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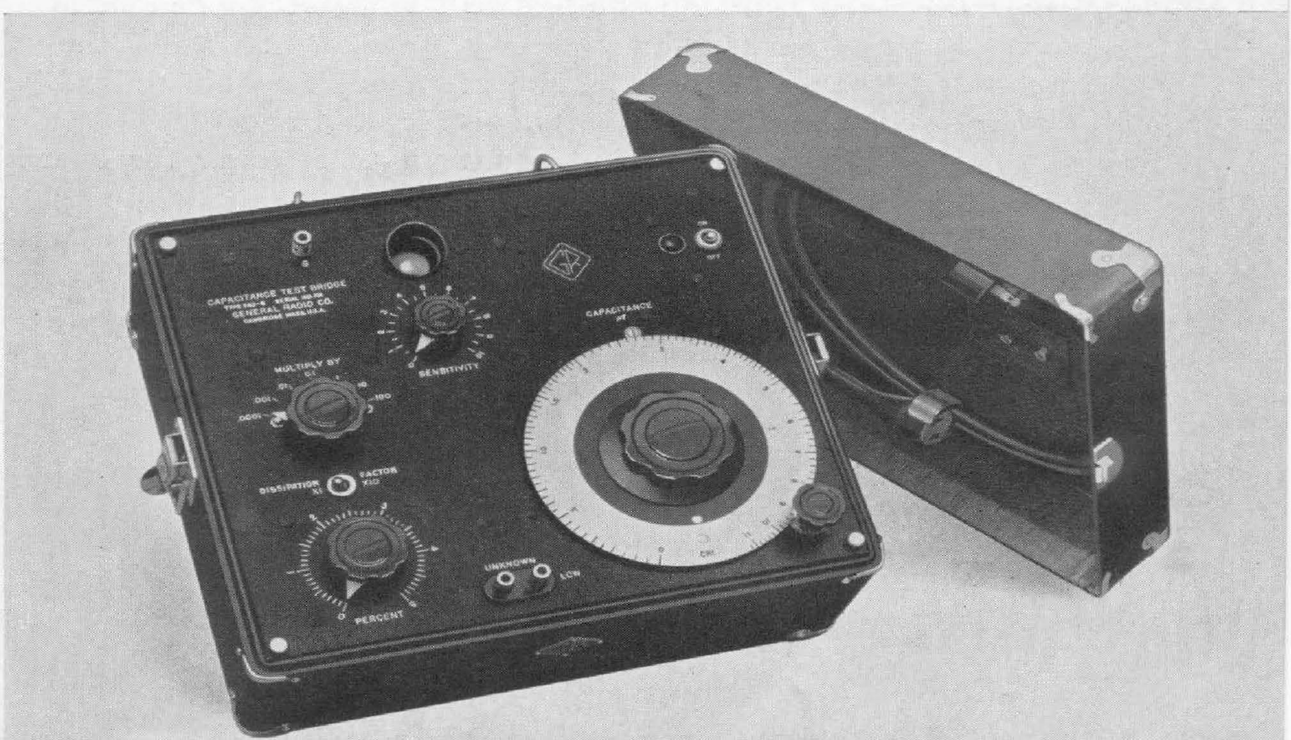
ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also IN THIS ISSUE

A WIDE-RANGE CAPACITANCE TEST BRIDGE

● THE OUTSTANDING FEATURES of the new Type 740-B Capacitance Test Bridge are its accuracy, portability, simplicity of operation, and wide range of capacitance and dissipation factor — features which make the bridge suitable for industrial use. The bridge is intended for use (1) by the condenser manufacturer or user for checking paper, electrolytic, and mica condensers; (2) by cable and insulated-wire manufacturers for measuring specific inductive capacity, direct and mutual capacitance between conductors, and capacitance between conductors and shields; (3) by transformer manufacturers for measuring winding capacitances and capacitances between winding and case; (4) by spark-plug manufacturers for checking spark-plug capacitance in the production line; and (5) in general capacitance testing.

Figure 1. Panel view of the Type 740-B Capacitance Test Bridge with cover removed



In this new bridge a visual indicator replaces the earphone method of null indication. In industry earphones are prohibited because they are too fatiguing to the operator and because they are unsuitable in the presence of the high noise levels existing in most factories. The Type 740-B Capacitance Test Bridge with its visual indicator overcomes these difficulties and offers in addition the utmost in simplicity of operation.

SIMPLICITY

Every effort has been made to minimize the number of controls and to keep manipulation as simple as possible. Referring to the panel photograph, Figure 1, the only dials are the capacitance dial and multiplier switch, which read directly in capacitance; the direct-reading dissipation factor dial; and a sensitivity dial which allows the operator to adjust the sensitivity of the visual indicator to any desired value. Batteries and external or internal oscillators are avoided, and, being designed for 60-cycle operation, the bridge can be set up and operated at any location where a 115-volt, 60-cycle line is available.

To make the bridge entirely suitable for portable use, it is mounted in a light carrying case, of airplane-luggage construction, with cover and handle, so that it can be carried anywhere without damage to knobs, dials, or other important parts. The construction is so rugged that there is little danger of damage, even in inexperienced hands.

Five micromicrofarads to 1100 microfarads for capacitance and 0 to 50% for dissipation factor are the ranges of the bridge — ranges which make it suitable for almost every industrial or laboratory application. At one end of this range is the cable and wire manufacturer, who is generally interested in measurements below 1000 micromicrofarads, and at the other end is the electrolytic condenser manufacturer, who is interested only in capacitances of the order of 10, 100, and 1000 microfarads.

The loss balance control of the bridge is calibrated in per cent dissipation factor ($R\omega C$), and all references to this loss factor will be made in terms of dissipation factor rather than power factor. This is because dissipation factor and power factor equal each other only for values less than 10%. Therefore, in view of the 0-to-50% range of the bridge, it would be a misnomer to refer to the loss factor as anything but dissipation factor.*

THE BRIDGE CIRCUIT

The bridge circuit is shown in Figure 2. The standard arm consists of a fixed condenser in series with a variable resistor. One ratio arm is variable in decade steps and the other is continuously variable and calibrated directly in capacitance.

The power for operating the bridge

*See Table 1, page 7.

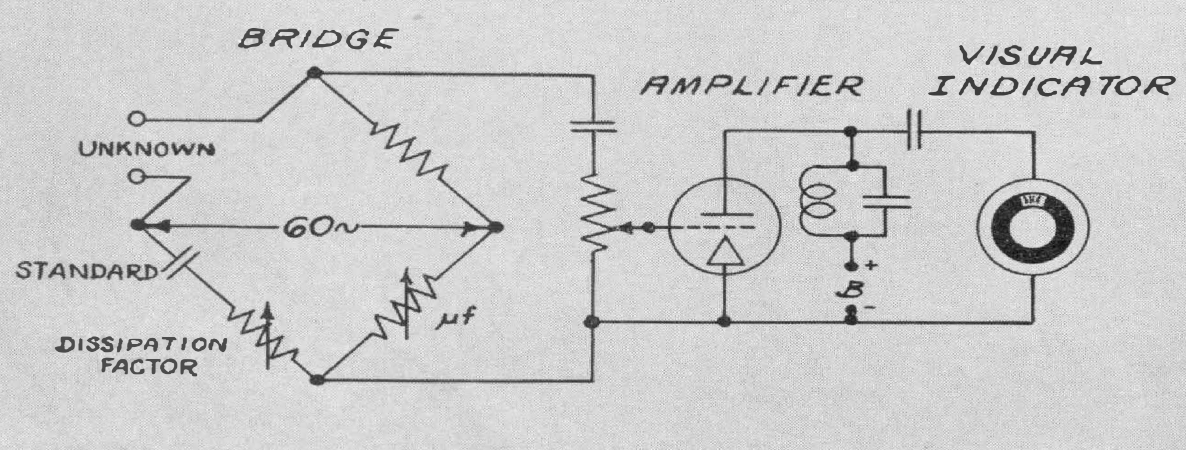


Figure 2. Simplified wiring diagram of the Type 740-B Capacitance Test Bridge.

circuit is obtained from the 60-cycle line through a shielded isolating transformer. Care was taken in the design and construction of this power transformer to insure complete isolation of the bridge circuit from any variations that might occur in the supply line and to insure a minimum of capacitance between generator terminals and ground. These precautions are necessary in order to maintain the high degree of accuracy of which the bridge itself is capable.

The voltage impressed across the UNKNOWN terminals varies continuously with the bridge setting. For very small capacitances measured on the .0001 capacitance range, the voltage across the unknown condenser is approximately 35 volts, and with increasing capacitance the voltage decreases, so that at 100 microfarads the voltage is approximately one volt.

THE AMPLIFIER AND NULL INDICATOR

The problems involved in obtaining a satisfactory visual null indicator are considerably more exacting than those in obtaining a suitable acoustical indicator. For the acoustical method of balance, the ear can tolerate the presence of considerable harmonic distortion and extraneous electrical noise without materially reducing the accuracy to which the balance can be obtained. In this bridge, an electron-ray tube (the so-called magic eye) is used as a detector. With this type of visual indicator, however, the presence of harmonics or electrical noise causes the "eye" at balance to appear fuzzy, and unless these noises and harmonics are filtered out, a sharp, accurate balance is impossible.

By using a high-gain amplifier and a sharply tuned filter circuit, a visual null indicator having the sensitivity of the amplifier-earphone combination has been obtained. The schematic diagram, Figure 2, shows the connections of the detector circuit. The sensitivity potentiometer controls the gain of the amplifier and hence controls the sensitivity of the visual indicator. This sensitivity control is extremely useful when the full sensitivity of the bridge is not desired or when the bridge is being used as a limit indicator.

RANGE AND ACCURACY

The capacitance readings of the bridge are taken from the settings of a seven-point decade multiplier switch and a six-inch dial having a scale which is approximately logarithmic over one decade. For capacitance the bridge is direct reading from 5 micromicrofarads to 1100 microfarads, and its accuracy over most of this wide range is within ±1%.

Dissipation factor readings are taken from a dial which is linear in dissipation factor over two ranges, one of 0 to 5% marked in divisions of 0.1% and the other of 0 to 50% marked in divisions of

FIGURE 3. As shown, the capacitance test bridge is small, light in weight, and easy to carry.

1%. The dissipation factor range chosen is selected by a toggle switch. The accuracy of dissipation factor readings over practically the entire range of the bridge is within ±¾ of one of the smallest scale divisions. This means that on the 0-to-5% dissipation factor range the error in dissipation factor reading is ±0.075%, and on the 0-to-50% range the accuracy is to within ±0.75%.

60-CYCLE MEASUREMENTS

Intended for industrial use, the new Type 740-B Capacitance Test Bridge was of necessity designed for 60-cycle operation. To the cable, transformer, and electrolytic condenser manufacturer 1000-cycle measurements have been of little value, since much of the equipment manufactured in these industries is intended for low-frequency operation.

Neither of the UNKNOWN terminals is actually connected to ground, although at balance the low terminal of the bridge is effectively at ground potential. Having both terminals ungrounded makes it possible to use the bridge for (1) direct capacitance measurements between transformer windings and between conductors in multi-conductor cables, and (2) for direct measurements of the direct and mutual capacitance between conductors and shields and between transformer windings and cases.

Figure 4. The capacitance test bridge set up for the rapid testing of mica condensers.

Specific inductive capacity and its change with moisture absorption are other measurements which can be made, and because of the extremely wide range of the bridge it can even be used for making these measurements on standard 10-foot test samples of insulated wire.

POLARIZING VOLTAGE FOR ELECTROLYTIC CONDENSER MEASUREMENTS

In the standard Type 740-B Capacitance Test Bridge no provision has been made for the connection of a d-c polarizing voltage. Terminals for the connection of a polarizing voltage have been purposely left off, so as to keep the bridge free from terminals which are not always required and which may be confusing to the inexperienced operator. The bridge circuit, however, is so arranged that a d-c polarizing voltage up to 500 volts can be applied, and, for those who are interested in using the bridge for checking electrolytic condensers, special bridges can be supplied with terminals for introducing a polarizing voltage. Figure 5 shows the manner in which the d-c polarizing voltage can be introduced in the circuit.

USE AS A LIMIT BRIDGE

The visual indicator makes it possible to use the bridge for production condenser testing. After a single preliminary adjustment, one condenser after another can be placed across the UNKNOWN terminals and the electric eye will indicate immediately whether or not each condenser is within the allowed tolerance. When the bridge is so used, capacitance checks are made almost instantly and without requiring any careful meter reading or dial adjustment.

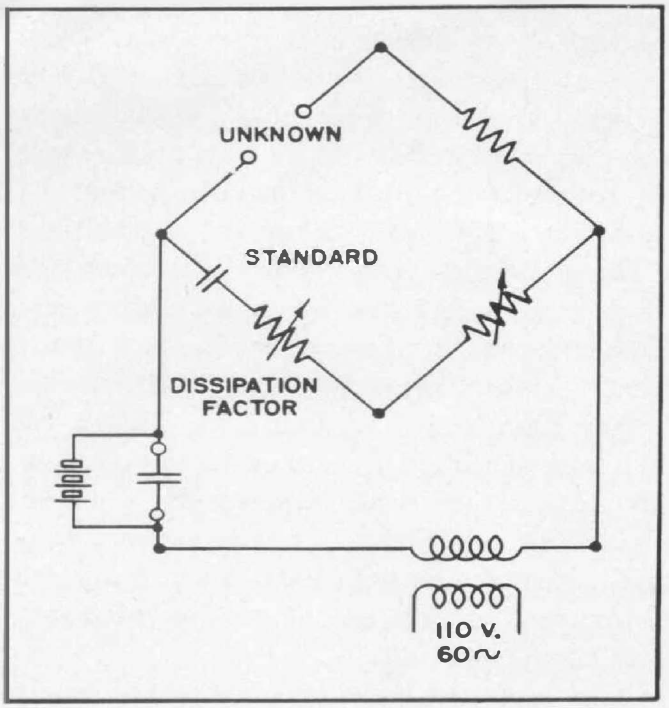


FIGURE 5. Circuit showing method of introducing polarizing voltage.

This capacitance test bridge sets a new standard for accuracy, ruggedness, portability, and simplicity, and makes commercially available a capacitance measuring instrument suitable for production use, as well as routine laboratory measurements. — L. E. PACKARD

SPECIFICATIONS

Power Supply: 115 volts, 60 cycles.

Power Input: 15 watts.

Vacuum Tubes: One each of types 6X5, 6J7, 6E5; all are supplied with the bridge.

Mounting: Portable carrying case.

Net Weight: 19 pounds.

Dimensions: (Length) 14½ x (width) 15 x (height) 9¼ inches, over-all, including cover and handles.

Type		*Code Word*	*Price*
740-B		BABEL	$140.00
Extra terminals installed for polarizing voltage			10.00

This instrument is licensed under 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

A 60-CYCLE SCHERING BRIDGE

● **MEASUREMENTS OF THE DIELECTRIC PROPERTIES** of insulating materials are acquiring a constantly increasing importance to industry. These measurements include not only the testing of materials used as dielectrics in capacitors, and as insulation in transformers, cables, and electrical machinery, but also a multitude of tests on ceramic, fabric, and paper products to determine their composition, moisture content, and the effects of temperature, humidity, and voltage gradient upon them. For such measurements, it is desirable that the necessary bridge equipment be simple and capable of rapid routine measurements. Since much of the material so tested is for use at commercial power frequencies, it is convenient to use the a-c line as a source of bridge power, which eliminates the need for a separate oscillator.

The TYPE 671-A Schering Bridge is designed for this sort of measurement. The power source may be any 115-volt, 60-cycle line.* The voltage across the unknown capacitor can be varied continuously from zero to ten times line voltage by means of a potentiometer and input transformer. A meter is provided, reading in kilovolts the rms potential applied to the bridge and, essentially, to

*The bridge will operate at any frequency between 40 and 60 cycles.

the unknown capacitor. Both the input and output transformers are astatically wound, and the bridge is electrostatically shielded, so that external 60-cycle fields do not affect the measurements. Certain sources of error, difficult to eliminate in a direct-reading type of Schering bridge, are avoided in this bridge by using a substitution method of measurement.

The bridge network consists of two fixed equal resistance arms, R3 and R4 (see Figure 2), shunted by the capacitors, C3 and C4, and two capacitance arms, one containing a fixed capacitor, C1, and the other a standard capacitor, C21, and its trimmer, C22. The unknown external capacitor is connected in parallel with the standard, C21. A suitably shielded and resonated transformer joins the bridge network to some form of null-balance detector not included in the bridge. The junction of the capacitance arms, the metallic housing cabinet, and one terminal of the unknown capacitor are grounded in operation. The input transformer isolates the bridge from grounds in the power supply.

In the TYPE 671-A Schering Bridge the *capacitance balance* is made by means of a TYPE 722 Precision Condenser, C21, the scale of which reads directly the capacitance, C_x, of the unknown capacitor. This scale is calibrated in steps of 0.2 $\mu\mu$f. The maximum capacitance is 1020 $\mu\mu$f. Unknown capacitors of larger value than 1020 $\mu\mu$f may be measured indirectly by a series substitution method. The precision of absolute C_x values measured on this bridge is better than 0.1% of full scale value, or ± 1 $\mu\mu$f. Small differences between two capacitors, or small changes in a given capacitor with time, temperature, humidity, voltage gradient, etc., may be determined with an accuracy of from ± 0.1 to ± 0.3 $\mu\mu$f.

The *resistive balance* of this bridge is accomplished by a separate variable capacitor, C4, the scale of which is calibrated, at 60 cycles, in terms of the function:*

$$S = D_x C_x$$

in which C_x is the capacitance in micromicrofarads and D_x the dissipation factor of the unknown capacitor. The S scale is, therefore, calibrated in micromicrofarad units. The dissipation factor, defined as the ratio of resistance to reactance and hence a pure number, is numerically equal to:

$$D = R_x \omega C_x$$

*A correction factor must be applied for other frequencies.

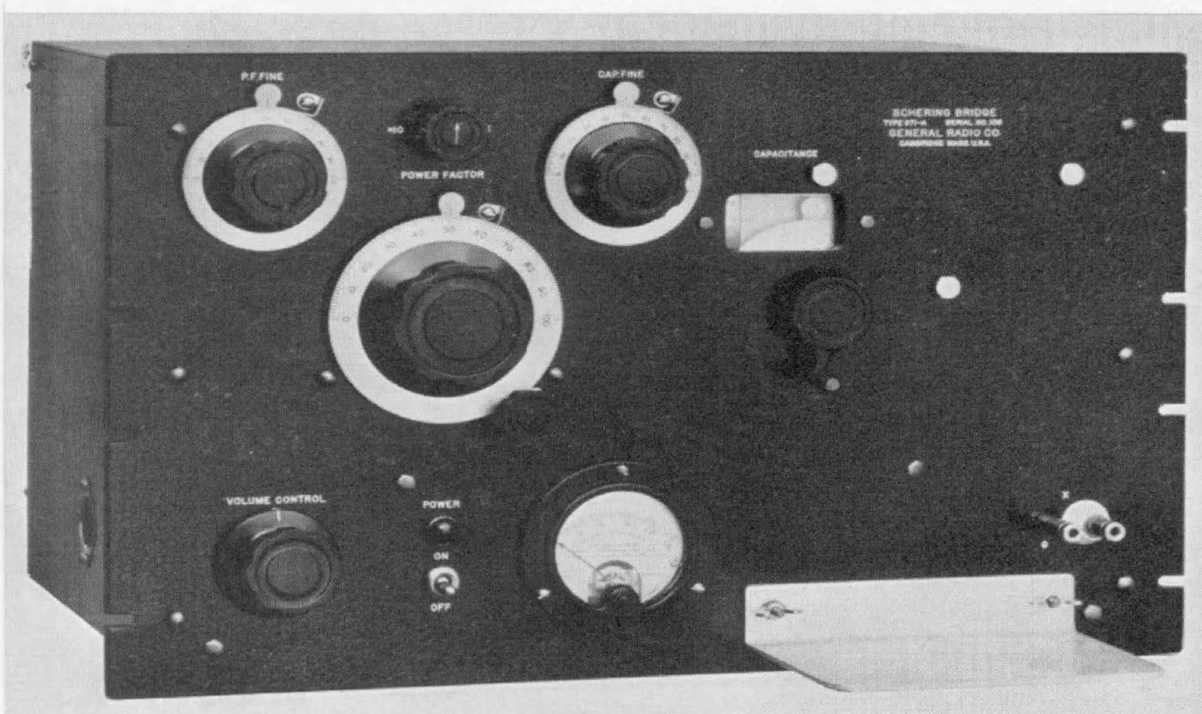
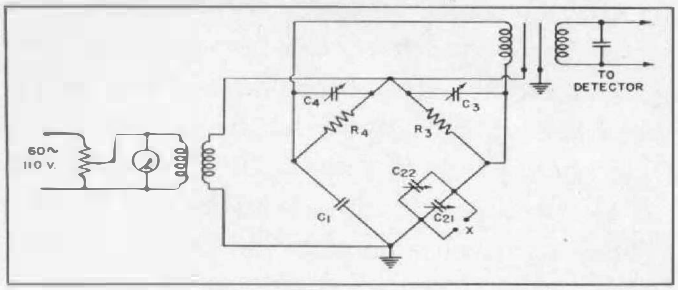


FIGURE 1. Panel view of the 60-cycle Schering bridge. Note the convenient shelf for test specimens.

FIGURE 2. Circuit diagram of the TYPE 671-A Schering Bridge with the power factor multiplier switch in the X1 position.



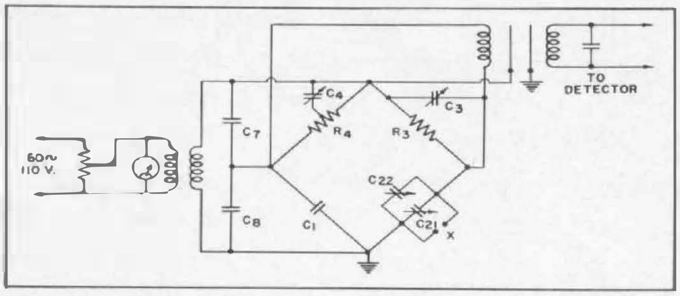


FIGURE 3. Circuit diagram of the bridge with power factor switch in the X.1 position.

where R_x is the equivalent series resistance in ohms and C_x the equivalent series capacitance in farads of the unknown capacitor.

The dissipation factor, D_x, obtained on the Schering bridge is the cotangent of the phase angle or the tangent of the loss angle of the unknown capacitor, while the power factor is the cosine of the phase angle or the sine of the loss angle. Power factor and dissipation factor are essentially equal for low loss dielectrics. The relationship among these four quantities is indicated in Table 1 below.

The maximum S scale value is about 80 $\mu\mu$f. Capacitors having larger values of D_xC_x may, however, be measured by a series substitution method. For the measurement of values of S less than 8 $\mu\mu$f, the range of the power factor dial can be reduced by a factor of ten, thereby increasing the precision of measurement. This is accomplished by throwing a switch which connects the power factor capacitor, C4, as shown in Figure 3. The compensating capacitors, C7 and C8, are also connected in this switch position to retain the same initial capacitance and resistive balances.

The first scale division on the power factor dial is unity in the normal position, or 0.1 in the low-range position. The maximum error in the determination of the value of S for the 1.0 multiplier is $\pm 2\%$ of the dial reading or ± 0.2 $\mu\mu$f, whichever is the larger. The maximum error in the determination of S with the 0.1 multiplier is $\pm 2\%$ or ± 0.05 $\mu\mu$f whichever is the larger. The absolute error of the computed dissipation factor involves this figure in addition to the error of C_x measurement specified above.

The trimming capacitor, C22, and the capacitor, C3, are used in establishing the initial balance of the bridge before the unknown capacitor is attached.

The bridge is provided with a cord for connecting it to the power main, a specially shielded lead for joining it to the

TABLE 1

Phase Angle	*Loss Angle*	*Dissipation Factor*	*Power Factor*	$\frac{DF-PF}{DF}$
90°	0°	.0000	.0000	0
85°	5°	.0875	.0872	0.34%
80°	10°	.1763	.1736	1.53%
75°	15°	.2679	.2588	3.4 %
70°	20°	.3640	.3420	6.1 %
65°	25°	.4663	.4226	9.3 %
60°	30°	.5774	.5000	13.4 %

$$\text{Power Factor} = \cos \cot^{-1} D_x$$

null detector, and a horizontal shelf for supporting small external capacitors when used in a relay-rack mounting.

For all of the contemplated uses of this bridge, it has been found that no guard circuits are required. In the interests of simplicity of operation and minimum expense, no provision for such guard circuits has been made, and thus the bridge is capable of measuring only two-terminal capacitors.

Some form of null-balance detector is, of course, required for use with this bridge. The customary headphones are not satisfactory at commercial frequencies. The best detector is some form of visual null indicator having the required sensitivity and a sufficient degree of selectivity to eliminate all harmonics of the applied frequency which are unavoidably present in the output of a Schering bridge balanced at the fundamental of the applied frequency. The a-c operated TYPE 707 Cathode-Ray Null Detector,* complete in one unit, is ideal for use with this bridge, or a suitable selective amplifier followed by a rectifier type of meter may be employed. For example, the TYPE 814-A Amplifier, the TYPE 814-P3 60-Cycle Filter, and the TYPE 488-D1 Rectifier Meter make a satisfactory combination (see the General Radio *Experimenter* for January, 1938). — HORATIO W. LAMSON

*This new null indicator will be described in a forthcoming issue of the *Experimenter*.

SPECIFICATIONS

Power Supply: 115 volts, 60 cycles.
Power Input: 30 watts.
Mounting: 19-inch relay-rack panel.
Net Weight: 36½ pounds.
Dimensions: Panel, 19 x 12¼ inches; depth behind panel, 9¾ inches.

Type		*Code Word*	*Price*
671-A		BEGET	$325.00

MISCELLANY

● **MR. H. W. LAMSON** read a paper at the spring meeting of the Acoustical Society of America in Washington on "A Method of Observing Sound Decay and Measuring Reverberation Time."

● **RECENT SPEAKERS** at General Radio afternoon colloquia include Messrs. Hill, Young, Sawin, Pace, and Crites of Westinghouse Electric and Manufacturing Company; Messrs. Riley and Cutts of General Electric Company; and Messrs. Ehle and Marsten of the International Resistance Company.

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