the GENERAL RADIO Experimenter

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PRINTED IN U.S.A.

The General Radio Experimenter

Vol. V, No. 8 JANUARY, 1931

FIELD-INTENSITY MEASUREMENTS

By Robert F. Field *

THE measurement of the intensity of the electromagnetic field produced by a transmitting station at a distant point has been a problem of considerable interest since the earliest radio-telegraphic transmission. In fact every reception of a radio signal constitutes a field-intensity measurement, provided an estimate of the strength of the audio signal is made and the approximate over-all sensitivity of the receiving set is known. These two conditions were, however, the stumbling blocks which until quite recently prevented all but qualitative results.

The earliest measurements of the strength of the received audio signal were made by shunting the head tele-

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Fairchild Aerial Surveys, Inc.

FIGURE 1. Radio field intensity in millivolts per meter from a survey made by Bown and Gillett (see reference [7], page 3) for a transmitter located at 24 Walker Street in lower Manhattan, New York City. We reproduce the photograph with the kind permission of the authors, the American Telephone and Telegraph Company, and the Institute of Radio Engineers

phones, so that the signal was rendered either just intelligible or just audible. From the value of the shunting resistance and the impedance of the telephones, the amount of attenuation introduced could be calculated and thence the strength of the original unattenuated audio signal. This type of measurement depends on the existence of a threshold of audibility. This threshold is, however, a function of the audio frequency heard and of the physical condition of the listener, and varies considerably among different people. Many types of audibility meters were built which conveniently performed this shunting and indicated the ratio of the current producing the full signal to that necessary for the threshold value.

On the other hand, little was known concerning the sensitivity of the receiving set. A large antenna was used to give the maximum radio-frequency voltage. This could not be transported nor duplicated, so that the early field-intensity measurements were confined to the study of the variation of field strengths at one point throughout the day and year. A survey of the variation of field strengths with position around a transmitter was impossible.

The advent of the vacuum tube and its use as amplifier, oscillator, and detector, both non-regenerative and regenerative, greatly widened the scope of field-strength measurements. L. W. Austin[1] in 1917 described a method of measuring the sensitivity of the receiving set. An oscillating vacuum tube produced in a tuned circuit a radio-frequency current which was measured by a thermocouple and galvanometer. To this circuit was coupled the receiving set, whose output was measured with an audibility meter.

[1] L. W. Austin, "The Measurement of Radiotelegraphic Signals with the Oscillating Audion," *Proceedings of the I.R.E.*, Vol. 5, No. 4, August 1917, pp. 239–246.

In the discussion of this paper, C. R. Englund[2] suggested that this sensitivity measurement be made for every field-strength observation, in such a way that the signal introduced into the receiver by the local oscillator produced in the telephones the same response as that obtained from the radio signal being measured. The voltage thus introduced into the receiver, as calculated from the reading of the thermocouple meter and the constants of the circuits, is equal to that similarly introduced from the antenna.

In order to obtain the voltage induced in the antenna by the electromagnetic wave, the constants of the antenna and its coupling to the receiver must be known. It is impossible to introduce the comparison voltage directly into the antenna, thus making the antenna system a part of the receiver, because generally the observer has no control over the transmitter and cannot shut it down when he wishes to make a comparison measurement. G. Vallauri[3] in 1919 described the use of two similar loop antennae, so oriented that one received the radio signal with maximum intensity, while the other was in the null position with reference to this signal, and so could have the comparison signal introduced into it at will.

C. R. Englund[4] in 1922 used a single loop which could be rotated through 90° from the maximum to null position. He used a **T**-section attenuator to control the voltage introduced into the loop instead of the more usual method of varying a mutual inductance. He

[2] C. R. Englund, Discussion on L. W. Austin's Paper, *Proceedings of the I.R.E.*, Vol. 5, No. 4, August 1917, p. 248.

[3] G. Vallauri, "Measurement of the Electromagnetic Field of Waves Received during Transoceanic Radio Transmission," *Proceedings of the I. R. E.*, Vol. 8, No. 4, August 1920, pp. 286–296.

[4] C. R. Englund, "Note on the Measurement of Radio Signals," *Proceedings of the I. R. E.*, Vol. 11, No. 1, February 1923, pp. 26–33.

also used a plate-current meter in the detector-tube circuit, in place of telephones whenever possible. Englund's methods were thus identical with present practice. All of the early measurements were made on long-wave telegraphic transmitters. The dot and dash signals and heavy static interference were the factors that prolonged the use of head telephones and the audibility meter as instruments of comparison.

The advent of broadcasting on the frequency band, 500 kc.[5] to 1500 kc., stimulated the interest in field-intensity measurements and expanded the points at which measurement should be made to a large number scattered over the area around the transmitter and extending outward some hundreds of miles. A portable set built to meet the new conditions imposed by the higher frequencies involved was described by Bown, Englund, and Friis[6] in 1923. The most serious problems were those of shielding the loop from the local oscillator and of building an attenuator whose calibration would hold at a frequency of 1000 kc. The latter consideration caused a reversion to the old antenna practice of introducing the voltage from the local oscillator into the receiving set, that is, placing it across the grid of the first tube. This increased the magnitude of this voltage by the step-up ratio of the loop, perhaps a fifty-fold increase, and by that much reduced the severity of the demands on the attenuator, which took the simple form of a voltage divider.

Surveys of the field around certain transmitting stations in the larger cities followed. Bown and Gillett[7] in 1923 made surveys in New York and Washington. Expressing field strength as the millivolts per meter of height which would be induced in a vertical antenna,[8] they plotted contour lines of equal field strength around the transmitter ranging from 100 to 0.1 millivolts per meter. The shapes of these contours are determined in the densely populated city areas by the location of the tall buildings and in the outlying districts by the topography of the country, especially by river valleys and large water areas. Tall buildings cast shadows and cause rapid attenuation while water courses allow minimum attenuation.

Bown, Martin, and Potter[9] extended the New York City survey and discovered peculiarly shaped contours to the northeast of the city which suggested interference between waves which have traveled by slightly different paths to reach a given point.

Two recent surveys are those by McIlwain and Thompson[10] in Philadel-

[5] *kc.* is here used to mean kilocycles per second and *cps.* to mean cycles per second.

[6] R. Bown, C. R. Englund, H. T. Friis, "Radio Transmission Measurements," *Proceedings of the I. R. E.*, Vol. 11, No. 2, April 1923, pp. 115–152.

[7] R. Bown and G. D. Gillett, "Distribution of Radio Waves from Broadcasting Stations over City Districts," *Proceedings of the I. R. E.*, Vol. 12, No. 4, August 1924, pp. 395–409. A. G. Jensen, "Portable Receiving Sets for Measuring Field Strengths at Broadcasting Frequencies," *Proceedings of the I. R. E.*, Vol. 14, No. 3, June 1926, pp. 333–344.

[8] The relation between a field intensity e, expressed in microvolts per meter, and the total voltage E which it induces in a loop is

$$E = \frac{2\pi f A N}{v} e$$
$$= 2.09 \times 10^{-8} fANe$$
$$= he \quad \text{(microvolts)},$$

where f = frequency in cps.
A = area of loop in square meters
N = number of turns on loop
v = velocity of light in meters per second $= 3 \times 10^8$
h = the equivalent height of loop in meters $= 2.09 \times 10^{-8} fAN$.

[9] R. Bown, D. K. Martin, and R. K. Potter: "Some Studies in Radio Broadcast Transmission," *Proceedings of the I. R. E.*, Vol. 14, No. 1, February 1926, pp. 57–131.

[10] K. McIlwain and W. S. Thompson, "A Radio Field Strength Survey of Philadelphia," *Proceedings of the I. R. E.*, Vol. 16, No. 2, February 1928, pp. 181–192.

phia and by C. M. Jansky, Jr.,[11] in Minneapolis. McIlwain and Thompson made their receiving set into a direct-reading portable field-strength meter by calibrating it in the laboratory and by providing sufficient controls to assure the constancy of this calibration. While their work shows that this is an entirely feasible method, the consensus of opinion at the present time seems to favor the older comparison method. It is much easier to stabilize an oscillator and attenuator with their one thermocouple meter than a multistage radio-frequency amplifier having a voltage gain of a million fold at its maximum. The extra care necessary to insure the constancy of calibration of this multistage receiver certainly balances the time taken by the comparison measurement with the local signal generator, and the latter procedure removes the possibility that a whole day's work will be lost by a change in calibration, discovered only at the end of the day's run.

The survey reported by Jansky covered a greater rural area than the earlier urban surveys and in it is discussed the quality of reception accorded large farming districts in a sparsely settled community. It appears that the field strengths of 5 to 30 millivolts per meter, which are usually considered necessary in urban areas to raise the signal level sufficiently above the high static level (mostly man-made) existing there, are unnecessary for the rural dweller. Artificial interference is much less in the country, and the demands for continuous service are perhaps not as exacting. At any rate, a field strength of 100 microvolts per meter is an acceptable lower level. This report is typical of recent surveys in its emphasis on the economics of broadcasting and on the general principles which must govern the allocation of broadcasting stations in this country.

Edwards and Brown[12] in two recent papers have discussed the coverage in city and suburban areas which may reasonably be expected from transmitters of different power ratings. The latest equipment used by the Radio Division of the United States Department of Commerce is also described. It is a refinement of the sets described by Friis and Bruce[13] and has a frequency range of 200 kc. to 6000 kc. and a field-strength range of 10 microvolts per meter to 4 volts per meter. These large ranges are obtained by introducing into the loop a voltage from the local signal generator large enough to be measured by a vacuum-tube voltmeter and attenuating this large signal in the intermediate-frequency amplifier of the superheterodyne receiver. This transfers the difficulties attendant on the design of an attenuator giving 110 db attenuation at these frequencies to those arising from the design and calibration of a detector which may operate linearly over an equal voltage range. This method is applicable only where the signal generator, attenuator, and receiver are constructed and calibrated as a unit.

The older method, where the signal generator and attenuator are a unit independent of the receiver and indicating instruments, is illustrated schematically in Figure 2. The signal generator produces a radio-frequency

[11] C. M. Jansky, Jr., "Some Studies of Radio Broadcast Coverage in the Middle West," *Proceedings of the I. R. E.*, Vol. 11, No. 10, October 1928, pp. 1356–1367.

[12] S. W. Edwards and J. E. Brown, "The Use of Radio Field Intensities as a Means of Rating the Outputs of Radio Transmitters," *Proceedings of the I. R. E.*, Vol. 16, No. 9, September 1928, pp. 1173–1193. "The Problems Centering about the Measurement of Field Intensity," *Proceedings of the I. R. E.*, Vol. 17, No. 8, August 1929, pp. 1377–1384.

[13] H. T. Friis and E. Bruce, "A Radio Field Strength Measuring System for Frequencies up to Forty Megacycles," *Proceedings of the I. R. E.*, Vol. 14, No. 4, August 1926, pp. 507–519

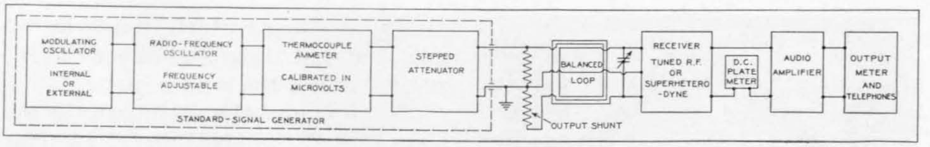

Figure 2. Schematic arrangement of apparatus for measuring radio field intensity by the comparison method described in this article

voltage at the input terminals of the attenuator which is adjusted so that there is introduced into the loop the same voltage as that induced by the incoming signal. The attenuator is set at zero when the incoming signal is observed, with the loop turned for maximum response, while the loop is set at its null with respect to the incoming signal when the local signal is used. The attenuator may be shunted, if the resistance which it introduces into the loop is comparable to that of the loop, thereby increasing the selectivity and sensitivity of the receiver. This shunt is usually so chosen as to decrease the resistance of the attenuator and also the induced voltage by a power of ten. It should have a balancing resistance if the loop is balanced. The receiver may have either a multiple-stage radio-frequency amplifier, or a detector, oscillator, and intermediate-frequency amplifier. Its low-frequency detector is used as an uncalibrated vacuum-tube voltmeter. The direct-current meter in the plate circuit of this detector indicates by the equality of its deflections when the local signal has been made equal to the incoming signal. Its reading is independent of whether the carrier is modulated or not, except as the modulation affects the output of the transmitter. Thus, field-intensity measurements may be made at any time that the transmitter is operating without interruption of its regular schedule.

Some audio amplification is usually added to make easy the finding and identifying of any incoming signal with head telephones. With an output meter replacing the head telephones, the response produced by a modulated radio signal may be observed. The variations in the fractional modulation of the transmitter may be observed qualitatively. When the field strength produced by any two transmitters has been measured in the manner just described, using the direct-current meter, the audio-frequency responses produced by their modulations may be compared by noting the corresponding deflections produced on the output meter and correcting for any difference in field strength between the two stations. These readings indicate the degree to which these stations utilize their respective carriers.

If the signal generator can be modulated, the fractional modulation of the incoming signal may be estimated. A field-strength measurement is made and the attenuator set to give equality of carriers of local and incoming signal. The fractional modulation of the signal generator is then varied until equal response is indicated on the output meter for the local and incoming signal.

The following equipment is necessary for making field-strength measurements by the method schematically illustrated in Figure 2. A Type 403-C Standard-Signal Generator[14] with 400 cps. internal modulation and self-contained attenuator feeds a balanced loop through a Type 403-P10 Output Shunt, which shunts the attenuator to one-tenth its normal resistance and inserts one ohm into each side of the

[14] Charles T. Burke, "The Standard-Signal Method of Measuring Receiver Characteristics," *General Radio Experimenter*, IV, 10, March 1930. Also General Radio Company, Catalog F, pp. 88–90.

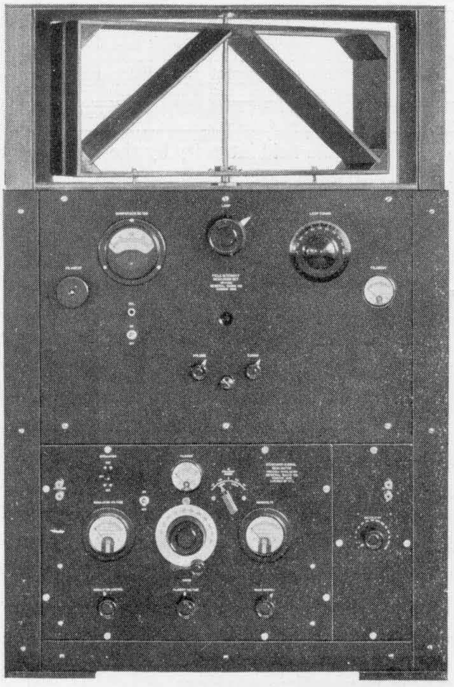

FIGURE 3. A field-strength measuring set making use of a TYPE 403-C Standard-Signal Generator. See accompanying description

loop. The normal frequency range of the signal generator is that of the broadcast band, 500 kc. to 1500 kc. The voltage range extends from 5 microvolts to 50,000 microvolts used directly or from 0.5 to 5000 microvolts using the output shunt.

A receiver having, with one stage of audio amplification, a sensitivity of 10 microvolts per meter will give satisfactory results. The better grade of present-day broadcast receivers meets this requirement. The greatest drawback to their use is the large capacity low-voltage storage battery needed to heat their alternating-current tubes. A micro-ammeter is inserted in the plate circuit of the low-frequency detector. The head telephones and a TYPE 486 Output Meter[15] are connected in the output circuit of the audio amplifier, which must be so arranged that there is no direct-current voltage across the output meter.

The design of the attenuator in the TYPE 403-C Standard-Signal Generator is such that its maximum error at maximum attenuation is less than 15 per cent. The shielding of the signal generator as built at present[16] is such that at no point more than six inches away from the case is the effect of the magnetic field on a loop greater than that of an electromagnetic field of 50 microvolts per meter. At a distance of 2 feet above the generator, the equivalent field is less than 2 microvolts per meter.

A recent installation of a TYPE 403-C Standard-Signal Generator in a portable field-strength set for use by the Shepard Broadcasting Service of Boston, Massachusetts, is shown in Figure 3. Here a rack-type mounting is used with the loop and signal generator separated by the receiver. The loop is turned by the handle at the center top of the panel through bevel gears. The leads from the loop pass down through the hollow shaft and then in shielded cable, one pair to the receiver and one pair to the output shunt mounted on the signal generator. The receiver is a Radiola Superheterodyne, Model 80, with the alternating-current tubes supplied from a large storage battery (not shown). Their control rheostat and switch are shown at the left on the receiver panel. Near them is the 200-

[15] John D. Crawford, "A Rectifier-Type Meter for Power Output Measurements at Audio Frequencies," *General Radio Experimenter*, IV, 2–3, July-August 1929. Also General Radio Company, Catalog F, p. 106; Bulletin 932, p. 40.

[16] The recent improvements in shielding consist in: doubling the thickness of copper on the top over the oscillator coil; soldering all parts of the box lining; encasing the modulation and output voltmeters in copper shields; and placing an L-shaped shield along the upper front edge. These changes may be made on the older TYPE 403-C Standard-Signal Generator at a cost of $22.00. All signal generators ordered on or after January 24 have the new shielding.

micro-ampere Weston meter in the plate circuit of the low-frequency detector. The dial at the right tunes the loop. This unit is mounted immediately behind the driver's seat in a Ford truck.

Figure 4 shows the field-strength measuring set mounted in the truck. The passenger's seat has been tipped forward to give a full view of the panel.

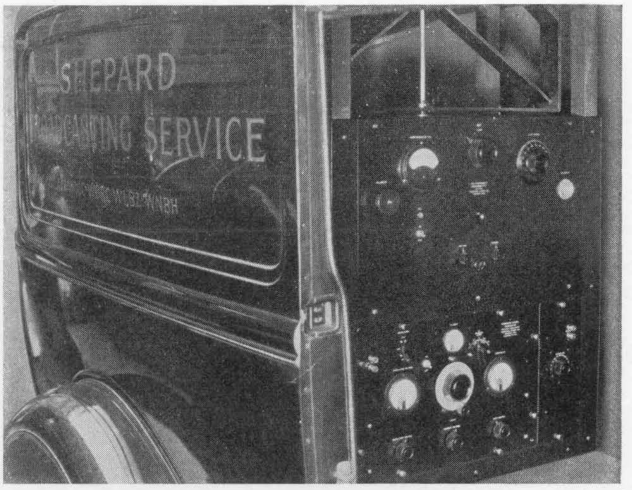

Figure 4. The measuring set in position

MISCELLANY

SINCE the publication of the anniversary number of the *Experimenter* last June, two new members have been added to our Engineering Department. They are William N. Tuttle and Roy L. Steinberger.

Mr. Tuttle received his doctor's degree for work in physics at Harvard University last year. He is specializing in problems pertaining to acoustics.

Mr. Steinberger is also from Harvard. He has completed the necessary work for his doctor's degree and, after a year and a half of part-time work, is now able to devote all of his time with us. During this period, he has been working on special applications of magnetostriction, particularly those relating to subaqueous communication. This work has been carried on under the direction of Dr. G. W. Pierce of Cruft Laboratory at Harvard, with whom we have just executed a patent license which will permit us to investigate the subaqueous field in an active manner.

* * * *

The Type 403-P10 Output Shunt is obtainable for a price of $4.00. It is fitted with plugs for connecting to the output terminals of the standard-signal generator and with three binding posts for connecting to the loop. We are prepared, on request, to supply it without extra charge in place of the Type 418 Dummy Antenna usually supplied with the Type 403-C Standard-Signal Generator.

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

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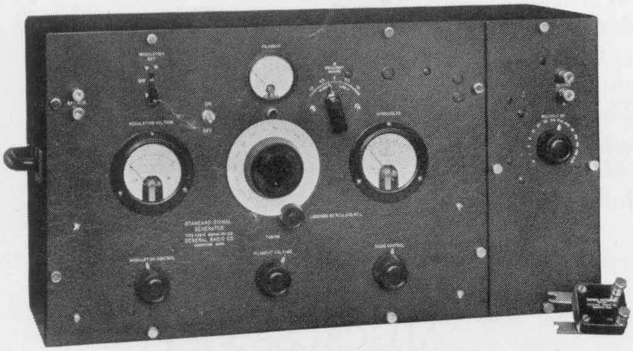
MEASURING FIELD STRENGTH



Type 403-C Standard-Signal Generator. Price $600.00

SENSITIVITY measurements on radio receivers and measurements of radio field intensity by the comparison method require the same basic instrument, a General Radio TYPE 403-C Standard-Signal Generator. Several are now being used successfully in field-strength surveys, the information obtained being a valuable asset to the engineer responsible for obtaining good coverage from his broadcast transmitter.

Field-strength measurements are described in the January, 1931, issue of the *General Radio Experimenter*. Extra copies are available on request. Please address Section X, Engineering Department, for further information.

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RUMFORD PRESS
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The General Radio Experimenter

VOL. V, No. 9 — FEBRUARY, 1931

ATTENUATION MEASUREMENTS ON TELEPHONE AND TELEGRAPH LINES

By J. W. HORTON *

IN its most elementary form the measurement of the attenuation of a telephone or telegraph circuit consists of measuring the power delivered to the line at the transmitting end and of measuring the power delivered by the line at the receiving end. The attenuation-frequency characteristic of a line is obtained by repeating these measurements at a suitable number of known frequencies.

In making these measurements, the impedance of the load to which the line delivers energy is generally made equal to, or matched to, the characteristic impedance of the line, which can usually be considered as a pure resistance without appreciable error. If this matching condition is met, the power delivered by the source of energy to the line is identical with the power which the same source would deliver to the load, were the latter connected to the source in place of the line. Furthermore, when the line is connected between the source and the load, the voltage across its input terminals and the voltage across the load terminals may be used as an indication of the power received and delivered, inasmuch as these voltages are impressed upon circuits of equal impedance.

In practice, therefore, the measurement of line attenuation is effected by terminating the line in a suitable load impedance, and in measuring the voltages across its input and output terminals. From the ratio of these two voltages, the attenuation of the line, in transmission units, is obtained by the following equation:

$$N = 20 \log_{10} \frac{V_{in}}{V_{out}} \text{ decibels.}$$

* Chief Engineer, General Radio Company.

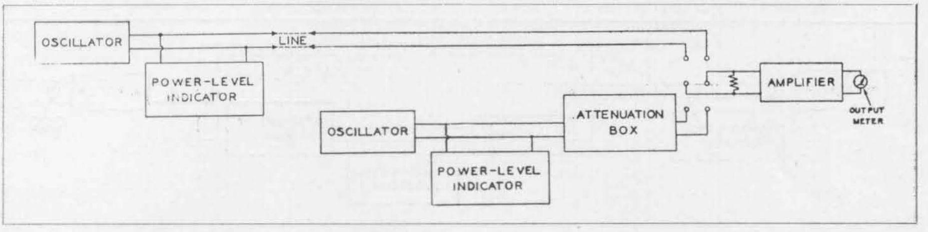


FIGURE 1. Apparatus and connections for measuring line attenuation by the modification of the standard method described in the accompanying article

In practice, the voltage at the receiving end of the line generally has a magnitude so small that it cannot be measured by any available calibrated instrument. It is customary, therefore, to resort to a substitution method in which a calibrated attenuator, having the same impedance characteristic as the line, is used at the receiving terminal. The arrangement of circuits is shown in Figure 1.

The attenuator receives energy from a source similar to that connected to the transmitting end of the line. The voltage across the input terminals of the attenuator is adjusted to be equal to the voltage across the input terminals of the line; hence, as the impedances are equal, the power delivered is the same in each case. An amplifier having an input impedance equal to the characteristic line impedance, and therefore suitable for use as a load, is connected alternately to the line and to the calibrated attenuator, and the latter adjusted until the output of the amplifier as indicated by any suitable instrument is the same for both connections. When this condition is reached, the voltage set up across the load by the line is equal to the known voltage set up across the same load by the calibrated attenuator. For convenience, the latter is calibrated in transmission units — generally in decibels — and, hence, the attenuation of the line is indicated directly by the setting of the attenuator

As has already been noted, the calibrated attenuator must have the same characteristic impedance as the line. This condition applies only to the input terminals of the attenuator, and it is imposed in order that equal voltages across the input to the line and the input to the attenuator shall indicate equal amounts of power. When this condition is met, it is apparent that the calibrated attenuator presents the same impedance to the secondary source as would the load, were the secondary source and the load connected directly together.

Provided that the input impedance of the attenuator is the same as the load impedance, it is unnecessary for the output impedance of the attenuator to match the load impedance, inasmuch as the indicated attenuation for any setting refers to the actual ratio between the power supplied to the attenuator and the power delivered by the attenuator to the load. In other words, in those attenuation networks which present a constant impedance to the source only (i. e., **L**-type networks) the loss due to the impedance mismatch on the load side is included in the calibration.

In making the measurement outlined in the preceding discussion it is, of course, necessary to be sure that the frequency of the current supplied to the line and the frequency of the current supplied to the calibrated attenuator are identical. In order to avoid the necessity for repeatedly making this adjustment, and also to permit the measurement to be made in cases

(*Continued on page 7*)

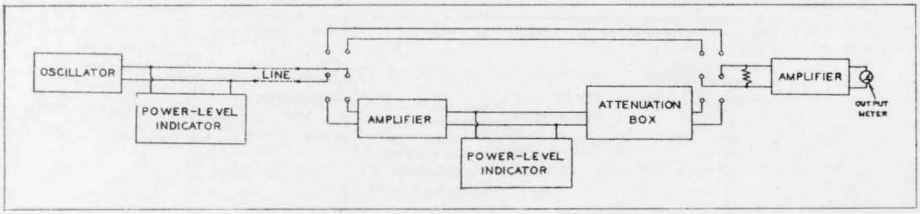


FIGURE 2. A method of measuring line attenuation like that of Figure 1 except that an amplifier replaces the oscillator at the receiving end of the line

SIMPLIFIED INDUCTANCE CALCULATIONS

By JAMES K. CLAPP*

WHILE much material has been published on the calculation of the inductance of coils,† the formulae given are in general not convenient for engineering use. Two difficulties are encountered in applying the results in engineering practice, one being the involved computations and the other the fact that differences in form and wire sizes and errors in the measurement of these factors introduce errors in the calculations which largely vitiate the utility of precise formulae.

For single-layer coils at radio frequencies (and, with slight modification, for bank-wound coils), Nagaoka's formula probably is the best for general engineering use. While neglecting the shape and size of the cross-section of the wire, the self-capacity of the winding and the variation of inductance due to skin-effect, it may be shown that the formula gives about as good results for high-frequency inductance as can be obtained.

Tables of the values of Nagaoka's correction factor have been prepared, but require considerable time to use due to the necessity for interpolations. The table values may be plotted in the form of a curve, but a more convenient interpolation is made possible by plotting these values on logarithmic scales, as has been done in Figure 3. Where much work of this type is done, the scales may be transferred to a slide-rule

* Engineer, General Radio Company.

† See in particular the publications of the U. S. Bureau of Standards and the Proceedings of the Institute of Radio Engineers.

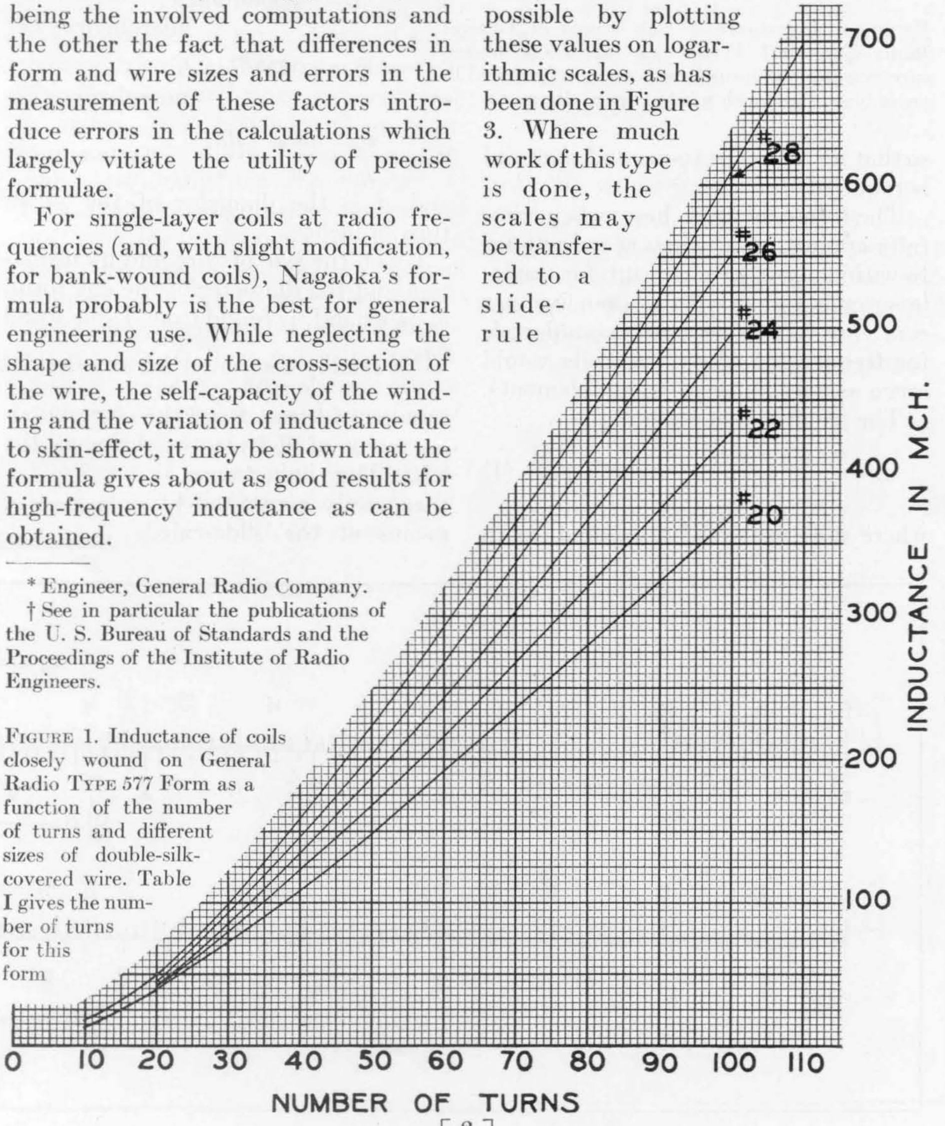


FIGURE 1. Inductance of coils closely wound on General Radio TYPE 577 Form as a function of the number of turns and different sizes of double-silk-covered wire. Table I gives the number of turns for this form

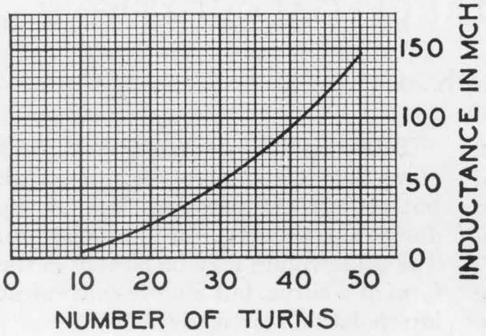


FIGURE 2. Inductance of coils wound on General Radio TYPE 577 Form with double-silk-covered wire in which the turns have been equally spaced in order to fill the 2-inch winding space. Here, $n_o = \frac{1}{2}n$

so that no reference to printed material is required.

The formulae given here, when carefully applied, give values of inductance to within about two per cent. for single-layer coils and to within about five per cent. for four-layer bank-wound coils for frequencies where the coils would serve as normal tuned-circuit elements.

The general formula is

$$L = \frac{0.1003a^2n^2K}{b}, \quad \text{microhenrys (1)}$$

where a is radius of a mean turn in inches, n is the number of turns, b is the length of the winding in inches, and K is Nagaoka's correction factor which is a function of $\left(\frac{2a}{b}\right)$ or the ratio of diameter to length of the winding.

If n_o is the number of turns per inch, the inductance and ratio of diameter to length are more conveniently given by:

$$L = 0.1003a^2nn_oK, \quad \text{microhenrys (2)}$$

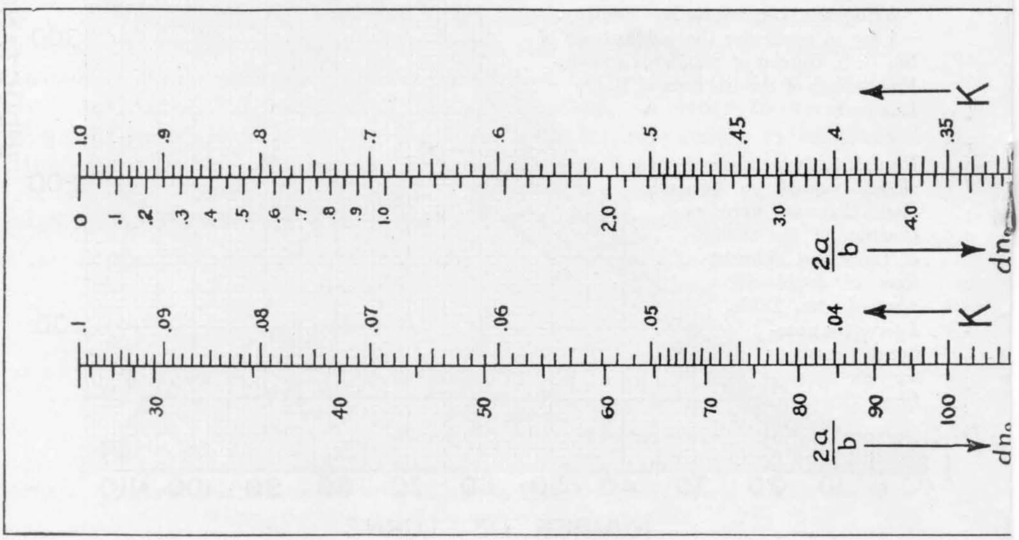
$$\text{or } L = 0.0251d^2nn_oK, \quad \text{microhenrys (3)}$$

$$\text{where } \frac{2a}{b} = \frac{2an_o}{n} = \frac{dn_o}{n} \quad \text{numeric (4)}$$

and d is the diameter of the mean turn in inches.

Given the size of wire and its insulation and the diameter of the coil form, n_o as wound, is found from Table I and $\frac{dn_o}{n}$ is readily computed for any desired number of turns. Read the corresponding value of K from the scales at the left. The inductance is then easily computed by means of the slide-rule.

FIGURE 3. Values of
different values of $\frac{2a}{b}$ =



For banked windings of not too great depth as compared with the diameter, a close approximation for the inductance is obtained by using Nn_o for the turns per inch (where N is the number of banks) and $\frac{dNn_o}{n}$ for the ratio of diameter to length.

Then $\frac{2a}{b} = \frac{dNn_o}{n}$ numeric (5)

and $L = 0.0251d^2Nnn_oK$, microhenrys (6)

The number of turns required for a desired value of inductance cannot be directly calculated since K varies as n is varied. With given types of windings experience will indicate an approximate value for the number of turns. If the computations are carried out and the inductance obtained is near the desired value, the correct number of turns to give the desired value may be obtained by readjustment, since K does not vary rapidly with n. Where many values are required it is simpler to calculate a sufficient number of values for a curve. The required values may then be read off directly. (See Figures 1 and 2, for example.)

TABLE I

WINDING DATA FOR CLOSELY WOUND COILS

SIZE OF WIRE B & S	TURNS PER INCH					TOTAL TURNS FOR FULL 2-INCH FORM
	Enamel	Single Silk	Double Silk	Single Cotton	Double Cotton	Double Silk
20	29	27	25	27	25	50
22	36	34	30.5	34	30	61
24	45	43	38	41	35	76
26	57	52	45	50	41	90
28	71	64	53	60	48	96
30	88	80	66	71	55	110
32	120	95	76	84	62	124

EXAMPLES OF CALCULATIONS

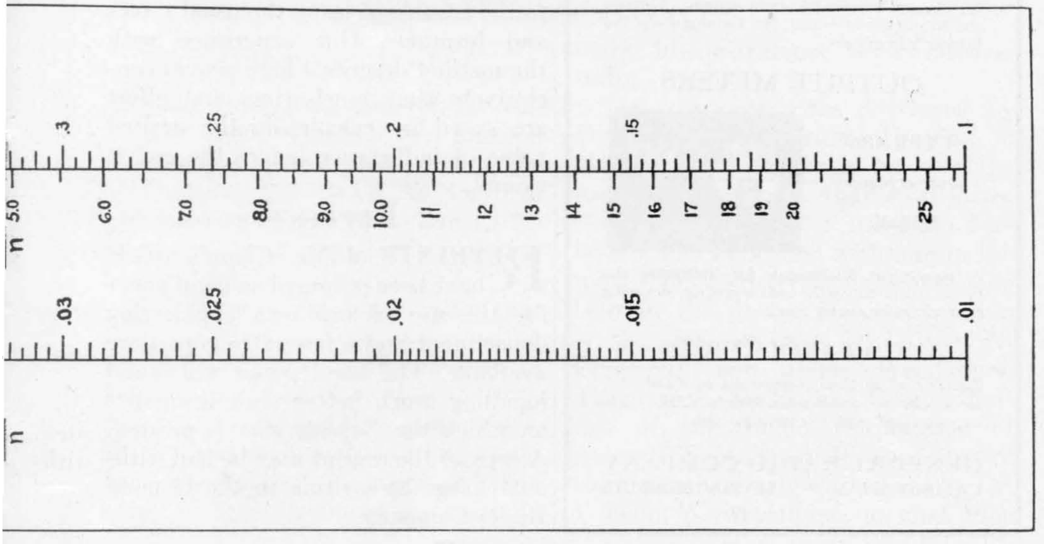
Given: Form diameter = 2.75 inches (General Radio Company TYPE 577 Form). Wire size = No. 20 double-silk-covered. *Find:* The inductance for coil of 35 turns.

Procedure: In Table I find $n_o = 25$

$$\frac{dn_o}{n} = \frac{\left(2.75 + \frac{1}{25}\right)25}{35} = 1.99$$

From scales, opposite 1.99 for $\frac{dn_o}{n}$, read

Nagaoka's constant K for $\frac{dn_o}{n}$ on a logarithmic scale



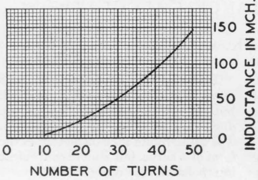


FIGURE 2. Inductance of coils wound on General Radio TYPE 577 Form with double-silk-covered wire in which the turns have been equally spaced in order to fill the 2-inch winding space. Here, $n_o = \frac{1}{2}n$

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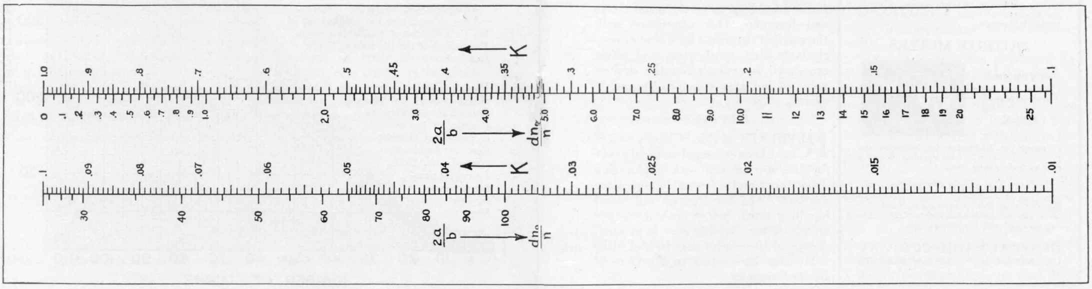
FIGURE 3. Values of Nagaoka's constant K for different values of $\frac{2a}{b} = \frac{dn_o}{n}$ on a logarithmic scale



$K = 0.526$

$L = 0.0251 \times (2.79)^2 \times 35 \times 25 \times 0.526$
$= 90.0$ microhenrys.

For a rough estimate, the diameter of the form may often be taken as the diameter of a turn. In the above example this procedure gives $\frac{dn_o}{n} = 1.965$, $K = 0.530$ and $L = 88$ microhenrys, which differs from the previous value by about 2.5 per cent.

For bank-wound coils an example is as follows:

Given: $d = 2.75$, $n_o = 25$, $N = 4$, and $n = 200$

$$\text{Then, } \frac{dNn_o}{n} = \frac{\left(2.75 + \frac{4}{25}\right) 25 \times 4}{200} = 1.455.$$

From Figure 3, $K = 0.604$

$$\text{Then } L = 0.0251 \times \left(2.75 + \frac{4}{25}\right)^2 \times 4 \times 25 \times 200 \times 0.604 = 2570 \text{ microhenrys.}$$

Many experimenters and many engineers "design" inductors by guessing at the number of turns, then peeling off wire until the correct value of inductance is obtained rather than go to the trouble of using the usual tables and formulas. Our experience with the method described here proves conclusively that much time and effort are saved by calculating the desired value of inductance before the coil is wound.

REPRINTS

REPRINTS of Mr. Clapp's article have been prepared on bond paper for the use of our own engineering department and a few extra copies are available. The bond paper will stand handling much better than the paper on which the *Experimenter* is printed. A copy of the reprint may be had without charge by writing to the General Radio Company.

Horton: Attenuation Measurements

(*Continued from page 2*)

where a duplicate source may not be available at the receiving end, it is possible to carry out the measurement as indicated in Figure 2. In this figure it will be noted that the oscillator of Figure 1 is replaced by an amplifier which may be connected to the line whenever the load is connected to the output of the calibrated attenuator. The amplification of this secondary source amplifier is adjusted until the voltage across the input end of the attenuator at the receiving terminal is the same as the voltage across the input end of the line at the transmitting terminal. In this case, it is apparent that the frequency of the current delivered to the attenuator must be identical with the frequency delivered to the line. One objection to this method lies in the fact that the wave supplied to the attenuator may fail to duplicate exactly the wave supplied to the line, due to the presence of interference picked up by the latter.

It should be noted, in connection with the alternative source of local current just described, that it is unnecessary for the input impedance of the secondary source amplifier to match the line impedance, inasmuch as the efficiency of this connection plays no part in the measurement. It should further be pointed out that it is quite unnecessary to know the gain or amplification of the source amplifier, or of the load amplifier used in making the voltage comparison; the frequency characteristics of these amplifiers are, consequently, of no importance in connection with the attenuation measurement, provided that the gain is adequate at all frequencies.

To summarize the requirements imposed on the measuring equipment, therefore, we note that the calibrated attenuator must be designed so as to have the same input impedance as the line with which it is to be compared, and that the impedance of the voltage-indicating amplifier, which is connected alternately to the line and to the calibrated attenuator, must match this characteristic impedance.

Miscellany

Cardiotachometer

In the July, 1930, issue of the *Experimenter*, Horatio W. Lamson described an instrument called the cardiotachometer which he built in collaboration with Paul Bauer, for measurement of a patient's heart at rest or during exercise.

Two of our readers have written that a similar instrument was described by Dr. Ernst P. Boas in the *Archives of Internal Medicine* for March, 1928. Mr. Lamson did not then know of Dr. Boas' cardiotachometer or he would have referred to it, inasmuch as it had many features he found necessary to make his instrument work satisfactorily.

The instrument was developed by Dr. Boas at Montefiore Hospital in New York City, while he was the medical director of that institution. From the outset, Dr. Benjamin Liebowitz was associated with him in the work. They were fortunate in obtaining help in the design and construction of the amplifier from Dr. Alfred N. Goldsmith and Julius Weinberger, Theodore A. Smith, and George Rodwin of the Radio Corporation of America. Subsequent developments of the instrument were worked out by Dr. William W. Macalpine, at that time fellow in the department of physics at Columbia University.

Dr. Boas has given us a great deal of information about the use of the apparatus and anyone interested in heart measurements should read the results of his measurements in the following articles: Boas and Goldschmidt, "Continuous Recording of the Heart Rate During Operations," *Journal American Medical Association*, XCIV (1930), 1210; Boas and Weiss, "The Heart Rate During Sleep as Determined by the Cardiotachometer," *Journal American Medical Association*, XCII (1929), 2162; Boas and Goldschmidt, *Klinische Wochenschrift*, IX (1930), 1115; and Boas, "The Ventricular Rate in Auricular Fibrillation Studies with the Cardiotachometer," *American Heart Journal*, IV (1929), 449.

* * * *

PRECISION WAVEMETERS

OWNERS of General Radio TYPE 224, TYPE 224-A, and TYPE 224-L Precision Wavemeters will be interested in knowing that we have just completed the preparation of a new instruction book to cover all three instruments. If you have one of these precision wavemeters, you are entitled to a copy without charge. Please mention the type number and serial number of your wavemeter in your request.

VOLUME CONTROLS

ACCORDING to some of the General Radio Company's advertising, an article on the use of volume controls in high-quality sound systems was to have appeared this month. Unfortunately, it has been necessary to postpone the appearance of this article to a future issue of the *Experimenter*. We hope that no reader has been inconvenienced.

* * * *

SUPERHETERODYNE

ENGINEERS working on the design of superheterodyne receivers can now obtain a special inductor for covering the range between 200 kc. and 150 kc. with the TYPE 403-C Standard-Signal Generator. This makes it possible to make selectivity and sensitivity measurements on the intermediate-frequency amplifier.

The new inductor, when uncalibrated, is designated TYPE 403-P8 and is priced at $16.00; when calibrated it is designated TYPE 403-Q8 and is priced at $24.00. For other notes applying to additional inductors, please refer to Catalog F, page 90. If you haven't a copy, ask us for Catalog F-X2.

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GENERAL RADIO COMPANY
CAMBRIDGE A, MASSACHUSETTS

RUMFORD PRESS
CONCORD, N. H.

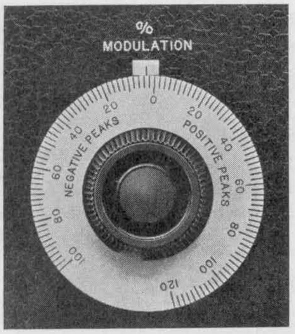
The General Radio Experimenter

Vol. V, No. 10 — March, 1931

Modulation Measurements on Broadcast Transmitters

By W. N. Tuttle*

IN radio broadcasting, much attention has been given recently to the problem of obtaining high percentage modulation of the transmitter output. The broadcasting stations were first interested in employing high modulation because of the greater area which can be served with the same output power. If a certain area can be covered effectively with high power and low percentage modulation, it can be covered just as effectively with less power and higher percentage modulation. In addition, the interference caused will be very much less. Federal regulations now require that the second of these alternatives be employed.



It is a complicated technical problem to obtain high percentage modulation without distortion. It is made still more difficult by the fact that the transmitter must simultaneously satisfy certain efficiency requirements.

Most of the problems of design have been satisfactorily solved, but due to the criticalness of the requirements, rather slight misadjustments of the transmitter have a marked effect on the quality of the modulated output. The use of high percentage modulation means that even with the best modern transmitters it is necessary to make tests on the modulated output to make certain that the best adjustment is maintained.

Modulation tests are needed not only to check the transmitter adjustment but also to determine the maximum modulation which may be employed without distortion and, finally, to insure that the modulation stays within the required limits during the transmission of a program. Attention has consequently been focused on the various methods available for modulation testing.

Let us consider the measurement of percentage modulation in the simple case where the transmitter is operating properly and the signal is not distorted.

* Engineer, General Radio Company.

Under these circumstances, if the transmitter is modulated by a pure tone, the envelope of the radio-frequency wave will also be sinusoidal. Example I of Figure 1 shows this case. The percentage of modulation is the percentage by which the peaks of the envelope deviate from the average envelope value. This is the ratio p/A or n/A expressed in per cent.

For the particular case of a perfectly operating transmitter, it is not a difficult matter to make a radio-frequency measurement of this ratio.[1] Under these ideal conditions, the average envelope value A is the same as the unmodulated carrier amplitude C. The quantities A and $(A+p)$ are therefore the values of the peak radio-frequency voltage before and after the signal is modulated. From these two quantities measured by means of a peak voltmeter the percentage of modulation is readily computed. This method is very useful where the percentage modulation employed is not high, but is subject to serious errors in cases encountered in present-day broadcasting.

This method is perfectly satisfactory only as long as the assumptions upon which it is based are valid. It is therefore accurate only for transmitters which are in perfect adjustment and for which the percentage modulation is safely below the allowable limit. This method is consequently of little use in diagnosing misadjustments of the transmitter.

Examples II, III, and IV are cases where the method just described is not applicable. It is seen that the average value of the envelope is not equal to the amplitude of the unmodulated carrier, and the deviations, p and n, of the peaks from the average are not in general equal. It is evident that in these cases no single quantity can describe the modulation. To describe these cases, we need to know p/A and n/A independently, and also the amount by which A differs from C.

A detailed oscillographic study has been almost the only means of getting this information. It requires skill and time, however, to make such an investigation. Photographs must usually be taken if accurate numerical values are

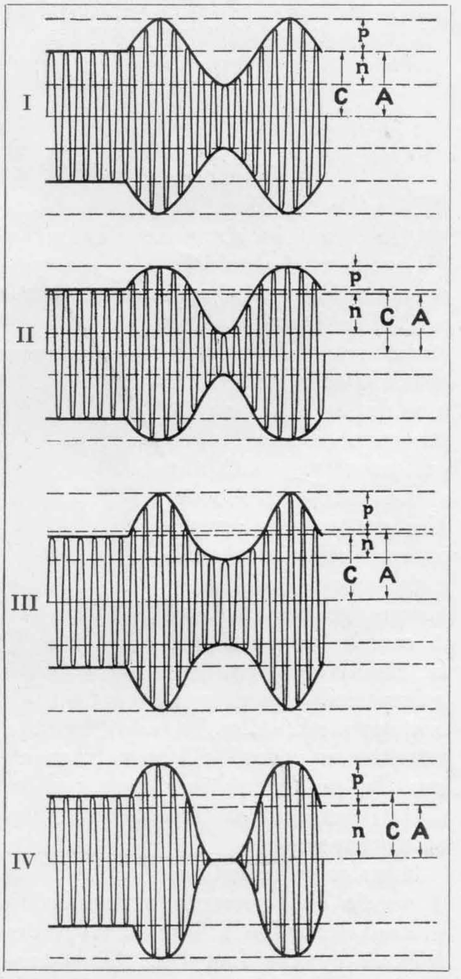


FIGURE 1. Four conventional representations of modulated-carrier envelopes showing that the average amplitude A during modulation is not necessarily equal to the amplitude of the unmodulated carrier C

[1] C. B. Jolliffe, "The Use of the Electron Tube Peak Voltmeter for the Measurement of Modulation," *Proceedings of the I. R. E.*, Vol. 17, No. 4, April, 1929, 660–663.

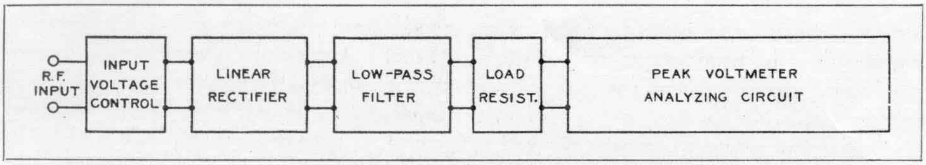


Figure 2. Functional arrangement of the elements in the General Radio Type 457-A Modulation Meter

to be obtained, or if a permanent record is desired. While these considerations do not detract from the value of an oscillograph for such purposes as making a complete study of the operation of a new transmitter, they do indicate

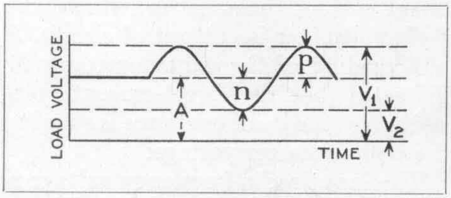


Figure 3. Voltage delivered to the peak voltmeter analyzing circuit if the carrier of Example I, Figure 1, were applied to the input terminals of the modulation meter

that some more convenient instrument is needed for obtaining modulation data.

The instrument to be discussed gives directly and numerically a description of the modulated output of a transmitter. It analyzes a modulated waveform without reference to the characteristics of the transmitter producing the signal. The ratios p/A and n/A are given by dial readings, so that no computation is necessary. The percentage by which A deviates from C may also readily be determined.

The quantities p/A and n/A will be called *positive-peak modulation* and *negative-peak modulation*, respectively. The best single quantity to describe percentage modulation is the average of the positive-peak modulation and the negative-peak modulation above defined. It is this average modulation which is defined by the Committee on Standardization of the Institute of Radio Engineers [2] as the percentage modulation.

The elements of the Type 457-A Modulation Meter are shown in Figure 2. The voltage to be analyzed (usually most conveniently obtained by means of a small pickup inductor coupled to the output circuit of the transmitter) is applied to a linear rectifier. The low-frequency components of the rectifier output are analyzed by a special type of vacuum-tube peak voltmeter. In Dr. Jolliffe's method which was just described, the peak voltmeter measures the radio-frequency voltage directly. In this instrument, however, the peak voltmeter analyzes the output of a rectifier. The interposition of the rectifier makes it possible to observe the minimum value of the envelope as well as the maximum value.

Since the rectifier is designed to be linear [3] in its characteristics, the output voltage, after the radio-frequency components have been removed by the filter, will be a replica of one-half of the envelope of the applied modulated voltage.

In other words, if the voltage at the input terminals is of the form shown in Example I of Figure 1, the voltage across the load resistance will be that shown in Figure 3. The problem of measuring percentage modulation has thus been reduced to the comparatively simple problem of measuring the two peak values of a low-frequency voltage relative to a direct-current voltage.

[2] Yearbook of the I. R. E., 1929, p. 55.

[3] Stuart Ballantine, "Detection at High Signal Voltages," *Proceedings of the I. R. E.*, Vol. 17, No. 7, July, 1929, 1157.

The apparatus in Figure 2 to the right of the load resistance is for the purpose of making direct measurements of these ratios.

This part of the apparatus is shown in Figure 4. A two-element rectifier *D* is connected across the load resistance in series with the galvanometer *G* and an adjustable direct-current voltage which opposes the envelope voltage of Figure 3. This opposing voltage is obtained from the battery *E* and the voltage divider *P*.

The heart of the peak voltmeter is the tube *D* in which the plate current, as indicated by the galvanometer *G*, flows only when the plate is positive with respect to the filament. The tube is used to determine when the opposing voltage has been made equal to the peak voltage of the envelope.

When, therefore, the reversing switch *S* is thrown to the left, there will be a galvanometer deflection when the voltage across terminals *1* and *2* becomes positive. With switch *S* reversed, the plate and filament connections are interchanged, and a deflection will now take place when the voltage across terminals *1* and *2* becomes negative. The values of the opposing voltage at which the galvanometer just begins to deflect for the two positions of the switch *S* will be the two voltages V_1 and V_2 shown in Figure 3. In a modulation meter devised by van der Pol and Posthumus,[4] these two voltages are measured on a direct-current voltmeter connected across the voltage divider *P* and the fractional modulation *m* obtained from the expression

$$m=\frac{V_1-V_2}{V_1+V_2}=\frac{p}{A}=\frac{n}{A}.$$

In the TYPE 457-A Modulation Meter things are arranged so that *m*, expressed in per cent., may be read directly on a dial which is attached to the voltage divider *P*. This is accomplished by means of a preliminary direct-current balance in which the peak voltmeter is cut out of circuit. A null reading of the galvanometer now indicates that the direct-current voltage across the load resistance is equal to the potentiometer voltage.

The input radio-frequency voltage is adjusted so that the voltage *A* in Figure 3 is equal to the voltage across 100 divisions of the dial on the voltage divider *P*. The zero point of the dial is then automatically at voltage *A*, and furthermore, the voltages *p* and *n* read on the dial on either side of the zero point will be expressed in per cent. of *A*.

[4] B. van der Pol and K. Posthumus, "Telephone Transmitter Modulation Measured at the Receiving Station," *Experimental Wireless*, 4, March, 1927, pp. 140–141.

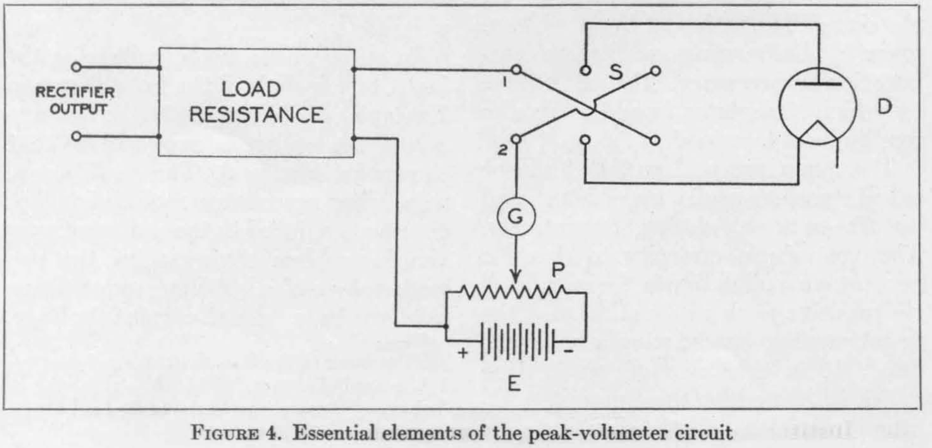


FIGURE 4. Essential elements of the peak-voltmeter circuit

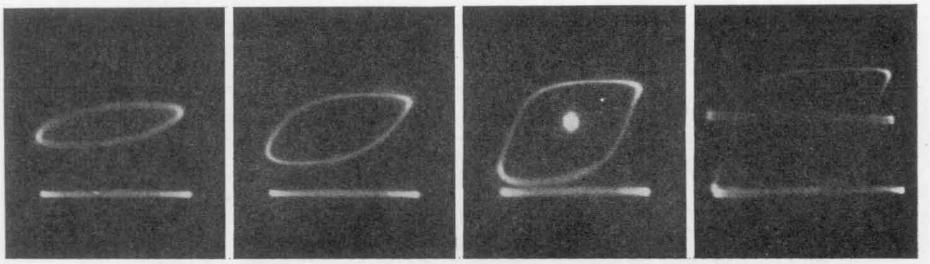


FIGURE 5. Cathode-ray oscillograms made on a modern commercial broadcast transmitter for different values of percentage modulation. Horizontal deflections were due to the sine-wave modulating voltage, vertical deflections to the carrier envelope

This important preliminary balance thus serves the dual purpose of making the instrument direct-reading in percentage modulation and of enabling positive-peak modulation and negative-peak modulation to be determined independently.

The preliminary balance can not be made exactly as described above, because the direct-current balance circuit would appreciably change the audio-frequency voltage applied to the linear rectifier. To avoid this difficulty the voltage across only a very small fraction of the load resistance is used to obtain balance, when the adjustment of the input voltage is made.

The new modulation meter makes a sufficiently detailed analysis of a modulated signal so that abnormal modulation may be detected. Helpful information may also be obtained when adjustments of the transmitter are being made. The maximum allowable modulation may be determined, and since the instrument is direct-reading, it is convenient for use in monitoring to see that the modulation limit is not exceeded.

In monitoring, the instrument may be conveniently used to give an indication whenever a predetermined maximum percentage modulation is exceeded. For example, if the dial is set at 50%, the galvanometer needle will remain stationary as long as the percentage of modulation is below this value. As soon as this percentage is exceeded, however, there will be an abrupt deflection which is approximately proportional to the excess modulation. The transmitter volume control may therefore be turned up until the louder portions of speech or music begin to cause deflections of the galvanometer.

It is interesting to compare the modulation-meter measurements with results obtained by means of a cathode-ray oscillograph. Figure 5 shows the patterns for the output of a modern transmitter for four different percentages of modulation. The pure sinusoidal voltage used to modulate the transmitter was connected to one pair of plates causing deflections along the horizontal axis. The signal voltage was connected to a linear rectifier, the output of which was applied to the other pair of plates. The patterns therefore show simultaneous values of the envelope voltage and the modulating voltage. If both of these voltages are sinusoidal, a perfect ellipse or diagonal straight line is obtained. This is seen to be the case in the first photograph. The distortion at higher percentages of modulation causes the ellipse to become increasingly deformed, as the other three photographs show. In all four photographs, the horizontal axis is shown for reference. In III and IV, an

TABLE

COMPARISON OF PERCENTAGE MODULATION AS DETERMINED FROM OSCILLOGRAMS AND TYPE 457-A MODULATION METER

	Case I		Case II		Case III		Case IV	
	Oscillogram	Modulation Meter	Oscillogram	Modulation Meter	Oscillogram	Modulation Meter	Oscillogram	Modulation Meter
Positive Peaks	28%	32%	43%	48%	58%	60%	76%	70%
Negative Peaks	30%	32%	57%	56%	86%	87%	100%	100%

exposure was also made to locate the ordinate corresponding to the unmodulated carrier.

Since the maximum and minimum envelope values are the top and bottom points of the pattern, the percentage modulation may readily be computed from the ordinates measured on the photographs.

In the accompanying table the values obtained from the oscillograph patterns are compared with those measured directly on the modulation meter. Since the carrier may shift during modulation, the values given are referred to the unmodulated carrier voltage C rather than to the average envelope value A. The quantities tabulated are, therefore, the ratios p/C and n/C of Figure 3, expressed in per cent.

The check is seen to be quite satisfactory, as the errors in the oscillograph method are probably at least as great as those in the modulation-meter measurements.

The results show clearly that for this adjustment of the transmitter the positive peaks cut off considerably before the negative peaks. In Case IV, both peaks are cut off almost equally but the average envelope value A has fallen considerably below the unmodulated carrier value C. Since the average envelope value is the carrier value during modulation, it is seen that the carrier output decreases quite appreciably at high modulation. The operation of this transmitter was considerably improved by slightly decreasing the carrier voltage applied to the modulated amplifier.

These results indicate definitely that even with high-quality modern transmitters there is need for accurate testing of the modulation characteristics in order that satisfactory adjustment may be maintained.

PRECISION FREQUENCY MEASUREMENTS

By JOHN D. CRAWFORD*

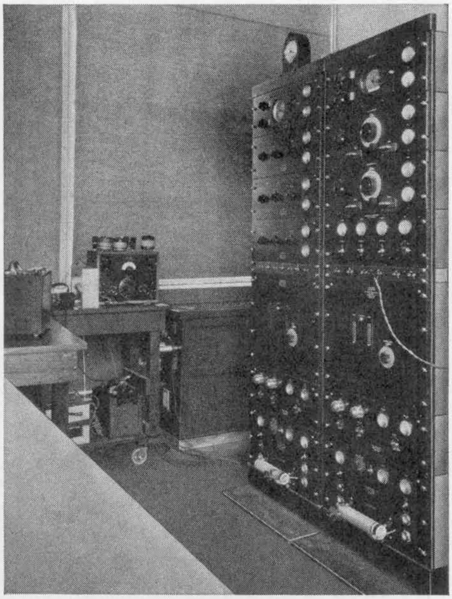
SINCE early this year, the Bureau of Standards has been sending from WWV a weekly high-precision standard-frequency schedule[1] at a frequency of 5000.00 kilocycles per second (60 meters).

* Editor, *General Radio Experimenter*.

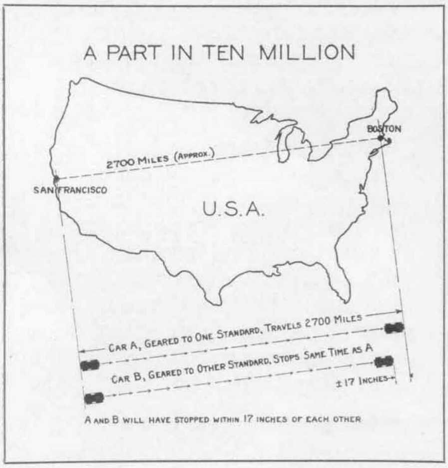
[1] Transmissions are at present being sent from 1:30 to 3:30 and from 8:00 to 10:00 P.M., Eastern Standard Time, every Tuesday except that week (usually the week of the 20th) in which the regular monthly transmissions are scheduled. Complete schedules, field-intensity data, and other information are published in the *Proceedings of the I. R. E.* and in both the *Radio Service Bulletin* and the *Technical News Bulletin* of the United States Department of Commerce.

The preliminary announcements of the schedule issued by the Bureau of Standards stated that the transmissions were "accurate to a few parts in a million." Subsequent measurements by them and other observers indicate that this stability has been exceeded and that, in general, the signals are reliable to within a part in a million.

The new schedule and the willingness of the Bureau to coöperate with observers in other laboratories are particularly helpful to those who are maintaining primary standards of frequency. We have on several occasions reported our measurements on this standard-frequency transmission to the Bureau and have received from them statements showing how the two simultaneous measurements compared. The ultimate universal standardization of frequency is thus brought one step nearer to realization by having a highly stable test signal upon which several laboratories can make simultaneous checks. International comparisons will be possible, especially if the proposed one-kilowatt transmitter is installed.



A corner of the General Radio frequency-standards laboratory. The standard-frequency assembly at the right is used in general experimental work; the one next to it is the primary standard, in terms of which the General Radio Company does all its frequency calibration and measurement work



Two cars, each geared to a frequency standard, would, if the standards agreed to one part in ten million, have rates of speed which were equal to within one part in ten million. Two such cars could travel 2700 miles and be only 17.1 inches apart at the end of the trip

It is interesting to note, in this connection, that our measurements on these standard-frequency transmissions have been in agreement with those made by the Bureau of Standards to well within one part in a million and that several observations agreed to within one part in ten million. The true significance of so close a check between two independently operated systems will probably be better appreciated if we construct an illustration to show what is meant by "one part in ten million."

Suppose, as suggested in the drawing, we start from San Francisco two automobiles, the velocities or rates of speed of which are known to be equal to within one part in ten million. These two cars could travel all the way to Boston, a distance of approximately 2700 miles, and, at the end of the trip, one car would be only 17.1 inches ahead of the other.

The primary standards operated by the Bureau of Standards and by the General Radio Company [2] utilize specially constructed piezo-electric quartz crystals, the average frequencies of which are determined in terms of the Mean Solar Day as defined by the corrected time signals of the U. S. Naval Observatory. In both systems, the working frequency of the quartz crystal is divided in special electrical circuits to a value suitable for actuating a synchronous-motor-driven clock. By comparing clock time with observatory time, the average frequency of the standard crystal can be determined. If the clocks in both frequency-standard systems were keeping time to within one part in ten million, the two would differ by not more than 0.0086 second in a day, or 3.1 seconds in a year.

[2] The General Radio Company's primary standard is a standard-frequency assembly, described in Catalog F. Ask for a copy of Catalog F-X3.

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.

The General Radio Experimenter

Vol. V, No. 11 April, 1931

A Continuous-Film Camera for the Oscillograph

By Horatio W. Lamson *

An oscillograph, as the name implies, is a device which enables one to observe the waveform of an electrical current and to note any changes in this waveform with the passage of time. This is accomplished by converting the varying electrical current into mechanical vibrations which are a more or less perfect reproduction of the variations in the amplitude of current. A spot of light reflected from such a vibrating system, or the shadow of some portion of the system itself, focused to a point, will vibrate back and forth and will, accordingly, trace a straight line upon a viewing screen. The length of this line will be proportional to the amplitude of vibration but no indication of the waveform will appear on the viewing screen because the coördinate of time is lacking.

There are two methods whereby a proper time element, perpendicular to the direction of vibration, may be introduced. One of these consists of causing the vibrating shadow or spot of light to be reflected, before striking the viewing screen, from a single or multiple-sided plane mirror which is rotating about an axis parallel to the line of vibration of the spot. The shadow spot or light spot will then be given an additional displacement, proportional to time, at right angles to its vibration due to the amplitude variations in the electrical current, so that a waveform, that is, a trace showing the relation of amplitude and time, will appear on the viewing screen. If the current waveform is a repeated and sustained one and if the rotation of the mirror is synchronized at a proper speed, a stationary trace will appear on

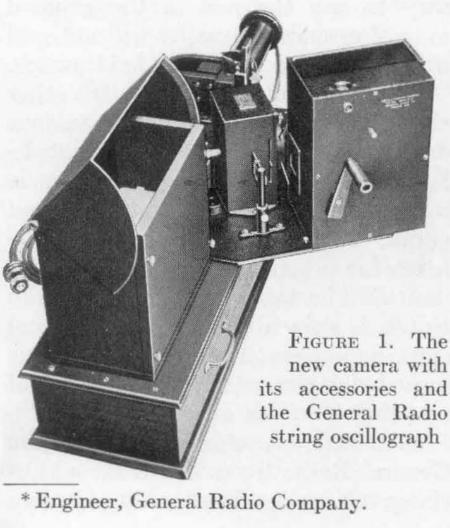


Figure 1. The new camera with its accessories and the General Radio string oscillograph

* Engineer, General Radio Company.

the screen. This method is used in the General Radio TYPE 338-L String Oscillograph* and in all other forms of oscillograph making use of the rotating-mirror principle.

If the screen upon which the vibrating line is traced is capable of retaining an instantaneous picture of the shadow spot or light spot, that is, if it is of the nature of a photographic film, then the second method of introducing the time axis may be employed. This consists merely of pulling along the screen continuously in a direction perpendicular to the line of vibration, thereby giving the required trace of amplitude versus time.

This method is employed in the new continuous-film camera which the General Radio Company has recently perfected to be used for obtaining permanent oscillographic records. Obviously, records obtained in this manner may show either sustained or transient phenomena.

This instrument, designated as the TYPE 408 Oscillograph Camera, was designed primarily to be used as an adjunct to the TYPE 338-L String Oscillograph, but with proper arrangements it may be adapted for use with other makes of oscillograph. The instrument is intended to use 100-foot reels of standard 35-millimeter perforated motion-picture film or paper, so that individual exposures of any length up to this amount may be made. If only a single copy of the record is required, Eastman No. 2 perforated recording paper may be purchased on 100-foot reels provided with leaders which permit loading of the camera in daylight. This paper, while quite sensitive, is much easier to handle than negative film stock and, if it is developed with Eastman x-ray developer, produces a contrasty and very satisfactory record.

The camera consists of a rectangular aluminum casting having three separate compartments. The lower compartment on one side serves as a magazine for the unexposed film or paper. This film passes over a driving sprocket and through a light-tight slit into the upper compartment, which serves as a magazine for the exposed film. A duplicate reel is provided herein which is driven through a slipping clutch and serves to wind up the exposed film properly. As the film passes up over the driving sprocket, it is momentarily exposed through a horizontal slit running transversely across the film. If the shadow spot or light spot is then made to vibrate in a horizontal plane to and fro along this slit, a white trace on a dark background or a dark trace on a white background, respectively, will be produced on the photographic paper.

Independent sliding shutters give access to these two camera compartments so that the exposed magazine may be opened without illuminating the other. If short records, under four feet only, are required, it is not necessary to use the reel in the exposed magazine since the paper will not curl up of its own accord as it is fed through.

The third compartment on the other side of the camera contains the various driving mechanisms. It need not be light-tight. The driving sprocket is rotated directly by a suitable hand crank, but provision may easily be made for substituting a motor drive if desired. The take-up reel with its slip clutch is driven through a chain and sprocket system. A resetable counter is provided for recording the amount of film that has been exposed.

In order to use this camera with the General Radio TYPE 338-L String Oscillograph, the TYPE 409 Camera

* In the General Radio TYPE 338-L String Oscillograph, the vibrating element consists of a single fine tungsten filament passing through a magnetic field supplied by a permanent magnet. The shadow image of the center portion of this string is thrown into the rotating-mirror viewing box or into the camera.

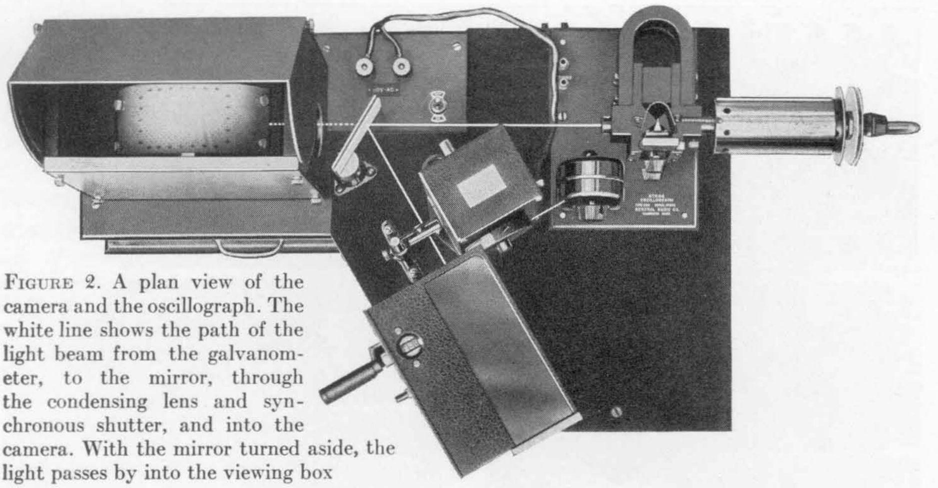


FIGURE 2. A plan view of the camera and the oscillograph. The white line shows the path of the light beam from the galvanometer, to the mirror, through the condensing lens and synchronous shutter, and into the camera. With the mirror turned aside, the light passes by into the viewing box

Shelf is required. This aluminum shelf is properly drilled for aligning the several parts. It is easily attached to the oscillograph underneath the galvanometer. As a part of the shelf is supplied a two-position plane mirror and mounting. This operates similar in principle to a Graflex camera, a turn of the wrist serving to throw the image of the vibrating element from the rotating-mirror viewing box into the camera, and vice versa. Simultaneous visual observations and photographic records are not possible, but one may closely follow the other.

Another part of the shelf equipment consists of a mounting carrying a cylindrical lens having a horizontal axis. This lens is for the purpose of condensing the pencil of light rays from the galvanometer into a narrow horizontal beam focused along the slit, thereby increasing the intensity of illumination many fold.

The TYPE 338-L String Oscillograph is designed to be operated from 110-volt, 60-cps. current. In the majority of cases the frequency of such a source of current is carefully stabilized so that it may be used to drive synchronous clocks. It is frequently desirable to utilize this regulated 60-cps. power supply as a reference scale of time on the oscillograph records. For this purpose, the TYPE 407 Synchronous Shutter serves to provide transverse time lines across the film. The shutter consists of an enclosed synchronous motor driven by the 60-cps., 110-volt current. The shaft of this motor, and the spoked wheel carried thereon, rotate at an exact speed of ten revolutions per second. This motor is not self-starting but is easily brought up to synchronous speed by rotating the shaft with the fingers. The shutter is so mounted on the camera shelf that, as the spokes come into a horizontal position on one side, they momentarily cast a shadow along the slit, thus giving a transverse line on the film.

A five-spoke wheel is provided which will, of course, mark the film in 0.02-second intervals with one spoke shortened to identify 0.1-second intervals. Models carrying a ten-spoke wheel have been provided to mark the film in 0.01-second intervals, likewise identifying the 0.1-second intervals. The former is to be recommended except for timing very high speed films. Through a reduction gear system a separate spoke marks the film along one edge at one-second intervals. This is advantageous in timing long exposures.

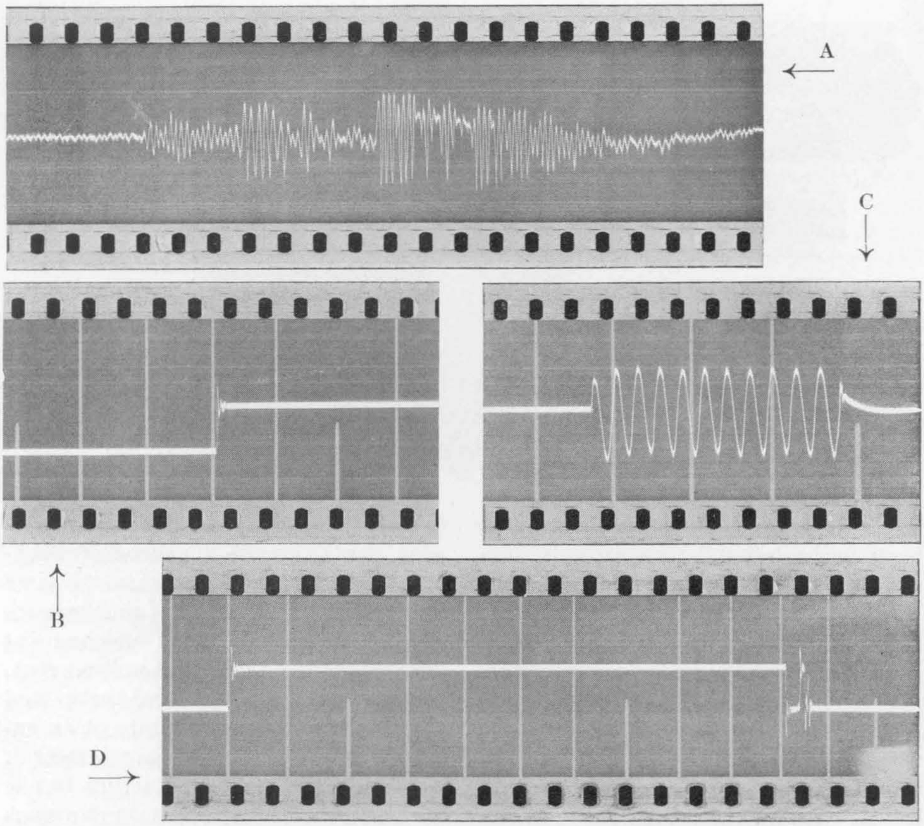


FIGURE 3. Typical records taken with the string oscillograph and camera. The vertical timing lines and the white spot (lower right corner of *D*) were marked at 1/50th-second and 1-second intervals by a synchronous shutter. *A* is the record of a watch tick; *B* and *D* show the operation of a relay; *C* shows the starting and stopping of a vacuum-tube oscillator. Time increases from left to right

The accuracy of these time markings is, of course, the accuracy with which the alternating-current supply is maintained at 60 cps. The addition of the synchronous shutter, which affords accurately timed small-interval indications on the film, makes the whole equipment a very accurate and useful form of chronograph even though the film speed of the hand-driven camera may vary slightly. It is readily possible thereby to time intervals to 0.002 second and with care to 0.001 second. Obviously, any other regulated source of current may be used to drive this synchronous shutter, as, for example, an electrically-driven tuning fork.

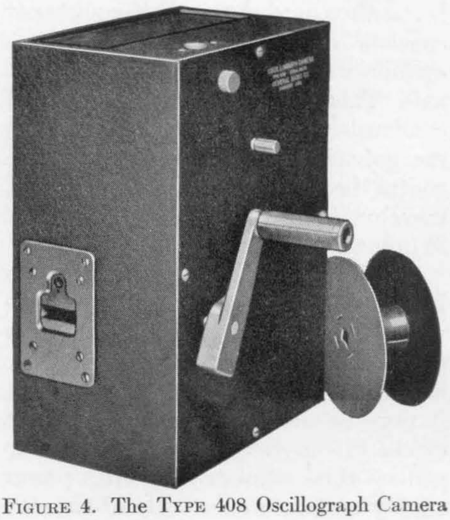


FIGURE 4. The TYPE 408 Oscillograph Camera

With the No. 2 paper, the optical system of the oscillograph provides sufficient illumination for satisfactory photography at any speed up to about 30 inches per second, which is about as fast as the crank may be turned by hand. The camera and oscillograph may readily be used in open daylight, the condensed illumination from the galvanometer lamp being sufficiently intense compared with ordinary illumination. It is best, however, not to have a strong light shining directly into the camera.

The many uses of the camera oscillograph which will suggest themselves to the experimenter may in general be grouped into two classes: first, applications wherein a record of sustained or transient waveforms is desired; and, second, chronographic tests involving the accurate measurement or comparison of time intervals. Double-string records showing two independent phenomena may, of course, be made as readily as single-string records by substituting the double string-holder in the galvanometer.

As examples of the former class may be cited records showing the sound impulses produced by small moving mechanisms such as clocks and watches, records of the sounds produced by heart beats, and records showing the making and breaking action of relay contacts, etc. As examples of the latter class may be cited the timing of seismic waves in geophysical researches pertaining to the location of oil, the accurate comparison of two clocks, and numerous other time-measuring problems. Actual records showing some of these applications are shown in the accompanying illustrations.

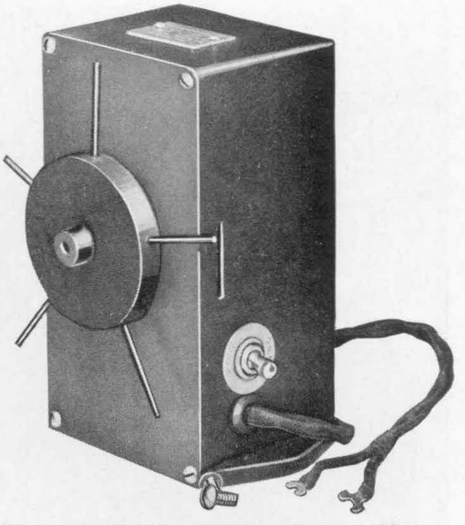
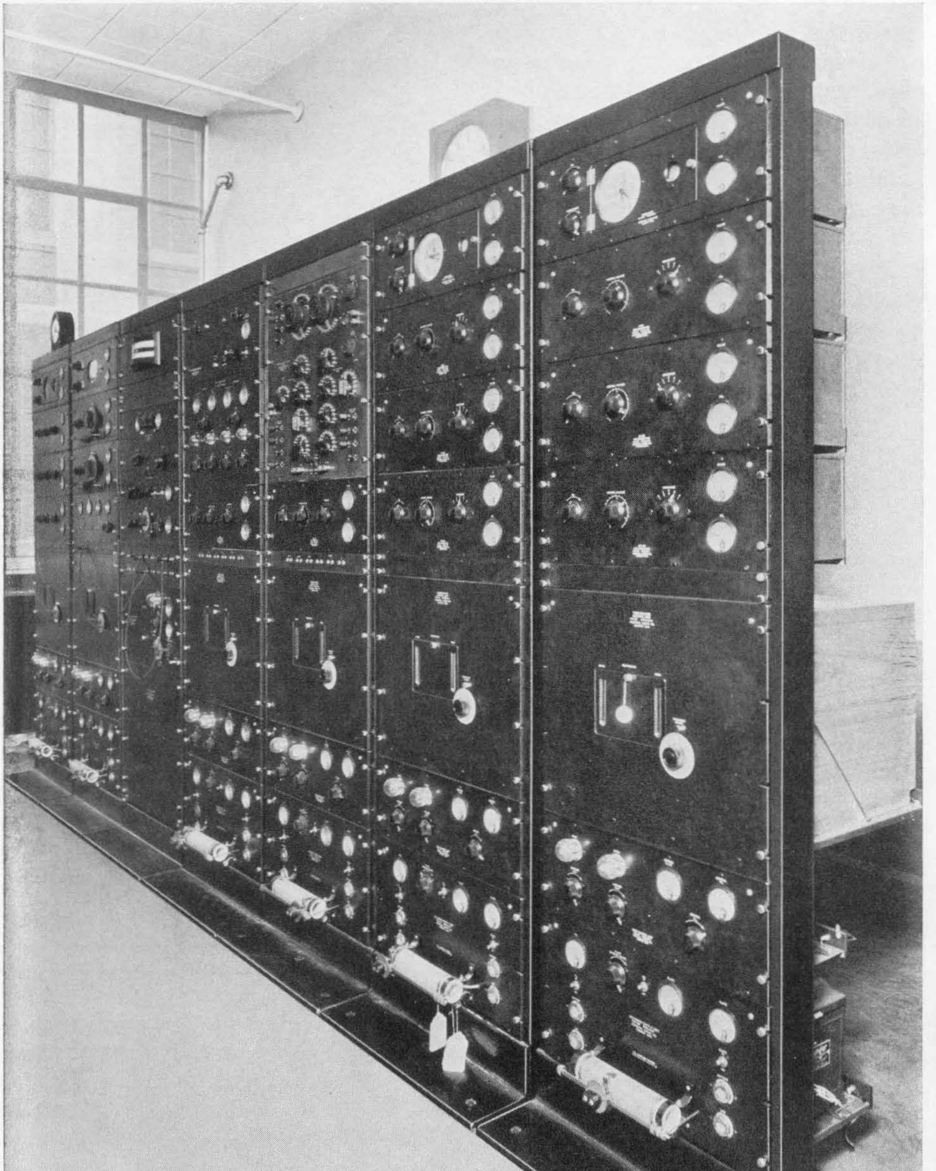


FIGURE 5. The TYPE 407 Synchronous Shutter



The General Radio Company's frequency-standards room. At the extreme left is a relay rack carrying the standard-frequency assembly we use for our own frequency measurements, and at the extreme right are two assemblies being tested before shipment to purchasers. The remainder is experimental equipment

A USEFUL SECONDARY FREQUENCY STANDARD

By JOHN D. CRAWFORD *

CURRENT radio literature places a great deal of emphasis upon the truly remarkable degree of precision in frequency measurements which one can obtain with a primary standard like the ones shown on the opposite page. For a great many purposes, however, a good secondary standard yields all the necessary accuracy. In many college laboratories, in radio transmitter monitoring rooms, and in broadcasting stations, for example, a secondary standard is usually sufficient, especially when used with multivibrators for extending the range.

Last fall, J. K. Clapp, a General Radio engineer, published data[1] showing that under normal conditions, a General Radio TYPE 376 Quartz Plate operating in the broadcast band, would maintain its frequency to within ±10 parts per million, when used in the new TYPE 575 Piezo-Electric Oscillator. He has continued the work with other kinds of plates and finds that a group of specially mounted 100-kc. plates[2] can be relied upon to within ± 4 parts per million. I hope to be able to publish his results in an early issue of the *Experimenter*. It is sufficient for present purposes, however, to realize that a frequency stability of from four to ten parts per million can be expected from commercially available secondary standards.

If a multivibrator is connected to a 100-kc. piezo-electric oscillator, a long series of harmonic frequencies can be made available over a wide band of frequencies. Suppose that — and this is usually the most convenient arrangement — the multivibrator is made to operate at a fundamental frequency of 10 kc., its tenth harmonic being under the control of the 100-kc. oscillator. There will then appear in the multivibrator output circuit harmonics of 10 kc. all the way to the 300th. In other words, the piezo-electric oscillator and the multivibrator yield radio frequencies at 10-kc. intervals from 10 kc. to about 3000 kc., and the frequency of each is known with the same percentage accuracy as the frequency of the 100-kc. oscillator is known; in other words, to within four to ten parts per million.

The importance of a system of harmonics, evenly spaced at 10-kc. intervals, cannot be overemphasized. To the broadcaster it means that he can monitor the frequency of his own or of any other station and, if the Radio Commission shifts his frequency assignment to another channel, there is no need for buying another set of monitoring crystals. To the radio inspector it means that he can measure the frequency of any station which he can hear. To the radio laboratory it means that a reliable source of standard frequencies is available for calibration and frequency measurements work.

There is another feature of this system which is now important and which will become increasingly so as the art of frequency standardization makes progress. By tying in another multivibrator with a fundamental frequency of 100 kc. it is possible to derive a frequency of 5000 kc. which may be checked against the weekly standard-frequency transmission of the U. S. Bureau of Standards. The same scheme is used by Mr. Clapp in the General Radio frequency laboratory for comparing primary standards with WWV, the results of which were described in the last *Experimenter*.

---

* Editor, *General Radio Experimenter*.

[1] James K. Clapp, "The Frequency Stability of Piezo-Electric Monitors," *General Radio Experimenter*, V, October and November, 1930.

[2] As soon as a number of minor details are arranged, the new 100-kc. quartz plate will be formally announced and cataloged.

GENERAL ORDER 106

By CHARLES T. BURKE*

A RECENT General Order (106), of the Federal Radio Commission dealing with the maintenance of a station log, requires checking and recording of the transmitter frequency at 30-minute intervals. The purpose of this measurement is presumably to reveal large changes in frequency, due to loss of control in the case of piezo-control transmitters, or failure to maintain the transmitter frequency when a monitor is being used, or changes due to such contingencies as failure of the temperature-control devices.

While the General Radio TYPE 532 Station Frequency Meter is not suited for use as a secondary standard in present-day practice, it is very well suited to the measurement of small frequency drifts since it may be read to about 20 cycles, that is, frequency differences of 20 cycles may be observed, although the instrument will not retain calibration of this order over any great period of time.

The frequency meter should be checked at intervals against the piezo oscillator (master oscillator or monitor) when the piezo oscillator is known to be operating under standard conditions. It will then constitute an excellent means of observing drifts in the transmitter from the monitor frequency or loss of control in a master-oscillator system.

The TYPE 532 Station Frequency Meter consists of the usual resonance-circuit type of wavemeter with some additional features. A large fixed condenser is shunted across the variable, so that the entire scale of the meter covers only 0.3% of the station frequency, with the station frequency in the center. There are ten scale divisions per kilocycle. In addition to the spread scale, another feature contributes to the accuracy of setting of the TYPE 532 Station Frequency Meter. A small auxiliary condenser may be connected across the main condenser by depressing a push button. The capacitance of this condenser is sufficient to shift the resonant frequency of the meter from one side of the transmitter peak to the other. The frequency meter is adjusted until the galvanometer reading is unchanged when the button is depressed. This method of locating the center or peak of the resonance curve is much more accurate than attempting to set to the top of the curve by observing maximum galvanometer deflection.

TYPE 532 Station Frequency Meter

The price of the TYPE 532 Station Frequency Meter is $130.00.

* Engineer, General Radio Company.

GENERAL RADIO COMPANY
CAMBRIDGE A, MASSACHUSETTS

RUMFORD PRESS
CONCORD, N. H.

The General Radio Experimenter

VOL. V, No. 12 MAY, 1931

ELECTRON OSCILLATIONS

By EDUARD KARPLUS*

WITH regular three-element tubes, oscillations of about 3 meters can be produced without great difficulty. Most of the tubes would oscillate at still higher frequencies, but the output is decreased rapidly. It has been possible to produce oscillations as low as 0.5 meter with special tubes, but these have been only laboratory experiments. One of the difficulties in making a tube oscillate at these high frequencies is the fact that the inter-electrode capacitance of the tube is too high and that it is not possible to build tuned circuits with a high enough impedance. Another difficulty in the circuit is that the time required for the electrons to get from one electrode inside of the tube to another is too long, so that capacitance

* Engineering Department, General Radio Company.

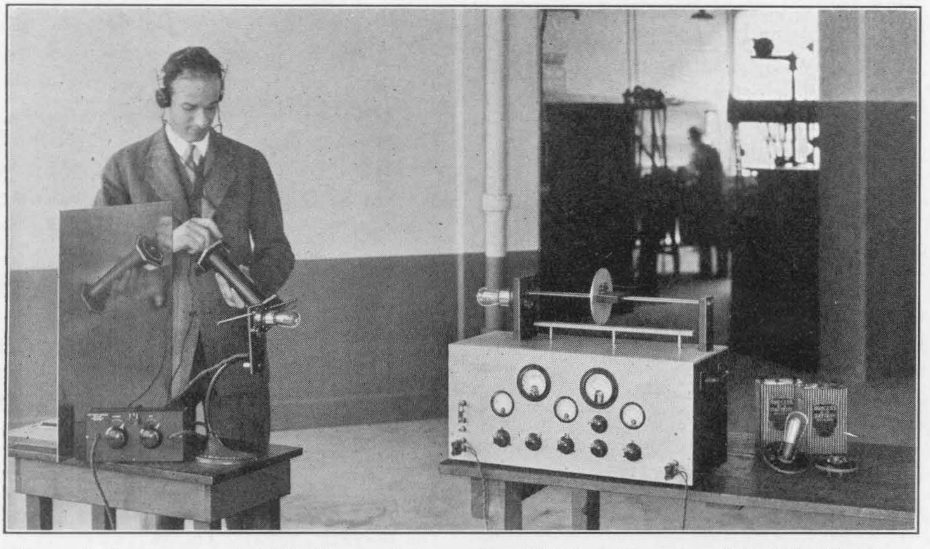


FIGURE 1. An experimental "Barkhausen" transmitter (right) and receiver (left). Mr. Karplus is measuring the wavelength of the receiver with his small reaction-type wavemeter. Two socket adapters are on the table at the right

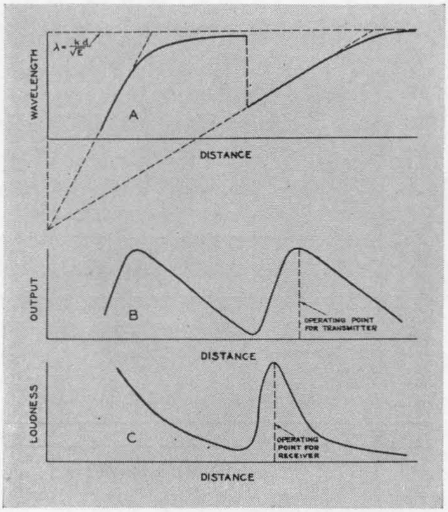


FIGURE 2. Relations between wavelength, power output, and loudness of received signal in an electron oscillator as a function of the "distance" or length of the Lecher wire system

and inductance are no longer the sole frequency-determining elements of the circuit.

An absolutely new method of producing waves in tubes was first described by Barkhausen and Kurz.[1] The frequency of these oscillations is not determined by a tuned circuit, but essentially by the period at which clouds of electrons oscillate in the space between the electrodes of a tube. These are called electron oscillations. The theory of these oscillations is very complicated and the first formula for the wavelength, given by Barkhausen, is only approximately correct.

$$\lambda = \frac{1000\, d}{\sqrt{E}},$$

where λ and d represent wavelength and the distance between electrodes in centimeters, respectively, and E represents the voltage between the electrodes. The formula contains only one distance and one voltage, and, indeed, only two electrodes are necessary to produce electron oscillations. In practical application, however, three-element tubes are used and the third electrode is used to modulate oscillations in a transmitter and to detect oscillations in a receiver. Contrary to the first theory, Gill and Morrell[2] have shown that outside connections to the tube influence the frequency to some extent. A more recent analysis of these oscillations has been given, for instance, by Hollmann.[3]

Figure 1 shows on the left side a receiver and on the right side an oscillator for electron oscillations. The high-frequency part of both of the instruments consists only of the tube and a few parts immediately connected to it. On both sides of the tube the doublet can be seen at the receiver, and at the oscillator these are the two rods at the right side of the tube. A condenser in the form of a round disc can be moved on these rods. The different dials and instruments shown in the two boxes are necessary to control the voltages applied to the tube. Figure 2 shows schematically in its upper part how the wavelength of an oscillator is changed when the system connected to the tube is changed. In the oscillator shown, that system is changed by sliding the round disc on the two rods which form a system of Lecher wires. It can be seen that by increasing the length of the Lecher wires the wavelength is increased almost linearly at first and then reaches a constant value. Then the wavelength drops suddenly to a smaller value, increases again, and reaches the same constant value as before. That process can be repeated over the whole length of Lecher wires.

[1] *Zeitschrift für Physik*, Vol. 21 (1920), 1.

[2] Gill and Morrell, *Philosophical Magazine*, Vol. 44 (1922), 161 and Vol. 49 (1925), 369.

[3] H. E. Hollmann, *Proceedings of the Institute of Radio Engineers*, Vol. 17, No. 2, February, 1929, 229.

We have said that the wavelength of electron oscillations depends on the tube, the voltages applied, and to some extent, on the connected system. To decrease the wavelength, the voltage must be increased. The efficiency of an electron oscillator is very small, however, and by increasing the voltage, the losses in the tube are rapidly increased. In a three-element tube, the electrode which is affected to the greatest extent is the grid which has to dissipate all the lost energy. As the grid of standard tubes is not designed for that purpose, the voltage that can be applied is very limited. With most of the standard tubes, waves of about 40 to 50 centimeters can be attained. The UY-227, for instance, can be used with 60 volts on the grid and oscillates then at roughly 70 centimeters. With 8 volts on the grid, two-meter waves can be produced. A tube that can be used at shorter waves is the old CG-1162,[4] for instance, that oscillates at 40 centimeters when 150 volts are applied. Figure 1 shows three different socket adapters so that different tubes can be used in the oscillator. With specially-designed tubes supplied with a much stronger grid, waves of about 5 centimeters have been attained. The energy available in electron oscillators generally would not exceed 0.1 watt.

We mentioned above that quite a satisfactory theory has been established about electron oscillations, but the question of receivers has not yet been solved, at least theoretically. Besides the crystal detector, none of the other receiving methods used at longer waves can be applied for electron oscillations. It is possible, however, to use an electron oscillator quite efficiently as a receiver when an audio amplifier is connected to the plate circuit instead of the microphone used in the transmitter. It has been possible to communicate with telephony over a distance of twenty miles, using almost the same oscillator on both ends as transmitter and receiver. The two lower curves in Figure 2 show the best operating points when an electron oscillator is used as a transmitter or as a receiver.

Figure 1 shows a wavemeter for 0.5 to 1 meter. It can be seen that the whole inductance of the tuned circuit is built of the same piece of metal as the plates of the condenser. The bakelite tube can be used as a handle and is made long to avoid any capacity influence. The wavemeter is direct-reading and calibrated in wavelengths.

Besides scientific research, such as the determination of dielectric constants at high frequencies, heating and changing of different chemicals, and the biological influence on living substances, waves produced by electron oscillations can be very successfully used in communication. The characteristics of these waves roughly between 10 centimeters and 1 meter are straight-line propagation, a very low noise level, the possibility of concentrating energy, and the possibility of modulating with very high frequencies. Most important is the application in the navigation of ships and aircraft. A system very similar to the beacon system, applied in much longer waves, is used to a great extent. The advantage of the short waves, however, is that a great many stations can operate without interference in a small area as the radiation is much more limited to short distances by nearly optical laws and can be concentrated much more effectively with comparatively small reflectors.

[4] These tubes are now becoming scarce, but we believe that some are still available in salvage stocks. — Editor.

BEAT-FREQUENCY OSCILLATORS

By CHARLES T. BURKE *

THE distinguishing characteristic of the beat-frequency type of oscillator is a wide range of output frequency with a small variation in circuit constants. The output of the beat-frequency oscillator is, with proper design, substantially constant in voltage over the range for which the instrument is designed. An instrument of these characteristics has a number of applications in the fields of test and laboratory measuring equipment. It is particularly adapted to making rapid adjustments in apparatus designed to operate over a particular frequency range and in testing such apparatus. In both of these applications the important feature is the ability to make a large percentage change in frequency by the adjustment of a single control.

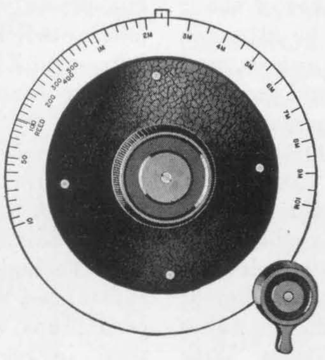


FIGURE 1. Main tuning control for the new beat-frequency oscillator

The desirable qualities of the beat-frequency type of oscillator are obtained by the use of two oscillating circuits. In general, one circuit is of fixed frequency while a means is provided for varying the frequency of the second oscillator. The difference, or beat, frequency is detected and amplified to the desired voltage output of the instrument. By proper choice of the operating frequencies of the two component oscillators, any desired range of frequency may be covered with a change in circuit constants within the limits of conventional design of adjustable inductance and capacitance units. The distinction between this feature of the beat-frequency generator and the operation of a vacuum-tube oscillator appears from a comparison of the factors governing the oscillator frequency. In an oscillating circuit the frequency of oscillation is inversely proportional to the square root of the capacitance and the inductance in the circuit, consequently a given percentage change in frequency requires a percentage change in capacitance twice as great. Mechanical requirements of design of condenser units are such that the change in capacitance required to vary the frequency of an oscillating circuit from, say, 10 cps.[1] to 10,000 cps. would require the adjustment of several controls. In the beat-frequency generator, however, a comparatively small percentage change in one of the component oscillators will make a large change in the difference frequency. If the component oscillators operate, for example, at 100 kc., a change of only 10% in frequency is required to cover the range of 0 to 10,000 cps. The corresponding change in capacitance is one that may be accomplished in a single adjusting unit.

Several formidable design problems are encountered in the construction of a commercial beat-frequency oscillator. The very feature which we seek in the instrument, that is, a large frequency variation with a small change in circuit constants, presents a serious obstacle. If the instrument is to be at all satisfactory, the output frequency must be reasonably stable, yet a change as small

* Engineer, General Radio Company.

[1] cps. is used for "cycles per second" and kc. for "kilocycles per second" throughout.

as 0.01% in the frequency of either of the component oscillators at 100 kc. would result in a 10% change in the output frequency at 100 cps. Variations in frequency due to time and temperature variations in the circuit constants will be greater than this under usual conditions. It was at first suggested that the use of a piezo-electric oscillator for the fixed-frequency oscillator of the system would be of benefit in overcoming this trouble. Actually, the use of a piezo-electric oscillator makes matters worse since it eliminates in large measure the possibility of drifts of the two instruments offsetting each other. Frequency changes, for example, due to battery voltage, affect both oscillators alike if they are similarly constructed. The effect on the difference frequency is greatly reduced. As a matter of fact, the beat-frequency type of generator is inherently unstable as to frequency and while skilful design will reduce such variations, the instrument cannot be made to equal the conventional type of oscillator in this respect.

A second deficiency of the beat-frequency type of generator is likely to be impurity of waveform. This may take two forms: the presence of additional frequencies in the output due to beats between harmonics of the component oscillators, and distortion due to tube-circuit characteristics. The former effect can be reduced by means of careful filtering of the detector output and by care in eliminating any coupling between the two oscillators except that which occurs through the detector. The avoidance of distortion due to tube and circuit characteristics depends upon the correct operation of

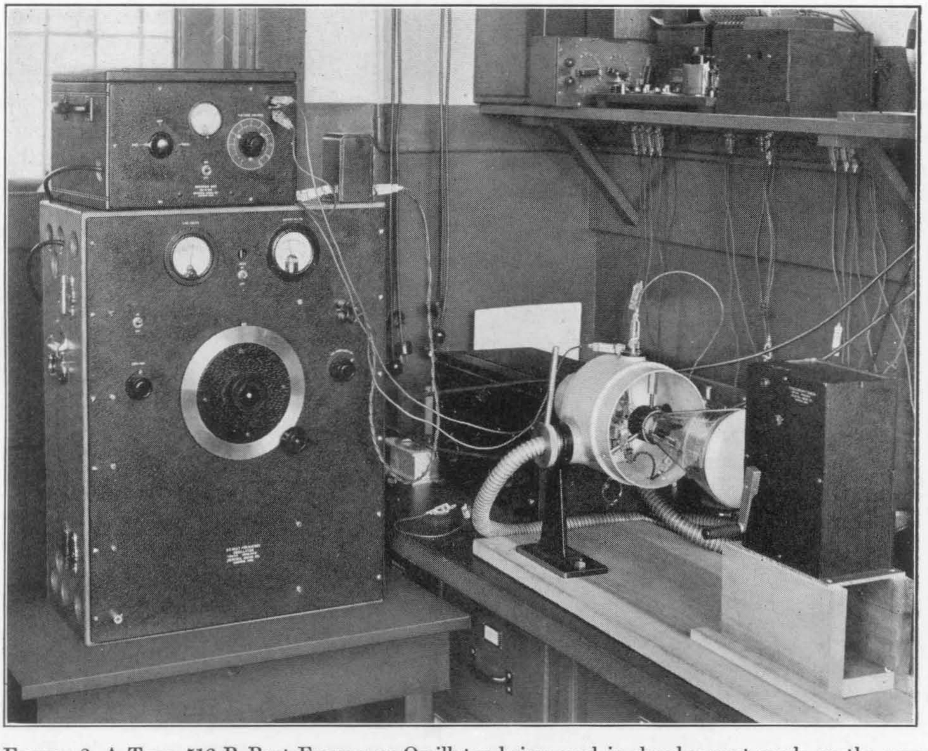


FIGURE 2. A Type 513-B Beat-Frequency Oscillator being used in development work on the new cathode-ray oscillograph which is soon to be announced

tubes, at low levels, and the use of linear circuit elements. Circuits containing iron-cored elements are particularly to be avoided.

The illustrations of this article are taken from a commercial design of beat-frequency oscillator which includes a number of rather interesting features which were developed in order to meet the design difficulties confronted in this type of instrument. This beat-frequency oscillator was developed by Messrs. Eastham and Arguimbau of the General Radio Company's Engineering Department.

In order to reduce temperature effects so far as possible, the portions of the circuit most susceptible to such variations have been enclosed in balsa wood compartments. The heat conductivity of this material is extremely low and by its use the circuits are protected from the effects of minor temperature variations. An effort has also been made to equalize the temperature within the unit by the arrangement of the metallic shelving. The tubes are all placed at the side of the instrument, and the important parts of the circuit are enclosed in an aluminum compartment formed by the shelves. The flow of heat through the walls of this compartment tends to equalize the temperature within the cabinet.

With all of these precautions, however, frequency drifts are still present in the oscillator. In order to correct for the effects of such drifts on the instrument, a zero adjustment has been provided. This consists of a small condenser by means of which capacitance can be added to one of the oscillator circuits in order to restore the circuit condition existing when the instrument was calibrated. As a calibration check on the zero adjustment, a vibrating reed is included in the instrument. The natural period of the reed is about 100 cps. and is accurately determined when the instrument is calibrated. The reed setting is then engraved on the main frequency dial. This provides a means by which the calibration of the instrument may be accurately checked at any time.

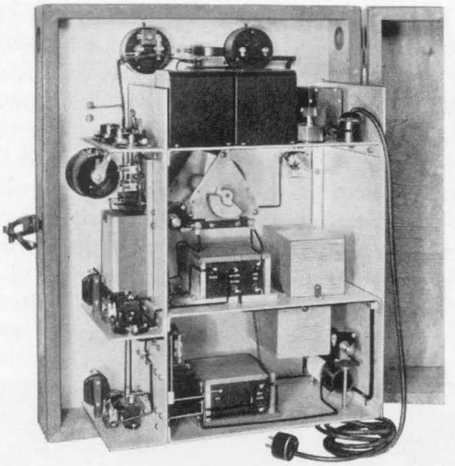


FIGURE 3. Type 513-B Beat-Frequency Oscillator, interior view

The means taken for the elimination of harmonics are not so obvious from the assembly photograph of the instrument. They include the use of filters and the arrangement of parts and wiring. An important feature is the use of toroidal coils in the oscillating circuit. The use of these results in a great reduction in coupling between the oscillating circuits as well as in the stray field of the oscillator itself.

Another interesting feature of this instrument is in the dial. It is desirable to spread the scale as much as possible in order to permit an accurate calibration and an accurate setting to frequency in using the oscillator. A straight-line-frequency condenser with a 270°-rotation has been used and in addition to this a dial of large diameter (8 inches). This combination permits a scale which is open and easily read throughout the range of the instrument.

Miscellany

Your Address

WITH the May issue of your Experimenter we enclosed either a card or a letter which we asked you to return if you wished to remain on the mailing list. We take this opportunity of thanking those who have already replied and of reminding the others that we expect to base our mailing list for the June issue on the results of the returned cards and letters. If you received no such notification, please let us know at once, enclosing, if possible, the envelope in which this issue of the Experimenter was mailed. No enclosures were sent to Canadian subscribers or to those whose names were added after April 1, 1931.

* * * *

New Catalog

EARLY this month we mailed to every one of our laboratory-instrument customers a booklet, Part 2 of Catalog F, which lists the new instruments we have developed since last June when Catalog F appeared. If you are entitled to a copy and have not received it, please let us know.

A supplement to our Parts and Accessories Catalog (Bulletin 932) is in preparation and will be mailed out shortly to all holders of this bulletin.

* * * *

Type 371

THE demand for the Type 371 Potentiometer in the 50,000 ohm size has increased so much that this size is now carried in stock, and we are able to drop the price from $6.50 to $6.00.

* * * *

Standard Inductors

WE have available a very limited quantity of the Type 106-H 5-Millihenry Inductance Standards. These standards are the same as our regular cataloged ones, but are of a discontinued size. They formerly sold for $25.00. We are selling them at $10.00 while they last.

* * * *

Vacuum-Tube Sockets

WE are announcing a new group of vacuum-tube sockets similar to our standard line of sockets except that Isolantite has been substituted for a moulded material. This material is non-porous and has low dielectric loss at very high frequencies and low surface conductivity. These sockets are designed for use where such qualities are of importance, that is, in high-frequency oscillators and in photo-cell work.

Three sockets are being made of this material. The Type 556 Socket has a metal shell and is suitable for mounting four-prong tubes either with or without the bayonet lock. The location of the bayonet lock may be shifted to 45 degrees to accommodate the Western Electric Company's E Tube. The TYPE 657 Socket is designed for standard four-prong tubes and the TYPE 658 for standard five-prong tubes. Both sockets have a raised ring around the tube to guide the prongs when inserting the tube.

THERMOCOUPLES

IN the catalog description of the TYPE 493 Thermocouples it should be noted that the heading over the third column should read "*Current to Give 10 Millivolts Open Circuit,*" and that the current for the TYPE 493-A Thermocouple should be 275 and not 100 milliamperes.

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.

The GENERAL RADIO EXPERIMENTER

VOL. VI. No. 1 JUNE, 1931

ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

VOLUME CONTROL IN VOICE CIRCUITS

THE development of circuits and apparatus for controlling the volume or power level in voice transmission circuits has been a gradual and interesting one. In the modern broadcasting station, sound transcription, and talking motion picture studios, the control of the power level in practically all of the audio-frequency circuits is accomplished by attenuation networks built up of resistive branches.

It is possible, of course, to regulate power level by changing the efficiency of a circuit element such as the microphone or one of the amplifiers. An affect of this sort can be realized by varying the biasing voltage of a condenser microphone, by a change in the direct current through the carbon-button microphone, or by regulating the plate and grid voltages of some of the amplifier tubes. This, however, is obviously not good practice because all such elements are designed to give the most effective performance by lack of distortion, lowest noise level, etc., with fixed electrical values.

Resistive networks can be designed to introduce no distortion of themselves and to give at once precise and almost noiseless control of amplitude.

A typical volume control problem that is encountered in a broadcasting or sound studio might be outlined something like this:

It is desired to control the power output of three studio microphones and an incoming telephone line so that any one of the group may be operated independently of the other, and so that two or more may be worked simultaneously into a high-gain speech amplifier. This calls for a "mixer control panel" on which are mounted four resistive attenuation networks of suitable design. These are termed "mixers" and have two important electrical characteristics. One is that they have a constant impedance as seen from its output and the other that they introduce no extraneous noise into the circuit. Figure 2 shows the diagram of such a circuit.

The mixer controls are of the L type. Attenuation is accomplished by decreasing the shunt resistance at the same time increasing the series resistance by a compensating amount. The

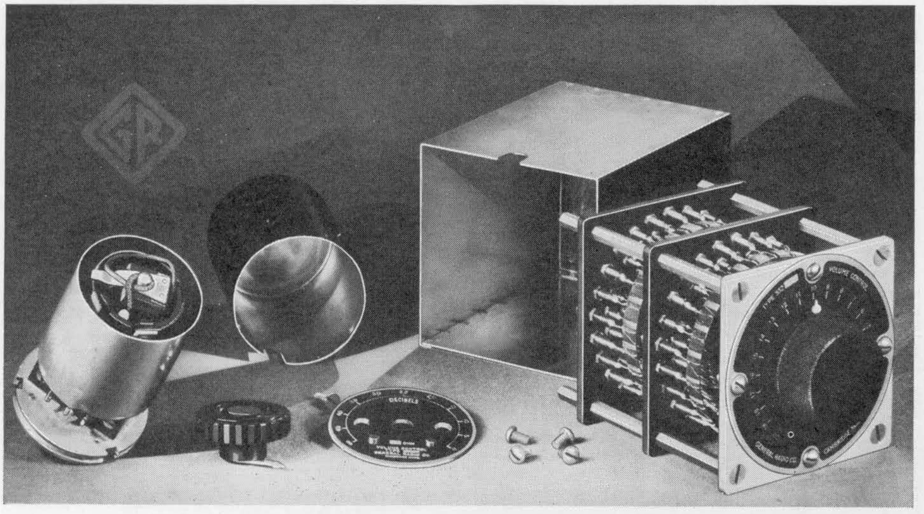


FIGURE 1. General Radio volume controls for recording and broadcast studio use. At the right, the TYPE 552 Volume Control; at the left, the TYPE 652 Volume Control with its dust cover, knob, and dial removed

two switch arms move together and the resistances that they cover for a given angular rotation of the shaft are so chosen that there is no change in the output resistance of the combination regardless of their position. This is very important because if the output impedance did change, all of the remainder of the units would be working into an impedance which varies with the setting of one mixer. Thus their combined output levels would be affected by the setting of any one control.

The impedance of an L-type control on the microphone input side varies widely. This, however, is not important because it simply changes the reflection loss at the junction between the microphone and mixer. Since this loss is taken into account in a properly designed L-type network, it is of no further concern.

In Figure 2 the impedance of the controls is shown as 50 ohms, the four connected in series giving a total impedance of 200 ohms. It is nearly always necessary to have, in the circuit following the mixers, a master gain control. This is to regulate the levels of all of the speech sources together. The customary network for this work is the H-type illustrated. The H-type is chosen because it is possible to obtain good balance to ground of the mixer circuit and the speech amplifier. This balance tends to eliminate to a great extent pickup and cross-talk noises in the leads from the mixer circuit. If the leads are not too long, or if the studio and control room are free from power line disturbances, a T-type network may be used. Both the H- and T-type networks have a constant impedance in both directions. This is also important, because the speech amplifier is designed to work from one definite impedance. A change from this impedance is apt to cause frequency dis-

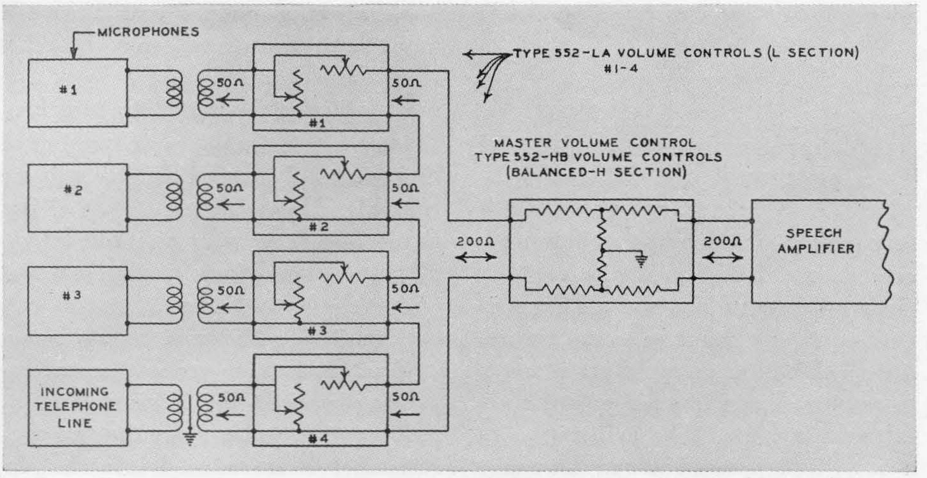


FIGURE 2. Schematic diagram for a typical four-channel mixer and master gain control installation

crimination at the input transformer.

The impedance of the complete mixer circuit is 200 ohms. The impedance of the master gain control is 200 ohms both at the input and output, and the speech amplifier is designed to work from 200 ohms. Thus perfect impedance matching has been accomplished throughout the circuit. The mixer impedance of 50 ohms and the amplifier impedance of 200 ohms have been selected merely because they are common values. The usual output impedance of the microphone circuit is 200 ohms. The proper impedance-matching transformer between this and the 50-ohm mixer has been indicated in Figure 2. If it were desirable to eliminate these transformers or to work at a higher impedance, say 200 ohms, the mixers should be designed for this impedance and connected in the series-parallel arrangement. That is, a pair of 200-ohm mixers connected in series will have an impedance of 400 ohms, and two pairs connected in parallel will have a resulting total mixer impedance of the desired 200 ohms. The usual impedance of telephone lines is about 500 ohms, therefore, a suitable impedance-matching transformer is required here.

As distinguished by mechanical construction there are two general types of volume controls in use. The first is one in which the resistance is made continuously variable by sliding switch contacts across wound wire resistors in the manner of a potentiometer. The other is one in which the control is constructed of a number of small fixed resistors connected to suitable fixed contacts. A switch arm connects these contacts in the proper circuit arrangement and changes the attenuation by discrete intervals. Figure 1 illustrates a balanced-H network of the latter type. Each construction has its own particular advantages. In general, the contact type has a lower noise level, being between 6 and 15 decibels below the slide wire controls. It has a larger contact sur-

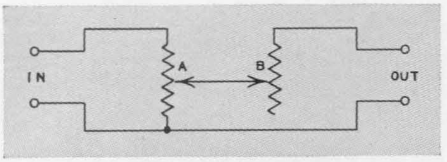


FIGURE 3. This circuit is common in mixer installations

face for the switch and a switch properly designed will wipe the contacts clean of accumulated dust. This is of particular advantage in sound recording work where every effort is made to reduce extraneous noise to the absolute minimum. The calibration of a step-by-step control can be made very accurate without difficulty, and readings can always be exactly repeated. This is important when the over-all efficiency of the system is checked frequently. It is also valuable to be able to do this so that the change in efficiency of the system may be accurately checked when an alteration is made in one of its units.

A step-by-step attenuator should have a considerable number of discrete steps in order to allow for accurate adjustment of the level. The average ear can detect a volume change of about two decibels. It is reasonable, then, that a change per step of this value or a little less should be about correct for a control in a voice circuit. The TYPE 552 Volume Control illustrated in Figure 1 has twenty steps of one and one-half decibels each.

The step-by-step type is almost universally used as a master gain control. As was mentioned previously a relatively complicated H- or T-type network is used in this position. It is of the greatest importance that no failure occur in this circuit since such an accident would probably put a bank of microphones and a speech amplifier out of commission. For this reason this control should be of the most foolproof construction possible.

There are a considerable number of different designs of slide wire volume controls in general use. They differ in mechanical construction but nearly all employ some form of the electrical circuit shown in Figure 3. In this sort of circuit one slider *A* moves along a shunt resistance across the microphone output in the manner of a potentiometer. At the same time a series resistance is introduced into the circuit by a second slider *B* which helps to compensate for the decreasing impedance as seen from the amplifier side as the switches move downward toward zero output. The series resistance also puts some additional attenuation into the circuit. This circuit, or a variation of it, has been in use for a long time and has proved to be reasonably satisfactory.

The principal cause of trouble in a slide wire volume control is the noise which it is apt to bring into the circuit. They are used at places having a very low power level and are followed by a large amount of amplification. For this reason any small noise caused by moving the control is immensely increased and consequently every effort is made to keep it at a low level. There are four important sources of noise in a slide wire control:

1) The contact potential resulting, if the slider and the wire are of different materials. Unlike metals placed in contact with one another in air will generate a feeble e.m.f. which is enough to be very noticeable and annoying under some conditions.

2) Small dust particles getting between the slider and the wire thus causing a momentary increase in resistance or even an open circuit.

3) Ordinary electrostatic pickup in the winding which is usually introduced by hand capacitance.

4) The difference in potential between adjacent turns of wire produces a small click as the slider progresses from one turn to the next.

The contact potential trouble may be corrected by using similar metals for both the resistance wire and the slider.

A good dust cover and an occasional cleaning with carbon tetrachloride helps to correct the difficulty from noise due to dust and dirt. The electrical pickup can be largely eliminated by a shield around the windings and by placing them a little distance from the panel so as to insure a fair separation from the operator's hand. Winding the resistor unit with a large number of turns of small wire reduces the potential difference between turns to a very low value and, if carried to a limit, will practically eliminate the trouble. The limit is when the wire size becomes too fine for ordinary handling and wear.

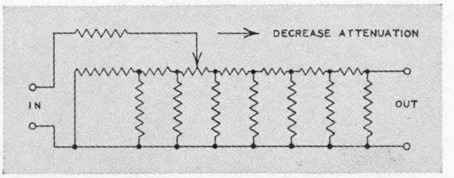


FIGURE 4. The ladder network has several advantages in mixer work. It is used in the new TYPE 652 Volume Controls

The ladder circuit shown in Figure 4 is admirably suited for microphone mixer and other volume control uses.

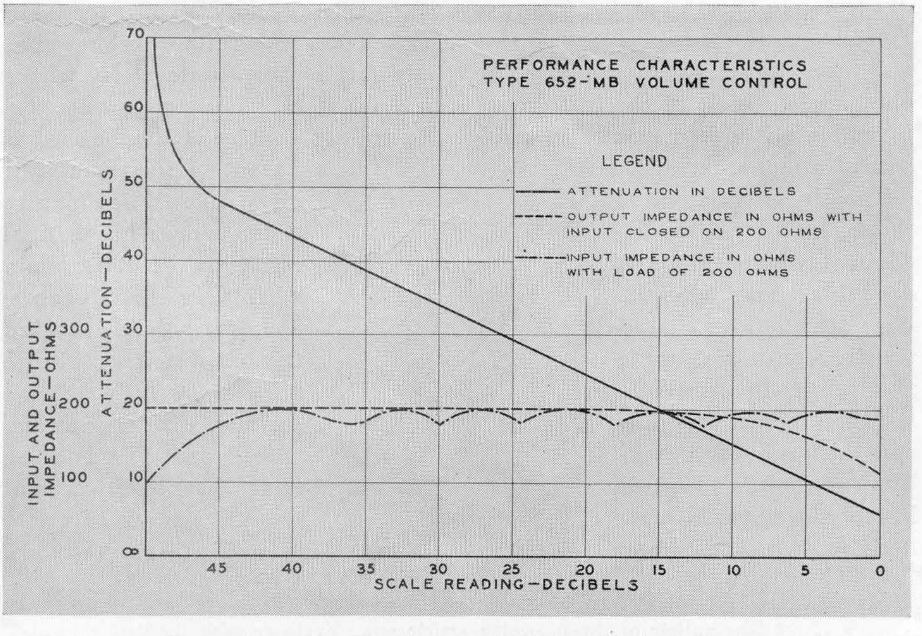


FIGURE 5. Terminal impedances and attenuation for a 200-ohm ladder type volume control as a function of scale reading

FIGURE 6. A dial from a TYPE 652 Volume Control

This type of network has been used for some time in attenuators of General Radio standard-signal generators. Its application in a modified form to volume control devices in audio circuits was suggested by W. Robert Dresser of Paramount News, Inc.

It has been utilized in the new General Radio Type 652 Volume Control illustrated in Figure 1 and in Figure 6. The electrical characteristics of this unit are shown in Figure 5. The photo-etched scale of the instrument is calibrated approximately in decibels of attenuation and is linear.

The linear attenuation characteristic will be noted as being particularly desirable. This straight-line attenuation characteristic continues up to about forty-five decibels, and then increases rapidly and uniformly to cut-off. The minimum insertion loss of the network is six decibels, which is lower than in most controls of this type. The output impedance remains constant over the greater part of the scale and drops to a minimum of 120 ohms. The fact that the impedance does not change from 200 ohms at infinite attenuation is valuable because if several units, such as microphones, are set at zero output they will cause no impedance change in the system.

The input impedance varies around 200 ohms with a total change of only 12 ohms from 0 to 45 decibels. At cut-off the input impedance is 100 ohms. When working from a microphone circuit it is not necessary to keep the impedance constant, providing that the reflection loss is considered in the calibration, but the fact that the impedance does stay so constant suggests that the unit may be used in any circuit where an approximately constant impedance in both directions from a control is necessary.

The ladder type of network requires only one sliding contact. By wiring to the switch by a pigtail connection, the sliding contact at the bearing is also eliminated. The resistance card on which the slider moves has a total resistance of 1200 ohms. This high resistance makes it possible to wind the card with a large number of turns of fine Advance wire. The switch itself is of Advance metal backed by a stiff phosphor bronze strip to insure a firm contact.

ARTHUR E. THIESSEN

The author of the foregoing article is an engineer with the General Radio Company. Volume-control and volume-measurement problems are two of his specialties

MISCELLANY

YOUR ADDRESS AGAIN ▲ ▲ ▲ So heavy has been the return of letters and cards sent out with the April *Experimenter* that our mailing room has been swamped. We had hoped to base the mailing list for this issue on the returned letters and cards, but we are deferring this action for another month.

If you wish to continue receiving the *Experimenter* and have not already indicated your desire to continue, please do so at once. A card mentioning your name and address as it appears on the envelope enclosing this issue will do the trick, if you didn't get a letter or card in April. New readers and those residing in Canada may safely ignore this suggestion.

✦ ✦ ✦

RADIO SHOW ▲ ▲ ▲ Not everyone interested in General Radio instruments visited our demonstration at the Radio Manufacturers' Association Trade Show in Chicago. It is for the benefit of those who did not that the following brief description of our exhibits is presented:

Descriptive articles about each instrument will appear in future issues of the *Experimenter* as well as in a series of catalog supplements. The latter will not, as in the past, be mailed to all of our laboratory instrument customers until the fall when Part 3 of Catalog F will be issued. In the meantime, catalog supplements may be had on request. Ask for them by the number (*e.g.* F-300-X) appearing at the end of each of the following descriptive notes.

Volume Controls — A small wire wound unit for use as a mixing control in the recording or broadcast transmission studio has just been developed. Quietness, uniformity of attenuation variation, and constancy of terminal impedance are its features. (See the article in this issue of the *Experimenter* or send for "F-300-X.")

Standard-Signal Generators — One of the new units is an inexpensive, yet accurate, instrument for measuring receiver sensitivity in production and for maintenance work on high-frequency police and airplane-beacon receivers. Frequency range: 90-6,000 kc.; output range: 1-150,000 microvolts.

The second unit was designed for rapid and precise measurement of sensitivity, selectivity, and fidelity of receivers in the broadcast band. Its important applications are in circuit development work and in making thorough sampling tests on the production line. Output range: 0.1 to 316,000 microvolts.

Both instruments are described in "F-306-X."

Cathode-Ray Oscillograph — The General Radio oscillograph consists of a new tube, a mounting for it, and a power-supply unit for operating the tube from the alternating-current line. Extreme brilliance of the images, long tube life, and alternating-current operation are the principal features. (Send for "F-303-X.")

MISCELLANY — Continued

Output Meters — With the aid of a more sensitive meter, output meters similar to the TYPE 486 Output Meter are now being built with impedances of 8,000 and 20,000 ohms as well as 4,000 ohms. (Send for "F-302-X.")

Audio Oscillator — This is an alternating-current operated oscillator with high output (0.5 watt) giving frequencies of 200, 300, 400, 600, 800, 1000, 1600, 2000, 3000 and 4000 cycles per second. (See "F-304-X.")

Laboratory Amplifier — Operating from self-contained dry batteries, this unit has the stability and high gain necessary for adapting photo-electric cells to photometric and other measurements. (Send for "F-301-X.")

The General Radio Company mails the Experimenter, without charge, each month to engineers, scientists, and others interested in communication-frequency measurement and control problems. Please send requests for subscriptions and address-change notices to the

GENERAL RADIO COMPANY
30 State Street
CAMBRIDGE A, MASSACHUSETTS

PRINTED IN U.S.A.

The GENERAL RADIO EXPERIMENTER

VOL. VI. No. 2 JULY, 1931

ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

WHAT'S NEW IN RADIO

IN previous years, the main interest at the Trade Show of the Radio Manufacturers' Association has centered in technical developments of various sorts which have traced the development of radio receivers. In these shows the number and types of tube, the type of loudspeaker, and similar features have attracted great interest. Whole years have been identified by such developments as power tubes, alternating-current tubes, screen-grid tubes, and dynamic speakers. The prevailing emphasis at this year's show seemed to be price rather than any technical development. The price range is wide, with many receivers available at $40.00 to $60.00, complete with tubes. One receiver was shown at approximately $10.00.

As might be expected, no marked performance improvements occur in these sets as compared with the higher priced sets current in previous years. The sensitivity of the characteristic receiver this season is in the neighborhood of 30 to 50 microvolts—materially less than that of previous seasons. Considerable sacrifice of fidelity has undoubtedly been made in a number of cases. Selectivity seems to be reasonably well maintained. Whether or not radio presents better values than previously is a difficult question to answer, since we are dealing with intangibles. The user must answer for himself the value in dollars of an increase in the effective reproducing range of a receiver.

A number of interesting technical developments appear in this year's receiver and contribute materially to the price levels, although it would seem that little advantage has been taken of the possibilities of these developments in improving performance as distinguished from performance at a price. The superheterodyne circuit is almost universally used. The emergence of this circuit is, of course, not due primarily to a technical development, but to the release of the patents which have been available to RCA licensees only since last August. The outstanding advantage of the superheterodyne receiver is improvement in selectivity and, in particular, a gain in uniformity of selectivity over the tuning range of the receiver. The commercial models of receivers having this circuit do not seem to be any more sensitive than those of previous years using the tuned radio-frequency circuit.

Another development which is incorporated in a number of receivers is the so-called variable mu tube. This is a recently developed vacuum tube in which the amplification factor is a function of the signal voltage impressed on the tube, the amplification factor decreasing as the signal voltage is increased. The effect of this tube is to limit increases in volume and to decrease crosstalk and distortion in the radio-frequency stages of the receiver.

Another technical development is the pentode or five-element power tube. This tube greatly increases the power-handling capacities of a stage of amplification using a single tube and greatly reduces the cost of the audio amplifier for a given output. An increase in phonographic attachments and accessories is noticeable. A large variety of automatic record changers of various types were on display. Home "talkie" equipment was shown by a number of manufacturers.

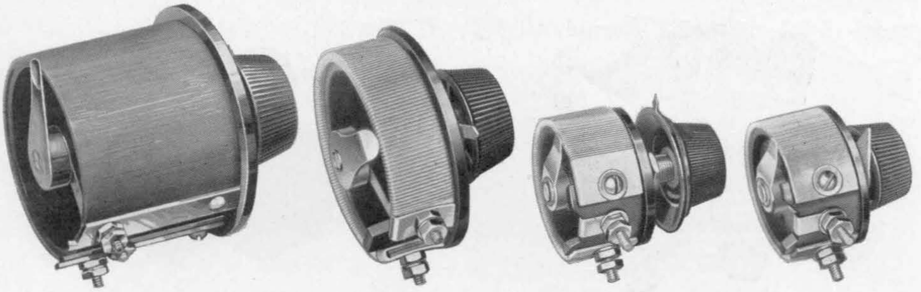
The public interest in television is obviously intense. Developments along this line continue to progress slowly. Demonstrations of two types which are in operation in connection with regular broadcasts were given. The principal advance has been the increase in area of the receiving screen and also the increase of the receiving field to the point where full length figures may be reproduced. When one ponders on the probable type of television program of the future in the light of present audible broadcast programs, one wonders if the vast amount of time and effort being put into the development of television could not be directed in a more useful and productive channel.

CHARLES T. BURKE

The author of these comments on the R. M. A. Trade Show is a veteran attendant at radio shows. He is an engineer with the General Radio Company

BEST SELLERS

NINETEEN HUNDRED AND TWENTY-FOUR and its desperate efforts to keep up the weekly production of condensers seems long ago. The growth of radio from hobby to industry is well illustrated as it is reflected in the following illustrations of a small condenser and a standard-signal generator. In 1924 the General Radio Company was selling condensers and transformers by the hundred thousands while preaching constantly the



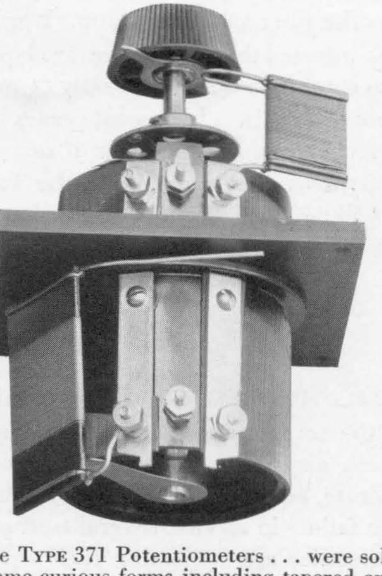
" . . . the rheostat-potentiometer group. . . . " Left to right are arranged the TYPE 371, TYPE 214, TYPE 410, and TYPE 301 Rheostats and Potentiometers

gospel of better laboratory methods to the few receiver manufacturers of that day. Most of the laboratory equipment, however, was sold to governments. One of the largest orders for laboratory equipment that year came from Japan, to replace apparatus destroyed in the great Tokyo earthquake. A business in laboratory equipment that was already large in '24 has grown with changes in the industry until now it forms the company's main objective. Many radio companies have come and gone in those seven years, but it is interesting to note that our largest accounts in the instrument field at that time are still the large accounts in 1931.

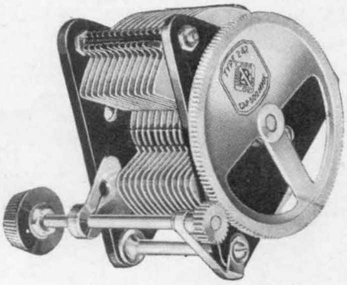
As radio came out of the kitchen and great manufacturing companies were organized to develop it, great sums were spent on developing the art and in perfecting manufacture. Gradually the emphasis shifted until this year our best seller, instead of a small condenser costing $5.00, is a complicated piece of laboratory equipment costing $600.00. Much radio history is summed up in that transformation. Need we add that the comparison is made not in units but in dollars.

Changed hardly less than our product is the plant and organization. Interesting years — years of change and growth usually are. Midnights when trucks stood in the driveway while equipment passed from work bench to test laboratory (and sometimes, alas, to work bench again) to shipping room and to waiting truck—to be in operation in the morning three hundred miles away.

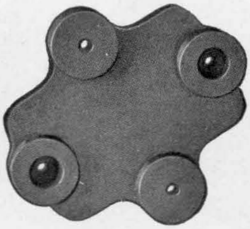
Curiously enough some parts are selling better than ever before, mostly to manufacturers who use them in assembling laboratory and testing equipment. Thus the combined total



"The TYPE 371 Potentiometers . . . were sold in some curious forms including tapered and compensated windings"



"The old TYPE 247 Condenser has fallen far from the days of its glory"



"In every race there has to be a finalist. . . ." The TYPE 309 Socket Cushion

of the rheostat-potentiometer group actually tops the signal generator. It also exceeds the precision resistor group. The TYPE 214 Rheostat was the best seller of the group, being largely used as current controls. The TYPE 371 Potentiometers ran a very close second. They were sold in some curious forms including tapered and compensated windings. This instrument is used very extensively for volume controls.

Far ahead in number of units, though only tenth in dollars sales, was the plug and jack group. It must be confessed that one of our rare lapses into commercialism was partly responsible for this. In recent years we have been equipping most of our apparatus with terminals to fit the TYPE 274 Plugs. The attention of purchasers is thereby forcibly attracted to the convenience of the plug connectors and the habit is soon formed irrevocably. The plugs have found all sorts of uses both in our own laboratories and in others. They have been also adapted on some of our standard equipment, and are sold in a number of convenient combinations. The ingenuity of the user suggests new combinations constantly.

The old TYPE 247 Condenser has fallen far from the days of its glory. A 1924 week's production would last five years now. While the condenser group was fifth, the TYPE 247 Condenser was topped by several types of laboratory condensers.

In every race there has to be a finalist — evidently the 1931 tube does not require much cushioning.

AIRPLANE BEACONS ▲ ▲ ▲ Because of the severe service conditions under which airplane beacon receivers must operate, and because of the seriousness of a failure in service, several transport companies are subjecting their equipment to rigorous inspection tests at regular intervals. Sensitivity is the most important point to be stressed, since most of the difficulties caused by aging tubes, condensers, and resistors show up in this measurement. The new TYPE 601-A Standard-Signal Generator was designed for this service.

THE CALIBRATED VOLTAGE DIVIDER

One of the most annoying jobs encountered in a small laboratory is that of obtaining accurate static characteristics of vacuum tubes. Usually it consists of varying a grid bias—by a tapped battery, for instance—observing the value of this bias on a voltmeter, and then measuring the plate current. By the time the grid voltmeter has been read, and the voltage adjusted to even values so as to make curve plotting easy, the vacuum tube may have aged somewhat and its characteristics changed. Where precise and rapid measurements are required, some simple means of obtaining the desired grid voltage in decimal steps is required.

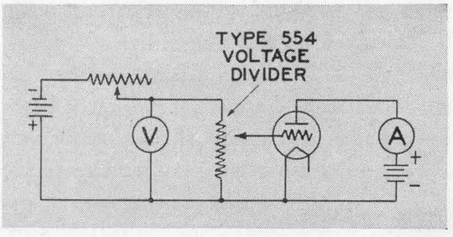


FIGURE 1. Circuit for taking grid voltage, plate-current characteristics of a vacuum tube. A calibrated voltage divider facilitates many measurements of which this is a simple example

The need for a voltage source adjustable in decimal steps is by no means confined to the problem just mentioned. In fact this one problem is typical of a host of others that frequently arise, and enough of them occur in routine laboratory measurements to justify our designing a suitable instrument.

This instrument is the General Radio TYPE 554 Voltage Divider. It is a calibrated potentiometer in which the use of tapped precision resistors permits obtaining any decimal voltage ratio between 0.001 and 1.000 from a source of either alternating or direct current. It is the practical equivalent of the expedient adopted by many laboratory workers when they use two decade resistance boxes connected in series. To make adjustments in this case, the total resistance is maintained constant by removing from one box the same value of resistance added to the other. This method is obviously entirely feasible,

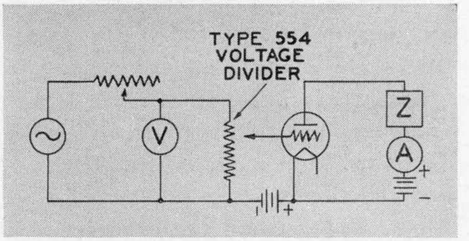


FIGURE 2. Many quantitative studies of detector behavior may be worked out in low-frequency "model" circuits. This diagram shows how plots of plate current, as a function of carrier voltage, are obtained

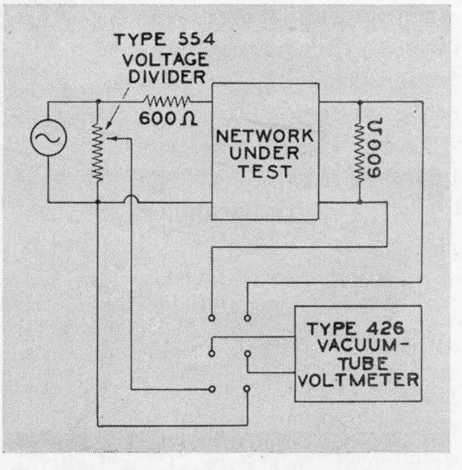


FIGURE 3. Circuit for measuring the loss in a network having terminal impedances of 600 ohms. The voltage divider, in this set-up, indicates directly the voltage ratio when the voltmeter reads the same for both positions of the switch

but it has the disadvantages of being clumsy to manipulate and of requiring vigilance to make sure that the sum of the two resistances remains constant.

Four typical uses for the voltage divider are shown in the accompanying diagrams. Figure 1 represents the taking of vacuum-tube characteristics. Figure 2 shows how the behavior of a detector tube may be investigated by the use of a low-frequency carrier. In the model circuit, *Z* has the same value (magnitude and phase angle) at the low frequency as the load circuit would have at the true carrier frequency. Inter-electrode capacitances in the tube are neglected, but even these may be simulated by suitably placed condensers of the proper value.

A way of measuring the insertion loss of a network is shown in Figure 3. This gives the loss directly as a voltage ratio which may be converted into decibels if desired. If the voltage divider be placed in the vacuum-tube voltmeter circuit, the arrangement becomes suitable for measuring voltage gain.

Figure 4 shows the usefulness of a decade voltage divider in experiments on gaseous conduction. In the example it is desired to find the value of potential V_g through which electrons emitted from the cathode must fall to ionize the gas inside the tube. When ionization occurs, the positive ions are attracted to the negative "plate" and current flows in the electrometer circuit.

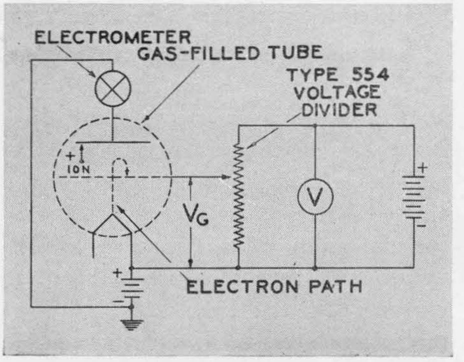


FIGURE 4. A schematic representation of a typical ionization potential measurement. The ionization potential for the gas in question is the value of V_g, which is just sufficient to produce ionization as shown by deflection of the electrometer

These are only a few of the possibilities of the TYPE 554 Voltage Divider, but they are enough to demonstrate the fact that it is a handy laboratory accessory.

JOHN D. CRAWFORD

The author of these notes on the decade voltage divider is an engineer with the General Radio Company and the editor of the EXPERIMENTER

BRIDGE WORK ▲ ▲ ▲ Preliminary experimental work here in the General Radio Company's laboratories indicates that the combination of a stable amplifier (like the TYPE 514-A Amplifier), with an output meter, compares favorably with the vibration galvanometer as a null detector in bridge measurements. The amplifier-meter combination has, moreover, certain advantages in price and in freedom from tuning difficulties.

JUDGING METERS ▲ ▲ ▲ Output meters and other meters having multipliers should be so designed that they have a practically constant percentage accuracy. This can be evaluated when judging the suitability of such a multi-range meter by plotting the full-scale values for the different multiplier settings on logarithmic paper. The points obtained should be approximately equally spaced. The new General Radio Type 483 Output Meters closely approximate this ideal.

SIMPLE TUBE TEST ▲ ▲ ▲ A tube manufacturer has suggested a new use for the General Radio Type 404 Test-Signal Generator. Arguing that the only interesting fact about a tube is whether it will or will not function normally in a set, the suggestion is made — why not try it in a set? Of course such a test is not conclusive if the tube is just stuck in the set and the set tuned to a broadcast station and a listening test applied. If, however, the receiver checked for input required to give normal output, the tube performance is very accurately checked, and noise may be observed at the same time. The tube may be checked in its normal position in the receiver, and the receiver takes care of the supply of proper voltages.

We suggest the use of a Type 404 Test-Signal Generator and Type 486 Output Meter (equipment which we trust is available in every well equipped service laboratory). The input is adjusted and output measured for each tube, and defective tubes are shown up, or good tubes vindicated in a manner certainly more convincing to the customer than any tube tester provides.

THE GENERAL RADIO COMPANY ***mails the Experimenter, without charge, each month to engineers, scientists, and others interested in communication-frequency measurement and control problems. Please send requests for subscriptions and address-change notices to the***

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PRINTED IN U.S.A.

The GENERAL RADIO EXPERIMENTER

VOL. VI. No. 3 AUGUST, 1931

ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

SPEEDING UP THE STANDARD-SIGNAL GENERATOR

This article describes the mechanical features of a new precision standard-signal generator which materially speeds up routine standard measurements on broadcast receivers. The next article by the designer of the instrument discusses its electrical features

A YEAR or more ago, the General Radio Company began a study of measurement technique in the development and design laboratories of the radio industry. Attention naturally focused on the standard-signal generator and its accessories, since one of the set designer's most pressing problems is the evaluation of his models by means of the standard I.R.E.-R.M.A. broadcast-receiver tests. These tests even take precedence over many important details of design, because every engineer is a member of a commercial manufacturing organization whose management must be kept informed of the performance of its product in competition with that of other companies in the field.

Conferences with representative engineers in the industry shortly uncovered the fact that improvements in both the electrical and mechanical design of standard-signal generators would be welcome. Electrical improvements would include such points as the minimizing of frequency modulation, the so-called fly-wheel effect, and stray fields. Mechanical improvements would include a rearrangement of controls so that the standard tests could be made with greater speed. This would involve something of the same kind of transformation that radio sets went through in their progress from the "three dial" to the "single control" stage.

The result of the study was the new Type 600-A Standard-Signal Generator in which many radically new ideas in electrical and mechanical design were worked out.

* * *

Any increase in the speed of manipulating a standard-signal generator must, of necessity, be dependent on the operation of two controls: the output voltage adjustment and the frequency adjustment. A third, the frequency control of modulation voltage for fidelity tests, must also be considered, even

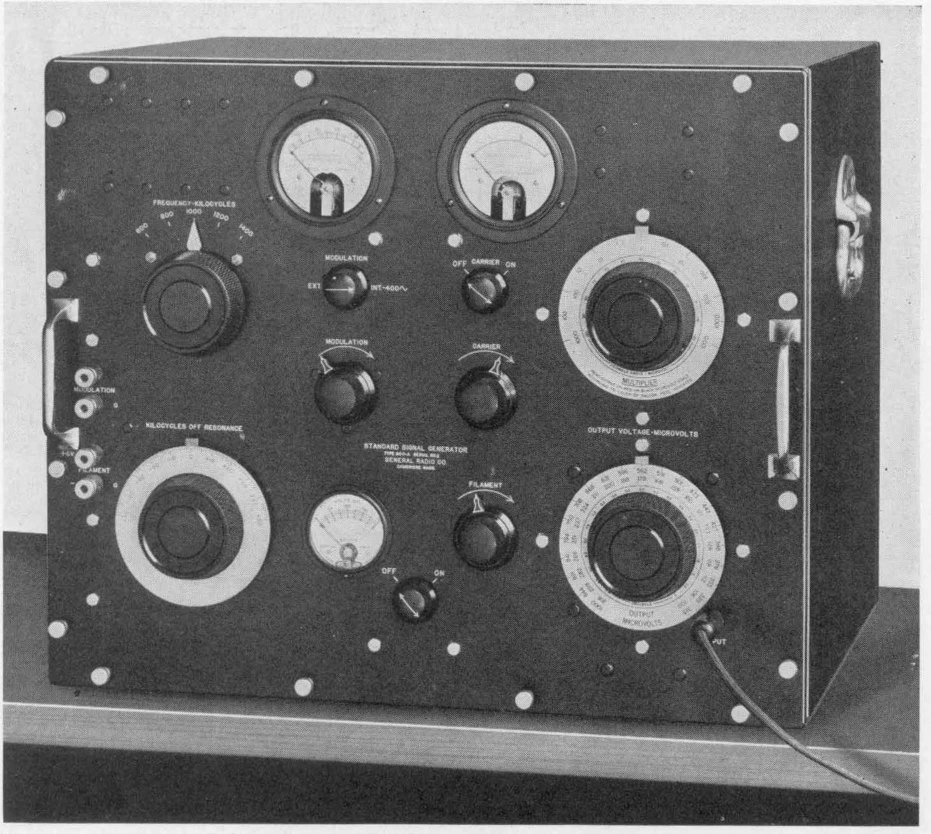

FIGURE 1. Panel view of the TYPE 600-A Standard-Signal Generator. At the upper left is the channel selection switch and immediately below it the selectivity or "kilocycles-off-resonance" control. At the right is the two-stage attenuator shown in detail in Figure 3 and to the left of it the voltmeter for indicating attenuator input

though this audio-frequency source is not usually a part of the standard-signal generator proper. This point can be disposed of at once by noting that the recently developed TYPE 513-B Beat-Frequency Oscillator meets all the usual modulation-source requirements as to power output, purity of waveform, and ease of manipulation.

A study of the different methods for adjusting the output voltage of a signal generator showed that a marked increase in speed could be obtained if an attenuator were built to cover the entire range in small enough discrete intervals to make reading a meter unnecessary. Previous practice had been to use the attenuator only as a multiplier for the ammeter or voltmeter indicating the attenuator input. This was excellent for certain types of work but a great handicap where speed is essential. This was due not only to the necessity for an added control but to the fact that interpolating on a meter is a time-wasting process.

When the actual design of the attenuator for the TYPE 600-A Standard-Signal Generator was considered, it was found that the decibel or logarithmic type had many mechanical advantages. The logarithmic attenuator is not only easier to build, but it makes possible incremental variations in accordance with Weber's law for the response of the human ear to an exciting stimulus. This fact was recognized when the standard I.R.E. plotting paper was laid out, since output voltages, which are the ordinates on the selectivity and sensitivity and band-width charts are arranged logarithmically. Another advantage appeared in the making of selectivity test, and this will be referred to later on.

A clue to the solution of the frequency-adjustment problem was furnished by the specifications for the I.R.E.-R.M.A. standard tests. These standards recommend the testing of broadcast receivers for sensitivity and fidelity at 600, 800, 1000, 1200, and 1400 kc., and the testing for selectivity and band-width at 600, 1000, and 1400 kc. Since only these frequencies are required, the obvious solution was to build an oscillator whose frequency was adjustable to the desired values by means of a switch. This eliminated all calibration charts and the loss of time occasioned by changing from one frequency to another. Later on it was also found that this permitted simplifications in the arrangements for taking band-width and selectivity runs.

By making selectivity tests at the three standard frequencies only, we could include an auxiliary dial controlling three straight-line-frequency condensers, one for each test frequency. Then, by building a switching arrangement into the main channel selector switch, the frequency adjustments for all tests were reduced to their simplest terms.

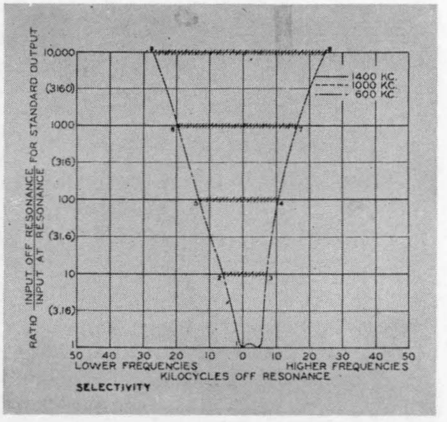

Figure 2. A selectivity curve, one of three made by the writer in three and one-half minutes with the Type 600-A Standard-Signal Generator. The horizontal bar lines represent band widths for their respective values of input to the receiver under test

The significance of these radical changes in the design of the output and frequency-adjustment controls can best be appreciated by noting the important fact that these adjustments give, respectively, the ordinates and abscissae on the plotting paper for all of the standard I.R.E. tests. These materially speed up the curve-plotting operation; in fact it is entirely feasible to take data directly on the plotting paper.

To show the possibilities of the new mechanical design, the writer, without previous experience, made a three-channel selectivity run on a commercial broadcast receiver in three and one-half minutes, using the Type 600-A Standard-Signal Generator. This involved the taking of nine points on each of three channels, a total of 27 separate measurements.

Figure 2 shows the curve for the 600-kc. channel as plotted on paper, which differed from the standard I.R.E. paper in two respects only: the "kilocycles-off-resonance" scale was ex-

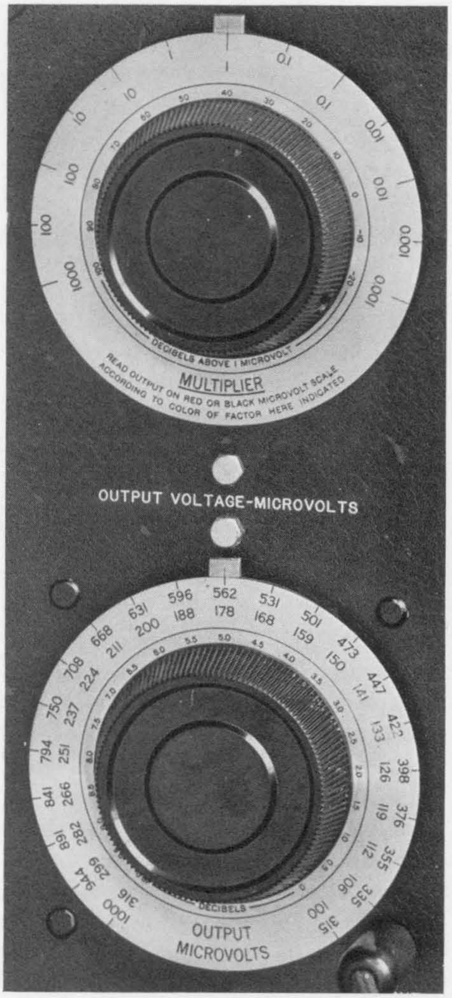

FIGURE 3. Output voltage controls for the TYPE 600-A Standard-Signal Generator. The dials are now set for 178 microvolts or 45.0 db above a reference level of 1 microvolt. If the upper dial were moved clockwise one division, the output would be 562 microvolts or 55.0 db

tended to 50 kc. instead of 30 kc., and an intermediate set of ordinates was inserted between the lines representing ratios of 1, 10, 100, 1000, and 10,000. The "kilocycles-off-resonance" scale was extended because the selectivity control on the TYPE 600-A Standard-Signal Generator spans that range. The intermediate scale of ordinates was inserted to enable us to make a curve having a greater number of points than are called for in the standard testing specifications. These were not used in the test we are discussing, the numbered points only being taken. The small hump located at the base of the curve was taken in another test as proof that 6% voltage increments could give all necessary detail.

The logarithmic or decibel control of output voltage on the standard-signal generator is arranged as shown in Figure 3, the steps of the upper scale being placed at intervals of 10 db, and the steps of the lower scale being placed at 0.5-db intervals. Therefore, turning the upper knob increases the output voltage 3.16 times for one step and 10 times for alternate steps; turning the lower knob increases the output voltage by about 6% for each step.

Since the output level for successive ordinates on the standard selectivity curve increases 10 times for every interval, it may be seen at once that the process of taking a selectivity run with the new standard-signal generator has been simplified considerably.

Refer to Figure 2, for example. Point No. 1 is obtained by setting the channel selector at 600 kc., and the "kilocycles-off-resonance" dial at zero, then adjusting the output voltage until standard output is obtained. The value of voltage thus obtained, is, incidentally, the sensitivity of the receiver at 600 kc.

Then the upper attenuator dial is advanced two steps which gives an "off resonance" to "at resonance" ratio of 10 to 1. Point No. 2 is obtained by turning the selectivity control until standard output is restored, after which the control is turned to the high frequency side to obtain Point No. 3. This process is repeated until all nine points have been obtained, when the curves for 1000 kc. and for 1400 kc. may be run.

On most receivers the overload point is sufficiently low to protect the output meter from damage as the dial is swung through resonance on its way from Point No. 2 to Point No. 3. On others a satisfactory arrangement is to shunt down the output meter for a moment.

Note that the data for band width at each input level are given directly by the sum of the selectivity control dial readings for the two (high- and low-frequency) positions.

As we said before, a complete run of three curves was made in three and one-half minutes, a time which would probably be reduced considerably by an experienced operator. Similar savings in time are obtained with the tests for sensitivity and fidelity.

Compared with the time taken by older methods, the new method seems unbelievably fast, more so in fact when it is realized that these tests are made with greater accuracy than has ever before been possible with a commercial standard-signal generator. The benefits of this to a busy engineer are obvious. —John D. Crawford

A LINEARLY MODULATED OSCILLATOR

The use of high percentages of modulation by commercial broadcasting stations has materially altered the problem of receiver design. A square law detector when operated at low percentages of modulation gave entirely satisfactory fidelity, since over small regions a parabola is reasonably linear. With high fractional modulation, however, such a receiver causes marked distortion. This trouble has been decreased considerably by the use of so-called "power" detectors which are much more nearly linear. A standard-signal generator to test such a receiver should clearly be capable of linear modulation up to 100%.

A further requirement is imposed on signal generators by the greatly increased selectivity of modern receivers. In measuring the sensitivity of a receiver, it has been customary to vary the input to a coarse-step attenuator by means of a potentiometer, obtaining the output voltage as the reading of a thermocouple meter multiplied by a certain attenuation factor. This scheme, while satisfactory with the broadly tuning sets of a few years ago, causes trouble with very selective sets, since the potentiometer setting has an inherent reaction on the oscillator frequency. The increased sharpness also emphasizes the importance of freedom from frequency modulation.

To meet these newly arisen demands in the testing of modern broadcast receivers, the General Radio Company set about the design of a new standard-signal generator, the Type 600-A Standard-Signal Generator mentioned in the preceding article.

The problem of varying the output without reacting on the frequency was readily met by the use of two resistance networks. One (serving as a multiplier) varied the input to a **T** network arranged to give ½ db (6%) increments.

By means of these two networks (with proper precautions to avoid leakage effects), it has been possible to provide a voltage output range of 3 million to 1 (0.1-316,000 microvolts).[1] At the high levels (100,000-316,000 microvolts), the attenuator reacts somewhat on the frequency. This reaction is not very serious in practice, since data at such high levels are not needed with nearly as high precision as at the lower levels.

The main difficulty in design was experienced in attempting to get an oscillator which would modulate linearly up to 100%. The usual plate modulation system having a grid leak and condenser in the oscillator circuit gives fairly good characteristics with modulations up to about 50%, but at higher values it becomes seriously non-linear. Even at low modulations the calibration of the modulation meter depends appreciably on plate voltage and simple corrections are not always accurate. Furthermore, attempts to modulate it at high frequencies lead to dynamical effects (sometimes called "fly-wheel" or "inertia" effects), due to the finite time taken for the oscillations to change in amplitude when the plate voltage is changed. These considerations led to the discarding of conventional types of oscillators and made it necessary to develop an entirely new circuit.[2]

[1]Space does not permit a discussion of this part of the work. Special heterodyne circuits in conjunction with a harmonic analyzer made it possible to check all of these levels with an accuracy of better than 2%.

[2]This circuit has been described by the writer in a paper presented before the International Scientific Radio Union (U. R. S. I.) at Washington, D. C., in May, 1931. It was entitled "A Vacuum-Tube Oscillator Having a Linear Operating Characteristic." It is being presented to the Institute of Radio Engineers for publication.

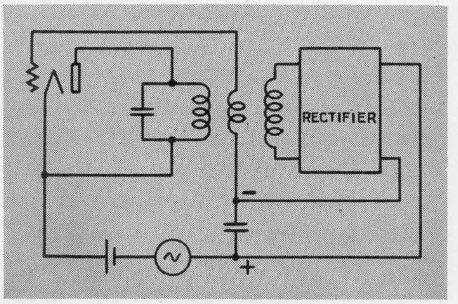

FIGURE 1. Functional schematic of the new oscillator. Fractional modulation is given by the ratio $\frac{Em}{Eo}$, where *Em* is the peak voltage of the modulating source (represented by the generator symbol) and *Eo* is the rectifier voltage output which is proportional to its high-frequency input. In practice, the grid battery is the control for carrier amplitude and is adjusted to keep *Eo* constant

As is well known,[3] in order to establish equilibrium in an oscillator, the vacuum tube must operate at a certain effective plate resistance, the value of this resistance being determined by the constants of the resonant circuit and by the amplification factor of the tube. This resistance is usually obtained in practice either by overloading of the tube due to its non-linear characteristics or by adjusting the external circuit to match the tube conditions by means of a variable feed-back control. In the newly developed circuit this matching of plate resistance to the circuit is brought about by means of an auxiliary rectifier which shifts the oscillator grid bias by an amount proportional to the amplitude of oscillations. Since for oscillatory equilibrium the plate resistance, and hence the effective grid bias, must stay constant if the oscillator bias is arbitrarily

[3]See, for example, L. B. Arguimbau, "A Low-Frequency Oscillator," General Radio Experimenter, October, 1929.

shifted by external means, the detector output must shift to compensate for it. But this means that the amplitude of oscillations must change by an amount proportional to the change in bias. This fact provides the key to the whole situation.

The interdependence of oscillatory amplitude and rectifier bias together with the external bias provides an oscillator whose amplitude varies linearly with a modulating voltage. All that has just been outlined holds equally well if the bias is varied slowly by an audio source. This means that the oscillator provides a modulated wave whose envelope varies linearly with the instantaneous voice amplitude.

A little consideration will show that under these conditions the fractional modulation is given directly by the ratio of the peak modulating signal (applied in series with the rectifier) to the average rectified output. In practice it has been found convenient to use the rectifier bias as a measure of the input to the signal generator attenuator, keeping the reading constant by means of a variable grid-battery bias. This means that whenever the oscillator-output meter on the generator is "set to the red line" the rectifier output voltage has a definite value. This fact enables us to calibrate a voltmeter connected across the modulating source directly in percentage modulation without making any corrections for circuit conditions.

The use of this circuit makes it possible to approximate quite closely to

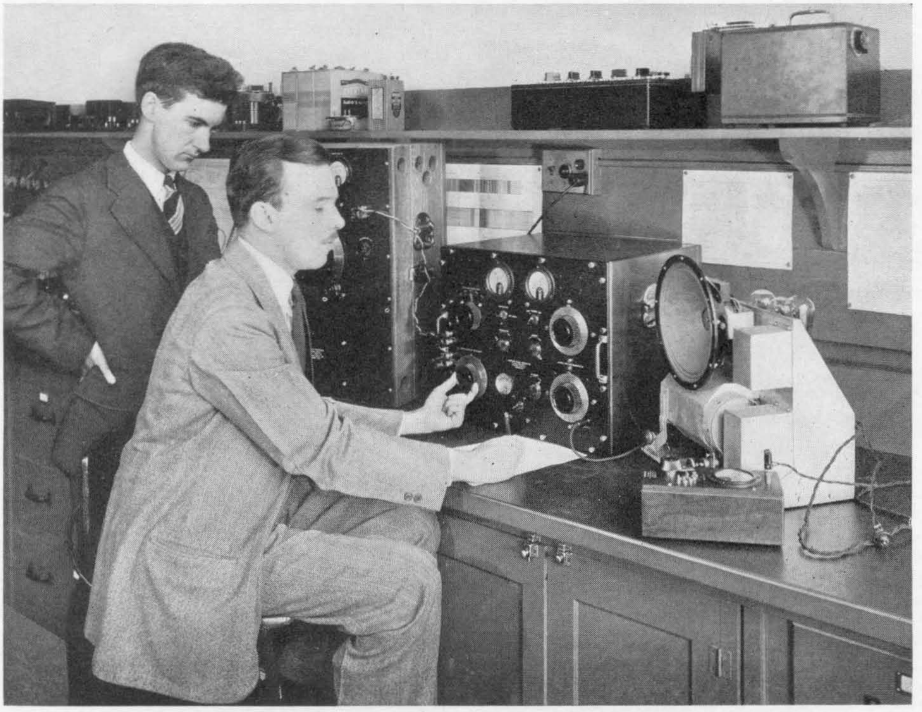

FIGURE 2. L. B. Arguimbau (left), designer of the TYPE 600-A Standard-Signal Generator, showing John D. Crawford, another General Radio engineer, how to operate the instrument

the ideal broadcasting station even replacing the usual single-frequency modulation source by the output of an actual speech amplifier if desired, varying the output until the modulation meter jumps most frequently somewhere near the required percentage modulation. —L. B. ARGUIMBAU

CATALOG SIZE ▲ ▲ ▲ Last spring when we mailed out address revision cards to our mailing list, we asked some 5000 readers to tell us which of two possible sizes they would prefer for the General Radio catalog. The two sizes were 6 by 9 inches (like the present *Experimenter*, the *Proceedings of the I.R.E.*, and a number of other technical publications) and 8½ by 11 inches (like standard letter paper and other material that is intended for storage in a standard drawer-type filing cabinet).

The results were overwhelmingly in favor of the smaller 6 by 9-inch book. The reasons for preferring one to the other were almost as numerous as the number of readers reporting, but all seem to depend on the reader's favorite method for storing catalogs when not in use. Some used the drawer file; others a bookcase or desk drawer.

The actual results were as follows:

For the 6 by 9-inch size	54.5%
For the 8½ by 11-inch size	35.2%
Not voting or "either size"	10.3%

What clinched the argument was the majority preference for 6 by 9 inches and a reason best expressed in the comment received from a well-known consulting engineer. After invoking divine wrath on the larger size, he adds, "General Radio catalogs are as likely to live with the reference books as with the catalogs—or to perch in the top desk drawer. The large size is a damned nuisance in those places—*the small size goes anywhere*—including files."

We (the editorial we) feel that the larger page makes the mechanics of layout a little more simple; "*the small size goes anywhere*" is, however, an almost indisputable argument.

Too many suggestions were received to permit our acknowledging each one individually. We, therefore, take this opportunity of thanking those who wrote in, and of assuring them that we appreciate their assistance.

TYPE 600-A ▲ ▲ ▲ Formal commercial information about the new TYPE 600-A Standard-Signal Generator is contained in Catalog Supplement F-306, announcements concerning which have appeared in previous issues of the *Experimenter*. Extra copies are available and will be sent without charge to interested persons.

The price of the instrument is $885 complete with tubes and dummy antenna.

THE GENERAL RADIO COMPANY mails the Experimenter, without charge, each month to engineers, scientists, and others interested in communication-frequency measurement and control problems. Please send requests for subscriptions and address-change notices to the

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The GENERAL RADIO
EXPERIMENTER

VOL. VI. No. 4 SEPTEMBER, 1931

ELECTRICAL COMMUNICATIONS TECHNIQUE
AND ITS APPLICATIONS IN ALLIED FIELDS

SOME USES FOR A PRECISION CHRONOGRAPH

THE term chronograph may be applied to any instrument which furnishes a record of events with reference to their time of occurrence. Devices of this sort have long been known and have found wide use in industry and the arts.

Several examples of the chronograph are to be seen in the recording barometer, the recording thermometer, the recording wattmeter, etc. In these devices a rectangular or circular graph is obtained on which one co-ordinate is calibrated in some scale of time, while the other co-ordinate is calibrated in terms of pressure, temperature, power, or whatever quantity is to be measured. Records of this sort are obtained by moving a strip or disc of paper at a uniform predetermined rate while a pen or stylus travels across the paper in a direction perpendicular to the motion of the latter, the deflection of the pen being proportional to the quantity recorded.

Another use of the chronograph is that of recording time intervals, as exemplified by the siphon recorder, wherein the to-and-fro motion of a pen upon a moving strip of paper traces a record indicating intervals of short and long duration (dots and dashes) which may be interpreted as Morse Code in the transmission of intelligence.

Still another application of the chronograph has to do with the measurement of time intervals. It is with this latter use that we shall deal in the following. There are two separate methods which may be employed for measuring time intervals by means of the chronograph.

In one of these, means are provided to produce a uniform motion of the recording paper and to measure the time interval directly in terms of the linear displacement of the record. The drum type of chronograph falls into this class. A piece of paper is mounted upon a uniformly revolving cylinder and records of events are indicated by the displacement of a line drawn by a pen or by minute holes punctured in the paper by means of an electric spark at the beginning and end of the interval. Obviously, the precision of such measurements depends upon the uniformity with which the paper is moved.

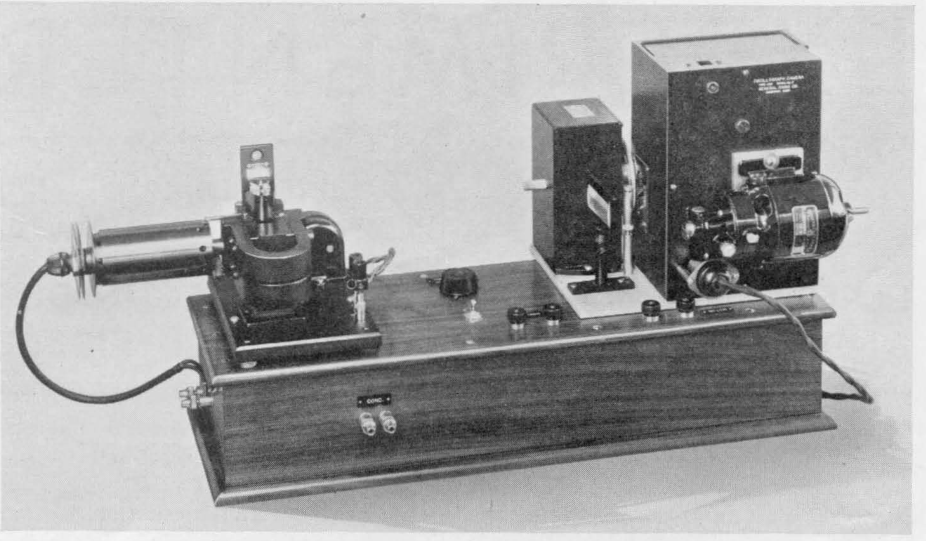


FIGURE 1. The chronograph, consisting of a TYPE 338-L String Oscillograph in which a motor-driven TYPE 408 Oscillograph Camera replaces the usual rotating-mirror box, and a TYPE 407 Synchronous Shutter fitted with a special shutter wheel

The second method, which is inherently capable of greater precision, consists of making two simultaneous and adjacent records upon the paper, the motion of which need be only approximately uniform. One record is produced by the phenomenon to be measured, while the indication of the second record is produced independently at stated and accurately timed intervals and serves therefore as the timing scale. An example of such a double record is seen in Figure 2.

This procedure may be extended to the more elaborate triple record shown in Figure 3. Here the time interval between two separate phenomena is measured against the time scale which is here given by the spaced dots along one side of the paper.

There has recently been developed in the laboratories of the General Radio Company a high-precision chronograph capable of making time-interval measurements to better than the nearest 0.001 second. Such precise measurements could not reliably be obtained with any more-or-less ponderous pen or stylus. The vibrating strings of the TYPE 338-G String Galvanometer, which is of the nature of an Einthoven galvanometer, because of their small mass and short period of vibration, are inherently more quick and reliable in response and more suitable for the purpose. These strings are tuned to have an undamped natural frequency of the order of 2000 cycles per second. Applying the oil-drop damping to the strings renders them essentially aperiodic. This chronograph consists, therefore, of the TYPE 338-G String Galvanometer, together with the TYPE 408 Oscillograph Camera described in the *General Radio Experimenter* for April, 1931. For greater convenience and to obtain higher paper speeds than can be realized by hand cranking, this camera has been

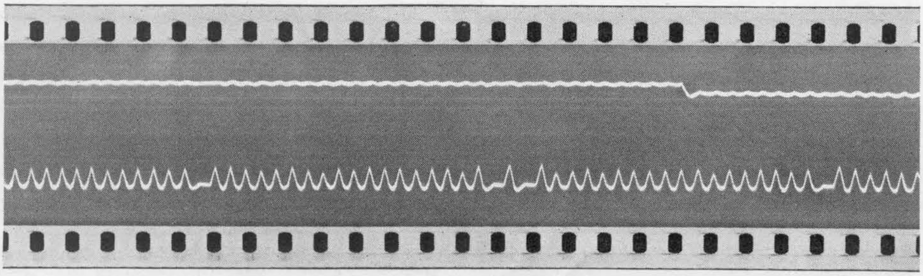


FIGURE 2. A double timing record (full size) obtained by applying signal voltages to both strings in a TYPE 338-P2 Double String Holder. Time increases from left to right

provided with a motor drive. A paper speed of from 80 to 100 inches per second is possible, using a highly sensitive recording paper (Eastman Kodak Company No. 697).

The timing scale record shown in Figure 2 was obtained as follows: A synchronous motor having a shaft speed of 10 revolutions per second was driven either by the 60-cycle mains or by the 1000-cycle frequency obtained from the primary standard of the laboratory. The shaft of the motor carried a disc having a concentric ring of 100 uniformly spaced holes, the spacing between holes approximating their diameter. This "phonic" disc, shown in Figure 4, was equipped with a mercurial stabilizer, thereby minimizing any chance hunting of the motor. By means of a radial slit, a light beam was alternately projected through one hole at a time and eclipsed. These light impulses, 1000 per second, were passed into a photocell which was followed by an overloaded amplifier. The output current wave from this amplifier was applied to one of the two strings of the galvanometer, the vibration of which produced the sharply peaked waves 0.001 second apart. Measurements to about 0.00025 second may be made against such a time scale. The accuracy depends obviously upon the accuracy of the frequency driving the synchronous motor. For convenience, every twentieth impulse (0.020 second) was omitted by leaving out the corresponding hole in the disc. The tenth-second interval (one point on the disc) was specifically marked in the manner shown. By thus indicating the multiple

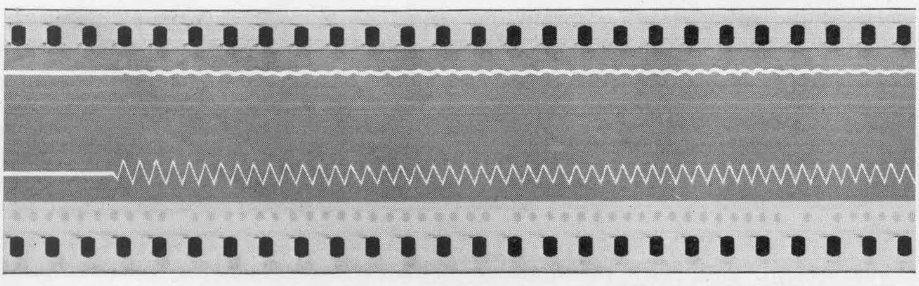


FIGURE 3. A triple record having in addition to the two traces of Figure 2 a third one made by a synchonous motor-driven shutter

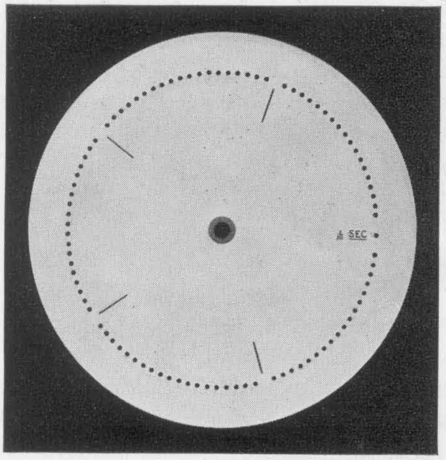


FIGURE 4. A "phonic disc," suitable for mounting on the shaft of a TYPE 407 Synchronous Shutter rotating 10 times a second. Each hole then represents 1 milli-second, the ⅒-second and 20 milli-second intervals being indicated by the spaces shown

time intervals, the records are easily and quickly read and the chance of personal error minimized. The use of a phonic wheel and the photocell is manifestly superior at these speeds to any form of mechanical vibrating contact and, in addition, permits the desirable multiple unit markings.

The timing record, shown in Figure 3, was obtained by a similar 100-hole disc driven by a synchronous motor. This timing unit, shown in Figure 5, is so placed that the disc intercepts directly the edge of the light beam falling on one end of the camera slit and accurately prints a series of dots 0.001 second apart along one side of the paper. The same system of multiple interval markings is employed. The latter procedure eliminates the photocell and amplifier, gives a record readable at least to 0.0005 second, and, with the double-string element in the galvanometer, permits a triple record.

The complete assembly of the chronograph shown in Figure 1 consists of the TYPE 338-G String Galvanometer and base cabinet together with the camera and synchronous shutter which are mounted in place of the rotating mirror viewing box. The instrument is, of course, a photographic recording oscillograph. Obviously the oscillograph assembly shown in the April, 1931, *Experimenter* may be used as a chronograph by adding the motor drive to the camera for high speed work.

One of the important uses for which this precision chronometer is well adapted is the accurate comparison of two clocks. Separate impulses from the clocks may, at stated times, be put individually upon the two strings and a triple record obtained showing the time interval between these impulses, so that highly accurate rates of the clocks can be measured hour-by-hour or day-by-day. It is wise, when working with such precision, not to introduce relays, etc., with their variable time lags, between the clocks and the galvanometer strings. Some technique employing photocells and eclipsing light slits carried by the primary moving member of the clock, that is, the pendulum, is to be recommended.

It is proposed shortly to make an interesting use of this chronograph in a routine daily measurement in our laboratory. The General Radio piezo-electric primary frequency standard contains a synchronous clock driven by the standard 1000-cycle frequency. This clock is checked daily against Mean Solar Time by means of the U. S. Naval Observatory radio time signals. The motor shaft driving this clock, and turning ten revolutions per second, carries an electromagnetic generator which gives an electrical impulse of exceedingly short duration once per revolution. These impulses, spaced 0.100 second apart, are recorded on one string of a triple record while the other string receives the audio note of the radio time signals, the "nose" of which is thus compared with the synchronous clock. Although the impulse from the clock generator is less than one millisecond in duration, the recorded impulse on the string lasts about ten milliseconds. This is due to the action of the energy-storing elements of the amplifier. The nose of this clock impulse can, however, be determined with great accuracy. A heterodyne type of radio receiver is employed with suitable audio tone filters which serve to minimize extraneous disturbances and to render the nose of the time signal more clearly defined. By averaging the records of several successive seconds, a comparison to about 0.0002 second is anticipated.

In order to minimize the amount of photographic paper required for such a series of observations, a "sampling" technique has been perfected. By means of an auxiliary synchronous cam contact driven by the standard frequency and closed for about 0.2 second every second, it is possible to start and stop the camera motor for a short period during each second, thus using about 18 inches instead of 100 inches of paper for each second recorded. By proper adjustment of this cam "within the second," the paper will be traveling at maximum speed at the instant of arrival of each nose of the radio time signals.

Many and varied applications of such a precision chronograph will occur to our readers. The time of throw of a relay armature between back and front contacts, and also the time lag between the application of voltage to a relay and the make and break of its contacts are readily measured. Numerous problems involving the precise measurement of velocity would offer possibilities for this instrument. The "pick-up" and speed of an athlete or motor vehicle traveling over a race course and intercepting a succession of light beams passing into photocells may be measured with a precision far exceeding that obtained by any stop-watch technique.

Another application which should be of considerable importance concerns the measurement of the speed, the acceleration, and the deceleration of any form of revolving shaft. This merely requires some form of phonic disc or its equivalent mounted upon the shaft to intercept a light beam passing into a

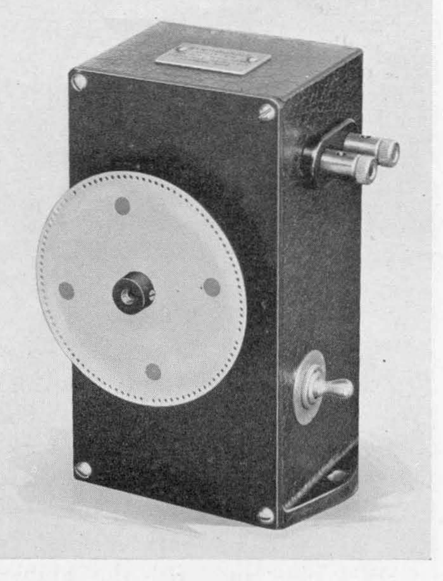


FIGURE 5. A TYPE 407 Synchronous Shutter, fitted with a shutter wheel like that shown in Figure 4

photocell which in turn energizes one of the galvanometer strings with a pulsating current whose increasing or decreasing frequency may accurately be measured against the time scale. If, on the other hand, it is mechanically feasible, the phonic disc on the shaft may intercept directly the light passing through the camera slit and thereby print a photographic record on the recording paper. In this manner automotive engineers might apply such equipment to study the irregularities of shaft rotation due to lack of balance and to investigate the "slip and grab" action of brake systems.

In the fields of medicine and psychology there are many uses for the chronograph as, for instance, in the timing of nerve action currents and in measuring reflex responses to shock or to visual and aural stimuli. The acoustical engineer is interested in the measurement of short time intervals in the study of reverberation characteristics of enclosed spaces. Here is an instrument which should give accurate data of this sort.

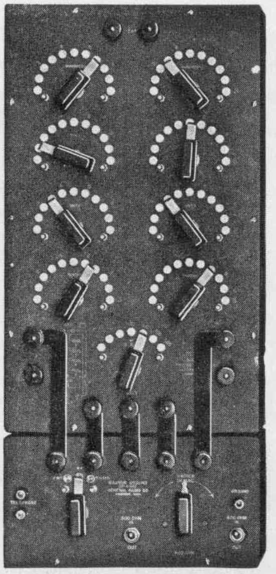
The study of radio wave propagation and the timing of sky wave echoes requires some form of high speed chronograph. With these random suggestions we leave it to our readers to expand the list of possible applications.

The price of the chronograph equipment, complete with motor-driven camera and synchronous shutter for operation from a 110-volt, 60-cps. supply, is $468.50. All items but the motor drive for the camera and the special "phonic disc" are carried in stock.

—Horatio W. Lamson

WAGNER GROUNDS ▲ ▲ ▲ There are two possible means of avoiding errors in bridge measurements due to unbalances of the power source to ground. One is to isolate the power source from the bridge by means of a well shielded and balanced transformer; the other is to employ a Wagner Ground which, in effect, shifts the ground point of the power source to agree with the ground point of the bridge. Unbalances of the power source are annoying because they introduce shunt impedances on opposite sides of the bridge which are not in the same ratio as the ratio arms. In some circuits this is particularly troublesome and unless precautions are taken large errors are introduced.

Where the ratio arms are fixed and equal, as in the Type 216 Capacity Bridge, it is possible to design a power-



The Type 193 Decade Bridge with a Type 193-P1 Wagner Ground attached supply transformer which isolates the bridge from the source and introduces shunt capacitance equally on the two sides of the bridge. In a bridge with adjustable ratio arms, such as the TYPE 193 Decade Bridge, however, it is obviously impossible for a single transformer to achieve balance under all conditions. For this work the General Radio Company recommends the Wagner Ground and has developed a unit for attaching to the latter instrument.

The TYPE 193-P1 Wagner Ground consists of a 400-ohm potentiometer which is intended to be connected in parallel with the power source. This unit, with the ratio arms of the bridge, forms an auxiliary bridge, balance of which indicates that the apparent ground of the power source and the ground in the bridge are at the same potential. Provision is made for inserting an additional 500 ohms on either one or both sides of the potentiometer.

A switch is also incorporated in the unit for connecting the phones or other balance indicator either to the bridge or to the Wagner Ground. At the same time this switch furnishes an easy means for shifting the resistance balance arm from one side of the bridge to the other.

The price of the unit is $20.00.

WAVEMETERS ▲ ▲ ▲ Recent experimental work by General Radio engineers seems to indicate that the precision frequency meter of the future will be similar to those shown in the accompanying photograph. These were built for the United States Coast Guard and had their counterpart in another design and construction order from the United States Navy.

Calibrating a group of special self-checking heterodyne wavemeters designed and built by General Radio for the United States Coast Guard

In general, a self-calibrating heterodyne wavemeter consists of a heterodyne oscillator fitted with interchangeable coils and a straight-line-frequency condenser for covering a wide band of frequencies. A piezo-electric oscillator is also included, harmonics from which serve to furnish points at which the calibration of the heterodyne may be checked. It is also possible by this arrangement to abandon the use of a calibration for the heterodyne except as a rough one is needed to help identify harmonics. By giving sufficient attention to the linearity of the tuning condenser, it is possible to so construct the instrument that interpolation between adjacent crystal harmonics is carried out by a simple graphical process.

As an example of the possible range of such an instrument, the ones shown in the photograph covered 150 to 500 kc. and 2200 to 4280 kc. using two piezo-electric oscillators, one at 100 kc. and one at 110 kc.

CAPACITY BRIDGE, TYPE 216 ▲ ▲ ▲ A new instruction book for the Type 216 Capacity Bridge has just been completed and copies are available without charge to those who own the bridge. The book not only gives suggestions for the use of the bridge but includes a detailed discussion of its principle of operation. Two charts to aid in computing power factor and dielectric constant are included.

Please mention the serial number of your bridge when writing for your copy of the book.

THERMOCOUPLES ▲ ▲ ▲ In addition to the line of contact-type vacuum-mounted thermocouples described in Part 2 of Catalog F, the General Radio Company is about to announce separate heater thermocouples mounted in the same style of bakelite case. An article discussing the general principles of thermocouple design and describing the General Radio thermocouples will appear in the next issue of the *Experimenter*.

THE GENERAL RADIO COMPANY mails the Experimenter, without charge, each month to engineers, scientists, and others interested in communication-frequency measurement and control problems. Please send requests for subscriptions and address-change notices to the

GENERAL RADIO COMPANY

30 State Street - Cambridge A, Massachusetts

The GENERAL RADIO EXPERIMENTER

VOL. VI. No. 5 OCTOBER, 1931

ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

THERMOCOUPLES

IN the practical system of electrical units, there are two fundamental quantities, namely: the unit of electrical charge (the coulomb) and the unit of resistance (the ohm). All other units are defined in terms of these two. The measurement of all electrical quantities, and hence the calibration of electrical meters, must, therefore, be referred back ultimately to the coulombmeter.

The coulombmeter can measure only the preponderance of charge-motion, or current, in one direction. Its use is, therefore, restricted to the uni-directional motion of electrical charge.

In order to measure alternating movements of electrical charge, we are obliged to utilize some manifestation of charge-motion which is independent of the direction of motion. This may be done most satisfactorily by converting the energy of charge-motion into heat energy in the electrocalorimeter. If a charge Q is moved through a resistance R in a time T the amount of the heat energy (measured in joules) produced is given by multiplying the resistance (ohms) by the square of the ratio of the charge (coulombs) to the time (seconds). Thus the electrocalorimeter for alternating currents plays an analogous role to the coulombmeter for uni-directional currents.

If we assume a state of thermal equilibrium in the resistance, the temperature of the resistance will be a function of the square of the derivative of Q with respect to T, that is, a function of the square of the instantaneous value of the current. A convenient method of measuring the temperature of this resistance is to associate with it a thermocouple junction, the operation of which depends upon the Peltier effect, which may be described briefly as follows: If a circuit is made up of two materials, A and B, there must be two points, M and N, where A meets B. If the junctions M and N are of different temperature, there will exist in the circuit an electromotive force (Peltier voltage) whose magnitude depends upon the nature of the materials A and B and upon the temperature difference between the junctions M and N, and whose polarity is determined by the

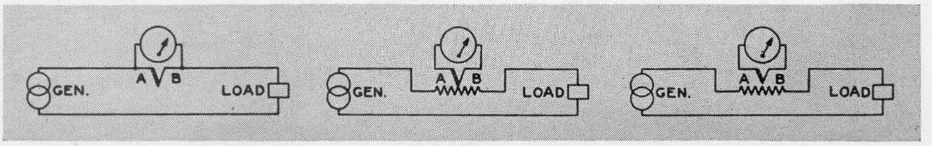


FIGURE 1. Typical thermocouples. *Left:* Mutual type. *Center:* Contact type *Right:* Separate heater type

relative temperatures of M and N. From the foregoing it will be evident that, if one of these junctions is brought into association with a resistance which is carrying a current and which is in thermal equilibrium, the open circuit voltage developed will be accurately a function of the root-mean-square value of the current in the resistance.

Such an instrument is called a thermocouple and, indicating as it does exact root-mean-square values of any varying current, it may well serve as the primary reference instrument for all alternating-current measurements. The thermocouple may, of course, be calibrated in terms of direct current by reference to the coulombmeter or to a d'Arsonval ammeter which, in turn, has been calibrated with reference to the coulombmeter.

Thermocouples may be classified into three separate types: the mutual type, the contact type, and the separate heater type (see Figure 1). In the mutual type, the elements of the junction constitute a resistance which is common to the circuit carrying the current to be measured and to the galvanometer circuit used to measure this current in terms of the thermoelectric current produced by the heated junction. In the contact type of couple there is no mutual impedance between the two circuits, the junction being in electrical contact with the heater resistance at one point only, while in the separate heater type the junction and the heater resistance, although they may be physically joined, have no conducting path between them.

The mutual type, which is the simplest to manufacture, possesses some serious disadvantages due to the mutual impedance. Since the current from the generator divides between the galvanometer and load, a *shunting error* is introduced which, being a function of the frequency, makes it somewhat difficult to calibrate this type of thermocouple in terms of direct current. Furthermore, unless a condenser intervenes, a part of the thermoelectric power is dissipated through the generator and load which, of course, reduces the sensitivity. The mutual couple has also a *reversal error* which makes the calibration in terms of direct current a function of the direction of the current. This reversal error may be eliminated by taking the trouble to find the mean of two reversed direct-current readings for each point observed in calibrating the device. If, however, the alternating-current wave from the generator is not symmetrical with respect to the zero axis, the reversal error may introduce an appreciable discrepancy in the readings.

Using a mutual type junction, if we wish to alter the current sensitivity by changing the value of the mutual resistance of the junction, we are obliged to change the resistance of the galvanometer to match if we are to obtain maximum over-all efficiency.

These objections are very much minimized in the contact type of couple. Here the shunting error is negligible and the reversal error may be made very small (less than 1%) so that an accurate direct-current calibration may be obtained by taking the mean of reversed direct-current readings. The frequency error is nil except at very high frequencies where the heater resistance becomes modified due to skin effect and the presence of an appreciable amount of leakage reactance due to the distributed capacitance of the heater or capacitance to ground.

The separate heater type, of course, can have no reversal error. In the earliest types, the junction was usually inserted within a helical heater. However, in order to obtain a maximum sensitivity equivalent to that of the contact type, the junction and heater are generally bound in physical contact by means of a bead of insulating material. The thermal capacity of this bead renders the separate heater type of couple somewhat more sluggish in response to heater-current changes than the contact type. The separate heater type, which was first introduced in 1919 by the General Radio Company, is often very useful in certain high-frequency measurements where the capacitance of the galvanometer system to ground would introduce very appreciable errors should the contact type of couple be employed.

In the separate heater and contact junctions the resistances of heater and couple are independent, permitting a single couple resistance to be combined with various heaters giving couples which may be used interchangeably with a single meter.

The temperature of a given heater resistance passing a given current and, hence, the sensitivity of a thermocouple, can be increased considerably by placing the couple in an evacuated container, thereby minimizing greatly the cooling action due to convection currents.

The General Radio Company has provided a series of vacuum thermocouples of both the contact and the separate heater types. These couples are mounted in a convenient moulded bakelite housing which is provided with four pin plugs, giving an assembly designated as the Type 493 Thermocouples. The name plate indicates the heater and couple terminals, as well as the heater and couple resistance and the rated current. This assembly contains also an eccentric alignment pin which prevents interchange of the terminals when the assembly is inserted into suitable switch jacks. The Type 274-RJ Mounting Base and the Type 298-B Meter Mounting are both convenient for use with these interchangeable thermocouples.

For use with such thermocouples, the General Radio Company has provided the Type 588-AM Direct-Current-Meter. This meter has a resistance of 10 ohms, requires 500 microamperes (5 millivolts) for full-scale deflection, and has a uniform 50-division scale graduated from 0 to 50 which is very convenient for making and using thermocouple calibrations. This meter is supplied mounted in the Type 298-B Meter Mounting.

A list of the thermocouples carried in stock, together with descriptive data, appears in Catalog F, Part 3, pages 221 and 222. — Horatio W. Lamson

A STABLE LABORATORY AMPLIFIER

THE recent development of oxide-rectifier instruments has produced a high impedance alternating-current voltmeter useful over the entire audible frequency range. In this device, advantage is taken of the high sensitivity and high resistance of direct-current instruments, using them in conjunction with a copper-oxide rectifier.

The characteristics of the oxide rectifier and associated meter limit the best voltage sensitivity which may be obtained to approximately two or three volts full scale. In applying such instruments to circuits requiring a more sensitive indicator, such as the detector of a bridge circuit, greater sensitivity is required. This amplification of sensitivity can readily be obtained by means of a vacuum-tube amplifier.

An amplifier for this purpose should have a wide band of transmitted frequencies and a high gain. The power output is of secondary consideration, since comparatively little power is required to operate the indicating instrument.

The General Radio Company has recently developed an amplifier for this and similar applications. This amplifier (TYPE 514-A) has a gain of about 250 and a transmission range of approximately 20 to 100,000 cps. The power output is about 7 milliwatts.

If an amplifier of these general characteristics is employed as a detector in a bridge circuit using a 20,000-ohm meter as an indicator, substantially the same sensitivity of bridge balance can be obtained at all frequencies within the range of the amplifier as is possible with telephones applied directly to the bridge at 1000 cps. The advantage of the visual indicator even at 1000 cps. is very great, particularly where a large number of observations are to be made. The amplifier and meter extend the range well beyond that possible with telephones or alternating-current galvanometers of any commercial type.

If used with a common indicating device which will respond at super-audible frequencies, the amplifier offers a null detector for bridge circuits operating at frequencies as high as 100 kc. Throughout a good deal of the audible range, the sensitivity is equivalent to that possible with standard telephones applied directly to the bridge, since telephone and ear sensitivity fall very rapidly as the frequency departs from 1000 cps. The sensitivity when using the oxide meter and amplifier is somewhat less than that obtained with the best direct-current wall galvanometers, but is comparable to that obtained with the less expensive direct-current galvanometers. The high input impedance of the amplifier is a distinct advantage in high-impedance bridges. If, instead of a meter, telephones are used on the output of the amplifier, a far greater bridge sensitivity is available at 1000 cps. than can be obtained

TYPE 514-A Amplifier and a TYPE 588-DM Alternating-Current Voltmeter with any commercial galvanometer at direct current or at natural period for vibration galvanometers.

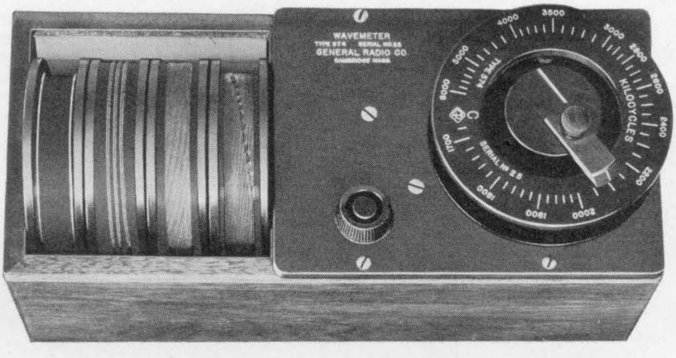
Where very great sensitivity is required, it is possible to cascade two of the TYPE 514-A Amplifiers. Where this is done, some protection of the first unit from acoustic vibration is essential. With two of the amplifiers in cascade, a greater sensitivity is obtained than is possible with any commercial type of galvanometer.

The TYPE 514-A Amplifier is, of course, not limited in its application to bridge circuits. It can be used as a voltage multiplier in general measurement work and when so used, can be calibrated. Other applications include photo-cell work. An interesting feature of the amplifier is a terminal plug which permits use of the amplifier batteries for external circuits. This feature is of particular advantage when using the amplifier in photo-cell circuits.

The TYPE 514-A Amplifier has a flat frequency characteristic from 20 to 100,000 cycles. The amplification is approximately 250 to 1 over this range. The input impedance is one megohm and the optimum load impedance, 20,000 ohms. Twelve volts will be maintained across this load with a 230-type tube in the output. For lower impedance loads, a 231-type tube is recommended. With this tube in the output, 15 volts will be maintained across an external load of 50,000 ohms and the voltage amplification will be in excess of 50 to 1. A potentiometer is provided for control of amplification.

The TYPE 514-A Amplifier can be provided either for cabinet or rack mounting. The price of the cabinet type is $70.00. — CHARLES T. BURKE

A GENERAL-PURPOSE WAVEMETER



TYPE 574 Wavemeter

MANY uses may be found for a simple direct-reading wavemeter covering a wide range of frequency. The new TYPE 574 Wavemeter, which is calibrated in terms of frequency and which has a nominal precision of 1%, is valuable as a general-purpose instrument and also for obtaining rapid supplemental readings in conjunction with high-precision equipment.

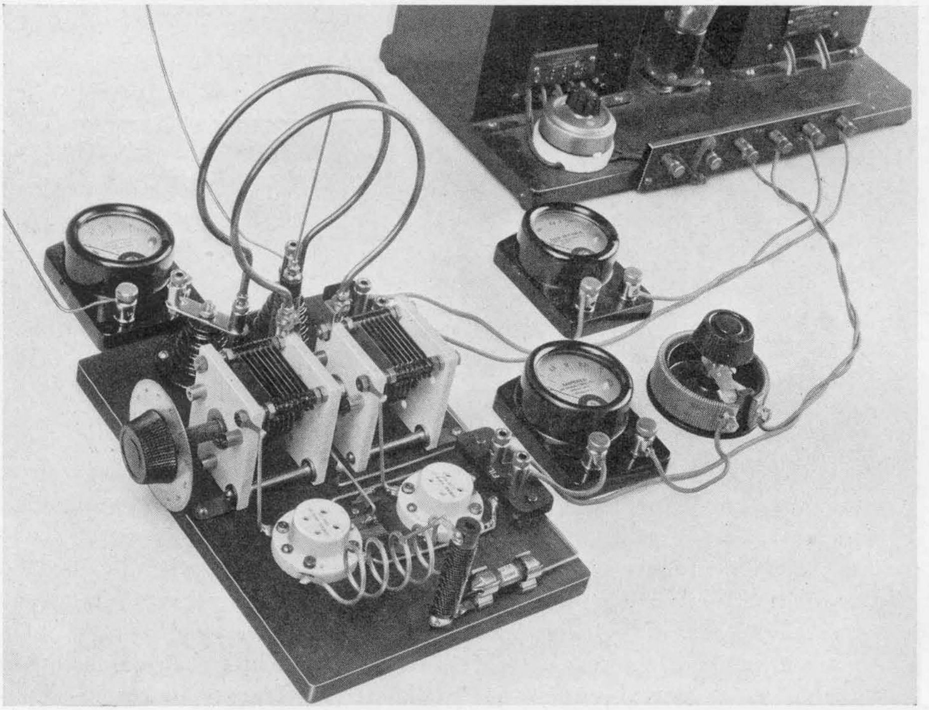
The scales, which are hand-calibrated in terms of our primary frequency standard, are engraved directly upon each of the five interchangeable plug-in bakelite coil forms (4 inches in diameter and 1 inch long) which are used to cover a continuous range from 166 kilocycles per second to 70 megacycles per second (1800 to 4.3 meters). The vernier-driven condenser is mounted on a bakelite panel attached to a polished walnut case which contains storage space for the four coils not in use. Measuring 11 inches long by 5 inches square and weighing but 4½ pounds, this meter is easily handled and may be placed in any position for use. Intended to be used in reaction observations, no resonance indicator is included. The TYPE 574 Wavemeter is priced at $50.00, and the code word is CARRY.

A FIVE-METER TRANSMITTER

R. L. Tedesco (W 1CAC) and his brother, Albert (W 1BMB), have designed a successful five-meter transmitter which we are pleased to bring to the attention of Experimenter *readers*

A FIVE-METER phone transmitter built with General Radio parts has worked out very successfully. The oscillator, modulated by the constant-current or Heising method proved to be a good method of voice transmission over short distances. The most desirable thing about it is the absence of the interference encountered on the other bands. It is also possible to radiate directively by the use of reflectors in the antenna system.

The push-pull Armstrong or TNT circuit was used, a practical description of which was given by J. J. Lamb in the July, 1931, issue of *QST*.

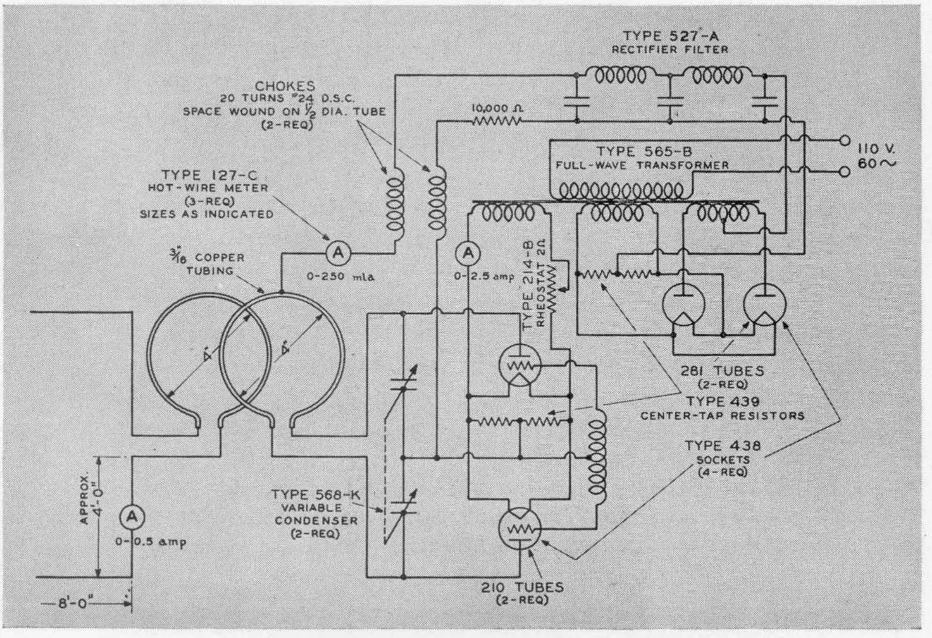


The 5-meter transmitter described in the accompanying article

The condensers are mounted in tandem with a common shaft, giving a common rotor and split stator condenser. The stators carry the plate-coil sockets which are General Radio Type 274-J Jacks mounted in a right-angle bracket as shown. These are held in place by the nuts of the stator plate rods. The plate coil is a 4-inch turn of 3⁄16-inch copper tubing or heavy wire with two Type 274-P Plugs soldered or threaded to the ends. A plate-voltage feed wire, which is soldered to the exact center of this loop, also carries a plug-in pin at the opposite end.

Nearby are mounted two Type 657 Sockets, separated so as to allow the proper spacing for wiring and other units. These carry the grid coil which is made of 4 one-inch turns of No. 10 copper wire and soldered to the grid terminals of the sockets. A fair amount of spacing should be allowed between coil and baseboard. A tap made at the exact center of this coil goes directly to the radio-frequency choke made up of 20 turns of No. 24 D.S.C. wire, double-space wound on a ½-inch wooden or hard rubber dowel 2″ long. A Type 437 Center-Tap Resistor is mounted between the sockets, by soldering directly onto the filament-supply wires. Note that the condenser rotors are at ground potential.

Two Type 274-K Binding-Post Assemblies mounted on the baseboard with spacers allow means for making connections to the power supply, both for filament and plate voltages. Power may be derived from a rectified and filtered alternating-current supply of 550 volts for the plates of two 210-type tubes. 7.5 volts are necessary to light the filaments. Such a unit consists of a full-wave transformer (Type 565-B) and a Type 527-A Rectifier Filter



Circuit diagram for 5-meter transmitter

with 281-type tubes as rectifiers. The filament posts connect to the 7.5-volt secondary on the transformer with a 2-ohm rheostat and a 2.5-ampere ammeter in series with the tubes. A plate milliammeter is also desirable because it not only indicates the amount of current the plates are drawing but also shows when the tubes are oscillating. It also indicates when circuit is tuned to resonance.

The antenna coupling coil is mounted on a pair of TYPE 260 Wall Insulators which have a strap of 1/16-inch brass, 1/2-inch wide fastened at the center, with 2 TYPE 138-V Binding Posts at each end of the strap. One pair of binding posts support the antenna coil and the other pair make connections to the antenna feeder system. The distance between the plate coil and antenna coil (same construction as the plate coil) is approximately 1 1/2 inches.

The proper length of the antenna and feeder is very important. For five-meter operation 8 feet of horizontal wire in each leg is necessary and the distance from binding post to the flat top should be either 4 or 8 feet as is most convenient. An antenna current meter should be inserted in one of the legs of the doublet antenna to indicate the resonance peak and amount of current. It is important to tune the antenna to the oscillator if the maximum amount of power is to be radiated from the antenna. The antenna wires should be properly insulated also, a very convenient form of insulator being the General Radio TYPE 280 Strain Insulator which may also be used as a feeder separator.

After all units are assembled on the baseboard, a power supply unit is on hand, and a final inspection of all wiring made, apply the power from the power supply and proceed to adjust the apparatus.

When tubes are oscillating properly a plate current drain of about 80-90 milliamperes should be indicated by the plate-current meter. Adjust the tuning condenser until maximum current is read on the antenna-current meter, an indication that the maximum amount of power is being transferred into the antenna system. It is possible to further increase the transfer of energy into the antenna by reducing the coupling but that tends to cause instability in the oscillator. No tuning of the antenna system is necessary if the specified directions for the feeders and antenna are observed. When using a pair of 210-type tubes as oscillators with 550 volts on the plates a current of about 500 milliamperes should be indicated by the antenna current meter.

This oscillator can be used either for C W or phone. Keying for C W can be accomplished by inserting a key in the grid-return; modulation, by inserting a modulation tube at the same point.

— R. L. TEDESCO

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VOL. VI. No. 6 NOVEMBER, 1931

ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

A BRIDGE-TYPE FREQUENCY METER

INSTRUMENTS for the measurement of audio frequencies are usually based on one of the numerous bridge circuits in which frequency enters explicitly. The familiar tuned-circuit wavemeter has not made a satisfactory audio-frequency meter because of the large amount of power lost in it when the usual current indicator is used. The resonance bridge makes use of a similar tuned circuit in one arm, the other arms being pure resistance. For any reasonable values of inductance the capacitance required to tune to the lower audio frequencies is so large that an air condenser cannot be used. The capacitance then is fixed and the inductance made variable in order to have continuous adjustment. Different ranges are obtained by changing the capacitance. The bridges of Campbell and of Kennelly and Velander make use of a variable mutual inductor and a number of fixed condensers.

Bridges using inductance, either self or mutual, have two serious defects. The shape of the frequency scale depends upon the characteristics of the variable inductor used and cannot be appreciably altered. The magnetic field of the inductor is such that it cannot be satisfactorily shielded from the source of frequency being measured.

The Wien bridge circuit has been chosen for the TYPE 434-B Audio-Frequency Meter because it eliminates both of these objections. Since it uses only resistance and capacitance, it has no external magnetic field. The two variable resistors may be so constructed that the frequency scale has the most desirable shape. A schematic diagram is shown in Figure 1. The conditions for balance of this bridge are:

$$f = \frac{1}{2\pi\sqrt{PQC_PC_Q}}$$

and

$$\frac{C_Q}{C_P} = \frac{A}{B} - \frac{P}{Q}. \qquad (1)$$

In order to provide a single control, upon which the frequency scale may be mounted and to maintain the second balance condition, the two resistors P and Q and the two condensers C_P and C_Q are made equal, and the two ratio arms are made two to one:

$$\frac{P}{Q} = \frac{C_Q}{C_P} = 1 \text{ and } \frac{A}{B} = 2. \qquad (2)$$

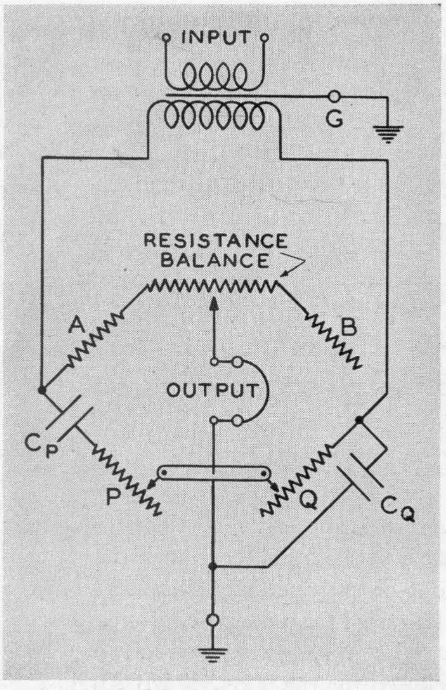


FIGURE 1. Schematic wiring diagram for the TYPE 434-B Audio-Frequency Meter

Thus the second balance condition is always fulfilled and the first condition reduces to

$$f = \frac{1}{2\pi P C_P}. \qquad (3)$$

The two resistors P and Q are wound on tapered cards of such a shape that the frequency scale is logarithmic. Equal frequency ratios occupy equal intervals on the scale. Hence the fractional accuracy of reading is constant. There are fixed resistors in series with the variable parts of P and Q having about one-tenth the value of the variable resistor, which limit the range of the frequency scale to a ratio of ten to one. The three frequency ranges, differing by factors of ten from one another, are obtained by the use of three sets of condensers C_P and C_Q, which also differ by factors of ten. The same engraved scale is used for all three ranges. The frequency ranges chosen are 20 to 200, 200 to 2000, and 2000 to 20,000 cycles per second.

It is impracticable to keep the resistors P and Q and the condensers C_P and C_Q exactly equal as demanded by equation (2). An auxiliary control consisting of a small potentiometer is provided between the ratio arms A and B to whose sliding contact the null detector is connected. This alters the effective ratio A/B and satisfies equation (1). If this adjustment is not made, however, the setting of the frequency dial is not altered but merely dulled.

The null detector most often used for setting the frequency dial is a pair of head telephones. These are satisfactory in the frequency range from 300 to 5000 cycles per second. If the source of frequency to be measured contains harmonics, they will not be balanced out by the bridge and will be impressed on the telephone. The human ear can discriminate against a considerable amount of harmonic content. It must be aided by the use of a low-pass filter connected between the bridge and the telephones for high harmonic content or for the measurement of frequencies less than half the natural frequency of the telephones. When the voltage available to be applied to the bridge is small, an amplifier must be used to obtain sufficient sensitivity. The General Radio TYPE 514-A Amplifier is exactly suited for this purpose because it maintains its voltage gain of 200 approximately constant from 20 to 20,000 cycles per second.

For frequencies outside the range of telephones a sensitive alternating-current voltmeter and amplifier must be

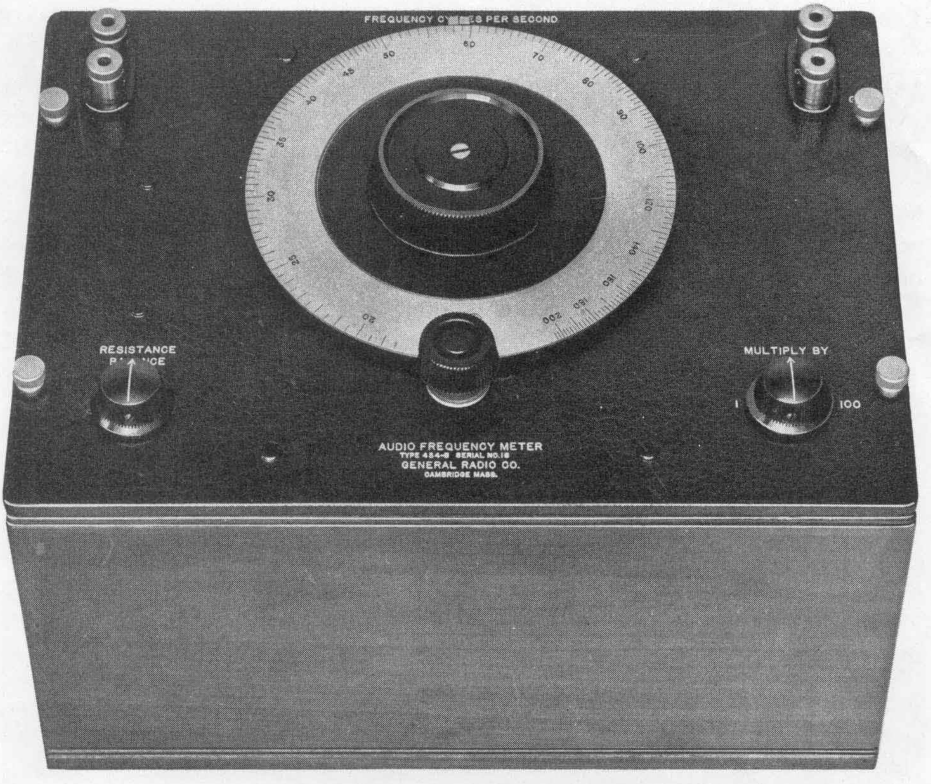


FIGURE 2. The TYPE 434-B Audio-Frequency Meter

used. The TYPE 488 Alternating-Current Voltmeters are well suited to this use. A suitable low-pass filter should be used because the alternating-current voltmeter lacks the power of discriminating against harmonics.

The frequency dial is hand calibrated to an accuracy of 0.5%. It may be set to an accuracy of 0.1% when sufficient amplification is provided, this figure being determined by the spacing of the individual wires on the variable resistors *P* and *Q*.

The TYPE 434-B Audio-Frequency Meter will measure any frequency from 20 to 20,000 cycles per second. The usual sources are vacuum-tube oscillators of all kinds, tuning forks, and the lower range of magnetostriction rods. The meter is equally suitable for measuring the frequency of the beat note obtained from two high frequency oscillators. An accuracy of 0.5% in the determination of this beat note means that the difference between the two high frequencies is known to 0.1 cps for a 20-cps beat and proportionally for higher frequencies. When an unknown high frequency is compared with a standard crystal oscillator there are usually available harmonics spaced 1000 cps apart. The beat note can then always be made less than 1000 cps so that the unknown frequency is measured in terms of the standard crystal to within 5 cps.

The price of this frequency bridge is $125.00. —ROBERT F. FIELD

A VACUUM TUBE VOLTMETER

While the copper-oxide rectifier type of voltmeter, which can be made in a portable form with a full-scale deflection of 2 volts and with an impedance of the order of 10,000 ohms per volt, is a very convenient and useful instrument for many alternating-current measurements, it has, unfortunately, two disadvantages in that its impedance varies with the applied voltage and that its calibration error increases with the frequency.

For making measurements of small voltages in circuits of high impedance, —as, for instance, in measuring the gain at various points in amplifying systems—for all voltage measurements at high audio, supersonic, and radio frequencies, and for tests upon resonant circuits, the thermionic or vacuum-tube voltmeter is much to be preferred and may, in fact, be indispensable. The accompanying illustration shows the new alternating-current-operated thermionic voltmeter being used to measure frequency response curves of tuned interstage transformers intended for operation at high audio frequencies.

Over a year ago, the General Radio Company announced the bridge-type thermionic voltmeter (Type 426-A) which was energized by a 22.5-volt battery. To eliminate the necessity for such a battery and thus fulfill the pres-

Measuring the response characteristic of an interstage coupling transformer with the Type 626-A Vacuum-Tube Voltmeter. The meter is on the bench at the right ent-day desire for more convenient equipment energized solely by a 110-volt 60-cycle circuit and to supply a meter which shall be reliable at radio frequencies, the TYPE 626-A Vacuum-Tube Voltmeter is now offered to the experimenter.

This instrument is a rugged, serviceable, direct-reading, moderately-priced meter of the compensated, depressed-zero type, having a full-scale deflection of 3 volts, r.m.s. From 0.5 volt to 3.0 volts the scale is approximately uniform. The filaments of the 227-type tube (thermionic voltmeter) and the 171-type tube (rectifier) used are run at subnormal voltages so that their normal life is considerably increased. Proper circuit design minimizes the wandering of the zero or aging. By incorporating an 874-type ballast tube, the chief source of error, fluctuation in line voltage, is reduced to only .05% of full scale value per volt change. A rheostat is provided for compensating a change in line voltage over a range from 100 to 120 volts. Due to the large thermal capacity of the cathode of the 227-type tube, small erratic changes in line voltage are ordinarily negligible.

These meters are individually calibrated to within 1% of full-scale value. Below 1500 kilocycles, the frequency error is negligible. At 3000 kilocycles, it is less than 2%, and at 4000 kilocycles, less than 4%. The input impedance is constant and approximately 10 megohms and no external direct-current path is required. Housed in a walnut cabinet 11 inches long by 8½ inches square, this instrument weighs fourteen pounds. The price, complete with tubes and attachment cord, is $100.00 and the code word is ETHIC.

—HORATIO W. LAMSON

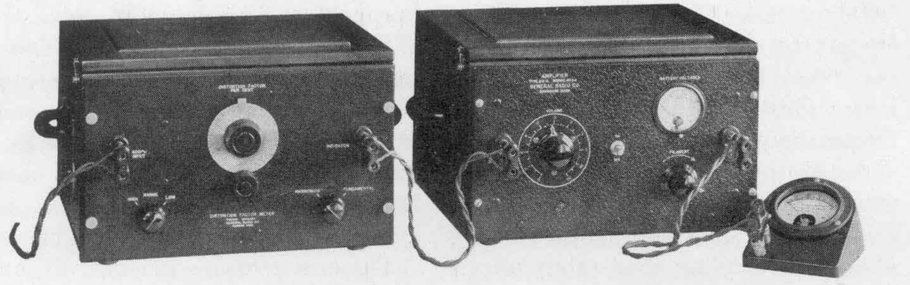
DIRECT MEASUREMENTS OF HARMONIC DISTORTION

DEVELOPMENT work has recently been completed on an instrument which has a wide field of usefulness in the testing of apparatus for the electrical transmission or reproduction of speech, music, or vision.

The new instrument, the TYPE 536-A Distortion-Factor Meter, will measure the harmonic distortion in the modulated output of a broadcast transmitter. It can then determine how much of the distortion is due to the speech amplifiers. In a receiving set it can measure the harmonic distortion produced in the detector or in the audio amplifiers. By its means, also, measurements can quickly be made which will determine what load resistance should be used with a pentode output tube to obtain the maximum power output for various allowable distortion limits.

The distortion-factor meter was developed so that distortion measurements could be accurately made by a very much simplified technique. After a preliminary observation, the total harmonic distortion is given directly by a dial reading. Less than thirty seconds is required for the entire measurement.

In the system employed the voltage to be tested is applied to two filters in parallel, one of which passes the harmonics only and the other of which passes the fundamental. A voltage divider is placed in the line passing the fundamental. This is varied until the output voltages of the two lines are



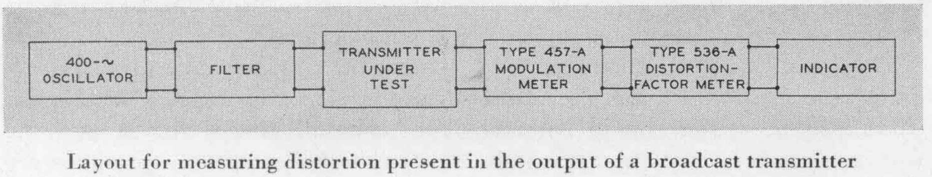
Apparatus for determining harmonic distortion. *Left to right:* Type 536-A Distortion-Factor Meter, Type 514-A Amplifier, and Type 488-HM Alternating-Current Galvanometer

equal. A dial, attached to the voltage divider, then reads directly the harmonic content.

The distortion-factor meter is not to be confused with a harmonic analyser. This latter instrument is a sharply selective device which will measure the amplitudes of the various components of a complex current or voltage wave. It is very laborious to use a harmonic analyser for distortion measurements. A separate measurement must be made for each harmonic present, and the results combined to obtain a useful result. The distortion-factor meter, on the other hand, is designed so that one of the filters transmits equally all the harmonics, while suppressing the fundamental and any power-supply hum which may be present. If a root-mean-square indicating instrument is employed, therefore, the reading obtained with the distortion-factor meter will give directly the desired ratio of the effective value of the combined harmonics to the value of the fundamental. No computation whatever is required.

Let us consider in more detail one of the applications of the instrument, the testing of broadcast transmitters. As the distortion-factor meter is designed for testing at 400 cps, a fairly pure voltage source of this frequency must be available. With most oscillators, a filter must be employed to obtain sufficient purity. The filtered oscillator output is applied to the input of the speech amplifiers.

If it is desired first of all to check the operation of the speech amplifiers, the distortion-factor meter may be used to test the output of the modulator tube or of any amplifier stage preceding it. Finally, the most important measurement of distortion in the modulated output may be made after first rectifying the high-frequency voltage with a high-quality rectifier. A carefully designed linear rectifier is incorporated in the Type 457-A Modulation Meter, and terminals are provided for connection to the distortion-factor



Layout for measuring distortion present in the output of a broadcast transmitter meter. The complete layout is indicated in the figure.

It is believed that this measurement of modulation distortion is the final index of the quality of the output of a broadcast transmitter, as far as harmonic distortion is concerned. It lumps together all the sources of harmonic distortion in the transmitter and measures their combined effect on the shape of the output voltage wave.

This discussion of the application of the distortion-factor meter to the single problem of the testing of broadcast transmitters will serve as an indication of its many uses in electric communication technique.

The price of the Type 536-A Distortion-Factor Meter is $140.00.

—W. N. Tuttle

A WAVEMETER FOR THE 1 - 15 METER BAND

A new instrument has been added to the line of General Radio wavemeters. It is the Type 419-A Rectifier-Type Wavemeter, covering the range from 1 to 15 meters or 300 to 20 megacycles per second. The instrument is primarily intended for laboratory and

Type 419-A Wavemeter

service use where a rapid and fairly accurate measurement is required. In this way, inaccurate and bothersome Lecher wires are eliminated where wave lengths are measured with a yard-stick. Stable oscillators have made it possible to use heterodyne methods even at 1 meter and to calibrate the TYPE 419-A Rectifier-Type Wave-meter in terms of the General Radio primary standard of frequency.

Besides measuring oscillators, trans-mitters, and receivers, the instrument can be used as an aural detector of modulated oscillations and as an un-calibrated vacuum-tube voltmeter. The accompanying photograph shows the instrument. Dimensions and weight of the cabinet have been reduced as much as possible and a handle is provided on the panel. This way it is possible to hold the instrument with one hand and bring it in any desired position with re-spect to the apparatus which is to be measured.

Four inductors, each with a fre-quency ratio of 1:2, cover the entire range of the wavemeter. A large dial makes it possible to read settings to within 0.1%. With respect to errors that are likely to occur due to the presence of metal parts in the field of the inductor and "transformer action," the accuracy has been conservatively set at 1%.

As an indicating device a vacuum-tube voltmeter is used, the high sensi-tivity of which is very advantageous, since it makes it possible to use a very loose coupling between the wavemeter and the apparatus under measurement. Besides the permanently connected in-dicating instrument, plugs are provided for the connection of headphones. The cabinet of the wavemeter contains the four plug-in inductors and four sepa-rate calibration charts. The calibration is given in terms of frequency, but on each chart a conversion curve is pro-vided which makes it possible to read in wave length as well. The price of this meter is $100. —EDUARD KARPLUS

RESISTANCE BOXES ▲ ▲ ▲ Prices on three sizes of the TYPE 102 Decade-Resistance Boxes have been reduced as follows:

TYPE 102-L, $58.00 (*was $75.00*)
TYPE 102-M, $70.00 (*was $100.00*)
TYPE 102-N, $62.00 (*was $75.00*)

The TYPE 102-L Decade Resistance Box is a four-dial box, having a maxi-mum resistance of 111,100 ohms, ad-justable in steps of 10.0 ohms; the TYPE 102-M Decade-Resistance Box has five dials with a maximum resis-tance of 111,110 ohms in steps of 1 ohm; and the TYPE 102-N Decade-Resistance Box is a five-dial box with a maximum resistance of 111,111.0, adjustable in steps of 0.1 ohm.

THE GENERAL RADIO COMPANY mails the Experimenter, without charge, each month to engineers, scientists, and others interested in communication-frequency measurement and control problems. Please send requests for subscriptions and address-change notices to the

GENERAL RADIO COMPANY
30 State Street - Cambridge A, Massachusetts

PRINTED IN U.S.

The GENERAL RADIO EXPERIMENTER

VOL. VI. No. 7 DECEMBER, 1931

ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

A PIEZO-ELECTRIC OSCILLATOR OF IMPROVED STABILITY

SINCE the studies of performance of the TYPE 575-A Piezo-Electric Oscillator described in the *Experimenter* for October and for November, 1930, increased demands have been made for even higher accuracies and higher stabilities, notably as a result of the Federal Radio Commission General Order No. 116 requiring broadcasting stations to maintain their frequencies within plus or minus fifty cycles of the assigned value. The new TYPE 575-D Piezo-Electric Oscillator described below was developed primarily to serve as a frequency standard in conjunction with the TYPE 581-A Frequency Deviation Meter as a visual monitor complying with the requirements of the General Order.

The rigid requirements which must be met by such frequency standards led to investigations of various circuits to improve the frequency stability and the operating characteristics. One of the more serious defects of the older oscillators was the necessity of calibrating the quartz plate in the oscillator with which it was to be used. If changes occurred in the circuit constants due to shipment or to ageing, the user was not aware of these changes or the resulting shift in frequency. Further, in cases where readjustments or recalibrations were to be made it was necessary to return not only the quartz plate but the entire oscillator to our laboratory.

The circuit finally chosen overcomes most of the objections. A definite indication of proper adjustment is provided by the plate current meter which indicates a minimum current when the circuit is properly adjusted. Regardless of changes in the circuit constants, supply voltages, and tubes, adjustment of the circuit to the minimum plate-current point will give the same frequency to within exceedingly small limits.

The schematic circuit is shown in Figure 1. A screen-grid tube is employed to reduce the capacitance between control grid and plate. The

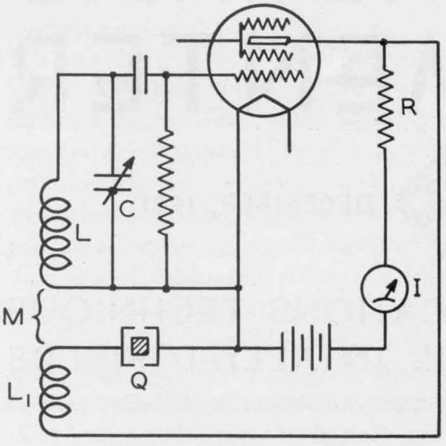


FIGURE 1. Functional diagram for TYPE 575-D Piezo-Electric Oscillator

quartz plate is connected in the plate circuit in series with the feed-back coil L_1. The resistance R serves to supply plate voltage to the tube from the plate battery and also serves as a radio-frequency coupling mechanism. The small capacitance between grid and plate and the resistor R serve to prevent the circuit from functioning as an inverted crystal oscillator of the usual type* where feed-back is obtained in the inter-electrode capacitance and the crystal presents an inductive reaction of appreciable magnitude. It will be noticed that the current through the crystal is the current through the feed-back coil L_1 — consequently the crystal may be thought of as controlling the oscillator by control of the feed-back. Current in R produces no feed-back.

The performance of this oscillator is characterized by (*1*) oscillation over a very narrow range of adjustment of C, (*2*) very reliable oscillation when the condenser is adjusted to the middle of this range, and (*3*) a minimum plate current indicated by the meter I when adjustments are properly made.

Performance data for a representative broadcast-frequency quartz plate are presented below in the same form as the data of the article in the November, 1930, *Experimenter*. The deviation resulting from changes in any variable, the other factors remaining constant is summarized below:

Temperature Changes (*Figure 2*). The quartz plate employed was of the "Y" or "30-degree" cut having a positive temperature coefficient. It will be noticed that for a change of ±0.1°C from the normal temperature of 50°C (1/5 of 1%) the resulting frequency change is within ±2.5 parts per million, which is definitely lower than for the same type of crystal in the older circuit. Dotted lines indicating the range of ±0.025° (which may be maintained under average room temperature conditions by the temperature control system furnished in the unit) show that ordinarily the frequency changes resulting from temperature variations will be less than ±0.75 part per million.

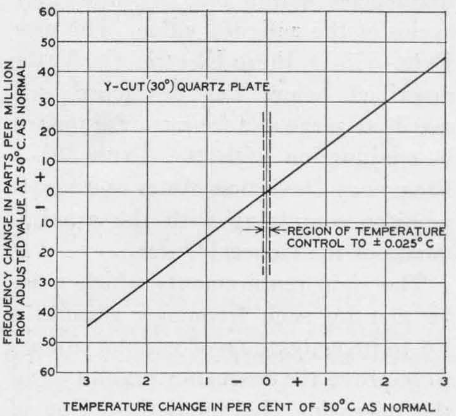


FIGURE 2. Variation in frequency of the new oscillator as a function of the temperature of the quartz plate

*That is, one in which the crystal is placed in the plate circuit and the tuned element in the grid circuit.

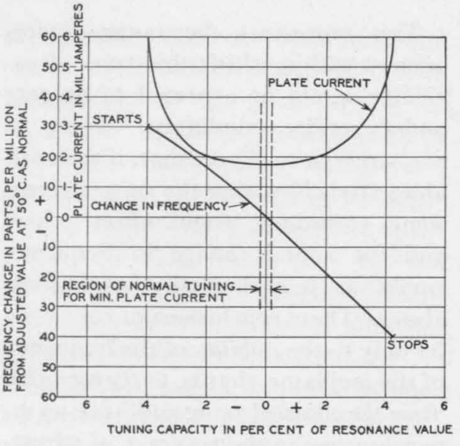


FIGURE 3. Variation in frequency as a function of grid-tuning capacitance

Tuning Changes (*Figure 3*). The frequency of oscillation is altered, when the grid tuning condenser is varied. In the region of the plate current minimum, where definite changes in the reading of the plate current meter are observable (as shown in the upper curve) the change in frequency is within ±1.5 parts per million.

Plate Voltage Changes (*Figure 4*). It is at once evident that moderate changes in plate voltage have no effect on the frequency of oscillation. This is in definite contrast to the changes obtained with the older circuit.

Filament Voltage Changes (*Figure 5*). For changes in filament voltage of several per cent., which are easily observed on the filament voltmeter of the new oscillator no appreciable change in frequency results. If the filament voltage is decreased far enough, the frequency rises, as shown by the upper curve. But if, for each value of filament voltage, the tuning condenser is readjusted to give minimum plate current, the change in frequency is entirely negligible, as shown by the lower curve.

Tube Changes (*Figure 6*). Changing tubes, the circuit being readjusted to minimum plate current for each tube, resulted in the frequency changes shown. Twelve tubes, some of which were new and some old, all gave operating frequencies within ±1 part per million. If tubes No. 2 and No. 5 were rejected, the remaining 10 tubes give frequencies practically within the limits of the ±0.5 part per million.

Vibration. In making tests for vibration, the entire unit was subjected to heavy shocks. These resulted in two types of frequency change: that due to motion of the quartz plate in the mounting, and that due to shifts in the tuning of the grid circuit. The latter could be compensated for by readjustment of the tuning condenser for minimum plate current. With readjustment, the shifts remaining after the

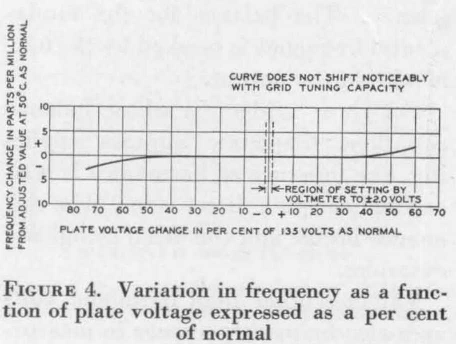


FIGURE 4. Variation in frequency as a function of plate voltage expressed as a per cent of normal

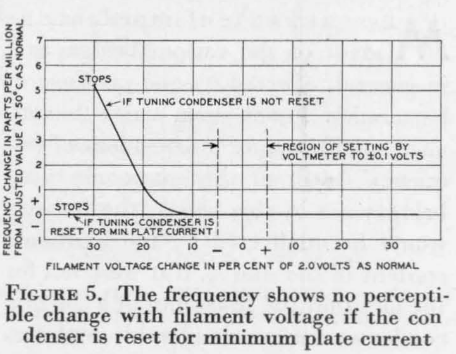


FIGURE 5. The frequency shows no perceptible change with filament voltage if the con denser is reset for minimum plate current

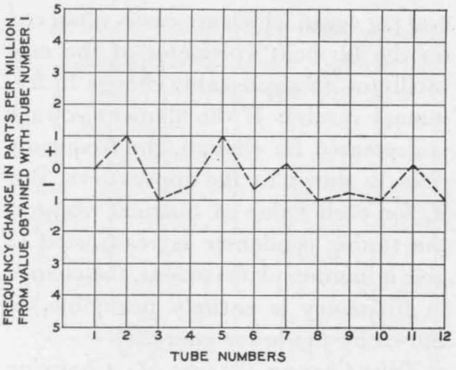


FIGURE 6. Frequency shifts very slightly when tubes are changed

vibration stopped were within ±1.5 parts per million.

As an estimate of the absolute constancy of frequency of the system, it may be assumed that all of the variations observed take place in the same direction:

Variable	Range of Variation	Frequency Variation (parts per million)
Temperature	0.025°C	0.75
Tuning (by plate meter)		1.5
Plate voltage	2.0 volts	0.1
Filament voltage	0.1 volts	0.05
Tubes	(average)	1.00
Vibration	(heavy shocks)	1.5*
	Total	4.9

*Remaining after shock.

This represents the range of frequency within which this type of oscillator would be expected to operate under service conditions. There is every reason to expect that, if the variables are held within the ranges given, some variations would offset others and the actual change in frequency would be less than the total given above. These conclusions of course refer only to the *stability* of the frequency of the oscillator, that is, to *the variation from the adjusted value* and have no direct bearing on the accuracy of adjustment of the oscillator to a specified frequency.

Quartz plates suitable for use in the TYPE 575-D Piezo-Electric Oscillator and guaranteed to within ±0.002% for a period of one year are available. They are known as TYPE 376-J Quartz Plates. In adjusting these plates, the frequency is brought within one cycle of the specified frequency as determined by our primary frequency standard which is operated continuously and checked in terms of Arlington time.

The price of the TYPE 575-D Piezo-Electric Oscillator is $215.00; of TYPE 376-J Quartz Plates $85.00.

— JAMES K. CLAPP

ELIMINATING HARMONICS IN BRIDGE MEASUREMENTS

MEASUREMENTS of impedance as made on the various bridges are, in general, affected by the presence of harmonics. For those in which the balance conditions are independent of frequency (most of the commonly used bridges are in this class), the balance would be unaffected by the harmonic content of the source, if it were not for the fact that the resistance of a coil or a condenser varies considerably with frequency. The balance for the fundamental frequency is masked by the harmonics in the output.

For those bridges in whose balance equations frequency appears explicitly, the presence of harmonics is serious and causes a direct error. The resonance bridge and the Wien bridge are examples.

Voltages other than harmonic voltages also frequently appear in measuring circuits. They are induced in the circuit electromagnetically and electrostatically by the fields, usually of commercial frequency, which exist in most laboratories. They become important when the voltage to be measured is reduced to a sufficiently small value. For that reason they become the limiting factor in bridge balances by preventing the attainment of complete silence in the head telephones.

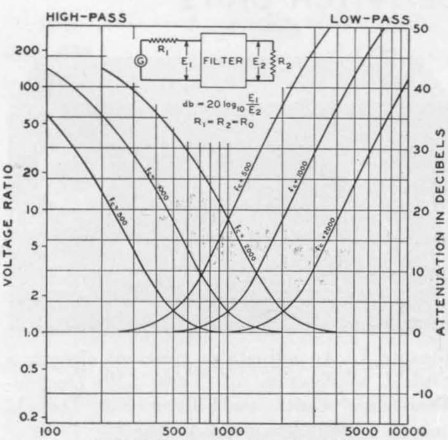
Spurious voltages, harmonic or non-harmonic, may be decreased in magnitude by the use of suitable filters which may be connected directly to the power source in order to decrease the harmonic content of the voltage applied to the measuring circuit. They would be so placed for the measurement of any element which might be affected by such spurious voltages.

Filters may also be connected between the bridge and the null detector. This is usually the preferable position, because in general the impedance of the null detector is greater than that of the bridge. Filters have in general sharper cut-offs the higher the impedance to which they are connected.

A band-pass filter made up of low-pass and high-pass sections is satisfactory for measurements made at a single frequency. The characteristic impedances of these sections should be chosen to be equal to or less than the load into which they work. Low-frequency non-harmonic voltages are suppressed by the high-pass section; high-frequency non-harmonic voltages, and all harmonic voltages by the low-pass section. The cut-off frequencies of these sections may be so chosen that the applied frequency may vary considerably without affecting their action.

The TYPE 330 Filter Sections* are built for three different cut-off frequencies, 500, 1000, and 2000 cps, and two different characteristic impedances, 600 and 6000 ohms. The attenuation obtainable with these sections

*Described in Catalog F, page 97.



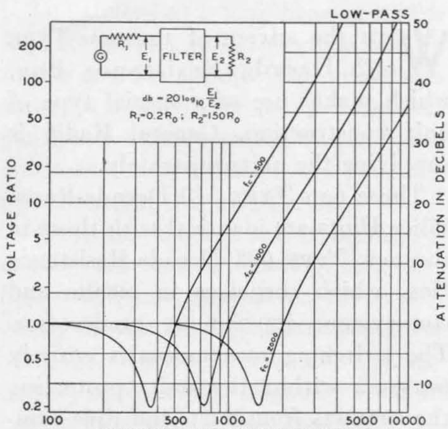


FIGURE 1 (left) and FIGURE 2 (right). Attenuation characteristics of TYPE 330 Filter Sections for the values of terminating impedance shown. *fc* is the cut-off frequency and *Ro* is the characteristic impedance (either 600 or 6000 ohms) specified in Catalog F when terminated in their characteristic impedances are shown in Figure 1. The three curves for each type of section are alike, being merely displaced along the frequency axis.

The 500-cps high-pass filter section is suitable for suppressing the usual low-frequency non-harmonic voltages. The three low-pass filter sections are suitable for suppressing the high-frequency harmonic voltages. The attenuation to the second harmonic, which is usually the strongest, exceeds that to the fundamental by at least 15 db (a voltage ratio of 5.5 to 1). The frequency of the fundamental may increase by 50% before the attenuation to it becomes 10 db.

When a filter section is connected to a load resistance much larger than its characteristic impedance, the ratio of input to output voltage is decreased in the transmission band, if, in addition, the input resistance is made much smaller than the characteristic impedance of the filter. This ratio becomes less than unity at a frequency near the cut-off frequency, thus giving a voltage characteristic similar in some respects to that of a resonant circuit.

Such curves for the three low-pass filter sections are shown in Figure 2. They are for the case of input and load resistances 0.2 and 150 times their characteristic impedance. The attenuation to the second harmonic is on the average the same as for the previous case. The fundamental frequency may, however, vary from 0.6 to 1.5 times the cut-off frequency, without causing the discrimination between fundamental and second harmonic to fall below 15 db. Within this range the attenuation to the fundamental varies between —14 db and +10 db. The range of the three filter sections overlap and together they cover the frequency band from 300 to 3000 cps. Other sections may be built on special order, which will extend this range up to 7500 cps and down to 60 cps.

— Robert F. Field

CONVENIENT DECADE-SWITCH UNITS

With the advent of the new Type 602 Decade-Resistance Box, which makes use of a special type of unit construction, General Radio is supplying the units separately.

These new Type 510 Decade-Resistance Units are identical with those in the new Type 602 Decade-Resistance Box, which surpasses in results and convenience its famous predecessor. The switching mechanism is entirely enclosed within the unit, protecting the contacts from dust, and thus eliminating a frequent source of poor contact and leakage. Each individual unit is provided with a cylindrical shield and an etched dial plate to facilitate mounting on a panel.

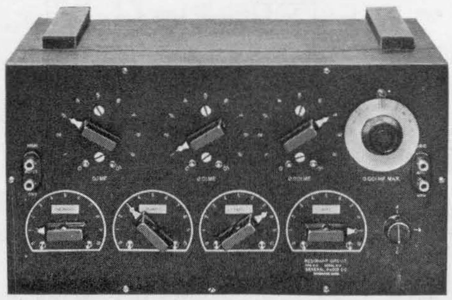


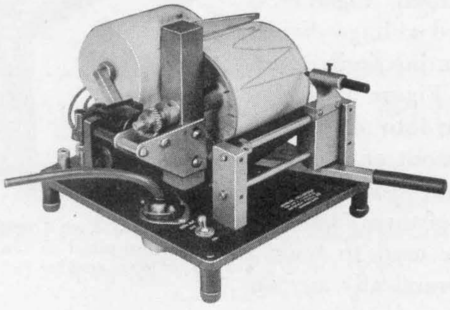
Figure 1. An adjustable resonant circuit, a typical application of Type 510 Decade-Resistance Units and Type 380 Decade Switches and Condensers

(Continued on page 8)

A MANUAL RECORDER

CURVE-DRAWING equipment makes it possible for engineers to record variable phenomena and interpret or compare results at their convenience.

Early in 1927 the TYPE 289 Fading Recorder was developed by the General Radio Company* in conjunction with the study of radio transmission carried on by G. W. Pickard. The TYPE 459-A Manual Recorder shown on this page has just been designed. In this new instrument standard 3½ inch adding machine paper is carried past a recording point at a uniform rate and the position of this point may be varied manually to follow and trace the curve of the variable being studied.



TYPE 459-A Manual Recorder. Moving the handle simultaneously moves the pen and the slider on a potentiometer

The main drum is driven by a small 60-cps, 110-volt synchronous motor and the gearing is so adjusted that the paper travels exactly one inch a minute. The drive is made positive by small points projecting through the drum, and these are so spaced that the perforations caused by them in the paper are exactly one inch apart.

The drum on the standard units makes five complete revolutions an hour, but the gearing of course can be changed to meet special conditions, giving a rather wide variation of speeds. The drum may also be loosened from the drive shaft by a thumb nut. A spring slider carries both the recording point and the contact arm of a potentiometer. A lever makes it possible to follow the desired variations either by maintaining a constant deflection or a null point on a galvanometer.

The TYPE 459-A Manual Recorder is used in a manner similar to the earlier TYPE 289 Fading Recorder for the study of fading of radio transmissions. In recording the variation in signal intensity, the necessary changes of the arm to balance them result in a trace on the recording paper of magnitudes corresponding to the changes in signal strength.

The potentiometer in the standard instrument is a tapered card having a maximum value of approximately 2000 ohms. To meet special conditions this card may easily be replaced.

The slider has a long bearing and is kept in contact with the guide bar by means of a flat spring. This allows the slider to move freely at all times but eliminates unnecessary side play and compensates for contact friction on both the potentiometer and the drum.

While the original intent of the recorder was to study fading, it is felt that it will serve to draw curves so necessary for the intelligent interpretation of many other phenomena. For example, the recorder might be used in conjunction with a beat-frequency oscillator driven by a similar synchronous drive in studies of acoustics. The price is $85.00.—H. S. WILKINS

*See *General Radio Experimenter* for April, 1927.

(*Continued from page 6*)

These units can be used in many ways. For instance, they are invaluable in the construction of adjustable impedance-matching networks, special attenuators, or harmonic analyzers. Provision has been made so that several units can be "ganged" together. A very useful calibrated voltage divider can be made by mounting similar units "back to back" (see Figure 3) so that when resistance is cut into one unit, it is simultaneously cut out of the other, thus keeping the total resistance constant. Any number of these "back-to-back" units may be used to build a voltage divider for practically any desired range and degree of precision.

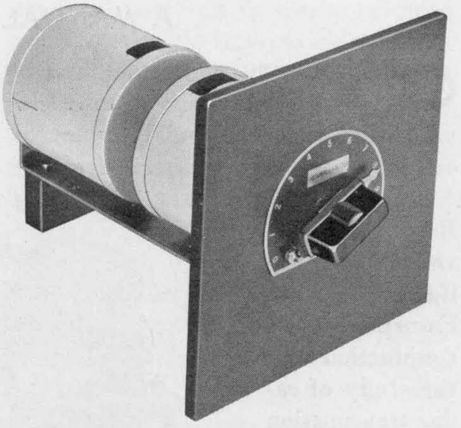


FIGURE 3. Two TYPE 510 Decade-Resistance Units mounted in tandem to make a voltage divider (potentiometer)

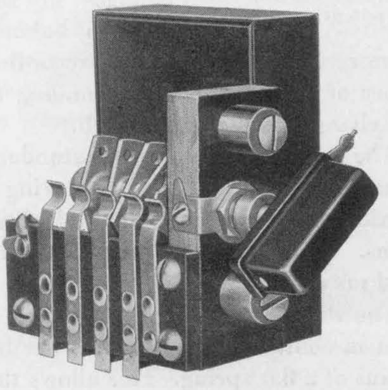


FIGURE 2. TYPE 380 Decade Switch and Condensers

Another example of the decade-unit idea is the TYPE 380 Decade Switch and Condenser, which provides a corresponding unit for capacitance.

These decade-condenser units (see Figure 2) are identical with those in the TYPE 219 Decade Condenser. Due to their compact construction, they are very useful in the construction of oscillators, harmonic analyzers, and other laboratory equipment.

Figure 1 shows a typical piece of laboratory equipment using both decade-resistance and decade-condenser units. The advantage to any engineer in being able to obtain these self-contained decade units is evident. Complete technical information regarding their characteristics is contained in Catalog F.

— H. H. SCOTT

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