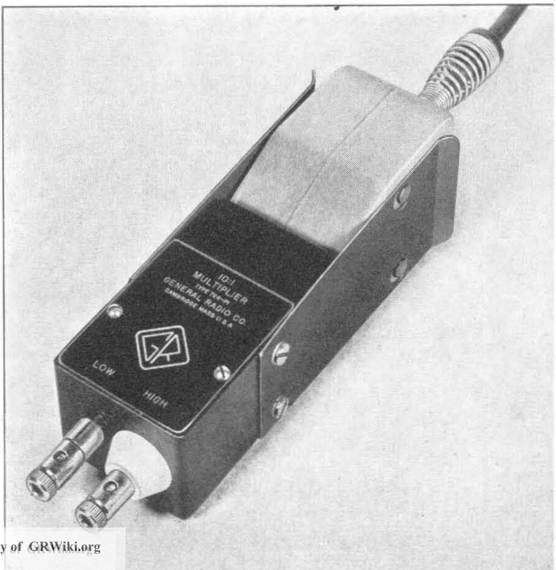
A VOLTAGE MULTIPLIER FOR USE WITH THE VACUUM-TUBE VOLTMETER AT RADIO FREQUENCIES

● **THE TYPE 726-A VACUUM-TUBE VOLTMETER*** has been widely adopted for measuring voltages from 0.1 v to 150 v in the frequency range from 20 cycles to 100 Mc. With external condenser shunts it has also been used as a radio-frequency ammeter.†

In order to extend still further the usefulness of this instrument by increasing the voltage range, the TYPE 726-P1 Voltage Multiplier, shown in Figure 1, has been designed. By means of a capacitance type voltage divider a reduction of 10 : 1 is obtained between the voltage applied to the multiplier and the voltage appearing across the voltmeter terminals. The use of the multiplier therefore extends the upper voltage that can be measured to 1500 volts.

The frequency error of the multiplier is plotted in Figure 2. Over the frequency range from 1 Mc to 100 Mc the error is negligible. At lower frequencies, where the input admittance of the voltmeter probe has an appreciable conductance

FIGURE 1. The voltmeter probe plugs into the 1500-volt multiplier as shown here.



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*"TYPE 726-A Vacuum-Tube Voltmeter," General Radio *Experimenter*, Vol. XI, No. 12, p. 1, May, 1937.

†"The TYPE 726-A Vacuum-Tube Voltmeter as a Radio-Frequency Ammeter," General Radio *Experimenter*, Vol. XIII, Nos. 3/4, p. 1, August/September, 1938.

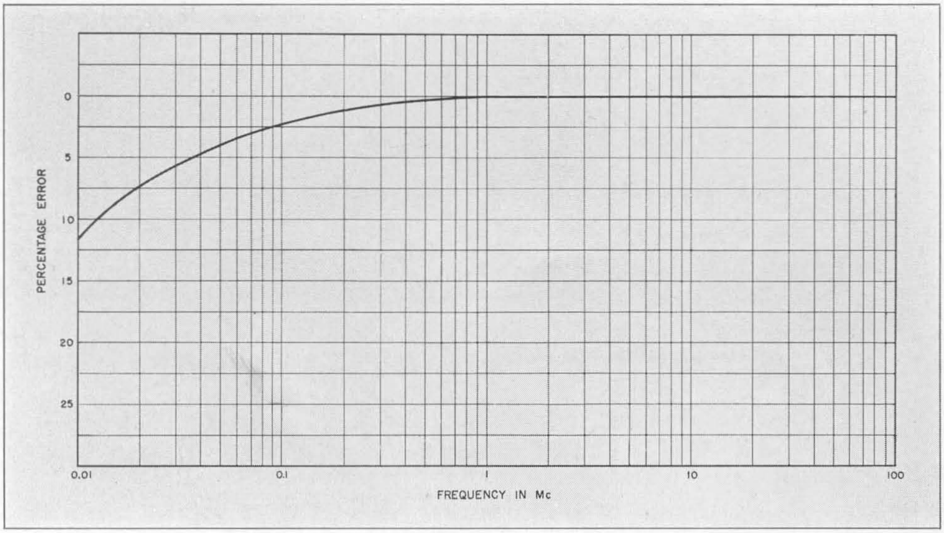


FIGURE 2. Plot of the error in multiplier ratio as a function of frequency.

component compared to the capacitive susceptance, an error appears that increases as the frequency decreases, becoming 5% at a frequency of 40 kc.

The input admittance of the multiplier has been made even lower than that of the voltmeter probe itself, being equivalent, over the frequency range from 100 kc to 100 Mc, to that of a 4.5 $\mu\mu$f condenser of less than 0.5% power factor.

From the design standpoint, an interesting feature is that the flanges used to secure the multiplier to the voltmeter probe, when it is plugged in, are also used to complete the electrostatic shielding of the voltmeter probe. This complete shielding is necessary in order to insure that there is no direct electrostatic pickup to the probe from the voltage to be measured.

— D. B. SINCLAIR

SPECIFICATIONS

Multiplier Ratio: 10 to 1. This gives a total range of 1 volt to 1500 volts when the multiplier is used with the TYPE 726-A Vacuum-Tube Voltmeter.

Frequency Error: The frequency error is shown in Figure 2.

Dimensions: The multiplier adds about 3 inches to the effective length of the probe.

Net Weight: 12 ounces.

Type		*Code Word*	*Price*
726-P1	....	ALOUD	$15.00

SUBSTITUTION MEASUREMENTS AT RADIO FREQUENCIES

AND THEIR APPLICATIONS TO THE TYPE 516-C RADIO-FREQUENCY BRIDGE

● **ACCURATE MEASUREMENTS OF UNKNOWN IMPEDANCES** are made almost universally by some type of substitution method because in this manner fewer elements of the measuring circuit need to be calibrated. In general, only those standards of reactance and resistance which are varied in order to effect the substitution will enter into the final equations. The substitution may be complete or partial. In the former case the entire reactance standard is removed from the circuit when the unknown impedance is connected, and this standard must be calibrated for total reactance. In the latter case the standard need be calibrated only for differences, since it remains in circuit at all times. The unknown impedance may be connected either in parallel or in series with the reactance standard, thus giving rise to the two methods, of parallel substitution and of series substitution.

The adjustable reactance standard is almost always an air condenser, both because an air condenser can be accurately calibrated and because it holds its calibration at high frequencies. The only defect of an air condenser when used at low frequencies is that it has dielectric losses. These losses occur in the fixed capacitance of the stator supports and in a properly designed condenser are unaffected by the position of the rotor. For this reason they do not appear in the final results obtained from the parallel substitution method. Other losses, however, which vary with the position of the rotor, such as those caused by dust or moisture on the surface of the condenser plates, will produce errors in parallel substitution measurements. On the other hand, in the series substitution method the dielectric losses also introduce errors.

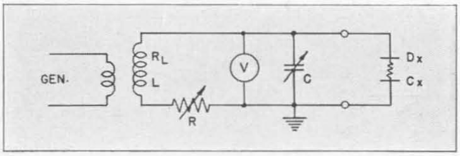
In the parallel substitution method the resonant circuit is first tuned, or the bridge is first balanced, with the unknown impedance disconnected. The unknown is then connected in parallel with the standard condenser and the circuit returned to its original condition. The unknown reactance is always measured by the change in capacitance of the standard condenser. Its dissipation factor is found from the change in setting of whatever circuit element is used for resistance balance, either resistance in series or parallel with the standard condenser, or capacitance in parallel with a resistance arm in a Schering bridge.

The use of series resistance in a resonant circuit is illustrated in Figure 1. The unknown capacitance C_x and its dissipation factor D_x are given by

$$C_x = \Delta C \qquad D_x = \frac{C'^2}{C_x}\,\omega\Delta R \tag{1}$$

where $\Delta C = C' - C$ and $\Delta R = R' - R$ and the initial values, when the unknown is not in circuit, are denoted by primes. Values of the coupling and tuning inductance L and its effective resistance R_L do not enter these equations.

FIGURE 1. Circuit for measuring a condenser by the parallel substitution method, in which the dissipation factor is determined by the change in setting of the series resistance *R*.



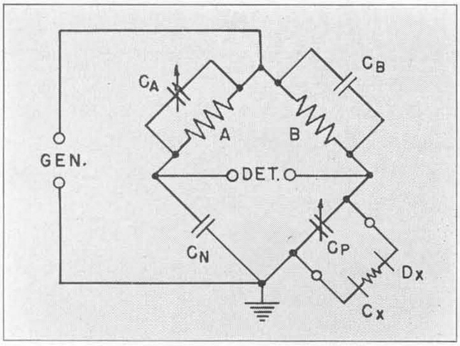


FIGURE 2. Circuit for parallel substitution method with a Schering bridge. The dissipation factor of the unknown is determined from the change in setting of C_A.

In the Schering bridge shown in Figure 2 the expressions for C_x and D_x are

$$C_x = \Delta C_P$$
$$D_x = \frac{C'_P}{C_x}\Delta Q_A \qquad (2)$$

where $\Delta C_P = C'_P - C_P$ and $\Delta Q_A = Q_A - Q'_A = (C_A - C'_A)\omega A$. Here the resistance arm A enters, but only as a factor. None of the elements in the B and N arms appear.

ERRORS AT RADIO FREQUENCIES

In addition to the dielectric loss in the stator supports, an air condenser has two other residual impedances, series inductance and series resistance, in the leads to the stator and rotor and in the condenser plates themselves.[1] The effects of these two residuals in parallel substitution measurements are negligible at low frequencies, but at high frequencies they become of great importance. On the other hand, they produce no error in series substitution methods because they also are practically unaffected by the position of the rotor.

These residuals can also occur in all parts of any measuring network and constitute the real difference between high- and low-frequency measurements.

A good representation of an air condenser is shown in Figure 3. The series inductance L_C increases the total capacitance according to the equation

$$\hat{C} = \frac{C}{1 - \omega^2 L_C C} \qquad (3)$$

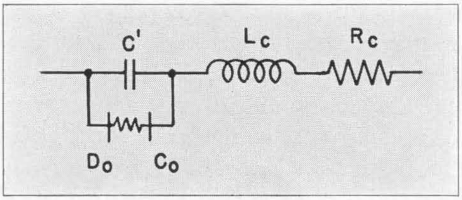
where $C = C' + C_0$. For a TYPE 722-D Precision Condenser L_C is 0.06 μh. For a capacitance setting of 1000 $\mu\mu$f the error introduced by this inductance becomes 0.1% at about 600 kc. At higher frequencies the error increases rapidly because frequency appears squared in Equation (3). The errors occurring for various capacitances at different frequencies are shown in Figure 4. This error has increased to 10% at 6 Mc, while at 20 Mc this 10% error occurs for only 100 $\mu\mu$f. In the TYPE 722-N Precision Condenser L_C has been reduced to 0.006 μh. The curves of Figure 4 may be applied to this condenser by multiplying by 3 the frequency assigned to each curve.

The series resistance R_C increases the dissipation factor D of the air condenser according to the relation

$$D = \frac{D_0 C_0}{C} + R_C \omega C \qquad (4)$$

where D_0C_0 is the figure of merit of

FIGURE 3. Equivalent circuit of an air condenser. D_0, C_0 represents the fixed capacitance and dissipation factor of the solid dielectric. This is in parallel with a lossless variable capacitance, C'. L_C and R_C are series inductance and series resistance of the leads, plates, and supports.



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[1] R. F. Field and D. B. Sinclair, "A Method for Determining the Residual Inductance and Resistance of a Variable Air Condenser at Radio Frequencies," Proc. I.R.E., Vol. 24, No. 2, February, 1936.

the air condenser. For a Type 722-D Precision Condenser $D_0C_0 = .04\ \mu\mu\text{f}$ and $R_C = .02\ \Omega$ at 1 Mc. Even at this frequency skin-effect is complete, so that the series resistance varies as the square root of the frequency. Values of the two components of dissipation factor are plotted in Figure 5. Even at a frequency of 1 Mc the component of dissipation factor contributed by series resistance equals that from dielectric loss at a capacitance of 600 $\mu\mu$f. In the Type 722-N Precision Condenser $R_C = .005\ \Omega$ at 1 Mc. The curves of Figure 5 will apply to this condenser by multiplying by 2 the frequency assigned to each curve.

When these effects of series inductance and series resistance are taken into account by substituting Equations (3) and (4) in Equations (1) and (2), the expressions for capacitance and dissipation factor become

$$C_x = \frac{\Delta C_P}{1 - \omega^2 L_C \Sigma C_P}$$

$$D_x = \frac{C'_P}{C_x}\,(1 + \omega^2 L_C C'_P)\Delta Q_A + R_C \omega \Sigma C_P \qquad (5)$$

where $\Sigma C_P = C'_P + C_P$ and where terms containing higher powers of ω than the square are omitted. Since ΣC_P is always greater than ΔC_P, the errors introduced by series inductance and resistance are always greater than those shown in Figures 4 and 5 on the assumption that abscissae of these plots are the unknown capacitance C_x.

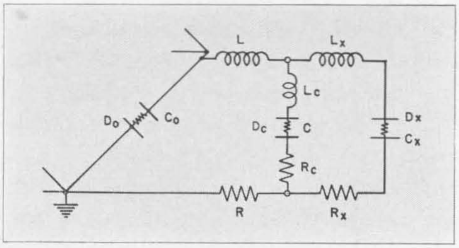


Figure 6. Circuit showing the residual impedances affecting substitution measurements with the radio-frequency bridge.

TYPE 516-C RADIO-FREQUENCY BRIDGE

Substitution measurements can be made on the Type 516-C Radio-Frequency Bridge either by using the internal calibrated condenser or an external Type 722-D Precision Condenser. In either case there will be additional residual impedances, beside those shown in Figure 3, in that arm of the bridge containing the capacitance standard.

Figure 4. Percentage error in capacitance of a Type 722-D Precision Condenser as a function of setting for frequencies up to 20 Mc.

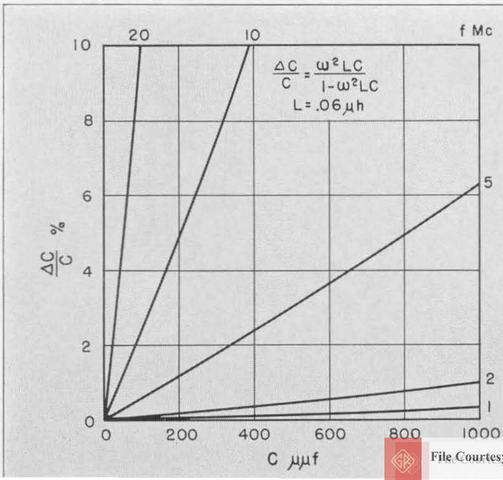
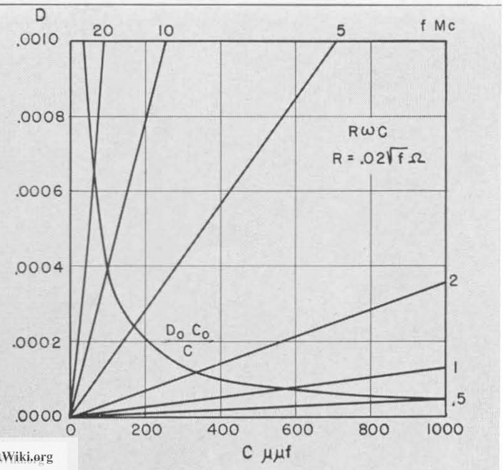


Figure 5. Plot of the two components of dissipation factor as functions of frequency and scale setting for Type 722-D Precision Condenser.



As shown in Figure 6, these include inductance L and resistance R in series with the standard condenser and capacitance C_0 shunted across the whole arm. In addition, inductance L_x and resistance R_x are shown in series with the unknown condenser C_x, since frequently it is impossible to connect the unknown impedance directly to the terminals of the standard condenser. The expression for the equivalent capacitance of the unknown condenser is unchanged from that given in Equation (5); while the expression for dissipation factor is expanded to take in the effect of the added residuals.

$$\hat{C}_x = \frac{\Delta C}{1 - \omega^2 L_C \Sigma C}$$

$$(6)$$

$$\hat{D}_x = \frac{C'}{C_x}\left[1 - \omega^2 C'(L - L_C) + \frac{C_0}{C'}\right]\Delta Q_A + R_C \omega \Sigma C$$

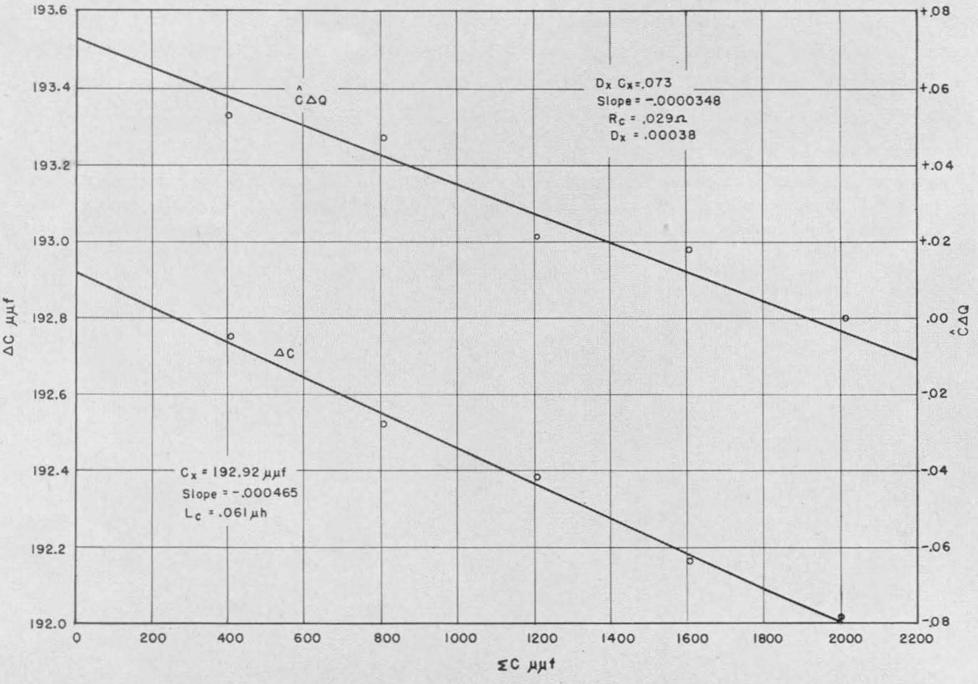
Subscripts P are omitted so that Equation (6) may be applicable to either bridge arm. If the connection residuals L_x and R_x can be determined the values of C_x and R_x are given by:

$$C_x = \frac{\hat{C}_x}{1 + \omega^2 L_x \hat{C}_x} \qquad (7)$$

$$D_x = \hat{D}_x - R_x \omega \hat{C}_x$$

In the TYPE 516-C Radio-Frequency Bridge the two shunt capacitances C_{NO} and C_{PO} are adjusted to equality with an average value of 40 μμf. Similarly, the two series inductances L_N and L_P are adjusted to equality with an average value of 1.9 μh. The correct value to be used for L in Equation (6) depends on which standard condenser, external or internal, is used. For an external TYPE 722-D Precision Condenser connected into the P-arm, the inductance of the leads from bridge to condenser must be added. This inductance can be calculated with sufficient exactness by allowing 0.03 μh per inch of the

FIGURE 7. Examples of straight-line plots for obtaining values of the residuals L_C and R_C.



pair of leads.[2] A reasonable length is 3 inches, giving an inductance of 0.1 μh and a value for L of 2.0 μh. For the internal condenser the leads to the PARALLEL CONDENSER terminals connect to the internal condenser leads at some distance from that condenser, with the result that the series inductance L_C is 0.28 μh. This leaves 1.6 μh for L in the N-arm. The series resistances for the two condensers at a frequency of 1 Mc are, for the external Type 722-D Precision Condenser 0.02 Ω, for the internal Type 539 Condenser 0.04 Ω. The leads up to the PARALLEL CONDENSER terminals have a combined length of 3 inches and hence have an inductance of about 0.1 μh. The values of these residual impedances are collected in Table I. Values of L_x and R_x for the P-arm depend upon the length of the leads used. Their inductance may be calculated from their length, diameter, and spacing.[2] Both residuals can be measured by using a condenser which can be connected both to the ends of the leads and directly to the terminal of the external precision condenser.

Exact values of the condenser residuals L_C and R_C can be found by measuring a given fixed condenser using different values of initial capacitance C'. The capacitance of this fixed condenser should lie between 200 and 500 μμf in order to obtain a sufficient dispersion of points while still allowing sufficient fractional accuracy for each individual measurement. While it is possible to calculate the values of the residuals from any two sets of observations, it is preferable to obtain at least six sets and plot them in such a manner as to yield straight lines. Transposing Equation (6) for this purpose

$$\begin{aligned} \Delta C &= -\omega^2 L_C C_x \Sigma C + C_x \\ C'\left[1 - \omega^2 C'(L - L_C) + \frac{C_0}{C'}\right]\Delta Q_A &= -R_C \omega C_x \Sigma C + D_x C_x \end{aligned} \tag{8}$$

The quantities to be used as co-ordinates for plotting are ΣC for abscissa in both plots and ΔC and $\hat{C}\Delta Q_A$ as ordinates. The residuals L_C and R_C are obtained from the slopes of the resulting straight lines, while the intercepts yield the capacitance C_x and dissipation factor D_x of the fixed condenser. Plots of data thus obtained using a Type 505-B Mica Condenser and an external Type 722-D Precision Condenser are shown in Figure 7. The values obtained are typical and the differences from the nominal values given in Table I are what must be expected. In order to obtain even as good consistency of the observed data as is shown in Figure 7, the precision condenser must be provided with a worm correction and the dissipation factor dial of the bridge must be balanced and read to 0.00001. For this reason data obtained with the internal standard condenser are much less consistent, for it is hardly possible to read total capacitance on the internal condenser to 1 μμf.

It will be found best for all ordinary measurements to use Equation (6) and the data of Table I in reducing observations. Only in quite special cases is it worth while to take sufficient data to make the straight line plots. On the

Table I

	N-arm	*P-arm*
C_0	40 μμf	40 μμf
L	1.6 μh	2.0 μh
L_C	.28 μh	.06 μh
R_L	.04 Ω	.02 Ω
L_X	.10 μh	

---

[2] This value holds for a pair of No. 16 wires ¾ inch on centers. The inductance of two parallel wires a cm long, d cm in diameter, and D cm apart between centers is $L = 0.004\,a\,(2.303 \log_{10} \frac{2D}{d} - \frac{D}{a} + .25)$ μh.

other hand, it is well to obtain data of this nature at intervals to check the adjustments and constants of the bridge and to appreciate the care with which the bridge balances must be made in order to obtain accurate results.

— R. F. Field

MISCELLANY

● **GENERAL RADIO** engineers have delivered several technical papers in the last few weeks. The measurement and analysis of sound and vibration were discussed by H. H. Scott before the Boston Section, A.I.E.E. on April 9, and at a meeting of the Physics Research Academy of Boston College on April 10. On April 12, Mr. Scott also addressed the Boston Power Transmission Club and the Boston Plant Engineers' Club on the subject of "Electronic Equipment in the Mechanical Field."

R. F. Field spoke, on March 20, before a group of engineers at the General Electric Company, Pittsfield, Mass., on "Impedance Measurements at High Frequencies." Mr. Field was also the speaker at the April 11 meeting of the Worcester Section, A.I.E.E. His subject was "Dielectric Measurements Over a Very Wide Range of Frequency."

A. E. Thiessen was the speaker at the April 19 meeting of the Baltimore Section, I.R.E. His subject was "Recent Developments in Measuring Instruments."

● **RECENT VISITORS** to the General Radio plant and laboratories include B. J. Thompson of RCA Radiotron, H. P. Corwith and L. B. Root of Western Union, P. E. Nokes of United Shoe Machinery Corporation, and S. Silverman of DuPont Rayon Company.

The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in communication-frequency measurement and control problems. When sending requests for subscriptions and address-change notices, please supply the following information: name, company name, company address, type of business company is engaged in, and title or position of individual.

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THE General Radio EXPERIMENTER

VOLUME XV NO. 1 JUNE, 1940

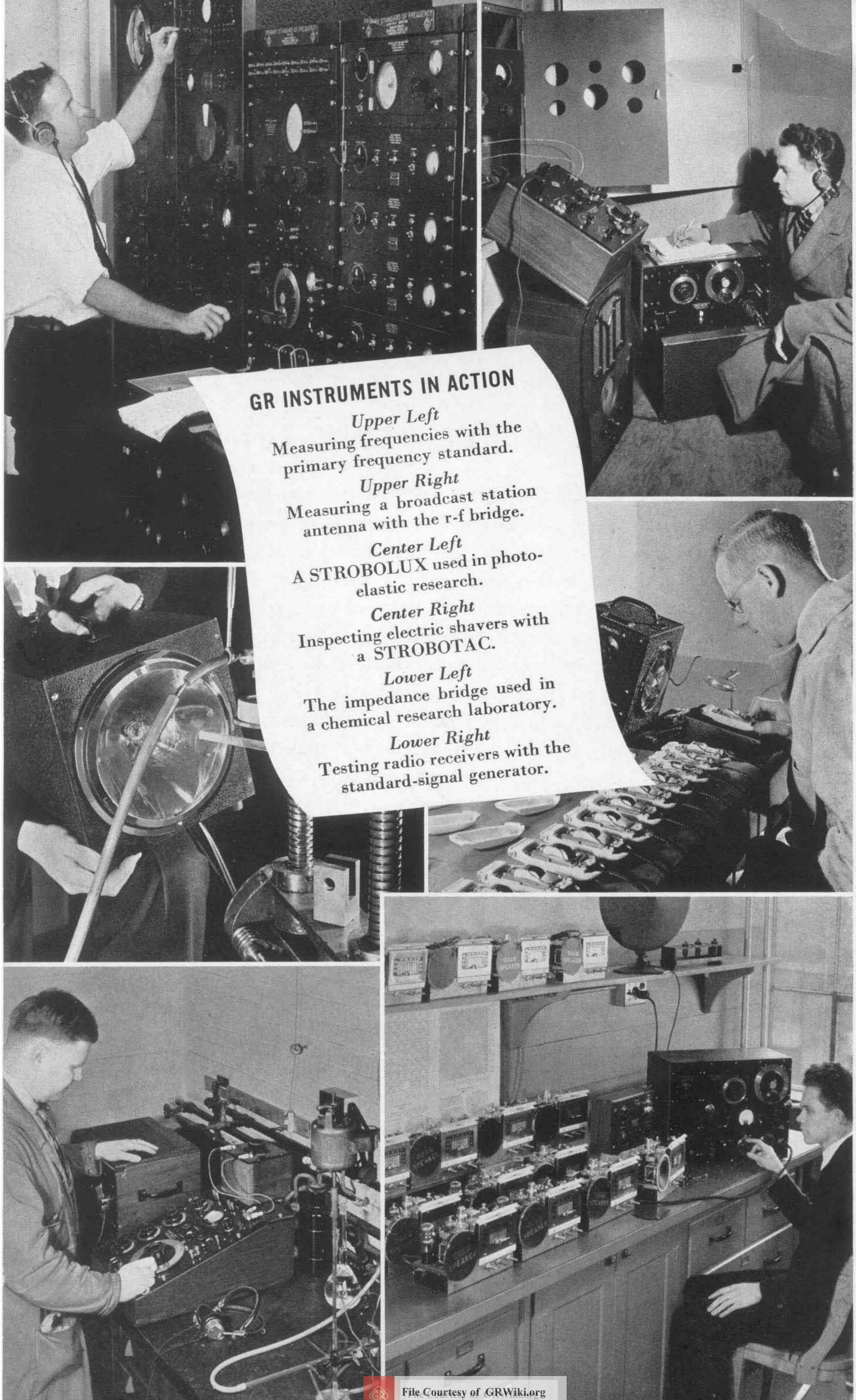
TWENTY-FIFTH ANNIVERSARY, 1915-1940

THE GENERAL RADIO COMPANY

● **IN THE TWENTY-FIVE YEARS** since its founding, the General Radio Company's products and markets have grown considerably beyond the limits implied by its name. Established in 1915 to supply laboratory measuring equipment to the infant radio industry, the Company now makes electrical instruments for varied applications, such as measuring the performance of broadcasting stations, the sensitivity of radio receivers, the noise generated by machinery, the speed of yarn spindles, and the vibration of crankshafts.

As its products and market have grown more complex, the General Radio Company has developed methods of handling engineering, sales, production, and personnel that are peculiarly suited to its type of business and its philosophy of management.

Questions asked by visitors to our plant have indicated a keen interest in our way of doing things, an interest which has prompted us to devote this anniversary issue of the *Experimenter* to a description of the General Radio Company as it is today.



GR INSTRUMENTS IN ACTION

Upper Left
Measuring frequencies with the primary frequency standard.

Upper Right
Measuring a broadcast station antenna with the r-f bridge.

Center Left
A STROBOLUX used in photo-elastic research.

Center Right
Inspecting electric shavers with a STROBOTAC.

Lower Left
The impedance bridge used in a chemical research laboratory.

Lower Right
Testing radio receivers with the standard-signal generator.

INTRODUCTION

General Radio is a small manufacturing company, but a medium-sized instrument company. Its plant consists of three connected buildings of four floors each, providing about 75,000 square feet of floor space. Here 215 employees design, build, test, and sell more than a million dollars' worth of General Radio products each year.

Since most of these products are electrical instruments designed and built for the specialized types of electrical measurement and testing that are rapidly becoming a necessary part of modern industrial processes, it is evident that planning, designing, servicing, and selling are necessarily engineering functions. Consequently, men with engineering background predominate in many departments. In fact, of the complete personnel, about 20% have college degrees, most of them in the engineering field.

The management and administrative organization are in many ways unique. To allow as much latitude as possible for individual initiative and ability, the simplest possible form of organization has been the aim. This has resulted in the development of an organization in which management is centered, for functional purposes, in the work of committees.

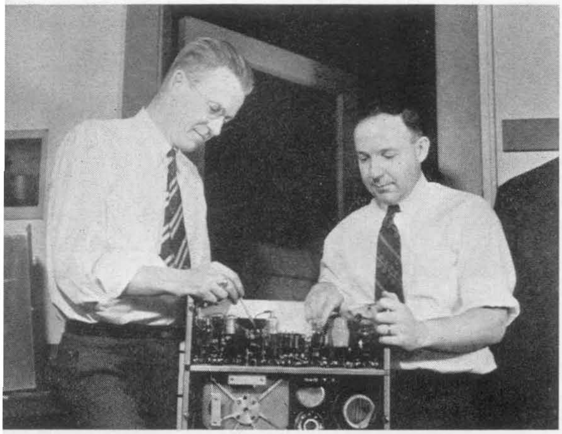
Active management of Company affairs is in the hands of the Management Committee, which consists of Company officers and several men in responsible positions in various Company departments. This committee meets weekly to discuss management problems.

Henry S. Shaw (*left, above*) has been associated with the General Radio Company since 1917, becoming Chairman of the Board in 1926. Melville Eastham (*right*) has been President of the Company since its founding in 1915.

Commercial, financial, and sales matters are supervised by H. B. Richmond, Treasurer (*right, above*), who joined the Company in 1919. At the left is F. L. Tucker, Comptroller. The patron saint of all treasurers looks down from the wall.

Prompt handling of all orders is the responsibility of the Commercial Department. In the photograph at the right, C. E. Hills, Jr., Commercial Manager (*right*), and H. P. Hokanson (*left*) look over the morning's orders.

Dr. D. B. Sinclair, Engineer (*left*), and C. A. Woodward, assistant, specialists in high-frequency measurements, are shown working on a new impedance bridge for use at high frequencies.



The primary frequency standard and the new broadcast frequency monitor were developed by J. K. Clapp, Engineer (*left*), and H. H. Hollis, assistant, General Radio's specialists in frequency standardization and measurement.

ENGINEERING

In the Engineering Department, "while there are loose groupings for administrative and accounting purposes, there is no chief engineer, and no such thing as an organization chart exists. Direction is at a minimum, and a very great responsibility is placed on individuals, not only with respect to immediate problems, but also to a degree as to their own future development. The direction of engineering development consists to a large extent of the co-ordination of effort in harmony with Company plans rather than the supervision of technical details."*

This co-ordination is accomplished through the work of two committees, an Engineering Planning Committee, which plans the development engineering program, and a Design Committee, which supplements the work of the Planning Committee with detailed instrument specifications. Within the limits of these specifications the actual design of an instrument is largely the responsibility of the development engineer.

Other than purely engineering considerations enter into the planning and executing of the development program. Since it is the policy of management to provide, if possible, constant employment for all departments of the plant, the general state of business and the load in the production department must be considered. When work in the plant slackens, the effort must be placed on projects that can be completed quickly, and, conversely, when the plant is oper-

Dr. W. N. Tuttle, Engineer (*left*), and R. G. Alexander, assistant, look over the experimental model of a frequency-modulated signal generator. Dr. Tuttle is Chairman of the Engineering Planning Committee and has designed a number of General Radio instruments, including the TYPE 561-C Vacuum-Tube Bridge and the TYPE 726-A Vacuum-Tube Voltmeter.

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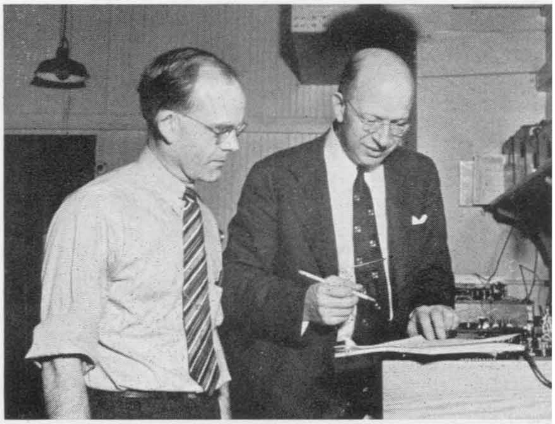
*C. T. Burke, "Engineering Administration in a Small Manufacturing Company," *Proceedings of the Institute of Radio Engineers*, January, 1940. Since this paper is a complete treatment of engineering administration in the General Radio Company, the subject is discussed only briefly here.

ating at capacity, more attention can be given to long-range projects.

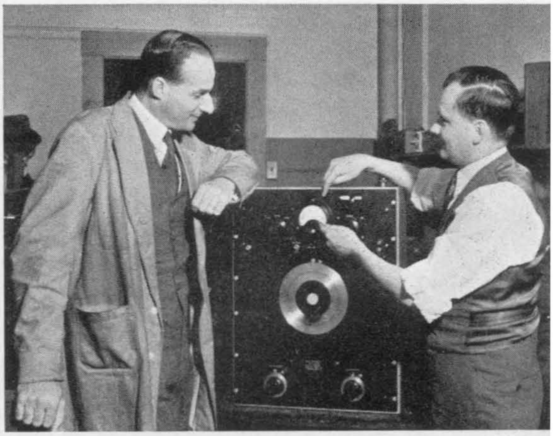
Another important consideration is the rapid change that is characteristic of the instrument business. New fields of measurement become important, and new tubes, circuits, and methods become available, necessitating the periodic redesign of old instruments as well as the development of new ones. About one-half the instruments sold in a given year have been developed or radically redesigned within two years.

Both engineering and sales effort are planned with a view to keeping the line of products diversified, so that no single product accounts for more than 10% of total sales.

Development engineers work in individual laboratories that are equipped with bench, desk, and storage space. A completely equipped model shop, staffed by eight mechanics, is adjacent to the engineering laboratories. An engineering assistant is usually available to the development engineer for much of the detailed experimental work. Only about 60% of an engineer's time is devoted to assigned projects. The balance is spent on correspondence with customers, the preparation of technical papers, attendance at technical meetings, and reviewing technical literature. The development engineer prepares operating instructions and serves in an advisory capacity on advertising and sales promotional publications. Favorable reports from users, as well as complaints, failures, and service difficulties are referred to him for comment.

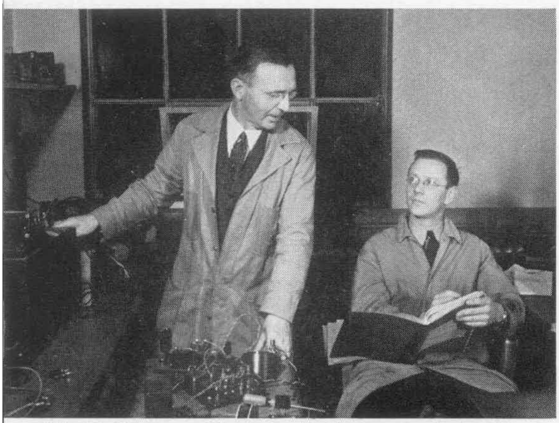


R. F. Field, Engineer, shown at the right, above, with D. H. Chute, assistant, works in the field of impedance measurement at commercial, audio, and radio frequencies. Mr. Field has designed many of the impedance bridges in our catalog.



Eduard Karplus, Engineer (*left*), and A. G. Bousquet . Engineer (*right*), have collaborated on the design of many instruments, including the Type 605-B Standard-Signal Generator. Mr. Karplus is also one of the originators of the Variac.

Shown here with the experimental model of a new standard-signal generator are H. H. Scott, Engineer (*center*), H. Chrystie (*left*), and E. E. Gross (*right*), assistants. Mr. Scott has developed a wide variety of instruments, including the Type 759-A Sound-Level Meter, the Type 760-A Noise Analyzer, the Type 608-A Oscillator, and Type 814-A Amplifier.



H. W. Lamson, Engineer (*left*), is one of the old timers on our staff, joining the Company in 1921, and Dr. S. A. Buckingham, Engineer (*right*), is one of the newest members. Mr. Lamson has developed many catalog and special instruments, including tuning fork oscillators and magnetostrictive devices. Dr. Buckingham specializes in the design of Variacs.

Engineering models of new instruments are built in the experimental shop, supervised by H. S. Wilkins, Engineer (*right*). Knut A. Johnson (*left*), foreman of this shop, has been with the Company since its founding in 1915.

SALES

Practically all products offered to the domestic market are sold directly from the factory, and each product has only one price regardless of the commercial classification of the ultimate user. It is, of course, a standard commercial practice for manufacturers to establish a fictitious list price, and from this list price to offer discounts which vary with the class of customer, one scale for jobbers, another for educational institutions, and so on through a very complex system. Since, however, the major part of General Radio products are sold to organizations entitled to these so-called trade discounts, and since no dealer or distributor organization is employed, there is no necessity for using this cumbersome discount system. Accordingly, all published and quoted prices are net.

Users of General Radio instruments include government, educational, and research laboratories, and manufacturers of such products as machinery, radio receivers, telephones, chemicals, paper, and textiles. Although this diversified market presents an unusual selling problem, instrument applications are almost invariably in engineering fields. Consequently, sales and advertising are handled by engineers, many of whom have had considerable experience in instrument development and who are familiar with manufacturing problems. A considerable part of the everyday work of the engineers engaged in sales is in the handling of correspondence, supplemented by periodical trips to principal markets and to the plants and laboratories of the customers.

Users are made acquainted with the

The link between engineering and production is the drafting department, a situation that makes it a target for both sides. Shown here looking at drawings of a new instrument are P. K. McElroy, Engineer-in-Charge, and A. C. Rohmann, Chief Draftsman.

product chiefly through catalogs and other advertising media, and through correspondence with the factory or the two factory branch offices. These offices, one in New York City and one in Los Angeles, are maintained for the purpose of getting accurate information to and from the customers efficiently, and keeping in touch with the developments and requirements of the many fields where General Radio products find their applications.

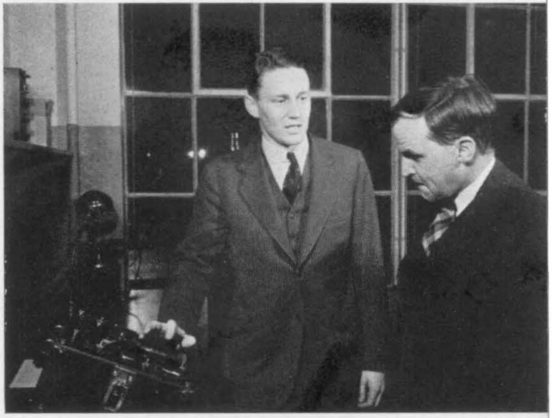
Direct-mail advertising effort is centered in the general catalog and in the *Experimenter*. These publications are circulated to about 23,000 individuals, nearly all of whom are associated with engineering or scientific work. Most of the articles in the *Experimenter* are of a technical nature describing instruments and their applications and are nearly all contributed by the engineering staff.

Bulletins describing specific instruments with specific applications are distributed periodically to selected groups from our mailing list. An attempt is made to send the literature only to individuals who will be interested in the equipment described, and not to send out bales of material for stuffing wastebaskets.

The direct advertising is concentrated in journals of technical societies and technical or trade magazines, about thirty all told. Research and experience have shown these to be the ones that most effectively reach our market. The aim of the advertising is to give complete, factual, useful information, and every advertisement carries the actual net price prominently displayed.

Foreign sales are an important part

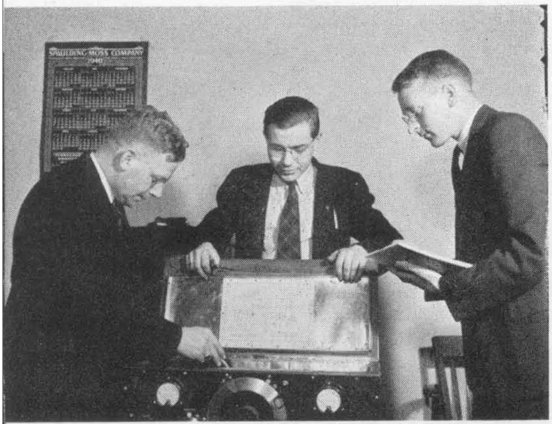
Selling General Radio instruments is the main activity of a group of application engineers, headed by A. E. Thiessen, Commercial Engineering Manager (*above*, *right*), who is also in charge of government contract work. At the left is M. A. Gilman, Engineer.



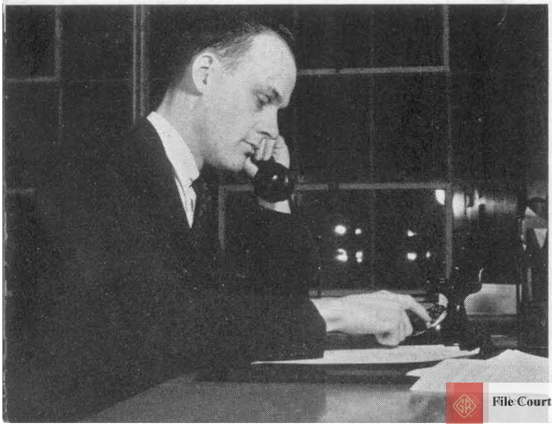
Even application engineers develop instruments. Here L. E. Packard, Engineer (*left*), whose usual field is sales, discusses a new power-factor bridge with C. T. Burke (*right*), Engineering Manager and Chairman of the Design Committee.

Advertising, the *Experimenter*, catalogs, instruction books, and similar material are prepared in the Engineering Department. (*Left*) J. M. Clayton, advertising, and (*right*) C. E. Worthen, publications.

When the Los Angeles Office was opened in 1937, M. T. Smith, Engineer, was placed in charge. Before going to Los Angeles, Mr. Smith was in charge of the New York Office.



Instruments returned for repair are sometimes twenty years old. Service Manager H. H. Dawes (*left*) looks over a returned instrument with S. R. Larson (*center*) and K. Adams (*right*).



of the total. About 30% of the plant output goes to foreign countries, and about 6000 of the 23,000 addresses on the *Experimenter* mailing list are foreign. Sales abroad are handled by resident sales representatives located in the principal countries of the world, who carry stocks of equipment and on whose staffs are trained engineers. Many of the General Radio publications are translated by these representatives into the language of their country before being sent to their own mailing lists.

The functions of the Service Department are closely allied to those of engineering and sales. This department is responsible for all repairs and replacements, and for correcting any operating difficulties that customers experience with General Radio instruments.

PRODUCTION

The production problem of the General Radio Company is basically one of manufacturing over 500 individual catalog items ranging in price and complexity from a 10-cent switch contact to a 2500-dollar frequency standard. There is no quantity production in the usual sense, although sales of small parts such as switch contacts amount to many thousand units per year. Instruments, in general, sell in numbers varying from 200 to 2000 during their useful life, which varies from two to five years. Production, therefore, is keyed to small lot manufacture. The smallest production lot of instruments is usually 10 units, the largest 200. The complete production cycle for the average instrument is three to four months, and the same instrument may repeat at six-month intervals.

Frederick Ireland, Engineer, is in charge of the New York Office. He was formerly associated with engineering and sales activities at the factory.

In accordance with the Company policy of attempting to give constant employment to all departments of the plant, schedules are set up so as to utilize constantly the facilities of all departments. To this end, orders are issued by the sales department to the plant for at least a six months' production period, and production operations are scheduled that far in advance.

After the engineering model of an instrument is completed, and passed by both the development engineer and the Design Committee, layouts are made in the drafting department and a sample production unit is built. Detailed manufacturing drawings, tools, and directions for the details of manufacturing are then drawn up. A test production run of 10 units follows, which serves to prove drawings, tools, schedules, etc. Routing and operations are thus determined, so that scheduling larger scale production is a matter of duplication of the test-run schedules.

Production operations in general call for skilled handwork rather than automatic machines, and consequently schedules are set up in man hours rather than machine hours. In contrast to mass-production methods, there are no moving assembly lines. For assembly, instruments are arranged on long benches designed to accommodate twenty-five of the largest units, and the scheduled set of operations is performed on each instrument in turn. The man moves, not the product.

Although the quantities handled are not large, every instrument of a given type must be exactly like all others of that type in appearance and perform-

The production department is supervised by E. H. Locke, Vice-President (*left*), and C. C. Carey, Superintendent (*right*). Mr. Locke has been associated with the Company since 1918 and has been Vice-President since 1920.

The scheduling and routing of production operations, and the subsequent follow-up in the plant, is the responsibility of R. J. Patterson (*left*) and W. T. Regan (*right*).

Purchasing is handled by W. H. Sherwood (*left*), Purchasing Agent, assisted by M. J. Folan (*center*) and A. W. Cleveland (*right*).

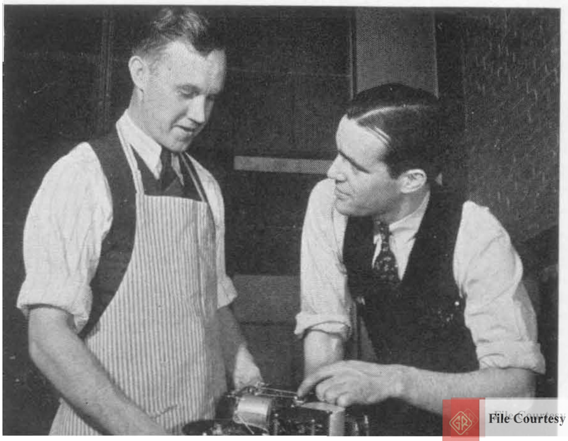
Production cost records tell not only what an existing instrument costs to build, but are also useful in estimating costs on new items. Shown here at the cost record system are (*left to right*) A. I. Corkum, cost accountant, and G. H. Sharp.

Finished parts stock is under the supervision of N. M. Mitchell (*right, above*) and S. H. Beck (*left*) shown seated at the perpetual inventory record of over 8000 items.

ance. This uniformity is achieved through complete interchangeability of component parts with a concomitant emphasis on narrow production tolerances. While many manufacturing operations are functionally similar to those of radio receiver manufacture, for example, they are more exact and require a far higher degree of skill on the part of the operators.

Assembly, for instance, is not a matter of repeating routine operations, because it includes many mechanical and electrical adjustments to produce smooth operation of moving parts and electrical contacts, and because appearance and permanence are important factors in the result. Consequently, many of the details of the assembly operation are left to the skill and ingenuity of the man performing the work.

Mechanical tolerances on the moving parts in rheostats, condensers, and switches are closer than is usually considered necessary for these products. Stainless steel shafts and their bearings for condensers and rheostats, for instance, are machined to ±.0005 inch; steel-core and bakelite shafts are held to ±.001 inch. This insistence on close tolerances makes it possible to stock completely interchangeable parts, so that a defective part can be replaced immediately by a good one, and it also assures uniform fit, smoothness of operation, and predictable wear on all moving parts. These factors are important when rheostats are to be used (as many of them are) in automatic indicators and recorders for long periods without replacement, when condensers must be capable of holding precise calibrations, and when slight



Production test runs of new instruments are made to prove tools and schedules. The supervision of the mechanical details of these runs is the responsibility of C. E. Rice (*right*) and H. T. Anderson (*left*).

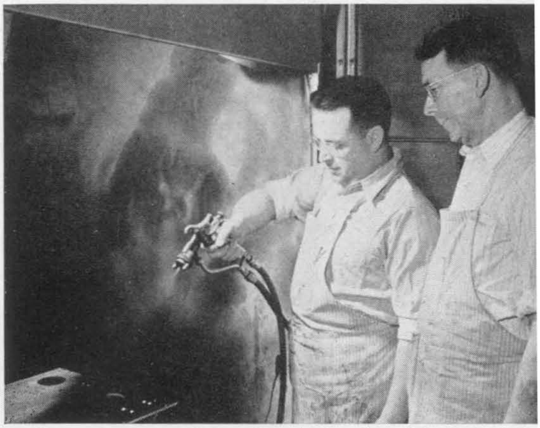
misadjustments in switches will lead to extreme wear and short life.

Similarly, both the casting and finishing of cast metal parts such as condenser frames are carried out with a greater degree of precision than that ordinarily required and receive the individual attention normally given to samples.

While it might be inferred that this emphasis on precision would lead to a relatively slow, master-craftsman type of production, experience has shown that the required precision can be obtained with a high degree of production efficiency, and that production can be operated on a premium system of pay so that efficient work is rewarded in proportion to individual output.

Close tolerances imply rigid inspection. While mechanical inspection is handled by relatively few men, parts and materials are carefully checked for both appearance and conformity to specifications. Sampling is used wherever manufacturing experience indicates its validity, but controls are set up so that defective lots of sampled parts can be detected and corrected with a minimum of waste. An excellent example of the degree of inspection used is afforded by the operations on an aluminum panel, which seems as trouble-free a part as might be encountered. Inspection occurs first after sawing, drilling, and finishing are completed, again after lacquering, a third time after engraving, and a fourth after complete assembly.

Even moderately precise operations on a production basis involve the use of a multiplicity of punches, dies, forming fixtures, jigs, and other tools. These are



Lacquer to produce the distinctive GR crackle finish is being sprayed on a panel by H. J. Goodall, while T. Palmer, foreman of the plating and finishing department, looks on.

The sheet copper linings of many General Radio cabinets are fitted by H. H. Chute (*left*), oldest employee of the instrument assembly department, under the direction of W. H. Fish (*right*), foreman of the department.

Condenser plates, laminations, and other sheet metal parts are made on punch presses. (*At the right*) J. D. Murray, foreman of the machine shop, examines a stamping produced at the punch press by C. Bertini.

all made in the General Radio plant by skilled tool and die makers. In the small plant the supervision and the work of tool making are more closely connected to the production process than in a large plant, so that the desired result is obtained more quickly and easily when the tools are made inside and can be hand-tailored to the job in the plant itself.

In the standardizing laboratory, twenty technicians, many of them with engineering degrees, test and calibrate all General Radio instruments. Each instrument is required to meet a rigid set of performance specifications. The accuracy specification, for test purposes, is set substantially closer than the published catalog figure. In order to simulate operating conditions in countries all over the world, each new design is subjected to tests under varying conditions of line voltage and frequency, ambient temperature, and humidity. This work is not performed in the engineering department, but is carried out as a production operation. Performance requirements are specified by the development engineer, but details of testing specifications and procedure are worked out in the production department.

Standardized procedure and equipment permit these performance tests to be carried out efficiently on production quantities of instruments. Laboratory benches, like assembly benches, are arranged to handle a substantial number at one time. Like development engineers, laboratory men tend to specialize. Some work on audio-frequency instruments, and some on radio-frequency, while others are specialists in "trouble shooting."

Measuring a condenser frame casting preparatory to making a drilling jig. (*Left to right*) E. S. Page (who is also president of the GR Credit Union) and G. G. Oberbeck, foreman of the tool and screw machine department.

Mechanical inspection is an important operation when close tolerances are imposed. (*Left to right*) W. A. Lewis, foreman of the inspection department, and J. L. Martin.

Several thousand panels a year are engraved in this department. Operating the engraving machine is W. J. Marvin (*left*) with J. F. N. Park, foreman (*right*).

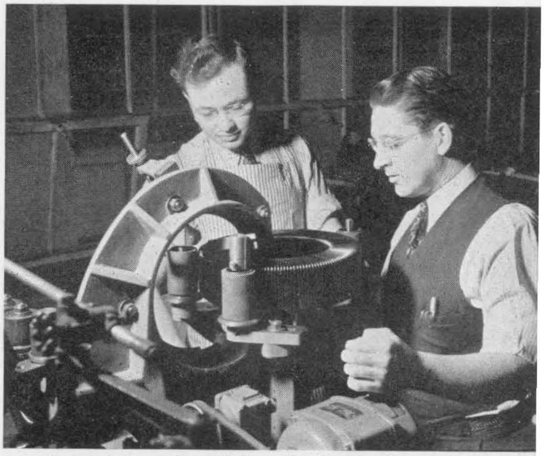
Standards of resistance, capacitance, and inductance are maintained as a basis for accurate instrument calibrations. Intercomparisons between units in each class are made periodically and absolute measurements are made yearly by the U. S. Bureau of Standards. The accuracy with which these standards are known is, of course, considerably in excess of commercial requirements. At the present time, our resistance standards are known to .005%, capacitance to .02%, and inductance to .04%. Frequency calibrations are made in terms of the Engineering Department's primary standard of frequency, which has an accuracy of .00001%.

In purchasing, the primary emphasis is placed on suitable quality rather than on price, and much purchasing effort is directed toward finding sources of supply capable of meeting specifications that have been laid down by the Engineering Department. Once a satisfactory source of material is located, substantial quantities of staple items and raw material are carried in stock. It is not uncommon to set ordering points at a level that will insure two years' normal supply. In this way production needs can be met regardless of temporary delivery situations.

WORKING CONDITIONS

One of management's primary functions is the maintenance of constant employment. Some measure of its success may be indicated by the record of the last ten years, in which there have been no lay-offs or discharges because of lack of work. Only twice in this decade has it been necessary, because of external conditions, to operate on shorter-than-

Parts assembly — L. L. Scott, a specialist in condenser assembly for 16 years, is shown working on a group of TYPE 755 Condensers, under the direction of H. J. Comrie, foreman.



One of the jobs of the winding and transformer assembly department is to produce Variacs. C. W. Whitehead (*left*) operates the machine winding a TYPE 50 Variac. At the right is R. W. Searle, foreman.

A department for special and small-lot production handles repairs, modification of standard instruments, and one-of-a-kind items. (*Left to right*) D. J. Martin, supervisor, J. E. Lundgren, and C. A. Batchelder.

normal hours of work, and during these periods the available work has been shared, as nearly equally as possible, by all production departments. This degree of stability has been achieved largely by carrying a flexible finished parts stock and a finished instruments stock as a buffer between sales and production. The finished stock is built up during periods when sales are low and serves as a reservoir to draw upon in the sudden buying periods that usually follow.

During periods of normal operation, all employees receive a semi-annual bonus, in which the share of each individual depends upon his contribution to the profitable operation of the Company. This contribution is determined by as equitable and impartial a system as the Company has been able to devise.

The standardizing laboratory is under the direction of W. G. Webster, Engineer (*left*), and M. C. Hobart, foreman (*right*). Great responsibility rests with this department, which performs the final test and inspection on all instruments.

Since 1919 the Company has operated on a five-day week, and has anticipated by many years other working conditions, many of which are now being required by law. All manufacturing employees who have been with the Company one year or more receive two weeks' vacation with pay and an additional week's pay on the 15th of each December. Non-manufacturing employees receive three weeks' vacation with pay.

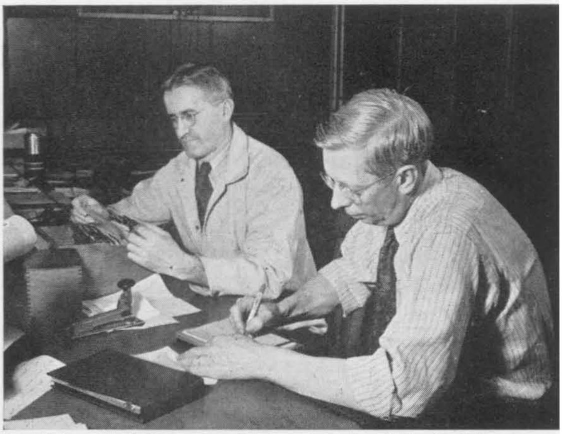
A group insurance plan provides $1000 of life insurance for each new employee after a 90-day trial period. Each year thereafter, $100 is added to the policy until a maximum of $2000 is reached. The cost of this insurance is borne entirely by the Company.

The employees operate a Mutual Benefit Association, which pays sickness and death benefits, and sponsors a summer picnic, parties, and other group activities. Employees also operate their own Credit Union to encourage thrift and to lend money for provident purposes. In the ten years that it has been in operation, the Credit Union has accumulated assets of more than $40,000.

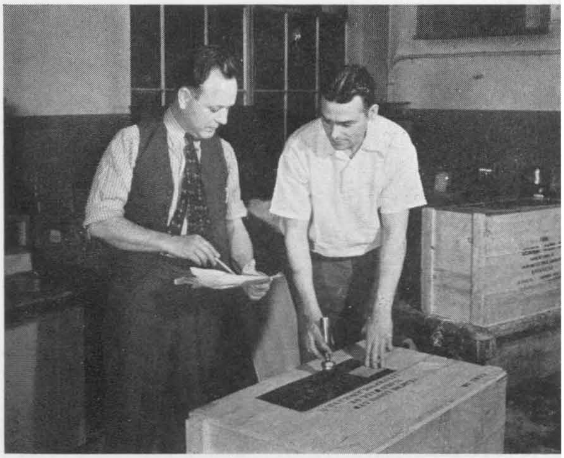
Among the other organized employee activities are a baseball team, a bowling team, golf and tennis tournaments, and a dramatic club. While the General Radio Company encourages all such activities and contributes to their support, it does not direct or control them.

Building maintenance is supervised by Paul Hanson, Engineer (*center*), shown with R. Cameron (*left*) and J. D. Polley (*right*), electricians.

In 1934, the Genradco Trust was formed, largely through the generosity of the Chairman of the Board of Directors, but assisted by a contribution from the Company itself. The funds of the Trust are entirely separate from those of the Company, and the income is used for the improvement, welfare, and benefit of employees of the General Radio Company and their families and for the aid of some scientific enterprises outside the Company, but with allied interests. The Genradco Trust assists in meeting unusual expenses beyond the means of employees, whether caused by sickness or by other unforeseen circumstances. It provides the services of a physician who is available several hours each week in the plant for consultation. At present a plan is being tried that extends, on a free-clinic basis, ordinary medical treatment to employees' families.

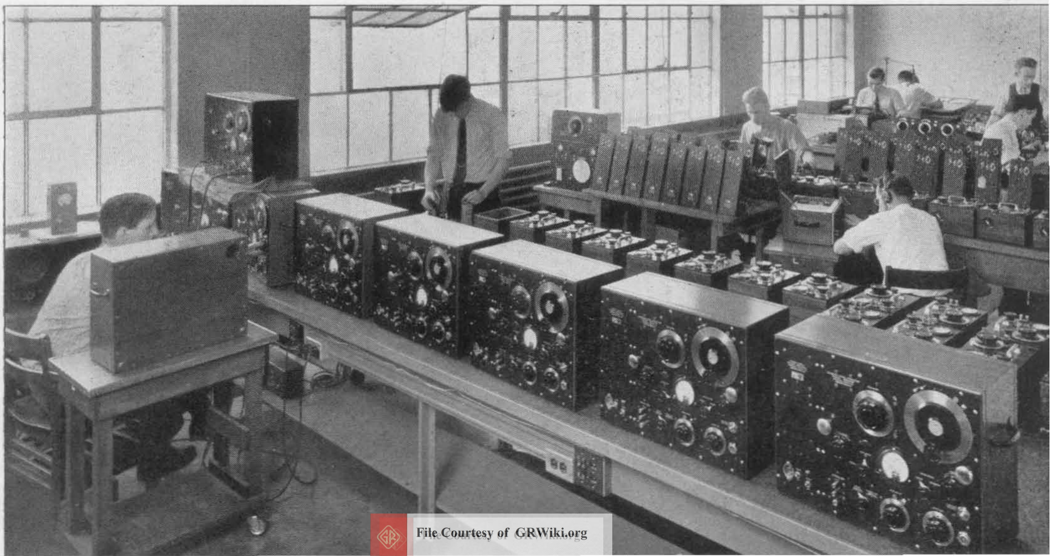


The receiving room is in charge of F. A. Howland (*right*); raw stock is handled by A. Stierli (*left*).



Everything from a switch contact to a frequency standard is carefully packed before shipment. Shipping room activities are supervised by F. W. Beck, foreman (*left*), and C. H. Riemer.

This view of the instrument calibration laboratory shows how instruments are handled in groups on long benches. In the foreground are TYPE 605 Standard-Signal Generators and just behind them a group of TYPE 419 Wavemeters.



Dr. M. T. Easton is shown here making an ophthalmic examination.

Recognizing that good eyesight is necessary for good craftsmanship, the Trust also provides the services of an ophthalmologist, who examines and treats eye difficulties, and glasses are supplied without charge to employees who need them. Space for these health activities is provided in the plant, and a registered nurse is in attendance during working hours.

It has never been the desire of the General Radio Company to become a large organization. It has always emphasized quality rather than quantity, and, accordingly, has kept its size at a point where every employee is personally known to those responsible for the management of the Company, and where every employee may feel free to discuss with the management questions pertaining to his work and even personal matters where help and advice are needed.

By these and other policies, the management endeavors to make the General Radio Company a desirable place in which to work, realizing that the continued successful operation of the Company depends upon attracting and keeping skilled employees. The measure of the success of these policies is that the average length of service of all employees is nearly eleven years. This is particularly significant because in the past dozen years the number of employees has just doubled and because the length of service of girls in the office is considerably less than that of factory employees. Only male labor is employed in the factory, and the Company has been fortunate in obtaining men of unusually desirable personal qualities.

Dr. Roy E. Mabrey (*center*) is in charge of medical work. Miss F. J. Ellinwood, R. N., is in attendance at the plant every day. The patient is C. F. Uhlendorf, Company photographer.

GENERAL RADIO COMPANY

30 STATE STREET - CAMBRIDGE A, MASSACHUSETTS

BRANCH ENGINEERING OFFICES

90 WEST STREET, NEW YORK CITY

1000 NORTH SEWARD STREET, LOS ANGELES, CALIFORNIA

PRINTED IN U.S.A.

THE General Radio EXPERIMENTER

VOLUME XV NO. 2 JULY, 1940

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also

IN THIS ISSUE

A PORTABLE MEGOHMMETER

● IN THE FOUR YEARS since the Type 487-A Megohmmeter was introduced, its use has spread to many different fields of application. This instrument, giving readings up to 50,000 megohms, was the first to extend the operating range of the ordinary direct-indicating ohmmeter to really high resistances. Since this instrument was introduced, many requests have been received for a similar meter not requiring a-c power for its operation and consequently better adapted to field use. The Type 729-A Megohmmeter is a new battery-operated design particularly intended for applications where portability is required.

An extremely compact arrangement has been worked out so that, even with cover and batteries, the volume and weight are both less than for the a-c operated Type 487-A instrument. Design improvements, including the sealing in vacuum of the highest-value resistance standard, insure that accurate indications will be obtained regardless

Figure 1. View of the Type 729-A Megohmmeter showing the compact portable construction. The cover, shown folded back, is removable.

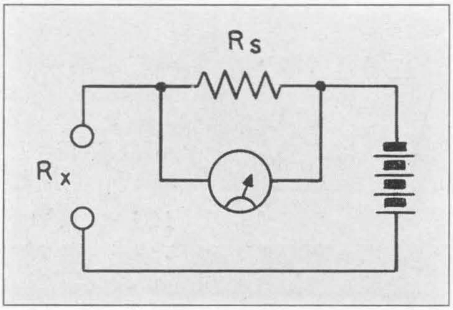


FIGURE 2. Simplified schematic of modified ohmmeter circuit, using a vacuum-tube voltmeter as the indicating element.

of adverse humidity conditions, which are particularly likely to be encountered in field use of the instrument.

The circuit employed both in the TYPE 729-A Megohmmeter and in the earlier TYPE 487-A instrument is the same as that of the ordinary ohmmeter used for testing relatively low-resistance circuits, except that a vacuum-tube voltmeter, having extremely high input resistance, replaces the simple d-c milliammeter of the latter.

In the simplified schematic shown in Figure 1, the battery voltage divides between the unknown resistance R_x and the standard resistance R_s depending on their relative values, and the reading of the voltmeter across the standard can be calibrated directly in the unknown resistance. Accuracy of the reading depends on the total circuit resistance, exclusive of the unknown, being constant in value. The contributions both of the voltage source and of the voltmeter to the total circuit resistance must either be negligible or sufficiently constant so that they can be included as part of the standard resistance determining the calibration. Variations in battery resistance affect the accuracy of the low-resistance ranges, and the grid-circuit conductance of the vacuum-tube voltmeter, on the other hand, affects only the very highest resistance measurements.

In the new TYPE 729-A Megohmmeter, the low grid-circuit conductance of the TYPE 487-A instrument has been retained, and the high-resistance limit is the same as for the latter, but with increased stability resulting from the new sealed-in-glass, high-resistance standard. An important feature of the new instrument is a tenfold extension of the range in the low-resistance direction. Five overlapping ranges are provided, so that at least a full division of deflection is obtained for resistances of all values between 2000 ohms and 50,000 megohms. The low-resistance ranges are a great convenience in testing for faults, as an indication of the nature of the trouble is afforded by the actual resistance reading in the defective part of the circuit. The improved performance results from a circuit modification in which the battery is placed directly in the measuring loop without any controlling resistances. The low-resistance limit at which readings can be made satisfactorily is thus determined by the internal resistance of the battery itself, which must not become comparable to the value of the standard resistance throughout normal battery life. Shift of the meter zero beyond a specified limit in switching to the low-resistance range warns the user that batteries must be replaced to avoid error from this cause.

The very wide range of resistances which can be measured makes the TYPE

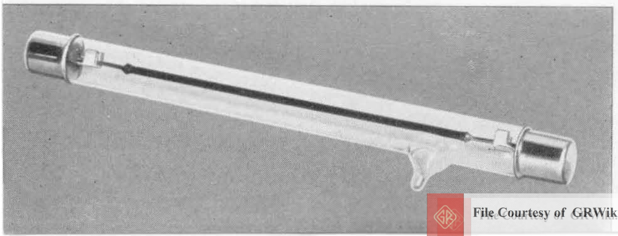


FIGURE 3. The new sealed-in-glass 1000-megohm standard resistance. In actual use the unit is coated to prevent surface leakage.

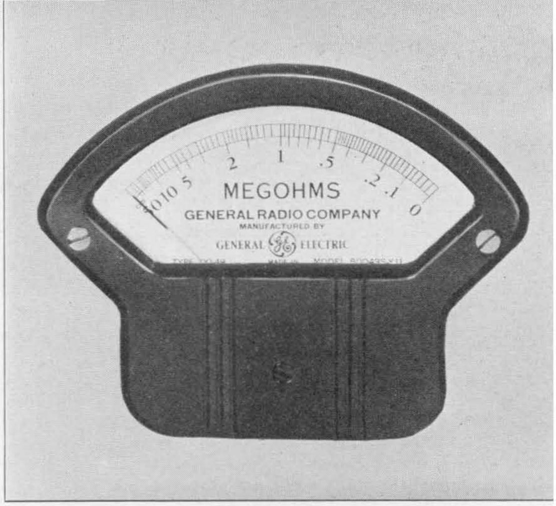


FIGURE 4. View of the meter scale. Except at the low end of the lowest range and at the high end of the highest range, only the center decade of the scale needs to be used.

729-A Megohmmeter particularly suitable for determinations of moisture content of various materials by the electrical conductivity method. In testing lumber for moisture content, for example, using the standard pin electrodes recommended by the Forest Products Laboratory of the U. S. Department of Agriculture, a range of resistances from 460,000 ohms to 22,400 megohms must be covered to determine moisture percentages between 7 per cent and 25 per cent in Douglas fir. A similar relationship appears to hold generally between the electrical resistance and the moisture content of other semiconducting materials such as paper, moist powdered chemicals, shoe leather, etc. With such materials the range of moisture content normally encountered corresponds to a relatively enormous variation in the electrical resistance. In the TYPE 729-A Megohmmeter, however, the resistance range which is covered, over twenty million to one, is more than sufficient for such applications.

As with the TYPE 487-A Megohmmeter, a limitation of the circuit employed is that the standard resistance is of the same order of magnitude as the unknown being measured. This is a handicap when large-value paper condensers having low leakage are tested, as the time constant of the circuit results in equilibrium being reached very slowly. For example, a condenser of 1 μf capacitance, having a leakage resistance of 1000 megohms, could be shown in a few seconds to have a resistance greater than 500 megohms, but perhaps a minute would be required to obtain the resistance within 10 per cent.

Errors in the resistance standards and errors from grid current in the vacuum-tube voltmeter, which have been referred to, both affect measurements in the high-resistance ranges of the instrument. Except for errors in the mechanical system and calibration of the meter itself, amounting to a maximum of about one per cent at center-scale reading, these are the only appreciable sources of error. The vacuum-tube voltmeter is made linear in its calibration, independently of the tube characteristics, by cathode-circuit degeneration, which has proved so advantageous in the TYPE 726-A Vacuum-Tube Voltmeter as well as in the TYPE 487-A Megohmmeter. The actual deflection of the voltmeter circuit, also, is stabilized by this connection, but this is unimportant as the sensitivity is adjusted when the zero is set each time the instrument is used. Actually, as the battery voltage drops during normal life the sensitivity of the voltmeter is increased, in the process of setting the zero, so that the correct resistance readings are obtained throughout the life of the batteries. Inability to set the zero indicates that the batteries need to be replaced.

—W. N. TUTTLE

SPECIFICATIONS

Range: 2000 ohms to 50,000 megohms in five overlapping ranges.

Scale: The standard direct-reading ohmmeter calibration is used: center scale values are .01, .1, 1, 10, 100, and 1000 megohms. Length of scale, 3¼"; central decade, 1⅝".

Accuracy: Within 2 per cent of the indicated value over the 30,000-ohm to 300,000-ohm range and within 5 per cent over the 300,000-ohm to 3000-megohm range when using the central decade for each multiplier. Outside the central decade, the accuracy is decreased because of the compressed scale.

Voltage on Unknown: The voltage applied on the unknown does not exceed 22½ volts and varies with the meter indication.

Tube: The tube, a type 1E5-GP, is supplied.

Batteries: The batteries required are two Burgess W30BP or equivalent and one Burgess 2F2H or equivalent. A compartment is provided in the case of the instrument for holding all batteries. A set of batteries is supplied with the instrument.

Mounting: The instrument is supplied in a walnut case with cover and is mounted on an engraved black crackle-finish aluminum panel.

Dimensions: With cover closed: (length) 11 x (width) 6⅝ x (height) 5⅞ inches, over-all.

Net Weight: 8¾ pounds, including batteries.

Type	*Description*	*Code Word*	*Price*
729-A	Megohmmeter...........	PIOUS	$85.00

THE STROBOSCOPE IN STRUCTURAL RESEARCH

● **ENGINEERS** have grown gray over problems difficult of exact solution by mathematics. In structural mechanics, although the laws governing the behavior of structural members are completely known, the exact operating conditions seldom are, and, consequently, the solutions of structural problems are necessarily empirical.

Professor Philip Bucky of the School of Mines, Columbia University, has developed in his laboratory a method of solving some of these problems in mining, hydraulics, aerodynamics, and civil engineering by means of small scalar models.

This particular application of the theory of models has been made possible by stroboscopic methods of observation and measurement, and is one of

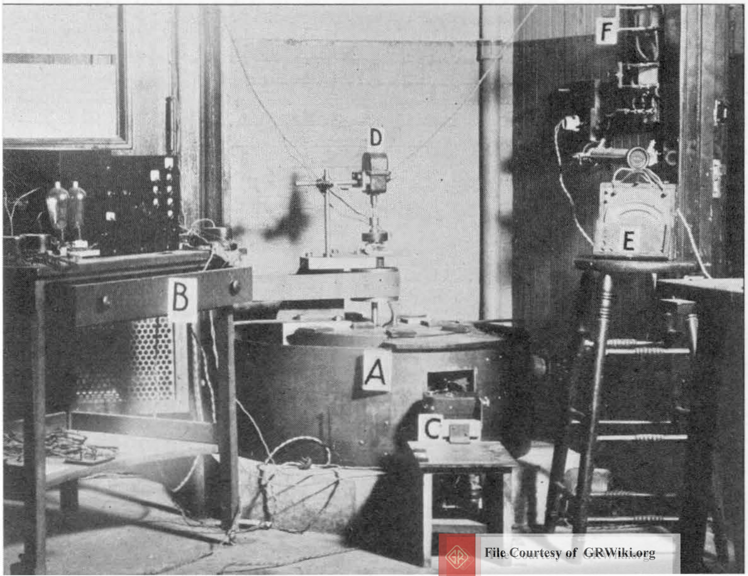


FIGURE 1. Photograph of the apparatus used for the centrifugal testing of models. The stroboscopic light source and power supply (B) was replaced, for later work with a General Radio TYPE 548-B Edgerton Stroboscope.

the most interesting uses of the electronic stroboscope which has come to our attention.

Professor Bucky has formulated the principle of similitude applying to the relation between a model and its prototype. He reduces an original structure of unwieldy proportions to a scalar model of more convenient size, and he artificially increases the pull of gravity on each particle in the same proportion as the linear dimensions have been decreased. This increased pull of gravity is simulated by spinning the model in a centrifuge and so substituting the centrifugal field for the gravitational field. When spun at such a speed that the centrifugal force is increased in the same ratio as the linear dimensions of the prototype have been decreased, the model behaves exactly like its prototype. Unit stresses at similar points in the model and prototype are the same, and the displacement or deflection of any point in the model represents to scale the displacement of a corresponding point in the prototype.

An early experiment was the testing of a model beam ten inches in span, one inch in depth, and two inches in width, which corresponded to an original beam one hundred times its size, or roughly, eighty-three feet in span, eight feet in depth, and sixteen feet in width. Spun in the centrifuge at a rate to obtain one hundred times the pull of gravity, observed with the stroboscope, and photographed by the camera, the model showed a deflection of one one-hundredth of an inch. This meant that the original two hundred and sixty-five ton beam, then, would sag one inch under its own weight.

The apparatus for centrifugal testing of models is illustrated in Figure 1. In the case (A) is mounted a rotating box. Models are placed in that box and observed through an observation port (C) where a mirror or camera is placed. Speed is measured by a generator (D) geared to the shaft, and can be read at (E), a voltmeter. The stroboscope on the table (B) furnishes a single light pulse each time the model comes to a selected position in front of the camera. The duration of the light pulse is so short (less than six millionths of a second) that the model does not have time to move and so to blur the picture. In stroboscopic light, accurate photographic records may be taken while the model rotates at any desired speed to give the required force upon the model.

One of the present successful applications of this method is in the field of mining, where the engineer can determine with these models what length of face wall can be worked and how far

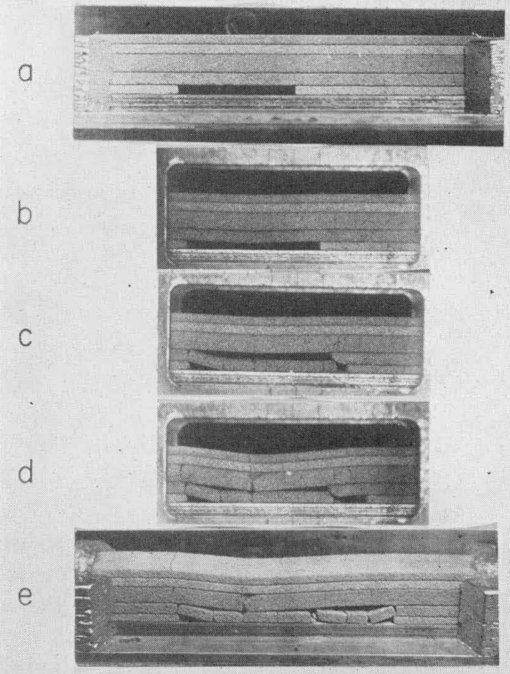


FIGURE 2. Photograph of successive stages of failure in a model face wall of a mine. The scale of the model is 1:480.

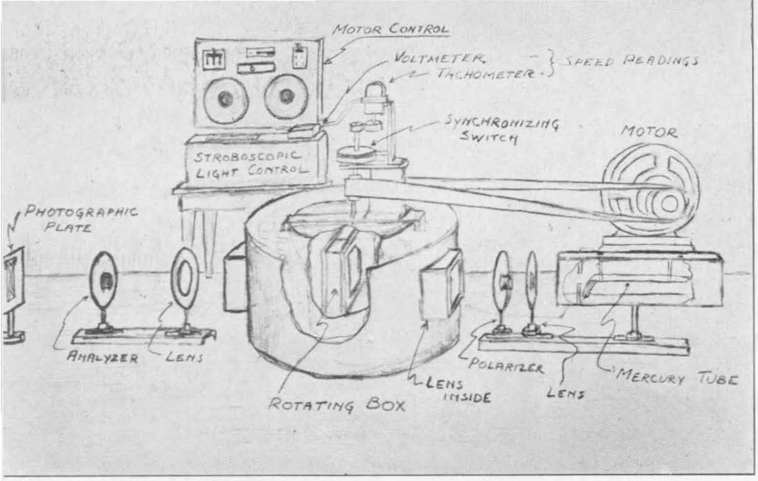


FIGURE 3. Sketch showing the arrangement of the combined centrifugal and photo-elastic apparatus.

the face wall may retreat before the structure caves in.

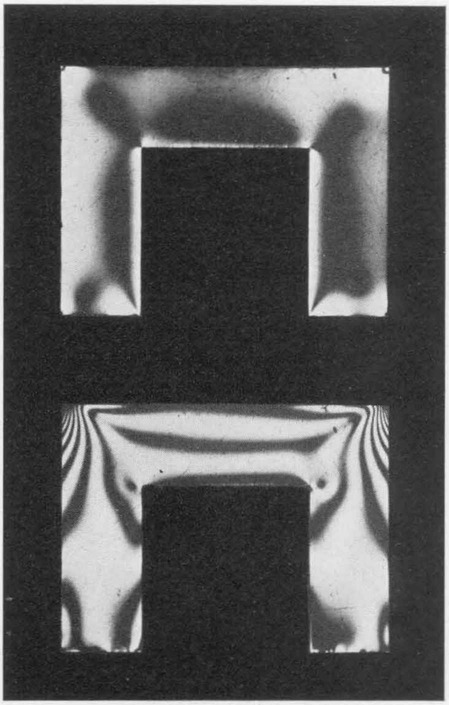
Figure 2 is a series of photographs illustrating experiments with a model face wall of a mine. The various strata of overweight and underweight are built to a scale of 1:480. In a beginning step (a) the model is shown outside of the centrifuge. While the model rotates in the centrifuge at a rate to produce a force 480 times that of gravity (b, c, and d), the roof is visibly caving. In (e), when the model has been removed from the centrifuge, the failure of the structure is plain. It is an interesting fact that the time scale, both in the model and in the field, is exactly the same.

The difficulty of determining the actual stress at any point in a structure has motivated a new development in the method. Professor Bucky is now using the photo-elastic technique to study the behavior of isotropic, transparent models in the centrifuge.

It has long been known that if a piece of transparent bakelite is stressed under static loading, and if that bakelite is then viewed by polarized light, the strain becomes visible as bands of colored light — yellow, green, and red, depending upon the intensity of the stress. In the photo-elastic set-up, a scalar model of transparent bakelite is placed in a centrifuge and the pattern and progress of its deflection under centrifugal force are photographed by means of the stroboscope.

Figure 3 shows the photo-elastic apparatus. Light from a tube source

FIGURE 4. Photographs of a bakelite model by polarized light. The upper photograph shows the model unstressed, while the lower shows the bands produced by static loading.



passes through a condensing lens and reaches the polarizer where the light is plane polarized. The light then passes through the inside lens and the stressed model in the centrifuge. The image of the model is focused by the lens through the analyzer and on to the screen.

Figure 4 (top) is a photograph of an unstressed model of bakelite. Below, static loading is shown clearly in the series of strain lines, or fringes, which can be counted and analyzed for engineering purposes.

The use of the centrifuge to simulate operating conditions, the stroboscope for observing displacements while the model is rotated at high speed, and the photo-elastic technique for analyzing the results have made possible accurate predictions of the performance of mechanical structures. The future of this method of analysis in applied mechanics seems assured.

The work being carried on is a research project of The Engineering Foundation and of Columbia University.

—F. Ireland

USING THE VARIAC WITH AUXILIARY TRANSFORMERS

● **AMONG THE MANY AND VARIED LABORATORY USES** of the Variac there are the occasional ones where currents or voltages exceeding the Variac rating must be obtained. When high currents are to be obtained at low voltages, or high voltages with low currents, an auxiliary transformer can be used, as indicated in Figure 1. An arrangement similar to that of Figure 1(a) is available commercially as the Type 90-B Variac.*

The 230-volt models of the Variac have a center tap, 6,† which is not furnished on the 115-volt model. In Figure 2 a 115-volt line is connected to the center tap and terminal 1, and the output is taken from terminal 1 and the brush. The Variac then acts as a 2–1 step-up transformer whose output is continuously variable from 0-230 volts. The current which can safely be drawn at the highest voltage is ½ rated current in this case.

When it is necessary to draw full rated current from a 230-volt Variac and when only a 115-volt line is available, the connections of Figure 3(a) may be used. Here an auxiliary step-up autotransformer is used so that the actual input to the Variac is equal to its rated voltage. In this case maximum current

Fig. 1a

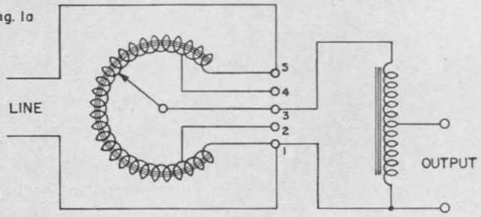


Fig. 1b

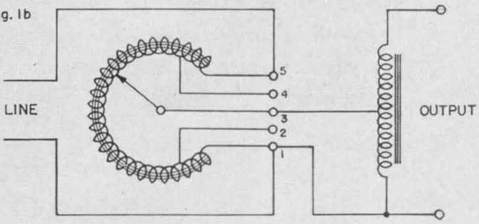
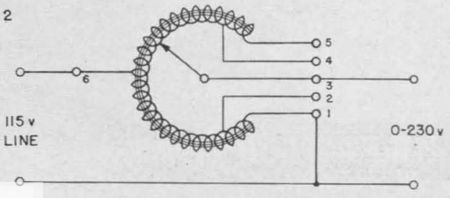


Fig. 2



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*"A Variac with Low-Voltage Output," General Radio *Experimenter*, Volume XIV, No. 2, July, 1939.

†Terminal numbers in this article are those used on Type 50 Variac. Other types are numbered differently.

Fig. 3a

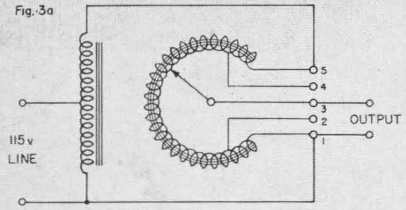


Fig. 4a

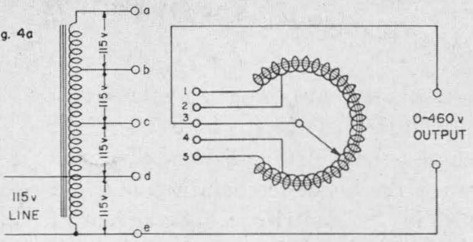


Fig. 3b

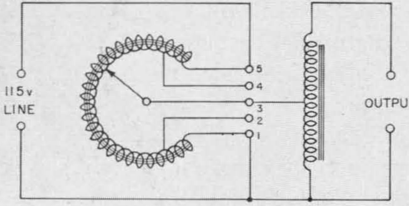
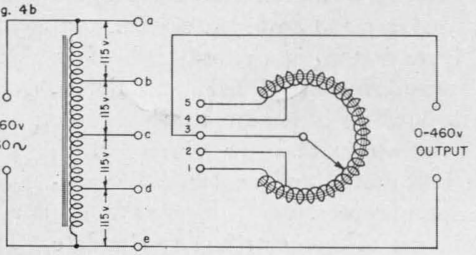


Fig. 4b



may be drawn at maximum output voltage.

Figure 3(b) is an obvious variation of the method of Figure 3(a). The auxiliary step-up transformer is used on the output instead of the input side of the Variac. This system is particularly useful when the output voltage is too high to be handled directly by a standard Variac. In this case, the output power available for a resistive load will be the volt-ampere rating of the Variac multiplied by the efficiency of the auxiliary transformer.

With the circuits shown in Figure 4, it is possible to draw rated current from the Variac at voltages considerably above the rated output voltage. An auxiliary step-up transformer is used to give the maximum voltage desired. The secondary is tapped to give voltages, between adjacent taps, not greater than the rated voltage of the Variac.

By means of suitable switching of the Variac from tap to tap, the output voltage can be varied from zero to maximum without interruption of the circuit. With terminal 1 connected to tap *e* and terminal 5 connected to tap *d*, rotation of the brush of the Variac increases the output voltage from 0 to 115 volts. Terminal 1 is then switched to tap *c* and the brush rotated in the opposite direction, raising the output from 115 to 230 volts. Terminal 5 is next switched to tap *b* and the brush rotated to vary the output from 230 to 345 volts. Finally, switching terminal 1 to tap *a* permits the output to be raised from 345 to 460 volts. When the output voltage is high, it is advisable to insulate the Variac from ground in order to eliminate the danger of voltage breakdown.

The auxiliary step-up and step-down transformers are shown in the diagrams as autotransformers. Inductively coupled transformers can, of course, also be used.

— S. A. Buckingham

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THE General Radio EXPERIMENTER

VOLUME XV NO. 3 AUGUST, 1940

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also

IN THIS ISSUE

DIRECT-READING WAVEMETER FOR ULTRA-HIGH FREQUENCIES

● **THE TYPE 758-A WAVEMETER** is a convenient instrument for measuring high frequencies in the laboratory, where quite frequently ease of operation is found to be more important than high accuracy. The direct-reading dial covers in a single rotation frequencies from 55 to 400 megacycles. This wide range of frequencies, which is covered without switching or changing coils, is particularly welcome in the high-frequency field where an oscillator may produce frequencies quite different from those for which the circuit was designed.

The Type 758-A Wavemeter is a tuned circuit instrument comprising a variable condenser and a variable inductance. The variable condenser is of the conventional straight-line frequency type. The variable inductance is obtained by sliding a silver spring, which is attached to the rotor of the condenser, along a silver strip connected to the stator. Because inductance and capacitance are varied simultaneously, a wider range of frequency is covered in a single band than when only one element is made variable.

Figure 1. Measuring the frequency of an ultra-high-frequency oscillator with the Type 758-A Wavemeter.

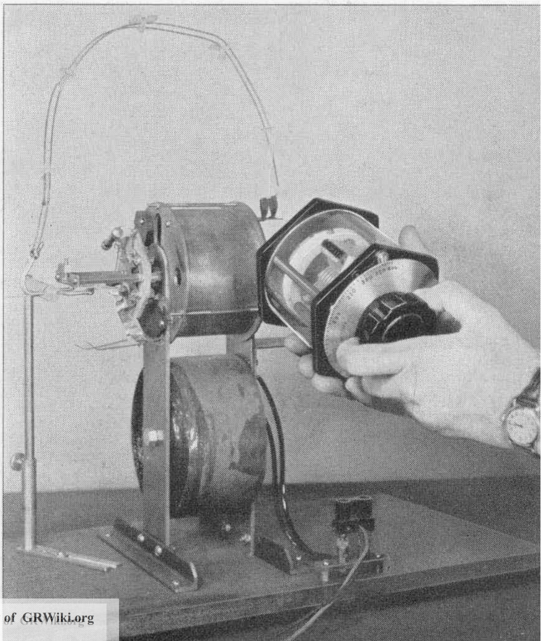


FIGURE 2. Direct-reading frequency scale of the TYPE 758-A Wavemeter.

Loosely coupled to the measuring circuit is an aperiodic indicator circuit. A flashlight lamp that will light readily with a 2-watt oscillator is used as an indicator of resonance. If the oscillator power is not sufficient to light the lamp, the wavemeter can be made to react on the oscillator and will change plate or grid current of the tube sufficiently to determine resonance.

The complete unit is mounted in a transparent but almost unbreakable case so that the indicating lamp can be observed from all directions. Since the location of condenser and coil of the wavemeter can be seen from the outside, effective coupling to an oscillator is obtained easily. The two bakelite end plates of the completed instrument are cut hexagonally so that the wavemeter can be rested in any one of six different positions.

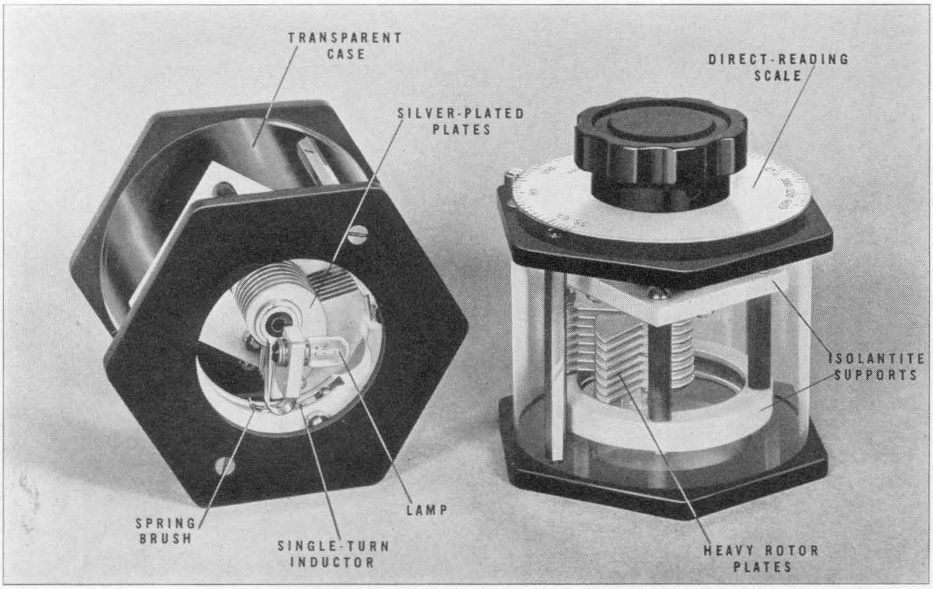
— E. KARPLUS

SPECIFICATIONS

Range: 55 to 400 Mc, direct reading.
Accuracy: 2%.
Resonance Indicator: Incandescent lamp.
Dimensions: 4¼ x 4⅞ x 4⅝ inches, over-all.
Net Weight: 1 pound, 10 ounces.

Type	*Description*	*Code Word*	*Price*
758-A	Wavemeter	WITTY	$28.00

FIGURE 3. Two views of the TYPE 758-A Wavemeter with the various parts identified.



LINE VOLTAGE CORRECTION WITH THE VARIAC

● **VOLTAGE CORRECTION** on under-voltage or over-voltage lines is a common use for Variacs. Figure 1 (a) shows the simplest connection for this purpose.

With this circuit a line whose voltage varies by ±13 per cent can be kept at its mean rated value. The rated currents, only, can be drawn from the Variac when the line voltage is at its minimum. When the line voltage is high so that the Variac is used as a step-down transformer, the flux density is higher than normal, which results in somewhat greater heating.

Figure 1 (b) illustrates a similar method, differing only in that line and output connections are reversed. The method has the advantage that the Variac always operates at its rated flux density. In using this method it is advisable always to return the brush to the neutral position (i.e., to a position over tap 4) before starting operations. If the brush is set for maximum step up, and the line voltage happens to be at its maximum, excessive no-load currents may be drawn by the Variac and it may become overheated. The rated current of the Variac may be drawn at any line voltage within the range of regulation.

Figure 2 (a) shows a circuit* using a Variac bridged across a section of a tapped autotransformer. This circuit is especially useful with line voltages higher than the rated voltage of the Variac and in cases in which it is desirable to use the full rotation of the Variac for fineness of control. Line currents up to the rated current of the Variac may be used. Figure 2 (b) is the inverse of Figure 2 (a) and has the same uses. Load currents up to the rated current of the Variac may be drawn.

Figure 3 shows circuits which are particularly useful where small line voltage variations are required and where the currents to be drawn are greater than can be supplied by any standard Variac.

In Figure 3 (a) a Variac across the

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*P. K. McElroy, "Extending the Field of Application of the Variac," General Radio *Experimenter*, Volume XIV, No. 5, October, 1939.

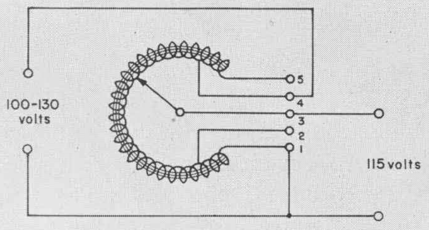

FIG. 1 (a)

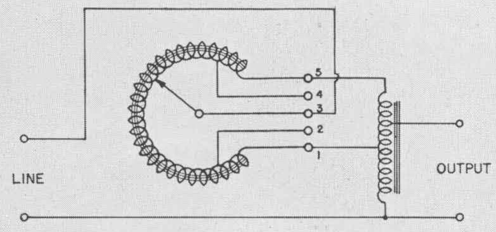

FIG. 2 (a)

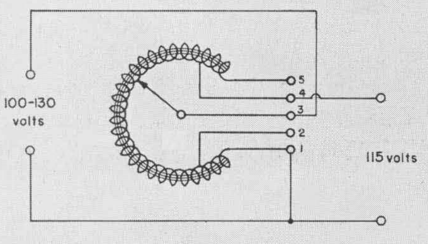

FIG. 1 (b)

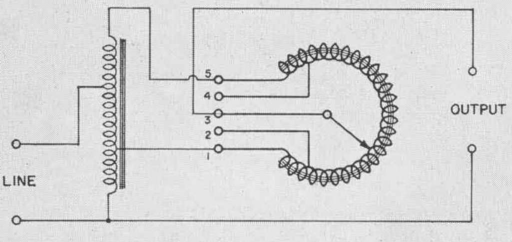

FIG. 2 (b)

line delivers a controllable voltage to the full winding of an auxiliary autotransformer, a part of whose winding is in series with the load. With the Variac brush in the 5 position, the series voltage introduced into the output circuit by the auxiliary transformer is zero, and line and output voltages are equal. Rotation of the brush increases or reduces the output voltage by an amount depending on the turns ratio of the transformer and the position of switch S_2.

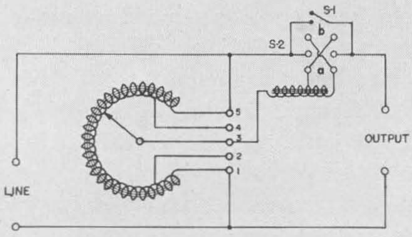

FIG. 3 (a)

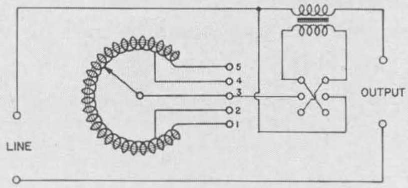

FIG. 3 (b)

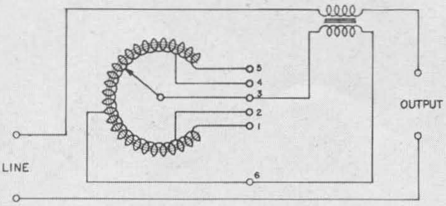

FIG. 3 (c)

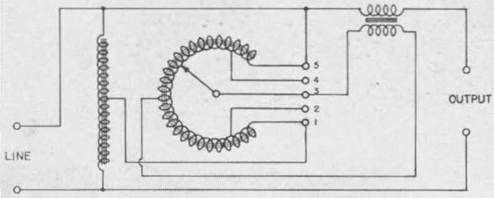

FIG. 3 (d)

Assuming that the line voltage to be compensated is at its maximum, we start with S_2 in position *a* and the brush at position 1. As the line voltage drops, the output can be held constant by rotating the brush toward position 5. This gives continuous control until the line voltage falls to normal output voltage. If the line falls below normal, switch S_1 is closed, switch S_2 is thrown to position *b* and then switch S_1 is opened. This operation changes the auxiliary transformer from a step-down to a step-up transformer without opening the output circuit. The output can now be kept at its normal value by rotating the Variac brush back toward position 5 as the line voltage falls to its minimum. Obviously, in the case of a line which is always too high or always too low, the switches may be omitted and the full range of control obtained by a single rotation of the Variac brush. Output currents up to rated current of the Variac times the turns ratio of the auxiliary transformer can be controlled.

Figure 3 (b) gives the same type of control as the circuit of Figure 3 (a). The operation and uses of this circuit are the same as for Figure 3 (a) except that the use of an inductively coupled transformer obviates the necessity of using a shorting switch to keep the output circuit closed while the reversing switch is being operated.

Figure 3 (c) gives a method by which a desired output voltage may be obtained from either a higher or a lower line without the necessity of any switching. This method requires the use of a center tap on the Variac.†

Figure 3 (d) shows an obvious extension of Figure 3 (c) which is useful in cases where the line voltage is higher than the rated voltage of any standard Variac. — S. A. BUCKINGHAM

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†Center taps are provided on 230-volt models.

NEW DIALS

● **THE TWO-INCH DIAL** used on several General Radio instruments has now been made available for general sale. Two types are listed, one with 100 divisions for 360-degree rotation, and the other with 100 divisions for 180-degree rotation. Both models are drilled for a ¼-inch shaft.

A new four-inch dial with 100 divisions for 360-degree rotation is also available in both direct- and friction-drive models.

These new dials are made of nickel silver with photo-etched scales and TYPE 637 Knobs. All dials are insulated from the shaft. An indicator, as shown, and a drilling template are supplied with each dial.

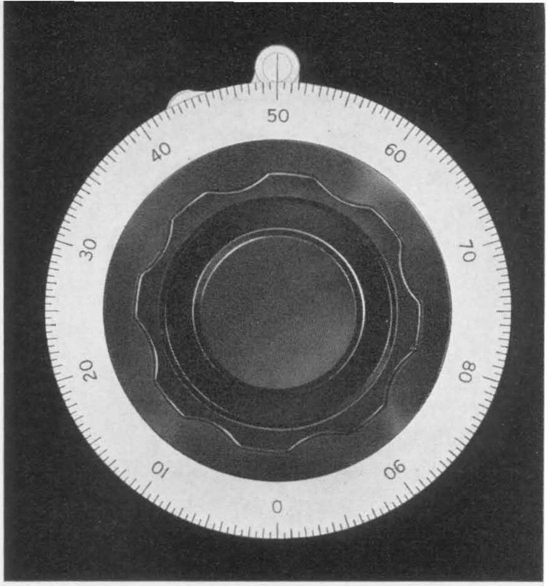
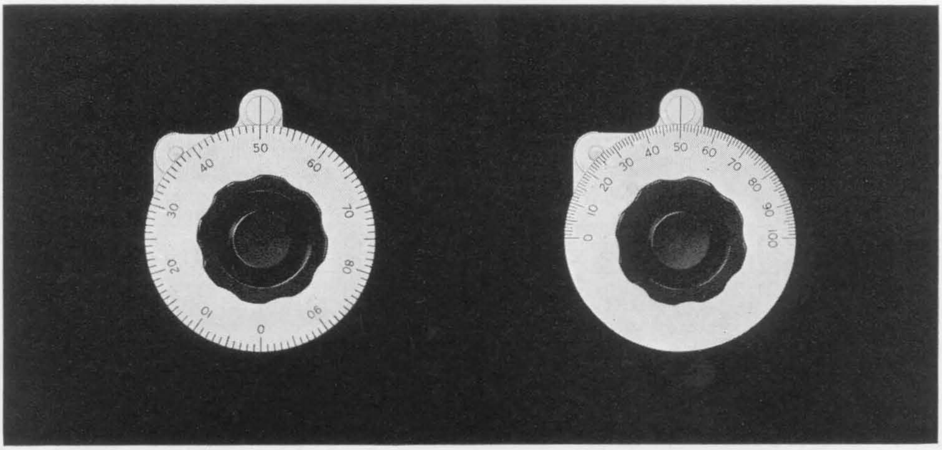


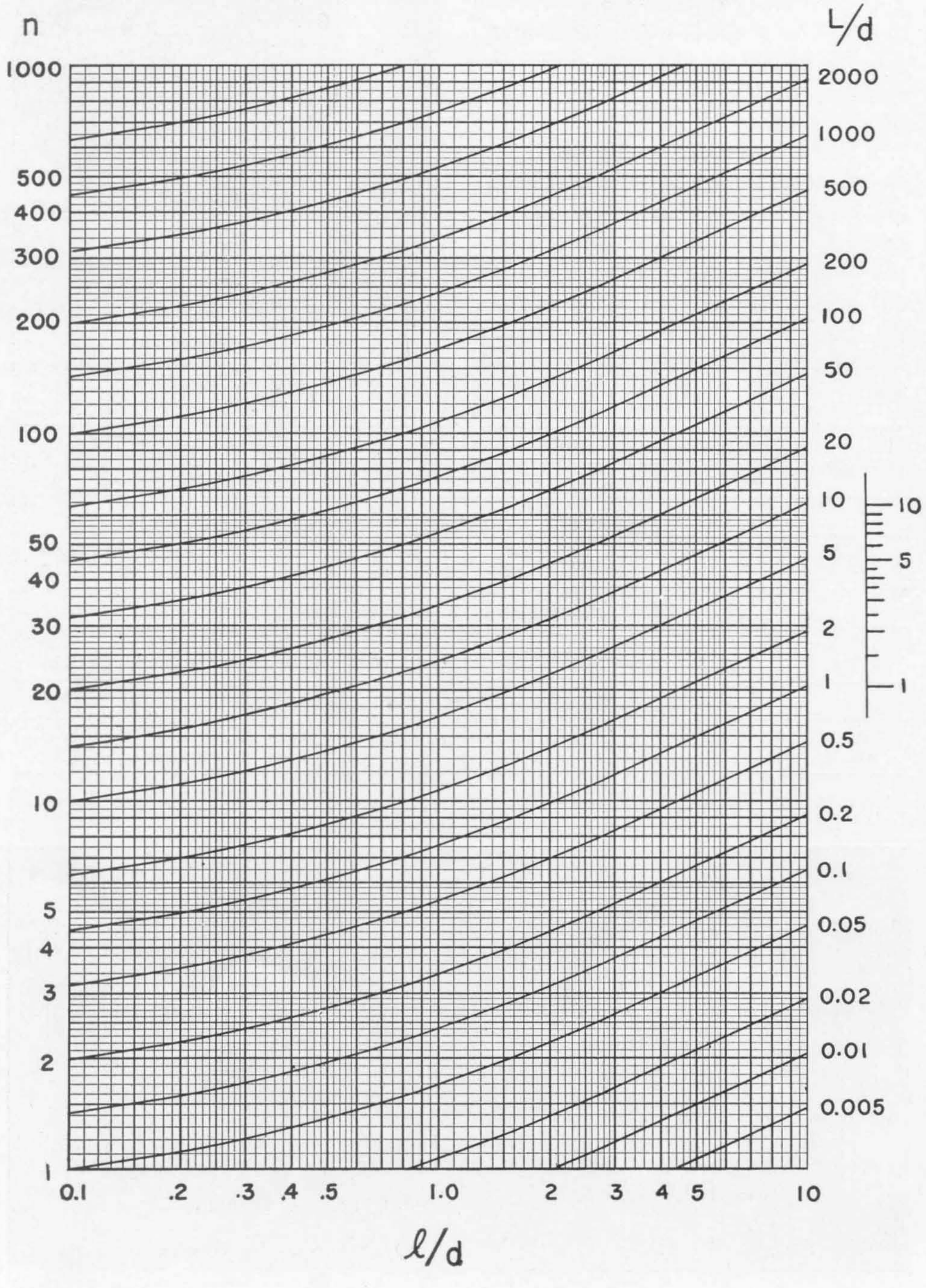
FIGURE 1. View of the TYPE 717-K or 717-L Dial. The dial is shown approximately ⅝ actual size.

Type	*Shaft Diam.*	*Dial*		*Friction Drive Ratio*	*Net Weight*	*Code Word*	*Price*
		Arc	*Divs.*				
4-Inch Diameter — Type 703 Friction-Drive Dials							
703-K	¼″	360°	100	1 : 5	8 oz.	DIHOP	$2.00
703-L	⅜″	360°	100	1 : 5	8 oz.	DIHIP	2.00
4-Inch Diameter — Type 717 Direct-Drive Dials							
717-K	¼″	360°	100	....	5 oz.	DIHUG	1.50
717-L	⅜″	360°	100	....	5 oz.	DIKEG	1.50
2-Inch Diameter — Type 701 Direct-Drive Dials							
701-A	¼″	180°	100	....	2 oz.	DILAP	1.25
701-K	¼″	360°	100	....	2 oz.	DILUX	1.25

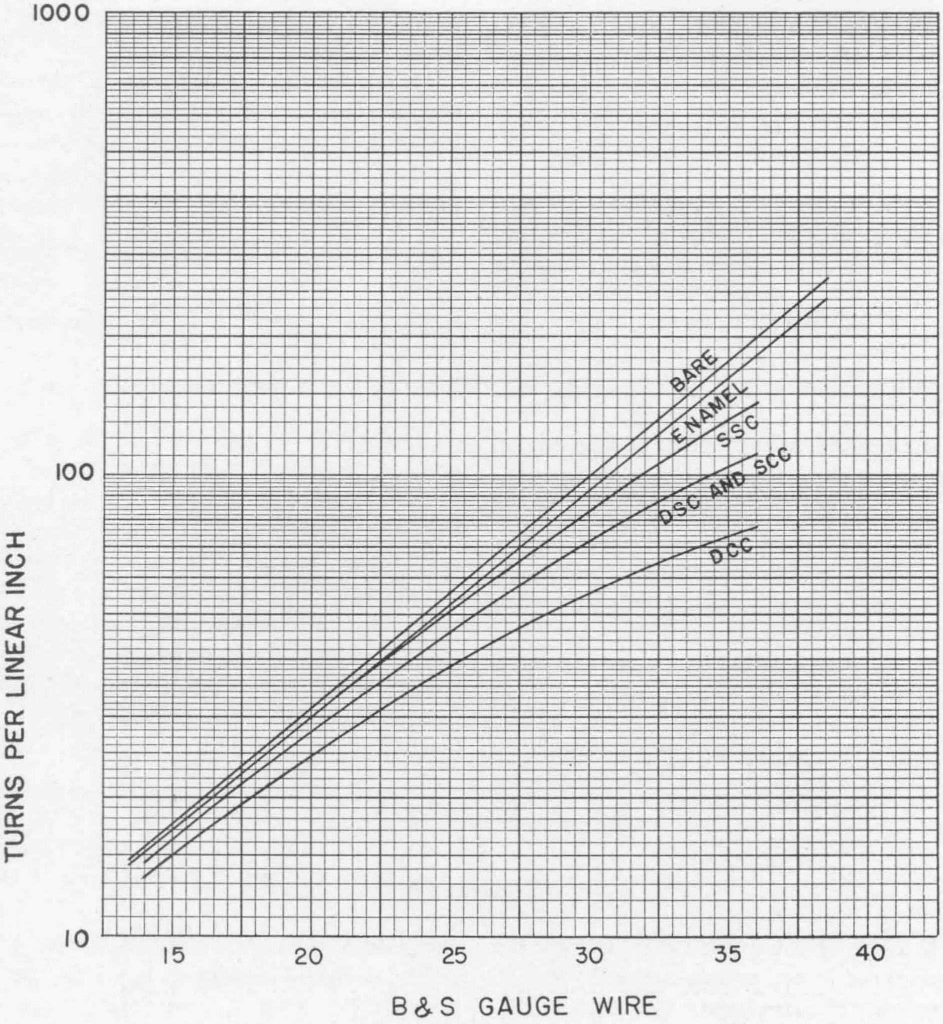
FIGURE 2. View of TYPE 701-K (*left*) and TYPE 701-A (*right*) Dials. The dials are shown approximately ⅝ actual size.



A CONVENIENT INDUCTANCE CHART FOR SINGLE-LAYER SOLENOIDS



File Courtesy of GRWiki.org



● **ON THESE TWO PAGES** are presented charts for determining the number of turns and the size of wire to be used in order to obtain a given inductance on a given winding form.

In the left-hand chart the variables are n, the number of turns, and $\frac{l}{d}$, the ratio of winding length to winding diameter. The ratio of inductance to diameter of winding $\left(\frac{L}{d}\right)$ is used as a parameter.

The curves were computed from the expression given in Circular 74 of the U. S. Bureau of Standards,* which, using the terminology of the chart, may be written,

$$L = \frac{.02508\, n^2 d^2}{l} K \qquad (1)$$

where L is the inductance in μh

K is Nagaoka's constant

and d and l are in inches.

---

* "Radio Instruments and Measurements," p. 252.

For a given inductance the number of turns is then,

$$n = \sqrt{\left(\frac{L}{d}\right)\left(\frac{l}{d}\right)(39.88)\left(\frac{l}{K}\right)} \quad (2)$$

This form of the expression is particularly convenient because, in designing coils, the engineer usually starts with a given coil form ($\frac{l}{d}$ known) and needs a given inductance L ($\frac{L}{d}$ easily calculated).

Since Nagaoka's constant depends on the ratio $\frac{l}{d}$, the use of this ratio for the horizontal scale makes all the curves parallel, so that, in plotting them, only one curve need be calculated. The other can be drawn from a template.

For interpolating between curves, a logarithmic scale covering one decade of $\frac{L}{d}$ is shown at the right of the chart.

The second chart is plotted from standard winding data published by wire manufacturers.

As an example of the use of these charts, consider the problem of designing a coil of 100 μh inductance on a winding form two inches in diameter, with an available winding space of two inches. The quantity $\frac{l}{d}$ is unity and $\frac{L}{d}$ is 50. Entering the chart at $\frac{L}{d} = 50$ and following down the curve to the vertical line $\frac{l}{d} = 1$, we find that n, as indicated by the left-hand vertical scale, is 54 turns.

With a winding space of two inches, this is equivalent to 27 turns per linear inch, close wound. The second chart shows that No. 18 enamel or single-silk-, No. 20 double-silk-, or single-cotton- or No. 22 double-cotton-covered wire would be used close wound. No. 25 bare wire, double spaced, could also be used.

ERRATA

● **THE FOLLOWING ERRORS** occurred in the article entitled "Substitution Measurements at Radio Frequencies," by R. F. Field, appearing in the May, 1940, issue of the *Experimenter*.

1. The values $L_C = 0.006$ μh and $R_C = 0.005\ \Omega$ apply not to the TYPE 722-N Precision Condenser as stated, but to a newly designed condenser used in the TYPE 821-A Twin-T Impedance Measuring Circuit, which will be described in a forthcoming issue of the *Experimenter*.

2. In Table I, first column, fourth line, R_L should be R_C.

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also

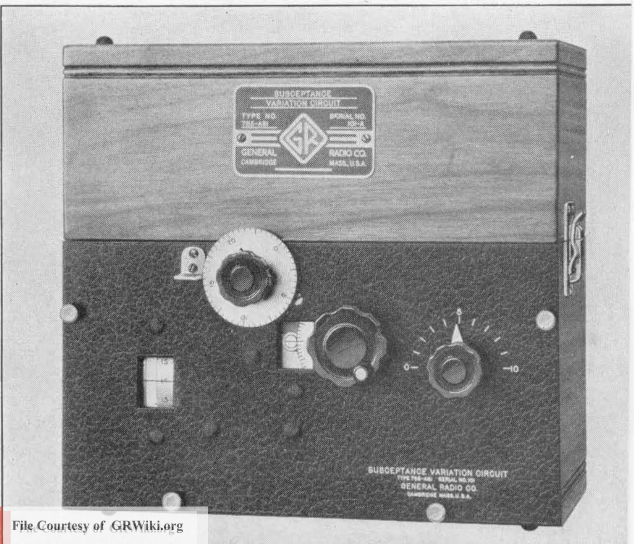
IN THIS ISSUE

AN IMPROVED MEASURING CIRCUIT FOR THE SUSCEPTANCE VARIATION METHOD

● **AN APPARATUS AND METHOD** for measuring dielectric samples at frequencies up to 100 Mc by the susceptance variation method were described in the *Experimenter* about a year ago.* With the special holder used at that time, the two resonance voltage readings were taken at the same setting of the standard condenser, thus eliminating the corrections that are necessary for the change in conductance of the standard condenser when the resonance readings occur at two different settings. The capacitance measurement, however, was made by changing the standard condenser, necessitating correction for the error in capacitance caused by the inductance of the condenser.

This latter correction is eliminated in an apparatus, shown in Figures 1 and 2, which was recently built for a large chemical company. In this arrangement, both resonance settings and the two settings on the sides of the resonance curve are made by means of a mi-

FIGURE 1. Panel view of the TYPE 755-AS1 Susceptance Variation Circuit.



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*D. B. Sinclair, "Impedance Measurements at High Frequencies with Standard Parts," General Radio *Experimenter*, Volume XIV, No. 4, September, 1939.

crometer drive on one of the electrodes between which the sample is clamped. This arrangement is shown clearly in Figure 2. The movable electrode is the grounded one of the pair, and its motion is measured by the dial that can be seen projecting above the panel. The electrodes are mounted above the TYPE 755-A Condenser. The massive blocks that support the electrodes serve as leads from the condenser and have a negligible inductance. The electrode faces are one inch in diameter. The screw that drives the movable electrode is ¾ inch in diameter and has 40 threads per inch. It is in contact with its nut for a length of ¾ inch, and no variation in contact resistance is noticeable, even at 130 Mc. The screw carries a 2-inch dial, calibrated to read directly in half ten-thousandths of an inch. A capacitance calibration is also supplied, which is accurate to 0.01 $\mu\mu$f or 0.25% up to 100 $\mu\mu$f.

Referring to the rear view of the unit (Figure 2), the oscillator is plugged in at the left-hand terminals, and the tuning inductance at the next pair. The vacuum-tube voltmeter plugs in at the extreme right.† The binding posts just at the right of the electrodes are provided for connecting unknown impedances other than slabs of dielectric.‡ The two pairs of screws on the tops of the electrodes are provided for the same purpose. These make it possible to connect practically any kind of unknown, or to mount an additional special sample holder, if desired.

The precision-drive condenser is not necessary for measuring dielectric samples, since all capacitance readings are taken from the micrometer drive, but it provides a ready means of checking the calibration of the micrometer, which may change as a result of straining in use, and also permits condensers beyond the capacitance range of the micrometer electrode to be measured.

The procedure for measuring dielectric samples is as follows:

(1) The sample is clamped between the electrodes and the circuit tuned to resonance by means of the precision condenser. The electrode dial reading d_r and the resonant voltage V_r are noted.

(2) The sample is then removed, and the circuit restored to resonance by turning the electrodes together. The dial reading d'_r and the resonant voltage V_r' are observed.

(3) The circuit is then detuned each

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†TYPE 684-A Modulated Oscillator and TYPE 726-A Vacuum-Tube Voltmeter are recommended.

‡When the unknown is an inductance it must be shielded from the tuning inductance.

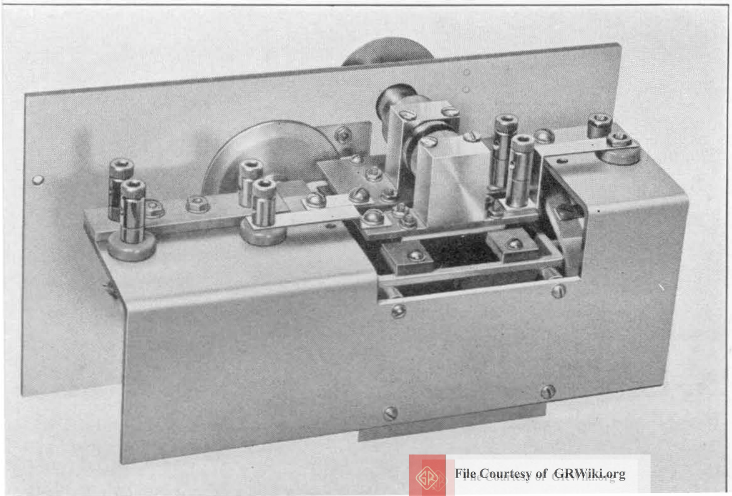

FIGURE 2. Rear view of the TYPE 755-AS1 Susceptance Variation Circuit, showing the micrometer condenser and the arrangement of terminals. The blocks that support the electrodes of the micro condenser are made massive to minimize inductance.

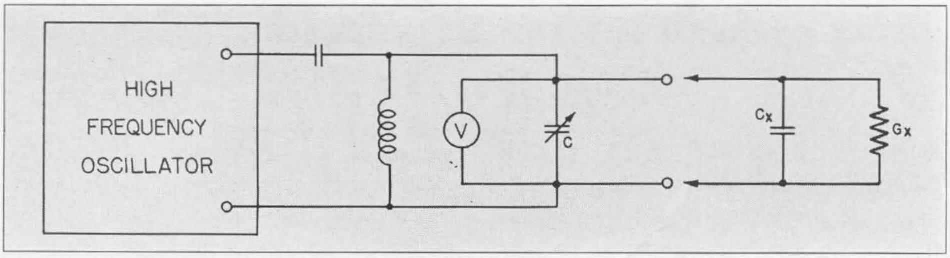

Figure 3. Circuit used in the Type 755-AS1 Susceptance Variation Circuit.

side of resonance to reduce the voltage to 0.707 V_r', and the corresponding dial readings d_1' and d_2' are noted.

(4) From the calibration of the electrode dial, the equivalent capacitance values|| C_r, C_r', C_1', C_2' are determined.

The capacitance of the sample is determined by the expression

$$C = \Delta C_r + C_a$$

where

$\Delta C_r = C_r - C_r'$

C_a = Air capacitance of sample§

The dielectric constant, K, is

$$K = \frac{\hat{C}}{C_a}$$

when the sample is the same size as the electrodes. Dissipation factor is calculated from the expression:

$$D_x = \frac{1}{2}\frac{\Delta C_r}{\hat{C}_x} \quad \frac{\Delta V_r}{V_r'}$$

—R. F. Field

||These are not, of course, total circuit capacitances, but merely the incremental capacitance values corresponding to the dial readings. They are used only to obtain differences.

§This can be calculated from the dimensions of the electrodes: $C_a = .0885 \frac{A}{t}$, where C_a is in μμf, and A and are in centimeters.

MONITOR CRYSTALS FOR THE BROADCAST FREQUENCY RE-ALLOCATION

● **BROADCASTING STATIONS** whose frequencies will be changed under the re-allocation plan will need new crystals for their General Radio Frequency Monitors. Some months ago we offered to supply these at a special price of $65 plus return of the old crystal, the offer being good until August 1, 1940. Because the date on which the re-allocation becomes effective has been extended into 1941, we are extending the time limit on this offer to March 29, 1941.

In order that a last-minute rush may be avoided, and in view of the present and prospective slowness of deliveries of raw materials, we recommend that orders be placed as early as possible.

NOTES ON THE CARE AND MAINTENANCE OF GENERAL RADIO INSTRUMENTS

● **PROPER CARE AND MAINTENANCE** are obviously necessary if optimum performance and long life are to be obtained from electrical and mechanical instruments, yet the experience of our Service Department with returned instruments indicates that most users of General Radio instruments do not follow a definite maintenance program. The fine degree of accuracy of many of our instruments is dependent in part upon the smooth operation of controls free from backlash, clean contacts, and the exclusion of dust and foreign matter.

A large part of the charge made for reconditioning instruments is for the labor of replacing parts that have not been properly cared for, cleaning contacts, lubricating moving parts, and removing foreign matter such as dust, grit, insects, bits of metal, salts from corrosion, and the like. Much of the inconvenience and expense of returning instruments for repair could be avoided if the user followed a program of periodic inspection and adjustment in his own laboratory. Of course, in many applications operating conditions are such that wear and corrosion are inevitable, but a definite maintenance program will help to minimize deterioration and failures. Although individual conditions of use will determine the details of any maintenance program, the following suggestions are offered to assist the user of General Radio equipment in any servicing he may choose to do.

Equipment used for production testing demands frequent servicing. An instrument operated occasionally may have to be serviced each time used because of the oxidation of contacts, switches, etc., presence of foreign matter, and possible moisture. Lack of lubrication and the presence of foreign matter on switches, contacts, bearings, controls, and mechanisms cause considerable difficulty even when an instrument is relatively new.

Instruments should be kept as clean as possible. A solution of half alcohol and half ether is recommended for switch and relay contacts, contact surfaces of wire-wound controls, slide wires, and mechanical contact surfaces of various types such as mouse-trap type attenuators, detent mechanisms, chain drives, gear trains, shafts, and bushings. To remove oxidation or corrosion, a fine abrasive such as crocus cloth may be used, but its use is limited to relatively large contact surfaces such as those on Variacs, attenuators, and relay contacts.

A very fine grade of sandpaper is recommended on certain types of contacts, although the residue must be removed with a fine brush for smooth operation. Fine sandpaper may be used on wire-wound controls, key switches, push switches, anti-capacity type switches, and multi-blade-contact rotary switches; also on contact buttons and relays.

Some assemblies, such as syncro-clocks, piezo-electric crystals, motors, and meters require special attention. Syncro-clocks should be carefully cleaned by one acquainted with fine mechanisms of this type. Quartz crystals should be returned to the factory. Electric motors demand the usual attention to commutator surfaces, brushes, and bearings.

Meters should not be cleaned except by one skilled in handling such fine work.

Proper lubrication is very important in the maintenance of precision instruments. Some bearing surfaces require a grease, while for others oil is best. When instruments are assembled at the factory, moving parts are lubricated with either "Lubriko,"* or a fine grade of clock oil, and the use of these lubricants is recommended in maintenance.

Lubriko has been selected because it is acid free and because it adheres to moving parts better than most lubricants. It is recommended for use on wire-wound controls, button contacts, attenuators, and the TYPE 200-B Variac. However, a very thin film should be applied, as a large quantity will cause foreign matter to collect.

For detent mechanisms, chain drives and gear trains, ball bearings, shafts, vernier drives, etc., a larger amount should be used. These moving parts require lubrication more frequently to prevent wear.

The use of a fine grade clock oil is recommended for slide wires, push-button switches, syncro-clocks, and condenser bearings. This type of lubricant should be applied in very small quantities. A thin film applied with the finger will suffice for a slide wire but this should be done frequently because of evaporation. The small gear on the shaft of the rotor of a syncro-clock requires lubrication every few months. Likewise the bearings should be oiled to insure proper operation. Condenser bearings (cone type) require occasional lubrication in small quantities.

Tubes and batteries in our equipment should be tested frequently and replaced if necessary. Only such types as recommended for our instruments should be used.

It is always well to inspect the wiring in an instrument. While every effort is made during manufacture to solder firmly each connection, occasionally one will break loose due to excessive vibration either in transit or in use.

Dials are lacquered and usually do not require much attention. However, the use of an oil polish will improve their appearance. For smooth operation slow-motion drives, either friction- or gear-type, must be cleaned occasionally. A fine brush and a cloth saturated with carbon tetra-chloride are satisfactory.

Air condensers require occasional attention and the dirt and lint between the plates can be removed with pipe cleaners. With calibrated condensers, care must be taken not to bend the plates. Foreign matter between terminals on a fixed condenser should be periodically removed. Otherwise, the combination of dirt and moisture will produce a low value of leakage resistance.

An oil polish may be used on wood cabinets, panels, and dust covers to improve appearances. The crackle finish can be restored to its original appearance by using an oil polish and carefully wiping afterward.

For specific instruments, these general suggestions often must be supplemented by more specific information, usually included in instruction books. Whenever additional service or maintenance instructions are needed, the Service Department will gladly supply the necessary information.

— H. H. DAWES

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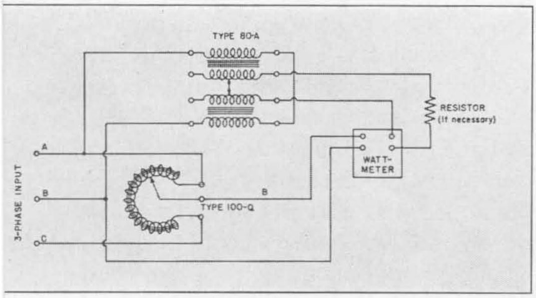
*Density MD, manufactured by Master Lubricants Company, Philadelphia, Pa.

VARIACS IN COMBINATION

● **TWO OUT-OF-THE ORDINARY** connections for Variacs have been brought to our attention by users. Both of these use the Type 80-A Variac Transformer in combination with Type 100 or Type 200 Variacs.

The first of these, used by Mr. Louis A. Paine, Chief Engineer of Therm Electric Meters Co., Inc., uses the Variac as a potential phase shifter for testing wattmeters. The Variac is connected across two wires of a three-phase line. The potential coil of the wattmeter is then fed from the Variac brush and the third line wire. The current coil of the wattmeter is supplied through a Type 80-A Variac Transformer. Using this connection an effective phase variation of 0 to 60° is obtainable, corresponding to a power-factor variation from unity to 0.5.

Figure 1 (*below*). Arrangement of Type 100 Variac and Type 80 Variac Transformer for varying the potential phase in testing wattmeters.



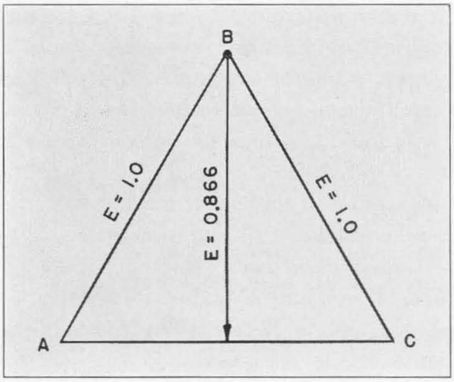
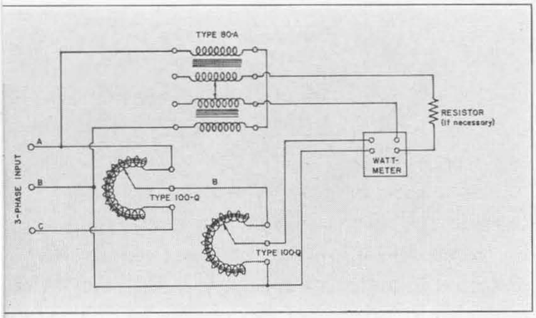


Figure 2.

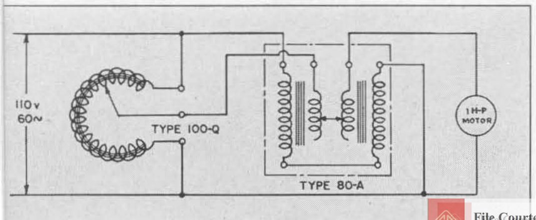
The use of a single Variac to supply the potential coils has the disadvantage that a voltage variation accompanies the desired phase variation. As shown in Figure 2, the voltage varies from unity at zero phase shift to 0.866 at 30° phase shift, and back to unity at 60° shift. This voltage variation can be avoided by using a second Variac as shown in Figure 3.

Figure 3 (*below*). By using two Variacs, the voltage can be held constant as its phase is varied.



The second application is furnished by Pierce Plastics of Bay City, Michigan. Here the Variacs are used for speed control on a repulsion-type motor. The circuit is shown in Figure 4. The general operating point is set by the Type 100 Variac and the 10-volt winding on the Type 80-A Variac Transformer permits a fine control of voltage around that point.

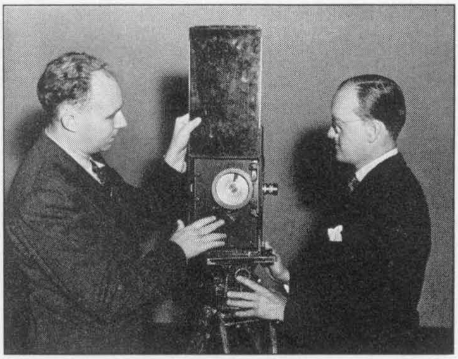
Figure 4 (*below*). Method of combining Type 100 Variac and Type 80 Variac Transformer to obtain a fine control of motor speed.



MISCELLANY

● **THE MOTION-ARRESTING PROPERTIES** of the Stroboscope are the theme of "Quicker'n a Wink," Pete Smith's latest Metro-Goldwyn-Mayer Specialty. Produced through the cooperation of Dr. Harold E. Edgerton of the Massachusetts Institute of Technology, consultant on General Radio Stroboscopes, this film features the Strobotac, the Strobolux, and the continuous-film high-speed camera (Type 651-A).

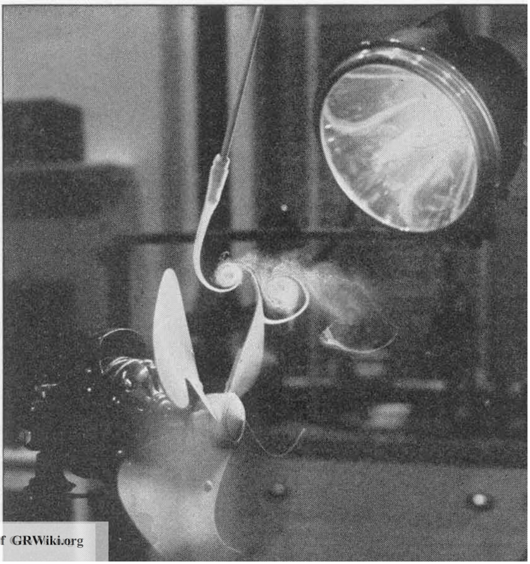
● **ENGINEERS** whose work involves the measurement and analysis of noise will be interested in a recent publication of the Underwriters' Laboratories, Inc., entitled "Noise in Burglary-Resistive Vaults under Normal and Attack Conditions,"* by H. D. Brailsford. This bulletin is "a report on a special investigation of the noise or sound in burglary-resistive vaults, conducted for the purpose of developing new and additional data on the requirements for burglar alarm systems operating on the sound-detection principle." The investigation, in which the General Radio Sound-Level Meter and Sound Analyzer were used, included measurements of sound-levels, frequency characteristics, and reverberation tunes. Methods of measurement are described in detail and an elementary explanation of the theory of sound and vibration is included.



Dr. Edgerton explains the operation of the high-speed camera to Pete Smith, Commentator of "Quicker'n a Wink." This camera will take pictures at the rate of *1500 frames per second.*

● **MEASURING APPLAUSE** for Willkie and for Roosevelt is the latest job for General Radio Sound-Level Meters. Two of these instruments are being used in the *New York Journal* and *American's* movie applause poll on the two major presidential candidates. Measurements are made in movie theaters in metropolitan New York.

● **LATEST** to join our engineering staff is Ivan G. Easton, whose work will be in sales engineering. Mr. Easton re-



Air currents around an electric fan are shown in this photograph, which was taken with a Type 648-A Strobolux. This is one of the scenes from "Quicker'n a Wink." Others include a bullet shattering a light bulb, a golf ball boring its way through a telephone directory, and a humming bird in flight.

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*Bulletin of Research No. 17, July, 1940.

Dr. Harold E. Edgerton of the Massachusetts Institute of Technology demonstrates the Strobotac and Strobolux in this scene from "Quicker'n a Wink."

ceived his B.S. degree from Northeastern University in 1938. While at Northeastern and after graduation, he was employed in the General Radio standardizing laboratory, leaving to continue his engineering education at Harvard University, from which he received his M.S. degree in 1939.

● **L. E. PACKARD** of the Commercial Engineering staff is now in charge of our New York engineering office, succeeding Frederick Ireland. Mr. Ireland, after a short period at Cambridge, will be in charge of the Los Angeles office, replacing M. T. Smith, who returns to the main office at Cambridge.

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

SINGLE-FLASH PHOTOGRAPHY WITH THE STROBOTAC AND THE STROBOLUX

● **FOR THE PAST SEVERAL YEARS** the effectiveness of single-flash photographs in stopping a multitude of types of motion has been vividly demonstrated in the popular press.[1] Suspended action photographs of dancers, runners, tennis players, golfers and other athletes have been taken by means of the powerful single-flash equipment designed by Messrs. Edgerton, Germeshausen, and Grier of the Massachusetts Institute of Technology,[2] under whose license General Radio Company manufactures the Strobotac and the Strobolux.

While the Strobotac and the Strobolux are intended primarily for visual observation of mechanical phenomena, these instruments can be

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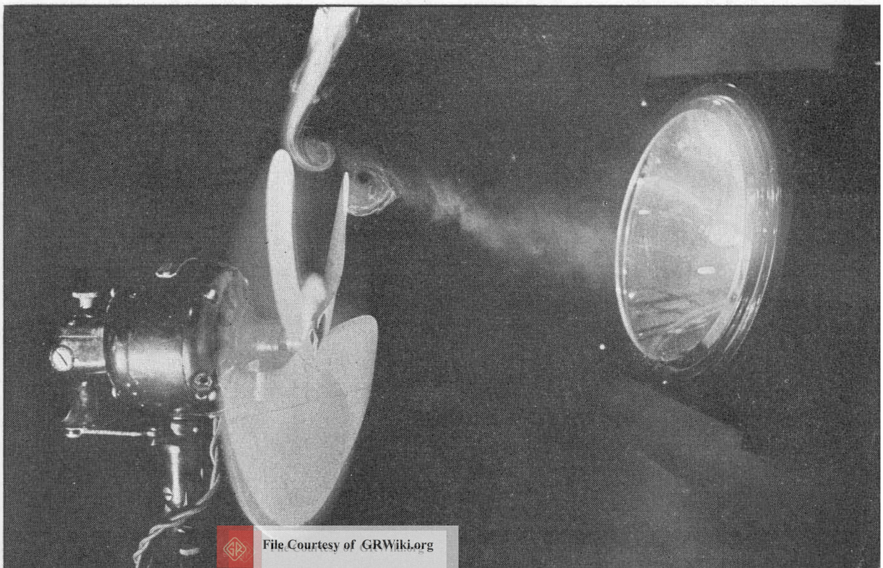
[1] See also the collection of striking single-flash photos taken by Edgerton, Germeshausen, and Grier in the new book, *Flash*, published by Hale, Cushman, and Flint.

[2] Eastman Kodak Company have recently placed on the market the Kodatron Speed Lamp which is a powerful single-flash stroboscopic light designed for general photography where extremely large areas are to be illuminated.

FIGURE 1. Smoke pattern around moving fan blades. Hand synchronization: Camera is focused, shutter opened, Strobotac-Strobolux fired by hand, and the camera shutter closed.



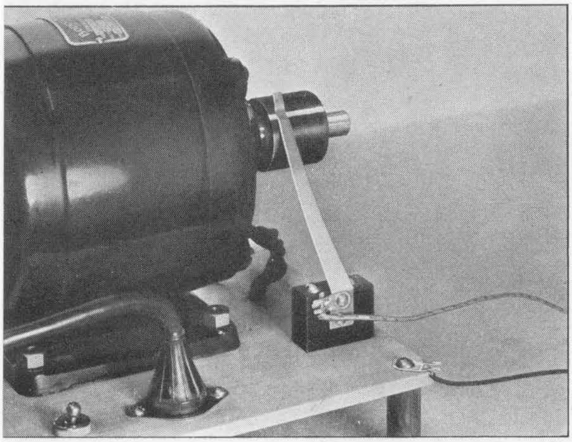


Figure 2 (*above*). Make and break commutator. By shifting the position of the commutator on the shaft, the Strobolux can be fired in phase with any desired motion of the machine being photographed.

used quite successfully for taking single-flash pictures when the area to be illuminated is relatively small. The Strobolux when used for single-flash work supplies about ten times as much light as it does when flashed continuously from the Strobotac. The duration of a single flash, however, is about 1/30,000th second.

When single-flash pictures are to be taken over an area not exceeding approximately two feet square, and when the motion to be photographed can be stopped in not over 1/30,000th second, the Strobotac and the Strobolux can be used quite satisfactorily.

The principal problem in using the Strobotac-Strobolux for single-flash pictures is the synchronization of the flash with the opening and closing of the camera shutter. It is the purpose of this article to describe a number of synchronizing methods which have been used successfully by many persons.

The indulgence of the camera-addict reader is asked for the elementary photographic statements, since many persons with *no* photographic experience may desire to take single-flash photographs.

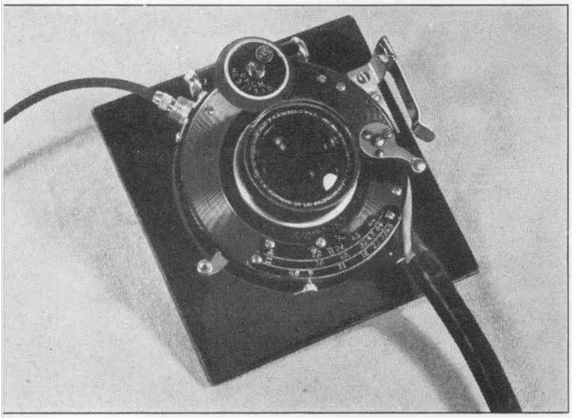
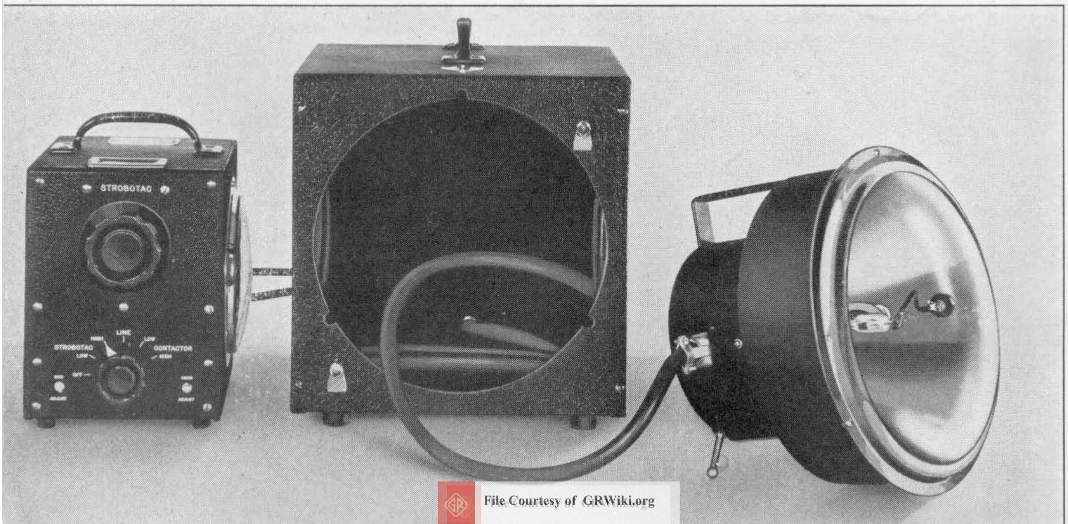


Figure 3 (*left*). Simple spring mechanism which fires Strobolux when shutter cocking lever is in mid-position.

Figure 4 (*below*). Type 631-B Strobotac and Type 648-A Strobolux. The Strobolux lamp is supplied with a 10-foot extension cable and can be removed easily from its case.



CAMERA AND LENS EQUIPMENT

The field of illumination supplied by the Strobolux is limited; accordingly, it is usually necessary to work quite close to the subject being photographed. It is also necessary to use the lens at moderately wide openings to secure sufficient exposure. For these reasons the depth of field is one of the important factors in selecting the size of camera for single-flash pictures. In general it will be advisable to use as large a film size as is compatible with the allowable depth of field in order that enlargements will not be needed to secure sufficient detail in the finished print. If the overall diffusion sometimes found in enlargements from miniature negatives is not objectionable, a small size negative (even as small as the 35 mm. motion picture size) may be used with correspondingly increased depth of field. If contact-sized prints are to be used, the upper limit in practical film size is normally about 4 x 5 inches.

With the films suggested below and with the Strobolux placed as close to the subject as possible, lens apertures

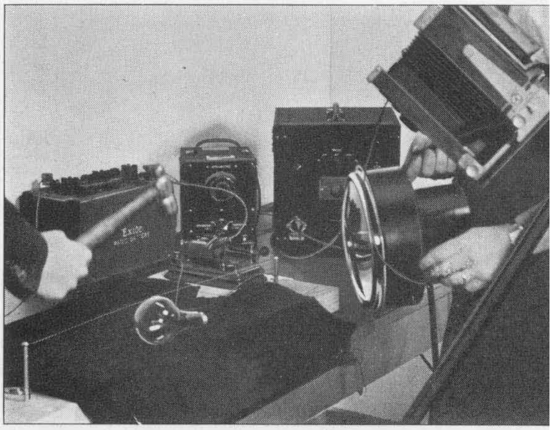


FIGURE 5 (*above*). Set-up for taking photograph by mechanical impact — breaking wire. The photograph is taken in semi-darkness; the hammer breaks the wire and the bulb, and fires the Strobolux.

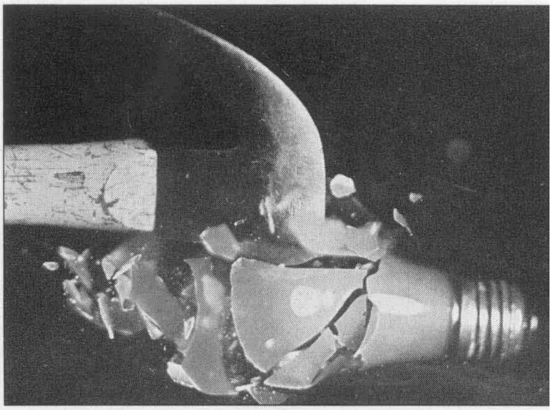
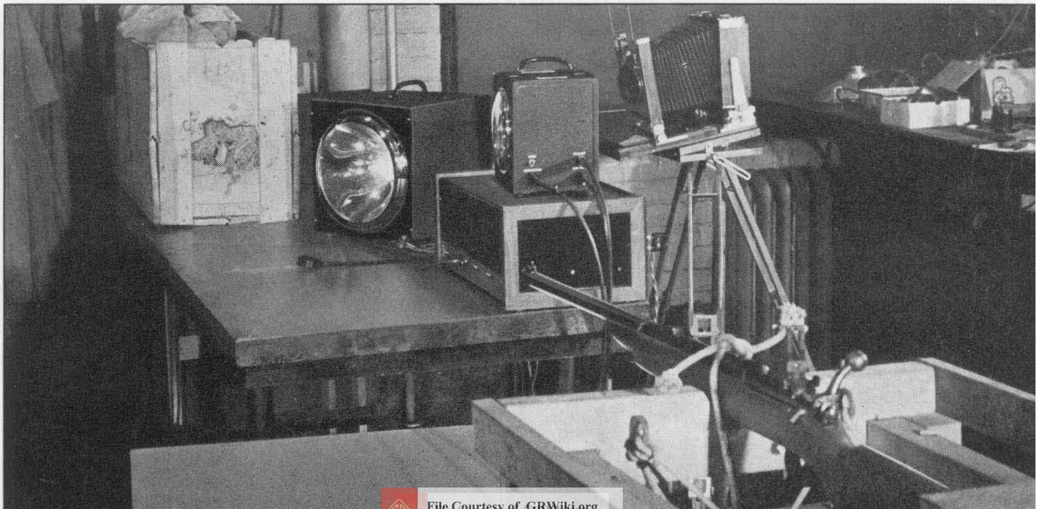


FIGURE 6 (*above*). Exploding electric light bulb taken with set-up shown in Figure 5.

FIGURE 7 (*below*). Set-up for photographing bullet breaking light bulb. The microphone on the table picks up the explosion which causes the Strobotac and Strobolux to flash. Exact timing is secured by moving the microphone.



vary between f/4.5 and f/11. Any modern anastigmatic lens having this range of diaphragm openings should be satisfactory. The focal length of the lens should be normal for the film to be covered; that is, it should equal, approximately, the diagonal of the film.

FILM

Normally only the fastest type of film should be used. The new Eastman Kodatron Panchromatic film is especially designed for use with stroboscopic light. This film is more sensitive to stroboscopic light than are Eastman Tri-X and Agfa Triple-S and it should be used when maximum sensitivity is needed. However, Tri-X, Super XX, and Agfa Superpan Press and Triple-S are satisfactory for most work. The Superpan Press should be used when the maximum contrast is desired. The Triple-S film has almost the same effective speed and is to be preferred when the subject contrast is high since this film furnishes negatives of average contrast. If the camera is equipped with cut-film holders, cut film has some advantages over roll film or film packs.

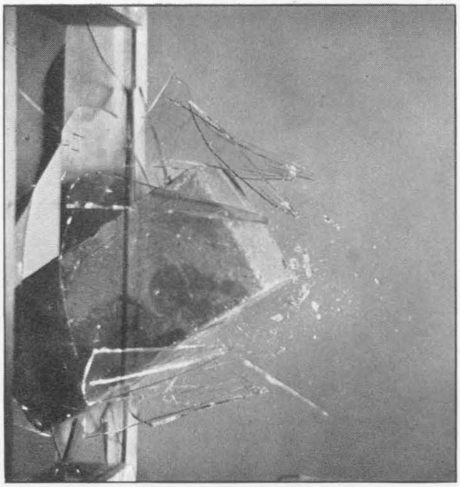


FIGURE 8. Brick breaking pane of glass. TYPE 759-A Sound-Level Meter, *placed twenty-five feet away from the plate of glass*, fed a TYPE 714-A Amplifier which in turn caused the Strobotac and Strobolux to flash.

LIGHTING

For the type of small-area photography discussed in this article, usually a single Strobolux supplies sufficient light. When necessary to relieve the shadow side of a Strobolux photograph, a white cardboard reflector can be used.

HOW TO "FIRE" THE STROBOSCOPE

Appropriate terminals and connecting cords are supplied with the Strobotac and the Strobolux so that they may be operated at single flashes. The two instruments are connected by these cords

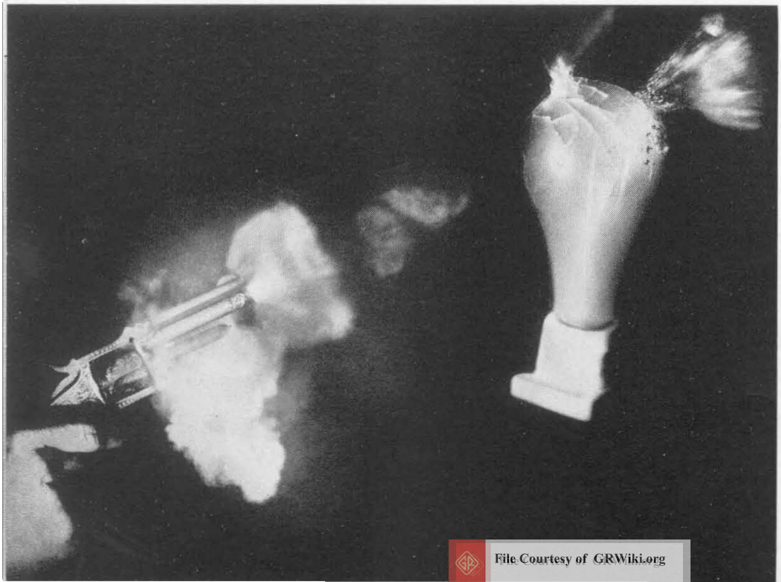


FIGURE 9. Composite photograph from two single-flash shots taken with set-up shown in Figure 7. The bullet is still inside the light bulb which has not had time to "explode."

and the plug is inserted in the CONTACTOR jack of the Strobotac. When the wires attached to the plug are short circuited, the Strobotac and the Strobolux produce a single flash. The voltages and currents present are so low that no precautions need be taken in handling the exposed ends of the wires.

The SPEEDS switch on the back of the Strobolux should be set at "slow" to secure maximum illumination at single flashes.

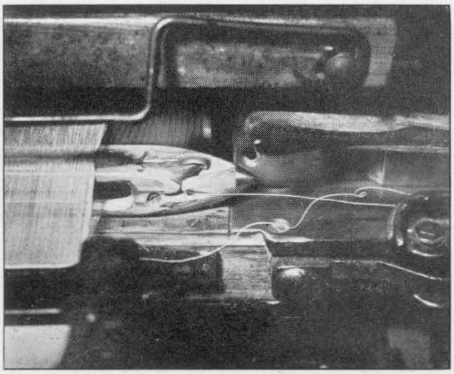
The exact manner in which the electrical contact, for producing the single flash, is synchronized with the opening and closing of the camera shutter will depend upon the particular problem and the ingenuity of the user. The following suggested methods of synchronism have been employed and will be adequate for many applications.

HAND SYNCHRONIZATION

Many mechanical applications in which the motion is cyclic can be photographed by synchronizing the flash and the exposure by hand. The subject is focused and composed on the ground glass or view finder of the camera, the camera shutter is opened, the two wires from the Strobotac CONTACTOR plug are momentarily connected, and a single flash is obtained; the camera shutter is then closed. Operation in this fashion presupposes two conditions; first, that the exact phasing of the motion is of no importance and, secondly, that the photograph can be taken in subdued light. Since the shutter of the camera probably will be open for a considerable time, and since the film used is very fast, it is difficult to avoid fogging of the film from any outside light which may be present. This type of synchronization is satisfactory in a large number of instances when the exact timing of the flash is not important.

FIGURE 10. Photo courtesy Hoosac Mills, New Bedford, Mass. Experimental loom operating at 180 picks per minute. Long rod in foreground was geared to a make-break contactor so that the exact phase of flash could be set by hand.

FIGURE 11. Shuttle just emerging from shed of loom shown in Figure 10. This shuttle is thrown horizontally through the shed, for a distance of approximately five feet, 180 times a minute. The exact shape of the loop of thread from the shuttle is of considerable significance.



ELECTRICALLY SYNCHRONIZED SHUTTER

It is quite easy to arrange a mechanical synchronizer on any type of Compur shutter so that the Strobolux flashes only when the shutter release is operated. A simple spring arrangement is attached to the lens board so that when the shutter cocking lever passes its approximate mid-position, electrical contact between the spring and the lever will be made while the shutter is open. Connection is made to the spring and to the metallic case of the shutter itself. The shutter should be set for some speed between 1/100th and 1/300th of a second.

To synchronize the shutter with the flash it is merely necessary to remove the ground glass and to look through the lens when the camera is pointed toward the Strobolux and release the shutter. If light is seen through the entire lens, synchronization is correct. Any light which reaches the ground glass should be the full flash. If the contacts are not synchronized, rotate the shutter in the mount until the contactor fires the Strobolux at the proper time.

With this type of synchronization the equipment can be operated in any room light that is not sufficiently strong to be photographically objectionable for any ordinary exposure at shutter speeds from 1/100th to 1/300th of a second.

MECHANICAL CONTACTOR ON MOVING SHAFT OR PART

Many applications require exact synchronization between a sequence in a mechanical operation and the exposure. Usually it is possible to fit a simple make-break contactor on a rotating shaft or moving part. By adjusting the position of the contactor the exact moment of flash can be phased accurately with the desired motion. To avoid more than one exposure it is necessary to place a quick acting switch in the single-flash contactor circuit so that this circuit can be opened by hand as soon as one flash has been obtained, unless the subject to be photographed has repetitive motion that will permit a series of flashes as often as the motion repeats itself.

In taking photographs with this type of contactor it is, of course, necessary that the equipment be operated in subdued light since the camera shutter must be operated by hand and is open materially longer than is required for the flash exposure alone.

MECHANICAL IMPACT — DIRECT ELECTRICAL CONTACT

A number of trick photographs, such as the shattering of a glass container full of liquid, can be taken by causing the impact between the falling object and two metallic plates upon which it falls to make the electrical contact

FIGURE 12. Set-up for taking photographs with TYPE 759-A Sound-Level Meter, TYPE 760-A Sound Analyzer, TYPE 631-B Strobotac, and TYPE 648-A Strobolux. The camera shutter is opened and closed by hand; the Strobolux is flashed at any particular frequency of sound selected by the Sound Analyzer.

for the single flash. More practical applications of this simple system are apparent in specific problems.

Two metallic plates are separated by means of crumpled pieces of paper between their corners. A wire is lead from each plate to the CONTACTOR terminals of the Strobotac, and the falling object causes the two plates to make electrical contact and flash the Strobolux. The camera shutter, of course, is opened before the object falls and is closed immediately after the flash. By varying the thickness and size of the paper separating the plates, the phasing of the synchronization can be changed to time the flash to almost any moment desired.

It is usually advisable to cover the plates with a piece of cloth or paper of a color contrasting strongly with the color of the object being photographed.

MECHANICAL IMPACT — BREAKING WIRE

In many cases synchronization can be obtained by stretching a very fine wire across the path of the moving body that is to be photographed. A simple open-circuited telegraph relay is connected to the wire through a battery. When the wire is broken the contacts on the relay *close.* The CONTACTOR wires from the Strobotac are connected to the contacts on the telegraph relay. The sequence is: the camera shutter is opened by hand; the moving object breaks the fine wire, which interrupts the battery voltage on the telegraph relay; the contacts on the relay close; the Strobolux flashes, and the camera shutter is closed by hand. The proper timing can be obtained experimentally in several ways. The physical position of the wire along the path of the moving object can be changed; the tension on the wire can be adjusted so that the wire will break at different times; the pull on the armature of the electromagnet on the telegraph relay can be adjusted over a considerable range; and the total throw of the armature and its contacts can be lengthened or shortened.

ELECTRICAL SYNCHRONIZATION — MICROPHONE

If the mechanical phenomenon to be photographed is accompanied by sound, it is possible to fire the Strobolux in a number of ways with a microphone and an amplifier. Several combinations of microphone pickup and associated equipment are possible; their selection will depend upon the particular application.

MICROPHONE AND AMPLIFIER

Since the output of most microphones is not great enough to trip the Strobo-

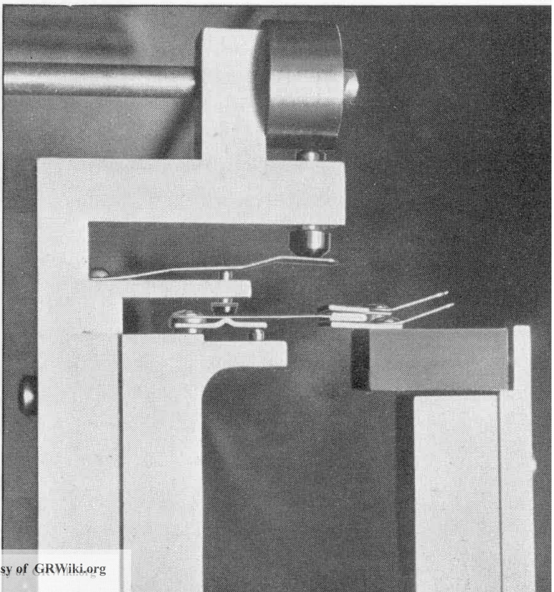


FIGURE 13. Photo courtesy Mu Switch Corporation, Canton, Mass. Another example of the hundreds of practical mechanical applications of single-flash photography. This set-up photograph was used by the Mu Switch Corporation to determine that their switches, once tripped, traversed the distance between contacts; that there were no intermediate positions of equilibrium. A motor-driven cam (at top of photograph) operated the switch and flashed the Strobolux.

tac directly, it is necessary to connect an amplifier between the microphone and the Strobotac. In many applications the General Radio Type 714-A Amplifier has been used successfully.

Through a long flexible cord, the microphone is connected to the input terminals of the amplifier, the output of which is connected to the CONTACTOR terminals on the Strobotac. Whenever a sufficiently strong sound wave strikes the microphone, the Strobolux flashes. Synchronization between the mechanism creating the sound and the flash is obtained by shifting the relative position of the microphone and the subject. Considerable delay between the sound and the single flash can be obtained in this manner.

When sequence photographs of repetitive operations are desired, the sequence can be obtained generally by shifting the position of the microphone between each exposure (and flash) on either a single film or on a series of films.

MICROPHONE AND SOUND-LEVEL METER

Use of the General Radio Type 759-B Sound-Level Meter and Type 760-A Sound Analyzer permits unusually effective single-flash photography when the subject to be photographed generates a sound wave of complex form. The sound is picked up by the Sound-Level Meter and the appropriate frequency component is selected by the Sound Analyzer which then fires the Strobolux only when sound of this particular frequency is present. Many applications of this type are obvious. This method is the only one possible for obtaining single-flash photographs of certain types of machine operations which produce a sound wave of complex form.

PHOTOELECTRIC CELL

If the subject to be photographed can be made to interrupt the beam of light between a photoelectric cell and an amplifier, these instruments can be used successfully to take single-flash pictures. Synchronization between the moving subject and the single flash is obtained by varying the distance between the subject and its position when it interrupts the beam. As the output from photoelectric cells is quite small, an amplifier is required to build up a sufficient voltage to operate the Strobotac.

DARKROOM MANIPULATIONS

The darkroom procedure in handling single-flash pictures differs only slightly from the normal photographic practice. As the illumination from the Strobolux is generally quite low and as most users employ only a single unit with correspondingly low light contrasts on the subject, the developing formula used for films should be of the maximum contrast type. Developers ordinarily used for positive motion picture film build up contrast quite satisfactorily. An increase of 50% to 100% in development time is also recommended for increasing the contrast.

Correspondingly, in a number of cases the contact or enlarging paper from which prints are made should be of maximum contrast grade.

— John M. Clayton

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also

IN THIS ISSUE

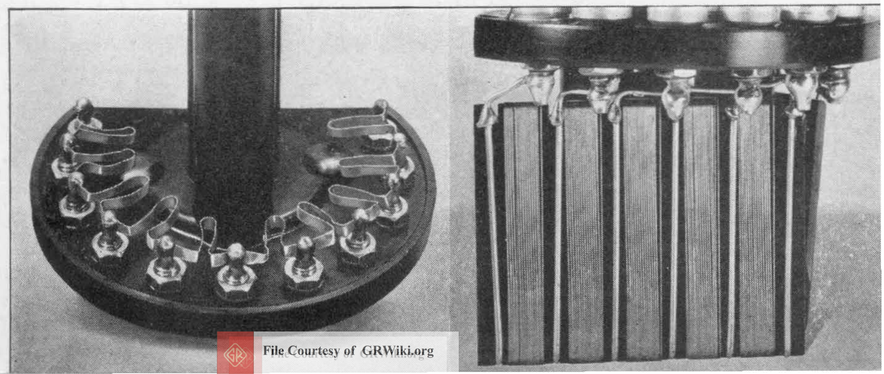
RADIO-FREQUENCY CHARACTERISTICS OF DECADE RESISTORS

● **FOR GENERAL MEASUREMENTS** at commercial and audio frequencies, decade resistors have been found invaluable laboratory tools. In these low-frequency applications their reactance components are usually negligible, and they consequently approach closely the ideal resistance standards desired for lumped-parameter circuits.

As the frequency increases, their reactance components become comparable with the resistance components, and the residual inductance and capacitance combine to change the effective terminal resistance from its low-frequency value. This change in resistance is generally augmented by skin-effect, and the general characteristics of the resistor deviate more and more widely from the ideal.

For many applications, however, the deviations from the ideal are not sufficiently important to offset the convenience and flexibility that are characteristic of decade resistors. The data contained in this article are presented to enable users of General Radio decade resistors to estimate the degree of departure from the ideal and to make corresponding corrections. They were taken with an experimental

FIGURE 1. (*Left*) Bifilar winding used on 0.1 Ω decades. (*Right*) Ayrton-Perry winding used on 1 Ω, 10 Ω, and 100 Ω decades.



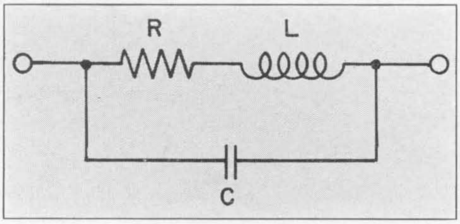


FIGURE 2. Equivalent circuit of a resistor having residual inductance and capacitance.

model of a new radio-frequency bridge[1] and, because of the improved technique that has been developed, are more accurate than previously published data.[2] This is particularly true of the resistance values, which formerly were extrapolated from low-frequency measurements and which are now measured directly at the high frequencies.

ANALYSIS

The approximate equivalent circuit commonly used to represent a resistor having residual inductance and capacitance is shown in Figure 2.

The expressions for the effective terminal resistance, R_e, and reactance, X_e, of this circuit are:[3]

$$R_e = \frac{R}{(1 - \omega^2 LC)^2 + (\omega CR)^2} \qquad (1)$$

$$X_e = \frac{\omega[L(1 - \omega^2 LC) - CR^2]}{(1 - \omega^2 LC)^2 + (\omega CR)^2} \qquad (2)$$

At low frequencies, where the terms in ω^2 are negligibly small, the effective resistance, R_e, is simply equal to the nominal resistance, R. The effective reactance, X_e, is equal to that of a constant effective inductance $[L - CR^2]$. For low resistance values the CR^2 term is negligible and the reactance positive; for high resistance values it is predominant and the reactance negative. In either case the reactance varies directly as the frequency.

At high frequencies, the terms in ω^2 become important and both the effective resistance and the effective inductance vary with frequency. For low resistance values the $(\omega CR)^2$ term is negligible and the effective resistance and inductance increase with frequency because of the resonance between L and C; for high resistance values the $(\omega CR)^2$ term is

---

[1] D. B. Sinclair, "A Radio-Frequency Bridge for Measurements at Frequencies from 400 kc to 60 Mc," *Proc. I. R. E.*, Vol. 28, No. 10, Nov. (1940).

[2] R. F. Field, "Frequency Characteristics," General Radio *Experimenter*, Vol. 6, No. 9, p. 1; Feb. (1932).

[3] These expressions are presented in normalized form in the General Radio *Experimenter*, Vol. 8, No. 8, p. 6; Jan. (1939) with families of curves in terms of the parameter $D_0 = R/\sqrt{\frac{L}{C}}$ and variable $\omega/\omega_0 = \omega\sqrt{LC}$. Because of the wide variation in D_0 and ω_0 in decade resistors, however, the expressions are more convenient in the form shown here.

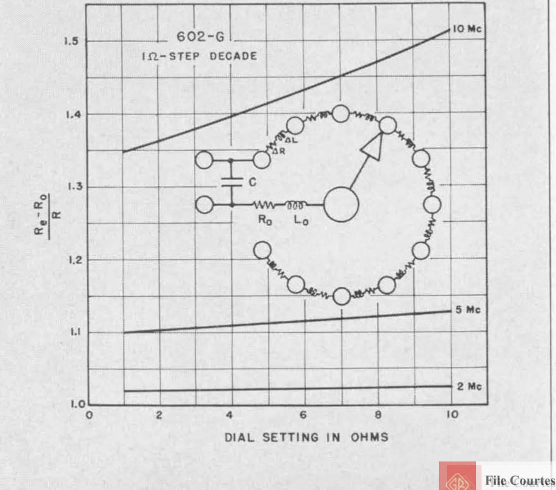


FIGURE 3. Plot of change in resistance of 1 Ω-step decade of TYPE 602-G Decade Resistance Box at frequencies of 2, 5, and 10 Mc. The values plotted refer to the change in resistance from zero setting. To obtain the absolute resistance, the zero resistance, R_0, must be added. The percentage increase varies approximately as the square of the frequency; the zero resistance varies approximately as the square root of the frequency. In the approximate equivalent circuit shown:

$\Delta R = 1\ \Omega$ (nominal)
$L_0 = 310 \times 10^{-9}$ h
$\Delta L = 52 \times 10^{-9}$ h per step
$C = 27 \mu\mu$f
$R_0 = 0.05\ \Omega$ at 2 Mc
0.09 Ω at 5 Mc
0.013 Ω at 10 Mc

The skin-effect in the resistance cards of this decade is approximately:

1.6% at 2 Mc
8.8% at 5 Mc
25% at 10 Mc

predominant, and the resistance and inductance decrease with frequency because of the shunting effect of *C*.

Proper proportioning of the residual parameters, *L* and *C*, for a given resistance value, will lead to the best design for a single fixed resistor and even to the best compromise design for a line of fixed resistors.[4] For a decade resistor, however, in which the resistance range is relatively large, the effect of the residual parameters can only be minimized by making the residual parameters themselves as small as possible.

TYPE 602-G DECADE-RESISTANCE BOX

At radio frequencies the resistance values most commonly encountered usually lie in the range from 1 Ω to 1000 Ω. The Type 602-G Decade-Resistance Box, which covers this range in three decades, was therefore chosen as representative.

In Figure 3 is shown the variation in resistance of the 1 Ω-step decade at frequencies of 2, 5, and 10 Mc. For convenience, the resistance change from zero dial setting to any other dial setting is expressed as a fraction of the nominal resistance at the final dial setting. The plot is therefore really of incremental resistance and is particularly useful when the resistor is left in circuit at all times and is varied to alter circuit conditions. The zero resistance, R_0, which arises in the wiring, must be added to the value indicated in Figure 3 to obtain the absolute terminal resistance at any setting.

The behavior of the equivalent circuit shown, with the constants listed in the caption, approximates closely that of the actual decade, both for resistance and reactance.

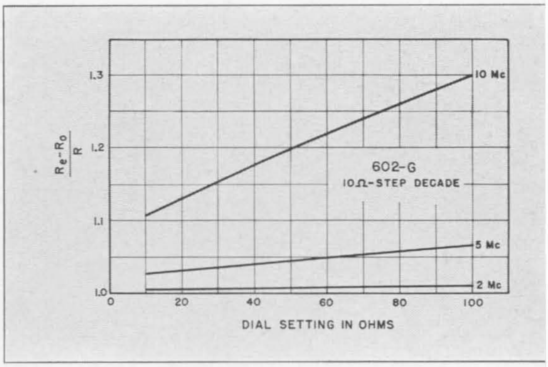


Figure 4. Plot of change in resistance of 10 Ω-step decade of Type 602-G Decade Resistance Box at frequencies of 2, 5, and 10 Mc:

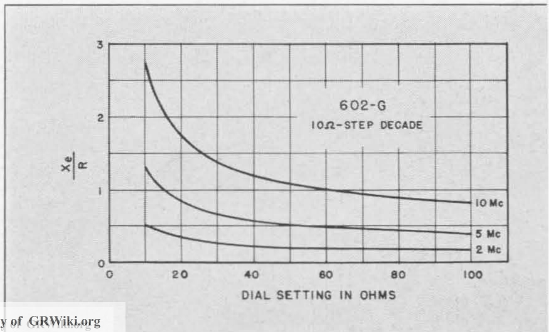
$\Delta R = 10\ \Omega$ (nominal)
$L_0 = 310 \times 10^{-9}$ h
$\Delta L = 110 \times 10^{-9}$ h per step
$C = 26.0 - 23.5\ \mu\mu$f
$R_0 = 0.05\ \Omega$ at 2 Mc
$0.09\ \Omega$ at 5 Mc
$0.13\ \Omega$ at 10 Mc

The skin-effect in the resistance cards of this decade is approximately:

0.0% at 2 Mc
0.3% at 5 Mc
1.2% at 10 Mc

The reactance, for all practical purposes, is that of an inductance equal to the sum of the zero inductance, L_0, which arises in the wiring, and the inductance of the resistance cards. The inductance of a card, $\triangle L$, is essentially independent of its location in the decade and is therefore listed as a constant value. For this decade, variations in the capacitance, *C*, could not be accurately deduced from the observed measurements and it is therefore assumed independent of switch setting.

Figure 5. Plot of ratio of reactance to nominal resistance of 10 Ω-step decade of Type 602-G Decade Resistance Box at frequencies of 2, 5, and 10 Mc.



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[4] See D. B. Sinclair, "The Type 663 Resistor — a Standard for Use at High Frequencies," General Radio *Experimenter*, Vol. 8, No. 8, p. 6; Jan. (1939). [Footnote 3.]

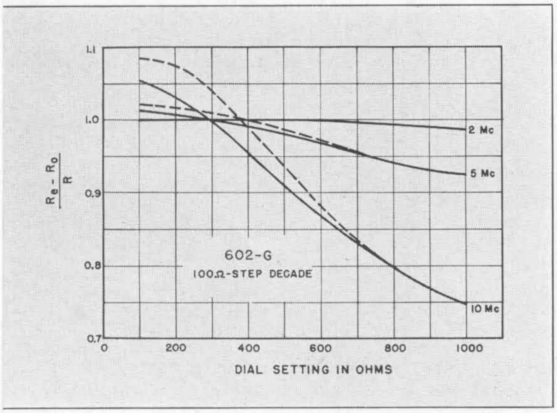


FIGURE 6. Plot of change in resistance of 100 Ω-step decade of TYPE 602-G Decade Resistance Box at frequencies of 2, 5, and 10 Mc. The solid curves represent measured values. The dotted curves are based on the following constants:

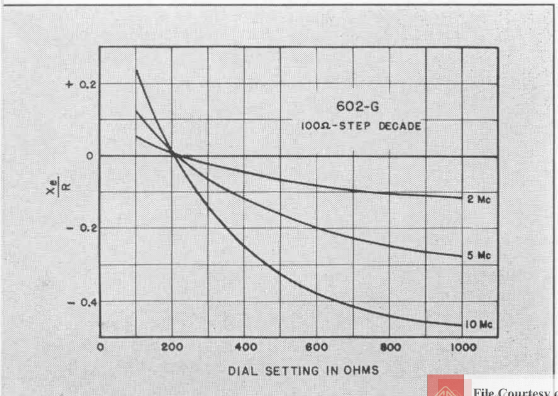
$\Delta R = 100\ \Omega$ (nominal)
$L_0 = 310 \times 10^{-9}$ h
$\Delta L = 287 \times 10^{-9}$ h per step
$C = 21.0 - 12.7\ \mu\mu$f
$R_0 = 0.05\ \Omega$ at 2 Mc
$0.09\ \Omega$ at 5 Mc
$0.13\ \Omega$ at 10 Mc

The skin-effect in the cards of this decade is negligible.

The rise in resistance at a setting of 1 Ω is largely caused by skin-effect, the further rise as the resistance is increased being caused by resonance between the residual inductance and capacitance.

In Figures 4 and 5 are shown curves of effective resistance and reactance for the 10 Ω-step decade. The skin-effect for this decade is much less than for the 1 Ω decade, and the resistance rise shown is largely caused by resonance at all settings. The relatively large rise at the 10 Ω setting occurs because the zero inductance in the wiring is considerably larger than that of the card itself.

FIGURE 7. Plot of ratio of reactance to resistance of 100 Ω-step decade of TYPE 602-G Decade Resistance Box at frequencies of 2, 5, and 10 Mc.



For convenience, the effective reactance is expressed as a fraction of the corresponding nominal resistance. The reason that the reactance curves rise at the low-resistance settings is again that the zero inductance in the wiring is large compared with the inductance of a card and so contributes proportionately more to the over-all inductance at low settings.

The listed circuit constants, when used in the equivalent circuit of Figure 3, yield a close approximation to the observed measurements of both resistance and reactance. To a first approximation the effective capacitance, for this decade, is found to vary linearly, as a function of dial setting, from 26.0 $\mu\mu$f, at a setting of 10 Ω, to 23.5 $\mu\mu$f, at a setting of 100 Ω. This comes about because capacitance from the resistance cards to ground is less effective when they are active than when they are out of circuit.[5] As the resistance increases, therefore, the capacitance decreases. It is lower, in general, than it is for the 1 Ω-step decade, because any capacitance to ground in that decade, which is between the 10 Ω-step decade and ground, is short-circuited.

In Figures 6 and 7 are shown curves of effective resistance and reactance for the 100 Ω-step decade. The resistance, for low settings, rises above the d-c value because of resonance. As the resistance increases, however, the terms containing R in Equation (1) become predominant, and the resistance drops because of

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[5] Because of the voltage distribution, the effective capacitance of the cards in circuit to ground is of the order of 1/3 of their total capacitance to ground.

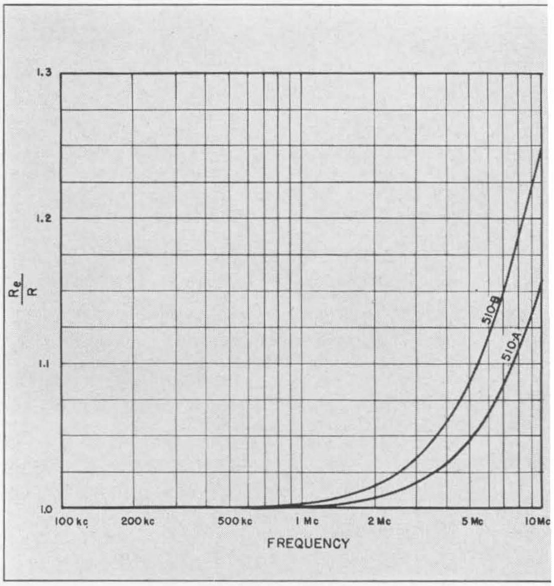


FIGURE 8 (*right*). Resistance rise of **TYPE** 510 Decade Resistance Units caused by skin-effect. For the 0.1 Ω-step unit (**TYPE** 510-A) and the 1 Ω-step unit (**TYPE** 510-B) the variation of resistance with frequency is almost entirely caused by skin-effect and is consequently independent of dial setting. The equivalent circuit constants are:

	510-A	510-B
ΔR	0.1 Ω	1 Ω (nominal)
L_0	22.6×10^{-9} h	22.6×10^{-9} h
ΔL	13.7×10^{-9} h	55.6×10^{-9} h

The zero resistance, R_0, for these units is about 0.01 Ω at 10 Mc.

the shunting effect of C. For the same reason the reactance, which is positive for low values of resistance, becomes negative for high values. The skin-effect for the resistance cards of this decade is negligible.

The values of the listed circuit constants, when applied to the equivalent circuit of Figure 3, give close agreement with the measured reactance and with the measured resistance at high-resistance settings. At low-resistance settings, however, the computed resistance deviates from the measured resistance as shown in the dotted curve of Figure 6. This deviation arises because the displacement currents to ground from the inactive cards in the 100 Ω-step decade pass first through the resistances of these cards as conduction currents. The consequent power loss is relatively great and causes a resistance shunting effect that decreases the effective resistance from the value it would have if the capacitance were loss-free.[6] The effect is a maximum at resistance settings of 200 and 300 ohms. For higher resistances the discrepancy decreases because the inactive cards become fewer; for lower resistances the discrepancy decreases because the resistance goes down more rapidly than the effective shunting resistance.[7]

FIGURE 9 (*below*). Plot of change in resistance of 10 Ω-step unit (**TYPE** 510-C) at frequencies of 5 and 10 Mc:

$\Delta R = 10$ Ω (nominal)
$L_0 = 22.6 \times 10^{-9}$ h
$\Delta L = 110 \times 10^{-9}$ h
$C = 7.7 - 4.5$ μμf
$R_0 = 0.004$ Ω at 2 Mc
0.007 Ω at 5 Mc
0.004 Ω at 10 Mc

The skin-effect in the resistance cards of this decade is approximately:
0.0% at 2 Mc
0.3% at 5 Mc
1.2% at 10 Mc

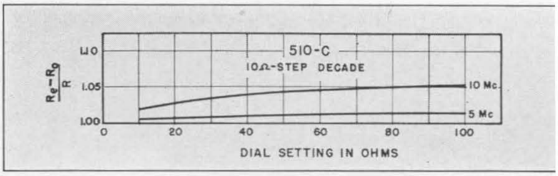
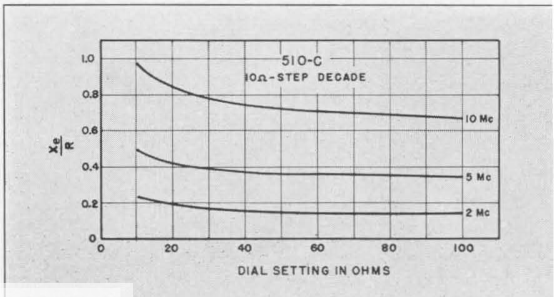


FIGURE 10 (*below*). Plot of ratio of reactance to nominal resistance of 10 Ω-step unit (**TYPE** 510-C) at frequencies of 2, 5, and 10 Mc.



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[6] See, for instance, Jones & Josephs, *Journal American Chemical Society*, Vol. 50, p. 1049, 1928, for a discussion of this "hung on" effect at low frequencies.

[7] Some discrepancy between computed and measured resistance would still be expected at the high-resistance settings of the 10 Ω-step decade. That this was not explicitly noted is ascribed to the necessarily approximate nature of the equivalent circuit and the method of deducing the values of L and C for use with it.

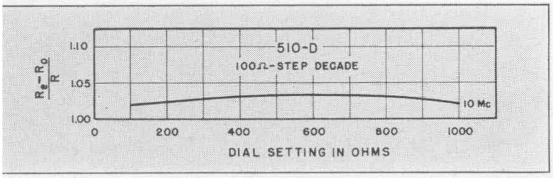


FIGURE 11. Plot of change in resistance of 100 Ω-step unit (TYPE 510-D) at a frequency of 10 Mc:

$\Delta R = 100\ \Omega$ (nominal)
$L_0 = 22.6 \times 10^{-9}$ h
$\Delta R = 287 \times 10^{-9}$ h
$C = 7.7 - 4.5\ \mu\mu f$
$R_0 = 0.004\ \Omega$ at 2 Mc
$0.007\ \Omega$ at 5 Mc
$0.01\ \Omega$ at 10 Mc

The skin-effect in the resistance cards of this decade is negligible.

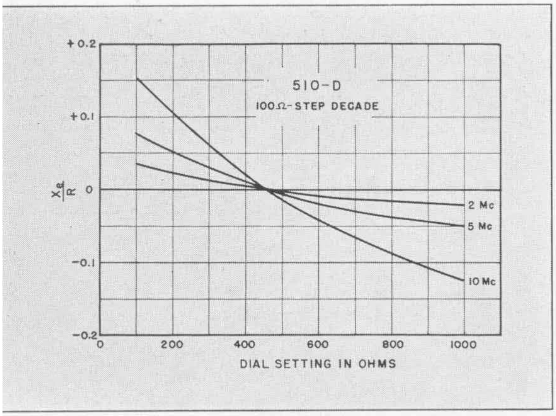


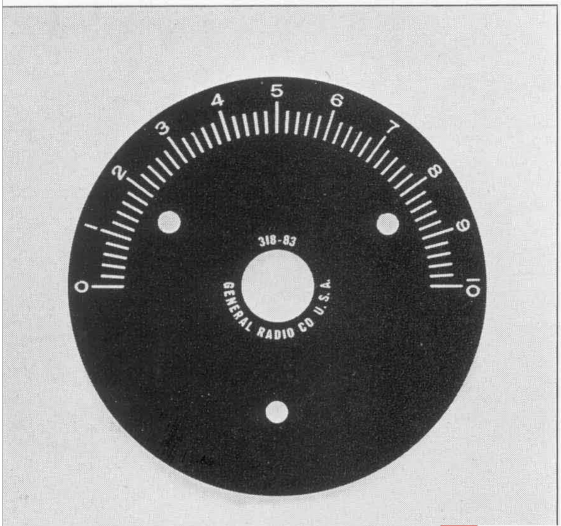
FIGURE 12. Plot of ratio of reactance to nominal resistance of 100 Ω-step unit (TYPE 510-D) at frequencies of 2, 5, and 10 Mc.

It should be emphasized that when resistance in more than one decade is being used, the plotted results cannot be combined directly because of the interaction between the residual parameters in the various decades. To a first approximation, however, the sum of the reactances can be assumed equal to the total reactance, and the multiplying factor for the resistance setting in the higher decade can be applied to the sum of the resistance settings.

The variations in resistance and reactance of the TYPE 510 Decade-Resistance Units that are used in the TYPE 602 Decade-Resistance Boxes are plotted in Figures 8 to 12. In general the variations follow the same pattern as those for the corresponding decades in the decade-resistance boxes, but the variations in resistance and the magnitudes of the reactance are less because the capacitance and wiring inductance are much reduced. They were measured without shield cans in order to make this reduction of capacitance as great as possible.

—D. B. SINCLAIR

NEW DIAL PLATE



● **THE NEW** TYPE 318-C Dial Plate, shown here, is intended for use with air condensers, variometers, and other variable circuit elements having a 180-degree angle of rotation. The scale progresses in a counterclockwise direction and has ten main divisions, each of which is divided into five small divisions.

The scale is photo-etched with raised

View of the TYPE 318-C Dial Plate.

nickel-silver graduations on a flat black background. The diameter of the plate is three inches. It can be used with a 1⅝-inch knob, either skirted or with pointer. The center hole will clear a ⅜-inch shaft.

Net Weight: ¾ ounce.

Type		*Price*
318-C	....	**$0.35**

USING THE VARIAC AT LOW FREQUENCIES

● **ALTHOUGH VARIACS** are designed for 60-cycle service, they can be used at lower frequencies provided the ratings are reduced.

Standard ratings are for 60 cycles, but an adequate margin is allowed so that the full 60-cycle rating can be obtained at 50 cycles. For frequencies lower than 50 cycles the voltage applied should be less than the rated voltage of the Variac in the same ratio as the reduction in frequency. For instance a 230-volt, 60-cycle Variac can be used on a 115-volt, 25-cycle line. The current rating remains unchanged and the volt-ampere rating is consequently halved.

Used at 25 cycles, the ratings for the 230-volt, 60-cycle Variacs are as shown in the table below.

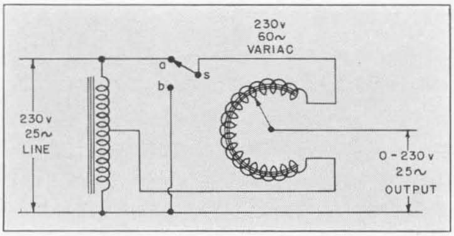


FIGURE 2. Circuit for handling more power than is possible with that of Figure 1.

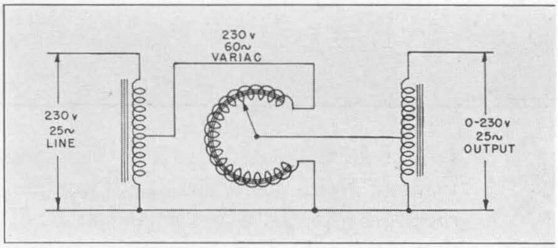


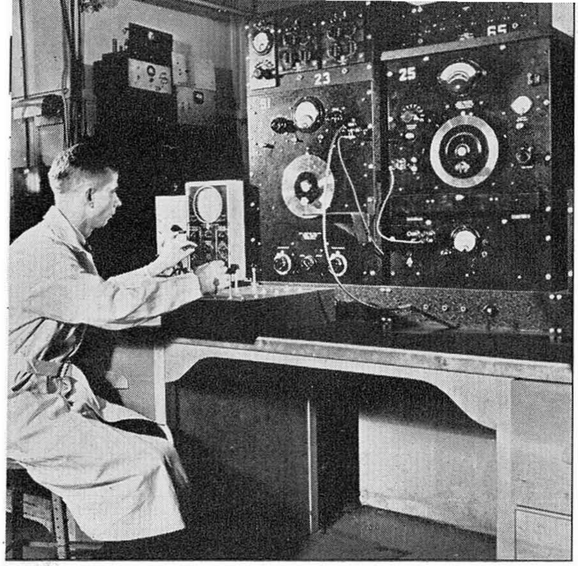
FIGURE 1. Showing how autotransformers are used with a Variac on 230-volt, 25-cycle circuits.

When it is desired to control a 230-volt line at 25 cycles, auxiliary transformers can be used.

Figure 1 illustrates the use of two auxiliary transformers, one for stepping down the input voltage to the Variac and the other for stepping up the output voltage from the Variac. Figure 2 illustrates a method for obtaining nearly twice the power output obtainable in Figure 1. With the switch "S" in position "b" the output may be controlled from 0-115 volts, while in position "a" control is from 115 to 230 volts. If the switching is done while the brush is at the end connected to the center tap of the auxiliary transformer, there will be no discontinuity in the output voltage, since the Variac is then effectively out of circuit.

— S. A. BUCKINGHAM

Type	*Load Rating*	*Input Voltage*	*Output Voltage*	*Output Current*	
				Rated	*Maximum*
200-CUH **200-CMH**	290 va	115 v	0-135 v	5 a	7.5 a
100-R	1 kva	115 v	0-135 v	9 a	9 a
50-B	3.5 kva	115 v	0-135 v	20 a	31 a



MISCELLANY

● **THIS PHOTOGRAPH** was recently made in the new engineering and research laboratories of Chrysler Corporation and illustrates one of the many uses that instruments designed for electrical communication are finding in industrial research laboratories. The beat-frequency oscillator, wave analyzer, attenuators, oscillograph, and other instruments shown here are used in the analysis of vibrations occurring in a moving automobile.

● **A PAPER** entitled, "The Measurement of Noise and Vibration," was presented by H. H. Scott at the I. R. E. Convention in Los Angeles in August. A longer technical talk on the same subject was delivered by Mr. Scott at Portland, Oregon, and Seattle, Washington, in September, and at Cincinnati and Cleveland, Ohio, in October.

Robert F. Field spoke before the Electrical Equipment Committee of the Pennsylvania Electric Association on October 15. His subject was "The Basis for Non-Destructive Testing of Insulation."

● **M. T. SMITH,** formerly in charge of our Los Angeles office, delivered a paper, entitled "The Twin-T Network, a New Type of Null Instrument for Measurements of Impedance up to Thirty Megacycles," at the October 15 meeting of the Los Angeles Section of the I.R.E. Frederick Ireland, now in charge of the Los Angeles office, spoke at the November 13 meeting of the San Francisco Section. His subject: "Comments on Recent Technical Developments and Current Problems." A film of manufacturing operations in the General Radio plant was shown.

THE General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in communication-frequency measurement and control problems. When sending requests for subscriptions and address-change notices, please supply the following information: name, company name, company address, type of business company is engaged in, and title or position of individual.

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