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The General Radio Experimenter

Vol. IV, No. 8 — January, 1930

An Equal-Arm Capacitance Bridge

By Robert F. Field

Summary—The effect of a grounded shield and the Wagner ground connection upon the bridge are discussed, and the substitution method for measuring the capacitance and resistance of condensers is described.

The Type 216 Capacity Bridge is a shielded equal-arm bridge with self-contained shielded input and output transformers. Its circuit connections are shown in Figure 2. The bridge is balanced by a simultaneous adjustment of one of the condensers C_A or C_B, and the resistor R which may be placed in series with the condenser having the lower resistance by means of a two-point switch. For silence in the telephones the conditions of balance are

$$\frac{M}{N} = \frac{C_B}{C_A} = \frac{R_A}{R_B} \qquad (1)$$

and, since the ratio arms are nominally equal,

$$C_A = C_B \text{ and } R_A = R_B \qquad (2)$$

where the resistor R is included in either R_A or R_B. The setting of the resistor R indicates the difference in resistance between the two condensers; therefore both the capacitance and resistance of one must be known in order that the capacitance and resistance of the other may be calculated.

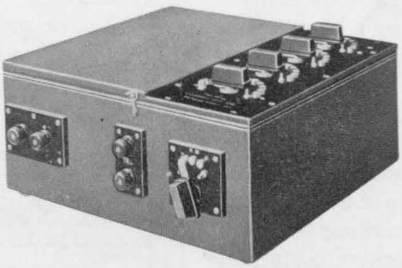

Figure 1. The Type 216 Capacity Bridge

The different arms of the bridge, the condensers being compared, the power source, and the balance detector may all have capacitances to ground, and to each other. These effects render the simple bridge equations (1) incorrect because neither the currents in the two equal arms nor the currents in the two condensers need be equal to produce silence in the telephone receivers. There are two general methods of minimizing the effects of ground and mutual capacitances, namely the use of the Wagner ground and of shielding.

The simplest type of Wagner ground consists (Figure 3) of a resistance PQ having an adjustable ground tap. By connecting a telephone receiver between the junctions of P and Q and of M and N, the latter junction may be brought to ground potential. Stratton* has discussed the use of the Wagner ground at considerable length and shows that the various ground capacitances, whether distributed or lumped,

* J. A. Stratton, "A High-Frequency Bridge," *Journal of the Optical Society*, XIII, October, 1926, 481.

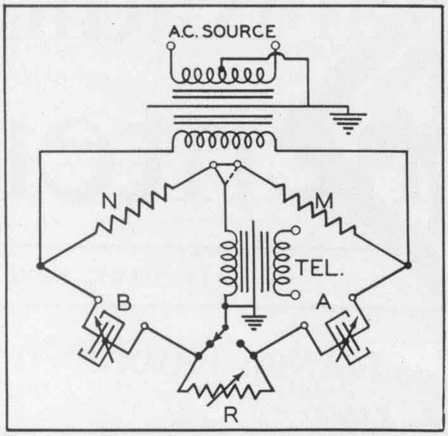

FIGURE 2. Wiring diagram for TYPE 216 Capacity Bridge

are equivalent to a resistance and capacitance, either in series or parallel, connected between each generator terminal and ground. These equivalent impedances may then be made to have the same ratio as the bridge arms *M* and *N* by a proper adjustment of the Wagner ground. For a complete adjustment, two variable condensers (shown dotted in Figure 3) must be connected in parallel with the ground resistance *PQ*. The two condensers may be made into one unit by rotating a single semicircular rotor between two insulated semicircular stators placed opposite each other. The values of the bridge arms are slightly altered if they have a distributed ground capacitance, but this is a second order effect. It may be eliminated by making the arms symmetrical, for the bridge equations are unaltered if *M* and *N* are equal impedances. Thus the Wagner ground minimizes the effect of fixed ground capacitances. It does not eliminate the effect of variable ground capacitances due to the change of position of the observer, the effect of mutual capacitances, and the effect of various voltages induced electrostatically or magnetically from outside fields. These effects may be reduced only by shielding.

In the TYPE 216 Capacity Bridge, this consists of a metallic grounded shield placed around the component parts of the bridge. The two equal arms need not be separately shielded if well spaced and kept symmetrical. The condensers being compared must be completely shielded and connected with their shielded terminals next to the detector. A condenser is of no value as a standard of capacitance unless this capacitance is independent of its position with respect to ground. Thus the use of the Wagner ground and the use of shielding are complementary and the one cannot easily supplant the other. The Wagner ground must be accompanied by moderate shielding of the bridge to eliminate induced voltages and body capacitance of the observer. On the other hand, the Wagner ground can be dispensed with if the bridge is shielded from the generating source and the balance detector by transformers whose primary and secondary windings are shielded by a grounded metallic sheath placed between them. If the bridge have equal ratio arms the center of the primary may also be grounded, and both primary and secondary made symmetrical with respect to the grounded iron core. If this shielding were perfect so that

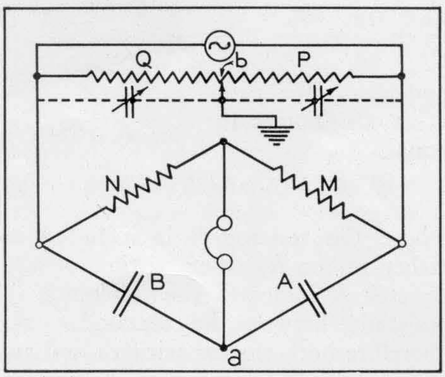

FIGURE 3. Wagner ground applied to an equal-arm bridge. When adjusting the Wagner ground one terminal of the telephone receivers is moved from point *a* to point *b*

there was no capacitance between primary and secondary, it would be necessary to shield only one transformer, but it is easier in practice to use less care and shield both. It is still essential, however, that the transformer and bridge be absolutely symmetrical, for otherwise the simple bridge equations cannot hold.

There are three possible ways of correctly comparing two condensers on a bridge thus shielded, even when the transformer and bridge are not symmetrical and the shielding of the input and output transformers is not perfect. First, a Wagner ground may be added across the secondary of the input transformer. Second, the condensers under comparison may be transposed. This method to a first approximation eliminates the value of the ratio arms M and N and gives as the value of the unknown capacitance the geometric mean of the two settings of the known capacitance. These values will be so nearly equal that their arithmetic mean may be used instead.

$$C_B = \frac{C_A + C_A'}{2} \text{ and } R_B = R_A + \frac{R + R'}{2} \cdot \quad (3)$$

Third, a substitution method may be used. In its simplest form the condensers under comparison are in turn connected in one arm of the bridge, while in the adjacent arm is placed a balancing condenser of equal capacitance which need not be calibrated. The bridge is balanced by adjusting the balancing condenser with the unknown in circuit, and by adjusting the known condenser with the known in circuit. This method is liable to error because of the use of two different means of balancing the bridge and because, if the condensers compared are dissimilar, their different capacitances to ground will affect the result unless both are perfectly shielded.

A modification of this method, which eliminates these difficulties and has at the same time an important advantage, consists in always keeping the known variable condenser in circuit. First the bridge is balanced with the two condensers, known and unknown, in parallel. Then the unknown condenser is disconnected on its unshielded side and the known condenser increased to produce balance again. The change in capacitance of the known condenser for the two positions of balance is the capacitance of the unknown condenser.

$$C_x = C_s' - C_s, \quad (4)$$

where C_s is the capacitance of the known or standard condenser for the first balance when the unknown condenser is in circuit and C_s' is its capacitance when the unknown condenser is out of circuit. The TYPE 222 Precision Condenser is suitable for use as the known or standard condenser. Any TYPE 246 Condenser or the TYPE 239-J Condenser may be used as the balancing condenser. With this equipment, condensers of less than 1500 mmf. capacitance may be measured to within

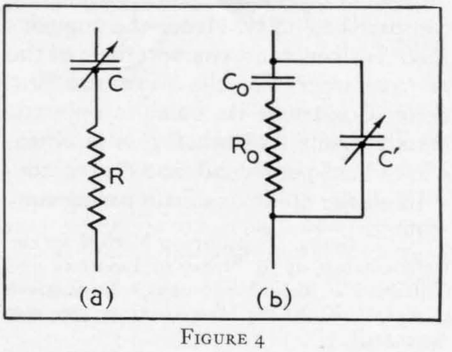

FIGURE 4

1 mmf., using the calibration chart provided with the TYPE 222 Precision Condenser.

Any air condenser is equivalent to two condensers in parallel: the one, a perfect variable air condenser having no energy losses; the other a fixed condenser (due to the solid dielectric) having all the energy losses. Since a condenser having an energy loss is equivalent to a perfect condenser in series with pure resistance, an air condenser having capacitance C and resistance R (Figure 4a) may be represented as in Figure 4b, where C_0 and R_0 are the capacitance and resistance of the solid dielectric condenser respectively and C' is the capacitance of the variable air condenser. Burke has shown * that

$$R\omega C^2 = R_0\omega C_0 \text{ and } C = C_0 + C'$$

provided that the power factor of C is negligible, i.e.:

$$R_0\omega C_0 << 1.$$

If the capacitance of the solid dielectric condenser does not change with the setting of the air condenser,† the quantity $R\omega C^2$ is constant at any fixed frequency because R_0 and C_0 are constant. For different frequencies the quantity $R_0\omega C_0$ which is the power factor of the solid dielectric, is approximately constant for good dielectrics, such as isolantite, porcelain, or hard rubber.‡ For such materials $R_0\omega C_0$ is of the order of 0.005, whose square is negligible compared to unity. Hence the quantity $R\omega C^2$ is a constant, characteristic of the air condenser. For the TYPE 222 Precision Condenser its value is approximately 0.06 x 10^{-12} when R is in ohms, ω in radians per second, and C in farads.

In all the methods of comparing condensers previously discussed, except the last, it was found that the resistance of the standard condenser must be known in order that the resistance of the unknown condenser might be determined. In the modified substitution method last described it is only necessary to know the law of variation of the resistance of the standard condenser with setting. This is due to the fact that this condenser is kept in circuit during both

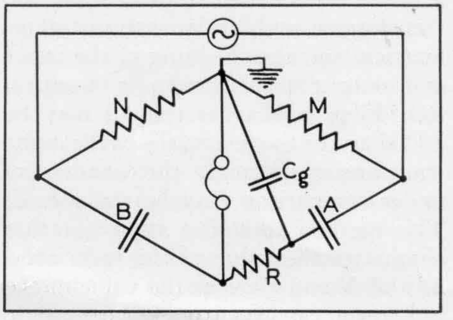

FIGURE 5

measurements. It may be shown * that the resistance of the unknown condenser is given by

$$R_x = (R' - R)\frac{C_s'^2}{C_x^2} \qquad (6)$$

where C_x is the capacitance of the unknown condenser obtained from equation (4); $C_s'^2$ is the total capacity in that arm of the bridge; and $R' - R$ is the change in resistance of the added resistor R of Figure 2, always taken as positive. If for these two settings the added resistor is transferred from one arm to the other, the sum of its reading rather than their difference must be taken.

There are two points at which a shielded bridge may be grounded to the shield, the junction of the ratio arms and the junction of the shielded sides of the two condensers. If it were not necessary to introduce a resistance between the two condensers to obtain the resistance balance, the junction

* C. T. Burke, "Substitution Method for the Determination of Resistance of Inductors and Capacitors at Radio Frequencies," *Transactions of A. I. E. E.*, XLVI, May, 1927, 483. See also Appendix I.

† This can be brought about by so building the air condenser that the electric field in the solid dielectric supports is independent of the condenser setting. The General Radio TYPE 222, TYPE 246, and TYPE 239 Condensers meet this requirement.

‡ An excellent discussion of the relation between the resistance and power factor of condensers is found in "Radio Instruments and Measurements," *Circular of the Bureau of Standards No. 74* (1st ed., 1918, or 2nd ed., 1924) pp. 122 to 129. (Government Printing Office, Washington, D. C.)

* Appendix II.

of the ratio arms would be the better point at which to place the ground, because then the capacitances to ground of the input transformer and bridge arms are placed in parallel with the ratio arms. But the ground capacitance of the condenser, in series with which the added resistance is placed, is a shunt across both the added resistance and the detector and turns the bridge into a triple network as shown in Figure 5. It may be shown* that while the effect on the capacitance is negligible, the true resistance is given by

$$R_x = (R' - R)\left(1 + \frac{C_g}{C}\right)\frac{C^2}{C_x^2}. \qquad (7)$$

Thus for a given ground capacitance C_g, the resistance R_x as calculated by the simple formula, equation (6), is always less than the true resistance and approaches it as the total capacitance C is increased. Its true value may be approximated by taking a set of observations for different values of total capacitance C and plotting the resistance as calculated from equation (6) against the reciprocal of the total capacitance. The intercept of this curve on the axis of resistance, where total capacitance is infinite, is the true resistance. The error introduced by this effect is greatest when the bridge and condensers are placed on a grounded table, and may easily amount to 50 per cent. for small values of the total capacitance.

When the ground is placed at the junction of the added resistance and the shielded side of one of the condensers, this correction is eliminated and the true resistance of the unknown condenser is given by equation (6). The ground capacitance of the condenser, in series with which the added resistance is placed, is a shunt across the added resistance only and has a negligible effect. But the capacitances to ground of the input transformer and bridge arms are now placed in parallel with the balancing and standard condensers, and any methods of comparing condensers involving a knowledge of the total capacitance of either condenser arm must be corrected for this added capacitance.

The value of capacitance which can be measured by the modified substitution method is limited to the range of the standard condenser. This is about 1400 mmf. for the TYPE 222 Precision Condenser. This limit may be raised in the following ways. Consider first the calibration of a variable air condenser of maximum capacitance greater than, but less than twice, this limit. It is calibrated in the ordinary manner up to the limit, using equations (4) and (6). Let the largest value of capacitance and the corresponding resistance be C_a and R_a respectively. Without changing the setting of the unknown condenser it is connected in circuit, the standard condenser is set at approximately maximum, the balancing condenser is increased correspondingly, and the bridge is balanced. Now of course the unknown condenser cannot be disconnected and the bridge balanced as usual by increasing the standard condenser, but the capacitance and resistance necessary for such a balance may be calculated from the previous measurement. Let C' and R' be this necessary capacitance and resistance respectively, and let C and R be the observed values of capacitance and added resistance after the capacitance was increased. Then, since for both cases the unknown capacitance and resistance are unchanged

$$C_a = C' - C \text{ and } R_a = (R' - R)\frac{C'^2}{C_a^2}$$

$$\text{or } C' = C_a + C \text{ and } R' = R_a\frac{C_a^2}{C'^2} + R. \quad (8)$$

* Credit for the original derivation of this case should be given to Mr. R. P. Siskind of the Department of Electrical Engineering, Harvard University.

These new values C' and R' may now be used for the remainder of the calibration as the capacitance and added resistance respectively, which would balance the bridge if the unknown condenser were disconnected. For a still larger condenser this process may be repeated.

Two condensers each larger than the standard variable condenser may be compared by this method if the difference of their capacitances is less than the capacitance range of the standard condenser. Two measurements are made, one with each condenser connected in parallel with the standard condenser. Let C_1 and R_1, C_2 and R_2 be the capacitance and resistance respectively of the two condensers, and C_s and R, C_s' and R' the corresponding capacitance of the standard condenser and the value of the added resistance respectively. It may be shown* that

$$C_2 = C_1 + (C_s - C_s')$$
$$R_2 = R_1 \frac{C_1^2}{C_2^2} + (R - R') \frac{(C_s + C_1)^2}{C_2^2}. \quad (9)$$

The limitation that the difference of the capacitances of the two large condensers must be less than the capacitance range of the standard condenser may be removed by the use of an additional

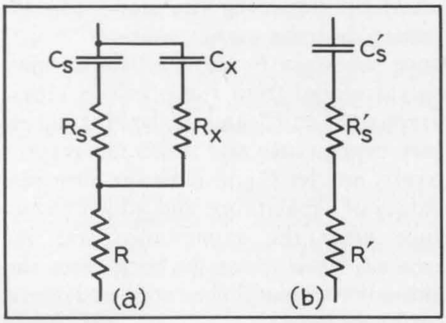

FIGURE 6

condenser of sufficient size to bridge this gap, whose capacitance and resistance are known. This method may be applied to the calibration of a set of condensers arranged to form a decade or a number of decades in terms of one of their number or in terms of the standard variable condenser. The decades may consist of ten similar units, or of four or more separate units of different values, such as the combinations 1, 2, 2, 5; 1, 2, 3, 4; and 1, 2, 3, 6.

In order to obtain resistance measurements of reasonable accuracy it is necessary to observe certain precau-

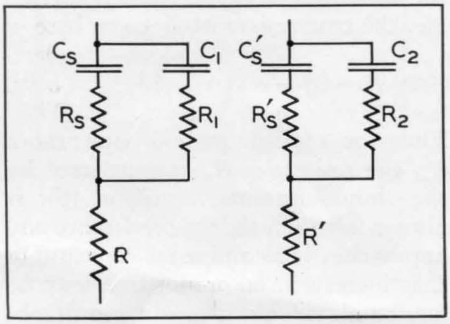

FIGURE 7

tions which are perhaps not as important for capacitance measurement. Due to the small power factor associated with the usual condenser, the capacitance balance must be made with great accuracy, much greater than that to which the standard condenser can be read or calibrated, except when very large capacitances are being compared. For the typical case of a total capacitance of 1000 mmf. the capacitance balance must be adjusted to .01 mmf. in order that the resistance balance may be made to 1 ohm. To attain this sensitivity a potential of at least 50 volts at a frequency of 1000 cycles must be applied to the bridge and a two-stage amplifier connected to the telephone transformer. The wire to the unknown condenser must remain in place and connected to the unshielded terminal of the standard condenser when the unknown is disconnected, its motion must be kept small, and, in order to keep its capacitance and

* Appendix II.

dielectric losses small, it should be uninsulated.

Since the resistance of a condenser varies inversely as the frequency, the frequency of the voltage applied to the bridge must be constant within much closer limits than are required for resistance or inductance measurements. The fluctuations of frequency must not be great enough to change the resistance balance by 1 ohm. This effect will be the greater, the larger the losses in the unknown condenser, for then the compensating effect of the resistance of the balancing condenser will be less. The generating source should also be as free from harmonics as possible. When the bridge is balanced for the fundamental, the resistance balance for the second harmonic and for all other harmonics is quite incorrect. Hence any harmonics in the source will be heard in the telephones in proportion to their magnitude. Due to their different pitch the trained ear can discriminate against them, but it is always easier to effect a bridge balance when they are small.

Occasionally, especially when measuring condensers containing poor dielectrics, the bridge balances, both capacitance and resistance, will appear to drift with time. This may be due to a frequency shift, but it is more likely due to an increasing temperature of the dielectric produced by its own energy losses. The temperature coefficient of resistance of solid dielectrics is large and for accurate measurements some sort of temperature control is necessary.

Appendix I

The general law for n condensers in parallel may be easily derived from a consideration of the energy relations involved. The power loss in a condenser is

$$W = I^2 R.$$

For the ordinary negligibility relation, namely $R^2 << X^2$,

$$I = \frac{E}{X} = E\omega C,$$

whence the loss in watts per squared volt is

$$\frac{W}{E^2} = R\omega^2 C^2.$$

Since power is additive,

$$\frac{W}{E^2} = R\omega^2 C^2$$

$$= R_1\omega^2 C_1^2 + R_2\omega^2 C_2^2 + \cdots + R_n\omega^2 C^2_n$$

$$= \sum_1^n R_m\omega^2 C_m^2,$$

or

$$R\omega C^2 = \sum_1^n R_m\omega C_m^2 \qquad (10)$$

and

$$R = \frac{\sum_1^n R_m \omega C_m^2}{\omega \sum_1^n C_m^2}. \qquad (11)$$

Appendix II

In the modified substitution method of comparing two condensers the two arrangements shown in Figure 6 must have identical impedances when the bridge is balanced for both. In (a) the unknown condenser is in circuit, in (b) it is disconnected. Constants of the standard condenser are indicated by subscript s and the added resistance is R. Primed letters indicate the second balance, when the unknown is disconnected. For identical impedances,

$$C_s + C_x = C_s'$$

$$R + \frac{R_s\omega C_s^2 + R_x\omega C_x^2}{\omega (C_s + C_x)^2} = R' + R_s'. \qquad (12)$$

Now, from the law of the air condenser (Equation 5)

$$R_s\omega C_s^2 = R_s'\omega C_s'^2$$

$$C_x = C_s' - C_s \text{ and } R_x = (R' - R)\frac{C_s'^2}{C_x^2}. \qquad (13)$$

In the comparison of two large condensers by the modified substitution method, the two arrangements shown in Figure 7 must have identical impedances.

$$C_s + C_1 = C_s' + C_2$$

$$R + \frac{R_s \omega C_s^2 + R_1 \omega C_1^2}{\omega (C_s + C_1)^2} = R' + \frac{R_s' \omega C_s' + R_2 \omega C_2^2}{\omega (C_s' + C_2)^2}. \quad (14)$$

From the law of the air condenser (Equation 5)

$$R_s \omega C_s^2 = R_s' \omega C_s'^2$$

$$C_2 = C_1 + (C_s - C_s')$$

$$R_2 = R_1 \frac{C_1^2}{C_2^2} + (R - R') \frac{(C_s + C_1)^2}{C_2^2}. \quad (15)$$

MISCELLANY

By THE EDITOR

IN spite of our promise to include in this issue a description of General Radio quartz plates, we are deferring it until the February issue so that we may publish in full Mr. Field's discussion of capacitance and condenser loss measurements. We feel that the subject is of general enough interest to justify this change in our plans.

* * * *

The TYPE 216 Capacity Bridge described by Mr. Field in this issue is now being manufactured with the ground connection made to the junction of the shielded sides of the two condensers. Those who have bridges in which the connection is made to the junction of the ratio arms may make the change themselves or have it done by the General Radio Company for $5.00.

* * * *

The price of the TYPE 481 Polar Relay described in the *Experimenter* for February, 1929 has been reduced from $30.00 to $25.00. The code word is NOMAD.

CONTRIBUTORS

A brief biographical sketch of ROBERT F. FIELD, the author of "An Equal-Arm Capacitance Bridge," appeared in the Miscellany column of the *Experimenter* for last October.

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PIEZO-ELECTRIC QUARTZ PLATES

By CHARLES E. WORTHEN

UNTIL the terminology for describing piezo-electric quartz plates becomes standardized, it is practically necessary that every paper on the subject be preceded by a glossary. Different investigators use different terms, and it is sometimes difficult to keep them straight even when one is working with them every day. The article that follows was originally intended to serve as an introduction to a catalog description of the mounted quartz plates sold by the General Radio Company, but it is hoped that enough information has been included to make it useful for reference when comparing nomenclatures.

The crystalline quartz which is used in piezo-electric oscillators is found in various parts of the world, the greater portion of it coming from Brazil. It is one of some seven crystalline forms of silica, but it is the only one that possesses marked piezo-electric properties. While other varieties exhibit them, the kind ordinarily used ("low" quartz) is the best. It has a structure similar to that shown in Figure 1, although in the natural state its shape may be imperfect, some pieces having no flat surfaces at all. For explanatory purposes, we assume that the crystal has a regular hexagonal cross section, but the shape has no definite bearing on its piezo-electric properties.

Regardless of its geometrical shape, a quartz crystal has four axes of symmetry, which means that if the crystal is rotated about any one of these axes, two or more positions are found where the same properties recur. The first, called the optic axis, extends through the crystal in the direction indicated in Figure 1 by the line ZZ. The other three are separated by an angle of 120° and lie in a plane perpendicular to the optic axis. These are known as electric axes because along the direction in which they lie the maximum piezo-electric effect is observed. If the section of the crystal perpendicular to the optic axis were perfect in cross section, the electric axes would be lines joining diametrically opposite vertices. The electric axes are indicated in Figure 1 by the lines XX, $X'X'$, and $X''X''$. In addition to these it is also useful to consider another set of axes designated by YY, $Y'Y'$, and $Y''Y''$. These lie in the same plane with and make angles of 30° with the electric axes. They are therefore perpendicular to opposite faces of the crystal. Mr. F. R. Lack of the Bell Telephone Laboratories, Inc., has used the name "mechanical

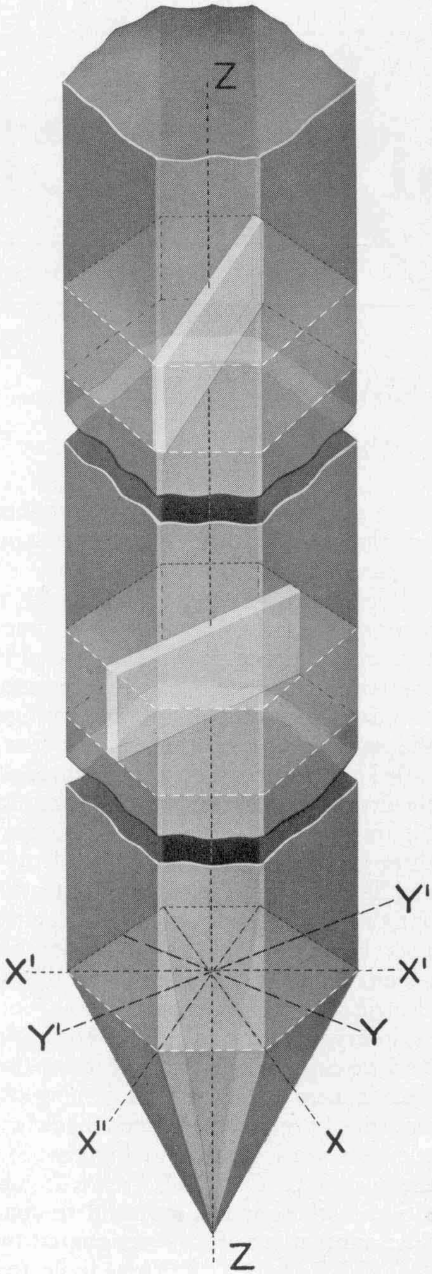

FIGURE 1. This drawing shows how X-cut and Y-cut quartz plates are oriented with respect to the electric (*X*), the mechanical (*Y*), and optic (*Z*) axes of the quartz crystal. The top section represents a Y-cut plate; the center section, an X-cut plate. The *Y''Y''* axis would coincide with the *ZZ* axis and is not shown

axes" to describe them and although they have had no universally accepted name, this one seems to be as good as any.

If mechanical stresses are applied in any direction through the uncut crystal, electric charges are set up on certain faces; and, conversely, if the crystal is placed in an electric field, dimensional changes along certain axes may be observed. This is known as the piezo-electric effect. Since it is a maximum in directions at right angles to the optic axis, quartz plates for commercial use are cut from sections at right angles to this axis. From these sections the plates are cut with either one of two orientations with respect to the electric and mechanical axes. These "cuts" and the sections from which they may be taken are represented in Figure 1, but a better idea of the angular positions involved can be gained from Figure 2.

The center section shows a "zero-angle cut" so called because its normal makes a zero angle with an electric (*X*) axis. It is also called "X-cut" because a *normal* to the face of the plate is parallel with one of the *X*-axes, or "face-perpendicular cut" because the face of the plate is perpendicular to an *X*-axis. This is also called "Curie cut" after the investigators who first used it in studying the piezo-electric effect. The top section shows a "30-degree cut," so called because its normal makes an angle of 30° with an electric axis. It is also called "Y-cut" because a *normal* to the face of the plate is parallel with a *Y*-axis, or a "face-parallel cut" because the face is parallel with an electric axis.

The diagrams of Figure 1 and Figure 2 should not, of course, be interpreted to mean that the plates must be cut to pass through the center of a section. Any portion of the crystal may be used so long as the proper orientation with respect to the electric and mechanical axes is maintained.

TABLE I
COMMON NAMES DESCRIBING THE TWO USUAL CUTS FOR PIEZO-ELECTRIC QUARTZ PLATES

X-CUT Because normal to face of plate is parallel with an electric (X) axis	*or*	ZERO-ANGLE CUT Because normal to face of plate makes angle of 0° with an electric (X) axis	*or*	FACE-PERPENDICULAR CUT Because face of plate is perpendicular to an electric (X) axis	*or*	CURIE CUT Because the Curies used crystals cut with this orientation when they discovered the piezo-electric effect		SHOWN Center section of Figure 1 and Figure 2b
Y-CUT Because normal to face of plate is parallel with a Y axis	*or*	30-DEGREE CUT Because normal to face of plate makes an angle of 30° with an electric (X) axis	*or*	FACE-PARALLEL CUT Because face of plate is parallel to an electric (X) axis				SHOWN Top section of Figure 1 and Figure 2a

Either X-cut or Y-cut plates perform satisfactorily in piezo-electric oscillators, although different characteristics for the two may be expected. For example, a plate suitable for stabilizing a vacuum-tube oscillator at a given frequency will require an X-cut plate about 7% or 8% thicker than a corresponding Y-cut plate. The different temperature-frequency coefficients of the two kinds of plates are referred to in a subsequent paragraph.

When attempting to memorize the location of the X- and Y-axes and the distinction between X-cut and Y-cut plates, the following may be helpful: (*a*) Remember that one set of axes joins opposite corners; the other set joins opposite sides of the crystal. (*b*) Associate the words *electric* and X with the corner-joining positions of the X-electric-diagonal axes. (*c*) Remember that the faces of the respective plates appear at first glance to be named incorrectly, i.e. the face of an X-cut plate lies parallel to a Y-axis and the face of a Y-cut plate lies parallel to an X-axis.

There is a definite relation between the direction of the electric and the mechanical stresses for the piezo-

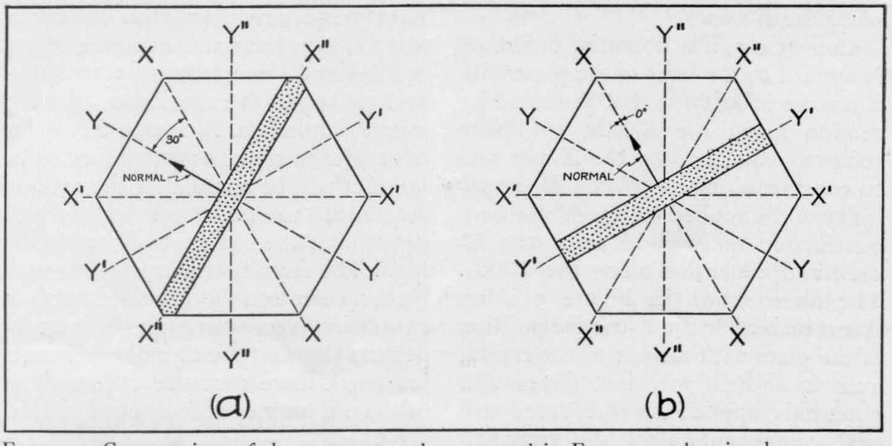

FIGURE 2. Cross sections of the quartz crystal represented in FIGURE 1 taken in planes perpendicular to the optic axis: (a) A Y-cut plate, (b) An X-cut plate

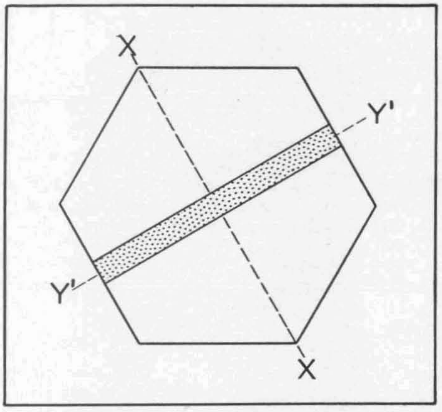

FIGURE 3

electric effect which holds no matter whether the plate is X-cut or Y-cut. If we refer to Figure 3, in which, to avoid confusion, only one pair of axes is shown, the following explanation is made clearer. If compression is applied along the *Y*-axis, opposite charges are developed on the two largest faces of the plate (in Figure 3, those parallel to the *Y*-axis). For tension, the signs of the charges are reversed. If the mechanical stresses are applied along the *X*-axis, tension gives charges on the same two faces of the same polarity as compression along the *Y*-axis, and compression produces the same polarity of charge as tension along the *Y*-axis.

Conversely, if a potential difference is applied to the faces of the plate with the same polarity as that produced by tension along the *X*-axis, the plate tends to expand along the *X*-axis and to contract along the *Y*-axis. If the polarity of the applied voltage is reversed, contraction takes place along the *X*-axis, and expansion along the *Y*-axis. The plate shown in Figure 3 is an *X*-cut plate. For the *Y*-cut the position of the plate with respect to the crystal axes is shifted 30°, but forces and potentials applied on the faces still have components along the axes, and the piezo-electric effect is similar in the two types of cut. Theoretically, there should be no piezo-electric effect along the *Z*-axis, but (due perhaps to imperfections in crystal structure) an electric field applied along this axis can often be made to produce changes in dimensions.

If a quartz plate is placed in an alternating electric field, the change in dimensions takes place at the frequency of the impressed field. The plate has a definite resonant frequency of mechanical vibration, depending on its dimensions, mass, elasticity, etc., and, if the applied voltage is of this frequency, amplitudes of vibration are obtained several times greater than at frequencies far from resonance. Since the phenomenon of resonance is the same in both mechanical or electrical systems, the piezo-electric nature of the quartz crystal furnishes a means of relating the two.

When used as the frequency-determining element in a vacuum-tube oscillator, the quartz plate appears to the rest of the oscillator circuit as a very sharply tuned resonant electrical network having values of resistance, capacity, and inductance which depend on the mechanical coefficients of the plate. As an example of the magnitudes involved, a given crystal* with a resonant frequency near 1100 kilocycles was found to have an inductance of 330 millihenrys, a resistance of 5500 ohms, and an apparent capacitance of 0.065 micromicrofarads. Although this value of resistance seems at first glance to be large, it will be noted that the ratio of reactance to resistance ($\frac{X}{R}$), which determines the sharpness of tuning, is high. The facts that this is very much higher than can be obtained with a tuned circuit consisting of coils and condensers and that the crystal coefficients are much more permanent than those of the ordinary electrical tuned circuit,

*Van Dyke, "The Piezo-Electric Resonator," *Proceedings of the I. R. E.*, June, 1928.

make the crystal an excellent device for stabilizing the frequency of a vacuum-tube oscillator. When used for this purpose, it takes the place of an electrical tuned circuit in determining the frequency of the oscillator.

It should be noted that the frequency of a vacuum-tube oscillator is not solely determined by the resonant frequency of the *LC* circuit, of the crystal, or of any other so-called frequency-determining element, because the oscillator operates at the frequency for which the total circuit reactance is zero. Since the tube itself has definite input and output impedances, these are a part of the circuit impedance and influence the frequency. In a piezo-electric oscillator, the capacitance due to the exciting electrodes and to the quartz and air dielectrics also modifies the operating frequency.

Figure 3 shows a piezo-electric oscillator circuit* in which the quartz plate is connected between the grid and filament and a parallel circuit of inductance and capacitance is connected in the plate circuit of the tube. The latter operates merely as an inductance for adjusting the plate load to the proper operating value. Since the quartz plate is shunted by the capacitance introduced by its holder and by the apparent input capacitance of the tube, it has an inductive reactance at the frequency assumed by the oscillator in order that the total circuit reactance be zero. The crystal has a resonance curve (reactance against frequency) sharper than an electrical tuned circuit, and a relatively small change in frequency is necessary to make the inductive reactance of the crystal sufficient to cancel the capacitance shunted across it.

The amount of this shunt capacitance and therefore the frequency of the oscillator are subject to variation: (*a*)

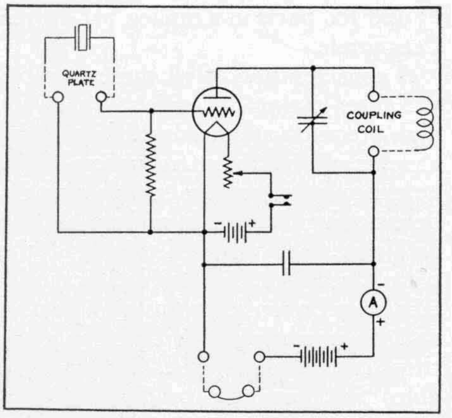

Figure 4. Wiring diagram for a typical piezo-electric oscillator

Due to the holder capacitance, by changing the electrode spacing; (*b*) Due to the tube input capacitance, by changing the plate voltage or the tuning of the parallel circuit. Some idea of the order of magnitude of these changes may be obtained from the results of measurements made upon an oscillator like that used in Figure 3. Using a low-powered vacuum tube operated at a moderate plate voltage it was found that tuning the plate circuit caused a frequency change of from 50 to 100 parts in a million and that changing the electrode spacing (air gap) caused changes of the order of 1000 parts in a million. Changes caused by varying the plate and filament voltages were negligible.

Another very important factor which influences the operating frequency of a piezo-electric oscillator is the fact that the resonant frequency of the plate changes with temperature by an amount which is somewhat different for the X- and the Y-cut plates. In an X-cut plate, the temperature coefficient is negative (i.e. the frequency decreases for increasing temperature) and amounts to between 10 and 25 parts in a million per degree Centigrade. The temperature coefficient of a Y-cut plate is positive and may be between

*This is the same circuit that is used in the General Radio Types 275 and 375 Piezo-Electric Oscillators.

25 and 100 parts in a million per degree Centigrade.

A consideration of all these possible variables makes it evident that, for high-precision standards of frequency, at least, the resonant frequency of the quartz plate is not the sole frequency-determining element in a piezo-electric oscillator. For work of this kind the plate, its holder, and the oscillator circuit must be considered as a single unit and the operating conditions for all of them carefully specified. Certain variables in operating conditions influence the frequency more than others, and, although it is often possible to ignore some of them, it must be remembered that this can be done only at a sacrifice in the precision with which the desired frequency is maintained. For example, some of the quartz plates manufactured by the General Radio Company are sold in their holders for use in any oscillator that the customer may select. He cannot, however, expect to obtain from them an accuracy in a specified frequency of more than 0.1 per cent.

It is the influence of factors outside the quartz plate itself which makes the problem of frequency control in power oscillators so difficult. Not only is the controlling plate subject to the usual variables that we have mentioned, but in addition its temperature is liable to change due to the internal heating caused by the passage of heavy currents in the crystal circuit. It is evident therefore that the production and calibration of power crystals are parts of the manufacturing of the power oscillator. This is the reason why the General Radio Company does not interest itself in the manufacture of power crystals, but confines its activities to the production of quartz plates for use in low-power frequency standards. It also explains why a power limit is imposed upon all General Radio quartz plates.

An interesting set of difficulties appears when the quartz plate is being given its final adjustment and test before being put into use. Some plates are found which exhibit the phenomenon known as "twinning," that is, a reversal in the piezo-electric effect in certain portions. This effect may be great enough to render the plate useless. Other plates control the vacuum-tube oscillator at more than one frequency. Here the operating frequency shifts or "jumps" as a result of making small changes in circuit constants or in the operating temperature. It is sometimes possible to correct this condition, but, if not, the plate must be discarded and another one prepared.

II

The General Radio Company can supply, for use as frequency standards, quartz plates and bars for any reasonable frequency and degree of precision. All must, of course, be made to order, but by establishing two definite groupings to meet most needs, it has been possible so to standardize the routine of specifications, manufacture of plates and holders, and calibration that the prices are considerably less than if each plate had to be processed as a separate unit. The type numbers 376 and 276-A have been assigned to these two standardized groupings, both of which are described in subsequent paragraphs.

General descriptions of plates and bars not in these two groups cannot be given inasmuch as questions of oscillator design, temperature control, and holder construction are usually involved.

TYPE 276-A Quartz Plates are supplied to have a frequency somewhere in the 160-meter amateur band. They are unmounted and their frequency can be relied upon to within 0.25 per cent. of the specified value. Plates for the 80-meter amateur band have been discontinued.

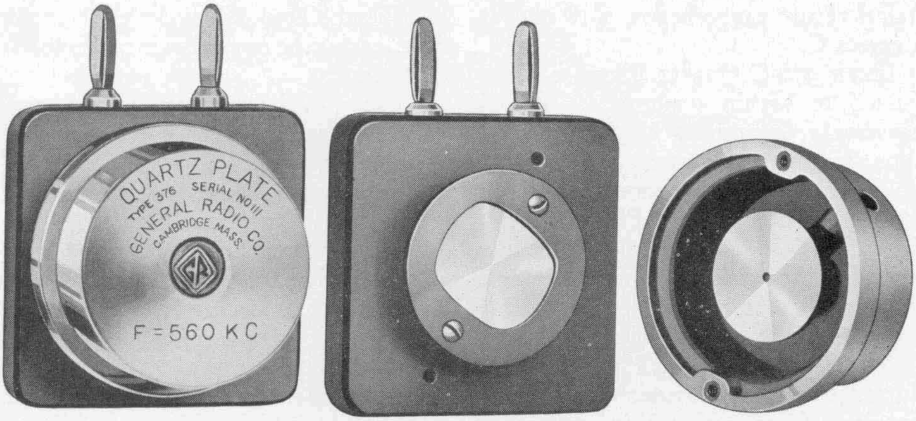

Figure 5. Plate holder for General Radio Type 376 Quartz Plates. The quartz plate rests on the lower electrode and is held in place by the fibre retaining ring

Type 376 Quartz Plates are calibrated and sold in the plug-in holder shown in Figure 5. This consists of a metal base plate mounted on bakelite over which is placed a metal cap carrying the upper electrode. The crystal rests loosely in a fibre ring and the frequency is adjustable over narrow limits by changing the air gap with the screw carrying the upper electrode. After the crystal has been adjusted to the correct frequency, the air gap adjustment is sealed. The frequency is again measured with the greatest possible accuracy in terms of the General Radio Company's highly precise standard-frequency assembly. The result of this measurement, expressed with the proper number of significant figures, becomes the certified frequency.

A certificate of accuracy is furnished which states the frequency of the plate, the conditions under which the calibration was made, and the range of operating conditions over which the guarantee of accuracy is valid. The certified frequency and the percentage accuracy is marked upon the plate holder.

A reclassification of General Radio crystals has recently been made and the classification and prices set forth in Catalog E, Second Edition, are discontinued.

Frequency Ranges

The following frequency ranges will be recognized:

100–200 Kilocycles: Plates in this range vibrate along the longest dimension and are Y-cut.

200–400 Kilocycles: Plates that will operate satisfactorily in this range cannot be mounted in the Type 376 Plate Holder because of their size and inasmuch as frequencies in this range can be obtained as harmonics from plates in the 100- to 200-kilocycle range, Type 376 Quartz Plates will not be supplied in this range. If necessary, plates for this range can be supplied in special mountings.

400–1800 Kilocycles: These plates vibrate along the thickness dimension and are Y-cut.

Accuracy Classification

Type 376-B Quartz Plates are adjusted to within 25 per cent. of any specified frequency within the above ranges, and their frequency can be relied upon to within 0.1 per cent. This accuracy is guaranteed if the plate is operated at low powers and within the temperature range between 18 and 32 degrees C.

TYPE 376-C Quartz Plates are adjusted to within 5 per cent. of any specified frequency in the above ranges. The statement of accuracy is the same as for TYPE 376-B Quartz Plates.

TYPE 376-D Quartz Plates are adjusted to within 0.1 per cent. of any specified frequency within the above ranges. The statement of accuracy is the same as for TYPE 376-B Quartz Plates.

TYPE 376-F Quartz Plates are adjusted to within 0.03 per cent. of any specified frequency and are calibrated only in a General Radio piezo-electric oscillator or with an oscillator which meets with our approval. The frequency of the oscillator and plate will be within 0.03 per cent. of the nominal frequency of the plate when the temperature is kept between 20 and 24 degrees C. (68 to 75 degrees F.). This class corresponds rather closely to the old Class E which was maintained to meet the requirements of American broadcasting stations. The Class F limit is equivalent to an allowable deviation of 500 cycles at the upper limit of the band (1500 kilocycles); at lower frequencies the deviation is correspondingly less.

TYPE 376-H Quartz Plates are supplied and calibrated to within 0.01 per cent. of any specified frequency in the above ranges. These plates must be calibrated in approved oscillators and the temperature must not deviate from a given value (near 50 degrees C.) by more than 0.25 degree C. Ordinarily it will be necessary for the customer to supply for calibration the temperature-control box he proposes to use, but before shipping an oscillator it would be well to get definite instructions on this point. When the temperature-control box is one built by the General Radio Company, it will not need to be returned.

PRICES AND CODE WORDS

Type	*Code*	*Price*
276-A	LABOR	$15.00
376-B	LAGER	40.00
376-C	LAPEL	45.00
376-D	LARVA	60.00
376-F	LEPER	70.00
376-H	LEVEL	85.00

MISCELLANY

By THE EDITOR

A NEW booklet giving complete operating instructions for the TYPE 443 Mutual-Conductance Meter is now available and will be sent without charge to owners of the instrument who request it. Address the Service Department of the General Radio Company, being sure to mention the serial number of the instrument with which it is to be used.

CONTRIBUTORS

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THE STANDARD-SIGNAL METHOD OF MEASURING RECEIVER CHARACTERISTICS

By CHARLES T. BURKE

THE "standard signal" method of rating radio receivers has met with general acceptance since its proposal several years ago. This method of receiver evaluation requires an accurately known voltage of known degree of modulation adjustable over a wide range, including values of very small magnitude. The input to the receiver is adjusted until a standard output power is obtained and the input voltage is taken as a measure of the receiver sensitivity.*

The functional diagram of Figure 2 illustrates the arrangement and use of the equipment required by these tests. The output of the modulated radio-frequency oscillator is passed into an attenuator consisting of a resistance

*L. M. Hull, *Proceedings of the Radio Club of America*, October, 1928; *I. R. E. Yearbook*, 1929, pp 106–128.

FIGURE 1. TYPE 403-C Standard-Signal Generator, front of panel view

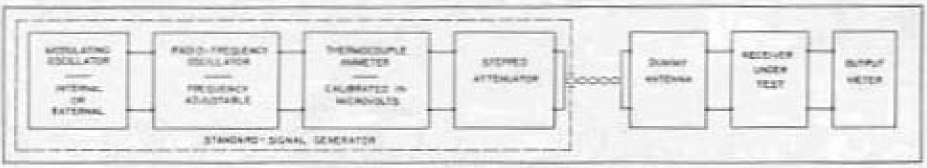


FIGURE 2. Outline showing component parts of the standard-signal generator and auxiliary equipment required for making sensitivity, selectivity, and fidelity characteristics on radio receivers

network so designed that its attenuation over the operating frequency range can be calculated from its constants. The attenuator is coupled to the receiver through a dummy antenna of prescribed constants. The power output of the receiver is measured by any one of several satisfactory methods.

The method of measurement outlined above forms the foundation for a complete test of receiver performance. In establishing the rating of a receiver, a series of sensitivity measurements at frequencies including the entire operating band would be taken. Selectivity curves, i.e., curves of sensitivity for signals differing in frequency by increasing amounts from that to which the receiver is tuned, at a number of frequencies throughout the band can be plotted from data obtained in the same manner. The output of the radio-frequency oscillator is adjusted as the oscillator frequency is changed in small steps, so that the receiver output is kept constant. The frequency to which the receiver is tuned, the frequency of the oscillator, and the voltage input to the receiver are recorded. From these data, a selectivity curve may be plotted showing the strength of interfering signal required to give the standard output as the separation between the received and interference signals is increased.

The same principle of measurement and type of equipment can be used in investigating the operation of portions of the receiver circuit. Thus a single radio-frequency stage or the entire radio-frequency amplifier could be measured, or detector characteristics could be investigated.

The principal component of the equipment required for these tests is a modulated radio-frequency oscillator provided with means for adjustment of its output voltage to known values over a wide range. The essential requirement of a generator for this purpose is that it produce an accurately known voltage between its output terminals and nowhere else. It is readily realized that if the receiver picks up energy from the generator in addition to that measured at its input terminals, the test will be of no value. The first two requirements of the generator are, therefore, adequate shielding and a means of adjusting and accurately determining its output voltage over a wide range including very small magnitudes. The problem of shielding, while quite troublesome, involves only the application of known principles.

It is necessary to obtain output voltages of a few microvolts. Since there is no known method of measuring such voltages directly, it is necessary to attenuate a measurable voltage by means of a calculable network in order to obtain voltages of this magnitude. The design of an attenuator which is accurate at broadcast frequencies is a problem of considerable difficulty. The voltages involved at the lower ends of the attenuator are so small that minute pickups and ground currents will greatly affect the output voltage. The design of such an attenuator involves not only the design and layout of units which will have negligible reactance in themselves, and between units in the attenuator assembly, but also the location of grounds and return conductors.

The General Radio Company in coöperation with the Radio Frequency Laboratories, Inc., brought out its original Standard-Signal Generator, the TYPE 403, in June of 1928. This instrument provided a modulated output in the broadcast range adjustable between 2 and 200,000 microvolts. Complete shielding of the generator permitted its use with unshielded receivers.*

While the TYPE 403 Standard-Signal Generator proved entirely satisfactory for the uses for which it was designed, development work directed particularly at the elimination of its three principal limitations was continued. First, and probably most important, it was not readily adaptable for use at frequencies outside the broadcast band. Second, the radio-frequency oscillator was required to deliver so much power that external batteries were necessary, which seriously impaired the usefulness of the instrument for such purposes as field-strength measurements where portability is an important consideration. Third, the elaborate shielding made the process of changing tubes or making other adjustments inside the generator excessively involved.

As a result of this program, the new TYPE 403-B Standard-Signal Generator was placed in production last summer. The most radical design change was the lowering of the power in the oscillating circuits. The older model used 112-type tubes with 135 volts on the plate, and its radio-frequency oscillator delivered 100 milliamperes to the attenuator system. In the TYPE 403-B Standard-Signal Generator 12-type tubes were used with a plate-battery voltage of only 45 volts; the input to its attenuator was only 5 milliamperes. This reduction in level of the power input to the attenuator accomplished two of the objects of the redesign. Since the amount of shielding largely depends upon the power level in the oscillator circuit, the change permitted a very extensive simplification of the shielding system. The smaller batteries could be

*"Rating of Radio Receivers," *General Radio Experimenter*, November, 1928.

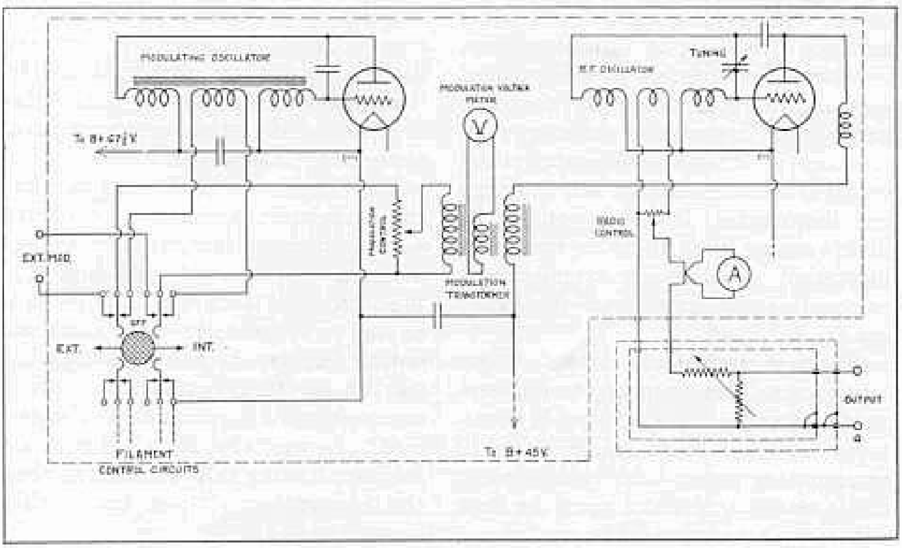


FIGURE 3. Functional schematic of TYPE 403-C Standard-Signal Generator

placed inside of the instrument without increasing the cabinet size. The oscillating circuit was also redesigned to permit the use of plug-in coils, thus extending the frequency range of the instrument.

Development work on the generator, particularly on attenuator systems, was actively continued, even after manufacture of the new instrument was started. The problem of attenuator design is peculiar in that it is more difficult to check the performance of attenuators at low output levels than to design them. The attenuator system had a total voltage attenuation ratio of 20,000 to 1 with minimum outputs of a few microvolts at radio frequencies. There is no known method of measuring a microvolt of alternating current directly. All methods of measurement of voltages of such magnitude are comparison methods and involve at least as great a possibility of error as does the attenuator system being checked. Four methods of comparison are available. Two attenuators of different construction but identical ratios may be connected in cascade. As the attenuation of one is increased and that of the other is decreased by the same amount, the output should remain constant. The validity of this method rests on the reasonable belief that two attenuation systems of different construction would not have compensating errors at all attenuations and at different frequencies. It is subject to the disadvantage that there is no direct indication as to which attenuator is responsible for any error that may appear.

Another method varies the current input to the attenuator as the attenuation is changed. This method is necessarily confined to a limited range of attenuation steps, since the current input to the attenuator must be kept within the operating range.

A third method of attenuator calibration is to observe the output of a radio receiver as the input is increased. This involves a knowledge of the detector characteristic of the receiver amounting to a calibration of the receiver. The difficulty of such calibration without a source of known input voltage is obvious.

A fourth method is to heterodyne the output of the attenuator under test, and amplify it at a lower frequency. An attenuator, calibrated at the lower frequency included in the low-frequency amplifier, is used to check the high-frequency attenuator.

All four methods depend upon an unknown receiver characteristic to determine the amount of difference in the two voltages compared. If there is no difference, however, the receiver characteristic does not enter the measurement except when the third method is used.

It is the opinion of those most familiar with the problem that it is impossible to obtain a voltage attenuation ratio of 2 to 1 at 1000 kilocycles with a smaller probable error than 1 per cent. The range of the attenuator used in the standard-signal generator includes fourteen 2 to 1 ratios. The probable error of such a system may, therefore, be about 15 per cent. It should be noted that this is a limitation of the method of checking the attenuator, not necessarily of the attenuator itself.

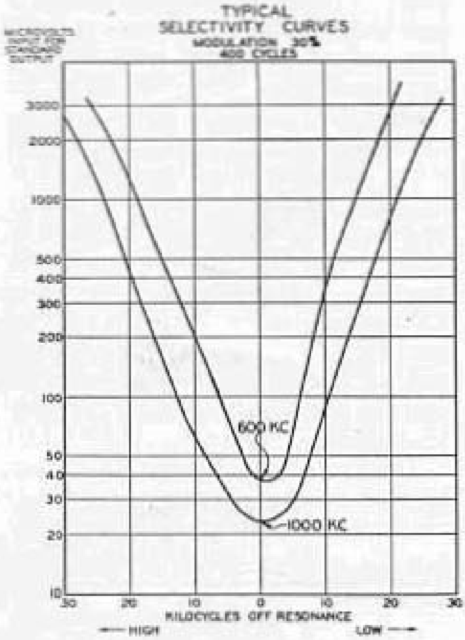
With improved methods of checking the attenuators, several sources of error were discovered, necessitating changes in the attenuator system. Coupling to the attenuator leads was found to exist, as well as coupling between input and output sections of the attenuator, which had a total voltage attenuation ratio of 20,000 to 1 in a single shielded compartment. It was also found that heavy currents flowing in the shielding about the attenuator set up fields which coupled into it.

Several measures were adopted to

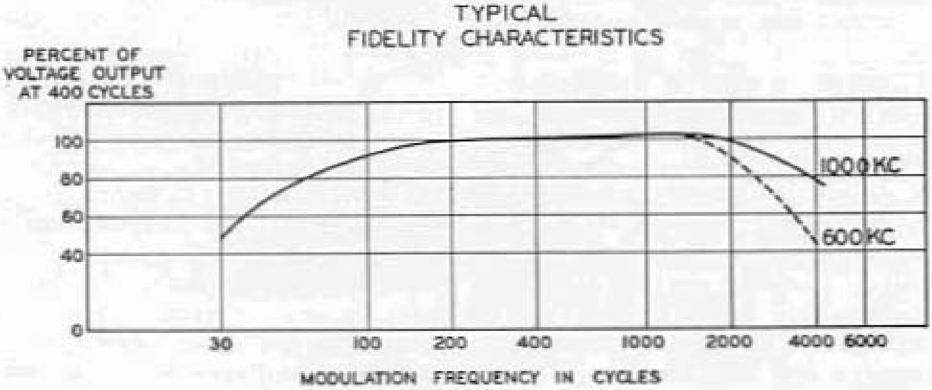
overcome these difficulties. The use of a type of concentric conductor in which the low potential side of the circuit forms a shield for the high potential side eliminated the trouble due to voltages induced in the wiring. Capacity coupling between the two ends of the attenuator was eliminated by dividing it into two sections and shielding them from each other. The entire assembly was then placed in a separate shielded compartment electrically isolated from the main shielding except for a connection at one point.

With the new attenuator, which is a conventional L-network, a maximum total probable error in the attenuator system of less than 15 per cent. is indicated. In other words, the error in the smallest output voltage due to the attenuator is less than 15 per cent. if all of the individual errors between steps were cumulative. The possible cumulative error, of course, decreases as more sections of the attenuator are removed from the circuit to obtain the higher voltages.

The Type 403-C Standard-Signal



Typical broadcast receiver characteristics: Figure 4—Sensitivity curve; Figure 5—Selectivity curve; Figure 6—Fidelity curve



Generator, as the latest design of the new instrument has been designated, consists essentially of a modulated radio-frequency oscillator. The tuning range covered by five coils extends from 15 to 1500 kilocycles. In addition to the main tuning condenser, a secondary frequency control is provided for use in taking selectivity curves, where a small change in frequency is desired. This control consists of a copper sector which moves in the field of the tuning coil and changes its inductance.

Since the frequency change due to this adjustment results from a change in inductance, the percentage change in frequency for a given setting is not directly affected by the setting of the main tuning control, which changes the capacity in the circuit. Modulation is provided for with a 400-cycle vacuum-tube oscillator included in the generator. Terminals for external modulation with input leads properly filtered to eliminate radio-frequency leakage are also provided. The external oscillator should be capable of maintaining about 15 volts across 2500 ohms in order to produce 30 per cent. modulation.

The input current to the attenuator is read on a thermocouple meter calibrated in microvolts, and the attenuator is calibrated as a multiplier. The attenuator has a non-reactive output impedance of approximately 10 ohms at all steps except the two corresponding to greatest output voltage.

The entire assembly is enclosed in a shielded cabinet. Filter circuits are included in the leads to the meters, making screening in front of the meters unnecessary. The instrument can be used with unshielded receivers without any pickup from the generator. The most sensitive receivers available have failed to detect any signal voltage when connected to the generator with the generator output switch set at zero.

A standard dummy antenna made in accordance with the specifications of the Institute of Radio Engineers is available. Its constants are:

Inductance . . .	20 microhenrys
Capacitance . .	200 micromicrofarads
Resistance . . .	25 ohms

The effective height is taken as four meters.

The TYPE 403-C Standard-Signal Generator requires two 12-type vacuum tubes for operation. Space is provided in the cabinet for the necessary batteries; i.e., 1.5 volts for the filament, and 45 volts and 67.5 volts for the plates of the radio- and modulating-oscillator tubes, respectively.

The TYPE 403-C Standard-Signal Generator possesses the features required for the measurement of receiver characteristics with facility. The voltage of the output system is continuously variable over a wide range. Leakage is reduced to a minimum, permitting the measurement of very sensitive receivers. Selectivity curves may be rapidly run by use of the fine adjustment on the frequency control. The use of external modulation makes over-all characteristics readily obtainable.

The curves of Figures 4, 5, and 6 are illustrative of the type of receiver data that is obtainable with the signal generator. The effect of side band cutting is noticeable on the audio-frequency characteristic of Figure 6.

While the standard-signal generator is used extensively in receiver testing, both in the laboratory and the production line, its uses are not limited to receiver performance tests. Another wide range of usefulness of an instrumnet of this sort, producing a known voltage of small magnitude, is in the measurement of the radio-field intensity (field strength) of transmitters. The portability of the instrument, with all batteries contained in the cabinet, is of particular advantage in this connection.

Straight-Line Wavelength, Straight-Line Frequency, and Straight-Line Capacitance Condensers

By John D. Crawford

FOR experimental work in the laboratory when an exact capacitance calibration is not required, high-grade variable air condensers built for sale to the radio broadcast and radio amateur experimental fields may often be used. This saves wear and tear on the calibrated instruments and materially reduces the investment in equipment. Most of the experimental condensers now on the market have been designed for use as tuning controls in oscillatory circuits where it is desirable that the angle of rotation be proportional either to wavelength or frequency. Since condensers with straight-line wavelength and straight-line frequency plates do not have their

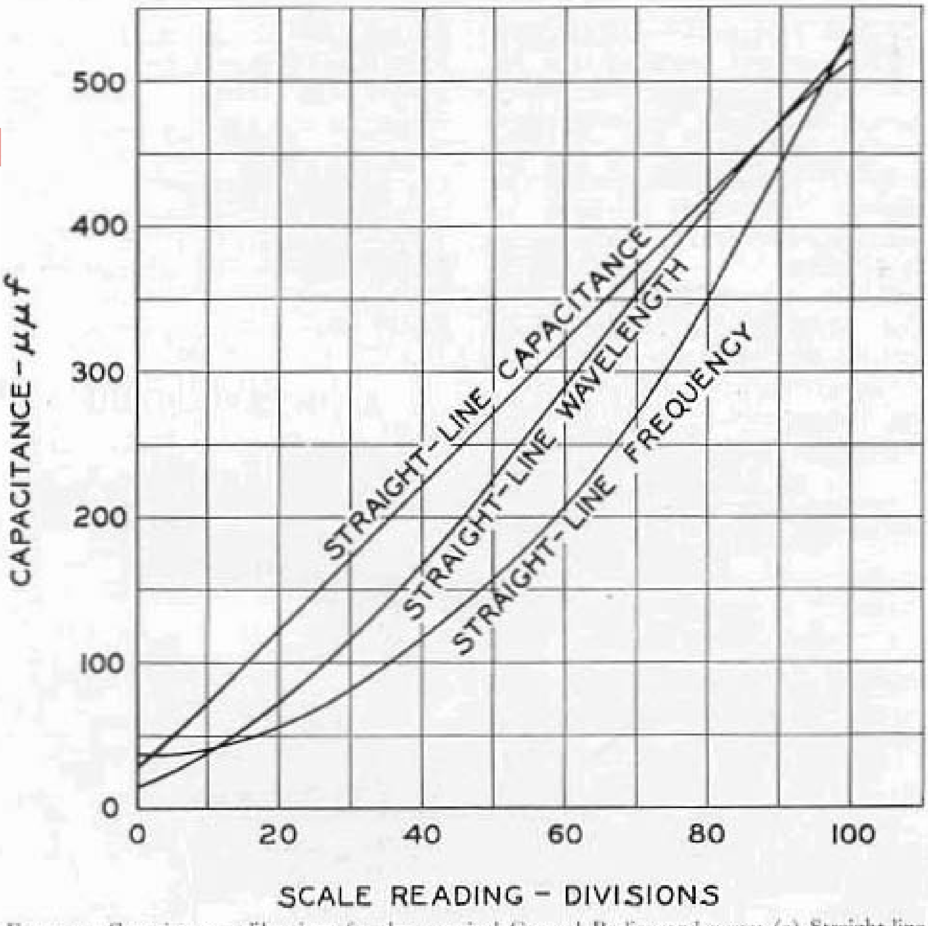


Figure 1. Capacitance calibrations for three typical General Radio condensers: (a) Straight-line capacitance, Type 247-G; (b) Straight-line wavelength, Type 247-F; (c) Straight-line frequency, Type 374-F

capacitances proportional to setting, one often wants to know how much the capacitance varies from the straight-line law.

It is obvious, of course, that the total capacitance in a circuit is directly proportional to the square of the wavelength and inversely proportional to the square of the frequency. A condenser to follow either a straight-line wavelength or a straight-line frequency law must have the slope of its capacitance calibration curve smaller during the first part and larger for the second part of the scale than for a condenser following the straight-line capacitance law. The curves of Figure 1 show better than words this difference. They are actual calibrations for three General Radio condensers, each of which has a nominal maximum capacitance of 500 micromicrofarads.

MISCELLANY

By THE EDITOR

THE TYPE 403-C Standard-Signal Generator described by Mr. Burke in this issue of the *Experimenter* is supplied with one TYPE 403-Q2 Inductor for covering the frequency band between 500 and 1500 kilocycles and with a TYPE 418 Dummy Antenna. The cabinet size is 27¼ inches by 13 inches by 10½ inches, the weight is 41 pounds, and the Code Word is SCALY. The price of $600.00 includes no tubes.

Plug-in coils are available for extending the operating range to other frequencies as follows:

Type	*Frequency Range*	*Price*
403-P2	500–1500 kc.	$12.00
403-P3	165– 500 kc.	12.00
403-P4	60– 175 kc.	22.00
403-P5	27– 60 kc.	22.00
403-P6	15– 33 kc.	22.00

Frequency calibrations for these are supplied only when ordered at an extra charge of $8.00 per inductor. The type numbers for the calibrated coils are 403-Q2, 403-Q3, 403-Q4, 403-Q5, and 403-Q6. The generator with which calibration coil will be used must be submitted with the order so that we can make calibrated and check the performance of the instrument.

The TYPE 403-C Standard-Signal Generator can be shipped from stock. Calibrated inductors for other frequency ranges will require another ten days.

CONTRIBUTORS

The contributors to this issue of the *Experimenter* are both members of the General Radio Company's Engineering Department:

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A TUNING-FORK AUDIO OSCILLATOR

By CHARLES E. WORTHEN*

FOR a variety of measurements in the communication laboratory, and for bridge measurements in particular, a fixed frequency oscillator is an indispensable instrument. Among the requirements which such an instrument should meet are good waveform, simplicity of construction, and low cost.

These requirements may be met by an oscillator using a tuning fork as the frequency-controlling element. The electrical circuit of such an oscillator is shown in Figure 1. Referring to this diagram, *F* is a tuning fork which serves as a frequency-controlling device. When this fork is set in motion, it vibrates at its natural frequency (depending on its dimensions), and causes the diaphragm of the microphone button *M*, which is mechanically coupled to the fork, to vibrate at the same frequency. The resistance of the microphone button varies in accordance with the motion of its diaphragm, and causes a corresponding variation in the current which flows in a circuit consisting of the microphone button *M*, the battery *B*, and the primary of the output transformer T_1. An alternating voltage of the fork frequency is then produced at the secondary terminals of T_1, and alternating current flows around the circuit consisting of the secondary of T_1, the drive coil *D*, the condenser C_1, and the primary of the output transformer T_2. A portion

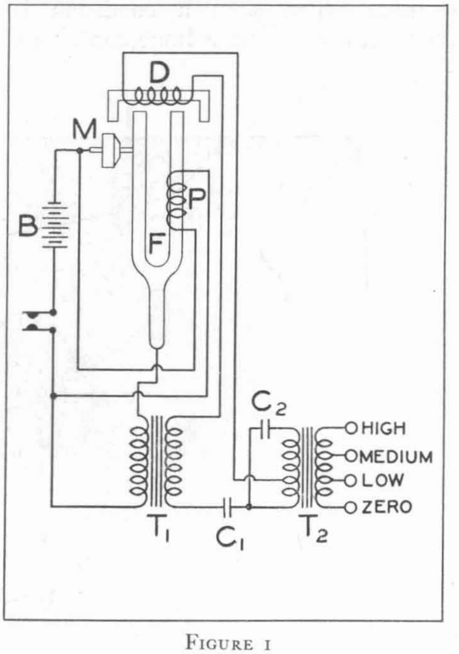


FIGURE 1

of the available energy is fed back through the drive coil to keep the fork in motion, and the rest is supplied to the load at the secondary terminals of the output transformer T_2. The condenser C_1 is used to shift the

* Engineering Dept., General Radio Company.

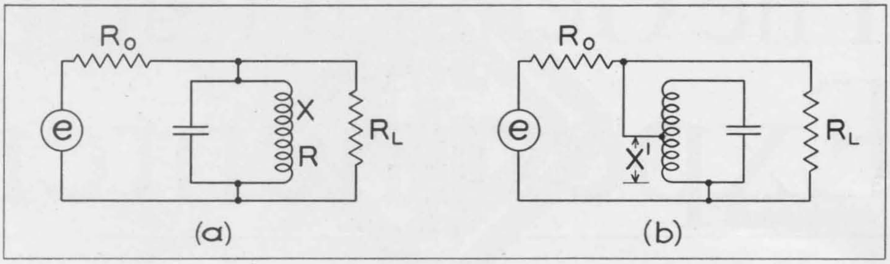


FIGURE 2

phase of the current through the drive coil to the value necessary to drive the fork. Since the fork is not permanently magnetized, a polarizing coil *P* is necessary to supply a constant magnetic bias. Without this, the fork would be driven at twice its natural frequency.

The circuit elements of Figure 1 exclusive of the output transformer can readily be adjusted for maximum output. When such a condition is reached, the output voltage contains a large number of harmonics of considerable magnitude, and to get good waveform, some method of filtering is necessary.

This can be accomplished by the arrangement shown at the right of Figure 1. This is, in effect, a parallel tuned circuit placed across the output.

If the output transformer (which is merely a means of matching impedances) is disregarded, the oscillator circuit may be represented as shown in

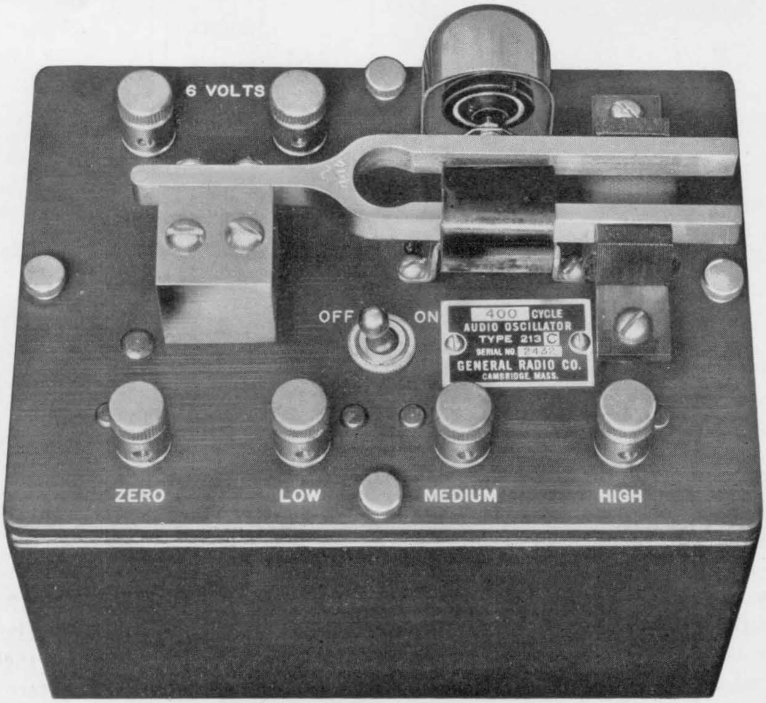


FIGURE 3. TYPE 213-C Audio Oscillator. TYPE 213-B Audio Oscillators are the same except that they have somewhat shallower cabinets

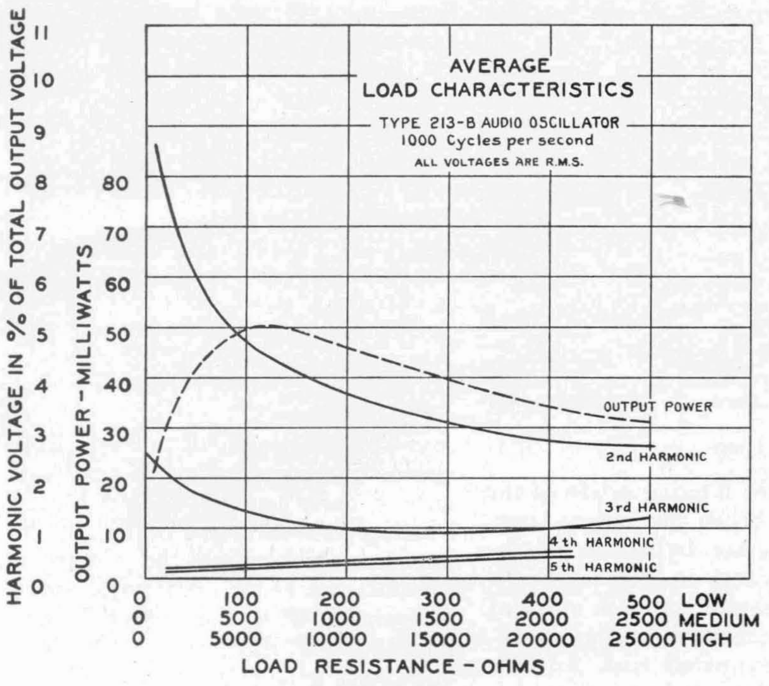


FIGURE 4. Average load characteristics: Upper left—TYPE 213-B Audio Oscillator, 1000 cycles per second; Lower right—TYPE 213-C Audio Oscillator, 400 cycles per second

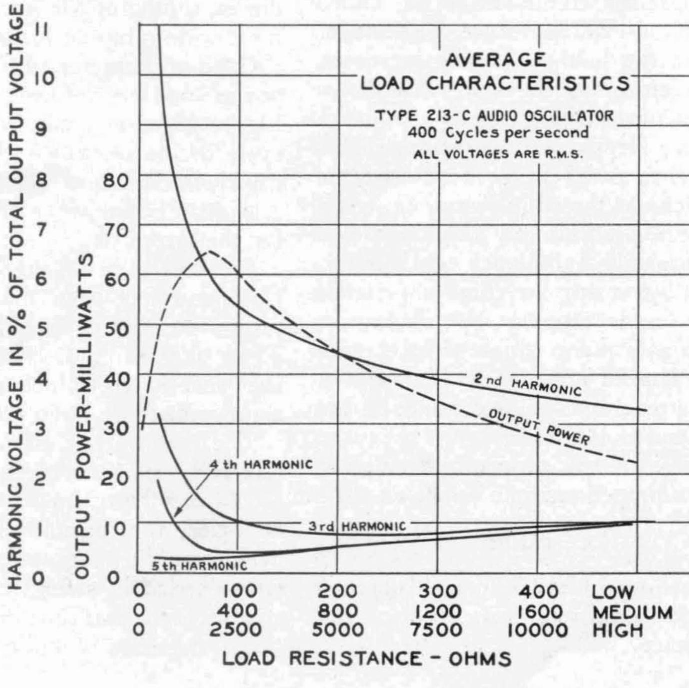


Figure 2a, where R_O is the internal impedance of the oscillator, R_L is the load resistance, and R and X are, respectively, the resistance of the tuned circuit and the reactance of one of its branches. The resonant impedance of the tuned circuit is a pure resistance and is equal to $\mathcal{Q}X$ where $\mathcal{Q}=\frac{X}{R}$. Its impedance at a harmonic frequency which is n times the fundamental is $\frac{n}{n^2-1}X$. The ratio of the fundamental impedance to the harmonic impedance is then $\frac{n^2-1}{n}\mathcal{Q}$, which is a measure of the filtering action of the tuned circuit. When this ratio is large, the harmonics are bypassed by the tuned circuit, and do not reach the load. This selective action is modified by the load resistance, and as R_L becomes large compared with $\mathcal{Q}X$, the ratio of fundamental to harmonic impedance approaches $\frac{n^2-1}{n}\mathcal{Q}$ for the parallel combination of tuned circuit and load resistance. This means that as the load resistance increases, the waveform improves, which is shown by the curves of Figure 4.

Since, for proper operation, a low-impedance tuned circuit is required, the arrangement shown in Figure 2a would require a prohibitively large value of condenser. This difficulty can be overcome by using a high-impedance circuit and tapping the inductive branch at a point which gives the desired value of impedance. If X and R are the reactance and resistance of the whole coil and X' (see Figure 2b) is the reactance of the tapped portion, the resonant impedance can be shown to be $X'\frac{X}{R}=X'\mathcal{Q}$ for values of coupling approaching unity. The coil acts as an auto-transformer to step down the impedance.

In order to save both space and material, the primary of the output transformer can be used as the inductive branch of the tuned circuit, as shown in Figure 1. As transformers are ordinarily used, where the winding reactances are large compared to the impedances between which they work, the primary cannot be tuned because the reactance seen on the primary side is extremely small. This difficulty is avoided by making the transformer reactances very small in comparison to the impedances to which they are connected, so that the load may be varied over wide limits without an appreciable change in the apparent primary reactance. If unity coupling is assumed and winding resistances are neglected, the impedance looking into the primary of a transformer is the primary reactance in parallel with the reflected load impedance. If, then, the reflected load impedance is large compared with the primary reactance, the impedance looking into the primary is approximately equal to its reactance. Under this condition, tuning of the primary will hold for a wide range of loads.

Output characteristics showing both power and waveform are given in Figure 4 for a 400-cycle and a 1000-cycle oscillator. Since $\mathcal{Q}$ for the coils used is lower at 400 than at 1000 cycles, a slightly better waveform is obtained for the latter.

For several years the General Radio Company has been manufacturing a 1000-cycle tuning-fork oscillator, the TYPE 213 Audio Oscillator. This has been redesigned to include the filtering arrangement we have just discussed.

The new output circuit makes it a relatively easy matter to build these oscillators for operation on other frequencies, and, in addition to the 400-cycle and the 1000-cycle models regularly carried in stock, instruments for any 100-cycle multiple in the 400-1500-cycle range can be built to order.

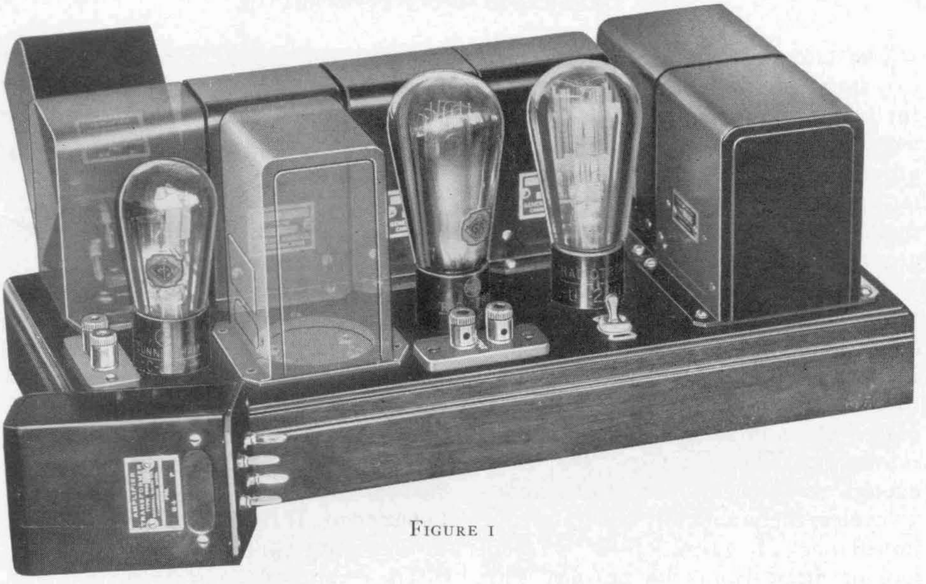


FIGURE 1

AN AUDIO AMPLIFIER FOR THE LABORATORY

By ARTHUR E. THIESSEN *

THE TYPE 645 Laboratory Amplifier illustrated in Figure 1 has been designed to fill the need for a two-stage audio amplifier of the greatest possible flexibility to be used for general experimenting. Because of the widely varying requirements of different experimenters and since the needs of every experimenter change from day to day, it is almost impossible to design one amplifier to serve all purposes.

By utilizing the plug-in principle for the input and interstage coupling units, the widest variety of circuit requirements may be met. The amplifier is supplied with jack plates, properly drilled to receive the TYPE 274-EP Transformer Mounting Base to which any type of coupling unit may be attached. Or, if it is necessary to use only a part of the amplifier, any standard TYPE 274 two-element plug may be plugged in at the desired point in the circuit; for example, across the grid of the output tube. The convenience of such flexibility is at once apparent to experimenters who have tried to adapt an amplifier to some purpose by the use of a soldering iron and clips.

Each amplifier is sold with two of the standard TYPE 274-EP Transformer Mounting Bases which fit the jack plates on the amplifier base and to which any form of transformer or coupling device may be attached. The bases are drilled especially to fit the General Radio TYPE 585 Transformers and the TYPE 573-A Resistance-Impedance Coupler.

Figure 2 shows the circuit diagram. The power transformer, filter, and grid-bias units are each in separate containers, all of which are connected together and grounded. The can covers for the removable units may also be grounded by means of the center jacks on the mounting jack plates. All of the wiring is done under the base, but is exposed so that changes can be made readily if necessary.

* Engineer, General Radio Company.

The circuit is similar to the usual two-stage amplifier circuit, except that the filament center tap rather than the negative plate-battery terminal is grounded. This is done so that the output terminal can be connected directly back to filament and to ground at the same time.

The output circuit consists of a 40-henry inductance and a 4-microfarad condenser. At 50 cycles, this circuit has an inductive reactance of over 12,000 ohms, and a capacitive reactance of 800 ohms in series with the output terminals. These values are large enough so that, at frequencies above 50 cycles, the practically constant tube impedance of 2,000 ohms is seen, looking back from the output. This impedance may then be matched to any sort of a load by a suitable impedance-matching transformer or network.

Numerous tests have been conducted on this amplifier, one of which may be regarded as typical. Figure 3 indicates the frequency-response characteristic of the amplifier using two General Radio TYPE 585-D Transformers which have a 1:2 voltage step-up ratio and are designed to work out of about 10,000 ohms. The curve was taken with the amplifier working out of 10,000 ohms and into 5,000 ohms. The curve shows the gain of the amplifier to be approximately 40 decibels over its flat portion — from 90 to 6,000 cycles — dropping off two decibels at 40 and 8,000 cycles. The response is down 5 decibels at 25 cycles, and 4 decibels at 10,000 cycles.

The amplifier is designed for operation on 105–115 volt 60-cycle alternating current. It requires a total of about 35 watts of power.

The residual alternating-current hum is very low. The hum voltage is 0.35 volt across 5,000 ohms. This is a hum power of 0.024 milliwatt, 24 decibels below a zero level of 6 milliwatts. The output tube is the 245-type which will deliver about 1,600 milliwatts of output power without introducing greater than 5 per cent. harmonic

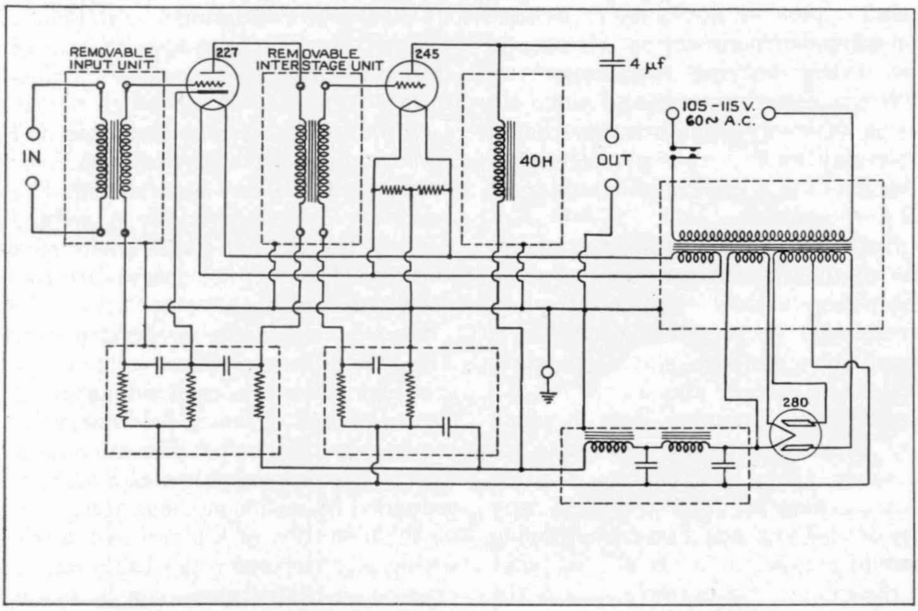


FIGURE 2. Wiring diagram for TYPE 645 Laboratory Amplifier

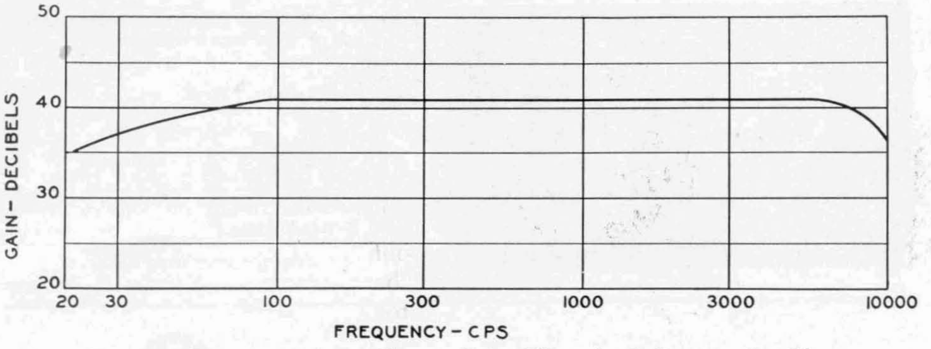


Figure 3. Frequency-response characteristic of Type 645 Laboratory Amplifier

distortion due to overloading. This corresponds to 89.5 volts across a 5,000-ohm load.

Any circuit containing iron will introduce a slight harmonic distortion to a pure sinusoidal voltage wave applied to it. With a direct-current bias the second harmonic is usually one of the worst generated from this cause. Its magnitude varies with the amount of power transferred through the iron circuit. The total second harmonic distortion present in the Type 645 Laboratory Amplifier, caused by the combination of the non-linearity of the iron, as well as that of the tubes in the circuit, has been measured. The amount can be expressed as a ratio between the amplitude of the pure sine wave and the second harmonic appearing at the output terminals of the amplifier, assuming that a pure sinusoidal wave is applied at the input. At 100 milliwatts output, the harmonic voltage is 35 decibels below the fundamental, and at 1,000 milliwatts output, it is down 26 decibels. This small distortion is by no means entirely due to the iron, but the curvature of the tubes' characteristics, particularly at the higher output, is a factor.

An amplifier should never be used to increase a very small power to a value that can be read on ordinary instruments unless all of the constants of the amplifier are definitely known.

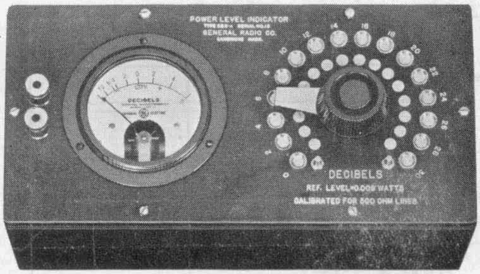
However, when *comparing* two or more low power sources the amplifier is invaluable because its constants enter into all measurements and cancel in the final result.

The General Radio Type 645 Laboratory Amplifier is suitable for all kinds or laboratory experimenting where a flexible and serviceable amplifier is needed.

The amplifier is sold without input or interstage transformers. Any good coupling unit may be used. We recommend the following, selected from our standard line.

Type	Unit	Voltage Ratio	Use
585-D	Transformer	1:2	plate-to-grid
585-H	"	1:3.5	plate-to-grid
585-G	"	1:3.6	line-to-grid
585-M	"	1:27	single button microphone-to-grid
585-M2	"	1:27	double button microphone-to-grid
573-A	Resistance Impedance Coupler	1:1	plate-to-grid

TYPE 586 POWER LEVEL INDICATORS



For measuring and monitoring power level in all kinds of voice transmission and recording circuits.

Range −10 db to +36 db

Prices

Cabinet Model $60.00
Relay Rack Model 64.00

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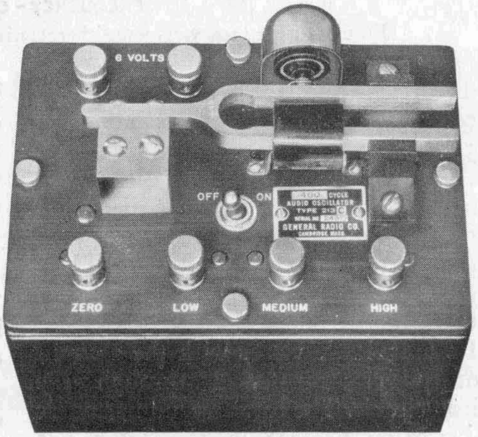
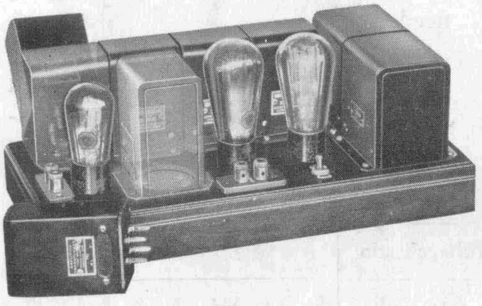
TYPE 213
AUDIO OSCILLATOR



The old Type 213 Audio Oscillator, long a necessary element of bridge measurements, has been redesigned, and a 400-cycle model has been added. Its advantages are good waveform, simplicity of construction, and low cost.

Type	*Frequency*	*Operated*	*Depth*	*Weight*	*Code Word*	*Price*
*213-B	1000 cps	6 volts, d.c.	5 in.	5 lb.	ANGEL	$34.00
*213-C	400 cps	6 volts, d.c.	6⅛ in.	5¾ lb.	AMUSE	42.00

* Both Type 213-B and Type 213-C are built for other frequencies on special order. Code words and prices apply only to frequencies here listed.



TYPE 645
LABORATORY AMPLIFIER

Plug-in interstage transformers, high gain, good waveform, handy for all kinds of experimental work.

No transformers are supplied with the Type 645 Laboratory Amplifier, but the necessary mounting bases, ready for connection, are furnished. The price of $78.00 does not include tubes.

Type	*Code Word*	*Price*
645	AMBLE	$78.00

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THE DYNATRON

By Charles E. Worthen*

A GREAT deal of attention has been given recently to the dynatron type of oscillator. The principle of the dynatron is not a recent discovery, a paper on the characteristics of such a device having been published by Hull† in 1918. The reason for a renewed general interest in the subject is doubtless due to the fact that low-priced receiving tubes with which the dynatron negative resistance characteristics may be easily realized are now available. These are the screen-grid tubes of the 222- and 224-types.

The static $I_p - E_p$ curves of a 224-type tube are given in Figures 1 and 2. In the range of plate voltage which lies roughly between 10 and 40 volts, the plate current decreases as the voltage is increased. This means that the internal plate resistance, which is the reciprocal of the slope of the $I_p - E_p$ curve, is negative, due, of course, to the emission of secondary electrons from the plate. When electrons emitted by the filament reach the plate, the impact releases some electrons from the plate itself which are immediately attracted away from it by the higher positive potential of the screen grid.

In the dynatron region referred to above, an increase in plate voltage produces a corresponding increase in the number of electrons flowing from filament to plate, but this produces a still greater flow of secondary electrons away from the plate and the net result is a decrease in plate current.

Any device which possesses a negative resistance characteristic will, provided certain other conditions are satisfied, produce self-sustained oscillations. If a parallel tuned circuit is connected as shown in Figure 3 to a tube operating in the negative resistance or dynatron region, oscillations will be produced, provided the impedance of the tuned circuit $\left(\text{which is closely given by } \frac{L}{CR}\right)$ is equal to or greater than the negative resistance of the tube. The frequency is then given approximately by $\frac{1}{2\pi\sqrt{LC}}$, and more exactly by

$$\frac{1}{2\pi}\sqrt{\frac{1}{LC}-\left(\frac{R}{2L}+\frac{1}{2Cr}\right)^2}$$

where R, L, and C are respectively the resistance, inductance, and capaci-

* Engineering Department, General Radio Company.

† A. W. Hull, "The Dynatron, a Vacuum Tube Possessing Negative Electric Resistance," *Proceedings of the Institute of Radio Engineers*, February, 1918.

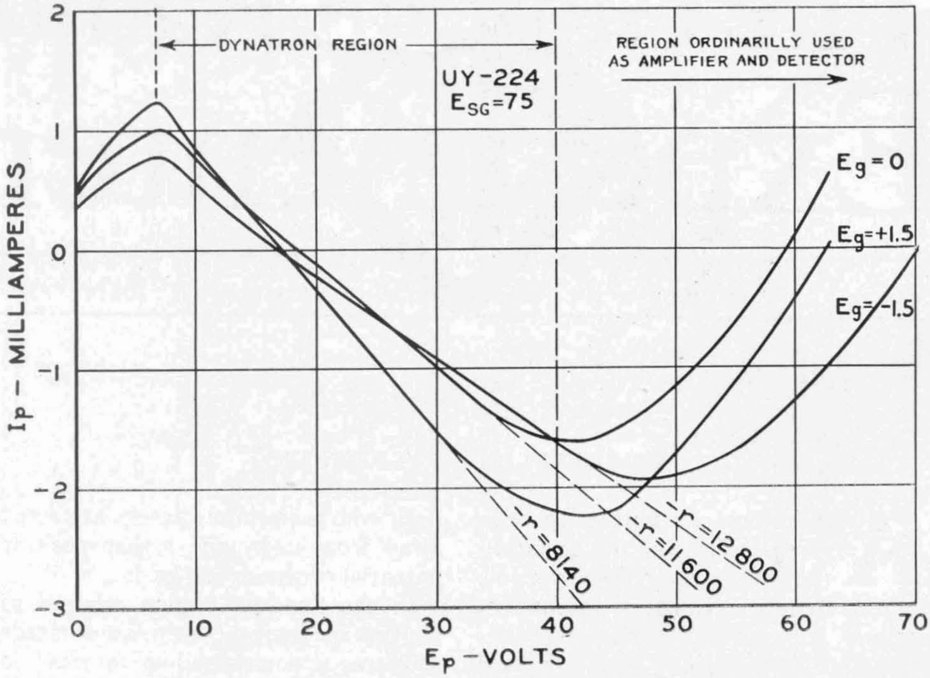
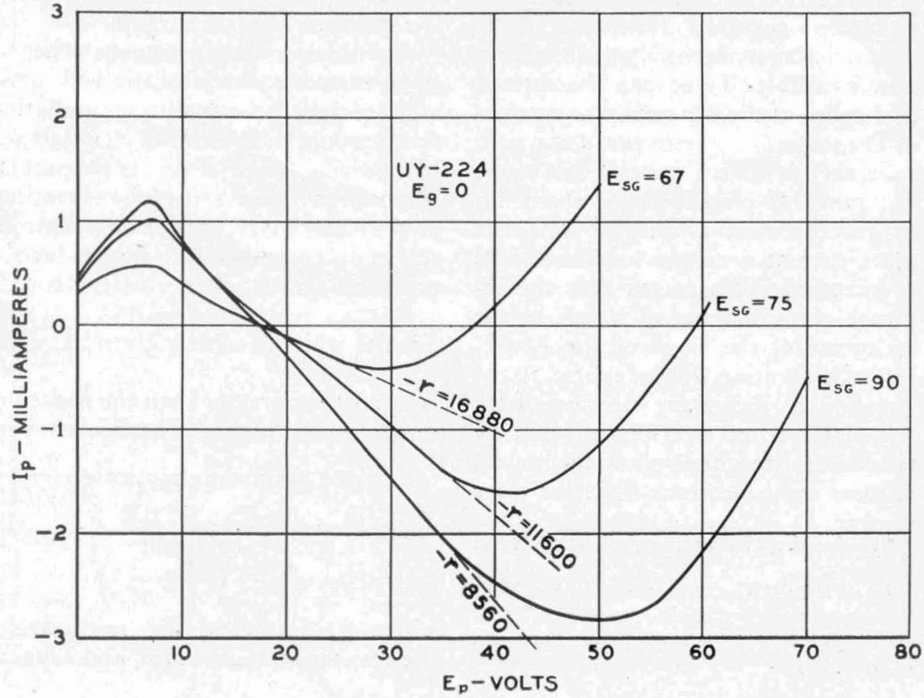


FIGURE 1 (*above*) — Plate-voltage-plate-current characteristic of a screen-grid tube in the dynatron region with constant screen-grid voltage and three different values of control-grid voltage

FIGURE 2 (*below*) — Plate-voltage-plate-current characteristic of a screen-grid tube in the dynatron region with fixed control-grid voltage and three different values of screen-grid voltage



tance of the tuned circuit and r is the absolute numerical value of negative resistance of the tube. In all the above expressions, the term C is the total effective capacitance of the tuned circuit which includes the plate-to-filament capacitance of the tube.

The frequency range over which the dynatron oscillator may be made to operate is extremely wide, frequencies from a few cycles per second to some 20,000,000 being obtained by merely changing the tuned circuit. At the very low audio frequencies and the very high radio frequencies care must be taken to keep the resistance of the tuned circuit as low as possible. The point at which oscillations cease is reached when r becomes greater than $\frac{L}{CR}$. For a given value of negative resistance r and assigned values of L and C (determining the frequency), the value of R will determine whether the system will oscillate. The negative resistance of the tube varies under ordinary conditions from about 8,000 to 16,000 ohms (see Figures 1 and 2) and in order to produce oscillations, $\frac{L}{CR}$ must lie roughly in this region. If the plate voltage is fixed, the value of the negative resistance decreases with increasing screen-grid voltage and also with increasing positive bias on the control grid. This may be seen from the characteristic curves of Figures 1 and 2.

A convenient way to operate the 224-type of tube is with the control grid tied directly to filament, with 22.5 volts on the plate and 67 to 90 volts (preferably 90) on the screen grid. This allows the use of the ordinary blocks of high-voltage batteries which are tapped at 22.5-volt intervals.

Changes in operating voltages produce a comparatively small change in

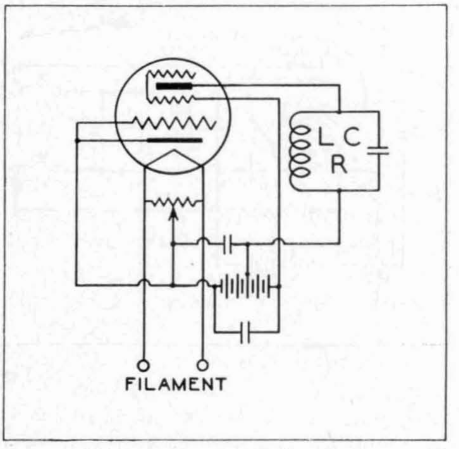


Figure 3

frequency. For most purposes, this is entirely negligible. Better frequency stability over an unusually wide range of frequency can be obtained with the dynatron oscillator than is possible with one of the conventional type using a 3-electrode tube. Its stability compares well with that of a piezo-electric crystal oscillator without temperature control. This allows it to be used for fairly precise measurements of frequency, since it can be calibrated against a known standard and will hold its calibration well for long periods of time.

Any resonant circuit wavemeter can be converted into a heterodyne wavemeter by using a dynatron to drive the tuned circuit. Also, the sharpness of indication of the wavemeter can be greatly increased by the use of a dynatron as a means of neutralizing the resistance of its circuit. This can be accomplished by putting sufficient negative bias on the control grid, or by decreasing the screen-grid voltage until the dynatron is just below the point of oscillation. Under this condition, the positive resistance of the wavemeter is largely canceled by the negative resistance of the tube which results in a much sharper resonance

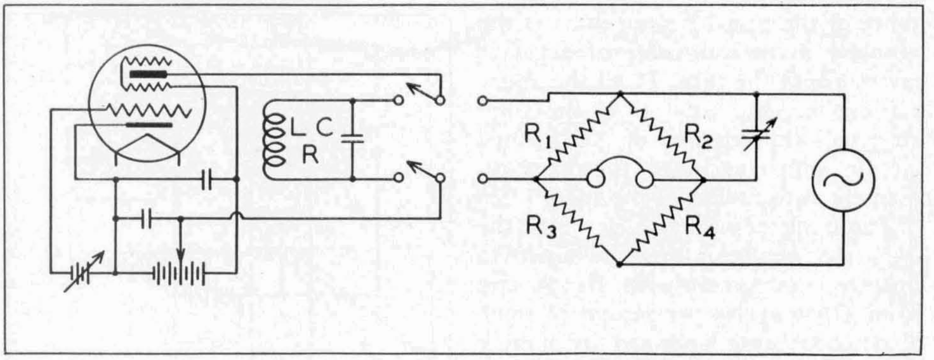


FIGURE 4

peak. When the dynatron is used for this purpose, its plate-current meter can be used for resonance indications.

If a pair of telephone receivers is connected in the screen-grid circuit of the oscillating dynatron, beats can be heard between the dynatron and other oscillators, at harmonics of the dynatron frequency as well as at the fundamental. Harmonics of the order of the fifteenth can be utilized in this way without additional amplification. This makes it possible to use a heterodyne wavemeter which has a limited range of fundamental frequency for calibration work over a much wider frequency range.

In addition to those mentioned above, the dynatron has many other applications. Hull* has described its use as an amplifier and as a detector. It can also be used to measure tuned circuit resistance. If the control grid bias is adjusted until the tube just oscillates, the impedance of the tuned circuit is equal to the negative resistance of the tube and the circuit resistance can be found from the expression $r = \frac{L}{CR}$. The negative tube resistance can be measured in a number of ways. Iinuma† used small positive and negative increments in plate voltage to determine it. Another method which works well uses an impedance bridge, as shown in Figure 4. The tube plate circuit is placed in parallel with a known resistance, the combination forming one arm of the equal-arm bridge. The negative tube resistance is then given by $r = \frac{R_1 R_2}{R_2 - R_1}$ since $R_3 = R_4$. Very precise measurement is possible with this arrangement.

The use of the negative resistance characteristic of the dynatron in a resistance-coupled amplifier has been described by Dowling.‡

* Op. cit.

† Hajime Iinuma, "A Method of Measuring the Radio-Frequency Resistance of an Oscillatory Circuit," *Proceedings of the Institute of Radio Engineers*, March, 1930.

‡ John J. Dowling, "A New Method of Using Resistance Amplification with Screened Grid Valves," *Experimental Wireless & The Wireless Engineer, Volume V*, No. 53, February, 1928.

USES OF POWER-LEVEL INDICATORS

By ARTHUR E. THIESSEN*

THE instrument which indicates the level of power in a telephone transmission circuit is an invaluable device for measuring the performance of the circuit, both while in use and for testing. It is called a power-level indicator, or a volume indicator; more simply, V. I.

When connected across a transmission line carrying a program of voice and music, one of its functions is to indicate to an operator between what approximate power limits the sound is being delivered past its terminals. Speech and orchestral music power vary between wide limits during transmission, but the indicator, not following each sudden variation, reads a mean which is known as the Average Power. Most power-level indicators are simply voltmeters which show the voltage across the transmission line at the point of measurement. The voltage is, of course, a function of the power.†

The measurement of the electrical power in the voice circuit is not difficult once a reference point has been determined. Two levels have been rather arbitrarily chosen as the zero or reference level of power. In some telephone and broadcast circuits, it is taken as 6 milliwatts; for carrier and certain other telephone circuits, it is 10 milliwatts. The choice is quite arbitrary, but 6 milliwatts is the most usual. With this as the standard reference level, power-level indicators are calibrated to read the ratio between the actual power and the reference power in decibels.

One example of the importance of maintaining a check on the signal amplitude of a telephone circuit is illustrated in Figure 1. *AA* and *BB* represent 4 electric conductors running close together, as in a cable, for example. In this condition there will be an appreciable amount of capacitance between them. The pair *AA* is being used for carrying speech originating at the transmitter; while someone is listening to an entirely different conversation on the pair *BB*. The capacitances between these 4 conductors form the familiar bridge arrangement. If the bridge were balanced, that is, if all of the capacitances were equal, none of the signal in *A* would appear in *B*. However, in the majority of actual circuits no such ideal balance is possible and some part of the signal in *A* is heard in the receivers. It can be found by experience at just what power level this interfering speech becomes troublesome. It is necessary then for an operator to observe the volume level of the speech at the power-level indicator and to hold it below the interfering level by means of the volume control. Besides the difficulty from such crosstalk, a power level which is too high may overload repeaters, amplifiers, or reproducers in the circuit.

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* Engineer, General Radio Company.

† The indicator, being a voltmeter, reads proportionally to both the power and the impedance of the line; i.e.

$E = \sqrt{ZW}$ when W = the power in watts and Z = the impedance in ohms.

The impedance, Z, of a transmission line is given by the formula:

$$Z = \sqrt{\frac{L}{C}}$$

where L and C are the inductance and capacitance of an infinite line. In practice, this method works out to be about 500 or 600 ohms. Power-level indicators are usually calibrated on this basis with 6 milliwatts as the reference level. The reference is thus about 1.73 volts.

On the other hand, there is a very definite level of extraneous noise present in all telephone circuits. Its magnitude depends on a number of factors. On outside telephone lines, interference may be picked up from nearby power lines. Atmospheric electricity affects the lines quite as seriously as it does radio. Poor contacts, generator noise, and microphone hiss all contribute to the unavoidable "noise level" in all voice circuits. In order that speech may be understandable, it is essential that its volume does not fall below the noise level of the system. The power-level indicator provides the means by which an observer can know when the speech power is below the noise level and can correct the condition.

Thus, there are two definite limits between which speech circuits must operate. The value of the power-level indicator is to tell the operator just what the speech power level is, in order that he can intelligently handle the circuit.

Considering the limits of speech power that may be used, there is an interesting analogy between telephone circuits and recording on wax records. Due to infinitesimal irregularities on the surface of the wax, there is always present a certain amount of surface noise or "needle scratch." This is the "noise level" of the wax record. Music or speech impressed on the record must have an amplitude in excess of this in order to be intelligible. On the other hand, the maximum amplitude is determined by the swing the needle can make without cutting through to the next groove. The usual safe amplitude for records used in talking picture recording is about 0.002 inch. There is danger of cutting over if any greater amplitude is used. This is the overload or "crosstalk" point and the signal must not be allowed to exceed it.

The maximum range between the allowable low and high levels on a wax record is about 36 decibels, a power range of about 4000 to 1. Ordinary speech will never approach this power range, but orchestras, unless especially trained and under the guidance of a careful conductor, will sometimes cover a volume range of 60 decibels, or 1,000,000 to 1. For this reason, the recording level must be carefully monitored and not allowed to exceed the limits defined by the record characteristics. The same is true with the film recording of sound. The maximum level is limited in this case by the width of the sound track, about 0.1 inch.

The use of the volume indicator is not, by any means, limited to monitoring work. It is often used as an aid in equalizing telephone circuits. An ordi-

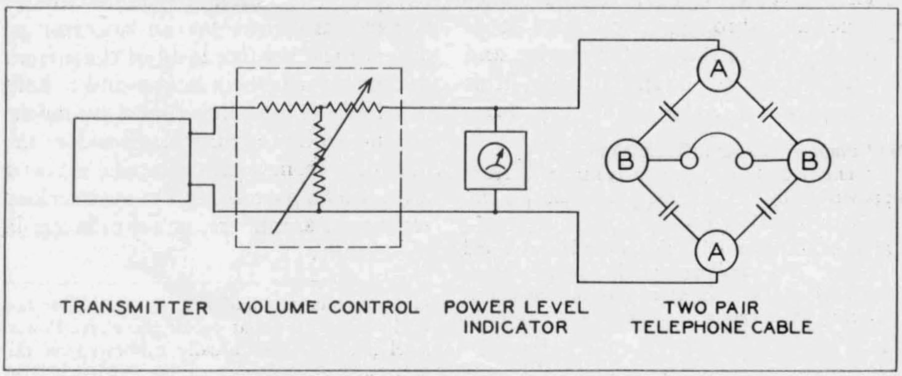


FIGURE 1

nary telephone circuit will transmit certain of the voice frequencies much better than others. For the transmission of speech with fair intelligibility, a frequency spectrum from 200 to 3,000 cycles is needed. But a line that is to be used for high quality transmission of both speech and music, for example, one connecting a broadcasting studio with its transmitting station, must have a flat characteristic from 50 to 5,000 cycles. In order to improve the frequency characteristic of a line so that it may be used for high quality transmission, corrective networks or attenuation equalizers are used. The structure of one of these is shown in Figure 2. The anti-resonant network is tuned to the frequency that it is desired to emphasize. The value of the resistance determines its effectiveness. Several of these networks are sometimes connected across one line and set for various frequencies. To adjust the equalizers, several discrete frequencies from an oscillator are sent, one at a time, into the line at a given amplitude as determined by a power-level indicator. At the receiving end another power-level indicator is connected across the line and the equalizers adjusted until the power level is approximately the same at all of the test frequencies. When this is done, the engineers are assured that the line has a uniform transmission characteristic over the frequency band.

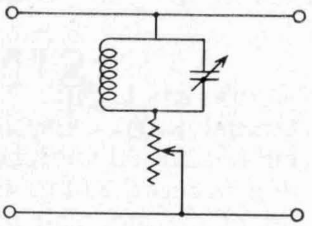


Figure 2

A gain or loss in power transferred through a network may also be found with some precision by reading the power into and out of the network on the power-level indicator. It is necessary to note that the impedance on both sides of the network being measured is the same. If it is not, the indicator reading must be corrected, because it will, for a given power, read high or low in accordance with the impedance across which it is connected.

Editor's Note: The June issue of the *General Radio Experimenter* will commemorate the fifteenth anniversary of the founding of the General Radio Company. On that occasion, the editor steps aside and yields his chair and blue pencil to an anonymous guest, whose identity will forever remain secret.

The General Radio *Experimenter* is published monthly to furnish useful information about the radio and electrical laboratory apparatus manufactured by the General Radio Company. It is sent without charge to interested persons. Requests should be addressed to the

GENERAL RADIO COMPANY
CAMBRIDGE A, MASSACHUSETTS

RUMFORD PRESS
CONCORD, N.H.

SINCE 1915

General Radio Company has been designing and manufacturing electrical measuring instruments for use at communication frequencies (0 to several million cycles per second). A list of the most important items in the line is given below. Many of them have application outside the laboratory.

Frequency Standards and Measuring Devices — Magnetostriction Oscillators — Piezo-Electric (Quartz) Oscillators — Wavemeters
Vacuum-tube Oscillators — Radio-Frequencies — Audio-Frequencies
Bridges for Measuring — Resistance, Inductance, Capacitance — Vacuum-tube Characteristics
Resistance Boxes
Precision Condensers
Calibrated Inductors
Attenuation Networks and Voltage Dividers
String Oscillograph
A-C Voltmeters — Vacuum-tube Type — Oxide-rectifier Type
Standard-Signal Generator (for radio-frequency voltage measurements)
Galvanometer Shunts
Transformers
Relays
Miscellaneous Accessories — Vacuum-tube Sockets — Rheostats and Potentiometers — Switches — Plugs, Jacks, Plug-in Mounting Bases

Our Engineering Department publishes a monthly magazine, *The General Radio Experimenter,* for free distribution to anyone interested in technical developments in communication engineering and allied fields. A memorandum with your name, mailing address, and business affiliation will place you on the mailing list.

GENERAL RADIO COMPANY

CAMBRIDGE A, MASSACHUSETTS

The General Radio Experimenter

Vol. V, No. 1 June, 1930

We Celebrate a Birthday

On June 14, 1915, the Secretary of the Commonwealth of Massachusetts issued a charter to the General Radio Company, thereby founding a new organization for a new purpose, namely, the manufacture of measuring apparatus suitable for use at radio frequencies.

While the history of a pioneer company is interesting to those associated with the development of an art, it is boring to most people. Although no attempt will be made to give a detailed history of the General Radio Company, there are a few high spots that should prove of interest to all engaged in the radio art.

Almost the first General Radio customer was George E. Cabot, one of the founders of the Holtzer-Cabot Electric Company, and his purchases in the early days of the Company contributed materially to preventing its early demise because of insufficient income. He is still purchasing General Radio instruments, and in his very well equipped laboratory has a sample of nearly every instrument built by us.

The first experience of the General Radio Company with Dr. DeForest's "audions," the erratic ancestors of the present triodes, was in the fall of 1915, when an inventor of a talking movie scheme wanted an amplifier designed and built. This Mr. Freistatter had the idea that a narrow band of fine iron filings could be cemented to the edge of a movie film, and sound stored as a magnetic charge, as was done with a wire in the Poulsen telegraphone. We built a two-stage amplifier, which could be used to get enough energy from the microphone to magnetize the filings, and also to reproduce the output of the film on a loud-speaker. The transformers designed for this amplifier were afterward sold in great quantities to experimenters. They were probably the first audio transformers, having closed cores, to be generally available for purchase. A frequency-response curve of such an early two-step amplifier would be very interesting to look at, but we suspect it would have little resemblance to that of a modern unit.

Building No. 1, erected 1924. Building No. 2 which was erected in 1925 is similar to No. 1 but is one story taller. Building No. 3 now under construction is similar to Building No. 2

Hardly had the Company started and supplied a few pieces of apparatus to pioneer institutions engaged in radio research, when the United States entered the World War. Plans for new developments had to be abandoned.

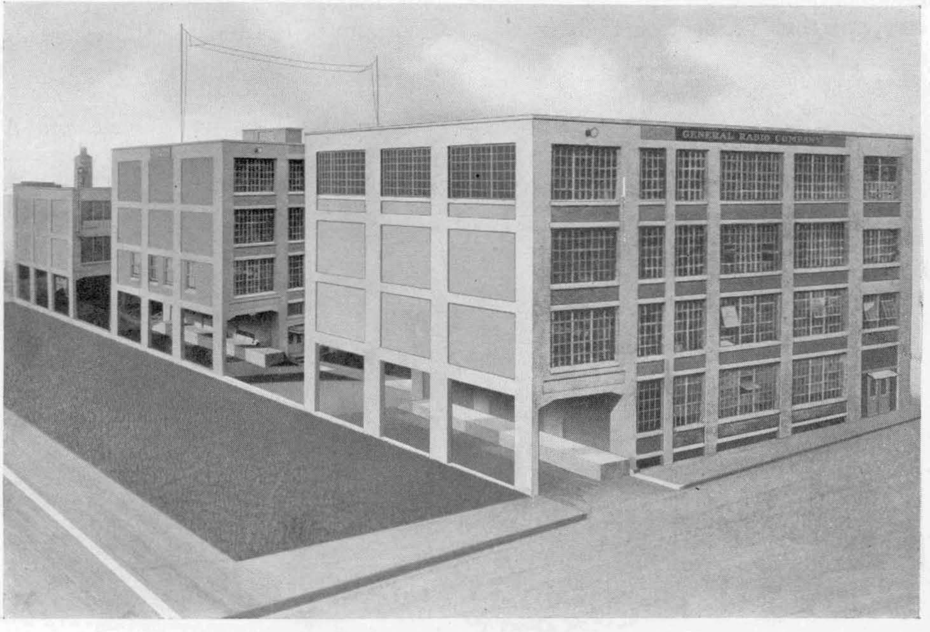
From a small organization largely engaged in research work, it was necessary to expand the Company to a large production group, capable of turning out quantities of war material. This material included radio training equipment, field equipment, airplane sets, and in general, radio equipment required by the Signal Corps and the communications service of the Navy.

As a matter of history, it is interesting to note that in one of the first shipments of war material there were included some of the early type of standard condensers. One of these condensers found its way into the United States Signal Corps laboratory in France. In that laboratory was Lieutenant, now Major, E. H. Armstrong, who was attempting to find a better method of radio communication. Requiring a condenser for use in one of his circuits, and having none available, he appropriated the laboratory standard. It was this circuit which worked, and thus, one of this Company's earliest condensers was incorporated in the first superheterodyne.

At the close of the war, the General Radio Company returned to its original purpose, namely, that of developing and manufacturing laboratory apparatus. In the spring of 1919, William Dubilier asked us to design a bridge which he could use to measure accurately the capacitance and power factor of mica condensers. The result was the TYPE 216 Capacity Bridge, which is now used in a great many laboratories. The TYPE 222 Precision Condenser was built at the same time, and was the first commercial condenser having low losses and great precision of reading. It had a low-loss insulated stator, cone bearings, rugged construction, and a worm gear arrangement for close readings, features which continue to distinguish it. Mr. Dubilier still has in use the first capacity bridge and precision condenser of our make in his laboratory. Perhaps some day we shall be able to get them back for our contemplated museum!

The post-war readjustment processes had just been completed when the furor of broadcasting broke out. Again the plans of the Company were put aside. The demands for equipment that could be assembled into radio receivers were so great that it became necessary to concentrate production activities on this class of material. The demand grew and continued to grow, until the Company found itself expanded to a greater extent than was necessary even during war time. This time, however, the expansion was different. It was not necessary that every effort be directed toward the production of equipment demanded by war conditions. While the expansion process went on, development work still continued. It was as if two companies had been set up under one roof. There was always the feeling that after the wave of novelty of broadcasting had passed over, there would no longer be a consumer demand for radio parts. It was anticipated that a new demand would come from new companies, organized to manufacture receivers under mass production methods, and that this demand would be for production testing apparatus.

That this prediction was right was proved by the end of 1927. A three-year plan, covering the years 1928, 1929, and 1930, was laid out to take care of the transition that would come in the type of product manufactured by this Company. New methods of selling and new ratios between research expenditures and manufacturing costs had to be arranged. New types of research, new methods of manufacturing had to be planned. Finally, came the item of increased plant facilities to take care of these activities. This was left as the last step in the three-year plan. This step was taken on April 7, 1930, when ground was broken for a new unit which, when completed this fall, will increase the plant capacity by 60 per cent. A very substantial proportion of this unit will be devoted to engineering laboratories and the manufacture



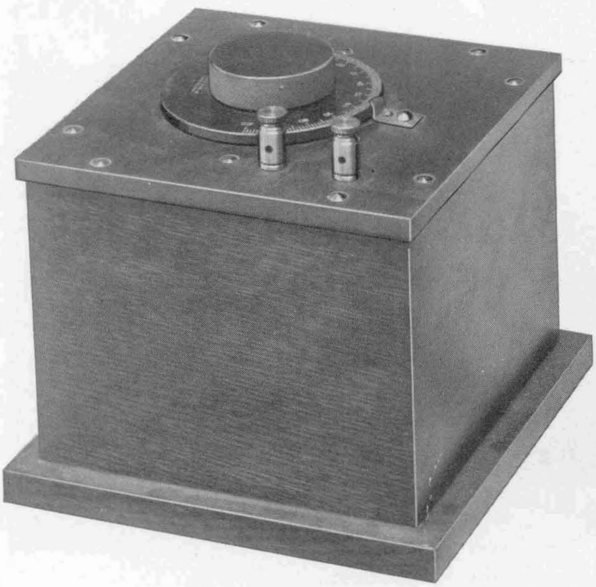
The General Radio Plant

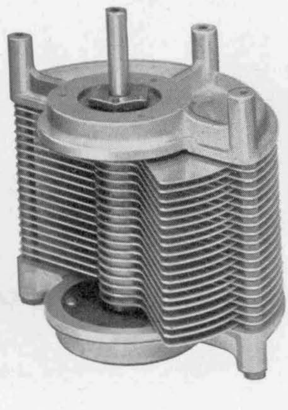
TYPE 105 Wavemeter. A pre-war frequency

of items requiring special production methods.

It is not brick, nor mortar, nor machines, nor capital that makes a successful organization. It is the persons whose lives are associated with the organization who give it its existence. It seems thus fitting to include in this issue of the *Experimenter* a bit of information pertaining to the people who take an important part in the affairs of the General Radio Company. As the *General Radio Experimenter* is an engineering publication, the sketches will be largely limited to those having contact with engineering activities.

A few weeks after the United States entered the World War, there appeared at the offices of this Company a man who offered his services to do whatever was possible to aid in the winning of the war. Knowing the position the General Radio Company occupied in the field of radio research, he felt that through it he would be best able to contribute his services. This man was Henry S. Shaw, now Chairman of the Board of Directors.





TYPE 101 Condenser. A 1915 pioneer in low-loss condenser design

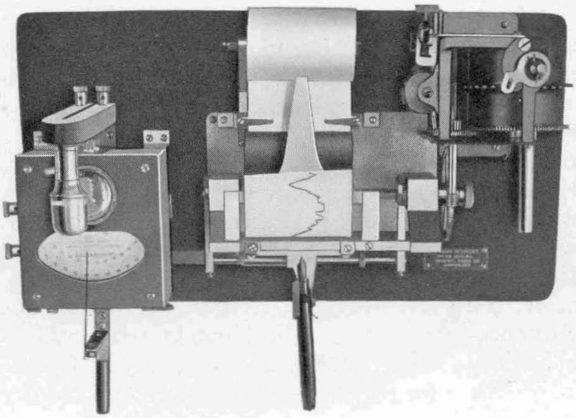
HENRY S. SHAW
Chairman of Board

Although primarily interested in science, and particularly in radio, Mr. Shaw had had considerable business experience, which experience proved to be of great value to the Company at a time when rapid expansion was necessary to meet war conditions. It was further largely due to his tireless activity and excellent judgment that the Company so successfully weathered the very trying days following the war, and the subsequent days of business readjustment. Mr. Shaw became Treasurer of the Company in January, 1918, and continued to hold that office until January, 1926, when he was elected Chairman of the Board of Directors, which position he now holds.

Mr. Shaw was born in Boston, November 29, 1884, and was graduated from Harvard University with the class of 1906. He is a member of the Institute of Radio Engineers, the American Institute of Electrical Engineers, and several other scientific societies. His interest in general business problems is evidenced by the fact that he is a director of a large Boston trust company, as well as several business corporations. Second only to his interest in science is his interest in natural history, particularly ornithology.

His scientific work has included studies of fading phenomena of radio signals, and for a score of years he has been interested in amateur radio, having operated early in 1924 what is believed to be the first crystal-controlled amateur transmitter. He is also interested in meteorology and other geophysical subjects.

When the General Radio Company started in 1915, Melville Eastham was elected President, and has been reëlected every year since then, which is quite a record in radio manufacturing circles. His activities, particularly during the last few years, how-



Type 289 Fading Recorder. A galvanometer and motor-driven recording tape used in studies of radio signal strength changes

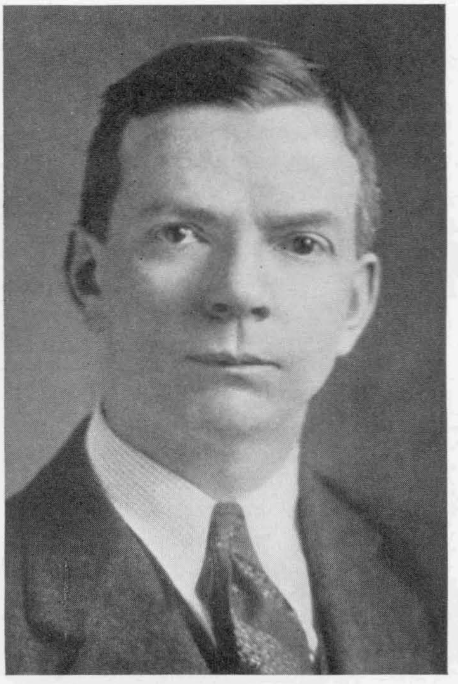
ever, are not properly described by his title, for he is rarely found at his presidential desk. His interests are almost exclusively in engineering work, and he may usually be found in his research laboratory, except during the summer, when he takes a long vacation, generally on the Pacific Coast or in Europe.

In the early days of the Company, he was instrumental in developing better variable air condensers having features which became almost universal, such as conical bearings, a moving dial in place of a moving pointer, and low-loss dielectric placed in a weak electrical field. He is the originator of the soldered-plate type of construction which has become so useful, particularly in condensers used at very high frequencies. His jig method of plate spacing has been an important factor in the production of uniform condensers with low assembly costs.

In 1919 the first TYPE 222 Precision Condenser with a grounded rotor was built. It used a worm and gear to make closer reading possible, and was almost exactly the same design that is still in use in most laboratories as a standard for comparing other condensers. The TYPE 216 Capacity Bridge for the measurement of small capacities was designed at about the same time, in connection with this precision condenser.

Mr. Eastham has been working during the last several years on beat-frequency oscillators, standard-signal generators, and other audio- and radio-frequency measuring equipment. Many of the simpler items of the General Radio line, such as sockets, rheostats, plugs, jacks, and others, are the result of his very practical turn of mind.

He was born in Oregon City, Oregon, on June 26, 1885, and is a Fellow of the Institute of Radio Engineers, the American Association for the Advancement of Science, the Acoustical Society of America, and a member of the



MELVILLE EASTHAM
President

American Institute of Electrical Engineers, the Optical Society of America, and the Radio Club of America. He was with the Clapp-Eastham Company, one of the early manufacturers of wireless equipment, from 1906 until the General Radio Company was founded.

Mr. Eastham has been active for many years in the affairs of the Institute of Radio Engineers, and is at present its Treasurer. He is an ardent swimming enthusiast.

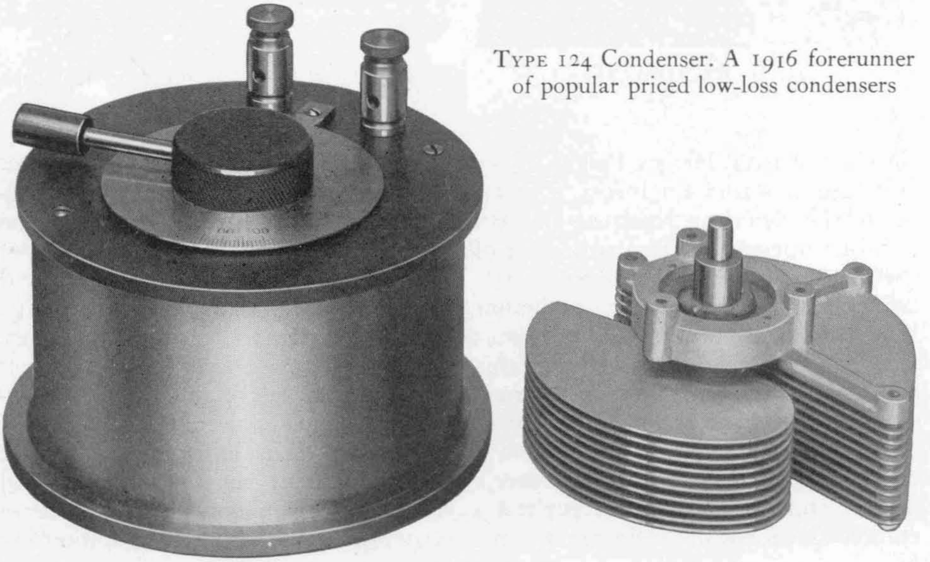
Another member who joined our organization during the war is our Vice President, Errol H. Locke. Although first associated with the Company in commercial activities, Mr. Locke was made Vice President in 1920, and for the past decade has been responsible for the entire production of our factory.

Born in Lexington, Massachusetts, on July 17, 1890, Mr. Locke has always made his home in that historic town, and has for a number of years been treasurer of the Lexington Historical Society, and is also a corporator of the Lexington Savings Bank. He is a graduate of Harvard University of the class of 1913. His hobby is the application of scientific methods to his Vermont dairy farm.

ERROL H. LOCKE
Vice President

In May, 1917, an instructor in electrical engineering at the Massachusetts Institute of Technology, who was also an officer in the Coast Artillery Reserve Corps, was called to active duty. After two years of service in the United States and France, he received his discharge, and while waiting for the fall term to open to resume his teaching, he temporarily joined the General Radio Company. The work proved so attractive that he resigned his instructorship, and remained with the Company as an engineer. He was H. B. Richmond, who is now our Treasurer.

Mr. Richmond took over the commercial activities of the Company in the fall of 1920. On October 1, 1921, he was made Secretary of the Corporation, and in January, 1924, Assist-



Type 124 Condenser. A 1916 forerunner of popular priced low-loss condensers

ant Treasurer. Since 1926 he has been Treasurer of the Company, yet much of his time is devoted to the direction of its engineering policies.

Mr. Richmond was born in Medford, Massachusetts, on March 22, 1892, and was graduated from the Massachusetts Institute of Technology in

H. B. RICHMOND
Treasurer

the class of 1914. He is a Fellow of the Institute of Radio Engineers, a member of the American Institute of Electrical Engineers, and also a director of the Central Trust Company of Cambridge. For the past four years, he has been a director of the Radio Manufacturers Association, and just this month has completed a year as president of that organization. For a number of years, Mr. Richmond held a commercial first-grade radio operator's license, and has had an amateur radio station since 1908. While greatly resenting being called a New England farmer, one of his hobbies is flower-growing.

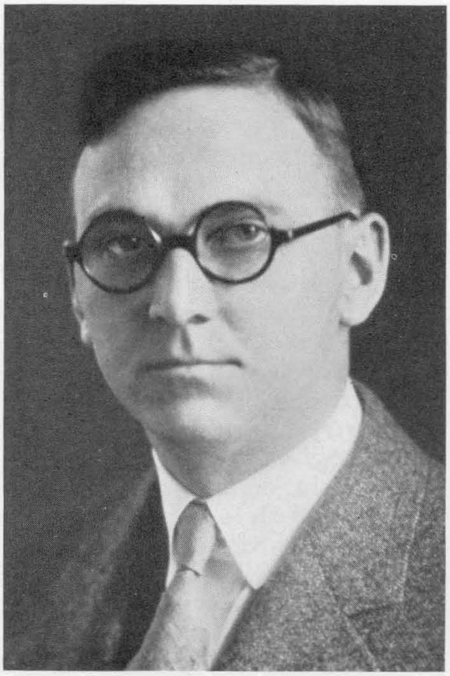
With the expansion of our engineering activities, it became necessary to obtain the services of an engineering executive, and in particular, one who had had considerable practical experience in the field of audio- and radio-frequency measurements. Where better could such a man be found than in the Bell Telephone Laboratories, which organization has contributed so many men to radio and allied industries?

After having spent twelve years in the Bell Laboratories on carrier telegraphy and telephony problems, on precision frequency measurements, and on television development, J. Warren Horton resigned in 1928 to join the General Radio Company as Chief Engineer.

A graduate in electrochemistry from the Massachusetts Institute of Technology, with the class of 1914, Mr. Horton continued there for two years on the instructing staff of the physics department. During the war he was engaged in problems relating to submarine detection, both in this country and at the U. S. Naval Headquarters in London.

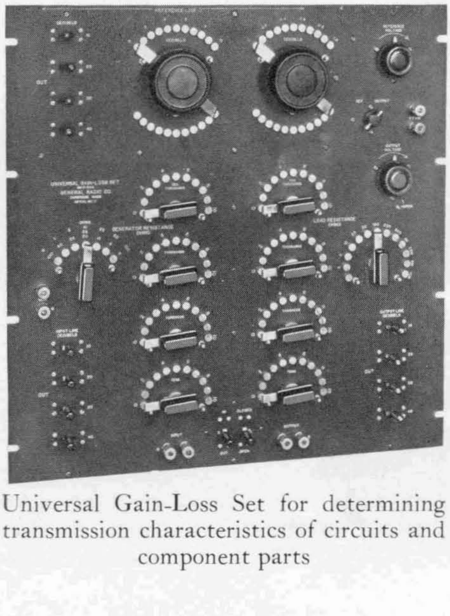
Mr. Horton holds membership in a large number of technical societies, being a Fellow of the Institute of Radio Engineers, the American Institute of Electrical Engineers, and of the Acoustical Society of America, as well as a member of the Physical Society, Society of Motion Picture Engineers, and others. Although now devoting a large part of his time to his executive duties, Mr. Horton still finds time to direct some personal development work, particularly on attenuation networks.

Assisting Mr. Horton is Lawrence B. Arguimbau. Mr. Arguimbau joined the Bell Telephone Laboratories in 1923, and his work was so promising



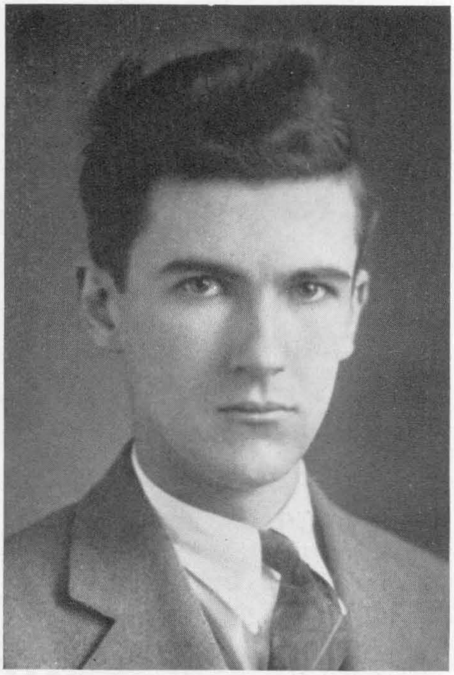
J. WARREN HORTON
Chief Engineer

that Mr. Horton, who was at that time with the Laboratories, felt that he should carry his studies further so as to



Universal Gain-Loss Set for determining transmission characteristics of circuits and component parts

include an engineering degree. He left the Bell Laboratories in 1926, and entered Harvard University, where he will be graduated in physics this year. During the four years he has been at Harvard, Mr. Arguimbau has spent his summers and much of the time



LAWRENCE B. ARGUIMBAU
Assistant Engineer

during the college year in our laboratories. His work has been quite largely on oscillator circuits with particular reference to their constants.

At the height of the home-built radio receiver days, every mail brought in large quantities of letters asking for information on receiver design. The task of answering this fan mail fell to Charles T. Burke. It is not alone in this field that Mr. Burke is proficient, for he has contributed much to the design of testing apparatus. In this latter field, particularly on equipment for service men, he now specializes.

Mr. Burke joined the General Radio Company in June, 1924, immediately after receiving his Master of Science

CHARLES T. BURKE
Engineer

degree in electrical engineering from the Massachusetts Institute of Technology. In the six years that he has been associated with this Company, he has been its representative at radio exhibitions throughout the country, and has become known to a large part of the radio industry. He has also been active in the engineering activities of the Radio Manufacturers Association. Mr. Burke is a Member of the Institute of Radio Engineers, and an Associate Member of the American Institute of Electrical Engineers.

About two o'clock one morning out on a lonely country road, a police officer came upon a man who stopped about every hundred yards and tapped on the road with a hammer. It took much persuasion to make the officer of the law believe that the man he found was neither an escaped inmate of a neighboring asylum nor a member of a yegg gang, but only a physicist carrying out tests on his newly developed terraphone, later to be used in oil-locating surveys. The man was Horatio W. Lamson, the specialist in theoretical and applied acoustics of our engineering staff.

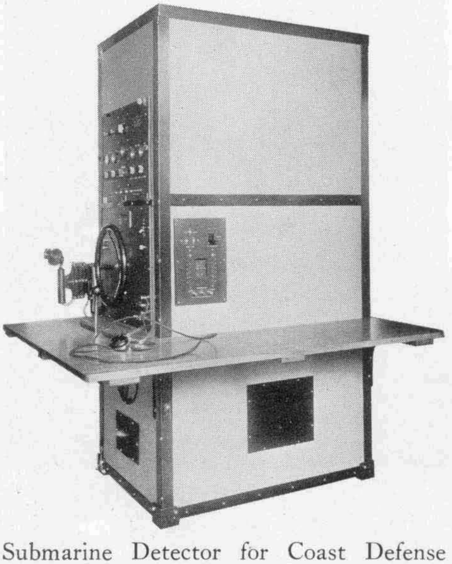
Mr. Lamson was graduated in physics from the Massachusetts Institute of Technology with the class of 1915, and in 1917 received a master's degree from Harvard University. During the war he was Assistant Radio Aide at the Charlestown Navy Yard, and later Chief Electrician, U. S. N. R. F., stationed at New London, where he

TYPE 355 Transformer Test Set. An early example of test apparatus

Recording Oscillograph
Used in oil-locating surveys

was engaged in research problems on submarine detection.

Since 1919, Mr. Lamson has either

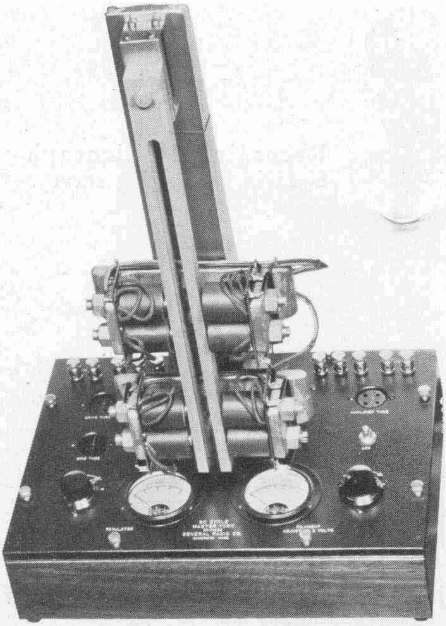


Submarine Detector for Coast Defense installation

been associated with Dr. G. W. Pierce in his laboratories at Harvard University on problems in which the General Radio Company was interested, or directly with this Company. His work has covered a wide range of activities, but more particularly those pertaining to electro-acoustics and to frequency determination. He has developed subaqueous sound-ranging devices, geophysical survey apparatus, precision electrically driven tuning forks, and numerous allied equipment.

Mr. Lamson's amateur radio activities date back a score of years, and for a number of years he held a commercial first-grade operator's license, having been employed summers during his college training as a ship's radio operator. He is a Fellow of the Acoustical Society of America, a Member of the Institute of Radio Engineers, and of the American Institute of Electrical Engineers.

HORATIO W. LAMSON
Engineer



60-cycle Electrically-Driven Tuning Fork of high precision

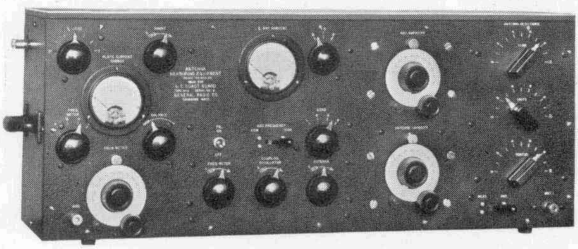
The engineer of our staff most familiar with actual radio operation, both from the commercial and from the amateur viewpoint, is James K. Clapp. Mr. Clapp not only has operated his own amateur station since 1909, but has been three years at sea as a regular commercial operator. During the Vermont flood of 1927, he organized a mobile radio group which went into the stricken region and rendered great assistance in establishing communication with the outside world. He spent two and a half years during the war in the U. S. Naval Communication Service, holding the rank of Ensign.

Mr. Clapp is devoting most of his time now to the accurate determination of frequencies. He is responsible for the present development and maintenance of our highly accurate frequency standards. In addition to this work, he has developed special equipment for measurement purposes for

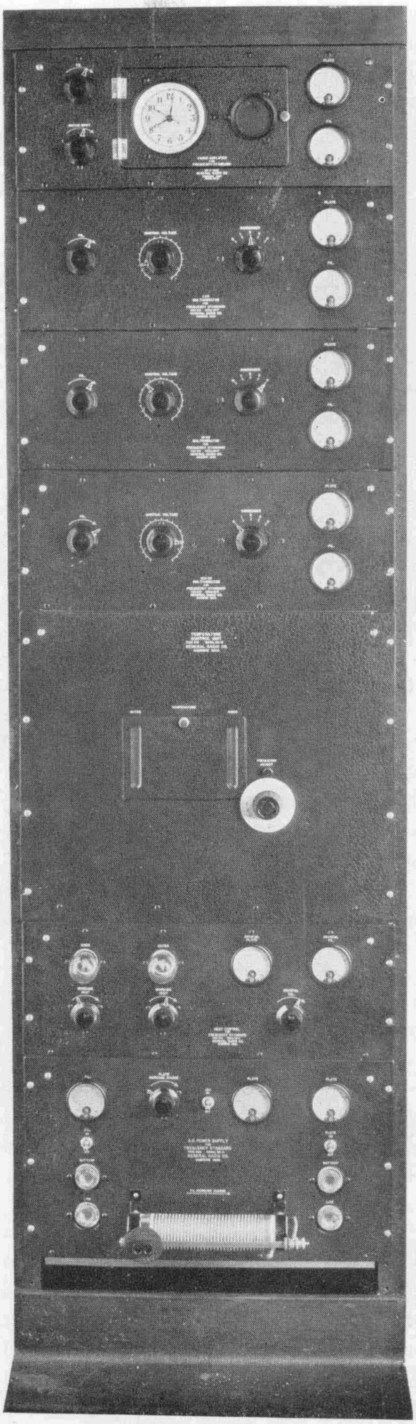
CHARLES E. WORTHEN
Assistant Engineer

the Navy, Coast Guard, and other governmental services.

Prior to joining this Company two years ago, Mr. Clapp was an instructor in electrical communications at the Massachusetts Institute of Technology,



Antenna-Measuring Equipment. A portable unit for studying antenna characteristics

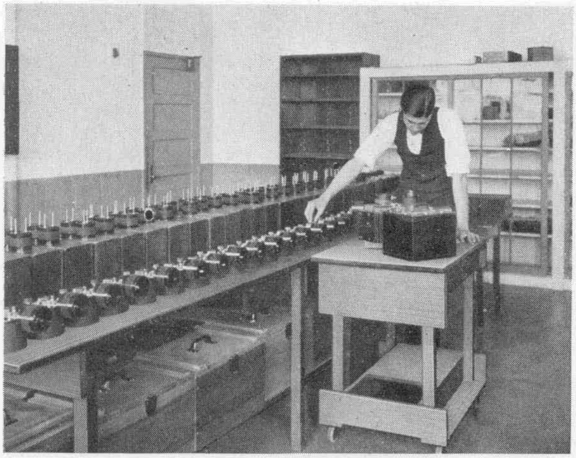


JAMES K. CLAPP
Engineer

from which he was graduated in electrical engineering in 1923, later receiving a Master of Science degree. He is a Member of the Institute of Radio Engineers, and is keenly interested in flying.

Assisting Mr. Clapp is Charles E. Worthen, who likewise is a graduate in electrical engineering from the Massachusetts Institute of Technology. Mr. Worthen came to us in June, 1928, immediately after graduation. In addition to the work done under Mr. Clapp's direction, Mr. Worthen has developed a 400-cycle tuning-fork oscillator, and made studies of paper condenser changes with age.

Piezo-Electric Controlled Frequency Standard which maintains an accuracy of within one part in a million. This is the General Radio Standard-Frequency Assembly



Individual calibration of TYPE 358 Wavemeters

Like so many in our organization, Mr. Worthen has had amateur radio experience. He is an Associate of the Institute of Radio Engineers.

With the increased precision obtainable in audio- and radio-frequency measurements, it became desirable to have as a member of our staff a man who through previous training and experience in the measurement field would be able to advance this art even further. Last October we were fortunate in obtaining the services of Robert F. Field, whose work in the measurement field is well known to radio engineers.

ROBERT F. FIELD
Engineer

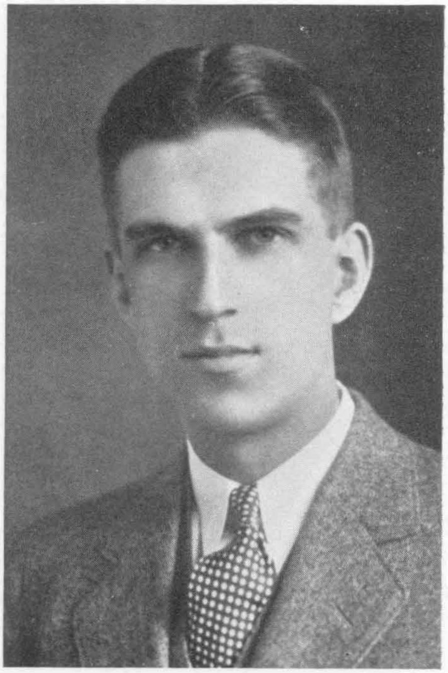
Mr. Field was graduated from Brown University in 1906, receiving a master's degree there the following year. He remained at Brown, teaching physics and electrical engineering, until 1915, when he left to take advanced work at Harvard University, receiving a master's degree in 1916. From 1918 until he joined the General Radio staff, Mr. Field taught at Harvard University. As Assistant Professor of Applied Physics he taught courses in communication engineering, specializing in electrical measurements.

During the war Mr. Field was engaged in research work pertaining to radio torpedo control and allied subjects. He is a Fellow of the American Academy for the Advancement of Science, a Member of the Physical Society, and an Associate of the Institute of Radio Engineers.

Although joining our engineering staff but eighteen months ago, Arthur E. Thiessen has made an exceptionally wide acquaintance in the radio and talking motion picture industries. During the past winter, Mr. Thiessen made a lecture tour of eight sections of the Institute of Radio Engineers, besides several other extensive business trips. Largely through these contacts Mr. Thiessen has become known to many engineers in the radio and talkie fields.

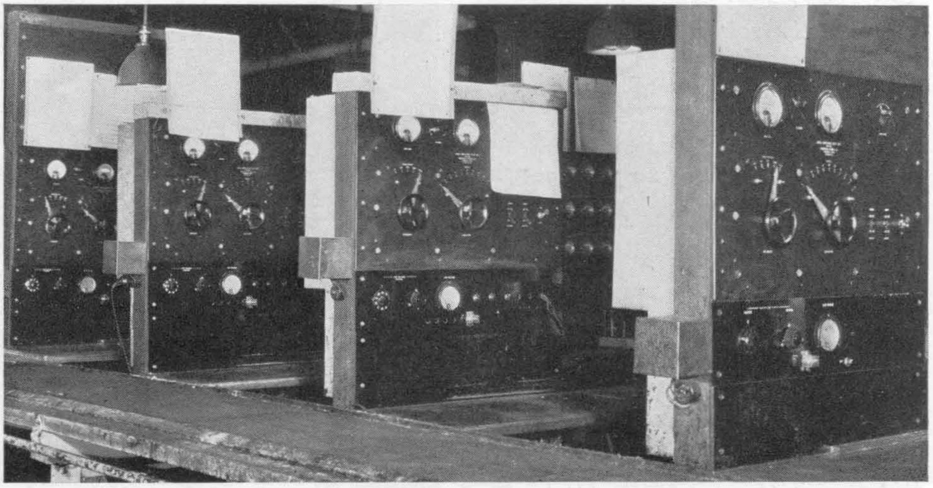
After being graduated with the class of 1926 in electrical engineering from Johns Hopkins University, Mr. Thiessen joined the Bell Telephone Laboratories staff, leaving there in December, 1928, to join our organization. He has been particularly interested in magnetic alloys and amplifier work. During the past year, he has, however, been devoting his time largely to the development of equipment for production testing of radio receivers and audio amplifiers, as well as special apparatus used in talking pictures.

Mr. Thiessen is a Member of the Institute of Radio Engineers. He is a former radio amateur, whose station was well known to Pacific Coast amateurs.

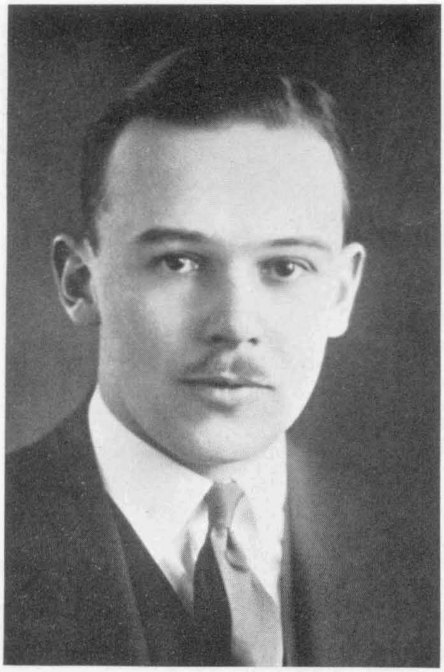


ARTHUR E. THIESSEN
Engineer

Technical literature requires a technical editor. It is, therefore, fitting that we should have as editor of the



A section of the audio-amplifier test installation developed for the Victor Talking Machine Company for production inspection tests on completed amplifiers



JOHN D. CRAWFORD
Engineer

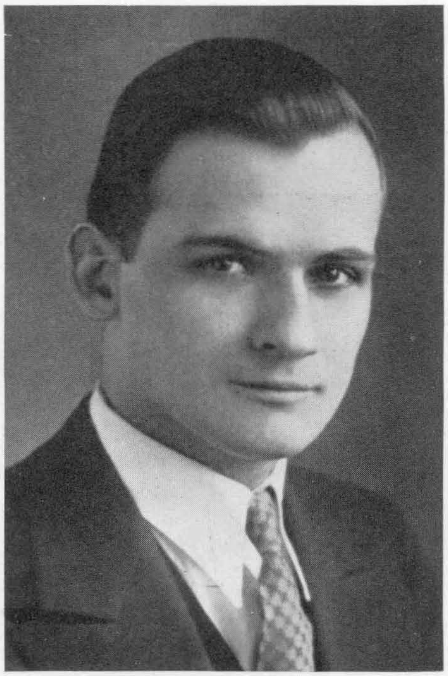
General Radio Experimenter and of our catalogs and engineering bulletins, one trained in the field of communication engineering. Our editor, John D. Crawford, is an electrical engineering graduate of the Massachusetts Institute of Technology with the class of 1927. Until joining the General Radio Company early in 1929, Mr. Crawford was Assistant Managing Editor of *The Technology Review*, an engineering journal published by the M. I. T. Alumni Association.

Mr. Crawford was at one time a radio amateur. He is an Associate of the Institute of Radio Engineers.

Another member of our Engineering Department who received training at the Bell Telephone Laboratories is Arthur G. Bousquet, who joined our staff last year. Mr. Bousquet was graduated in electrical engineering from Tufts College in 1928. He is devoting much of his time with us to studying our regular instruments, to determine their characteristics, under limiting conditions of operation.

Mr. Bousquet is an Associate of the Institute of Radio Engineers, and has recently become interested in amateur radio activities.

In addition to the work of our own staff we have been fortunate in having had the consulting services of two well-known physicists, namely, Professor G. W. Pierce, of Harvard University, and Professor Walter G. Cady, of Wesleyan University. For the past decade, we have had the advice of Professor Pierce on a variety of problems. He has been our consultant on subaqueous sound work, circuits for piezo oscillators, magnetostriction



ARTHUR G. BOUSQUET
Assistant Engineer

apparatus, and at the present time, we are working with him on the development of supersonic apparatus. We have rights under his patents and applications in these fields.

Professor Pierce received his doctor's degree from Harvard University in 1900, and except for a period of study at Leipzig, has been teaching there ever since. He is now Professor of Physics, and Director of the Cruft High Tension Electrical Laboratory. He is the author of textbooks on radio subjects and of numerous technical papers. His membership includes a large number of technical societies in several of which he holds the highest grade. He is a past president of the Institute of Radio Engineers.

DR. G. W. PIERCE
Consultant

The work of Professor Cady has largely made it possible for us to become so actively engaged in the field of supplying quartz crystals as frequency standards. Professor Cady was a pioneer in this field and through his consulting services and the issuing of rights under his patent, we have been able to develop and manufacture quartz crystal standards.

DR. WALTER G. CADY
Consultant

Professor Cady received his doctor's degree from the University of Berlin in 1900, and after two years as magnetic observer with the U. S. Coast and Geodetic Survey, joined the staff of Wesleyan University, where he is now Professor of Physics. He is the author of many papers on theoretical and applied physics. Professor Cady holds the highest grade of membership in several technical societies.

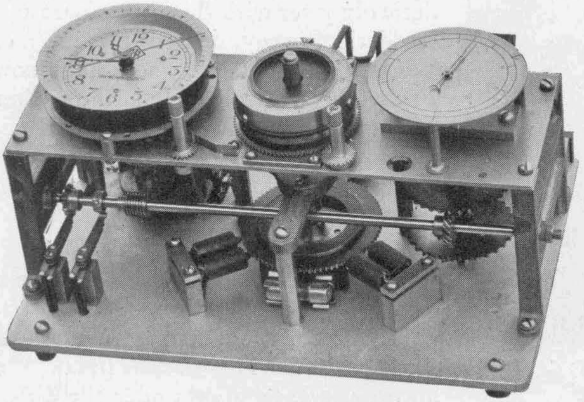
After the electrical engineers have developed breadboard models of apparatus, a complete experimental model must be made. This work is handled in an experimental shop under the direction of Harold S. Wilkins, our mechanical engineer. On Mr. Wilkins, the link between engineering and production, rests the responsibility of checking all apparatus for mechanical details before releasing it for production.

Mr. Wilkins was graduated in electrochemistry from the Massachusetts Institute of Technology with the class of 1914. His work has been quite varied but always on problems relating to mechanical and electrical engineering. It has covered such fields as storage batteries, woodworking machinery, electrical apparatus, oil burners, electrical refrigerators, and other household appliances. Since he has been with us he has developed gear mechanisms for a synchronous motor-driven clock for accurate time comparisons, and a recording oscillograph for special uses.

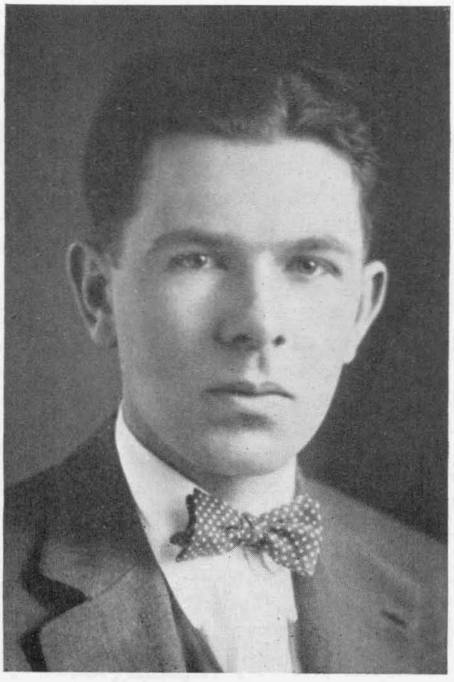
During the war Mr. Wilkins was with the Chemical Warfare Service, now holding the rank of Captain in the Chemical Warfare Reserve Corps. He is a member of the American Chemical Society, the American Electro-Chemical Society, and of the Society of Automotive Engineers. During his collegiate days he was a sprinter well known in the New England Intercollegiate meets and still retains his interest in outdoor sports.

HAROLD S. WILKINS
Mechanical Engineer

When a customer complains — and such things have really happened — about the delay in the delivery of some special order item, we look to "Mac" to straighten out the matter. Paul K. McElroy, with title of production engineer, operates a shop within a shop. In order that drawings and pro-



TYPE 511 Syncro-Clock with special micro-dial which permits time-interval comparisons to be made within 0.01 second



PAUL K. McELROY
Production Engineer

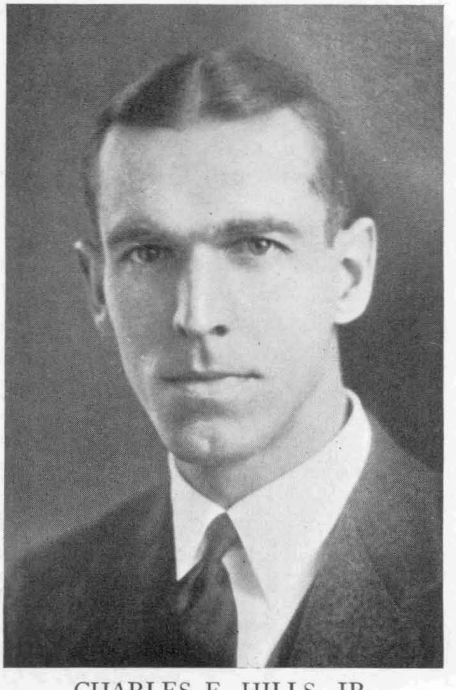
cesses may be approved before regular factory production starts, the first production samples of new instruments are made in this special shop. Here also special items in small quantities are made. In short, it is the liaison between engineering and production.

Mr. McElroy's collegiate training was interrupted by the war, during which he was stationed at the Ordnance Proving Ground, Aberdeen, Maryland. After the war he returned to Harvard University, graduating in physics in 1920. A year later, after obtaining a master's degree, he became associated with the General Radio Company on problems pertaining to the construction of submarine detectors.

Although perhaps to the discomfort of his neighbors, Mr. McElroy's hobby is playing the saxophone. He is a Member of the Institute of Radio Engineers.

After establishing contact between an engineer desiring measuring apparatus, and our Engineering Department, the efficiency with which the order is handled depends on the Commercial Department. That there may be an understanding of engineering requirements, Charles E. Hills, Jr., a graduate in electrical engineering of the class of 1921 of Northeastern University, has been chosen our Commercial Manager.

After a brief training in laboratory work with a large electrical company, Mr. Hills joined the General Radio Company in 1922. Before taking over his duties as Commercial Manager, he was associated with the production office in order to become familiar with production methods as well as the requirements of his own department. Mr. Hills is an Associate of the Institute of Radio Engineers.



CHARLES E. HILLS, JR.
Commercial Manager

SMALL LABOR TURNOVER

KNUT A. JOHNSON
Our Senior Employee

The manufacture of scientific apparatus, such as ours, requires not only skilled workmen, but men familiar with the particular construction of our instruments. It is, therefore, only fitting to find that the first man to join the General Radio organization is still with us. He is Knut A. Johnson, a skilled machinist who is now in charge of a department devoted to special items, whose manufacture is not adapted to routine production methods. It is in this department that individual items are manufactured to meet some unusual requirements of a customer.

Through vacation and holiday pay, through a profit-sharing bonus plan, and above all, through good working conditions, we try to keep labor turnover at a minimum. That this plan has been successful is evidenced by the fact that even with the increase in the number of employees, 15 per cent. of the shop personnel have been with us over ten years; 34 per cent. between six and ten years; 3 per cent. between three and six years; and only 48 per cent. less than three years.

Only male help is employed, except for the office personnel. Of the men in our office, a majority have been here over five years, while the purchasing agent and the chief draftsman are on their second decade. All the officers have been with the Company for over ten years.

A five-day working week was inaugurated in 1919, while group insurance wholly paid for by the Company was placed in effect two years prior to that. The employees operate by themselves a Mutual Benefit Association and also a Credit Union.

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The General Radio Experimenter

Vol. V, No. 2 — July, 1930

The Continuous Recording of Pulse Rates

By Horatio W. Lamson

An illustration of the interrelation of the sciences is to be seen in the increasing use which the members of the medical profession are making of electrical equipment in the diagnosis and treatment of the ills of mankind. For example, it is well known that muscular contractions are accompanied by more or less pro-

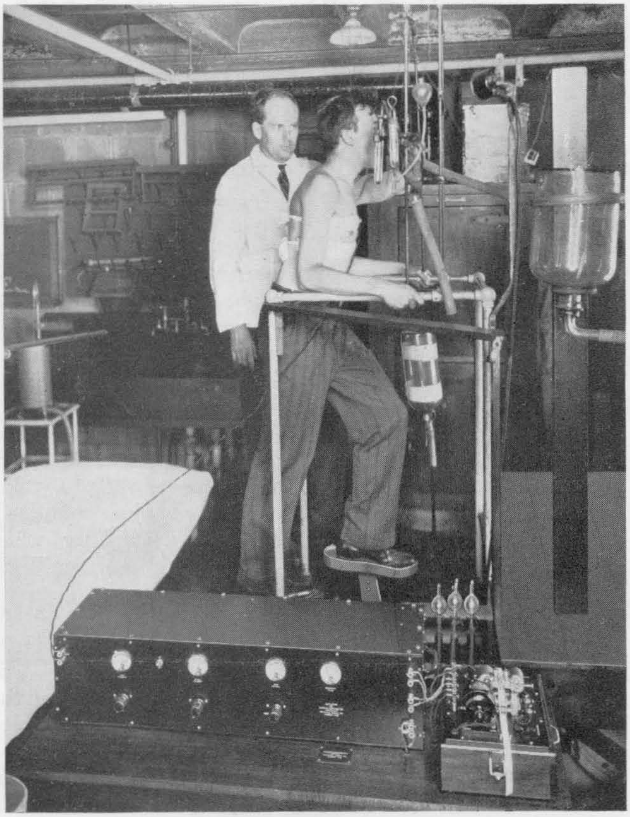

Figure 1. The cardiotachometer in use in the laboratory of Dr. A. V. Bock at the Massachusetts General Hospital, Boston. The patient exercises on the treadmill while continuous records of the pulse rate are taken

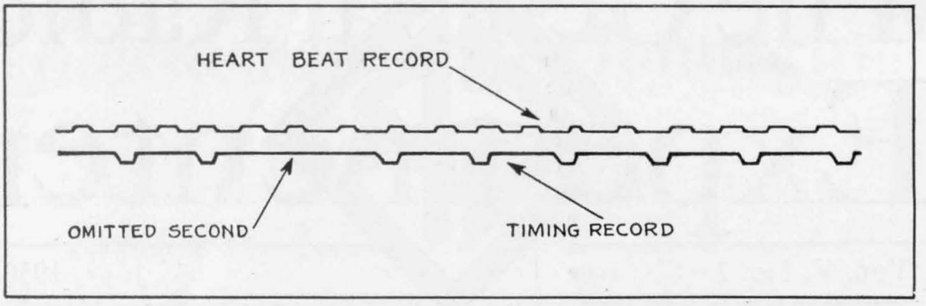

FIGURE 2. A full size sample record from the cardiotachometer

nounced electrical potentials. Extensive use has been made of this phenomenon in diagnosing and studying diseases of the heart.

By means of the electrocardiograph, the voltage wave produced by the systole, or contraction phase of the heart-beat cycle, may be introduced onto the vibrating element of an Einthoven or string galvanometer and thence recorded as an oscillogram upon a photographic film. For each complete beat of the heart, such a record shows a single pulse caused by the systole of the auricle followed by a quadruplex wave produced by the systole of the ventricle. This whole cycle is repeated about 80 times per minute. An analysis of the shape and timing of these complex waveforms gives the physician many data concerning the functioning of the heart.

In order that satisfactory records may be obtained from the electrocardiograph, the patient must be in a condition of comparative repose so that the systolic waves will not be confused or obliterated by other potentials due to the contraction of muscles not involved in the action of the heart. It is, therefore, impractical to use the ordinary electrocardiograph for recording or timing heart action when the patient is exercising or is in a state of physical exertion or muscular strain.

The heart is primarily a pump for supplying the revitalizing blood stream to all parts of the body. Mental emotion and muscular activity demand an increased supply of blood which is met, in part, by an increase in the pulse rate. It is, therefore, important to study in what manner the heart meets the demands made upon it, how soon it becomes fatigued, and how rapidly it returns to its normal rate after the cessation of muscular activity.

In carrying out such fatigue studies it was very desirable to have some technique for accurately measuring the pulse rate of the patient from moment to moment during exercise. For this purpose, as pointed out above, the electrocardiograph could not be used. Researches along these lines conducted by the Fatigue Laboratory at Harvard University disclosed the fact that the slow rhythmic electrical pulses, due to the systole of the heart, contained a certain "murmur" or higher frequency component of the order of 30 cycles per second. The magnitude of this murmur potential is very small compared to that produced by the primary systolic waves. Nevertheless, it is, fortunately, peculiar to the systole of the heart, and does not exist to any appreciable extent in potentials developed by the contraction of any of the voluntary muscles.

Use is made of this phenomenon in the cardiotachometer, or heart-beat counter, recently developed by the General Radio Company in collaboration with Paul S. Bauer, Scientific Assistant at the Fatigue Laboratory, Harvard University. This device contains a selective vacuum-tube amplifier which responds only to this "murmur" component of the systolic waves and is quite insensitive to the primary waves due to the systole or to any voluntary muscular contraction which, in either case, would have a much lower frequency than the murmur. In this manner, a distinguishable impulse may be obtained at each systole even though the patient be exercising. This impulse consists of an intermittent train of waves of 30 cycles per second frequency which is subsequently magnified and introduced into a "pulse amplifier" which, in turn, produces a single direct-current pulse at each systole of the heart. These direct-current pulses are then used to drive one pen of a duplex syphon recorder, while the other pen is operated uniformly by a clock-driven mechanism, the latter giving one impulse per second. In this manner, by comparing the two simultaneous records, an accurate and continuous timing of the heart rate is obtained. A sample record is shown in Figure 2.

It is obvious that records made in this manner may be used only for timing the systole, and that the waveform traced by the syphon pen which is energized by the heart has no relation, as far as its shape is concerned, to the primary waves obtained with the electrocardiograph.

In order to pick up these muscular potentials to the best advantage, two small disc electrodes made of Monel metal and about one inch in diameter are worn by the patient. These are carried by individual elastic belts and are in contact with the bare chest, one below the left breast and the other over the center of the chest as high as the belt, passing under the armpits, will permit. Such an arrangement places the electrodes approximately along the "electric axis" of the heart where the maximum systolic potentials are obtained. In order to minimize the electrical resistance of the skin, the areas of contact are well moistened with soap lather before applying the electrodes.

The pulse rate may now be measured with the patient standing, sitting, or reclining. He may run at various speeds upon a treadmill, pedal a bicycle, or exercise on a rowing machine, and while so doing, a continuous record of his pulse rate may be obtained both during the exercise and the subsequent recuperative period.

Through the courtesy of the Fatigue Laboratory at Harvard University, we show two interesting curves taken with the General Radio cardiotachometer.

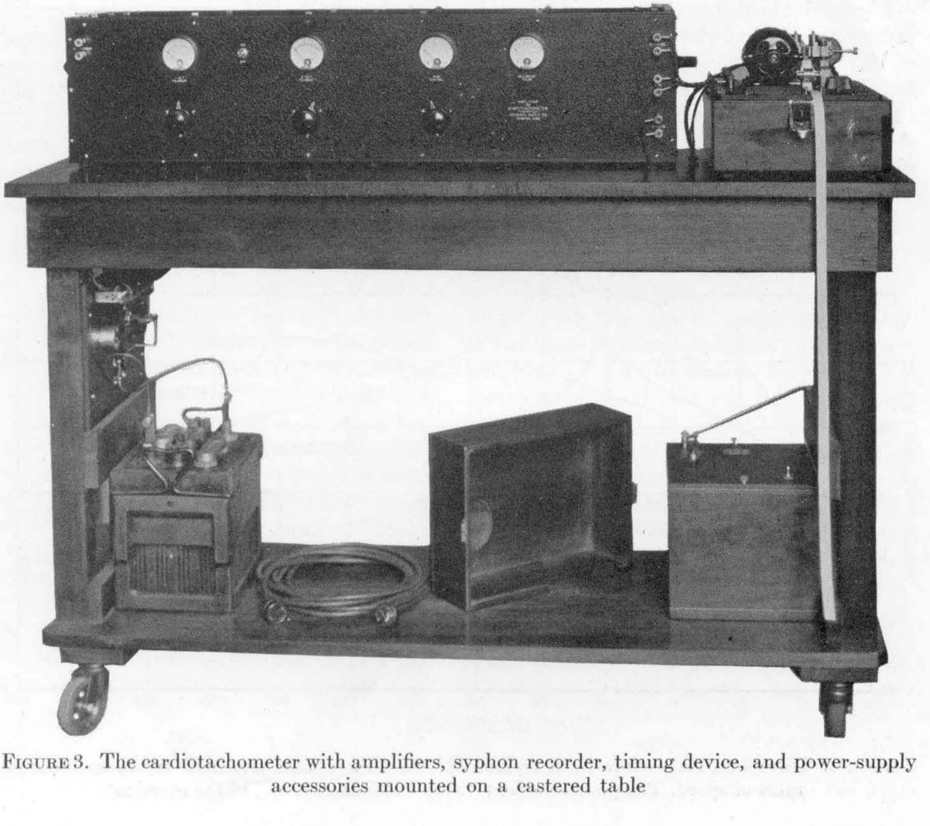

Figure 3. The cardiotachometer with amplifiers, syphon recorder, timing device, and power-supply accessories mounted on a castered table

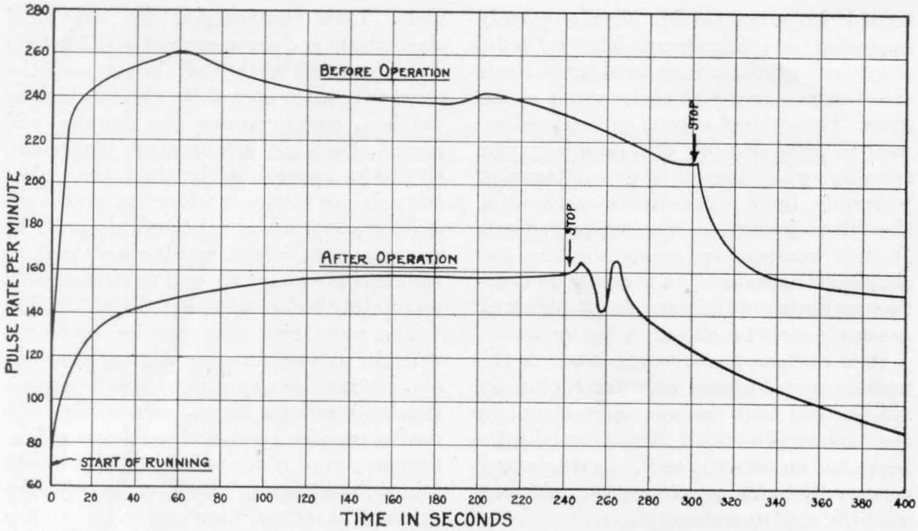

FIGURE 4. The behavior of a dog while running at full speed on a special treadmill. The upper curve was taken before the operation described below. The lower curve was taken after the operation

Figure 4 illustrates the variation in the pulse rate of a dog while running at a speed of 10.7 miles per hour upon a motor-driven treadmill. One curve shows the record for the normal animal, while the other curve shows the record of the same dog after complete recovery from an operation removing certain parts of the sympathetic nervous system. With the normal dog, the initial rise in rate is more rapid, reaching a considerably higher figure, and gradually subsiding after the first minute. After the operation, the rise in rate is seen to be much slower and no reduction occurs during the

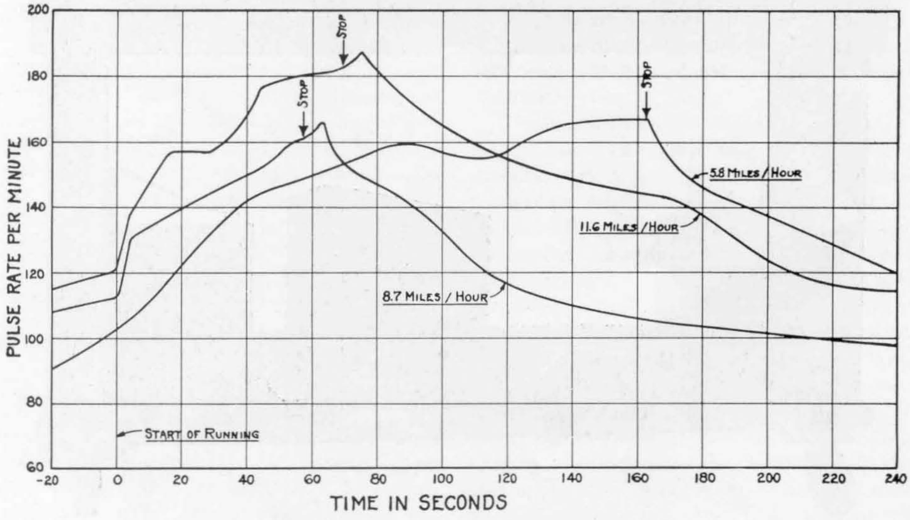

FIGURE 5. Three test runs made by a trained athlete on a special treadmill for three different rates of speed. The points marked "Stop" indicate the end of the exertion

exercise. The recovery of the normal dog after exercise is noticeably more rapid.

Figure 5 gives records obtained from an athlete running at different speeds upon the motor-driven treadmill. These curves are self-explanatory. It is interesting to note that the athlete's heart rate increases while he anticipates the exercise, an example of natural accommodation.

While experimenting with this equipment, the writer had an opportunity of making some interesting psychological tests to record the reaction of the heart rate of children, ages five and seven, while listening to the reading of "thrilling" fairy stories. A distinct irregularity, sometimes of acceleration and sometimes of deceleration, was observed during emotional passages of the stories. What data were obtained seemed to indicate that recovery to their normal rate was less rapid in the case of tales with which the children were thoroughly familiar than in the case of equally thrilling stories which they were hearing for the first time.

With the patient sitting quietly, a certain interval of time is required, with children at least, to become more or less unconscious of the presence of the electrodes. It is believed, however, that while exercising, muscular activity soon renders the patient sufficiently unconscious of the presence of the electrodes.

In addition to its application in fatigue researches, the cardiotachometer is useful in studying the time reaction of the heart to drugs and other stimuli. Likewise, by substituting an electric buzzer for the recording mechanism, arrangements may be made to enable the physician or surgeon to listen to the heart rate of the patient during treatment or operations. It is possible that equipment of this sort might prove of some value as a "lie detector" in criminal investigations.

Figure 3 shows the General Radio cardiotachometer. All of the equipment is mounted upon a castered table, thus making it readily portable. The three-stage amplifier unit utilizes special tuned 30-cycle transformers as the interconnecting-coupling units. Such transformers serve not only to eliminate low-frequency muscular potentials, but they also reduce, to a large degree, ordinary "background" potentials of audible frequency. The amplifier unit is followed by a small bridge-type oxide-junction rectifier and finally by a single-tube amplifier whose output plate current, consisting of pulses of from one to 10 milliamperes magnitude, energizes one of the pens of a newly designed duplex syphon recorder.

The magnet coil operating this pen carries two windings, through the second of which is passed an adjustable direct current, opposing or biasing the current pulses from the amplifier. This electrical method of adjusting the sensitivity and working range of the pen has been found to be the most suitable scheme for maintaining an optimum record, as the potential from the heart varies from time to time. These controls, together with the various plate-circuit and bias batteries, are contained in the metallic cabinet housing the amplifier.

The second pen of the syphon recorder is energized at one-second intervals by a clock-driven key contained in a cabinet on the lower shelf of the table. Provision is made for omitting every tenth second from the records in order to facilitate the counting of the tapes. The two independent pens, which are made from fine silver tubing and which operate upon the syphon principle, trace closely adjacent records upon standard ⅜-inch ticker tape, the magazine roll of which is conveniently mounted in a drawer in the base of this instrument. The timing pen may also be separately controlled by means of a hand-operated key, thus permitting the tape to be marked for identification of any particular occurrence during the record.

The cardiotachometer shown in the illustrations was a model designed to be operated from a 110-volt direct-current source. A charging panel on the end of the table affords means for charging the storage battery. A slight modification in the design would render the equipment operative from a 110-volt 60-cycle-current source.

MISCELLANY

By THE EDITOR

THE General Radio cardiotachometer described by Mr. Lamson in this issue of the *Experimenter* will undoubtedly interest everyone who is concerned with the applications of the thermionic vacuum tube to non-communications uses, as well as those who are working in the particular field of biophysics where the instrument itself might be used. The important element in the new instrument is, of course, the tuned amplifier which amplifies the desired impulses and at the same time filters out most of the extraneous ones.

As a result of its varied experience in the development, design, and manufacture of measuring instruments for the communications industries, the General Radio Company's organization is peculiarly well adapted for work in the rapidly developing industrial field for vacuum-tube measuring and control apparatus. The cardiotachometer is only one example of our present interest and as information about new problems becomes available, it will be presented in the *Experimenter*.

It is our hope that *Experimenter* readers will find such discussions as this of interest to them and that, when they have a particularly knotty problem to solve, they will give us a chance to assist. Our facilities are available for help in every phase of the manufacturing process: development, design, and production itself.

* * * *

The editing of a new catalog of General Radio laboratory apparatus has been completed, and the first copies are off the press. Catalog F, as the new book is called, replaces all previous issues, the two most recent of which were the First and Second Editions of Catalog E, issued in September and December, 1928, respectively.

As a preliminary step in the distribution of Catalog F, we made a careful survey of the *Experimenter* mailing list and chose from it the names of all persons whom we believed would be interested in the uses of General Radio laboratory instruments. To each name in this latter group, we have mailed Catalog F. If you would like to have a copy and feel sure that you could make good use of it, please feel free to ask us for one. Be sure, however, to use your business letterhead and mention what position you hold with your firm, because we have found it necessary to definitely limit distribution of the catalog to laboratories, engineers, and other users or prospective users of General Radio laboratory apparatus.

Besides its regular line of laboratory apparatus the General Radio Company manufactures testing instruments, components, and miscellaneous accessories for the use of radio servicemen, public-address men, sound technicians, custom set builders, experimenters, and amateurs. For the special use of these groups, an abridged edition of Catalog F is now being prepared. It will replace the present Bulletin 931, but it will also describe our complete line of meters and inexpensive general-purpose testing instruments. Copies of this abridged catalog will be mailed to everyone on the *Experimenter* mailing list who has not been sent a copy of Catalog F.

* * * *

A unique feature of the two new General Radio catalogs is the method for keeping you in touch with new developments. The General Radio *Experimenter* has, in the past, described some of them, but we propose to send out catalog supplements, which will give more detailed data than it is possible to include in the *Experimenter*. We are maintaining a record of your name and address, so that these catalog supplements can be mailed to you without delay. The addressing-machine stencil from which the mailing will be done is identical with the stencil that addresses your copy of the General Radio *Experimenter*. If, then, your *Experimenter* is correctly addressed, you may be sure that your name is correctly listed on our mailing list for all catalog supplements.

Please cooperate with us in our efforts to keep you posted by notifying us promptly of any change in address. As the *Experimenter* is now being mailed, the post office will not forward it to your new address.

When copies are returned to us, we immediately remove the name from our mailing list. It is essential, therefore, that you notify us of address changes as far in advance as possible.

* * * *

On pages 28 and 29 of Catalog F are described the series of TYPE 214 Rheostats and Potentiometers which are high grade popularly priced units for use in high grade experimental installations. Effective at once all of those priced at $1.75 in Catalog F carry a price of $1.50. The two items priced at $2.00 in Catalog F are not affected by this change.

* * * *

Occasionally we receive inquiries from readers who wish to maintain a regular file of the *Experimenter*, as the result of which we are interested in hearing from anyone who has developed for his own use or for the use of others a workable filing and binding scheme. We are primarily interested in methods which bind the complete issue, because they are usually much less complicated than those which involve clipping. A number of suitable binders are on the market, and we should like to know whether readers who have tried them have any particular preference for one type as against another.

For our own use in the engineering department of the General Radio Company, we use a simple three-ring binder, and this seems to us to be entirely adequate. It has been suggested that we allow a greater binding margin on the *Experimenter*, and we hope to make this possible in the near future.

CONTRIBUTORS

An adequate sketch of Horatio W. Lamson, the author of the article in this month's *Experimenter*, was given in the June issue of the *Experimenter*. The interested reader is referred to page 11 of that issue for a biographical note and a photograph.

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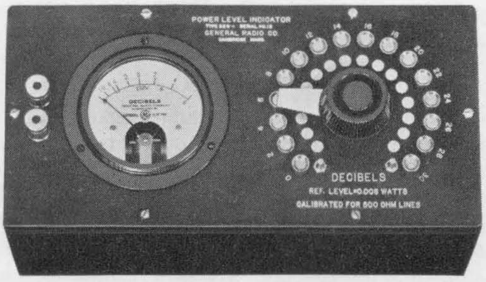

OUR NEW CATALOG F-X describes the power level indicator. Request it on your business letterhead and state the position you hold with your firm, because distribution is limited to laboratories, engineers, and other prospective users of laboratory measuring instruments.

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GENERAL RADIO COMPANY
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The General Radio Experimenter

Vol. V, No. 3 August, 1930

Accuracy Considerations in the Use of Tuned-Circuit Wavemeters

By Charles E. Worthen*

PROBABLY the most common type of frequency standard is the tuned-circuit wavemeter. The accuracy of measurements made with such an instrument depends not only upon the accuracy rating of the wavemeter itself, but upon a number of other factors as well, all of which should be considered in determining the ultimate accuracy.

The precision of setting of a wavemeter is as a rule somewhat greater than its rated accuracy. As a specific example, consider a low-frequency wavemeter of the General Radio precision type with a 2500-division scale, settings of which can be duplicated to within one tenth of a division. The condenser used in this instrument has a minimum capacitance of about 50 $\mu\mu$f and a maximum of 1500 $\mu\mu$f.

If we arbitrarily fix the lowest useable scale reading as 100 divisions, it would appear that this wavemeter could be set to one part in 1000 at the low capacitance end and one part in 25,000 at the high capacitance end. Since the capacitance of the condenser varies uniformly with scale setting, and frequency varies as the square root of capacitance, we could set to one part in 2000 or 0.05 per cent. in frequency at one end and to one part in 50,000 or 0.002 per cent. at the other end.

Actually, the sharpness of the tuned circuit and the characteristics of the thermogalvanometer resonance indicator determine the ultimate precision of setting. At the high capacitance end of the scale, the top of the resonance curve covers about 5 divisions and at the lower end about 0.5 division. Converting these values to frequency, the width of the peak is from 0.1 to 0.2 per cent. By setting to the center of the peak a precision of about 0.05 per cent. can be realized. By using the incremental capacitance method † to obtain the resonance indication, the pre-

* Engineering Department, General Radio Company.

† James K. Clapp, "Improving the Precision of Setting in a Tuned-Circuit Wavemeter," *General Radio Experimenter*, IV, September, 1929. This issue is now out of print. The method referred to involves the use of a small condenser which may be shunted across the main tuning condenser by means of a push button. The wavemeter is adjusted until the resonance indicator gives the same deflection when the incremental capacitance is in or out of circuit. In other words, the operation of the push button spans the resonance peak. This method of setting is used on the General Radio Type 624 Precision Wavemeter. — Editor.

cision of setting can be increased to one part in 20,000 or 0.005 per cent.*

The rated accuracy of the wavemeter is not as high as these figures would indicate. This is due to possible errors in calibration and to aging of the tuned circuit. Although extreme care is used in calibration, some errors are bound to occur in setting the driving oscillator to the frequency standard and still others in setting the wavemeter to the driver. A third source of error is the plotting of the calibration curves. If all these errors are cumulative (which is quite possible) the accuracy to within which the wavemeter can be guaranteed is materially reduced.

After the wavemeter is calibrated, the constants of the tuned circuit are subject to some drift due to aging effects in the materials of which it is constructed. Over a period of one year this may amount to as much as 0.1 per cent. The effect of temperature on the tuned circuit is of considerable magnitude, and in a high-precision wavemeter (guaranteed to 0.1 per cent.) special construction or a temperature correction must be used

If a metallic body is placed in the field of a wavemeter inductor, its effective inductance may be materially changed, and the calibration is no longer correct for the conditions under which it is used. Similarly, the capacitance of near-by objects will affect the frequency of an oscillator. When a wavemeter is placed near an oscillator, both effects occur: the wavemeter changes the oscillator frequency and the presence of the oscillator affects the wavemeter. Whether or not these changes are large enough to appreciably affect the accuracy of the measurement depends on the conditions under which the measurement is made and may best be determined by experiment.

Even when the capacity effects just mentioned are negligible, another error may occur, due to "transformer action." The coils of the oscillator and wavemeter act as the primary and secondary windings of a transformer, and the impedance of the wavemeter is reflected into the oscillating circuit. The magnitude of the reaction depends on the L/C ratios of the two circuits and the value of coupling between them. When the wavemeter is set to resonance, the impedance reflected into the oscillating circuit is purely resistive, and the change in oscillator frequency thus produced is negligible. If the wavemeter is not in resonance, the reflected impedance has a reactive component, and the frequency of the oscillator is materially changed.

As the capacitance of the wavemeter condenser is varied through resonance, the frequency changes as shown in the accompanying diagram, where the zero axis represents the frequency of the oscillator before the wavemeter is coupled to it.† The point at which this curve crosses the axis is the setting at which the wavemeter is in resonance and this setting should be used in entering the calibration chart.

The frequency change shown in the diagram can be detected by listening in a heterodyne detector as the wavemeter condenser is varied. If the heterodyne is set to zero beat with the wavemeter far from resonance, then as the wavemeter is tuned, the beat note will rise and then fall to zero twice. The direction of the beat-frequency change cannot, of course, be detected.

With a given wavemeter and oscillator and a given degree of coupling between them, the magnitude of the change is entirely independent of the

* The precision is inversely proportional to the figure given, that is, the lower the percentage figure, the higher the precision.

† This discussion assumes that the oscillator is uncontrolled, that is, that its frequency is determined by the reactance of its tuned circuit.

oscillator power. The higher the power of the oscillator, however, the smaller the degree of coupling necessary to produce a given deflection on the thermogalvanometer.

When the wavemeter is coupled to a controlled oscillator or to the output of a power amplifier, these effects are usually negligible. The capacitance effect of the presence of the oscillator or power amplifier upon the wavemeter is, however, still present.

When using reaction methods of resonance indication, the point of maximum reaction is where the greatest frequency shift occurs, so care should be taken to make the reaction as small as possible or else the setting should be made by listening to the beat note as outlined above.

In making frequency measurements with a wavemeter, if no care is taken to eliminate or minimize the various effects which have been discussed, the best accuracy which can be realized is about 0.5 per cent. but if due attention is given to them, the rated accuracy of the wavemeter can be reached. Even then the "rated accuracy" may be of a materially lower order than the percentage precision with which one is able to read the scale.

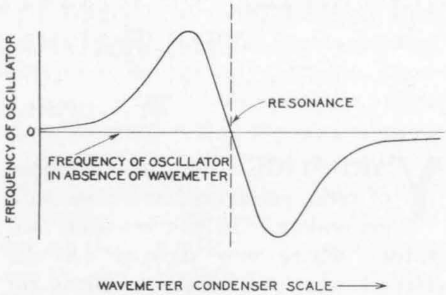

Figure 1. Reaction of a wavemeter upon the frequency of an oscillator to which it is coupled

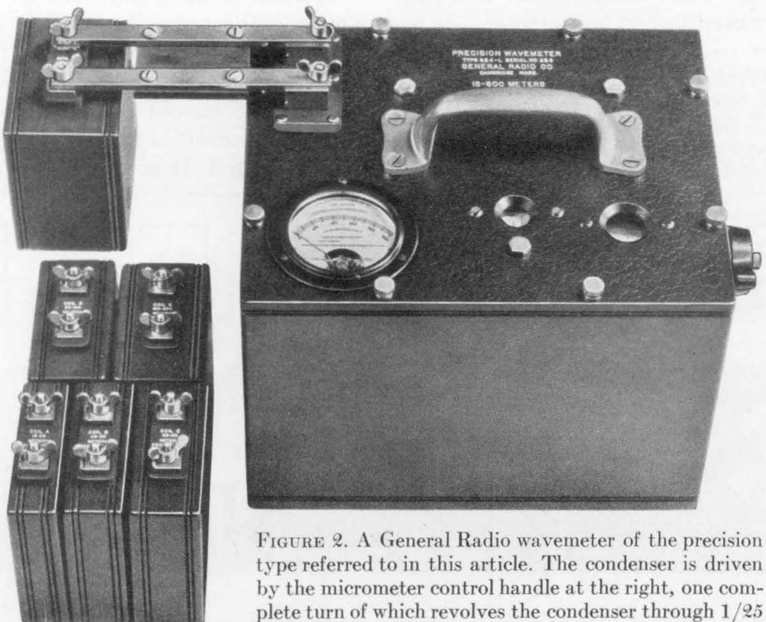

Figure 2. A General Radio wavemeter of the precision type referred to in this article. The condenser is driven by the micrometer control handle at the right, one complete turn of which revolves the condenser through 1/25 of a semicircle. The micrometer shaft carries an accurate 100-division scale, so that any desired setting of the condenser can be duplicated to within at least one part in 2500. Besides, tenths of divisions can be estimated

SIMPLIFIED SENSITIVITY MEASUREMENTS FOR THE RADIO SERVICE MAN

By CHARLES T. BURKE*

YARDSTICKS for the evaluation of radio receivers have come into general use. In the research laboratory where new designs are developed very elaborate systems of measurement have been set up, covering every feature of receiver performance.† Simplified tests are also in use on the production lines, where the performance of every set may be checked against the specifications determined by the development laboratory. There has been, however, no general means available for a performance check in the field. To a limited extent the methods used in the development laboratory have been applied to field checks by some of the larger organizations, but these methods are not generally suited to service testing.

It is recognized that a sensitivity measurement serves as an excellent indication of the receiver performance. Any serious fault in the receiver will be accompanied by a loss of sensitivity as compared with standard performance. The usual method of measuring sensitivity is illustrated in Figure 1. A modulated source of radio frequency is connected to the receiver through a dummy antenna. The power output of the receiver is measured in a standard output circuit. The magnitude of signal voltage required to give equal output power under standardized measuring conditions is of course a measure of the sensitivity of the receiver.

A number of simplifications may be made in the procedure outlined above to make it more suitable for service testing. A test-signal generator for service testing should be easily portable and all unessential adjustments should be eliminated. It is also desirable that

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* Engineer, General Radio Company.

† *I. R. E. Yearbook*, 1929, pp. 106–128. See also Charles T. Burke, "The Standard-Signal Method of Measuring Receiver Characteristics," *General Radio Experimenter*, IV, March, 1930.

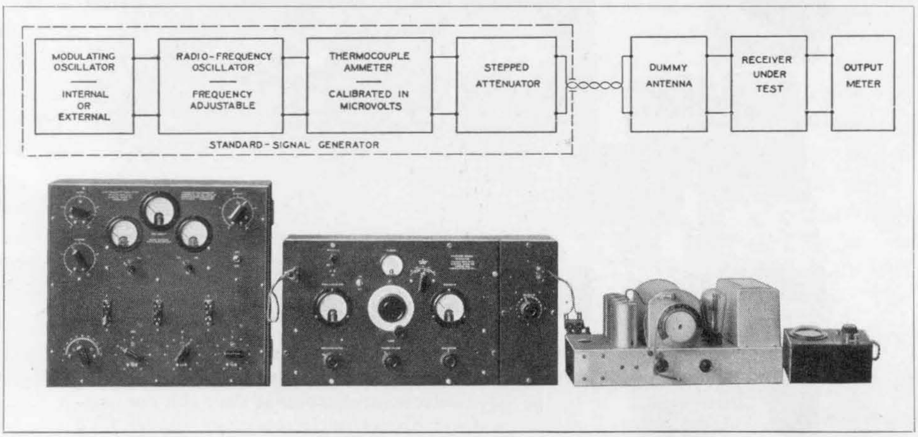

FIGURE 1. Component parts required for the standard-signal method of measuring sensitivity as recommended by the Institute of Radio Engineers. Above: an outline chart. Below (left to right): TYPE 377-B Low-Frequency Oscillator for supplying external modulation; TYPE 403-C Standard-Signal Generator; TYPE 418 Dummy Antenna; receiver under test; and TYPE 486 Output Meter

the instrument be alternating-current operated in order to avoid the necessity of carrying batteries for it.

Thorough shielding is a further requirement for any instrument with which comparative sensitivity measurements are to be made; otherwise differences in shielding of the receivers will introduce wide variations. The shielding must, of course, also include complete isolation from the alternating-current line if the receiver under test is also alternating-current operated. An adequate test-signal generator should provide a modulated radio-frequency voltage continuously adjustable in frequency and constant in amplitude over the broadcast range. It should also provide means for changing its output by definitely known amounts. This last requirement involves the design of an attenuator or voltage divider which will be accurate at high frequencies and also requires careful shielding of the instrument.

The uses of such a test-signal generator are numerous. It can be used on the demonstration floor to compare the sensitivity of different receivers, always extremely difficult to do under store conditions by other means. It is in the field of receiver servicing, however, that the test-signal generator has its greatest usefulness. Being easily portable, it can be taken to the job and with its assistance, the service man can immediately determine whether or not a real difficulty exists in the receiver. He can also isolate receiver troubles from troubles due to local conditions or to antenna and ground installation. If the trouble is in the receiver, the test-signal generator provides an immediate check on the efficacy of the means taken to remedy the defect, since the restoration of the receiver to normal sensitivity can be interpreted as a successful cure. This use of the generator permits the making of all kinds of minor adjustments of the receiver on the owner's premises and eliminates unnecessary transportation of the receiver to the shop. The test-signal generator is also used in the customary neutralizing and aligning adjustments where a source of modulated radio-frequency voltage is required.

The General Radio Company has been working for a considerable period on the development of a test-signal generator which will fulfill the requirements outlined above. The result of

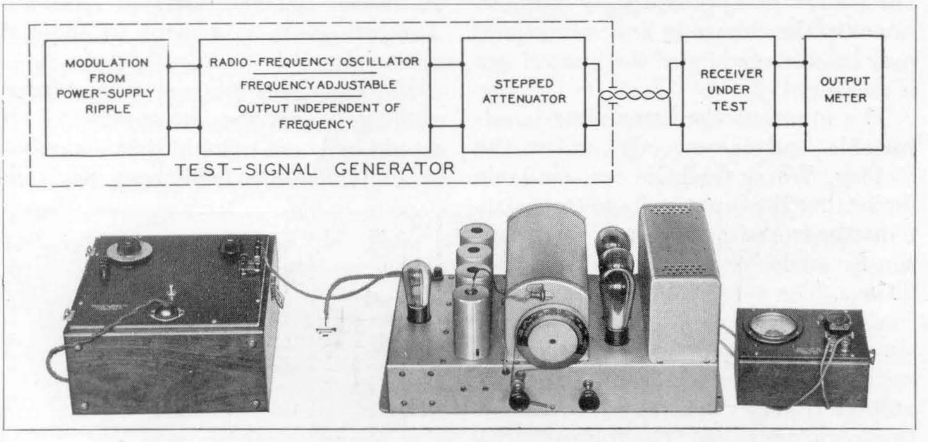

Figure 2. Component parts required for the simplified sensitivity measurement described in this article. Above: an outline chart. Below (left to right): Type 404 Test-Signal Generator; receiver under test; and Type 486 Output Meter. Note the similarity between this and the arrangement shown on the opposite page

this development is the TYPE 404 Test-Signal Generator. It consists of a constant-output vacuum-tube oscillator modulated by the rectifier ripple, and an attenuator, together with a power-supply transformer and rectifier.

The attenuator is carefully designed, and well shielded. The value of the instrument in making comparison depends entirely on the accuracy of the attenuator, and this portion of the circuit has, therefore, received particular attention. The attenuator has voltage ratios of 1, 2, 5, 10, 20, 50 and 100; a range that will include all modern types of receivers. An additional set of terminals provides an output of about 0.1 volt for making neutralizing and aligning adjustments. The error in attenuator ratios is less than 5 per cent. for adjacent ratios, and the cumulative error in the entire attenuator does not exceed 20 per cent. This means that the instrument will *compare* the sensitivity of two similar receivers with an accuracy of 5 to 20 per cent.

The absolute value of the output voltage may vary, due to aging of tubes or to changes in line voltage. The change in output due to line voltage variations is approximately proportional to the change in line voltage and may be corrected for, if the line voltage is measured.

The input to the attenuator is adjustable and is correctly set at the factory. Where facilities are available for setting the input voltage to the attenuator from time to time, correction can be made for changes in tube conditions. The total voltage attenuation from the point of adjustment to the lowest output point is 1:100,000. The oscillator is so designed that the output voltage is nearly constant over the entire frequency range. The voltage variation is less than plus or minus 5 per cent.

The test-signal generator is entirely alternating-current operated. This feature requires considerable care in the design of the instrument, in order to keep radio-frequency currents out of the line. Since the radio receiver is usually operated on the same line as the signal generator, any leakage into the line would be picked up in the receiver. A careful study of this problem has resulted in filtering in the line input to the generator, such that the receiver and the signal generator can be operated from the same socket without interference.

It should be emphasized that the test-signal generator does not give an absolute reading of sensitivity in microvolts. So many factors affect such readings that even a laboratory instrument may be 10 per cent. in error in absolute value. The TYPE 404 Test-Signal Generator has a series of relative output figures, and is primarily designed for comparative work, either against a standard, or as a straight comparison between two sets. The comparison does not have to be made at the same input level to the receiver, however, since the ratio between the output at various steps is indicated. The range of the instrument is of the order of 10-1000 microvolts, with an additional 100,000-microvolt terminal. The leakage is equivalent to about 2 microvolts.

In using the test-signal generator for making sensitivity measurements, it should be borne in mind that a number of simplifications have been made in

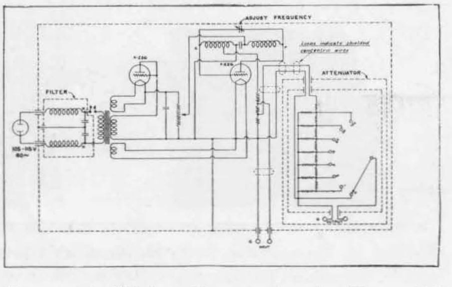

FIGURE 3. Wiring diagram for the TYPE 404 Test-Signal Generator

this instrument to make it best adapted to the requirements of receiver servicing. These simplifications in the test method are such that the measurements obtained with the test-signal generator cannot be compared with those obtained by other methods of measurements, such as the standard sensitivity test outlined by the Institute of Radio Engineers and generally used in development laboratories. The modulation in the test-signal generator is obtained from the rectifier ripple and is not adjustable either in frequency or in percentage. Readings taken with the test-signal generator are, however, comparable among themselves. If receivers of the same type are being compared, the generator can be connected directly to the antenna-ground posts of the receiver. If the receivers of widely differing types of input circuit are being compared, it is desirable to use a blocking condenser of about 100 $\mu\mu$f capacitance between the generator and the receiver under test. The sensitivity of a receiver is measured in terms of the radio-frequency voltage input required to give a certain output power. Of two receivers delivering the same power to the speaker circuit the more sensitive is, of course, that which requires the smaller input voltage. The general practice is to substitute for the speaker a suitable resistance load and a means for measuring either the current through or the voltage across it. A convenient value of output power is selected (50 milliwatts is often used because it is the Institute of Radio Engineers' standard) and the input from the signal generator adjusted to give this value of output for all the receivers measured.

MISCELLANY

By The Editor

WE are publishing Mr. Worthen's precautions for the use of a tuned-circuit wavemeter in the hope that it will dispel one of the common misapprehensions that are held by many users of precision wavemeters. This question has become serious since the announcement of the new Type 423 Vacuum-Tube Oscillator which enables the user to convert his General Radio Type 224, 224-A, or 224-L Precision Wavemeter into a heterodyne wavemeter. The greatly increased precision of setting which one can obtain by listening to the beat note has led many people to assume that they were making much more accurate measurements.

The point is that the frequency stability of a heterodyne wavemeter is no better than the stability of the tuning circuit with which it is associated. A heterodyne wavemeter may enable one to minimize the error in setting a given unknown oscillator to a desired frequency, but the reliability of that heterodyne wavemeter as a standard of frequency is no greater than the reliability of its tuned circuit.

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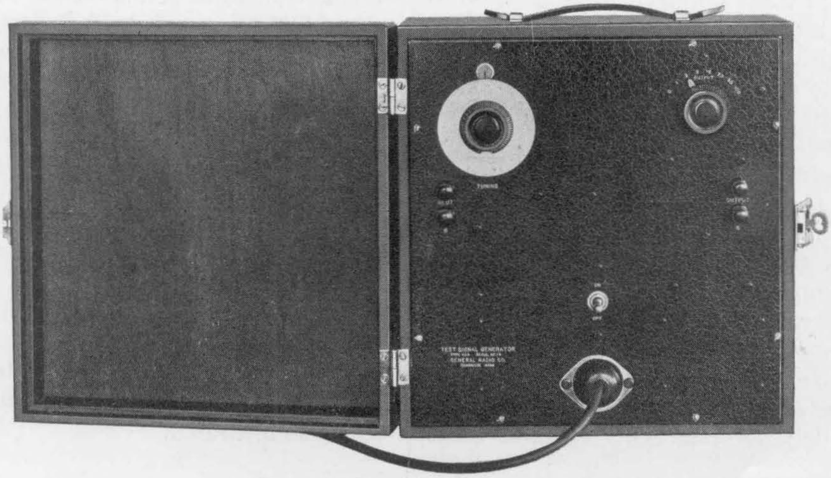

Type 404 Test-Signal Generator

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See this issue of the *Experimenter* for a discussion of test-signal generators in general and the TYPE 404 in particular. It will be cataloged in a new bulletin for the serviceman which will be mailed to all serviceman readers of the *Experimenter* on September 15.

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Electrically-Driven Tuning Forks

By Horatio W. Lamson*

Summary — The choice of a particular type of tuning fork depends largely upon the requirements of the problem at hand and upon the degree of frequency stability desired. Simplest and least precise are the contact-driven forks which, however, are capable of supplying considerable power output of approximately square-top waveform. When a sinusoidal output of good precision is desired, as, for instance, in the case of a tone source for bridge measurements, the single microphone drive serves admirably well. Still greater precision, more power, and purer waveform are to be had from the somewhat more complicated double-button fork. A high-precision standard demands the use of a freely vibrating fork, such as is exemplified by the vacuum-tube-driven type. The ultimate in precision so far attained is to be found in the freely vibrating fork with suitable provision for eliminating its temperature error.

Any simple vibrating mechanical system possesses a definite and constant period of vibration. Such a system may be used either as a standard of frequency or as a standard of time, if all of the individual factors governing the frequency of the system remain constant. These factors are, principally, the physical dimensions of the system and the amplitude and decrement of its vibration.

Consider, for example, the simple pendulum. Its frequency is inversely proportional to the square root of its length and decreases slightly with an increase in amplitude of vibration. This amplitude error is due to the fact that when the pendulum is displaced, the restoring force, gravity, is no longer parallel to the line between the point of support and the center of the bob. The error increases proportionately with amplitude.

If the pendulum bob is displaced and allowed to swing freely, it will execute a damped vibration. The frequency will continuously increase until it finally comes to rest. The less the damping, the less the amplitude change per cycle, and the more nearly constant will be the instantaneous value of the frequency. If we wish to maintain constant amplitude, we must effectively eliminate the damping by supplying the pendulum continuously or at uniform intervals with a sufficient amount of energy to offset all of the losses. This is accomplished in the ordinary clock by means of the spring-driven escapement mechanism.

The essential features for constant frequency of the pendulum are, therefore: (*1*) constant mechanical dimensions, (*2*) minimum amplitude of vibration, (*3*) minimum damping of vibration, (*4*) reception of sufficient power at each cycle from an external source to overcome damping.

The tuning fork is likewise a vibrat-

* Engineer, General Radio Company.

ing system subject to the same fundamental laws of frequency control. It consists usually of a U-shaped bar having a rectangular cross-section. When vibrating in its fundamental manner, the ends of the tines possess a maximum motion transverse to their length and in the plane of the fork. This transverse motion decreases continuously along the tines and becomes zero at the heel of the fork where the vibration occurs in a direction along the tines, because as the tines vibrate, their center of gravity is moved slightly to and fro in a direction along the tines with a frequency equal to twice that of the fork. In the tuning fork the amplitude error is due to the fact that when the tine is deflected the restoring force is not perpendicular to the axis of the tine.

In addition to the four requirements for constancy in the pendulum, the fork requires another: (*5*) The two tines must be exact mechanical duplicates and have equal amplitudes and damping.

Tuning forks have been used for many years as standards of pitch. The frequency is approximately inversely proportional to the square of the length of the tines and roughly proportional to the thickness of the tines in the plane of vibration. The dimension of the tines perpendicular to the plane of vibration has practically no effect upon the frequency. When used as a standard of musical pitch, a fork is ordinarily struck a single blow and allowed to execute a damped vibration. The slight change in frequency during damping is negligible from a musician's standpoint.

If, however, the tuning fork is to be used as a high-precision standard of frequency, it must obviously receive continuous excitation from an external source. Such excitation might be purely mechanical in nature, analogous to the escapement of a clock, but the form and motion of the tuning fork renders it particularly favorable to magnetic excitation, if the fork is constructed of magnetic material and is subjected to a series of magnetic pulses approximating the natural frequency of the fork. If, furthermore, these energizing pulses are in some manner synchronized by the motion of the fork itself, then the fork will become oscillatory at its natural frequency. We propose to discuss various methods by which this self-synchronized energizing of the fork may be accomplished.

A tuning fork intended to be used as a frequency standard would not be designed to furnish directly any great amount of acoustic energy since to do so would necessarily increase its damping. Obviously, if the fork is to be electrically driven an unlimited acoustic output may be obtained indirectly by means of vacuum-tube amplification.

In passing it may be noted that the frequency of all types of forks may be initially calibrated to a predetermined value by grinding the free ends of the tines. The natural frequency of a fork may be varied by means of adjustable weights on the tines. Great care must be exercised, however, to keep the tines symmetrically loaded. Loading is not to be recommended for forks of the highest precision.

Contact Drive — The earliest attempt at self-synchronized electrical driving of the tuning fork followed the principle of the ordinary electric bell or buzzer, and constituted the so-called contact-driven fork. Figure 1 shows a schematic diagram and Figure 2 a photograph of a fork of this type. Each tine of the fork is attracted outwardly by an electromagnet *D*. One tine of the fork carries a flexible spring *O* which makes contact with a stationary adjustable contact point *P* during a portion of the cycle when the tines of the fork are bent inward. This contact closes the battery circuit through the magnets

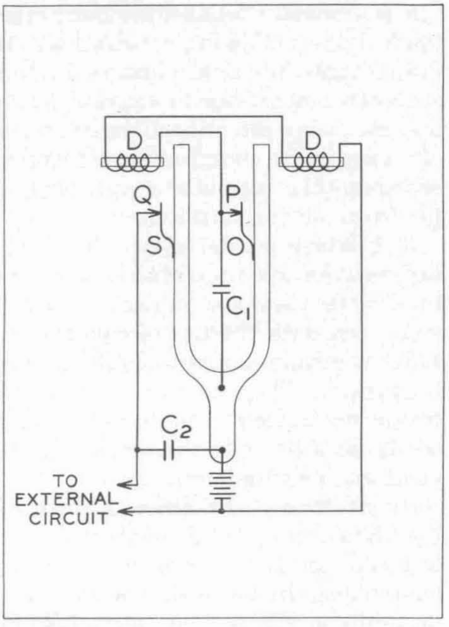

FIGURE 1. A contact-driven fork (schematic)

D, thus energizing them and drawing the prongs outward, which in turn serves to break the contact and deënergize the magnets. The released prongs then spring inward by virtue of their elasticity, thus reëstablishing electrical contact between *P* and *O*. This cycle is, of course, repeated with the frequency of the fork. The energy necessary to overcome the damping of the fork consists of the magnetic pulses imparted at each cycle of the tines and comes from an external source, the battery. The amplitude of vibration of the tines depends, among other things, upon the duration of the energizing pulses, that is, the duration of the contact between *P* and *O*. If this interval is less than one-half of one cycle, the amplitude may be kept relatively low, but the fork cannot be self-starting.

One of the principal uses of the tuning-fork standard is to supply a pulsating or an alternating current having a standardized frequency equal to that of the fork, or some integral multiple or sub-multiple thereof. By adding a second contact point and springs *Q* and *S*, interrupted current may be supplied to an external circuit in the manner shown. The relative duration of the off and on periods are controlled by the adjustment of *Q* with respect to *S*. Frequently, two contact points *Q* are supplied, one on each side of *S*. Such an arrangement gives an interrupted current having twice the frequency of the fork. The two condensers C_1 and C_2 are for the purpose of suppressing sparking at the contact points.

The contact-driven fork provides a simple and moderately precise standard. If it is necessary to deliver relatively large amounts of energy directly

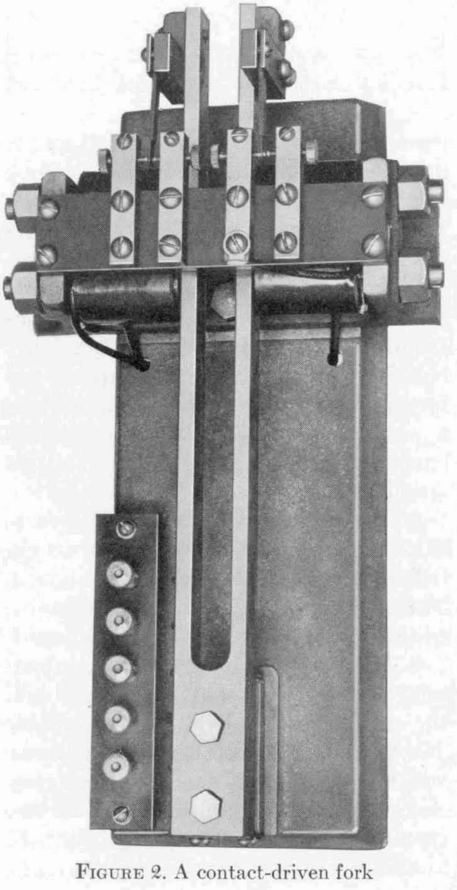

FIGURE 2. A contact-driven fork

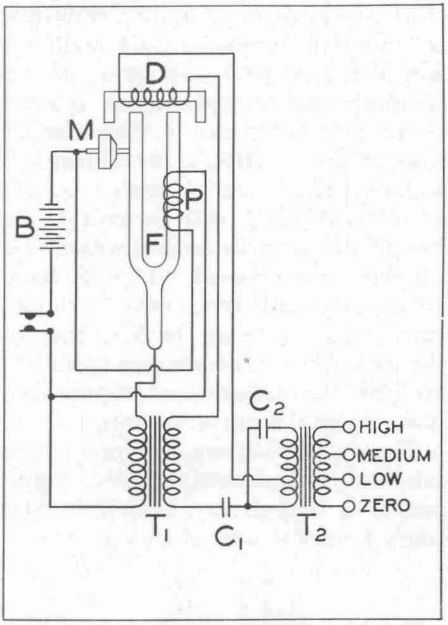

FIGURE 3. Single-button microphone-driven fork

from a fork, the two contacts *Q* and *S* are required, and therefore such a fork might as well be of the contact-driven type. This type has, however, some inherent defects which seriously handicap its use as a high-precision standard:

1. With a proper design of the contacts, the output-current wave may closely approximate the square-top form. If anything even approximating a simple sinusoidal wave is desired, considerable doctoring of the output circuits is necessary.

2. To obtain a satisfactory action of the contacts, a relatively large amplitude of vibration of the tines is required. This, we have seen, is not conducive to the highest precision of frequency.

3. The intermittent mechanical contact between the vibrating springs and the stationary points adds considerable damping to the motion of the tines, which likewise lowers the frequency stability. If the damping of the two tines becomes unsymmetrical due to inequality of the contact adjustments, further complications arise which make the fork less stable in its operation.

4. Minute physical changes in the contact members due to wearing, heating, etc., may alter the time intervals of magnetic energization, thereby changing the amplitude, and hence the frequency of vibration.

5. Contact points, even when well designed, are apt to be erratic in operation, since they are subject to wear, and, even with the use of condensers, suffer a certain amount of pitting due to sparking. They must be cleaned and readjusted at frequent intervals, which results in a possible change of adjustment and driving frequency.

Single-Microphone Drive — Some of the difficulties of the contact-driven fork are partially overcome in the microphone-driven fork shown schematically in Figure 3 and pictorially in Figure 4. On one tine of the fork is mounted one electrode of a carbon-button microphone *M;* the other electrode, being an integral part of the housing shell, is supported through a spring within a stationary protective metallic cup. Any vibration of the tines will jar the microphone and thus cause a synchronous fluctuation of the bat-

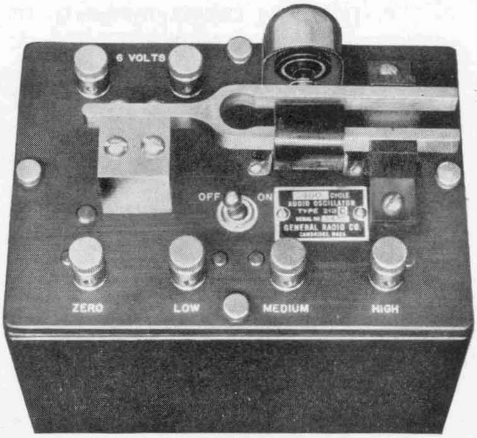

FIGURE 4. General Radio TYPE 213-C 400-cycle Audio Oscillator, a typical single-button microphone-driven fork

tery current through it and the primary of the transformer T_1. The secondary current from this transformer passes through a condenser C_1, a portion of the primary of the transformer T_2, and the driving coil D, so that the latter will supply magnetic pulses to the fork to compensate for its damping losses, thus maintaining a continuous vibration at some fixed amplitude and frequency. The condenser C_1 serves to obtain the proper phase relation between the driving current and the synchronous vibration of the microphone. The whole of the primary of T_2 is tuned electrically by means of the condenser C_2 to the natural frequency of the fork, thereby purifying the output waveform. A tapped secondary of T_2 enables various output voltages to be obtained. In order to prevent the tines from being energized at double frequency, they are magnetically polarized by a steady current from the battery passing through a shunt circuit comprising the coil P which surrounds one tine of the fork.*

This fork is free from contact troubles and may be operated with a much smaller and more constant amplitude and decrement and has, therefore, a more nearly constant frequency than the contact-driven fork. Furthermore,

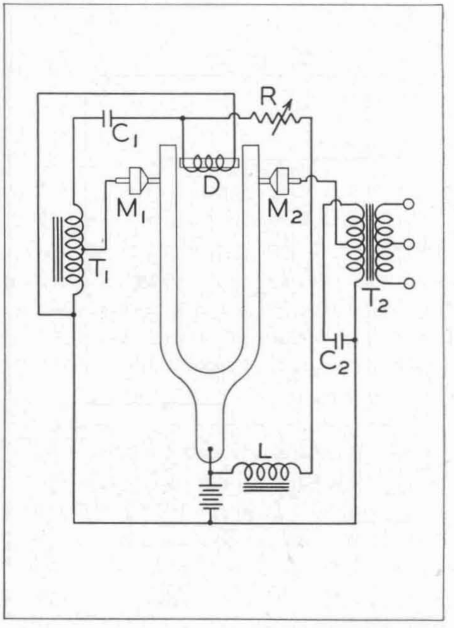

FIGURE 6. A double-button microphone-driven fork

it is capable of supplying directly a sinusoidal electrical output in which the harmonic content does not exceed 8 per cent. of the fundamental for ordinary resistive loads. However, owing to the fact that the total available output of the single-microphone button must be divided between the driving coil and the output load, the available output power is necessarily limited to about 50 milliwatts.

Double-Microphone Drive — In order to increase the available output, it is quite practicable to mount a microphone on each tine of the fork, giving the double-button type (see Figures 5 and 6). Battery current passes through the driving microphone M_1 and a portion of the auto-transformer, T_1. The full output of this transformer passes through the condenser C_1 and the driving coil D which energizes the tines in synchronism with their natural frequency and thus supplies the energy to overcome all damping. C_1 serves the dual purpose of properly

FIGURE 5. A double-button microphone-driven fork. Note the heavy brass inertia caps which house the microphone buttons

* This is the system used in General Radio TYPE 213 Audio Oscillators, a more extensive analysis of which will be found in an article by Charles E. Worthen, "A Tuning-Fork Audio Oscillator," *General Radio Experimenter*, IV, 11, April, 1930.

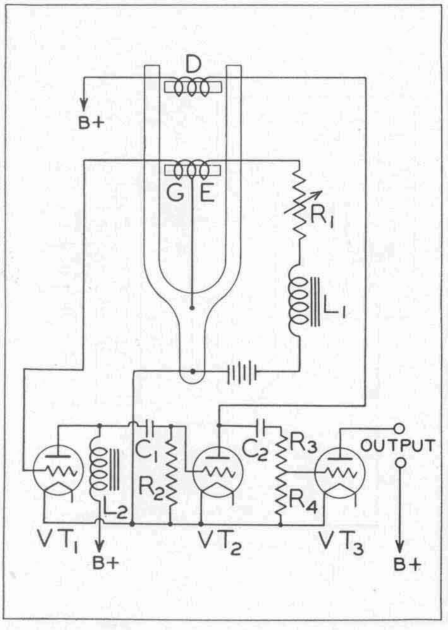

FIGURE 7. A schematic diagram for a vacuum-tube-driven fork

phasing the driving current and providing a blocking condenser for direct-current potential. The necessary polarizing current passes through the same winding *D* and the choke *L* and may be adjusted to the proper magnitude by means of the resistance *R*. The output microphone M_2 is energized by the same battery and feeds the output circuit through transformer T_2 having a tuned primary and a tapped secondary, as previously described.

Obviously, this arrangement is capable of delivering considerably more power than the single-button type. It possesses another distinct advantage in that both tines of the fork are symmetrically loaded and damped. This gives a purer wave and one more stable in power output and frequency. In order to further enhance the symmetry of the tines, the microphones are not supported from the rear through springs which are difficult to adjust and maintain as exact mechanical duplicates. Instead, inertia-type microphones are used suspended wholly from the tines, electric contact being obtained through light pigtail connectors of negligible mechanical effect. To improve this inertia action, the microphones are loaded with carefully designed inertia caps seen in the photograph.

Vacuum-Tube Drive — The double-button fork achieves many of the five enumerated requirements for a precision tuning-fork standard. Owing, however, to unavoidable variations in the stiffness and reaction of the diaphragm of the microphone buttons, as well as small shifts in their center of gravity due to the loose carbon granules, perfect symmetry in the loading and damping of the tines cannot be maintained.

The obvious solution of this difficulty would be to employ a system in which the tines of the fork are unloaded, fashioned in a simple form with extreme

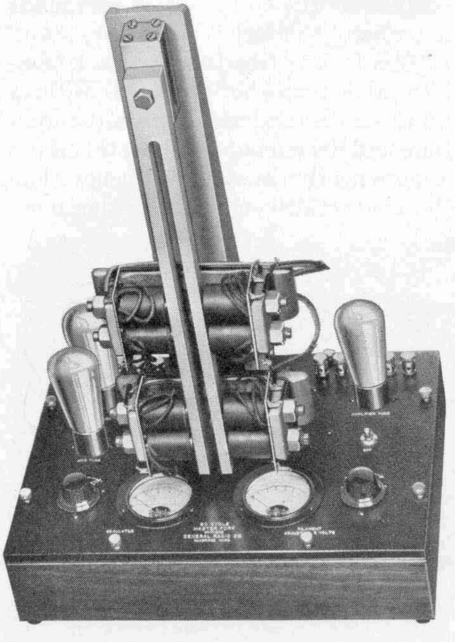

FIGURE 8. A 60-cycle vacuum-tube-driven tuning fork. The two lower pairs of magnets are the drivers

precision, and allowed to vibrate without any physical contact. These conditions are attained in the vacuum-tube-driven tuning fork. The fundamental principles of one method for driving such a fork are indicated in the schematic diagram (see Figure 7).

Vibration of the tines induces a potential in the "grid" winding G which is suitably polarized by a winding E, the latter being in a circuit comprising a battery, a choke L_1, and an adjustable resistance R_1. The potentials thus induced in G are applied to the grid of a vacuum tube VT_1, known as the "grid" tube, which, in turn, is coupled to a second tube VT_2 by the elements L_2, C_1, and R_2. The output of the "drive" tube VT_2 is consumed in the driving coil D which energizes the fork and maintains it in vibration. It will be noted that this driving current (and hence the magnetic pulses) are polarized also, i.e., are pulsating rather than alternating in character.

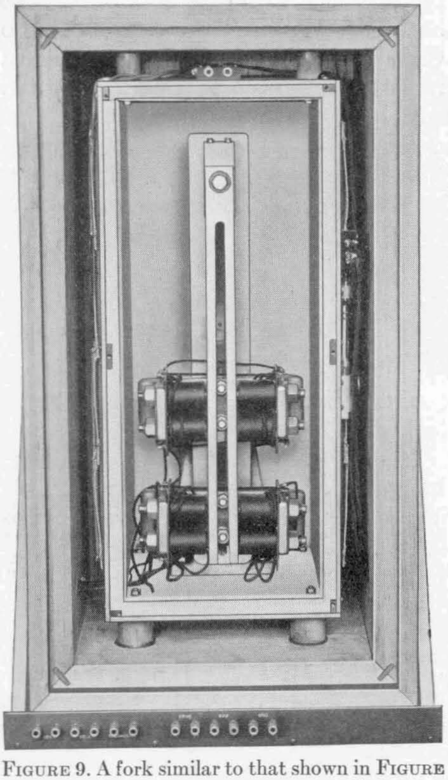

Figure 9. A fork similar to that shown in Figure 8 mounted in a temperature-controlled compartment

Although not apparent in the drawing, the two separate windings D and GE are so arranged that there is no magnetic coupling between them. We have, therefore, a regenerative amplifier system in which the feedback agent consists of the mechanical motion of the tines. The latter being entirely free, the fork vibrates at a frequency very close to its natural period and provides thus a high-precision standard.

The adjustment of the parts and the operating parameters of the tubes may vary the amplitude and hence the frequency of the fork to a very slight degree. Proper manipulation of these controls enables the precise adjustment of the frequency to some predetermined value with a much greater precision than can readily be attained by grinding the ends of the tines.

In order to realize a negligible reaction of the output load upon the driving circuits, a small portion of the output voltage of the drive tube VT_2 is applied through members C_2, R_3, and R_4 to the grid of one or more amplifier tubes VT_3.

An example of the vacuum-tube-driven fork is seen in Figure 8. In order to minimize the damping on the fork, a special mounting is provided for the heel which is somewhat elastic in a direction along the tines. This reduces the amount of vibrational energy transmitted to the support base and hence the damping.

A tuning fork of this type has such a high precision that, if the fork is fashioned from homogeneous high-grade tool steel, the greatest source of error ordinarily consists of the temperature coefficient of frequency (due to the elongation of the tines with temperature) which is of the order of one part in 10,000 per degree C. Their precision may, therefore, be improved by employing one or both of the following methods:

1. Construct a bimetallic fork, the heel and lower part of the tines being of one material and the outer part of the tines of another material, so chosen and proportioned that the fork, as a whole, possesses a much smaller temperature coefficient.

2. Enclose the fork in a thermostatically-controlled constant-temperature compartment.

An example of the latter procedure is seen in Figure 9. The multi-walled compartment is shown open with the fork unit, similar to Figure 8, located therein.

In this particular arrangement of a temperature-controlled tube-driven fork, the temperature could be kept fixed within 0.1° F., and, as a result, the frequency of the fork could be maintained accurately constant to the order of one part in 100,000. Such a fork was used to drive a synchronous-motor-driven clock so that the fork was actually a time-keeping device. The above-mentioned precision corresponds to better than one second per day in this time-keeping system.

Other Free-Fork Methods — The high precision obtainable by the use of a freely vibrating fork may be accomplished in other ways, as, for example, by employing an electrostatic rather than an electromagnetic pickup.

A condenser is formed having one stationary electrode and one moving electrode which is the vibrating tines. A steady polarizing potential is applied to this condenser so that a variation in its capacity produces pulsating currents which may be amplified to drive the fork electromagnetically.

The selection of a fork for a particular purpose is somewhat determined by the desired frequency. Forks having from a few cycles up to several hundred cycles per second may readily be contact-driven. Single-button forks have been constructed in the General Radio Company's laboratories covering a range of from 400 to 1500 cycles and double-button forks, from 300 to 2500 cycles. With proper design, vacuum-tube-driven forks may be made to cover at least the audible-frequency range.

MISCELLANY

By THE EDITOR

IN America tuning-fork oscillators have not received the popular attention they deserve, although many foreign investigators believe that tuning forks can be more stable than quartz plates and bars. We feel that there is a field of usefulness for the tuning fork which should not be overlooked.

All of the illustrations for Mr. Lamson's article are from typical tuning forks which have been built and operated in the laboratories of the General Radio Company.

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The Frequency Stability of Piezo-Electric Monitors

By James K. Clapp*

> ". . . The variations of the crystal-controlled transmitter are in general much less than those of the usual tuned-circuit master oscillator, but under extreme conditions the variations may be as great. It is a disappointing, but nevertheless true conclusion that implicit faith in 'crystal control' as the answer to every problem of frequency stability must give way to a modified view which will necessarily involve the application of more complex methods." — From the accompanying article.

The increasing demand for accurate maintenance of radio transmitters upon their assigned frequency is bringing to light the variations of frequency of the crystal-controlled master oscillators which are being more and more widely used to attain the desired stability. Where a piezo-electric oscillator is used as the master oscillator, economy of apparatus dictates that the oscillator be operated at as high a power level as possible in order to reduce the number of amplifier stages required to reach a given level for transmitter output.

Unfortunately, a piezo-electric oscillator so operated loses many of its most desirable characteristics as a constant-frequency device. Under powerful oscillation, heating in the quartz plate may be pronounced. This heating varies with any changes in the load imposed on the piezo-electric oscillator by the succeeding equipment, resulting in a frequency shift due to temperature change indirectly caused by these load changes. In some cases improper design for the plate-holder, or undue forcing of the oscillator, results in a pronounced brush discharge in the air gap resulting in further variations in the master oscillator frequency.

In spite of the undesired frequency changes in the master oscillator over long intervals of time, it is often found that the frequency may be held substantially constant for relatively short intervals. As the frequency of the system is adjustable by several means, among them circuit adjustment and temperature of the plate, it is possible

* Engineer, General Radio Company.

to bring the transmitter frequency into agreement with the frequency of a sub-standard† maintained for the purpose, and this agreement will then be maintained for a considerable period. The variations of the crystal-controlled transmitter are in general much less than those of the usual tuned-circuit master oscillator, but under extreme conditions the variations may be as great. It is a disappointing, but nevertheless true conclusion that implicit faith in "crystal control" as the answer to every problem of frequency stability must give way to a modified view which will necessarily involve the application of more complex methods.

With only reasonable care in operation, a piezo-electric oscillator may be depended upon to maintain its frequency to a degree of precision exceeding present requirements *provided the power level is kept low and the temperature of the quartz plate is kept constant.* If such an oscillator is then set up as a sub-standard and used as a monitor, the crystal-controlled transmitter frequency may be periodically brought back to its assigned value with a comparatively high degree of precision. As the frequency drift of the transmitter is not rapid after it has been in operation long enough to reach steady conditions, only an occasional check-up would be necessary to hold the transmitter frequency within rather close operating limits.

If an operating tolerance of ± 50 cps. is to be maintained, it is of course necessary that the sub-standard piezo-electric oscillator hold its frequency to within a much smaller tolerance, say ± 10 cps. This requirement demands careful temperature control, circuit stability, and low energy level.

In order to determine the frequency stability that can be obtained from a monitor consisting of a stock model piezo-electric oscillator using temperature control and commercially obtainable quartz plates, a thorough study of a typical system is being made by the author in the laboratories of the General Radio Company. Representative broadcast-frequency quartz plates are being studied and the variations in frequency resulting from all the possible influences recorded. The principal factors are:

1. Changes in any of the circuit elements due to age.
2. Replacement of tubes.
3. Mechanical vibrations of the system.
4. Variations in temperature.
5. Variations due to change of plate-circuit load.
6. Variations due to changes in supply voltages.

Of these the largest variations in frequency result from mechanical vibrations of the system, variations in plate load, changes in temperature, and changes in tubes. Of these, with a given system, the operator may largely control the effects of load and tubes. The effect of mechanical vibrations must particularly be reduced by the manufacturer of the system, and the temperature control must be developed by him to maintain substantially constant temperature under ordinary room temperatures and for long periods of time.

In the November issue the experimental results will be presented with particular reference to the causes of frequency variation outlined above.

† Sub-standard is here used in its commonly accepted sense. It is a descriptive term applied to a constant-frequency oscillator, the frequency of which is determined by comparison with a primary standard of frequency.

A primary standard of frequency is one in which the frequency is determined directly in terms of the mean solar second. See, for example, S. C. Hooper, "The Hague Conference," *Proceedings of the I. R. E.*, Vol. 18, No. 5, May 1930, 769.

SYNCHRONOUS MOTOR-DRIVEN CLOCKS

By HAROLD S. WILKINS *

TODAY a remarkably wide field of usefulness is being developed for small synchronous motors. These motors until comparatively recently were regarded perhaps as a curiosity. Now they are available in a wide range of power outputs and can be designed to run at speeds of from a few revolutions a second to several hundred, and on circuits of from 25 cps.† to perhaps 10,000 cps.

Consider for example the increasingly large numbers of electrically operated clocks that are being sold each year. The majority of these are operated by small synchronous motors, some of only a few thousandths of a horse-power, yet they run continuously and dependably. Various modifications in design have been developed, including wound, polarized, and shaded poles.

The simplest type may be represented by a laminated rotor of magnetic material having salient poles properly journaled between one or more pairs of stator poles, the number and size being determined by the frequency, power, and speed characteristics desired. The mechanism of operation in its simplest form may be regarded as a succession of equally spaced magnetic impulses, each one attracting in turn a corresponding rotor pole. When by some means the rotor is brought up to synchronous speed, the magnetic center line of rotor and stator poles coincide in succession at approximately the instant of maximum current and the motor continues to run.‡ The design is such that the reluctance of the magnetic path increases rapidly as the angular displacement of the center lines increases and a positive torque results. Varying power demands cause a variation in lag of rotor tooth behind stator tooth, resulting in an equivalent variation in the input power, making it possible for the rotor to carry varying loads while maintaining synchronous speed. This lag can never be greater than one-half the angular separation between two rotor teeth, which corresponds to 90 electrical degrees.

There is of course no accelerating torque in a synchronous motor of this simple type, which means that the motor must be brought up to synchronous speed by hand. It also means

FIGURE 1. The standard Model B Syncro-Clock enclosed in walnut cabinet

* Engineer, General Radio Company.

† cps., hereafter used to mean "cycles per second."

‡ Note that the magnetic pull between a rotor pole and a stator pole is independent of the *direction* of the current.

that if the system is overloaded or if the power supply fails even momentarily, the motor will stop. While the absence of an accelerating torque may be considered a disadvantage in a clock for domestic use, its absence is a decided advantage for many laboratory purposes. This point will be explained later.

Because such a motor runs in absolute synchronism, it may be considered to be a counter of vibrations. Every pair of poles that passes a given point represents a cycle, or, if the input circuit is properly biased, every pole represents a cycle. To illustrate this, consider Figure 2. In this figure the lower curve shows the original sinusoidal input current. The magnetic field varies similarly but the attraction between rotor and stator teeth will always be positive. If now the negative half of the wave is biased by an opposite current to reduce it practically to zero, a new current curve and magnetic field will be produced as indicated by the upper curve in this figure. The horizontal line represents the biasing current and the new alternating current is indicated by the top curve. It is readily seen that the magnetic field strength is increased and the frequency halved, making it possible to halve the operating speed, reduce the losses, and increase the power.

Fundamentally the motor operates as a tachometer counting every cycle, and when referred to time becomes a measure of frequency. This device, when referred to time indicates frequency, and, conversely, when referred

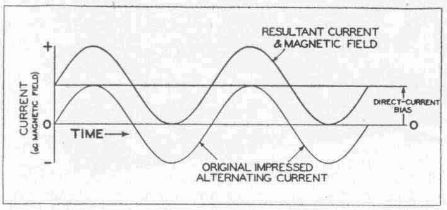

FIGURE 2

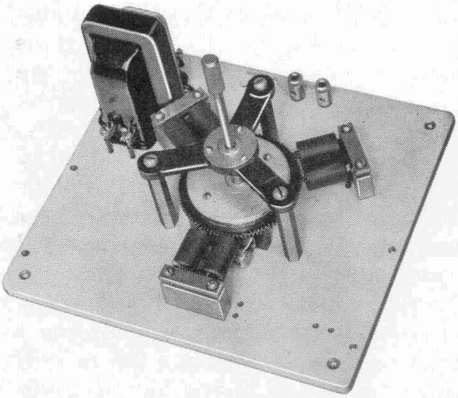

FIGURE 3. The motor assembly which may be employed to drive discs, contactors, and small generators

to a standard frequency, indicates time. Obviously the gearing of a clock dial to the motor offers the user a dual-purpose instrument. A third use is immediately apparent — controlled shaft speeds.

Nearly ten years ago the General Radio Company started to develop a synchronous-motor-operated clock. The first model * answered the purpose at that time, but the wide range of possible uses and demands for greater power output required a design markedly different. After considerable study and numerous experiments the TYPE 511 Syncro-Clock was developed to replace the old model.

Briefly, the rotor consists of a carefully milled laminated iron ring mounted on an aluminum damping disc, the shaft rotating in a jewel bearing and guided by a ball bearing. Power is supplied through three pairs of poles located 120° apart and having milled teeth corresponding to those on the rotor.

A decimal system of shaft speeds has been selected to better increase the adaptability of the motor and clock.

* The TYPE 411 Synchronous Motor, now obsolete, having been replaced by the TYPE 511 Syncro-Clock.

The rotor shaft speed is 10 revolutions per second and the secondary shaft is geared to rotate once a second, the final gearing being such that the clock keeps correct time at rated frequency. One thousand cps. is now generally available in the laboratory and the standard motor has a 100-tooth rotor which runs at 10 revolutions per second on properly biased 1000-cps. circuits.

As an indication of synchronism, a small neon glow tube is mounted under the edge of the rotor. This is lighted from the input circuit and at synchronism the stroboscopic effect causes the rotor teeth to appear stationary. Proper voltage to the tube is regulated by a transformer included with the motor assembly. A switch for controlling the lamp is also provided.

If the natural period of torsional vibration of the rotor is near the natural frequency of the circuit, hunting may become quite serious. This may be greatly reduced by proper design. To minimize hunting and to make starting easier, the damping disc has been developed. The rotating parts have been made as light as possible. To secure a relatively high moment of inertia, weight is provided by the addition of mercury. Due to its mobile nature if in hunting or due to change of load there is a phase shift, synchronism is easily maintained by the immediate shifting of the light rotor. Hunting or periodic vibrations are rapidly damped out by the energy given up or absorbed by the mercury. The mercury is sealed in the damping disc and baffled to increase the friction resulting in any change of speed between the disc and the mercury.

We have already mentioned that the stopping of the clock results after even momentary failures of the power-supply circuit and that this is an advantage for many laboratory purposes. When, for instance, one is using the clock to count the number of oscillations executed by a constant-frequency oscillator for comparison with time determined by some other system, it is important that the clock run in synchronism or else not at all, especially when one is making measurements of extremely high precision. It is highly desirable that any momentary perturbation of the circuit be made known at once, if erroneous results are to be avoided.

The motor is normally operated at from 100 to 125 volts at a frequency of 1000 cps. and biased with from 40 to 50 milliamperes of direct current. The rotor is brought up to speed by turning the knurled knob between the fingers until stroboscopic effect indicates synchronism. In many cases the clock will "pull in" itself if turned faster and then allowed to drift down to speed. The output of two 171-A-type tubes operated in parallel with sufficient amplification to bring the voltage up to

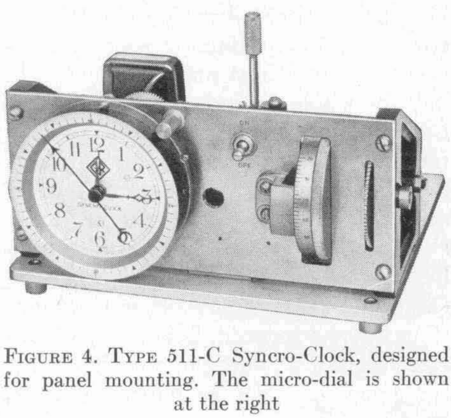

Figure 4. Type 511-C Syncro-Clock, designed for panel mounting. The micro-dial is shown at the right

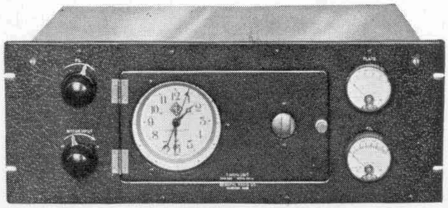

Figure 5. The clock and an amplifier may be assembled in one unit and used for relay-rack mounting

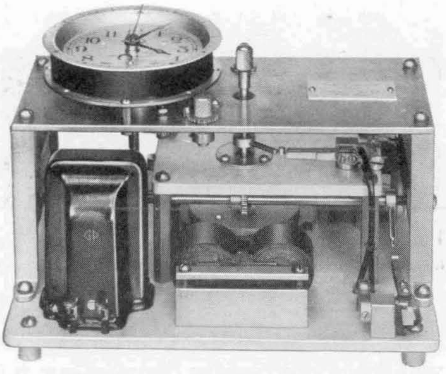

FIGURE 6. This clock designed to run on 60-cycle circuit has both a seconds and 0.1 second contactor

rated figure is recommended for general operating conditions. The direct current in the plate circuit must be allowed to flow through the motor windings. Supplied from such a source the starting is easy, operation is dependable, and satisfactory results are assured. Unless operating under very heavy loads one tube may burn out or tubes may be replaced or changed one at a time without stopping the motor.

The motor of course will run on widely different supply frequencies but standard shaft speeds are obtained only at rated frequencies. Experimentally a 1000-cps. motor has been satisfactorily operated on all frequencies between 250 cps. and 1750 cps. Of course for special purposes rotors can be designed to give standard shaft speeds on any source of from 60 cps. to 5000 cps. In such cases the number of teeth cut in the rotor is changed to meet conditions. The clock movement itself is a standard arrangement of gears to give hours, minutes, and seconds, but for convenience a separate scale graduated in seconds has been added on the outside diameter of the dial. The second hand may be adjusted by half seconds by means of a knob located just outside the dial and controlling an epicyclic gear train by means of which the seconds shaft can be rotated in either direction without interfering with the motor. A spring lock prevents motion of these gears except when manually operated.

The Syncro-Clock, used as a frequency meter, will give an accuracy of better than one part in 100,000 during a 24-hour interval by reading of the seconds hand. To increase this precision the micro-dial attachment makes it possible to check the clock by reference to Arlington Time Signals to within approximately 0.01 second. This makes possible a precision approaching one part in 10,000,000 for a 24-hour interval.

The operation of the micro-dial is quite simple. A revolving arm or cam on the seconds shaft of the clock closes a contact for a period just greater than the duration of the time signal. This point of closing may be made to occur at any point in a complete revolution by rotating the outer drum member. The signals are received by the phones and the dial is adjusted so that only the "nose" of the signal is heard. The difference of dial readings between successive periods indicates the change from true time. When operated on a standard frequency the micro-dial may be used to send seconds impulses and by means of a secondary program wheel almost any series of accurately spaced groups of signals may be obtained. The clock under this condition becomes a time piece having the accuracy of the frequency source. Contactors giving short pulses every tenth, half, or whole second can easily be attached and from these many secondary measurements may be made with surprising accuracy. By combining a seconds and a minutes contactor a very short and accurate minutes pulse may be secured. By choosing appropriate cams and gears many other combinations can be secured. Magneto generators offering a source of relatively low frequency of good waveform of from one to 100 cps. can be designed for operation with the clocks. In every case the precision with which the resulting frequencies and time intervals are known is essentially the same as the precision of the supply source. When a Syncro-Clock is operated from a General Radio standard-frequency assembly, for example, a precision of approximately one part in 1,000,000 may be expected.

To review briefly, the synchronous motor-driven clock may be used as a frequency meter, a standard clock, a sending device of time signals, a generator of impulses or low frequencies, and a constant-speed motor. Impulses are often employed to give a record on tapes or films and the motor may be used as a drive for stroboscopic work. In fact the uses are too varied to enumerate completely and it is hoped these comments will serve as a basis to suggest other applications.

The greater power of the new Type 511 Syncro-Clock Motor makes it possible to drive a large number of auxiliary attachments. Figure 7 shows a Syncro-Clock which has a micro-dial reading directly to 0.001 seconds. The hand at the right revolves once a second and under this may be seen the two magneto generator discs designed to give frequencies of 30 and 35 cps. The two adjustable contactors in the lower left corner make and break the circuit one and ten times a second respectively

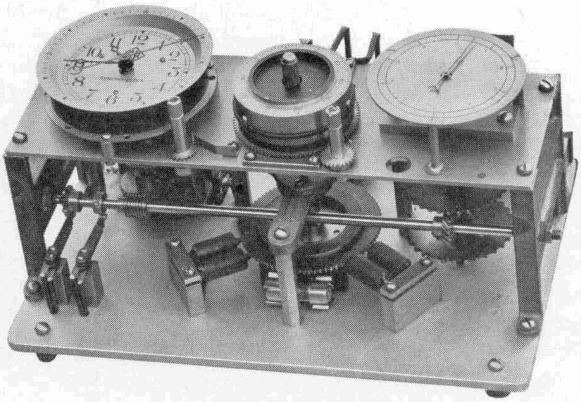

Figure 7

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The Frequency Stability of Piezo-Electric Monitors

By James K. Clapp*

II

THE performance characteristics of a typical temperature-controlled piezo-electric oscillator will be considered with regard to the various factors listed in the first part of this article,† i.e., (1) temperature changes, (2) plate load, (3) tubes, (4) vibration, (5) supply voltages, (6) aging of circuit elements.

The data here presented cover the performance of the equipment when using typical quartz plates operating at frequencies in the broadcast band of from 500 to 1500 kc.‡ The quartz plates were of the "30-degree" or "Y"-cut and were mounted in General Radio Type 376 Quartz-Plate Holders. The quartz plates and holders correspond to the production units classed as the Type 376-H Quartz Plates.

The changes in frequency, as observed, were referred to the frequency obtained when the assembly was operated under the conditions defined by:

"*Normal*" *operation*

Tube: Average UX-112A as determined by trial.

Temperature: 50° C.

Plate condenser: Set at lowest value for reliable oscillation.

Supply voltages: Filament 5.0 volts.
Plate 45.0 volts.

The observed frequency changes resulting from changes in any one variable, the others remaining constant, are indicated in the accompanying figures and are summarized below:

Temperature changes: (Figure 1)

The quartz plates employed were all of the "30-degree" or "Y"-cut type, having positive temperature coefficients, that is, the frequency of oscillation *increases* when the temperature of the plate is *increased*. The various plates did not differ widely in their temperature coefficients as indicated by the slopes of the curves of Figure 1. On the average, it should be noted from Figure 1, the variation in frequency for changes in temperature of ±0.1° C. (representing the control stability of a small temperature-con-

* Engineer, General Radio Company.

† James K. Clapp, "The Frequency Stability of Piezo-Electric Monitors," *General Radio Experimenter*, V, October, 1930.

‡ Kc. is here used to mean kilocycles per second.

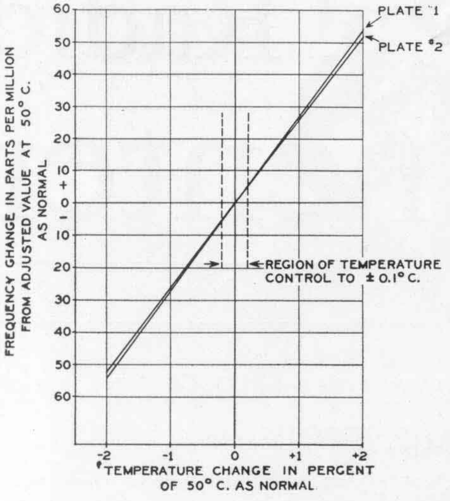

FIGURE 1. Variation in frequency of piezo-electric oscillator as function of temperature in region near 50° C.

trol unit of simple design) is within ±5 parts per million.

Plate-tuning changes: (Figure 2)

Other factors remaining constant, the frequency of oscillation is altered by changes in the tuning of the plate circuit of the tube. In the oscillator here employed (General Radio TYPE 575 Piezo-Electric Oscillator) the plate inductance is fixed and the capacitance is variable. The variations are plotted against per cent. of the higher value at which the system stops oscillating, which is practically the value at which the plate circuit is resonant to the crystal frequency. The frequency change resulting from the change of tuning capacitance is seen to be much more rapid as resonance is approached, that is, for the higher values of capacitance. As the driving tube circuits are not under temperature control in this case, it is desirable to operate the plate circuit in a manner to minimize the changes in frequency with any given change in the tuned circuit. For this reason, the assembly should always be operated with only enough capacitance to give reliable oscillation.

From the figure, it is seen that variations in the tuning capacitance of ±1.0 per cent. (resulting from arbitrary alteration of the condenser, or from aging or temperature effects) cause frequency changes of less than ±1 part per million.

Plate-voltage changes: (Figure 3)

Other factors remaining constant, changes in plate voltage produce the frequency changes shown in Figure 3. It is evident that minor changes in plate voltage produce very small changes in frequency. Within the region of ±1.0 volt from the normal of 45 volts, which is easily read on a small voltmeter, the frequency change is less than ±0.5 part per million. This change is not materially influenced by the setting chosen for the plate-tuning condenser.

Filament-voltage changes: (Figure 4)

Changes of filament voltage produce the changes in frequency shown in Figure 4. In this case, the frequency variation obtained depends upon the setting of the plate-tuning condenser to

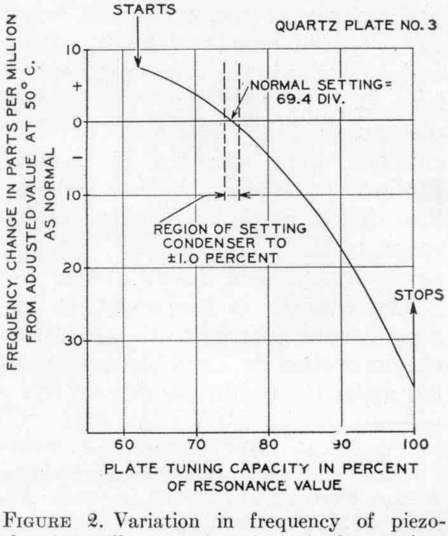

FIGURE 2. Variation in frequency of piezo-electric oscillator as function of plate-tuning capacitance

some extent, but in the normal voltage region, the variations thus obtained are of no serious consequence. Within the region of ±0.1 volt from the normal of 5.0 volts (which is easily read on a small voltmeter) the frequency change is substantially less than ±0.5 part per million for all useful operating conditions in the plate circuit.

Tube changes: (Figure 5)

Changing tubes, each being operated under the "normal" conditions, results in frequency changes as shown in Figure 5. It is seen that four out of five tubes operate to give a frequency within ±2 parts per million of the value obtained with Tube No. 1.

Vibration

Ordinary vibration of buildings does not materially alter the frequency of the system. A violent pounding of the base of the assembly sometimes produces a momentary shift of frequency as great as 10 parts per million, but the shift remaining after the pounding is stopped is usually much less than this value. In the tests, the plate-holder was plugged into jacks rigidly mounted on the walls of the temperature-control unit, which in turn was rigidly mounted on the supporting base. In cases where unusual vibration exists, the frequency

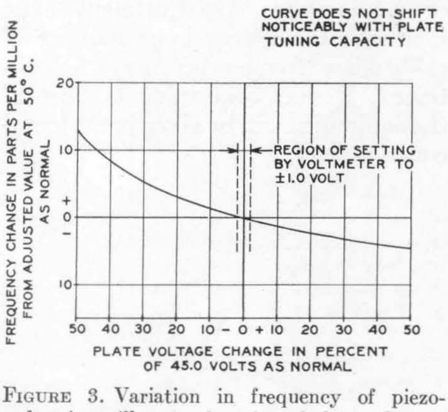

Figure 3. Variation in frequency of piezo-electric oscillator as function of plate voltage

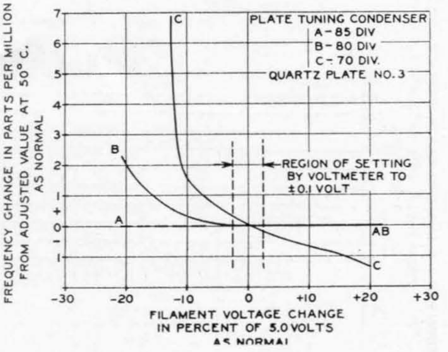

Figure 4. Variation in frequency of piezo-electric oscillator as function of filament voltage

shifts may be reduced greatly by supporting the plate-holder in soft batting, making the connections through small flexible leads, instead of through the plugs and jacks.

Summary of All Effects

As an estimate of the absolute constancy of frequency of the system described, it may be assumed that all of the variations observed take place and that the effects are all in the same direction. Then we have the following summary:

Variable	*Range of Variation*	*Frequency Variation (parts per million)*
Temperature	±0.1°C.	±5
Plate capacity	±1.0 per cent.	±1
Plate voltage	±1.0 volt	±0.5
Filament voltage	±0.1 volt	±0.5
Tubes	(average)	±2
Vibration	(heavy shocks)	±3*
	Total	±12

* Remaining after shock.

This represents the range of frequency within which the type of oscillator considered would be expected to operate under practical service conditions. There is every reason to expect some of these effects to offset others under average conditions, even if the variables are altered by the full range indicated. If the variables are not al-

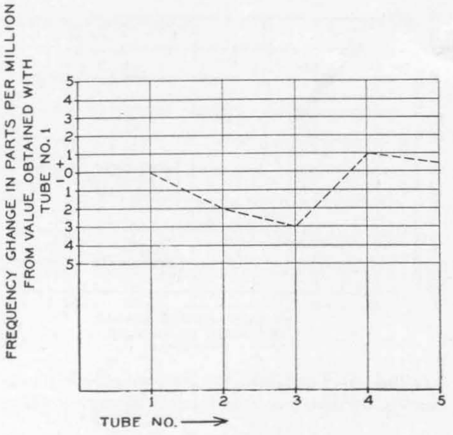

FIGURE 5. Variation in frequency of piezo-electric oscillator for different tubes, each operated under "normal" conditions

tered by the full range indicated, the frequency variation would naturally be reduced. All things considered, it seems reasonable to expect the frequency variations under service conditions to be less than ±10 parts per million. It should be borne in mind that the above conclusions are based entirely upon the premise that the oscillator system is operated at a *low power level* and that it is employed *only as a substandard or a heterodyne monitor*, that is, it is operated with such weak coupling to any associated apparatus that the effects of such equipment on the performance of the oscillator are entirely negligible. The conclusions refer only to the *variation* in frequency from the *adjusted value* and have no bearing on the accuracy of adjustment to a specified frequency.

It is believed that the effects of aging of any of the circuit elements, with the exception of the quartz plate and holder, can result only in changes of frequency of the order of magnitude encountered when arbitrary changes are made in these elements. Aging of the quartz-plate holder introduces, in the type of holder here used, very small changes in frequency which for the purposes under consideration are negligible. There seems to be little evidence that any aging effect takes place in the quartz plate itself. Changes in frequency which are often laid to this cause are undoubtedly due to changes in the plate-holder and not to changes in the quartz plate.

The combined piezo-electric oscillator and temperature-control unit (TYPE 575) used in this work is very well adapted for use as a simple laboratory standard. For such uses, it is convenient to employ a 100-kc. quartz plate. As these plates give somewhat different performance than plates in the broadcast-frequency range, data pertaining to them will be presented in a later article. Harmonics of the crystal frequency are available for calibration or monitoring purposes over a wide frequency range. In cases where it is desired to obtain calibration frequencies at intervals of less than 100 kc., use may be made of a multivibrator (such as the TYPE 592) of lower fundamental frequency, controlled by the 100-kc. crystal oscillator. By adjustment of the multivibrator a very large number of calibration frequencies may be obtained. Details concerning the use of the equipment will be given in the forthcoming article.

A STROBOSCOPIC FREQUENCY METER

By L. B. ARGUIMBAU*

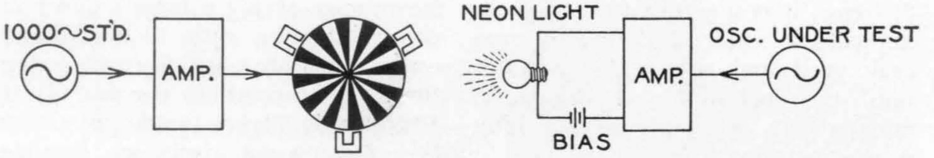

FIGURE 1

AT the time the range of the General Radio low-frequency oscillator was extended to 25 cps.,† the need for more accurate and convenient methods of measuring audio frequencies made itself felt. After some consideration of other methods,‡ it was decided to arrange for the stroboscopic comparison of unknown frequencies with a single primary standard. The method has proven so convenient that we believe a description of the details may be of interest.

In a previous issue of the *General Radio Experimenter* § a description was given of synchronous motors which can be driven by 60-cps. and by 1000-cps. signals. A motor of this type provides a shaft whose speed is determined exactly by the driving frequency. Thus, by its use a disc can be obtained whose angular speed is known with the precision of the source frequency.

It is well known that if any such rotating disc is illuminated solely by a light which flashes once every rotation, the disc will appear stationary, for the images received by the eye all correspond to one position. Similarly, if the wheel has n spokes spaced uniformly and is illuminated n times every revolution, it will again appear to stand still, since in this second case the images will all be seen when the spokes are in similar positions. An extension of this argument will show that a wheel of n spokes illuminated with a lamp flashing (a x n) times during each revolution will appear like a wheel having (a x n) spokes (where a is any integer). Similarly, if the lamp flashes n/b times per revolution (b is an integer), the wheel will still appear to have n spokes. In fact, if the light flashes any rational number a/b times per spoke period, the wheel will appear to have (a x n) spokes.‖ A brief consideration will show that if the frequency of the light flash differs from $k\left(\frac{na}{b}\right)$ by $1/b$ cps., the (a x n) spoked pattern will appear to revolve at a rate of one spoke per second, where k is the speed of the wheel in revolutions per second.

Having these well known facts in mind, an obvious method of frequency adjustment presents itself, namely, the comparison of a lamp driven by an

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* Engineering Department, General Radio Company.

† Cps. is here used to mean cycles per second.

‡ E.g., the use of calibrated tuned circuits and reeds, and Braun tube or string oscillograph comparisons with low frequencies derived from a primary standard.

§ Harold S. Wilkins, "Synchronous Motor-Driven Clocks," *General Radio Experimenter*, V, October, 1930.

‖ Provided, of course, that there is sufficient contrast to make the partially overlapping fringes visible. Practically this requires that a and b be small integers. Under favorable conditions a may be as high as 5, b as high as 10.

unknown source with an appropriate disc. For example, if a disc rotating at 10 revolutions per second is available and it is desired to set an oscillator at 300 cps., it is merely necessary to illuminate a wheel of 30 spokes once each cycle and adjust the oscillator until the spokes appear stationary. Such a flashing light can be readily secured by using a neon lamp biased so that it flashes only during a very small part of a half-cycle. A suitable arrangement for realizing the above condition is shown in Figure 1.

In our case it has been found most convenient to use the 1000-cycle output of a General Radio standard-frequency assembly * as a primary standard. Occasionally, however, other standard sources have been used.† Instead of using a spoked wheel several graduated discs have been made up each answering a specific frequency requirement. Two such discs (reduced in size) are shown in Figure 2. It will be noted that disc *A* covers a very wide range of frequencies, giving a large number of points. Starting with 10 cps. direct comparisons are possible (with a disc turning 10 revolutions per second) at 10-cps. intervals up to 100 cps. After this, direct comparisons are possible every 100 cps. up to 1000 cps., and then (with the exception of 1500 cps.) every 500 cps. up to 5000 cps. In addition to these fundamental points, all low rational fractions of these frequencies are available. Thus we have patterns for every 5 cps. up to 50 cps. and every 20 cps. from 100 cps. to 200 cps., etc.; likewise, all even kilocycle points up to 10 kc. are available. As a matter of fact, it is frequently more convenient to use such multiple patterns than it is to use the fundamentals. For example, when the lamp is lighted from a 60-cps. line, the 300-cps. pattern is immediately noticed, as well as the 60-cps. pattern; rotation of one spot in ten seconds for the 300-cps. pattern indicates a departure of 0.02 cps. or 1/30 of 1 per cent. in the line frequency. Disc B has been found very convenient for use in calibrating low-

* James K. Clapp, "Frequency Determination," *General Radio Experimenter*, Vol. 3, March, 1929; "A New Frequency Standard," *General Radio Experimenter*, Vol. 3, April, 1929. See also L. M. Hull and J. K. Clapp, "A Convenient Method for Referring Secondary Frequency Standards to a Standard Time Interval," *Proceedings of the I. R. E.*, Vol. 17, February, 1929.

† Horatio W. Lamson, "Electrically-Driven Tuning Forks," *General Radio Experimenter*, V, September, 1930.

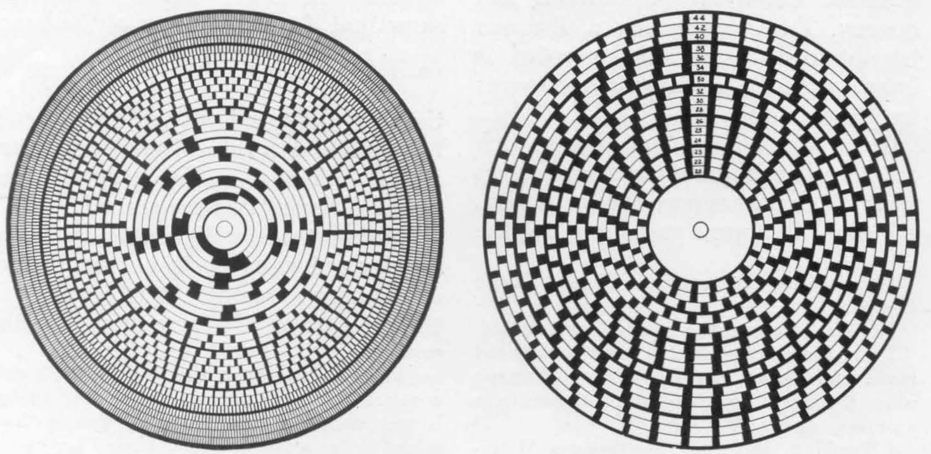

FIGURE 2. Typical 8-inch discs used with the frequency meter. Disc A (left) is for general use over the entire audio-frequency spectrum; Disc B (right) is very useful at commercial frequencies

frequency tuning forks since a large number of such multiples are present. By its use in conjunction with a stop watch, any preassigned frequency in a restricted commercial range can be measured directly in terms of the primary 1000-cps. standard.

In addition to these discs, all of which operate on reflected light, a few have been made for use with transmitted light. Several factors, such as the relative size of the absorbing and reflecting sectors, the use of reflected or transmitted light, the effect of motor "hunting" and of disc irregularities, and the duration of the light flash had to be considered in design, but are hardly of sufficient interest to be mentioned here.

Several stroboscopic frequency meters have been built for experimental use in the General Radio laboratories.

Figure 3. This synchronous motor is portable and connected to subsidiary amplifier circuits by a flexible cable. The disc makes use of transmitted light

The first model which is in service in the calibration laboratory includes self-contained amplifier circuits and is intended for operation on a laboratory work bench. Another, also with self-contained amplifier, has been mounted on a castered table so that it can be used wherever needed.

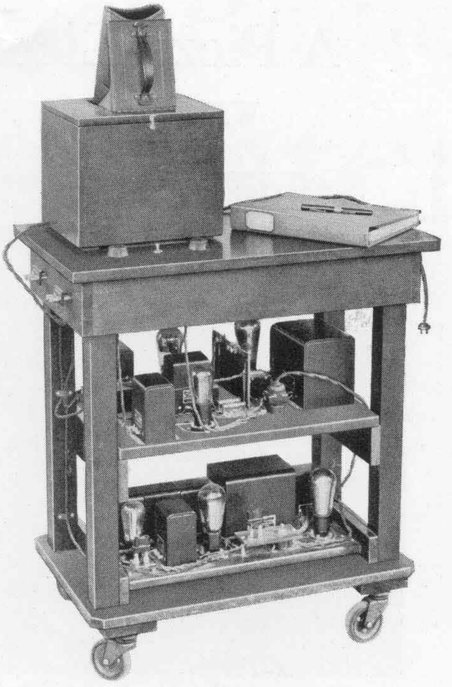

Figure 4. An experimental model of the stroboscopic frequency meter. Amplifier and power-supply circuits have been assembled with the synchronous motor on a castered table

In passing, it might be mentioned that a modified stroboscope has recently been built to provide a direct comparison between the primary standard and seconds pulses from a pendulum clock. This is done by watching the change in position of a single reflecting sector between successive seconds flashes.

Thus by the use of a synchronous motor in conjunction with a single standard it is possible to cover the range of audio, commercial, and finally of clock frequencies.

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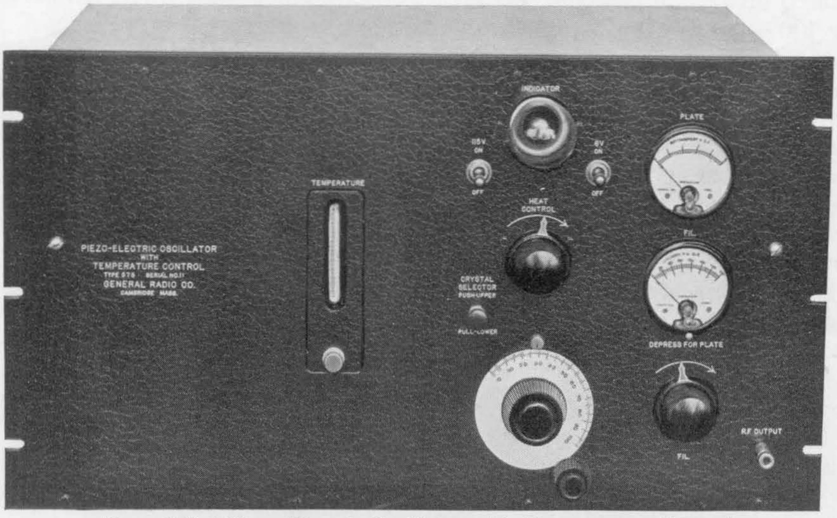
WITH TEMPERATURE CONTROL



TYPE 575-A Piezo-Electric Oscillator with Temperature Control

THE temperature-controlled piezo-electric oscillator used by J. K. Clapp in the work on quartz plates described in this issue of the *Experimenter* is now commercially available. It consists in effect of a TYPE 275 Piezo-Electric Oscillator and a TYPE 547-A Temperature-Control Box assembled on a single panel for relay-rack mounting.

The characteristics of the new instrument are essentially the same as for the two individual instruments which were described on pages 57 to 59 of Catalog F. The assembly in a single unit, however, greatly improves the stability with which frequency can be maintained. Danger from mechanical vibrations has been reduced and essential leads have been materially shortened.

So effective is the new unit that users of General Radio TYPE 376 Quartz Plates and the TYPE 575-A Piezo-Electric Oscillator with Temperature Control may expect to maintain frequency to within about ten parts in a million.

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THE NEW HOME OF THE ENGINEERING DEPARTMENT

By J. W. HORTON*

DATA are at present not available as to the extent to which the deplorable condition of the shoemaker's wife and the blacksmith's horse extends to the laboratories of instrument makers. However, in view of the reports prevalent on such matters the General Radio Company has given special attention to the new laboratory facilities recently made available to its engineering department.

The anniversary issue of the *Experimenter* referred to the new building

* Chief Engineer, General Radio Company.

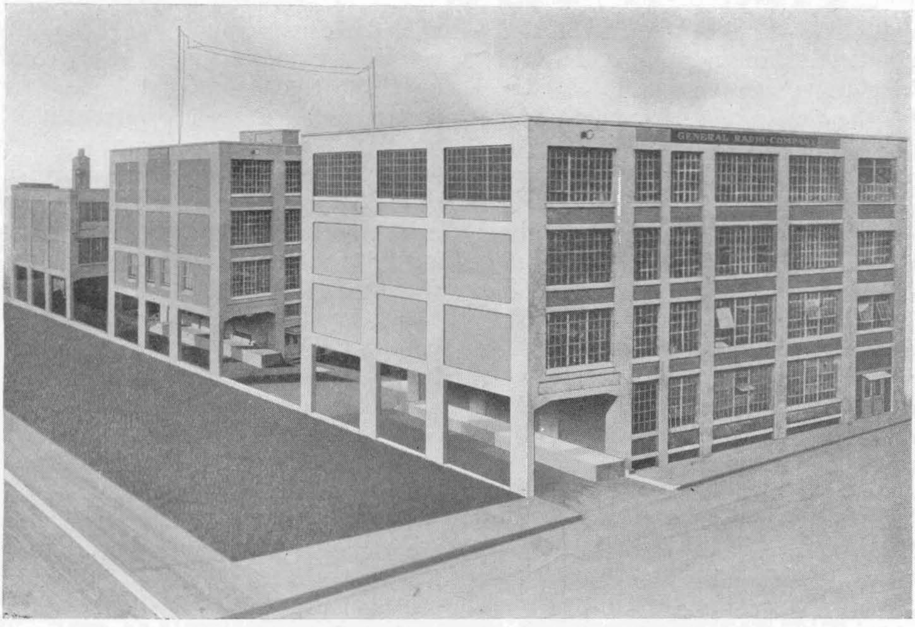

FIGURE 1. The plant of the General Radio Company at Cambridge, Massachusetts. The new laboratories occupy the second and third floors of the right-hand wing

FIGURE 2. A typical laboratory. It will be noted that the power outlets are so located that they may be used conveniently for apparatus on the bench or on the shelf. Each outlet has its own switch and pilot lamp

unit being added to the General Radio plant. The primary purpose of this new building was to provide suitable space for the engineering department which, due to its growth during the last two years, was finding its previous quarters somewhat crowded.

The laboratories in use have been designed with the particular requirements of our organization in mind. The nature of our engineering problems is such that both the technical and the commercial phases may most effectively be followed by a single individual, consequently each engineer's room is, to more than the usual degree, a combined laboratory and office. While convenience and orderliness are highly to be desired in any laboratory, they are especially necessary in one serving this dual rôle.

Beginning with the building itself, considerable pains were taken in planning the construction so that the engineering quarters might be as comfortable as possible. To this end the partitions have been constructed of material having sound-absorbing characteristics and the ceilings have been specially treated to make the rooms as quiet as possible. In addition, the heating system has been arranged to provide ventilation without the necessity of opening the windows, consequently both outside noises, including those from the remainder of the plant, and sounds made within the laboratory are so attenuated that they create little disturbance in the several rooms.

The results of this arrangement are more than gratifying and it is felt that the physical comfort thus provided will amply repay the effort made.

In planning the laboratory facilities,

the combined experience of the engineering department was called into consultation. The resulting arrangement is indicated in the illustrations of Figures 2 and 3. It will be noted that the space beneath the benches is entirely used for organized storage of apparatus which should be preserved or which should be continuously available. The danger of having this space exhibit the characteristic appearance of a back attic or a woodshed is thereby avoided. The cabinet space between the drawer sections is provided for batteries. The bottom shelf is arranged for filament batteries and the top shelf for high-tension batteries, which may be either dry cells or storage cells. Wiring to the batteries is facilitated by setting the benches forward a short distance so that a space is left between the backboard and the wall. This space is crossed by the supports of the benches and hence may be used as a convenient channel for leads when apparatus separated by an appreciable length of bench is to be connected. It has been found that this simple expedient contributes much to avoiding the clutter which so frequently exists when temporary circuits or experimental set-ups are involved.

The desirability of providing a centralized battery was considered. Several proposals were made but none had fewer defects than the simple system of maintaining an adequate supply of charged batteries and a regular routine for renewals. The batteries in each laboratory are inspected daily.

The shelf shown above the laboratory bench is planned to carry apparatus accessory to that on the bench proper. It is particularly convenient for the

FIGURE 3. A laboratory set-up. A study is being made of the performance of a number of tube-driven tuning forks. The relay-rack panel includes a constant-temperature container for housing a precision fork. A stroboscope accurately comparing two frequencies is shown in the foreground

occasional amplifier or oscillator used in conjunction with the experimental set-up on the bench. The height of the shelf has been chosen so that meters placed on it may be read conveniently by an observer working at any part of the bench.

It has been the practice in the General Radio laboratories for some time to mount certain apparatus units on small movable tables known, for obvious reasons, as tea wagons. In most of the laboratories space has been provided under the bench for parking this convenient accessory when not in active use.

As with the construction of the building itself, the reduction to practice of the ideas outlined above has been found to be more than satisfactory. In the time during which the new laboratory has been occupied by the engineering department it has been amply demonstrated that a single room may fill the needs of laboratory, office, or study without having any one rôle encroach on the others.

In addition to the laboratory rooms, which are in general each occupied by two engineers, a number of additional facilities are provided by the new building unit. One room has been set aside for standards. In this room will be kept the primary standards of the General Radio Company with the exception of the master standard of frequency which has quarters of its own. In the standards laboratory are also permanent bridge set-ups of a type which it is not advisable to move about. These will be continuously connected with the necessary auxiliary equipment so that measurements of the primary constants of any piece of equipment may be expedited. The value of such an arrangement to a laboratory engaged in circuit problems is obvious.

The apparatus continuously available in the standards laboratory is

FIGURE 4. The experimental shop. A variety of machine tools are available so that the shop may promptly supply the needs of the most enthusiastic experimenter

supplemented by other units such as oscillators, oscillographs, and the like, which may be readily moved from place to place, as mentioned above, but which are continuously available for use.

The importance of its master standard of frequency to the General Radio Company has become so great that a separate room has been assigned to it. The apparatus which has been in use for some time, and which has been described in the *General Radio Experimenter* and in other publications, is being set up in the new laboratory with certain additions which it is believed will increase still further its already high precision.

The Experimental Shop, which has for some time been a part of the engineering department, has also been provided with new quarters conveniently located to the laboratories. This shop is on the third floor of the new building unit. Figure 4 shows a general view of the arrangement of this division of the engineering department. As many of our readers know, the function of this experimental shop is primarily to facilitate the construction of apparatus needed by the engineers. Experience has shown that it is highly desirable to separate this shop from the regular production units, thus freeing the workmen from any contact with routine production schedules. The men employed in this shop have had long experience in this highly specialized type of work. The intimate contact thus possible between the engineer designing a piece of apparatus and mechanics familiar with the manufacturing processes is of inestimable value.

Figure 5. The engineering library. In addition to the usual library facilities this room provides space for the company's collection of historic apparatus. It also serves as a conference room for the Engineering Department

Uses for Plugs and Jacks in the Laboratory

By A. G. BOUSQUET*

IN the laboratory the space provided under the bench too often becomes the resting place for discarded "breadboards," a procedure which soon proves both unsightly and uneconomical. A satisfactory solution is a "universal breadboard" with possibly a "universal panel" provided with the necessary jacks for plugging in various circuit elements.

Again, the laboratory bench soon becomes cluttered with batteries in various stages of deterioration, if some system does not provide for locating all batteries in a battery compartment and make them available to any part of the laboratory by resort to a simple trunking system.

Distribution systems find many applications. In the laboratory they can be extended to include standard testing frequencies, and unassigned lines can be made available for special trunking purposes. The radio dealer finds a distribution system quite an asset in demonstrating different loud-speakers.

But the "universal breadboard" or the distribution system, to be effectively flexible, must be based on standard plugs and jacks spaced at predetermined intervals. To meet this need the General Radio Company has developed several devices built around the Type 274 Plugs and Jacks. A spacing of ¾ inch has been adopted.

Any number of small condensers, resistors, and inductors when individually mounted on Type 274-M Plugs can be readily paralleled or interchanged. A few examples are given in the photographs on the opposite page. Grid-leak clips, salvaged possibly from an old grid-leak holder, are screwed to the sides of a Type 274-M Plug by two 10–32 flat-head screws ¼ inch long, which replace the setscrews furnished with the plug and make the necessary electrical contact.

The experimenter knows the value of plug-in coils. Why not plug-in variable condensers, meters, rheostats, and even sockets? A Type 410 Rheostat and a Type 368 Variable Air Condenser are shown mounted on Type 274-M plugs. The Type 274-P Basic Plug screws very neatly into the binding posts on the General Radio Type 349 Socket which is designed for the UX-type tube. An extra plug in one of the socket-mounting holes provides a locating mechanism. The Type 438 Socket, designed for the UY-type tube, can be mounted on a bakelite strip fitted with five plugs to adapt it for interchangeability with the Type 349 Socket.

The Type 274 Transformer Mounting Bases increase the flexibility of an amplifier. To change from transformer to resistance coupling or to compare different types of transformers, it is simply necessary to plug in the required coupling device. The Type 274-HP 6-Gang Mounting Base can be used for mounting push-pull transformers and for grounding the transformer case. While the Type 274 Bases are designed primarily to mount General Radio transformers, an extra hole or two will adapt them to any device that may be required. As an example, a resistance-coupling unit is shown in the accompanying photograph. Not only the resistors but even the coupling condenser can be changed quickly to meet circuit requirements.

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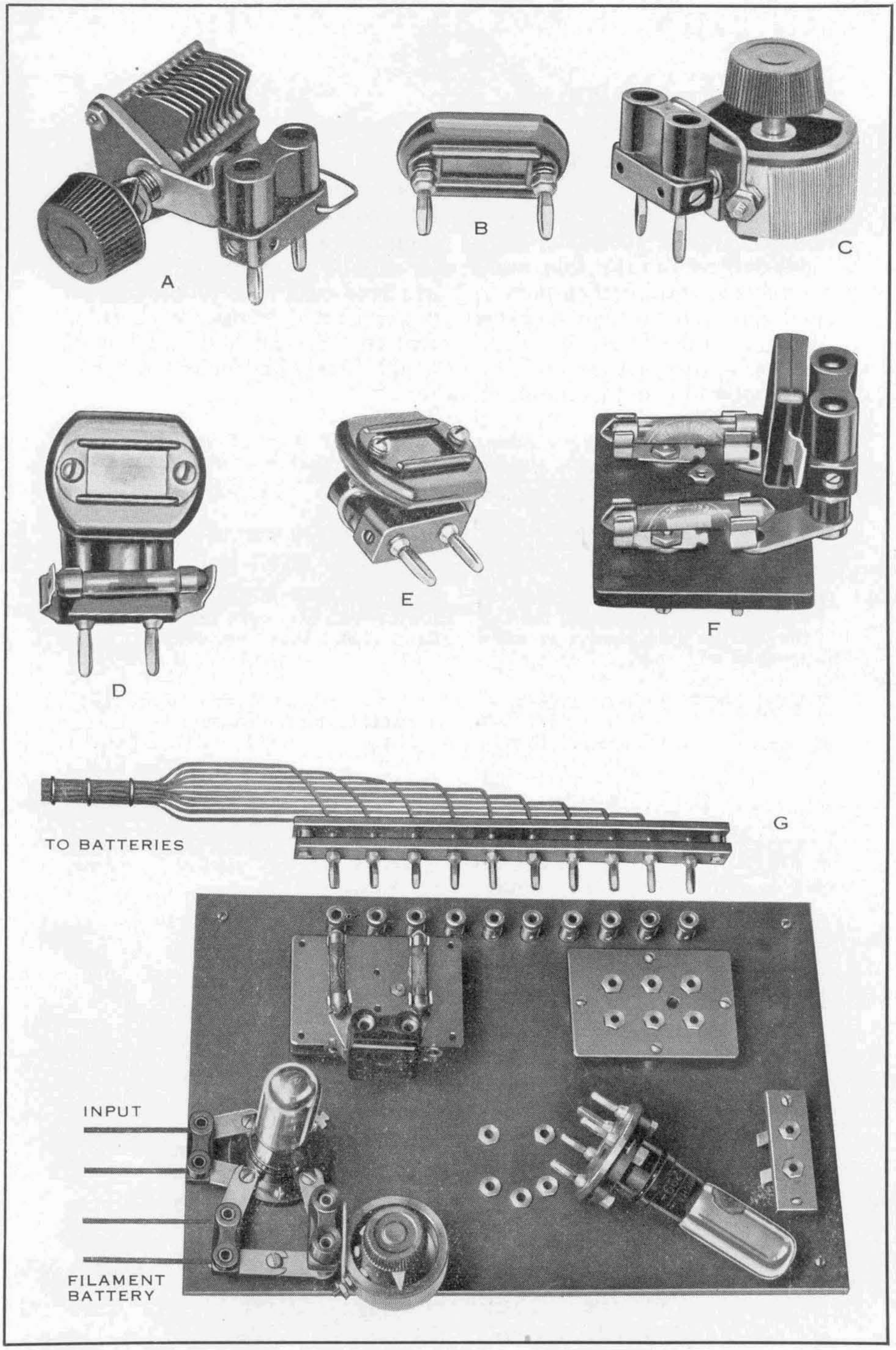
* Engineering Department, General Radio Company.



A few common plug-in circuit components, easily built up from standard Type 274 Plugs, Jacks, and Mounting Bases

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TYPE 277 Inductors. Just the thing for experimental circuits. Identical with TYPE 577 Inductors except for location of mounting pins. A, B, and C sizes.... Regular price $1.00 SALE PRICE **$0.35**
(3 for $1.00)

D¼ and D½ size.... Regular price $1.15 SALE PRICE **$0.40**

TYPE 440-A Filament Transformer. Power rating 70 watts with following voltages available: 2, 3.5, 5, 7.5; all windings separate. Operates from 110-volt, 60-cycle line. Regular price $7.00 SALE PRICE **$3.50**

TYPE 565-A Half-Wave Transformer for 110-volt, 60-cycle line. Power rating 200 watts. Secondary voltages 600, 2.25, and two windings of 7.5 volts each. Corresponding currents 200 mla., 4 amps., and 2.5 amps.... Regular price $13.50 SALE PRICE **$6.50**

	Regular Price	SALE PRICE
TYPE 301 10-ohm Rheostat (without knobs)	$0.80	**$0.20**
TYPE 309 Socket Cushion (sponge rubber)	0.25	**0.05**
TYPE 285 Amplifier Transformers (D, H, and L sizes available)	4.00	**2.00**
TYPE 171-F Switches	0.30	**0.10**
TYPE 587-B Speaker Filter	4.50	**2.50**
TYPE 587-C Speaker Filter	9.00	**4.50**

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