THE General Radio EXPERIMENTER

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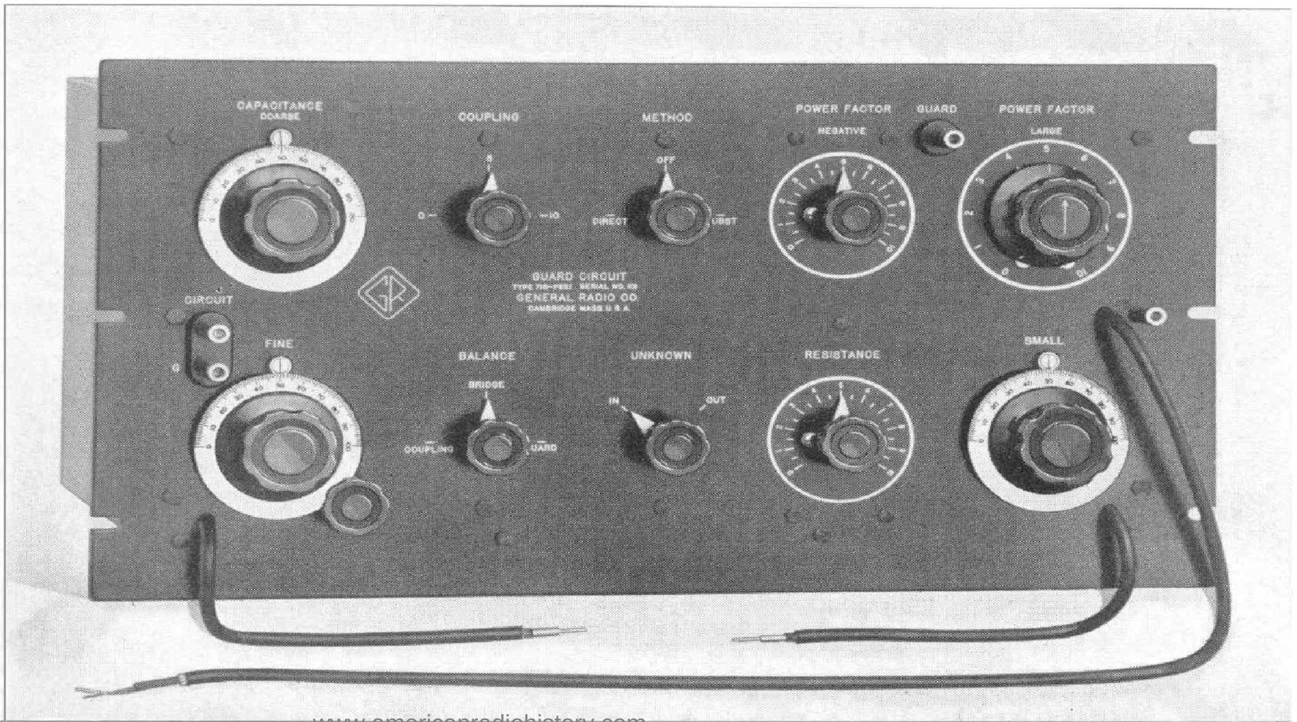
ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

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.

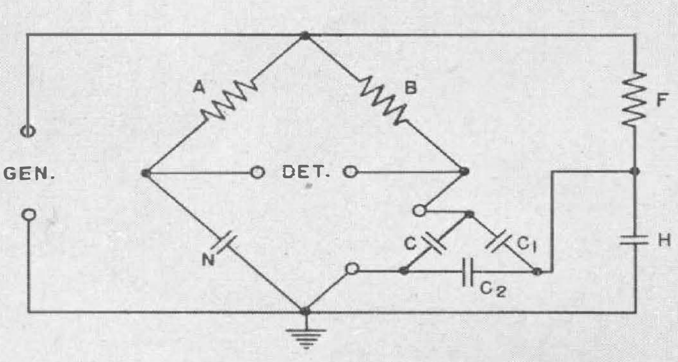
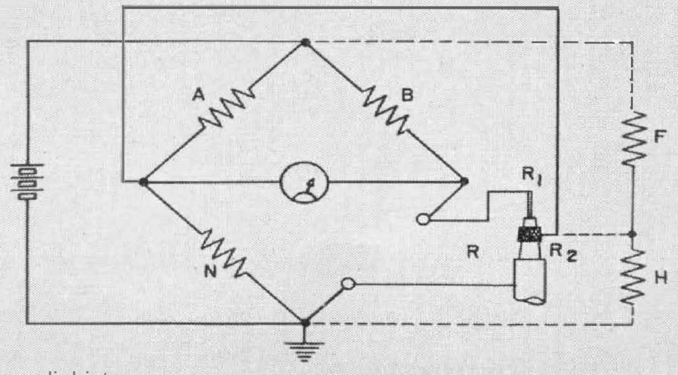


FIGURE 3. Diagram showing how a guard ring is connected to a bridge when measuring the insulation resistance of cables.



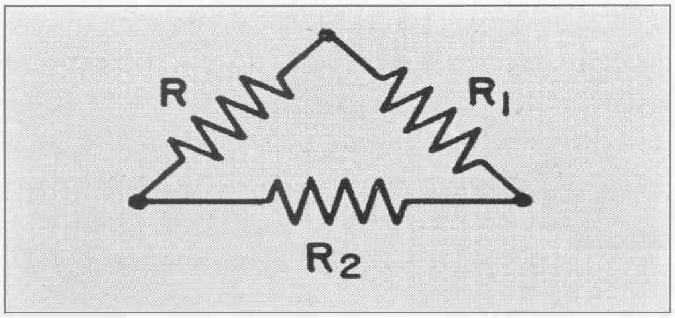


FIGURE 4. Equivalent circuit of the cable of Figure 3, showing how the resistance paths make up a three-terminal network.

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.

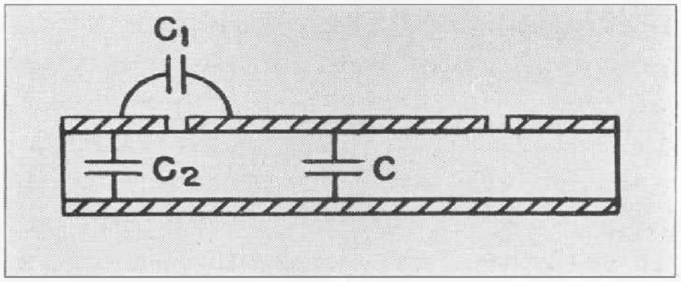


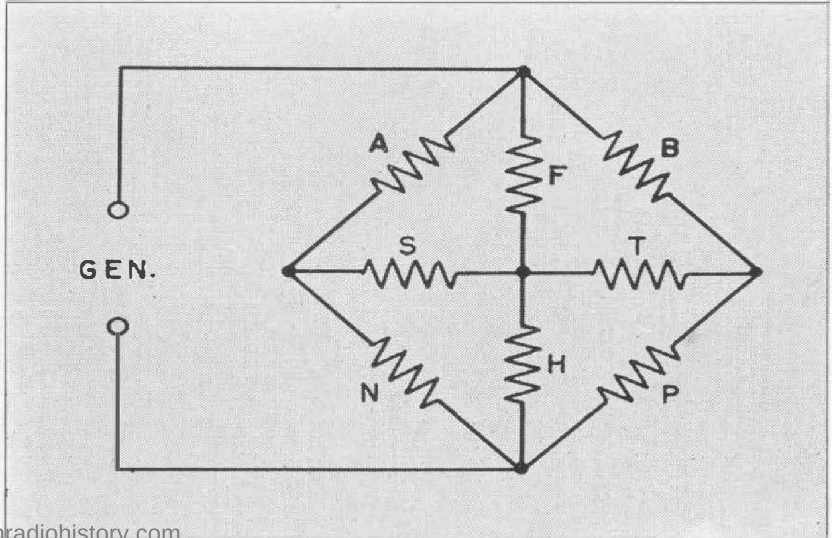
FIGURE 5. Sectional view of guard and measuring electrodes as used in determining the dielectric constant of a disk of insulating material.

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

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

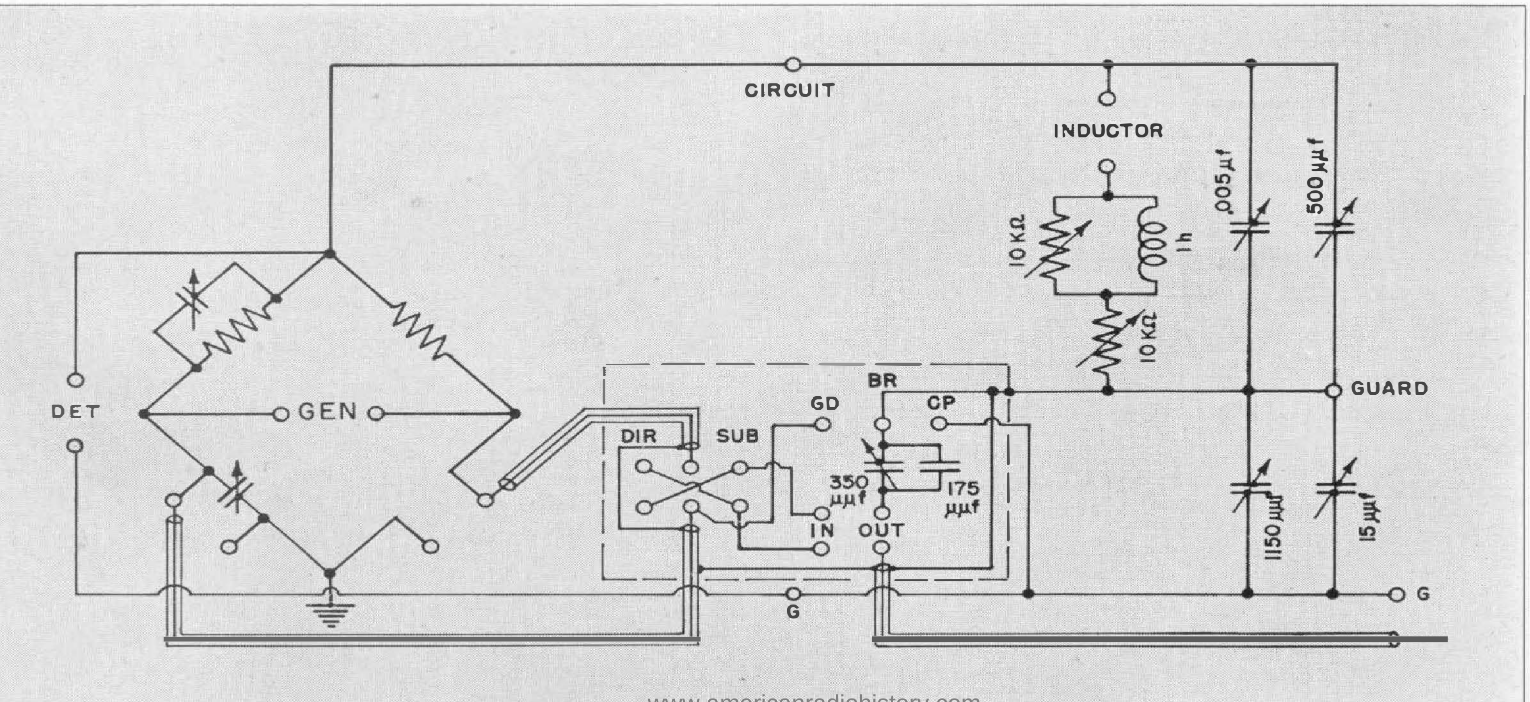
From the symmetry displayed in Figure 6, there is really no difference between guard circuit and coupling circuit. Equation (2) must follow from Equation (1) since the positions of generator and detector are interchangeable. These conditions have been studied recently in considerable detail by Balsbaugh[1] 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

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



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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.

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

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[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.

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 $\mu\mu$f 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 $\mu\mu$f.

Capacitance Arm: 40 to 1150 $\mu\mu$f with a fine adjustment.

Coupling Circuit: 180 to 525 $\mu\mu$f.

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 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.

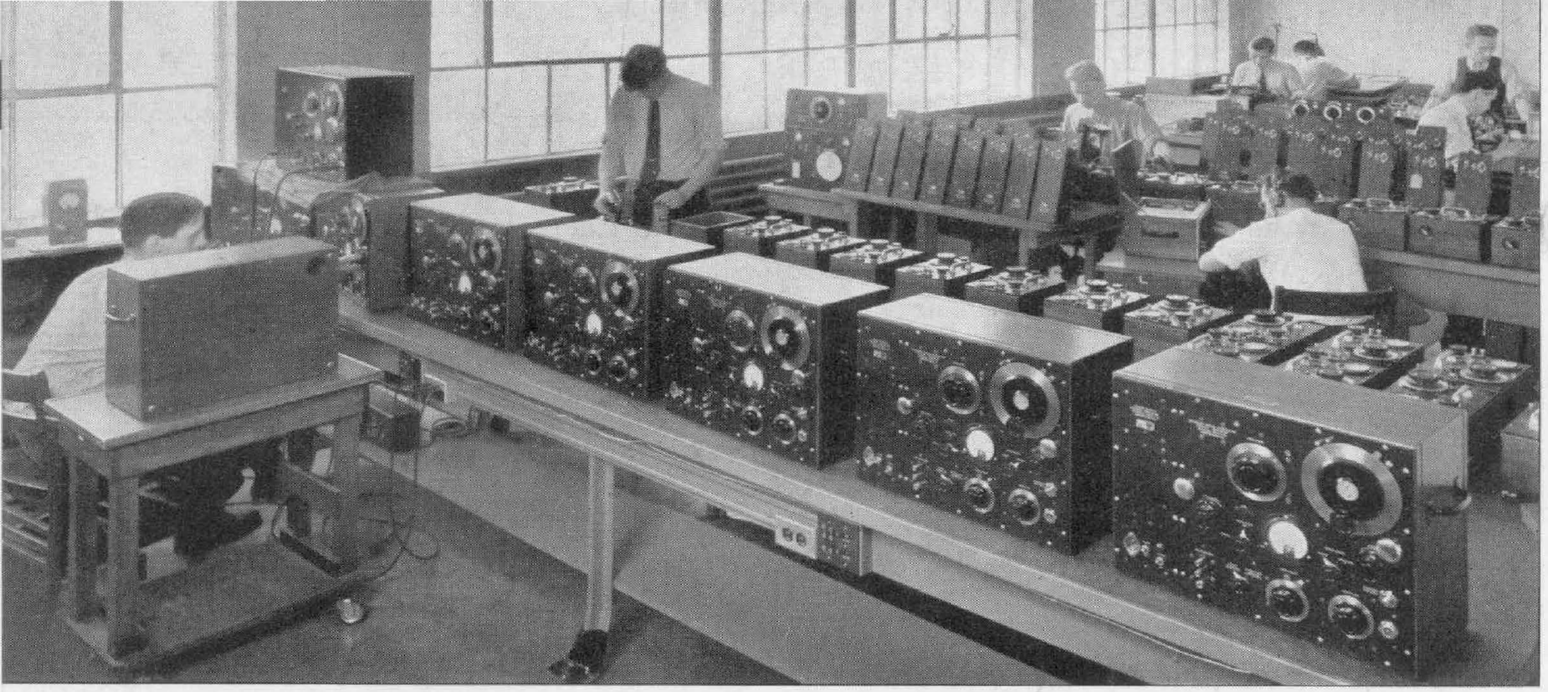
This unit, the P-489 Time Comparator, is essentially a 113-kilocycle amplifier which flashes a Strobotron lamp at the beginning of each Arlington signal and at the beginning of the time tone sent to the telephone subscribers. The flash shows through a slit in a disk turning once a second, and any variation 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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