the GENERAL RADIO Experimenter

GR Exp Index 1926-

VOL	Date	Feature Articles	Instruments
1-1	June 1926	Announcing A New GR Service For Experimenters Amplifier Ins & Outs By C.T. Burke	
1-2	July 1926	The "B" Battery Eliminator By H.W. Lamson A New Amateur Wavemeter A New Tube and a New Transformer	"B" Eliminator kit 358 Wavemeter 285-D Transformer
1-3	August 1926	The Design and Use of the Speaker Filter by H.W.Lamson	387 Speaker Filter 400 "B" Eliminator & Power Amplifier
1-4	October 1926	The Status of "A" Battery Elimination By C.T. Burke The Vacuum Tube Bridge By H.W. Lamson	405 Plate Supply 400 Power Amplifier & Plate Supply 361-A Vacuum Tube Bridge
1-5	November 1926	An Effective Method of Measuring Amplification by L.B. Root Coil Calculations by C.T. Burke	355 Amplifier Test Set
1-6	December 19**26**	Design & Testing of Plate Supply Devices, PartI-Design by P.K. McElroy	Piezo El Ocs
1-7			
1-8	Feb 19**27**	Study of Coil Resistance	383 Br.
1-9	Mar 27	Condensor Plate shapes	415 Amp, Plate supply
1-10	Apr **27**	New Tubes for Old	388 VT Reactivator, 413 BFO, Graphic L R
1-11	May 27	Coupling Methods, Acoustic Cht	411 Sync Motor
1-12			
2-1			
2-2	July 27	AC Operation, Power Amps	440-A Trans, 438 Soc, 439 Res, 410 Rheo
2-3	Aug 27	AC Tubes	410,440,438,439
2-4	Sept 27	Voltage Control	445 PS, 329 Att, 249 Att
2-5	Oct 27	Power Amp 441 pp amp	441, 285,373,367 trans, 387-A Fil, 445 PS
2-6	Nov 27	AC Op Power Amp, Synchrometer	467 fork, 473 Synch
2-7	Dec 27	Choice of Tubes	446 VD, 437, 439 Tap R

2-8	Jan 28	Hydrophone, Plate Supp	214-A Rheo
2-9	Feb 28	Service Lab, TC of R, Trans	338 React, 361-B VT Br
2-10	Mar 28	Use of UX250	565A&B Trans, 527 A Fil, 587-A Fil
2-11	Apr 28	Phono Amp, Parallel Feed	
2-12	May 28	Hydrophone, Artificial Cable	321-C Art Cable Box
3-1	June 28	Magneto St Osc (489),	489 Mag Osc
3-2	July 28	Consumer Policy, Trans, WaveMtr	585D,H Trans, 558 Wavemtr, Prices
3-3	Aug 28	Magneto St Osc -2, 330 Filter	330 Fil
3-4	Sept 28	Addr Sys, VTVM, FreqMtr, G Mtr	426-A, 532, 443 G Meter
3-5	Oct **28**	Hydrophone	320 Test Osc
3-6	Nov 28	Rating Receivers, HV Supply	403 Sig Gen
3-7	Dec 28	How & Why of Talkies	338 String, 369 L, 227,236,309, 301, 214
3-8	Jan **29**	Units of Transmiss, Talkies 2	
3-9	Feb 29	A New Relay (481), Direct C	481 relay, 554 VD, 389&489 Magst Osc
3-10	Mar 29	Freq Determination, Greq Mtr	558 P Freq Mtr
3-11	Apr 29	New Freq Std, RF Osc (384)	384, 487C Fil
3-12	May 29	Permolloy, C Unbal Test Set	
		SEE Bound Experimeters	**New Small Format**

I N D E X

to

GENERAL RADIO EXPERIMENTER
June, 1929 through May, 1931

Measurements, Precision Frequency
John D. Crawford (March, 1931)

Measurements, a Rectifier-Type Meter for Power Output at Audio Frequencies
John D. Crawford (July-August, 1929)

Measurements, Simplified Sensitivity for the Radio Service Man
Charles T. Burke (August, 1930)

Measuring Receiver Characteristics, the Standard-Signal Method of
Charles T. Burke (March, 1930)

Modulation Measurements on Broadcast Transmitters
W. N. Tuttle (March, 1931)

Monitors, the Frequency Stability of Piezo-Electric
James K. Clapp (October, 1930) (November, 1930)

Mutual Conductance, the Importance of in Testing Vacuum Tubes
Charles T. Burke (July-August, 1929)

Networks, Gain in Amplifiers and Other
Arthur E. Thiessen (December, 1929)

New Home of the Engineering Department, The
J. W. Horton (December, 1930)

New Testing Instruments for the Radio Service Laboratory
Unsigned (June, 1929)

Non-Polar Relay, A
Unsigned (November, 1929)

Notes on Power Measurement in Communication Circuits
John D. Crawford (October, 1929) (November, 1929)

Oscillator, a Low-Frequency
L. B. Arguimbau (October, 1929)

Oscillator, a Tuning Fork Audio
Charles E. Worthen (April, 1930)

Oscillators, Beat-Frequency
Charles T. Burke (May, 1931)

Oscillators, Temperature Control for Piezo-Electric
Unsigned (November, 1929)

Oscillograph, a Continuous-Film Camera for the
Horatio W. Lamson (April, 1931)

The GENERAL RADIO EXPERIMENTER

VOL. 3 NO. 8 JANUARY, 1929

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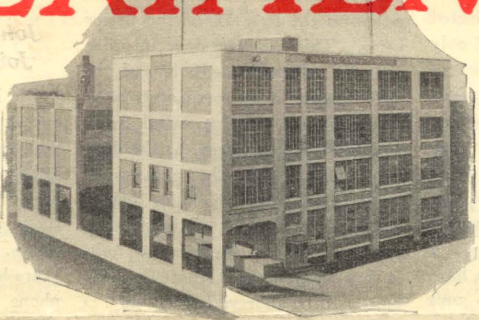


Units of Electrical Transmission

By *J. W. HORTON, Chief Engineer*

The communication engineer, although he deals generally with very small amounts of energy, is frequently concerned with ratios of energy having enormous magnitudes. The ratios between the rates of energy flow in different parts of a communication system, if expressed numerically, may be quite as impressive as the figures used by the power engineer. As an example the power delivered by an ordinary telephone transmitter is of the order of 0.01 watt. This may be used to control the output of a 100-kilowatt radio transmitter, in which case the ratio of the powers at the two ends of the system is ten million. Again it is quite possible for the energy delivered to its loud-speaker by a modern radio receiver to exceed the energy delivered by the antenna by one hundred million to one.

Because of the relations between the quantities involved the communication engineer finds it desirable in describing the efficiency of his apparatus to adopt a method differing markedly from that used by the power engineer. Until recently this method was to compare the performance of any piece of apparatus to that length of standard telephone cable which changed the amount of power delivered by the same ratio.

In making this comparison two factors must be taken into account, first the energy dissipation — or attenuation — within the apparatus, and second, the ability of the apparatus to receive and deliver energy across the junctions between it and associated circuits. To describe the performance of any apparatus, therefore, it is customary to consider the power which would be received by a given load circuit from a given generator circuit when they are connected directly together and the power received when the apparatus in question is included between them.

In the case of a length of standard cable it was assumed that the generator and receiver circuits were both long lengths of similar cable so that the only loss due to introducing the reference length was the dissipation within the reference length. Under these conditions the actual loss in a real cable when the current flowing has a frequency of 800 cycles per second is given by the expression:

$$P_1/P_2 = e^{0.218L} \qquad (1)$$

where e is the base of Napierian logarithms and L is the length of the cable in miles. From this the number of miles of standard cable which, when connected into a long length of similar cable, changes the amount of power received by the ratio P_1/P_2 is:

$$L = 4.587 \log e \; P_1/P_2 \qquad (2)$$

From the change in received power occurring when any piece of apparatus is introduced between given generator and receiver circuits the attenuation, or gain, of the apparatus expressed in equivalent miles of standard cable is given by the above formula.

One consequence of expressing performance in this way is that the over-all value for a system is computed by adding together the values expressing the performance of the several parts. This differs from the practice of the power engineer who multiplies together the percentage efficiencies of his components.

The above method of expressing the transmission efficiency of a piece of apparatus as some function of the logarithm of a power ratio has two decided advantages for the communication engineer. In the first place it fits in conveniently with his transmission formulæ, of which (1) given above is a typical example. In the second place it is most convenient when used in connection with the sensation of loudness, which also follows a logarithmic law. This latter fact can be demonstrated by determining the amounts of energy required to give a series of sounds differing by apparently equal intensity intervals. If these amounts of energy are compared it will be found that successive values bear a fixed ratio to one another.

In spite of its convenient logarithmic character the "mile of standard cable" or "800-cycle mile" has certain disadvantages. First, it is associated with an arbitrarily selected physical cable and is significant only for currents having a frequency of 800 cycles. Second, it requires, when used in mathematical computations, the use of an arbitrary constant based on the physical cable. Because of these disadvantages an effort has been made to standardize a new unit which will be of greater simplicity. Several such units have been proposed. In Europe a unit known as βl has been employed for some time. Here the number of units is given directly by the natural logarithm of the current ratio. In America the unit which has come into general use is such that the number of units is ten times the logarithm to the base 10 of the power ratio. That is,

$$N = 10 \log \frac{P_1}{P_2} = 20 \log \frac{I_1}{I_2}.$$

The European method is probably more convenient from the standpoint of mathematical computations. However, the use of one additional conversion factor is undoubtedly less confusing to the mathematicians than would be the use of natural logarithms to the relatively larger number of practical engineers. An immediate advantage of using the logarithm to the base 10 appears when it is recognized that the number of transmission units may be computed from the power ratio by the means of an ordinary slide rule or may be looked up in the nearest table of logarithms.

The use of the various units and their relative merits have been discussed at International Communications Conferences and it has been agreed that both shall be retained. The unit based on the logarithm to the base ten of the power ratio has for some time been known as the transmission unit (TU) for want of a more definite title. At the last meeting of the International Communications Conference, however, this unit has been given the name decibell. The nominal unit is such that the number of units is the logarithm to the base 10 of the power ratio. This has been done in order that the two units—the βl and the Bell—should be approximately alike in magnitude. The so-called practical unit will, however, be the decibell, which, since the number of units is 10 times the logarithm of the current ratio, is obviously one-tenth the size of the nominal unit. It has been decreed that the new unit shall be abbreviated as "db".

It was originally intended that transmission units should be used in referring to the performance of apparatus, that is, to the gain or to the loss resulting when the apparatus was employed. Since, however, the unit is based on power ratios it is only natural that it has come to be used for expressing amounts of power. This is most frequently done by selecting, arbitrarily, some amount of power as a "reference level" and describing other amounts of power as being so many transmission units above or below this reference level. It must be emphasized that a power level expressed in this way can have no significance unless the reference power is specified. There may be as many reference points as there are systems for electrical communication. In telephone lines for example the standard output of a repeater is spoken of as "zero level" and the rate of energy flow at other parts of the system is thus referred to this level. In high quality broadcast transmission a power level of 0.006 watts has been arbitrarily chosen as zero level. Thus when we say that an amplifier is capable of delivering a "plus 10 db level" we mean that it is capable of delivering 0.06 watts. The use of transmission units in describing power levels emphasizes the advantage of using a logarithmic unit in connection with such phenomena as hearing which itself follows a logarithmic law. The practice should, however, not be carried to the point where the reference power level is lost sight of.

Johns Hopkins Graduate Joins Engineering Staff

On December 1 we welcomed to our engineering staff Arthur E. Thiessen, a graduate of the Class of 1926 of Johns Hopkins University. Mr. Thiessen's undergraduate thesis was on the subject of magnetic alloys. For the past two and a half years he has been with the Bell Telephone Laboratories in New York City, working largely on apparatus for high speed cables.

As is true with most of our engineering staff, Mr. Thiessen is a former amateur. Pre-war amateurs on the Pacific Coast will undoubtedly recall Mr. Thiessen's spark transmitter at Portland, Oregon.

Dr. Hull Returns to Boonton

Since his return from Europe, where he attended the U. R. S. I. Conference, Dr. Lewis M. Hull has assumed the direction of the technical work of the Aircraft Radio Division of Radio Frequency Laboratories. He is, therefore, now making his headquarters at Boonton, New Jersey. Dr. Hull will be associated with our Engineering Department only in a consulting capacity. His work and interests have been principally in the line of radio-frequency measurements. One of his contributions along these lines is the Type 403 Standard-Signal Generator.

TELEVISION

We have received many inquiries as to whether we were contemplating putting out any television apparatus. The answer has been uniformly "No". The reason? Read "The Old Man's" article on this subject on page 24 of the January issue of "Q. S. T." This is one of the best summaries of the subject we have yet seen.

How and Why the Talkies

By HORATIO W. LAMSON, Engineering Department

Part Two

In the December issue of the EXPERIMENTER we outlined the general problems of the talking movies and discussed in some detail the wax disc method of recording and reproducing synchronized sound. We now propose to consider the optical method whereby a photographic record, corresponding to the fluctuating sound impulses, is obtained upon a film in the studio and subsequently reproduced as sound in the theater.

There are two fundamental forms which such a film record may take. The one most commonly employed has a constant transverse width and an intensity or "density" which varies from point to point along the film in accordance with the frequency and amplitude fluctuations of the corresponding sound waves. Such a record is shaded in appearance and similar in character to a photograph of a heavily banded light spectrum. It may be obtained by varying the intensity of the light source, either directly or indirectly, or by changing the effective width of the narrow slit opening through which the film is exposed. In either case the density across the record is constant at any given point along the film, giving thus the characteristic banded effect.

On the other hand, in the second type of record, a constant source of illumination is employed, while the electrical impulses corresponding to the sound waves operate a mechanism that serves to vary the relative amount of the transverse slit which is illuminated at any given instant. This produces a black-and-white non-shaded record having a fine saw-tooth appearance.

There are three distinct methods of optical recording which may be described here, all of which are fundamentally adapted to produce a banded type of record.

The first makes use of the neon or similar type of glow lamp which is so well known in the art of television. The intensity of the light emitted by such a lamp can be varied rapidly and easily by a fluctuating voltage applied to it. If, now, our film is driven uniformly along behind a narrow transverse slit which is illuminated on the opposite side by such a lamp, we have the means of producing a banded film record corresponding to the variations of the sound waves picked up by the studio microphones.

The second method utilizes a constant source of light and employs an ingenious device known as a "light-valve." This consists of two parallel duraluminum tapes each six mils wide and three mils thick. These are so placed in the optical system that, when at rest, they form an effective slit which, viewed against the source of light, presents an opening two mils wide by one quarter of an inch long. By means of a high grade optical system an image of this slit in the light valve is thrown onto the the film in the form of a transverse line of light one-eighth of an inch long and, normally, only one mil wide.

The two duraluminum tapes form an electrical loop circuit and they are so located in a steady magnetic field that, when a pulsating current is passed through them, they move in opposite directions. In this manner the effective gap opening between the tapes, and, hence, the width of the image line on the film, is varied according to the frequency and amplitude of the electrical impulses. Such a modulation of the light gives, of course, the characteristic banded record on the moving film. We note that in this case the time during which each spot on the film is exposed to a constant light source varies, while in the other two methods described each spot on the film record is illuminated for the same time interval by a modulated light intensity.

It is found desirable in practice to adjust the tension on the tapes until they have a natural frequency of about 7000 cycles per second. Under this condition a 100 per cent. modulation of the light, i.e., opening the valve slit to a maximum of four mils and just closing it completely requires about ten milliwatts of power at the lower audio frequencies and about 0.1 milliwatt at the natural frequency of the tapes.

A third method of optical recording utilizes an interesting device known as the Kerr cell. A beam of light of constant intensity is passed first through a Nicol's prism which polarizes the beam in a particular plane. It is then passed through a narrow gap between two electrodes and subsequently through a second Nicol's prism set at 45 degrees to the first. The gap between the electrodes in the Kerr cell is filled with nitro-benzol, a liquid which has the property of rotating the plane of polarized light passing through it when subjected to an electrostatic field to a degree proportional to the impressed voltage. Obviously, then, a modulation of the effective intensity of the light source may be produced by applying an alternating potential to the electrodes, so that, if we employ a fixed transverse slit against the film, a banded record will result. The separation of the electrodes and the length of the light path between them determine the voltage necessary to produce 100 per cent. modulation, i.e., variation between full transmission and total extinction of the light. As in the case of the neon lamp, the degree of modulation of the Kerr cell is essentially independent of frequency, but in the Kerr cell the degree of modulation is proportional to a cosine function of the amplitude which, obviously, limits the usefulness of this device.

In all three methods of optical recording the nominal effective time of exposure is about 1/18,000 second, corresponding to the nominal film speed of ninety feet per minute. This means that modulation of the record at a frequency of 18,000 cycles or higher would be nil with an increasingly better modulation as we go below 18,000 cycles. In the workable audio range, however, the modulation is satisfactory, or can be made so by the use of equalizers.

The technique of studio recording follows along the general lines previously described. The responses of the several studio microphones, properly mixed, are amplified sufficiently to operate whichever type of recording device is used. In general two separate film records are made, one for the sound and one for the photography. This permits a different technique of development for the two films, which is very desirable. Synchronization is accomplished by an interlocking electrical drive system, which contains mechanical filters in the drive of the sound film to maintain a constant and uniform rate of travel past the exposure slit.

It is customary in both disc or photographic recording to make two identical sound records and subsequently to choose the better for printing the released positive films or preparing the playing records. The optical sound record, as printed on the films sent out to the theaters, takes the form of a strip about one-eighth of an inch wide along one side of the picture. The picture and the sound strip are printed separately on the positive film, the space occupied by one being shielded from the light while printing the other.

Great care must be taken in selecting both the p_sitive and negative raw film stock to be used in sound picture work. Any irregularities in the transparency of the film or emulsion will, of course, generate unwelcome "background" noises in the final reproduction. While the eye can barely detect a two per cent. change in film density sudden irregularities of only one-tenth of one per cent. will give rise to an audible background noise.

In reproducing the optical sound record in the theater we employ another device used in the art of television, namely, the photo-electric cell. When subjected to a steady polarizing voltage the photo-electric cell allows a current to flow through it which is proportional to the intensity of light falling upon the cell. A narrow transverse slit is interposed between the cell and a constant source of light. This slit extends across the portion of the film carrying the sound record so that the intensity of the light passing at any instant into the photo-electric cell depends either upon the relative density of the banded film back of the slit or upon the width of the "cut-off" portion of the saw-tooth film record at the point in question.

Thus if the film is drawn uniformly at the original speed across the slit we will obtain a pulsating current in the photo-electric cell circuit which will be a reproduction of the current in the studio microphones.

When projecting a motion picture the film is advanced intermittently at the rate of sixteen "frames" per second, each frame being stationary for the brief instant during which light is passing through it to the screen. Obviously, then, the synchronized picture and sound record can not be adjacent on the film. In practice they are spaced about fifteen inches apart along the film, thereby allowing for a "loop" to take up the intermittent slack between them. Mechanical filters are used in the drive to insure an extreme uniformity of motion past the photo-electric cell slit.

The electrical impulses obtained from the photo-electric cell are extremely small in amplitude. A two-stage resistance-coupled amplifier is ordinarily necessary to bring them up to an energy level comparable with that obtained directly from the electromagnetic pickup used in the disc method of reproducing. On account of the high impedance of the photo-electric cell circuit, it is desirable to build this amplifier into the same container which holds the photo-electric cell. The output of this amplifier, at low impedance, is then carried to the fader and, from this point on, the same speech amplifying system used with the disc method is employed, likewise the same technique of fader operation, monitoring, and control of the output panel.

A large proportion of the theaters in which synchronized sound installations have been made are equipped with machines designed for projecting either the disc or the film type of record. They can, therefore, utilize the standardized product of all producers.

A few statistics may be of interest in closing. A number of concerns are now developing and placing on the market equipment for recording and reproducing sound pictures. Among them are: the Electrical Research Products, Inc., a subsidiary of the Western Electric Company, who use both the disc record (Vitaphone) and the film record (Movietone); the R. C. A. Photophone (a film record); and the General Talking Pictures Corporation (De Forest Phonofilm), likewise a film record.

Among the producers using the E. R. P. I. system are:

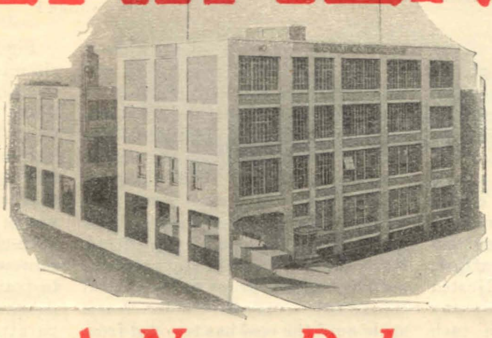
1. Paramount Famous Players Lasky Corp.
2. Metro-Goldwyn-Mayer, Inc.
3. Warner Brothers.
4. Fox-Case.
5. First National.
6. Universal.
7. Christie Comedies.
8. Victor.

The following producers are licensed under the R. C. A. Photophone system:

1. F. B. O.
2. Tiffany-Stahl.
3. Pathe.
4. Mack Sennett.
5. Educational.

In conclusion we wish to acknowledge our indebtedness to the Bell Laboratories Record for certain data used in this article.

The GENERAL RADIO EXPERIMENTER



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A New Relay

By C. T. BURKE, Engineering Department

With this month's EXPERIMENTER the General Radio Company announces a sensitive signal relay. This instrument, the Type 481 Relay, is illustrated in Figure 1. A permanent horseshoe magnet provides the field and forms a protecting shield about the coil and reed. The coil is mounted about midway of the sides of the magnet and the reed fixed near the toe. The distance from the center of the poles to the point where the reed is secured is $2\frac{1}{4}$ inches. The contacts with adjusting screws complete the instrument. An unusual feature of this relay is the distance between the pole pieces—0.47 inches. This wide separation provides a uniform field in the region through which the reed moves. The effect of this is to make the adjustment of the reed to the neutral position less critical.

In operation, the adjusting screws, which determine both the position of the reed in the field and its travel, are adjusted so that the reed takes up the neutral position in the field. The location of the neutral position will shift somewhat as a result of an average current in the coil, and in the case of high speed signals of considerable intensity, this shift may be comparatively large. With the reed in the neutral position, a signal (which may for convenience be supplied by an interrupter) is impressed on the relay coil. The contacts of the coil are adjusted so that the reed strikes evenly without chatter on either side. This adjustment may be made with a sounder, but it can be greatly facilitated by means of a visual type oscillograph.

The minimum operating current of the Type 481 Relay is one milliampere in the signal circuit, and it will follow impulses of frequencies as high as 125 cycles per second. The tungsten contact points will break one ampere without burning.

A relay of this type has many uses in the laboratory, as well as in the commercial communications field. The high sensitivity attained permits the use of the Type 481 Relay with little amplification for the actuation of chronographs from time signals, signal recorders, or other apparatus where remote control by means of radio, carrier or low-frequency current impulses is desired. Rectification is, of course, required where the impulse current is of high frequency.

The mechanical simplicity and ruggedness of the relay particularly recommend it for uses where little attention can be given to the apparatus.

The operation of the relay is best illustrated by a few oscillograms. The oscillograms of Figures 1 to 9 were taken on a string oscillograph, using the recently developed double string-holder which permits simultaneous viewing of the current in both the coil and the contact

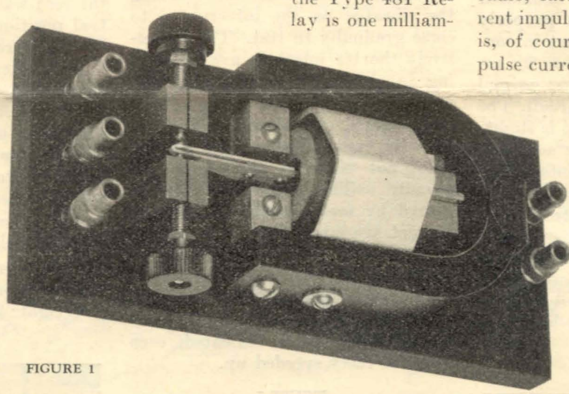
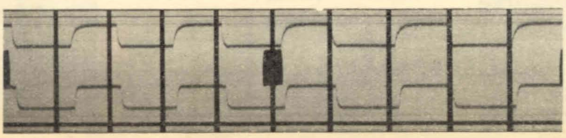


FIGURE 1



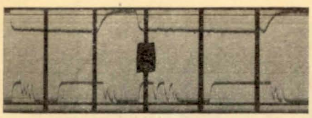


FIGURE 2

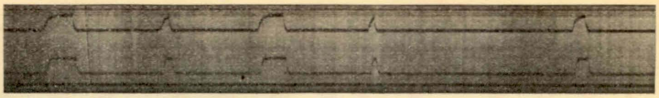
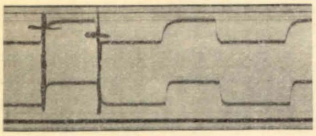


FIGURE 5

circuits. The oscillograms are all arranged with the coil current at the top and time proceeding from left to right. The zero current lines are at the bottom. The timing lines on the films mark 0.04-second intervals. Figure 2 shows the effect of a very badly adjusted relay. The effects of chattering and bouncing are very marked. The relay fails entirely on many impulses. For contrast, Figure 3 shows a well adjusted relay. A firm contact without any trace of bounce is made on each throw of the reed. The trace of the coil current shows plainly the gradual building up due to the inductance of the coil. The contact current shows no change until the coil current reaches a critical value, then rises almost at once to its final value. The effect is to give a sharper signal



on the contact side than on the coil side. This would not normally hold true in signal circuits, where the inductance of instruments would slow down the growth and decay of current. Such effects may be minimized by means of condensers properly placed. The important fact in connection with the relay is that its action is quicker than the normal growth of current in the circuit. The impulse on the contact side is slightly longer than that on the coil side, due to the fact that the contact current remains at full value until the coil current has decayed to critical value for the relay at this adjustment. The tendency of the contact to stick closed is plainly shown by the fact that the current required to hold the contact closed is less than that required to close it.

FIGURE 4

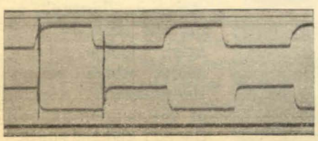


Figure 4 was made using the other contact so that an increase in coil current breaks the contact. A good relay adjustment with both contacts working similarly is indicated. The same gradual growth of current as occurred in Figure 3 will be observed. The contact stays open some time after the coil current drops. This lag is due to the sum of two effects. First, the reed does not start to move until the current drops to the critical value; and second, the contact is not made until the reed has traveled from contact to contact, i. e., the open-circuit period includes the travel time.

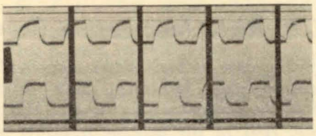


FIGURE 6 (Above)

FIGURE 3 (Left)

FIGURE 8 (Right)

The closed-circuit period, however, (Figure 3) includes no travel time. On this particular record the lag is somewhat excessive, and suggests that the back contact is not perfectly adjusted, a possibility that other oscillograms show to be a fact.

Figure 5 was made by allowing the vibrator on the interrupter to come gradually to rest. The successively shorter intervals are interesting in showing how the relay will respond to short impulses and ragged waveforms. Nowhere does the coil current record an impulse not recorded in the contact circuit. The slight chattering caused by irregularities in the coil current are interesting.

Figures 6 and 7 are for a higher frequency of signal impulses. Both oscillograms are for the front or closed-circuit contact. No chattering or bouncing is indicated, even with the relay speeded up.

FIGURE 7

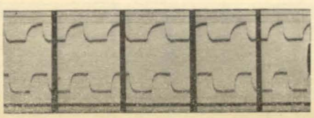
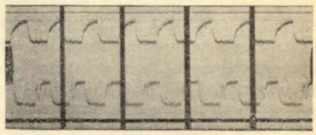


Figure 8 shows the back or open-circuit contact at high speed. The bouncing evident here reveals the faulty adjustment of this contact which Figure 4 led us to expect.

Figure 9 was made with the front and back contacts tied together, so that current flowed when the reed was in contact with either side. The open-circuit spaces on this record represent the time taken by the reed to travel across the gap. It will be noted that alternate spaces are comparatively large. Comparison with the other records reveal this to be due to the faulty adjustment of the back contact already observed.

The time of transit of the relay is an important characteristic, since it has a direct bearing on the speed of signal which may be followed. Comparison with the timing lines on the film which are spaced 0.04 sec-



ond apart shows that the shorter travel time was about 0.002 second and the longer about 0.008 second. The difference in time indicates that the reed was not exactly in the neutral position, and had a greater restoring force on one side.

It is interesting to note that the shorter time interval corresponds to a velocity of about 0.02 miles per hour, and an acceleration of about 20 miles per hour per second, or from standstill to sixty in three seconds without using the gears!

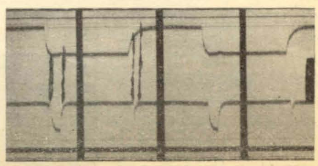
The price of the Type 481 Low-Current Relay is $30.00 net.

Code Word: NOMAD.

Dimensions: 6 x 2 x 1 inches.

Weight: 2¼ pounds.

FIGURE 9

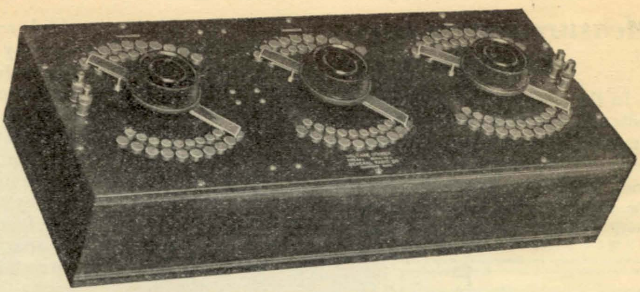


Three-Decade Voltage Divider

In laboratory procedure it is frequently desirable to subdivide a voltage with a greater precision than is possible using a single-dial type of divider. This may, of course, be accomplished by using two three-decade resistance boxes of appropriate ranges joined in series. Such an arrangement requires the second box to be set at the "complementary" reading whenever the first box is varied, if the total resistance of the divider is to remain constant, which at best is a bothersome procedure. This inconvenience may be eliminated by operating the dials of the two resistance boxes in pairs but in a reverse sense, and arranging the circuits as shown in Figure 10. Here the total resistance of the voltage divider across the input terminals remains constant, while a fraction of the drop along it is taken off at the output terminals.

If the resistance dials are progressive decades, the instrument will give a direct reading of the voltage ratio in three significant figures. For instance, in Figure 10 the dials are shown set to give a voltage ratio of 0.888. With this, as with any non-compensated voltage divider, the calibration in voltage attenuation is valid only when no current is drawn from the output terminals. The attenuation of such a multiple-dial divider must obviously be given in voltage ratios, that is, in a linear relation. Calibration in decibels, a logarithmic relation, is not possible. However, the attenuation in decibels, N, may be determined directly from the voltage ratio, R, by means of the equation:

$$N = 20 \log_{10} R$$



TYPE 554 VOLTAGE DIVIDER

It will be noted that this divider affords one common input and output terminal.

The General Radio Company has developed such a three-decade voltage divider known as the Type 554 Voltage Divider, which is shown in the illustration. This has a total resistance of 10,000 ohms subdivided into

9 steps of 1,000 ohms each
9 steps of 100 ohms each
10 steps of 10 ohms each

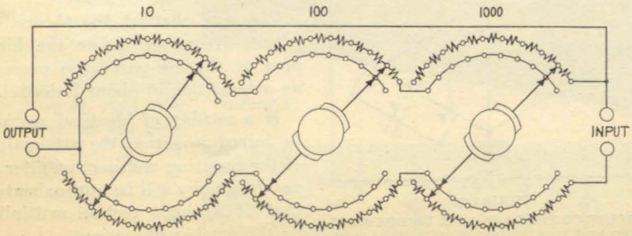
which enables a convenient direct setting of the voltage ratio from 0.001 to 1.000 in steps of 0.001. By using an external resistance of 90,000 ohms in series with the input terminals of the instrument, the voltage ratio may be adjusted from 0.0001 to 0.1 in steps of 0.0001, etc.

The Type 554 Voltage Divider is mounted in a walnut cabinet 22 x 9½ x 4 inches and is provided with a dust cover. The resistance units are wound to be non-reactive and are adjusted to a precision of 0.1%.

The net price of this instrument, assembled with a total resistance of 10,000 ohms, is $175.00.

Other resistance values may be made to special order.

FIGURE 10. WIRING DIAGRAM FOR TYPE 554 VOLTAGE DIVIDER



Coils for Types 389 and 489 Magnetostriction Oscillators

The General Radio Company has standardized a series of coils to be used with either of the Types 389 or 489 Pierce Magnetostriction Oscillators. These coils are designed to be used with ⅜-inch nichrome rods covering the frequency range from 5,000 to 50,000 cycles. Their applicability is indicated in the schedule below.

Coil	Frequency —Kilocycles per Second							
	5	7.5	10	15	20	30	40	50
389-A					X	X	XXX	XXX
389-B			X	X	XXX	XXX	X	X
389-C		X	XXX	XXX	X			
389-D	XXX	XXX	X					

x indicates coil may be used with rod of this frequency.

xxx indicates best coil for use at corresponding frequency.

It will be noted that Coils 389-B and 389-D together cover the entire range, although not always with optimum efficiency.

These coil assemblies carry a net price of $30.00 each.

The Experimenter to Have a New Editor

Starting with the next issue the EXPERIMENTER will have for its Editor, John D. Crawford who joined our Engineering Department on February 1. He is a graduate of the Massachusetts Institute of Technology and for the past two years has been Assistant Managing Editor of The Technology Review.

Measurement of Direct Capacity

In the design of vacuum-tube circuits it is sometimes necessary to distinguish between the capacity as measured between two tube terminals and the direct capacity between the elements. The capacity as measured between terminals includes the

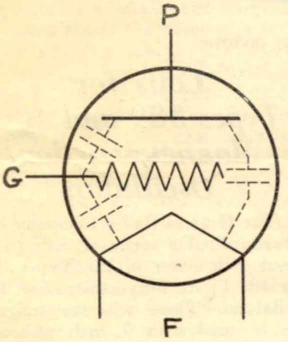


FIGURE 11

direct capacity plus the capacity to the third element. Referring to Figure 11, the measured grid-filament capacity consists of the capacity C_{GF} and in addition C_{GP} and C_{PF} in series, or

$$C_{GF} \text{ (Apparent)} = C_{GF} + \frac{C_{GP}\, C_{PF}}{C_{GP} + C_{PF}}$$

the symbols indicating direct capacity except where apparent capacities are specified. Similar equations may be written for the capacity between any pair of terminals, and the direct capacities may be computed from the three measured capacities.

The computation may be avoided, and the direct capacities measured, by means of a simple modification of a standard bridge circuit. The third element is brought to the junction point of the bridge arms. The bridge circuit with this connection in place is shown in Figure 12.

The bridge circuit in the figure is that of the General Radio Type 383 Bridge, in which the unknown is shunted across a calibrated variable capacity, and the circuit balanced against a fixed capacity before and after the addition of the unknown. In Figure 12 it will be seen that the direct capacity between terminals (e. g. grid-filament capacity) is shunted across the standard condenser. The grid-plate capacity is connected across the null indicator, and does not affect the measurement, since there is no voltage across it at balance. The third capacity (plate-filament) is shunted across one of the resistance arms of the bridge, and may be compensated for by the readjustment of the power-factor correction condenser. The capacity as measured with this circuit is, therefore, the direct capacity between the elements.

The following figures are illustrative of the values of capacity as measured by the ordinary method and the direct capacity.

Between	*Total Capacity*	*Direct Capacity*
P – G	10.6 mmf.	8.78 mmf.
G – F	6.75 mmf.	5.06 mmf.
F – P	6.4 mmf.	3.71 mmf.

Since the direct measurement is often needed, the Type 383-A Bridge will be provided with a terminal for the connection of the third element as standard construction.

The change can be made on bridges previously manufactured at a cost of $5.00.

The change consists of an additional terminal so placed that the three-plug plate supplied with the bridge will make the connection to the third element. If the filament must be kept hot i. e. is connected to a battery, or a particular terminal must be kept at ground potential for any other reason, it will be possible to make connection to the third bridge terminal by means of the three plug plate for only one of the two possible measurements. A flexible lead may then be used for connection to the third bridge terminal.

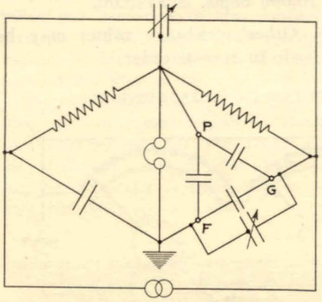


FIGURE 12
CIRCUIT OF THE TYPE 383-A BRIDGE MODIFIED FOR MEASURING DIRECT CAPACITY

Characteristic Curves of Filters

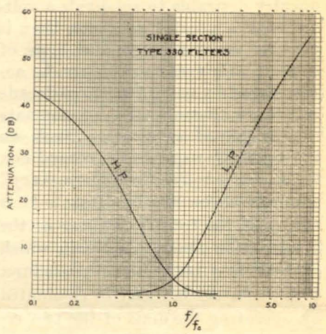


FIGURE 13

Assume that we have a series of single-section low-pass filters, having different values for cut-off frequency and iterative impedance, but constructed with a given type of inductance unit. A single curve may then be used to represent, with a good approximation, the attenuation characteristic of any one of these filters, providing we plot attenuation as ordinates and the ratio of the corresponding frequency to the theoretical cut-off frequency as abscissae.

Likewise, a single curve may represent the characteristics of a series of high-pass filters. This is illustrated in the figure which shows both the low-pass and high-pass characteristics for a single section of filter working between a generator and a load each having the impedance of the filter. The low-pass sections are of the π-type, consisting of one series (inductive) and two shunt (capacitive) elements, while the high-pass sections are of the *T*-type, comprising two series (capacitive) and one shunt (inductive) elements.

We note that at the theoretical cut-off frequency either the high-pass or the low-pass type presents an attenuation of about 3 decibels.

If a number of identical sections be joined in series, the attenuation of the resulting multisection filter at any frequency will be approximately that of a single section multiplied by the number of sections.

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Frequency Determination

By JAMES K. CLAPP

ONE need be only a casual reader of current radio literature to know that the precision determination of frequency is a most important engineering problem. The growing economic, political, and social significance of all radio channels is requiring an increasingly precise distribution of services over the useful frequencies of the spectrum. Already the Federal Radio Commission requires that the broadcasting station's carrier frequency at the high-frequency end of the band be maintained within three parts in 10,000, and one of the constantly-repeated suggestions to the Commission for the elimination of all heterodyne interference would, if put into effect, reduce that tolerance tenfold. What is more, the problem is international, which means that every radio-using nation must, in addition to using precise methods of frequency determination, maintain its working standards of frequency in agreement with those of the others.

A READER is likely to find the subject of frequency determination rather complicated unless he has an appreciation of the author's point of view. This article, although complete in itself, is the introduction for a series which will discuss the General Radio Company's attack upon the problem of standardization and precise determination of frequency. In addition to establishing a definite point of view the present article is general enough to enable one to fit into the picture the various systems that have been proposed and are now in use.

Mr. Clapp, a member of General Radio's Engineering Department, was the author (with L. M. Hull) of the paper on "Secondary Frequency Standards" appearing in the February Proceedings of the I. R. E.

It will be helpful to an understanding of what follows to realize that the precise determination of frequency is, essentially, the precise determination of a time interval. For example, the frequency of a commercial power supply may be 60 cycles per second, and the time required to complete a cycle is 1/60th of a second; the frequency of a clock's second hand is 1/60th of a revolution per second, and the time required to complete one revolution is 60 seconds; the rotational frequency of the earth is 1/24th of a revolution per hour, and the time required to complete one revolution is 24 hours. Frequency, then, is determined when the time interval is determined, and, what is more important, the standardization of a time interval at the same time establishes a standard of frequency. The two concepts are practically synonymous.

Various systems for the standardizing of a time interval have been proposed, among them some based upon the velocity of propagation of light in space, but the one generally used depends upon the high degree of uniformity in the rate of the earth's rotation upon its axis. It is argued that, theoretically at least, the rate of rotation can change from the effects of friction and variation in the earth's moment of inertia, but the probable deviation from absolute uniformity is said to be negligible, even over a period of a thousand centuries. Granting the possibility of a variation, the fact remains that the earth is a timekeeper many many times more reliable than the best man-built clock. The length of the Solar Day, as determined by the time between successive transits of the sun across the meridian of the observer, changes from day to day, and for everyday civil uses and for all non-astronomical scientific work as well, the standard interval is the Mean Solar Day, the average or mean of the length of all the Solar Days in the year. The second is a 1/86400th part of it.

Differing somewhat from this is the Sidereal Day which the astronomer defines as the interval between two successive transits of a particular "fixed star" across his meridian. The length of the Mean Solar Day bears an almost constant ratio to the length of the Sidereal Day and inasmuch as the former is an average not susceptible to measurement, all observatories check their clocks and radio and telegraphic transmission of time signals against astronomical determinations of the Sidereal Day.

As has already been pointed out, the universal acceptance of the Mean Solar Day as the standard time interval establishes the rotational frequency of the earth as the primary standard of frequency (1/86400th of a revolution per second) in terms of which all other frequencies must be expressed. But the frequency of this primary standard is so remote from any of the frequencies encountered in communications engineering that an intermediate or working standard is not only desirable but essential. It is the development of this working standard with a method of deriving from it all frequencies necessary for useful purposes that constitutes the so-called frequency determination problem.

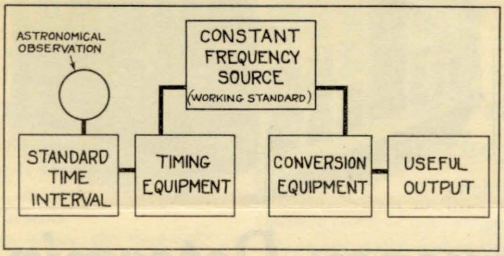

FIGURE 1. AN OUTLINE CHART FOR A PERFECTLY GENERAL FREQUENCY-DETERMINATION SYSTEM

II

In any general frequency-determination system such as the one we are discussing here, there are three essentials which are shown graphically in the accompanying "flow chart" (Figure 1). Each of them presents a distinct problem.

First: there must be provided a generator whose frequency can be maintained constant for an indefinite period. "Working standard" is a better name for the source in a general system than the purely relative terms "primary" or "secondary" standard. If the timing equipment directly links the source with the astronomical determination of the Mean Solar Day, the term "secondary standard" might be suitable, but if the source were timed against a clock which was in turn checked against radio time signals, "tertiary" or some higher order might be the better descriptive term. Working standard is, therefore, perfectly general and includes:

(*1*) Pendulums
(*2*) Tuning forks
(*3*) Magnetostriction oscillators
(*4*) Piezo-electric oscillators
(*5*) Vacuum-tube oscillators of special construction

Any of these may be used as a working standard; which one is chosen is entirely a matter of system design. By careful control each of these may be made to maintain its frequency with little variation, although some are inherently more steady than others.

Second: there must be provided a means of timing the working standard for determining its frequency in terms of the standard time interval, an operation which generally involves counting the number of cycles completed by the working standard during the interval. When the frequency of the working standard is low, the counter may be a chronograph or a synchronous impulse motor and clock train connected directly to the standard, but a high-frequency standard may require an intermediate frequency-dividing link before a counting mechanism can be conveniently operated.

The clock-train counter is used in exactly the same manner in the timing equipment as it is in a timekeeping clock. In the latter it serves to count the number of impulses of the pendulum (or balance wheel) for comparison with the number of impulses counted by a standard clock in the same interval. The chronograph, as its name implies, records graphically the impulses from the working standard and a time standard for comparison.

A working standard of high frequency (100 kilocycles, for example) could not operate directly an electromechanical counter, and intermediate frequency-dividing equipment is, therefore, essential. Several such schemes are in use, but almost all make use of some kind of generator, the fundamental frequency of which is low enough to operate the counting mechanism. A harmonic of the generator is either synchronized with or monitored against the frequency of the working standard, which is then known to be an integral multiple of the frequency driving the counter. Most of the devices mentioned in the next section are suitable for use as frequency dividers as well as frequency multipliers.

Third: once a working standard has been set up and timed against the standard time interval there remains the problem of deriving from it a sufficient number of useful frequencies. It cannot be expected to furnish them all, but enough should be available to make possible accurate interpolations. This may be accomplished by frequency multipliers and dividers of several kinds: some are capable of holding themselves in synchronism and others require manual monitoring. The list of suitable devices includes:

(*1*) Mechanical methods
(*2*) Quiescent harmonic amplifiers
(*3*) Controlled distorted-wave generators
  (*a*) Relaxation oscillators
    (*i*) Neon tubes
    (*ii*) Multivibrators
  (*b*) Vacuum-tube oscillators

Necessarily limited by size and speed, mechanical devices are most useful at comparatively low frequencies

(Continued on page 4)

A Better Frequency Meter for the Amateur

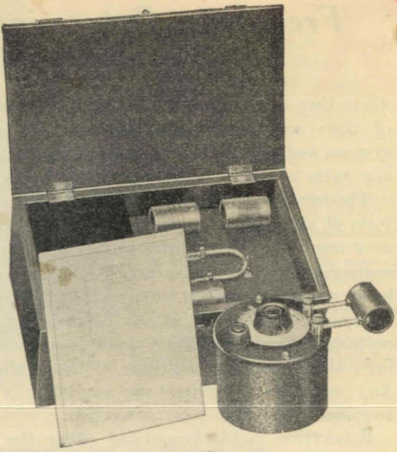

FIGURE 2
THE TYPE 558-P METER CONTAINS NO RESONANCE INDICATOR

BEFORE the amateur bands made necessary by the Washington Convention of the International Radio Telegraph Conference went into effect last January, wavemeters or frequency meters were not the absolute necessities that they are today. With not-too-tolerant commercial and military services in adjacent channels, services that are themselves required to hold closely to their assigned frequencies, it is little wonder that increased official emphasis is being laid upon the necessity of the amateur's keeping within bounds.

Realizing the necessity for such an instrument, the General Radio Company last July brought out the TYPE 558 Amateur-Band Wavemeter in which the accuracy of calibration was 0.25% over all five of the high-frequency bands. By the use of a tuning condenser designed to spread the band over the whole 180 degrees of the dial and by the addition of a specially constructed neon-tube resonance indicator, an instrument capable of unusually precise work was provided for the amateur. Later on the meters were calibrated in frequency instead of wavelength and the official title was changed to "Amateur-Band Frequency Meter."

Many users, inexperienced in making a frequency measurement upon an oscillator, failed to observe the one rule that must be followed when the meter circuit contains a resonance indicator: the coupling between the oscillator and the meter must be kept very loose. On many low-powered transmitters loose coupling could not be made to give an energy transfer sufficient to light the neon indicator. The coupling would then be tightened, but the frequency indicated by the meter might be considerably in error because of the mutual reaction of the meter circuit and the oscillator upon each other. The frequency meter could be made to give precise readings, but it had to be handled with care.

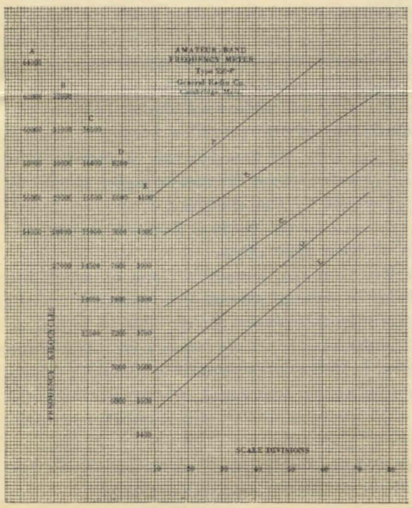

FIGURE 3. EACH INSTRUMENT IS INDIVIDUALLY CALIBRATED

In order to improve upon the amateur-band frequency meter and make it easier for the non-professional user to obtain high precision without in any way affecting its utility, the resonance indicator has been entirely removed from the instrument. This requires that some indirect method of indicating resonance be used, but a number of methods are available that are extremely sensitive and leave little to be desired in precision.

The best known of these is the so-called plate-reaction method. With loose coupling between the oscillator and the coil of the frequency meter, the plate-current meter of the oscillator will "kick" as the frequency-meter circuit passes through resonance. With some oscillators the current will increase, in others it will decrease, but the kicking point can usually be picked out with little difficulty and with much looser coupling than would be needed to operate a neon indicator. It may well be emphasized that a plate-current meter is not absolutely necessary in using this method. A flashlight bulb of the proper size may be used, and, especially when the filament is biased with an external battery, it is highly sensitive to small changes in the magnitude of the plate current.

The method recommended for use wherever it is possible (it always is possible in the amateur station) makes use of a monitor heterodyne oscillator. Although seemingly the method is little used outside the college and commercial laboratories it is one that deserves to be better known among amateurs. (See "Checking Tone and Wavelength of Transmitters" by James K. Clapp, *QST*, December, 1926.) Using the fundamental or a harmonic of the oscillating receiving set as the monitor, to beat with the fundamental or a harmonic of the transmitter, the fre-

(Continued on page 4)

Frequency Determination

(Concluded from page 2)

where they can be made to perform satisfactorily. Most of them are synchronous motor-driven tone-generator systems and are capable of being designed to give nearly any ratio of motor to generator frequency.

The harmonic amplifier is designed to distort the waveform of an alternating voltage impressed upon its input, as a result of which harmonics of the impressed voltage appear in the output circuit. It has the advantage of being quiescent; that is to say, when the applied voltage is removed, no voltage of any frequency appears in the output; the only possible output frequencies are, therefore, always integral multiples of the applied frequency. Any non-linear vacuum-tube amplifier is a harmonic amplifier, at least to a certain extent.

Relaxation oscillators utilize either the "cut-off" or the negative resistance characteristics of such devices as neon tubes, carbon arcs, and the usual forms of vacuum tubes to sustain oscillations in a circuit comprising a direct-current source, resistances, and condensers. The output of such oscillators is rich in harmonics. If a second oscillation of higher frequency be injected into the circuit, the relaxation oscillation may assume a frequency which is a submultiple of the injected frequency.

Although the neon tube is simplest, its control by the injected voltage is not as stable as that obtained from the multivibrator. The control of a multivibrator is not affected by variations in the magnitude or frequency of the injected voltage or the applied voltages on the tubes over reasonably wide ranges. This inherent stability of the system, together with the comparatively large output it is capable of delivering, makes it an excellent frequency converter for a multiplying or a dividing system.

By overloading, the output waveform of a vacuum-tube oscillator may be distorted to produce a relatively large number of harmonics, so that it may also be operated as a frequency multiplier or divider, under the control of an injected voltage; however, the control is less stable than that obtained in either type of relaxation oscillator previously mentioned.

The practical importance of the systems outlined above may be summarized by stating that each is capable of being operated in such a manner as to derive by frequency division, from a high-frequency working standard, lower frequencies which are suitable for operating a counting mechanism. Further, due to the large number of harmonic frequencies in the output, it is perfectly feasible to combine the functions of the conversion equipment with those of the timing system, in a single assembly, by frequency multiplication.

III

The foregoing outline has necessarily been brief, but it has emphasized most of the fundamental concepts involved in frequency measurements. Here it may well be pointed out again that the system under discussion has been a perfectly general skeleton upon which the elements of existing and proposed systems may be draped for easy classification. Most of the important system elements have been mentioned for the purpose of showing how they fit into the complete structure, but for detailed information on specific systems, the reader is referred to the papers and bibliographies appearing in the American and foreign technical periodicals (the *Proceedings of the I. R. E.*, in particular).

A Better Frequency Meter for the Amateur

(Concluded from page 3)

quency meter is next coupled rather loosely to it. As the frequency meter dial is swung past the frequency of the transmitter a change in the pitch of the beat note can be heard in the telephone receivers. The coupling between the transmitter and the frequency meter is then loosened until the variation in the beat note becomes almost inaudible. The setting of the frequency meter at which the beat note changes in pitch is the frequency of the transmitter. With this method it is possible to check the meter against standard frequency transmissions from such a station as WWV.

This raises the question of the accuracy of the Type 558-P Frequency Meter (the type number for the new meter without a neon indicator). Its calibration in the laboratory is made to within 0.25%, but how long that accuracy can be maintained depends in large measure upon the treatment that the instrument receives. The Type 224 Precision Frequency Meter costing ten times as much as the Type 558-P Meter is calibrated with the same accuracy, but it will retain that calibration longer and, because of its micrometer scale, be capable of a more precise setting than the little fellow. The Type 558-P Meter is carefully packed before shipment, and, if it is not roughly handled or subjected to extremes in temperature, the original calibration should hold closely. Even the calibration of the precision frequency meters is guaranteed for only six months; and it follows that the less sturdy amateur-band frequency meter should be checked by reference to the standard frequency transmissions or returned to the General Radio Company for recalibration at least that often.

There are five coupling inductors, four of which are wound on bakelite tubing threaded to insure that the spacing between turns remains fixed. The 5-meter inductor is a simple loop of heavy brass rod. The Type 558-P Frequency Meter is shipped in a strong packing case, in addition to the storage box supplied with the instrument. Each one is individually calibrated to within 0.25%.

Its price is $18.00, $2.00 less than the old Type 558 Neon-Tube Meter. The code word is WOMAN.

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GENERAL RADIO CO., Cambridge, Mass.

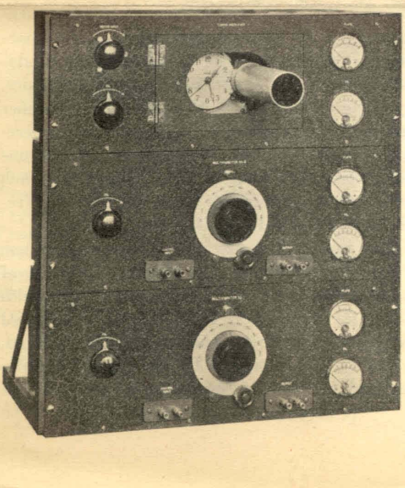
A New Frequency Standard

By JAMES K. CLAPP

FREQUENCY, like other physical quantities, is measured by comparing the unknown with a standard whose value has been established either absolutely or arbitrarily by general agreement. We measure length with a yardstick, which has been compared by means of many intermediate "measurements" with the length of a certain bar recognized as the international standard. Similarly, we may measure frequency by comparing the unknown signal with one from a piezo-electric oscillator, let us say, which is our standard. If we were to inquire how the frequency of the standard was determined, we should probably find that it was purchased from a manufacturer who compared it with a more accurate standard which he, in turn, had compared with another, still more accurate.

It is unnecessary to trace further the frequency standardizing sequence in order to understand why the General Radio Company is interested in the problem of standardization and the precise determination of frequency. As a manufacturer of piezo-electric and magnetostriction oscillators and tuned-circuit frequency meters, it is called upon to supply these instruments calibrated with an increasing degree of precision, largely because of the pressure being exerted upon all radio services to stay within their assigned channels. Although the laboratory standard used by General Radio is sufficiently accurate for all present needs, the possibility that even greater precision of calibration might be required made desirable a search for something better.

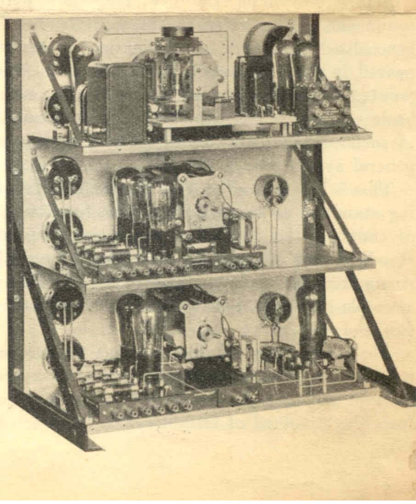
The requirements for General Radio's own frequency



THE TWO-STAGE MULTIVIBRATOR AND TIMING AMPLIFIER FOR THE NEW FREQUENCY-DETERMINATION EQUIPMENT

FIGURE 1. (LEFT)

(RIGHT) FIGURE 2.



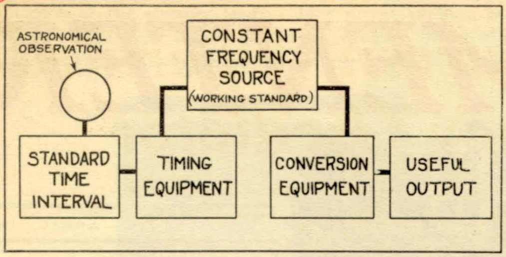


FIGURE 3. AN OUTLINE CHART FOR A PERFECTLY GENERAL FREQUENCY-DETERMINATION SYSTEM

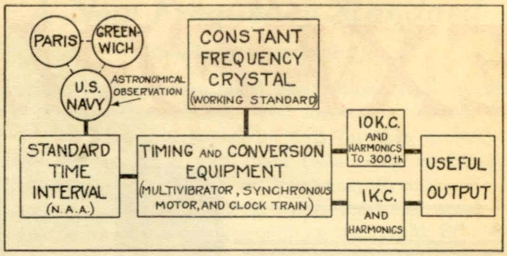


FIGURE 4. AN OUTLINE CHART FOR THE GENERAL RADIO COMPANY'S FREQUENCY-DETERMINATION SYSTEM

standard are essentially the same as those for any laboratory that interests itself in the precise measurement of all frequencies. A few of the most important considerations are:

(1) It must be compact. Space is usually at a premium.

(2) It should be possible to check regularly the frequency of the standard without transporting it to some other laboratory for comparison.

(3) Means should be provided for obtaining from the standard a large number of frequencies in all parts of the communication frequency spectrum. For instance, the General Radio calibration laboratory is often called upon to measure in succession a wide variety of frequencies: a frequency meter for short waves, a piezo-electric crystal for a broadcasting station monitor, and the reed of an airplane beacon indicator (60 or 70 cycles), for example.

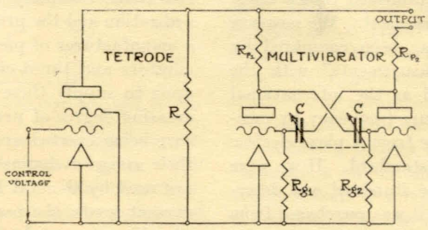


FIGURE 5. SCHEMATIC CIRCUIT OF THE MULTIVIBRATOR AND ITS AMPLIFIER

(4) It should be rugged, reliable, and inexpensive, and be capable of a precision of at least one part in a million.

Before describing the new frequency determination equipment, let us refer to the writer's discussion of a generalized frequency determination system which appeared in the EXPERIMENTER for March. There it was pointed out that any such system must consist of three basic elements. The principal methods available for use in each of these were listed and an outline chart of a general system was drawn up.

This is here reproduced as Figure 3. It shows a working standard or source of constant frequency, a method of counting the number of oscillations executed by the standard over a long time interval, and a method of deriving from the working standard, directly or by means of a simple auxiliary, a sufficient number of useful frequencies.

The article also pointed out that the frequency measurement problem is essentially one of measuring a time interval and that the standard time interval (and, therefore, the standard of frequency) is the Mean Solar Day of which the second is a 1/86,400th part. In any discussion of frequency measurements, this concept cannot be overemphasized, for if, by some means, the number of oscillations of a constant-frequency generator in a given time be counted, then the frequency or number of oscillations per second can be determined.

II

In the present system a piezo-electric crystal-controlled oscillator with a fundamental frequency of very nearly 50 kilocycles is employed as the working standard. This oscillator drives a step-down frequency converter of the multivibrator type, so that a voltage having a frequency one-fiftieth that of the working standard is available for running a synchronous-motor-driven clock. Crystal oscillator, frequency divider, and clock operate continuously, and, by the use of an attachment for comparing the clock time with radio time signals, the average frequency of the standard can be determined with a high degree of precision.

Besides driving the clock, the frequency divider furnishes continuously a 10 kilocycle fundamental with harmonics up to the 300th as well as a one kilocycle fundamental which also has a large number of harmonics. The 1000-cycle signal is available through a line amplifier at any point in the laboratory. The equipment, therefore delivers a large number of frequencies from one to 3,000 kilocycles, but, what is most important, each frequency is known with the same precision that the frequency of the working standard is known.

To show how this system fits into the general system outlined in the EXPERIMENTER for March, the chart of Figure 4 has been drawn up. It will be noticed that both the timing and the conversion of the working-standard frequency are provided for by the same multivibrators.

Figure 4 also calls attention to the fact that the radio time signals used for timing the working standard are

(*Concluded on page 4*)

An Alternating-Current-Operated Radio-Frequency Oscillator

EVERY laboratory has need, at least occasionally, for a radio-frequency oscillator. Some time ago the General Radio Company designed and built its TYPE 384 Oscillator which when equipped with plug-in coils would cover a wide range of radio frequencies. This instrument is battery-operated and uses a tube of the 199-type. Another oscillator of even greater utility is now announced. It is similar in many ways to the older one, but it has a considerably greater power output besides operating from the 110-volt alternating-current supply.

The new equipment is entirely self-contained except for the plug-in coils. It makes use of a 227-type tube as an oscillator and a 201-A type tube as a rectifier in the plate-voltage supply. A transformer and a smoothing filter for supplying the filaments of the two tubes and for the plate voltage supply of the oscillator tube are included.

The frequency range, using the standard TYPE 384 plug-in coils is from 10 kilocycles to 20,000 kilocycles. Tuning is done with a straight-line wavelength variable condenser having a maximum capacitance of 500 micromicrofarads, together with an auxiliary 50 micromicrofarad condenser for fine adjustment. Knowing the type of condensers used and the frequency band covered by each coil, some idea about the criticalness of tuning for each coil can be estimated.

The following table listing the coil ranges is taken from Catalog E with the wavelength ranges there listed converted into frequency:

Coil	Range		Price
Type 384-A	20,000—10,000	kc.	$3.00
Type 384-B	10,000—3750	kc.	3.00
Type 384-C	4,290—1500	kc.	3.00
Type 384-D	1,579—522	kc.	3.00
Type 384-E	531—176	kc.	4.00
Type 384-F	176—68	kc.	4.00
Type 384-G	68—25	kc.	5.00
Type 384-H	25—10	kc.	8.50
Type 384-D8	1,500—500	kc.	4.50

The Type 384-D8 coil is a figure-8 coil designed to have a minimum external field.

A strip mounted on the cabinet top is provided for storing coils that are not being used.

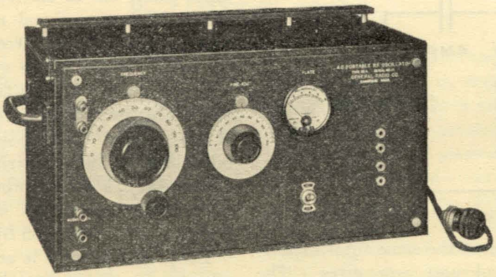


FIGURE 6. THE TYPE 584 A.C. PORTABLE R. F. OSCILLATOR. COILS ARE PLUGGED INTO THE FOUR JACKS AT THE RIGHT

The TYPE 584 Oscillator has a provision for injecting into its plate circuit a modulating voltage from any desired audio-frequency oscillator. A beat-frequency oscillator is suitable for this use.

A milliammeter is provided for indicating the average plate current of the oscillator tube. It is useful for showing when the tube is oscillating, and, in addition, it may be used as a reaction indicator in adjusting for resonance. Terminals for connecting a telephone head set into the circuit at a point of low radio-frequency potential have been provided.

The whole assembly measures 18 inches × 9-1/4 inches × 9-1/4 inches and weighs 22-½ pounds without tubes or coils. Being light in weight and relatively inexpensive, it is a handy addition to the equipment of any laboratory. It can be stored on a shelf when not in use and put into operation in only a moment when needed. It is the ideal laboratory heterodyne and general-purpose radio-frequency oscillator.

Price $140.00
Code Word..OZONE

A Speaker Filter for the 245-Type Tube

THE heavy plate current required by the tubes commonly employed in power amplifiers can seriously damage the winding of a speaker through which it flows. Some device is, therefore, necessary for isolating the speaker from the plate circuit of the output tube. Either a transformer or a so-called speaker filter can be used for this purpose.

When the reproducer has a high impedance the filter makes the most economical unit. In general it consists of a choke coil and condenser combination connected as shown in Figure 8 reproduced on page 4. For best operation the choke coil should have a high impedance and the blocking condenser a low impedance at all voice frequencies. The lower the frequency, the farther both of these values depart from the ideal, so that for good low-frequency response a large choke coil and a large condenser are required.

Sometimes a section of the blocking condenser is placed in each of the speaker leads. This serves to keep the high voltage plate supply out of the speaker, but it also reduces the total condenser capacitance. If a condenser

FIGURE 7. THE TYPE 587-C SPEAKER FILTER

were to be placed in either speaker lead in the example shown in the diagram each section would need to be of

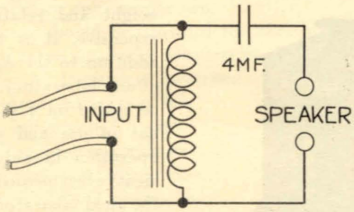


FIGURE 8. WIRING DIAGRAM FOR THE TYPE 587-C SPEAKER FILTER

eight microfarads in order to have the same total capacitance that the four-microfarad unit now gives. The single condenser section is, therefore, much more economical. The choke-coil inductance is 40 henrys with rated current flowing.

The TYPE 587-C Speaker Filter has been designed for use with reproducers having an impedance averaging about 3000 or 4000 ohms. A class which includes almost all of the speakers that are not of the so-called dynamic type. It was built primarily for use with a tube of the 245-type, and it will withstand without damage the maximum rated plate current of one of these tubes.

Connections can be made as shown in the diagram or the low potential terminal of the speaker may be connected to the negative side of the plate voltage supply. Sometimes regeneration occurs in an amplifier due to coupling in the common plate supply, but it can usually be minimized by the use of the alternative connection in which audio-frequency output currents are kept out of the B-supply.

SPECIFICATIONS

Maximum current	35 milliamperes
Choke coil inductance with maximum current	40 henrys
Direct-current resistance	700 ohms
Blocking condenser	4 microfarads
Impedance of choke coil at 25 cycles	6000 ohms
Impedance of blocking condenser at 25 cycles	1600 ohms

Code Word: FAVOR

Price: $8.00

A New Frequency Standard

(Concluded from page 2)

dependent upon astronomical observations made at the U. S. Naval Observatory. The observatory checks the time signal transmissions from NAA for their accuracy, and compares them with those from GBR at Rugby, England, and from FYL at Bordeaux, France. Each month a report is issued in which the daily error in transmission is recorded as well as the results of comparisons with the two above-mentioned foreign stations. Although the time signal as transmitted from NAA (on its 113-kilocycle channel) has an average lag from true time of about 0.05 second, the interval between two successive noon-to-noon transmissions is correct to about 0.005 second. That is to say that, on the average, the 24-hour interval defined by the time signals is accurate to within one part in 13 million.

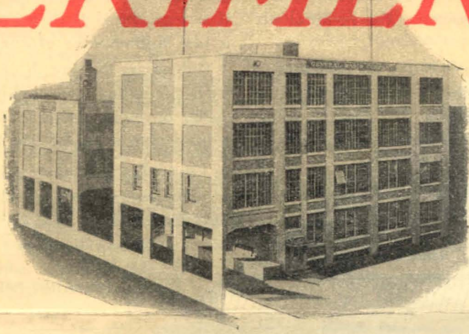
The clock used in the counting mechanism of the timing equipment consists of a Type 411 Synchronous Motor modified by the addition of a shaft carrying a shutter which makes one revolution per second. A neon lamp operated by a time-signal receiver is mounted behind the shutter, and with every received time dot the lamp flashes. By means of a suitable eye-piece, it is possible to compare the clock with the time signal to within 0.005 second. This precision is a close approach to the accuracy of time signal transmission, so that but little further refinement in the comparing device is needed at present. If necessary, however, other comparison methods already tried in our laboratory may be applied to increase the precision of comparison by at least five times.

Frequency division is accomplished by means of multivibrators, a circuit for which is shown in Figure 5. The multivibrator is a relaxation oscillator whose frequency is determined by the value of the condensers, C, and the resistances, R_p. The application of a voltage to the grid of the tetrode isolation amplifier results in an injection of a voltage of the same frequency into the multivibrator circuit, and, for a range of values of C, the fundamental frequency of the mutivibrator assumes discreet values that are submultiples of the control frequency and independent over that range of C. In this condition, the frequency of the multivibrator is determined by the frequency of the control voltage.

In the General Radio equipment, the 50-kilocycle working standard controls a multivibrator having a fundamental frequency of 10 kilocycles, and this multivibrator controls another with a fundamental of one kilocycle. Each multivibrator is also a source of harmonics of its fundamental frequency, which explains how this system can furnish so many useful, accurately determined frequencies for calibration and other comparison work.

A lack of space precludes a more detailed description of the new frequency-determination equipment, but the interested reader is referred for more details to a paper by L. M. Hull and the author appearing in the February issue of the *Proceedings of the I. R. E.*

The GENERAL RADIO EXPERIMENTER



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MAY, 1929

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Permalloy

By ARTHUR E. THIESSEN

PERMALLOY is a name given to the series of alloys of nickel and iron having a composition varying from about 30 per cent nickel and 70 per cent iron, to 85 per cent nickel and 15 per cent iron. They possess unusual magnetic properties. The position in the nickel-iron series of a given alloy is usually designated by a numeral which, preceding the word permalloy, gives the percentage of nickel in the composition: thus, 45 permalloy means an alloy containing 45 per cent nickel and 55 per cent iron.

Figure 1 shows how the initial permeability of the permalloy series varies with the composition. The extreme left of the curve is pure iron which has a permeability of about 4[illegible]. As the nickel content is increased, the permeability declines slightly until 30 per cent nickel is reached, when a sharp increase in noted. This increase reaches a maximum at about 45 per cent nickel, 55 per cent iron at which composition the permeability has reached 2,000. This value is maintained until the alloy becomes about 70 per cent nickel, where a second sharp rise occurs which reaches a peak at about 80 per cent nickel, 20 per cent iron. The permeability at this point is not definitely fixed but may vary with the mechanical treatment the alloy has received in preparation. Small amounts of foreign material such as magnesium, copper, and silicon affect it greatly. However, 12,000 or 15,000 permeability is not at all exceptional at this composition and the addition of a small percentage of chromium, which helps nearly all of the permalloys, together with proper heat treatment may raise the initial permeability to the astonishing figure of 100,000 or more. In the commercial preparation of permalloy, a fractional percentage of manganese is added to aid the malleability and ductility of the alloy which, without it, is quite springy and brittle.

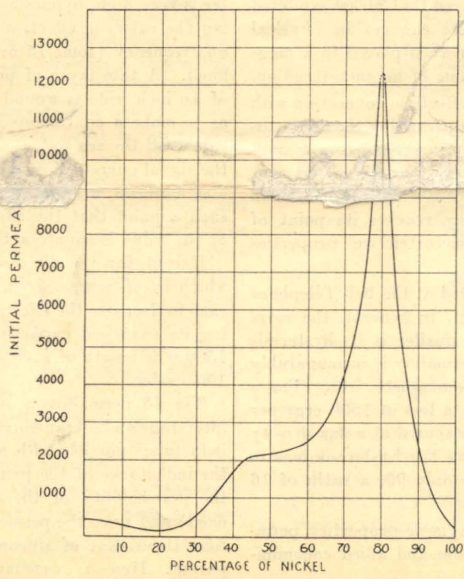

FIGURE 1. THE INITIAL PERMEABILITY OF PERMALLOY AS A FUNCTION OF THE PERCENTAGE OF NICKEL

Proper heat treatment is important in getting the best magnetic properties. The usual method is to perform all of the necessary mechanical operations before heat treating so that it is subjected to no undue mechanical strain after annealing and before being put into service. The heat treatment, which is the same for all permalloys, consists of heating the alloy in an air-tight nickel pot to about 1100 degrees Centigrade, holding it at this temperature for an hour, and then allowing it to cool very slowly to room temperature with the furnace in which it was heated. The pot is sometimes sealed with iron filings, which fuse together before reaching maximum temperature, at the same time forming an iron oxide with the air left in the pot. This prevents the residual air from oxidizing the alloy.

If, after the above heat treatment, the alloy is re-heated to 600 degrees Centigrade and allowed to cool rapidly, the permeability is found to increase to a still greater value. Due to certain limiting mechanical considerations, however, this double treating is not always feasible.

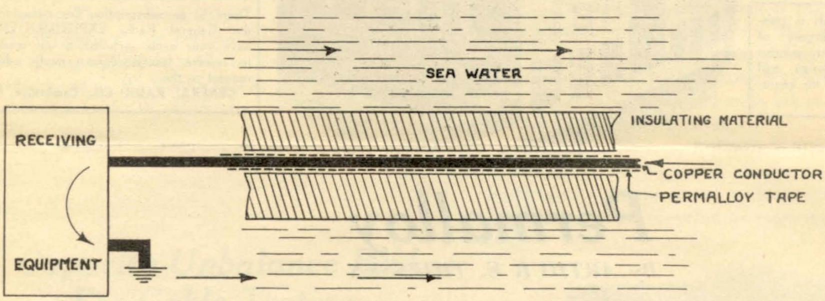

FIGURE 2. A CONTINUOUSLY-LOADED SUBMARINE CABLE SHOWING DIRECTION OF CURRENT FLOW

L. W. McKeehan found the phenomena of magnetostriction to be closely related to the remarkable magnetic properties of the permalloys. In 1842 Joule discovered that a specimen of iron on being magnetized actually increased its physical length along the axis of magnetization. Subsequently it was discovered that nickel exhibited exactly the reverse effect. These changes in physical dimensions of magnetic materials when placed in a magnetic field have been given the name of magnetostriction.

McKeehan, investigating these effects in connection with permalloy, found that at about 80 permalloy the magnetostriction became zero. The specimen expanded in a magnetic field as its composition became more iron, and contracted when the percentage of nickel became greater than 80 per cent. Thus, as the alloy reaches its point of maximum permeability its magnetostrictive properties pass through zero.

A series of experiments conducted at the Bell Telephone Laboratories seems to show that, in general, the more permeable an alloy becomes, the smaller is its hysteresis loss. The hysteresis loss in 80 permalloy is incomparably smaller than in the best available magnetic iron. For a very good grade of Norway iron, a loss of 1500 ergs per cubic centimeter per cycle when measured at a flux density of 5,000 lines is average, whereas the hysteresis loss in permalloy at this flux density is only 90, a ratio of 16 to 1.

Because of these remarkable magnetic properties, permalloy has found many uses in radio and allied communication fields.

The telephone companies make use of the alloys in many of their transformers, hybrid coils, loading coils, and sensitive low-current relays. The reasons for these extended uses in voice-frequency circuits are apparent when it is considered that a good flux density is required for a few milliamperes of current available in the windings.

Submarine telegraph cables, when continuously loaded with permalloy are capable of a transmission speed of 2,000 or more characters per minute as compared with a maximum speed of less than 250 letters per minute on the old style unloaded cables. The continuous loading of submarine cables has so revolutionized the art of trans-oceanic telegraphy that a few words of explanation may be interesting.

A submarine cable consists essentially of a heavy-gauge, single copper conductor surrounded by a one-quarter-inch layer of gutta percha, steel armor wires, and a layer of saturated hemp, the whole being about one or one and one-half inches in diameter. The sea water provides a return path for the current.

The capacity of the copper conductor to the sea water is very high, bypassing the high frequencies, and making the cable, in effect, a low-pass filter with a low cut-off frequency (some 15 or 20 cycles for the unloaded cables). A thin layer of permalloy tape about one-eighth of an inch wide is wound spirally around the copper so as to make a continuous layer of permalloy between the cable and the sea water. As may be seen from Figure 2, the signal current flux then links a core of highly permeable material, which raises the inductance of the path to such a point that the effect of the tremendous capacity of the cable is counteracted to a great extent.

Except for the direct-current resistance of the cable which is, of course, fixed, the permalloy loading may be said to decrease the effective length of the cable by reducing its electrical capacity. The cut-off frequency of a 1500-mile length of such a loaded cable may be well over 150 cycles.

The 45 permalloy is sometimes used for the cores of interstage audio transformers because of the high primary inductance possible with a small number of turns. Since the inductance of the primary is in direct proportion to the permeability of the core (other factors remaining fixed) and since the permeability of 45 permalloy is some four times that of silicon steel, the advantages are apparent. However, care must be taken in using permalloys

(*Concluded on page 4*)

Power Transformers for the 245-Type Tubes

THE General Radio Company is about to place upon the market two new power transformers for use with the recently-announced 245-type power amplifier tubes. One is designed to supply a single tube; the other, to supply two tubes.

It will be remembered that the 245-type tube has an undistorted power output rating between that of the 171-type and the 250-type. With the maximum of 250 volts on its plate, it is capable of delivering 1600 milliwatts, which is more than twice that of the 171- and about one-third that of the 250-type tube. At 250 volts the plate current is 32 milliamperes when the recommended grid-biasing voltage of -50 is supplied.

Either alternating or direct current may be used to heat the filament, which requires 1.5 amperes at 2.5 volts. This is the same voltage as is needed for the 227-type tube, so that it is entirely feasible to run the filaments of both kinds from the same transformer winding.

For the operation of a single 245-type tube, the new TYPE 545-A Power Transformer has been provided. When used with a full-wave rectifier of the 280-type and low resistance filter choke coils such as are contained in the TYPE 527-A Rectifier Filter[1], it will supply the correct plate and grid-biasing voltages for one 245 tube. The permissible current drain is over 50 milliamperes, more than sufficient to supply a 227- in addition to the 245-type tube.

In designing the filament supply windings of the TYPE 545-A Power Transformer this was kept in mind, and the 2.5 volt winding has a carrying capacity sufficient for one 245 and one 227. In addition there is a 5 volt winding for the rectifier tube.

When it is necessary to operate two 245-type tubes, a TYPE 545-B Power Transformer must be used. This is wound in the same manner as the TYPE 545-A Power Transformer previously described except that the high voltage winding has larger current-carrying capacity and a larger voltage to compensate for the increased voltage drop in the rectifier tube and in the filter. It will deliver full rated voltage with a drain of 80 milliamperes, so that it, too, can be used to handle one 227-type tube in addition to the two 245-type tubes for which it is rated. To perform satisfactorily, however, the TYPE 545-B Power Transformer must be used with a low-resistance filter like the TYPE 527-A Rectifier Filter.

If for any reason it is desired to use a high resistance filter—the TYPE 366 Filter Choke[2], for instance—the TYPE 545-B Power Transformer may be used to supply plate power for a single 245-type tube, since the additional voltage drop in the higher-resistance chokes is practically equal to the increased voltage of the larger transformer. Limitations in the ability of the full-wave rectifier tube, to withstand higher voltages, however, makes it impossible to further increase the transformer voltage in order to compensate for high-resistance chokes when two tubes are to be used. The only solution of the problem is to use chokes of lower resistance.

The following summary is presented for ready reference:

TYPE *545-A Power Transformer*

Supplies grid-biasing and plate voltages for one 227-type and one 245-type tube using a 280-type full-wave rectifier and low-resistance filter chokes.

Supplies filament current for one 227-type and one 245-type amplifier tube and one 280-type rectifier tube.

Code Word: POSSE — Price $10.00

TYPE *545-B Power Transformer*

Supplies grid-biasing and plate voltages for one 227-type and two 245-type tubes using a 280-type full-wave rectifier and low-resistance filter chokes.

Replaces TYPE 545-A Power Transformer when using high-resistance chokes.

Supplies filament current for one 227-type and two 245-type amplifier tubes and one 280-type rectifier tube.

Code Word: PRIOR — Price $10.00

Both of the new power transformers are scheduled for delivery by June 15.

[1]The TYPE 527-A Rectifier Filter contains two chokes, each having a direct-current resistance of 175 ohms.

[2]The TYPE 336 Filter Choke contains two independent sections, each having a direct-current resistance of 350 ohms.

Variable Air Condensers for Use with High Voltages

EXPERIENCE extending over several years has shown that the TYPE 334 Variable Air Condensers (double-spaced) for high voltage use have been too conservatively rated. When they were first produced, it was recommended that the voltage across them be limited to 2000 volts, but continued tests under actual operating conditions permits this rating to be increased to 2500 volts, root mean square, or 3500 volts, peak.

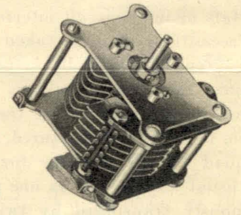

FIGURE 3. TYPE 334 DOUBLE-SPACED VARIABLE CONDENERS

The TYPE 334 Condensers are of the metal-end-plate-type. They are of the low-loss construction having soldered rotor and stator plates. Until now they have been available only in maximum capacitances of 50 and 100 micromicrofarads, but on June 15 a 250 micromicrofarad size will become available. Its voltage rating is the same as that mentioned above for others of the same type.

Prices

TYPE 334-R 250 mmf.	$5.50
TYPE 334-T 100 mmf.	2.75
TYPE 334-V 50 mmf.	2.50

Permalloy

(*Concluded from page 2*)

for audio transformer cores because they saturate at much lower values of current than silicon steel. Therefore, they must be used in plate circuits drawing only comparatively small currents unless special precautions are taken in the design. Amplifier transformer cores made of permalloy also have the disadvantage of being subject to damage by mechanical shocks which cause them to lose their permeability.

Acknowledgment for certain information contained in the foregoing article is made to papers published by H. D. Arnold and G. W. Elman in *The Bell System Technical Journal* and by L. W. McKeehan in *The Journal of the Franklin Institute.*

A Capacity Unbalance Bridge For Cable Testing

SOME time ago the engineers of a large organization engaged in the operation of long telegraph and telephone cables needed a bridge for measuring the capacity unbalances between the conductors in each group of four wires (or quad). Knowing that the General Radio Company has for many years been specializing in the design and manufacture of bridges, precision air condensers, and other apparatus for the measurement of capacity, they called upon this company to build a suitable instrument. The following is a brief description of it with an explanation of the problem involved.

The important limiting factor in the operation of long cables, especially when phantom circuits are used, is the amount of cross-talk or inter-circuit interference that can be tolerated. Precautions must be taken to minimize it by balancing the circuits as carefully as possible with respect to resistance, inductance, leakage, and capacity. In general, capacity unbalances cause the most trouble.

When the cable is being manufactured, each group of four wires or quad (which provides for two channels operated in the usual way as well as one phantom channel) are continuously transposed by twisting together the two wires for each physical or side circuit. Then the two twisted pairs are twisted together, and the result is a cable unit in which the capacity of any wire to any other wire is supposedly the same. Actually, however, small unbalances almost always exist.

When two long cables are to be joined together, the problem confronting the lineman is to determine how he shall connect the two quads together. There are eight possible ways of connecting the two pairs of a quad, some will give a large amount of unbalance, others will give less. It is, of course, necessary that he shall choose that combination which has the least, and it was for the selection of the best combination that General Radio built the capacity unbalance bridge.

Figure 3 shows the instrument, at the back of which are two sets of four binding posts for making connections to the two quads which are to be joined. By means of the switches on the panel, the lineman can connect the two together in every possible combination and measure the capacity unbalance for each with the bridge.

For any combination there are, of course, four terminals, which form the four corner points of a bridge network. The four capacity arms of the bridge are the capacities between conductors in the quad. Across one diagonal of the bridge corresponding to one pair of the quad is connected a small buzzer operating at about 400 cycles, and across the other is connected the telephone headset for indicating balance.

When the circuit capacities are not balanced, a means of measuring the degree of unbalance is provided. This consists of a double-stator variable air condenser having the stator plates connected to opposite bridge points and

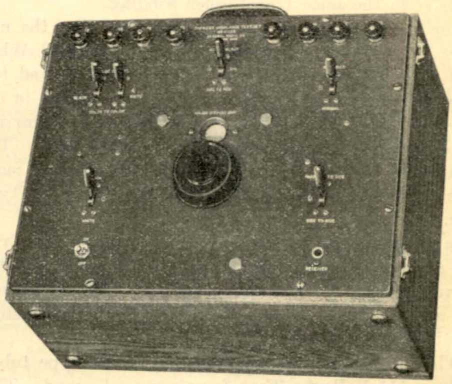

FIGURE 4. CAPACITY UNBALANCE TEST SET

the rotor connected to one of the remaining ones. By adjusting the condenser, it is possible to increase the capacity of either side of the bridge and reduce that of the other until a balance is secured. The setting of the condenser then gives directly a measure of the unbalance capacity.

The complete instrument is self-contained. It is light in weight and is equipped with an oak case and a weather-proof canvas cover. It is therefore, adapted for use by the lineman in the field.

Since the above described instrument was built, a new model has been prepared in which the unbalance is determined in only one quad at a time. The unit is smaller, more compact, and lighter than the larger one. In using this instrument the lineman measures unbalance in each of the quads which are to be joined. Then by knowing the magnitude and sign of the unbalance in each he can determine the best method of making the connection.

The General Radio Experimenter

Vol. IV, No. 1 June, 1929

Production Testing of Audio-Frequency Amplifiers

By Arthur E. Thiessen

HOWEVER much engineering development the manufacturer of an audio-frequency amplifier expends on its design, there remains the problem of comparing the performance of the quantity-produced unit with that of the laboratory model. Without rigorous inspection some defective units are likely to reach the user, which makes necessary expensive replacements and breeds ruinous ill will.

Some manufacturers check the component parts before assembly and follow this with a supplementary "try-it-and-see-if-it-works" test. This, however, is only partially satisfactory because errors in assembly may still creep in and because any kind of a trial inspection requires highly-competent, specially-trained inspectors if the tests are to mean anything. Even then, it is doubtful whether any listening test can be relied upon to detect small abnormalities in the performance of a high-quality amplifier under production conditions.

When preparing to manufacture their new radio receivers, the Victor Talking Machine Company realized the importance of thorough inspection and the limitations of the usual methods. They asked the General Radio Company to build suitable test equipment, and the engineering departments of the two organizations collaborated on the design of the audio-frequency amplifier test set that is described here. It makes possible a speedy and accurate test and is capable of operation by an inspector with no special training.

The most important characteristics of an amplifier's performance are its ability to show the required amount of gain or amplification over the desired frequency range and to deliver the required amount of power without overloading. It was decided that the test of the Victor Company's amplifiers should include an accurate measurement of both these quantities.

The method chosen for making the test for gain is based upon one sometimes used for making measurements in the laboratory. Figure 1 shows it in schematic form. An oscillator operating at the test frequency supplies energy through a calibrated attenuation network to the amplifier, in the output circuit of which is connected a suitable load and a meter for measuring the voltage drop across it. The network is adjusted until the voltage across the load is equal to that measured across the input terminals of the network. Then, if all the terminal impedances between units in the circuit have been properly matched,* the gain of the amplifier is equal to the attenuation or loss in the network. The complete gain-frequency characteristic is obtained by repeating this measurement at as many test frequencies as necessary.

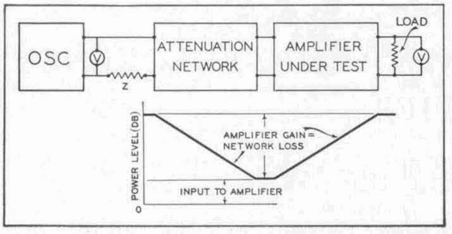

FIGURE 1. Outline chart and power level diagram for the gain-measuring method used in the amplifier test set. All impedances are assumed to be matched

The overload-level test is also based upon a laboratory method for determining where further increases in the input of the amplifier fail to produce proportional increases in the power output. The overload level is the ratio (expressed in decibels) of this power output to the standard reference level or normal test output† of 50 milliwatts.

The audio test panels as constructed are shown in the schematic diagram of Figure 2. A Hartley oscillator delivers voltages at each of five selected frequencies (40, 100, 400, 2500, and 6500 cycles) covering the audio-frequency band. At each of these frequencies the voltage of the oscillator is made the same by an adjustment of the respective feedback resistances.

From the standpoint of the inspector using the test set, it is desirable that the power output of the amplifier be constant at every one of the test frequencies, in spite of the fact that the amplifier gain is different for each one. Then it is only necessary for him to note whether or not the load voltmeter deviates from a fixed value marked upon the dial in order to tell whether or not the amplifier is up to standard. This is accomplished by inserting enough attenuation ahead of the amplifier to make the output the same at each frequency. This is the function of the compensation network shown in Figure 2. Both the frequency change and the throwing in of the proper compensation network are made by means of the large hand-wheel at the left of the panel shown in Figure 3.

An alternating-current-operated vacuum-tube voltmeter is used to measure the voltage across the load and to check occasionally the output voltage of the oscillator. It is sufficiently sensitive to indicate deviations of amplifier gain from normal by as little as one or two decibels. The voltmeter is the one in the center of the panel.

The input and output networks for making the overload-level test are controlled by the other hand-wheel. As its pointer is moved from left to right in ten successive steps, an attenuation of two decibels per step is inserted ahead of the amplifier, and, simultaneously, the same amount is removed from the output circuit. So long as the amplifier is operating below its overload level, the reading of the voltmeter remains fixed, but, when overload occurs, further increases of input fail to produce proportional increases in the output power. Thus, the overload level is indicated when the

* This requirement makes necessary the impedance Z. If the oscillator output voltage be maintained constant as shown by the voltmeter, the network behaves as though it were working out of a power source of constant internal electromotive force and internal impedance Z. See K. S. Johnson, *Transmission Circuits for Telephonic Communication* (New York: D. Van Nostrand Co., 1925), Chapter VIII, in particular.

† I. R. E. Standard. See *Year Book of the Institute of Radio Engineers* (New York, 1929), p. 107.

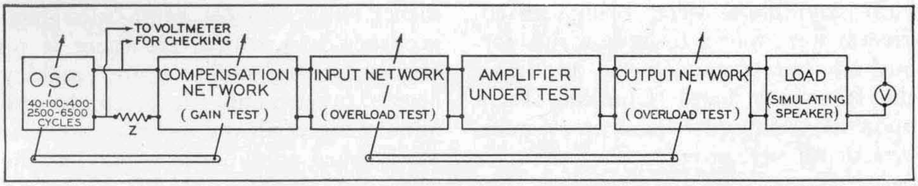

Figure 2. Schematic diagram of the test panel for making rapid measurements of gain and overload level in amplifiers

output voltage begins to drop off as the test switch is advanced.

In testing an amplifier under working conditions, it is merely necessary to connect it to the test panel by means of a set of flexible leads. With the overload-level switch set at zero the gain test is made at each of the five test frequencies, and, if the reading of the output voltmeter does not deviate from standard by more than a specified tolerance, the amplifier has been shown to have a gain-frequency characteristic like that of the laboratory model. The next step is to set the frequency control at some point — 400 cycles, for example — and to advance the overload-level switch until the output voltage begins to fall off. The setting of the switch where this occurs indicates in decibels the overload level of the amplifier referred to the reference level.

At the extreme lower right of the panel, next to the toggle switch for controlling the power supply to the test set, may be seen two key switches. One of these throws the voltmeter from the amplifier output circuit to the output of the oscillator for checking its voltage.

Since the audio amplifier is intended for use in conjunction with a phonograph pickup (low impedance) as well as the detector tube of the radio receiver, its input circuit has a low- as well as a high-impedance winding. Gain and overload-level tests are made for each winding, and the second key switch makes the necessary internal changes in the test panel.

By means of this extremely rapid check practically all of the possible errors in construction will have been shown up. When the first production-

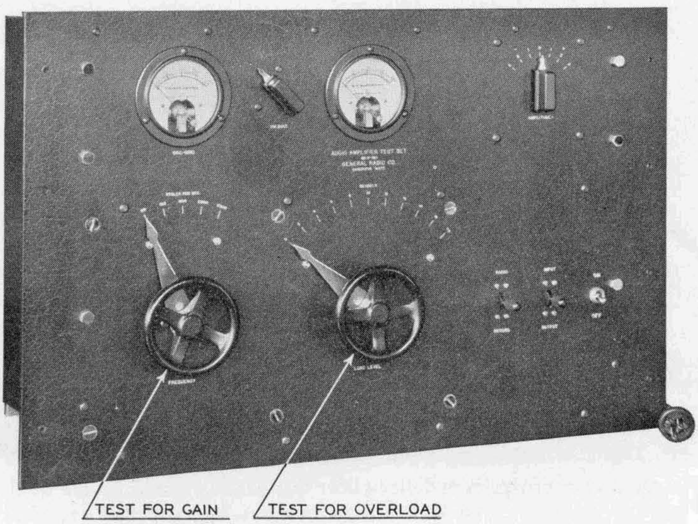

Figure 3. The audio-amplifier test set as built by the General Radio Company for the Victor Talking Machine Company

built amplifiers were being tested, several were found to have a sub-normal amount of gain in the middle of the frequency band. Checking them upon the elaborate laboratory gain-measuring set proved that the test panels were operating correctly, but the trouble could not be traced to any fault in the amplifier until it was discovered that the lower-grade wax used for impregnating the power transformers had been inadvertently used in the inter-stage coupling transformers. It is highly probable that a simple listening test would not have found the trouble, yet the accident is one that could happen in any assembly plant.

By the use of the General Radio Company's test panels, the Victor Company makes its production with great speed and accuracy and with a consequently low unit cost of test. The average time necessary for a complete check is about one minute, and the amount of deviation from standard is held to a tolerance of one and one-half decibels. This test compares favorably in accuracy with the more elaborate laboratory measurements requiring considerably more time, equipment, and technical skill. Such high accuracy is justified, for there is no excuse for the manufacturer making heavy investments in research and quality materials unless he is sure that the finished amplifier is as good as the approved laboratory model.

In addition to the check upon the completed amplifier, all of the component raw materials are tested before assembly. All input, interstage, and output coupling transformers are inserted in amplifiers of known excellence which are then tested on the test panel. If the amplifier shows normal performance, the transformers are shown to be satisfactory.

Ten of these amplifier test panels have been built for the Victor Company and five more are now in process.

The flexibility of the test set makes it adaptable for use with almost any audio-frequency amplifier, and it may be readily altered to take care of such changes in the design of the amplifier that may be made after production has begun. The method of working out the problem is general enough to show definitely that laboratory methods can successfully be applied to production tests.

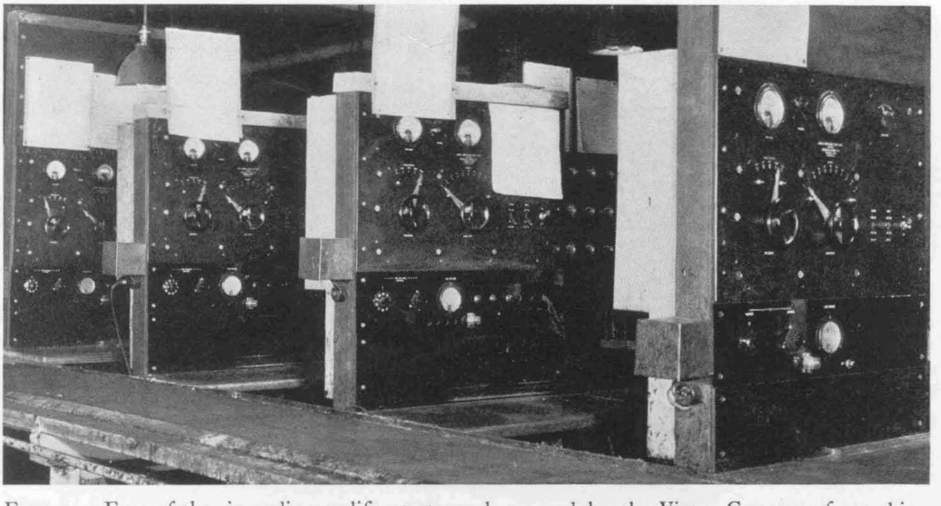

FIGURE 4. Four of the six audio-amplifier test panels as used by the Victor Company for making production inspection tests on completed amplifiers

New Testing Instruments for the Radio Service Laboratory

IN its exhibit at the R. M. A. Trade Show in Chicago early this month and in its advertising, the General Radio Company announced that several new items of test equipment for the radio service man were being developed. So many requests for information have been received that the following descriptions are being published, even though all three instruments are still in our laboratory undergoing their final tests. These specifications must, therefore, be regarded as preliminary and subject to revision before they are formally announced.

Type 486 Output Meter

This instrument will be suitable for measuring the power output of a radio receiving set at any frequency in the audio-frequency band. It will consist of a 4000-ohm resistor for replacing the speaker or output transformer and an alternating-current voltmeter of the copper-oxide-rectifier type connected across it. The voltmeter has a full-scale reading of 3 volts, but multipliers placed in circuit by a switch make it possible to increase this range by 5, 20, and 50 times to a maximum of 150 volts. The Type 486 Output Meter will, therefore, be capable of measuring any power output up to 5.6 watts.

Delivery upon this instrument has been set for August 1. A full description is scheduled to appear in the July issue of the *Experimenter*. The price will be $34.00 and the code word MALAY.

Type 360 175 & 180 K.C. Test Oscillator

This instrument will replace the Type 320 180 K.C. Test Oscillator built by the General Radio Company for aligning condensers and for neutralizing and making continuity tests upon superheterodyne receivers having an intermediate-frequency of 180 kilocycles. The new one will consist of a modulated vacuum-tube oscillator capable of furnishing test signals at any frequency in the broadcast band as well as at the two high frequencies mentioned in its formal title.

It will be operated by batteries. An output meter of either the copper-oxide-rectifier type or the thermogalvanometer type will be mounted in the cabinet which will be approximately 10¾ by 10¾ by 7 inches.

Type 404 Service Test Oscillator

This instrument is intended for the usual aligning of tuning condensers, neutralizing, and the making of continuity tests on radio receivers, but it will, in addition, make it possible for the dealer and the service man to make tests for receiver sensitivity.

It will have a modulated vacuum-tube oscillator capable of being operated at any frequency in the broadcast band. Across the output of this oscillator will be connected an attenuator or voltage divider so that known radio-frequency voltages may be impressed upon the input circuit of the receiver. By measuring output power (with the Type 486 Output Meter, for example) an approximate frequency-response curve may be obtained for the receiver.

It will be operated from the 110-volt alternating-current power supply. The cabinet will be approximately 10¾ by 10¾ by 7 inches.

No estimates of price or of delivery date on either oscillator can be made at the present time. Full information will appear in the *Experimenter* as soon as it is ready.

Direct-Current Amplifier Design

By Charles E. Worthen

A MEANS of magnifying the intensity of slowly-varying voltage pulses is often needed in experimental work. Amplifiers for television and for vacuum-tube voltmeters must respond to low frequencies and to direct current (zero cycles per second), but the usual types of audio-frequency amplifiers are not suitable because they do not operate effectively at frequencies much below 25 cycles per second.

Although there is nothing particularly new about a direct-current amplifier, we are describing here one of two stages built by the General Radio Company, because it presents an interesting example of amplifier design (see Figure 1). It was to be used in conjunction with an electrocardiograph, an instrument used by the medical profession in the study of heart action. During the heart beat potential differences of the order of a few millivolts appear between active and inactive heart muscle. These voltages are applied to the input of an amplifier and passed on to an Einthoven (string-type) galvanometer for recording.

From the schematic diagram of Figure 2 it may be seen that this amplifier is of the resistance-coupled type in which the grids of the vacuum tubes are held at the proper operating potential by means of batteries instead of the usual blocking condensers and grid leaks. With no signal voltage applied across the input terminals, each tube is operating at a suitable point on the linear portion of its grid-voltage plate-current characteristic. A voltage applied to the grid of the first tube causes a change in its plate current which, in turn, produces a change in the voltage drop across the plate resistor R_1 and alters the grid bias of the second tube. This produces a change in the plate current of the second tube and a change in the voltage across the output circuit. A scheme for balancing out the steady plate current of the second tube in the output circuit is provided. It will be described later.

If the proper operating points have

Figure 1. A two-stage direct-current amplifier, a piece of special equipment built by the General Radio Company

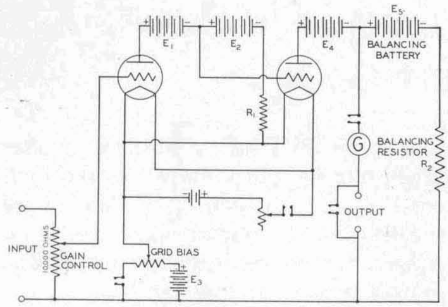

FIGURE 2. Circuit diagram of the direct-current amplifier of FIGURE 1

been chosen, the change in plate voltage in each tube is greater than the grid voltage change. The amount of this amplification depends upon the value of plate resistors used as well as upon the operating points chosen. The over-all amplification will, in general, be less than the product of the amplification factors of the tubes. It should also be noticed that successive voltage changes are out of phase by 180 degrees. If the change on the grid of the first tube be in a positive direction, that on the second grid is in the negative direction. This fact might be an important consideration when deciding whether an amplifier should consist of an even or an odd number of stages.

The considerations involved in the design of a direct-current amplifier can be better understood by means of the graphic analysis of Figure 3. This analysis holds only for small values of applied voltage on tubes biased to operate on the linear portions of their characteristics. The grid-voltage-plate-current characteristics are plotted as shown, that of the second tube being to the right of and above the first. If the two operating points are A and C, lines drawn from these points perpendicular to the axes will intersect at B.

For a given value of R_1, the drop across it is $I_{p0}R_1$. Through B, then, draw a line intersecting the voltage axis at an angle equal to $\tan^{-1}\frac{1}{R_1}$. From the geometry of the figure it is then evident that the distance subtended by this line on the voltage axis is equal to $I_{p0}R_1$. Since this gives the grid of the second tube too large a negative bias, the battery E_2 supplies enough positive bias to bring the grid to the selected operating point. Referring again to the diagram, it may be seen that $E_2 - I_{p0}R_1 = E_{g2}$. This graphic analysis makes it possible to study the effect of changing the values of the batteries and of R_1. It is extremely useful in designing direct-current amplifiers.

In order that no current shall flow in the output circuit except when a voltage is applied to the input, the steady plate current in the second tube

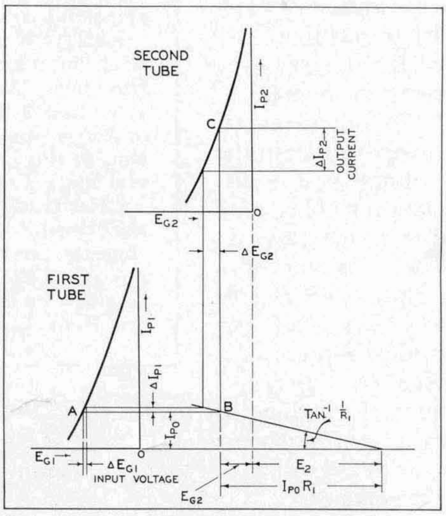

FIGURE 3. Graphic analysis for a two-stage direct-current amplifier

is balanced out. Referring to Figure 2, the balancing resistor R_2 is made equal to the plate resistance of the second tube, and the balancing battery E_5 is made equal to the battery E_4. Under these conditions, no voltage appears across the output circuit unless one is applied to the input. A zero-center galvanometer is provided in the instrument for indicating the balance condition.

MISCELLANY

By THE EDITOR

WITH this number, the first of Volume IV, the General Radio *Experimenter* appears in a new format. The new page is only one-half as large as the old one (6 inches by 9 inches instead of 9 inches by 12 inches), but doubling the number of pages makes it possible to include as much material as before. Besides making it easier to handle, the smaller size brings the *Experimenter* more nearly into uniformity with other publications which the reader keeps for reference.

No other radical changes either in the editorial or the distribution policies are contemplated. There is no subscription fee, and we ask only that our readers express a desire to continue upon the mailing list by returning the card sent out once each year. This year's card will go out sometime during the summer.

* * * *

The following excerpts from recent issues of one of the popular magazines arouse us sufficiently to suggest that their editors encourage contributors to show more respect for the decibel: (a) "With an input of 15 db at 30 cycles the inductor motor moves a ten-inch cone one-eighth inch." (b) "In all [of the author's] loud-speaker response curves, the sound intensity in db was plotted against frequency."

The decibel is, by definition, a measure of a ratio between two amounts of power, the number of decibels corresponding to a power ratio being given by $db = 10 \log_{10} r$, where r is the ratio. Obviously, specifying a power input or an intensity of sound in decibels is as devoid of meaning as the statement that the power input to a motor is 95 per cent. We admit, however, that "decibel" does sound more impressive.

It is possible, of course, to express an amount of power as so many decibels "above" or "below" a specified amount of power called the zero or reference level, but so many different reference levels are in use that it is always well to state which one is being used. Including it takes only a little more effort on the part of the author and greatly minimizes the chance of misleading the reader.

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THE IMPORTANCE OF MUTUAL CONDUCTANCE IN TESTING VACUUM TUBES

By CHARLES T. BURKE

THE behavior of a vacuum tube may be predicted if its amplification factor, plate impedance, and mutual conductance are known for the given conditions. Other factors such as inter-electrode capacitances affect its operation, particularly at the high frequencies, but it is usually justifiable to consider only the three as the principal parameters. They, or at least their names, have become so familiar that their physical significance is obscured until they tend to be considered mere mathematical constants.

This is particularly so of mutual conductance, which, because it can be derived from the other two, is sometimes thought of as a ratio without physical meaning. For testing purposes, however, mutual conductance is the most important of them all. It expresses the excellence of a particular type of tube as a power amplifier, as a detector, as a modulator, as an oscillator. It is readily measured, and, with tubes having a large plate impedance (screen-grid tubes, for example), it is the only one that can be measured with simple apparatus. In this article we propose to show why mutual conductance is so important.

The plate impedance of a vacuum tube may be defined as the ratio of the change in plate voltage to a corresponding change in plate current when the control-grid potential is held constant. It depends upon the area, nature, and temperature of the filament (electron-emitting surface), upon the area of the plate, and upon the spacing of the elements. Except at very high frequencies when the inter-electrode capacitances introduce appreciable amounts of reactance it may be considered to be a pure resistance.

The amplification factor μ, defined as the change in plate potential produced by a unity change in the grid potential when the plate current is maintained constant, depends only upon the spacing of the elements and upon the fineness of the grid mesh. It would be the all-important parameter for a tube delivering power to a load whose impedance was large as compared with the internal plate impedance, and it is, therefore, of great importance in so-called potential amplifiers (*i.e.* amplifiers which are supposed to magnify voltage variations and deliver little or no power to the load circuit). If such a circuit be well designed, the amount of voltage amplification* should approximate μ, the amplification factor of the tube.

It will facilitate an explanation to make use of Figure 1a which represents a vacuum-tube amplifier with a

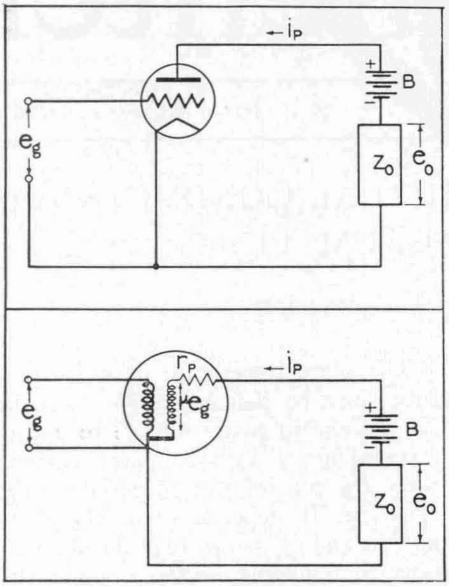

FIGURE 1. Schematic circuit for a simple vacuum tube amplifier: 1a, above; 1b, below

load in its plate circuit. This is an approximate equivalent to the diagram of Figure 1b where an ideal transformer with a turns ratio equal to μ has replaced the vacuum tube. In its secondary circuit is a resistor representing the internal plate impedance of the tube. The voltage μe_g is applied across Z_o and r_p in series, so we may write

$$\mu e_g = i_p r_p + i_p Z_o$$

or

$$e_g = \frac{i_p r_p + i_p Z_o}{\mu}.$$

Then the voltage amplification $\left(\frac{e_o}{e_g}\right)$ is

$$i_p Z_o \cdot \frac{\mu}{i_p r_p + i_p Z_o} = \mu \frac{Z_o}{r_p + Z_o}. \qquad (1)$$

This shows that when Z_o is much larger than r_p the quantity $\frac{Z_o}{r_p + Z_o}$ is approximately equal to unity and the voltage amplification is approximately equal to μ; and that, when Z_o is of the same order of magnitude or smaller than r_p, Z_o has an important effect upon the voltage amplification. For comparatively low values of Z_o the value of r_p is a dominating influence. Since, in general, the difficulty of building a load circuit increases with its impedance, it is desirable that it have as low an impedance as possible. This means that the tube should have a low impedance if the greatest amount of amplification is to be obtained. The desirability of the tube as an amplifier is proportional to μ and inversely proportional to r_p. The ratio of μ to r_p (called the mutual conductance) makes, therefore, an excellent figure of merit for expressing the desirability of a given vacuum tube as an amplifier.†

Physically, g_m, the mutual conductance of a tube is the ratio of the change in plate current that is produced by a given change in grid potential when the plate potential is held constant, assuming, of course, that there is no load in the plate circuit. Thinking of the mutual conductance as the effectiveness of grid-voltage changes in producing plate-current changes emphasizes the physical meaning of that quantity.

In circuits using the screen-grid type of tube the plate impedance is usually much greater than any value of load impedance that can be readily realized in practice. Referring again to Figure 1 and assuming that there is a screen-grid tube in the circuit it will be seen that e_o will be equal to $i_p Z_o$, and, because

* By voltage amplification we mean the ratio of the voltage appearing across the load in the plate circuit to the voltage applied to the grid of the tube.

† Mutual conductance is also a figure of merit for a tube used as a modulator, oscillator, or detector. For a more complete discussion see H. J. van der Bijl, *The Thermionic Vacuum Tube* (New York: McGraw-Hill Book Co., 1920).

r_p is large as compared with Z_o, $g_m=\frac{i_p}{e_g}$ by definition. Then the voltage amplification may be written

$$\frac{i_p Z_o}{e_g}=g_m Z_o,$$

from which we see that the voltage amplification in a screen-grid tube is given by the product of the mutual conductance into the impedance of the load. In the ideal screen-grid tube circuit the only tube parameter of importance is the mutual conductance.* The plate impedance of the 224-type tube, now in quite general commercial use, averages about 800,000 ohms, which is large enough, as compared with most circuit impedances, so that they need seldom be taken into account when making gain computations.

For the reasons set forth in the foregoing discussion, the mutual conductance of a vacuum tube may be measured and the resulting value taken as an index of the excellence of a given type of vacuum tube. Some care must be used in saying that one type of tube is better than another because it has a greater mutual conductance, but one can without hesitation say that among tubes of the same type the greater the value of mutual conductance, the better is the tube.

This fact makes it possible to use a measurement of mutual conductance as an inspection and acceptance test for tubes. Improper spacing of the elements and faulty emission will both produce a lowering in the value of mutual conductance. This test will not show what is wrong but it will show whether or not the tube is defective. That is why it makes a good test for the manufacturer's production line.

* Albert W. Hull and N. H. Williams, "Characteristics of Shielded-Grid Pliotrons," *Physical Review*, XXVII, April, 1926, p. 438.

II

Because mutual conductance is so important an indication of tube behavior, particularly in screen-grid tubes, methods of measuring it will be of considerable interest. The conventional method for making this measurement involves the use of a bridge circuit developed by H. W. Everitt,† which is shown in Figure 2.

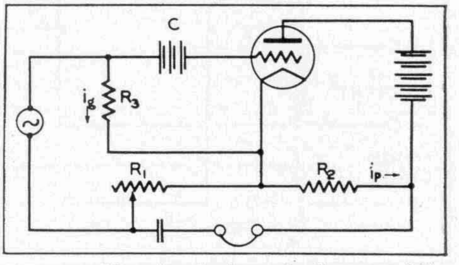

FIGURE 2. Functional schematic diagram of the bridge for measuring mutual conductance

Voltage from an oscillator is impressed across R_1 and R_3 and the output of the tube is connected across R_2. The phase relations in a vacuum tube are such that the control-grid voltage is opposite in phase to any voltage appearing across a resistance load in the plate circuit, which means that the voltage drops across R_1 and R_2 tend to cancel each other. If by adjusting R_1, the voltage drops across R_1 and R_2 can be made equal in magnitude, no current will flow through the telephone headset. In this condition of balance,

$$i_g R_1 = i_p R_2 \text{ or } i_p=\frac{i_g R_1}{R_2}$$

and $e_g = i_g R_3$,

$$\text{hence } g_m=\frac{i_p}{e_g}=\frac{i_g R_1}{R_2}\cdot\frac{1}{i_g R_3}=\frac{R_1}{R_2 R_3}. \qquad (2)$$

This result is the mutual conductance of the circuit which equals that of the tube when R_2 is negligible as compared with the plate impedance

† H. J. van der Bijl, *Op. cit.*

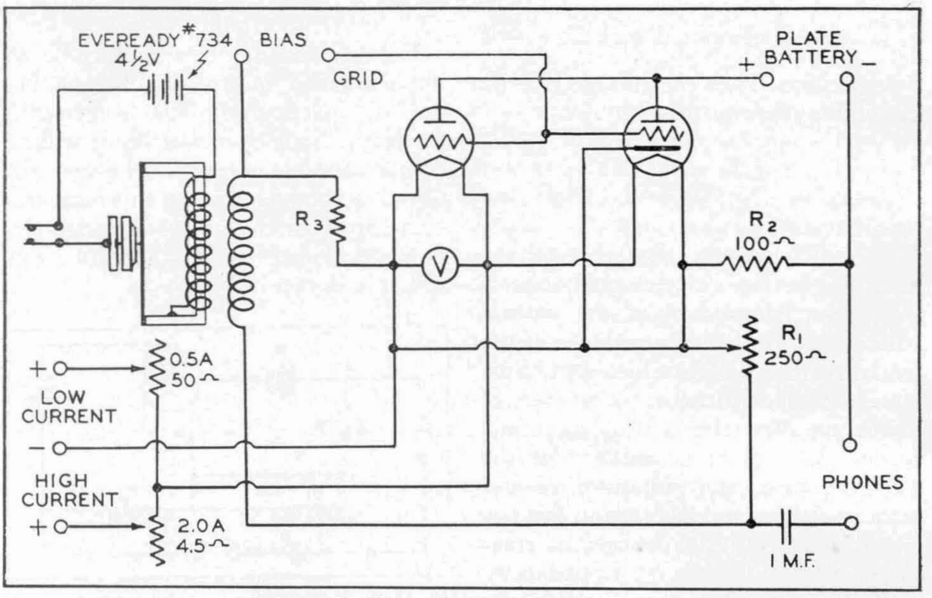

FIGURE 3. Wiring diagram for TYPE 443 Mutual-Conductance Meter. R_3 is given a value of 1000 ohms

of the tube. Since this is the only approximation involved in the bridge equations, this bridge method is more accurate the greater the value of the plate impedance of the tube. In practice R_1 is calibrated to read mutual conductance directly.

Consideration will show that this bridge may be used for making measurements upon screen-grid tubes without the necessity of shielding, even though at first glance it might appear that shielding must be used.

Shielding is necessary in any circuit only when there exist between circuit elements stray admittances that are comparable in magnitude to the circuit admittances between the elements. In this bridge the admittance between the plate and ground is of the order of 10,000 micromhos (R_2 usually being of the order of 100 ohms) and the admittance between control grid and ground is 1000 micromhos. Stray admittances ordinarily occurring between leads and between batteries will be negligible by comparison at the test frequencies of 800 to 1000 cycles used in practice.

To look at the matter in another way, we may say that shielding is necessary in a screen-grid amplifier circuit because of the very high voltage amplification given by this tube when used with a high impedance load circuit. Voltage amplifications of as much as 200 might be obtained. In the above described bridge circuit, however, the ratio of voltage drop across the load in the plate circuit to the voltage drop across the control grid is of the order of 0.1. In other words, the "voltage amplification" is about of 1 to 10 as compared with a ratio of 200 to 1 in the amplifier circuit.

III

The General Radio Company has developed for commercial use a bridge for measuring the dynamic mutual conductance by means of the bridge circuit that we have been discussing. Suitable fixed values of R_2 and R_3 are provided and the adjustment of R_1 is made by means of a dial which is calibrated directly in micromhos. Sockets are provided for both the 4- and 5-

prong tubes. A low-resistance high-current and a high-resistance low-current rheostat are included in the assembly as is a direct-current voltmeter for measuring filament voltages.

The Type 443 Mutual-Conductance Meter is suitable for making measurements on all types of tubes with an accuracy of 5 per cent. depending somewhat upon the skill exercised by the operator. It is simply necessary for him to insert the tube in the proper socket, check the filament voltage—and adjust the dial until he hears a minimum signal in his telephone headset. A true null balance is never obtained because the bridge makes no provision for eliminating the out-of-phase voltages caused by the inter-electrode capacitances of the tube under test.

The error in measurement introduced by neglecting the voltage drop across R_2 is greater for tubes having a small plate impedance, but if desired this error may be calculated and a correction applied. The meter reading is less than the true value by the product of $\frac{100}{r_p}$ into the meter reading.

When new plate batteries are used, the impedance drop through them will be small enough to be negligible. The internal impedance of the battery, however, increases with age, and, especially when measuring tubes with a low plate impedance—there may be an error due to this fact. It can be prac-

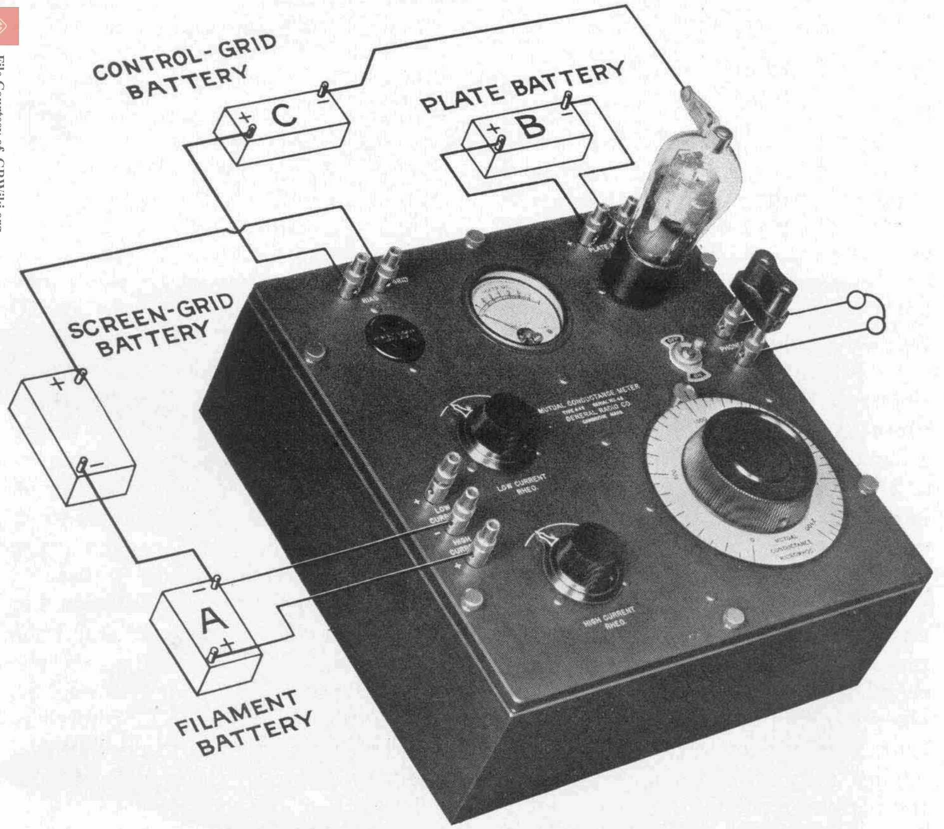

Figure 4. Type 443 Mutual-Conductance Meter showing connections for testing a 224-type screen-grid tube. The panel is engraved for triodes

TABLE I

REPRESENTATIVE VALUES OF MUTUAL CONDUCTANCE FOR VACUUM TUBES IN GENERAL USE

Type of Tube	Rheostat Used	Filament		Control Grid Bias	Screen Grid Bias	Plate Battery	Mutual Conductance
		Volts	Amperes	Volts	Volts	Volts	Micromhos*
11	LOW	1.1	0.25	−4.5	..	90	425
12	LOW	1.1	0.25	−4.5	..	90	425
112-A	HIGH	5.0	0.25	−9.0	..	135	1600
120	LOW	3.3	0.132	−22.5	..	135	510
171	HIGH	5.0	0.50	−40.5	..	180	1500
171-A	HIGH	5.0	0.25	−40.5	..	180	1500
199	LOW	3.3	0.063	−4.5	..	90	420
200-A	HIGH	5.0	0.25	0	..	45	670
200-B	LOW	5.0	0.125	0	..	45	670
201-A	HIGH	5.0	0.25	−4.5	..	90	740
201-B	LOW	5.0	0.125	−4.5	..	90	740
210	HIGH	7.5	1.25	−35.0	..	425	1600
222	LOW	3.3	0.132	−1.5	45	135	350
224	HIGH	2.5	1.75	−1.5	75	180	1050
226	HIGH	1.5	1.05	−9.0	..	135	1100
227	HIGH	2.25	1.75	−4.5	..	90	900
240	HIGH	5.0	0.25	−3.0	..	180	200
245	HIGH	2.5	1.5	−34.5	..	180	1800
250	HIGH	7.5	1.25	−84.0	..	450	1800
842	HIGH	7.5	1.25	−100.0	..	425	1200
865	HIGH	7.5	2.0	0	125	500	750

* The values of mutual conductance given in this table are not intended to be standard. For more information consult the data sheet issued by the manufacturer of the particular brand of tube under test and accept his rating. Some manufacturers express mutual conductance in milliamperes per volt; 1 milliampere per volt being equivalent to 1000 micromhos.

tically eliminated by shunting the plate battery with a condenser having a capacitance of about 2 microfarads.

The current-carrying capacity of R_2 is great enough to make the mutual-conductance meter available for measuring tubes having plate currents of as much as 250 milliamperes. High plate currents, of course, usually mean high plate voltages, and, inasmuch as the telephone receivers are connected into the plate circuit of a tube, it is important that the operator be protected against coming in contact with any of the plate-battery terminals.

It is desirable that tubes be tested for short-circuited elements before being placed in the mutual-conductance meter. A glance at Figure 2 will show that when any of the elements in the tube are short-circuited, the entire plate battery is impressed across R_2, and, although R_2 will carry at least 250 milliamperes, it will not withstand the heavy short-circuit current from the plate battery. If it is impractical to make a preliminary test for short-circuited elements, a protective relay or a fuse may be inserted in series with the plate battery.

A Rectifier-Type Meter for Power Output Measurements at Audio Frequencies

By John D. Crawford

IN the course of routine experimental work in the laboratory there often occurs the need for a convenient means of measuring the power delivered by a device at frequencies for which the ordinary dynamometer-type of wattmeter fails. This problem might, for instance, appear when testing the audio-frequency amplifiers of a public-address system or when making the standard fidelity, sensitivity, and selectivity tests upon radio receivers. In each instance the power output of the tested device is measured and then compared with a measurement of either power or voltage made upon the input.

The usual method for measuring power output is to make the device under test feed a resistive load whose resistance at the test frequency is known. Then, if the current to or the voltage drop across the load be measured, the power delivered to it can be easily computed from the relation

$$W = \frac{E^2}{R} \text{ or } W = I^2 R \qquad (1)$$

where W = power delivered to the load in watts
E = voltage drop across the load in volts
I = current to the load in amperes
R = resistance of the load in ohms.

The accuracy of this method depends, of course, upon the accuracy with which R and E or I have been determined. Since R enters directly, the percentage error in W caused by an error in R is the same as the percentage error in R, but, because the square of both E and I are involved, the percentage error in W introduced by errors in E and I is slightly more than twice as great. With an error in E or I of 5 per

Figure 1. The Type 486 Output Meter

cent., for instance, an error of 12.5 per-cent. in W results; with an error of 10 per cent., there is an error of 21.0 per cent. in W.

The entire question of accuracy in measurements of this kind is one that must be carefully considered in choosing instruments. They should be capable of giving as accurate results as are justified by the proposed test, yet, if too great an accuracy be demanded, the cost of the instrument may increase out of all proportion to its usefulness. In making the standard tests upon radio receivers, for instance, the radio-frequency voltage delivered by the best available calibrated generator for laboratory use has a possible error of 5 per cent. in voltage. Little would be gained if it were necessary to build a special power-measuring circuit having an accuracy very greatly in excess of this value.

The indicating instruments most often used for measurements over the audio-frequency band are the vacuum-tube voltmeter, the hot-wire ammeter, and the thermocouple ammeter, all of which may be designed to have excellent frequency-response characteristics. Coöperating with the General Radio Company, a large manufacturer of electrical instruments has developed a new alternating-current voltmeter which makes use of four small copper-oxide rectifiers connected in circuit with a direct-current galvanometer. When alternating voltages are applied, the resulting rectified current causes a deflection in the galvanometer which is calibrated directly in root-mean-square volts. The principal advantages of this instrument are its comparatively low cost and its ruggedness. It is able to withstand a considerable amount of overvoltage with no damage other than the bending of the pointer.

The General Radio Company has developed for use in the measurement of power output its TYPE 486 Output Meter, shown in the photograph of Figure 1. One of the new copper-oxide rectifier voltmeters with a full scale reading of 3 volts is equipped with a multiplier which increases the full scale reading to five, twenty, and fifty times this value. At the same time the input impedance of the instrument is kept at 4000 ohms so that, in effect, there is a constant 4000-ohm load circuit with an adjustable-range voltmeter connected across it. This is made possible by the **L**-type network shown in Figure 2. The

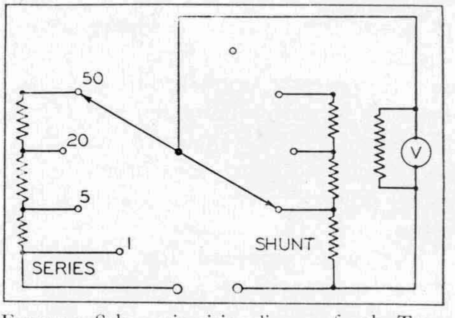

FIGURE 2. Schematic wiring diagram for the TYPE 486 Output Meter. The numerals beside each of the switch points at the left indicate the value of the multiplying factor for the voltmeter

total resistance of the series arm and of the shunt arm (including the meter circuit) is kept at a constant value of 4000 ohms, and the ratio of the impedance of the shunt arm and meter circuit to the total resistance of 4000 ohms is the multiplying factor for the voltmeter.

Inasmuch as the input impedance to the instrument is known, the power delivered to it can be computed from equation (1). The output meter with a maximum range of 150 volts and an input resistance of 4000 ohms can, therefore, be used to measure power outputs of as great as

$$\frac{(50 \times 3)^2}{4000} = 5.6 \text{ watts.}$$

In addition to the factors already mentioned, the accuracy of this instrument depends upon the accuracy of the multipliers. The voltmeter itself is accurate to within 5 per cent. of its full scale reading at frequencies between 25 and 5000 cycles. At frequencies between 5000 and 10,000 cycles, the accuracy is within 10 per cent. of the full scale reading. The resistance units in the output meter are designed and adjusted to have an accuracy that is consistent with the percentage error in the voltmeter itself.

There is inherent in all meters of the rectifier type an error that cannot be overlooked. The impedance of any rectifier is a function of the amount of current passing through it, and since the rectifier type of voltmeter that we have been discussing depends for its operation upon the measurement of different amounts of current, we may expect that its impedance will depend upon the voltage being measured. This has been found to be true and the Type 486 Output Meter has under some circumstances an error due to this fact.

Measurements made upon the voltmeter used in the Type 486 Output Meter show that the impedance varies in the ratio of about five to three for deflections between 0.5 and 3 volts (full scale). This variation is partially compensated by shunting the voltmeter with a resistance of such value that the total impedance of the resulting parallel circuit is 4000 ohms when the voltmeter indicates 2 volts (two-thirds full scale). For deflections other than 2 volts an error is introduced in power measurements which depends upon the input impedance of the output meter.

The error in the measured power is appreciable only when the multiplier switch is in the *1* position. Then the shunted voltmeter is connected directly to the input terminals and variations in its impedance appear directly as variations in the impedance of the output meter, and, consequently, as errors in measured power. At the 1.0-volt scale reading, the power error may be as great as 11 per cent.; at the 2-volt scale reading, the power measurement will be correct; and in the 3-volt scale position, the power error will be about 9 per cent. The measured power will be low at the low end of the scale and high at the high end of the scale.

When the multiplier switch is in any other position, there is connected across the shunted voltmeter the additional shunt arm of the **L**-type network, which minimizes the variations in impedance so that when the multiplying factor is five, twenty, or fifty, the error introduced in the input impedance and in the value of the multiplying factor is less than one per cent.

At first glance the error involved in the use of the directly-connected voltmeter in the output meter would appear to make it useless. Actually, however, most measurements of output power are made at power levels greater than the 2.25 milliwatts represented by a meter reading of 3 volts. For instance, the standard reference power level for use in making measurements upon broadcast receivers is 50 milliwatts, and practically the only use for the low range on the output meter is in the neutralizing and ganging of tuning controls by means of a low-power radio-frequency oscillator. The output meter will also be found useful for measuring the amount of power-supply hum that is present in the output of an audio-frequency amplifier. For all of these uses the error in measured power is not serious.

It is also a fact that the low range of the output meter will usually be used for measuring voltage rather than power. For this use, impedance variations will cause no appreciable error.

The impedance of the output meter was set at 4000 ohms because that value is fairly representative of the average impedance of a high-impedance (cone-type, etc.) loud-speaker. For making measurements upon amplifiers with self-contained output circuits for delivering power to a dynamic loudspeaker, the impedance of the output meter will be much too large. Here the instrument is intended to be used as a voltmeter connected across an external dummy load of suitable resistance (35 ohms, perhaps).

The TYPE 486 Output Meter cannot be used in circuits where direct current is present. The direct-current component may be eliminated by the use of a suitable transformer or speaker filter, or by connecting a large condenser in series with the output meter. The condenser should have a very small voltage drop across it as compared with the total drop across the output meter. For use at 25 cycles, for example, the condenser should have a capacitance of at least 2 microfarads; 4 microfarads would be better.

The price of the TYPE 486 Output Meter is $34.00, the panel size is 7-3/8 inches by 5 inches, its weight is 2½ pounds, and the code word is MALAY.

HOW AND WHY THE FADER

By HORATIO W. LAMSON

WE assume that all of our readers are familiar with the effective motion picture technique, the fade-out, whereby the close of a scene is dissolved by restricting the field of view towards the center of the picture frame, and, at the same time, reducing the intensity of illumination. This is usually accomplished in the studio by slowly closing one or two iris shutters while the camera is in operation, or the fade-out may be produced in the projection booth by the manipulation of an iris shutter on the projector. With the advent of synchronous and non-synchronous sound accompaniment for motion pictures, the need arose for an analogous acoustical fading-out device, the fader.

The purpose of this instrument* is twofold. The acoustical condition of a theater, due to its dimensions, architectural features, and especially the size of the audience, varies considerably from time to time, so that the fader serves first of all as a convenient means for controlling the volume level of the reproduced sound in order to achieve the most natural and pleasing results. The proper monitoring of a sound presentation to meet the existing conditions contributes greatly to the success of the program.

The fader also provides for reducing the output of an expiring film or disc sound track to zero and subsequently building up the level of the new sound track to the proper value. An abrupt change between the sound tracks at full volume levels gives rise to undesirable transients in the electrical systems. By the use of the fader the change from one to the other can be made in such small steps that it is not perceived by the audience, and transients are minimized even though the transfer is made as quickly as possible. To accomplish these purposes the fader is built in the form of a two-sided or bilateral attenuator. We propose to discuss the relative merits of various types of faders.

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*Horatio W. Lamson, "How and Why the Talkies," *General Radio Experimenter*, III, December, 1928, and January, 1929.

II

The simplest scheme is shown in Figure 2. P_1 and P_2 represent two pickups (for film or disc tracks), and s is a movable contact which slides along the resistances R and connects to the grid of an amplifier tube. Here, because the tube draws no energy, the fader operates as a simple voltage divider having a total resistance of $2R$. The load R in which each pickup is terminated should have a value approximating the impedance of the pickup if it is desired to match impedances.

The adjustable resistance in all of these faders may be constructed in one of two forms: as a continuously-adjustable slide-wire or as a step-by-step attenuator in which a contact-stud type of switch adjusts the attenuation in predetermined discrete increments to give any desired calibration scale, which, however, is usually made uniform in decibels. The slide-wire type may likewise have a scale calibrated uniformly in decibels if the form upon which the wire is wound be cut in the proper shape.

The calibration of the arrangement shown in Figure 2 is simple, since no power is drawn from the output. If r

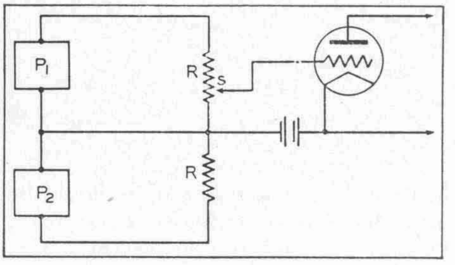

FIGURE 2

be the resistance between s and the filament, then the number N of decibels attenuation for any particular scale position of s is given by

$$N = 20 \log \frac{r}{R}. \qquad (1)$$

It is often desirable to interpose a transformer between the pickup and the amplifier. In this case the fader arrangement shown in Figure 3 might

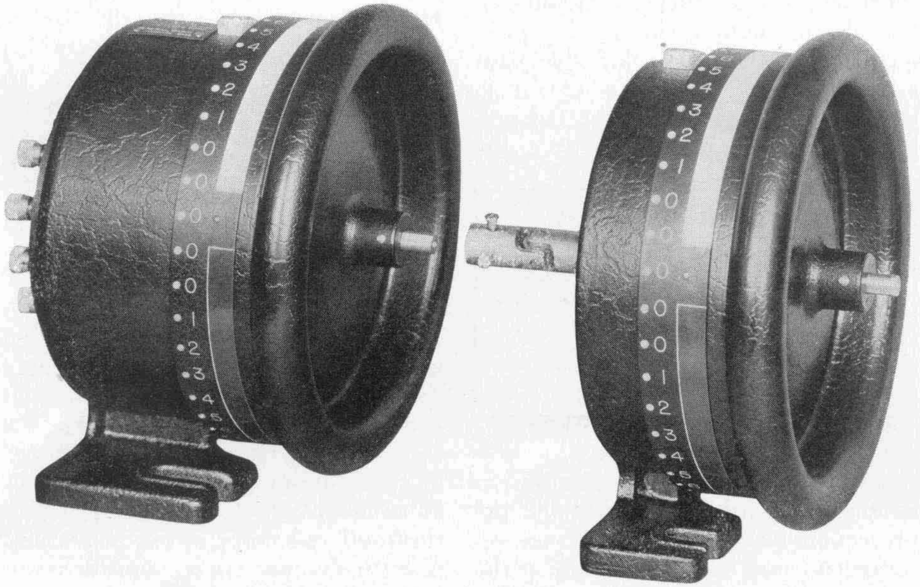

FIGURE 1. The General Radio TYPE 598 Fader. At the left is the fader proper; at the right is the "dummy" or auxiliary control. In practice the two are mechanically coupled

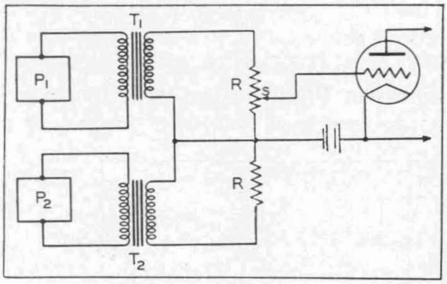

FIGURE 3

be used. Here the values of R should be quite large so that the currents drawn from the secondary coils of the transformers T_1 and T_2 will not be of sufficient magnitude to injure their frequency-response characteristics. The calibration equation is, of course, the same as that for the arrangement of Figure 2.

The faders function in both Figures 2 and 3 purely as voltage dividers. When these methods are used, it is highly desirable that the fader be made an integral part of the amplifier so that the lead connecting *s* to the grid of the tube may be shielded and kept as short as possible. Such a procedure is feasible in non-synchronized equipment, but it is not so desirable with synchronized apparatus where it is more convenient to have the fader in the form of a separate unit at a distance from the amplifier and adjacent to the operators standing beside the projection machines. This service requirement may be met by making the fader operate not as a voltage divider but as a current attenuator.

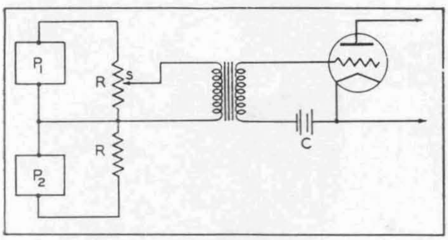

FIGURE 4

The method of Figure 4 suggests itself. This is an **L**-type network in which both the series and shunt arms are adjustable in such a manner that their sum remains constant and equal to R. Such an arrangement is, however, undesirable for two reasons. First, the matching of the pickup and load impedances in both directions is poor, and, second, the output circuit being largely inductive, the attenuation for a given setting of the fader is a function of the frequency. The resulting suppression of the higher harmonics causes distortion.

These difficulties may, of course, be largely overcome by employing a

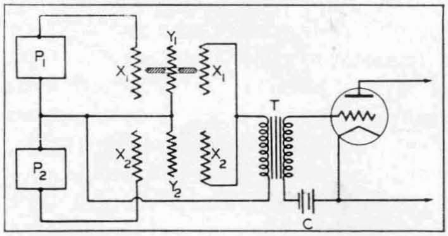

FIGURE 5

fader which consists of an adjustable **H**- or **T**-type network after the manner shown (for a **T**-type) in Figure 5 which requires three sliding contacts. To increase the attenuation the two resistances X_1 and X_2 are increased, and, simultaneously, the resistance Y is decreased. This ideal network requires a complicated and expensive switching mechanism which represents, for talking pictures, a greater refinement than is warranted in practice.

The first step toward obtaining an economical design without noticeably sacrificing quality is shown in the compensated fader of Figure 6 in which a compensating resistance C is adjusted in synchronism with R. This gives us an adjustable **T**-type network in which the total resistance of one series arm plus the shunt arm r remains constant. If the adjustable series or compensating arm C be located, as shown, on the side toward the pickup, it is possible by proper design to maintain the impedance into which the pickup works at a constant value. This is the most important matching requirement. The impedance looking back from the load will vary between R and some minimum value, but this is relatively unimportant. To increase the attenuation the sliding contacts are moved so as to reduce r and increase C. The calibration of such a fader presents too lengthy a problem for analysis here.

It has been found in practice that the fader shown in Figure 6 may be further simplified and still give suffi-

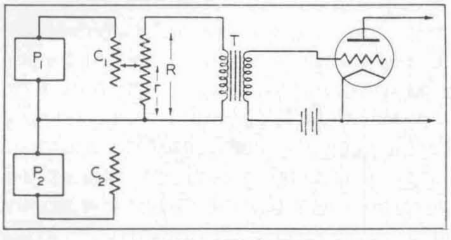

Figure 6

ciently correct impedance relations to prevent intoducing noticeable distortion. This is accomplished by giving C a fixed value of the proper amount. We now have a **T**-type network in which one series arm C is held constant, while the other series arm and the

Figure 8. View of Type 598 Fader showing connection panel and selector switch for changing from film to disc track

shunt arm are varied in such a manner that their sum remains constant and equal to R. This network gives the correct impedance looking out from the pickup at only one setting which in practice is chosen at approximately two-thirds of the full volume level.

The schematic diagram for a fader arranged for economy of resistance units and having fixed compensation and a step-by-step adjustment of attenuation is shown in Figure 7.

Faders for synchronized equipment frequently carry a selector switch (not shown in Figure 7) for shifting the pickup terminals from the film to the

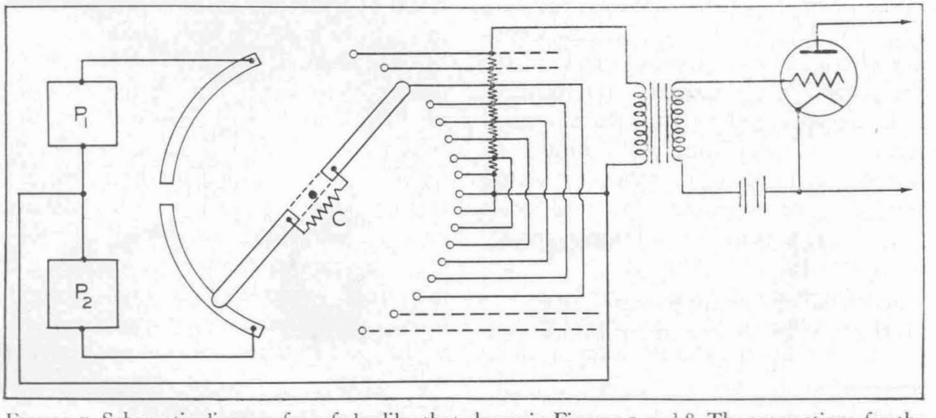

Figure 7. Schematic diagram for a fader like that shown in Figures 1 and 8. The connections for the selector switch are not shown

disc sound track. Such faders are usually provided with fifteen steps on each side which are calibrated to give about three decibels attenuation each. They may, of course, be designed to have any desired impedance and attenuation, but, in order to minimize inductive interference in these circuits which are connected to the input of a powerful amplifier* the impedance should be kept as low as possible. Thus, the very high impedance photo-electric cell is connected to an amplifier located adjacent to the cell. The signal from this amplifier, which has a low internal output impedance, is subsequently fed into the fader at approximately the same energy level obtained directly from the disc pickup.

In order to minimize impedance variations or to match unlike input and output circuit impedances, it is occasionally the practice to install fixed networks or pads before and after the fader. Such pads necessarily introduce a certain amount of attenuation which must be compensated for by an increase in the over-all gain of the amplifying system.

For convenience of the operators the fader is usually installed near one projector; and a dummy control unit, carrying a duplicate scale, is mounted beside the other, the dummy and the fader being joined by appropriate shafting. In certain installations auxiliary change-over switching mechanisms are placed in the dummy control unit.

In designing the various mechanical features of the fader, it should be borne in mind that motion picture theaters are scattered far and wide over the land and that a large majority of them do not have immediate access to a trained technician. Unlike a vacuum tube or a photo-electric cell, a defective fader cannot be replaced or repaired in a moment's time. A failure of this device would seriously interrupt a program schedule.

It is, therefore, of paramount importance that, in conjunction with the amplifiers and associated equipment, the fader be rugged in construction and as free from service troubles as good design, workmanship, and materials can insure. The containing cabinet and switching mechanism should be ruggedly built and rigidly mounted so that they will withstand an indefinite amount of ordinary handling.

If a dummy control be used, there must be no appreciable backlash between the dials of the dummy and master units. Early types of faders made use of a rack and pinion drive between the units. This was soon found to be unsatisfactory and was superseded by bevel gears and shafting equipped with universal joints to relieve inaccuracies in the mounting alignment. The most recent design, introduced by the General Radio Company and illustrated in Figures 1 and 8, eliminates the need for bevel gears and requires only straight shafting and universal joints between the dials of the master fader and the dummy control.

It has been found that a properly designed step-by-step contact switch is quieter and more reliable in its electrical operation than the ordinary form of continuously-variable slide wire.

Care must be taken, however, in the proper choice of materials for the contact studs and brushes in order to obtain a combination which shall be free from oxidation which might introduce erratic contact resistances. Minute current variations produced thereby, after enormous amplification, would introduce, especially at high volume levels, a disagreeable scratching noise in the loud speakers whenever the fader was manipulated or subjected to jarring.

* *Op. cit.*

MISCELLANY

By THE EDITOR

DURING the past few months the General Radio Company has been making extensive changes in its organization for the handling of engineering information. These changes have made necessary the combining of the July and the August issue of the *Experimenter*.

* * * *

Those readers of the *Experimenter* who followed the discussion of the new General Radio system for determining frequency that was described by J. K. Clapp in the March and April issues will be interested in knowing that more data is now available. The name "Standard-Frequency Assembly" has been given to this combination of working standard, multivibrators, and timing mechanisms.

Copies of the new descriptive literature may be obtained by writing for the Supplementary Information Sheets of the 500-series. At the same time, the particular problem in the measurement of time or frequency which interests you should be mentioned.

* * * *

There will be enclosed with the September issue of the *Experimenter* a return postal mailing card upon which readers will be asked to indicate whether or not they wish to continue upon the mailing list. We mention this now so that you may be looking for it.

* * * *

In Mr. Burke's article on the measurement of mutual-conductance he states (page 5) that the TYPE 443 Mutual-Conductance Meter may be used to make measurements upon tubes having plate currents as great as 250 milliamperes. This holds true only for instruments bearing a serial number of 73 or higher. Those with a smaller serial number have a maximum current-carrying capacity of about 65 milliamperes.

Anyone having a meter with the low plate-current rating who wishes to convert it into one with the high-current rating, may do so by replacing the plate resistor R_2. The price of the replacement resistor is $1.00. When it is installed by the General Radio Company, there is an additional charge of $3.00 to cover the cost of labor. There is no reason why anyone who can do a good job of soldering should not make the change for himself.

* * * *

In the June issue of the *Experimenter* we presented a few preliminary specifications about three new testing instruments that the General Radio Company was preparing to manufacture for radio service laboratories.

The situation with respect to the TYPE 360 Test Oscillator and the TYPE 404 Test-Signal Generator remains practically unchanged. The former is, however, about to go into production, pending an inspection by the Radio-Victor Corporation of America to see whether it meets the service testing requirements of the Radiola superheterodyne receivers. It will be a general-purpose testing instrument for use with all types of receiving sets with additional circuits for testing superheterodynes.

The price will be $110.00. Orders are now being accepted for delivery October 10, and final specifications will be announced in the next issue of the *Experimenter*.

The following is quoted from the preliminary description of the TYPE 404 Test-Signal Generator that appeared in the June issue of the *Experimenter:* "It will have a modulated vacuum-tube oscillator capable of being operated at any frequency in the broadcast band. Across the output of this oscillator will be connected an attenuator or voltage divider so that known radio-frequency voltages may be impressed upon the input circuit of the receiver. By measuring output power . . . an approximate frequency-response curve may be obtained for the receiver."

The price and delivery date of the TYPE 404 Test-Signal Generator will be made later on.

* * * *

The TYPE 598 Fader illustrated on page 11 is the newest design of fader that the General Radio Company is building for the talking motion picture industry. For a forthcoming issue of the *Experimenter* we are preparing a descriptive summary of the faders and of the resistance networks capable of being adapted for use as faders, which are manufactured by this company.

The TYPE 598 Fader is built only to order. Prices will be quoted on application.

* * * *

The General Radio Company takes pleasure in announcing that Harold S. Wilkins joined its staff on July 1, as a member of the Engineering Department, specializing on mechanical design problems. Mr. Wilkins was graduated from the course in electro-chemical engineering at the Massachusetts Institute of Technology in 1914. He has been with the Bureau of Mines and with the Chemical Warfare Service of the U. S. Army. Since 1919 he has been engaged in mechanical and electrical engineering work for Gray and Davis of Cambridge, H. C. Dodge, Inc., and the S. A. Woods Machine Company of Boston. In the year just passed he has been conducting a consulting business and making experimental investigations on electrical refrigerators, oil burners, and household appliances.

Mr. Wilkins is now working on several new instruments, among which is a new synchronous-motor-driven clock that will supersede the TYPE 411 Synchronous Motor.

CONTRIBUTORS

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Improving the Precision of Setting in a Tuned-Circuit Wavemeter

By James K. Clapp

THE difficulty in observing accurately the true resonance setting of the variable condenser in a tuned-circuit wavemeter is known to any one who has attempted to make precision measurements by looking for the current maximum. The peak of the resonance curve is so flat that the precision of setting the condenser is often far less than the inherent accuracy of a high-grade tuned-circuit wavemeter. These difficulties have led to the development of the incremental capacity method for indicating resonance and to its being included in the General Radio Company's Type 224-R Precision Wavemeter,* a special instrument to cover the high-frequency bands.

The essentials of the circuit are indicated in Figure 1, where the fixed inductance L, the variable condenser C, and the thermogalvanometer I make up the usual wavemeter circuit. The fixed air condenser (marked ΔC, for incremental capacity) and the push-button switch are the additional elements for making possible a more precise adjustment of C. The by-pass condenser, shown in dotted lines, makes the readings of the thermogalvanometer more nearly constant over the frequency range.

When testing for resonance by the incremental capacity method, the main tuning condenser C (which is of the worm-drive precision type) is slowly adjusted, and the push-button switch is alternately opened and closed. There will be found an adjustment of C where the thermogalvanometer reading does not change when the push button is operated. This is the desired adjustment.

The principle of this procedure is shown in Figure 2, where I_1 and I_2 correspond to the two settings of C, C_1 and C_2. Since I_1 and I_2 are equal, the thermogalvanometer shows no change in reading when the push button is operated. The scale reading of C, corresponding to C_1, is taken as the calibration setting for the frequency in question. This is allowable, since, in a given wavemeter circuit, there is a definite relationship between C_1, which corresponds to the scale setting observed, and C_0, which corresponds to the true resonance condition.

Suppose the main condenser C to be set at a value of capacity slightly less

*Although the Type 224 Precision Wavemeters have for some time been calibrated both in frequency and in wavelength, they are still known as *wavemeters* for catalog purposes.

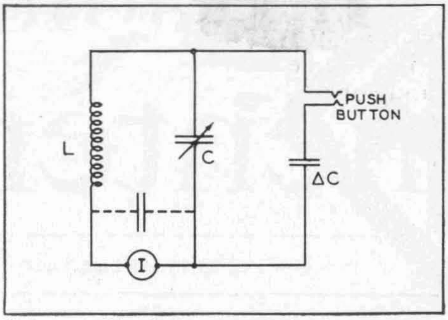

FIGURE 1. Circuit for a tuned-circuit wavemeter to be used with the incremental capacity method of indicating resonance

than C_1 (see Figure 2). The corresponding current is I'_1 which is less than I_1. When the push button is depressed and the condenser ΔC is shunted across C, there results I'_2, which is greater than I_2. For this setting of C, operating the push button causes the current to change from I'_1 to I'_2. This change, which is quite noticeable, makes possible a precise adjustment of C.

When using this method, it is only necessary to observe how the current I behaves when the push button is operated in order to tell whether the setting of C is too high or too low. If the setting of C be too *low*, depressing the push button will *increase* the reading of I; if the setting of C be too *high*, depressing the push button will *decrease* the reading of I.

A wavemeter which has been constructed and calibrated for use with the incremental capacity method must be used with some care and caution, since it is not in resonance with the frequency being measured for either position of the push button. The ordinary wavemeter calibrated for maximum deflection of the thermogalvanometer I is intended to be in resonance.

Inasmuch as a tuned-circuit wavemeter is coupled to the circuit being measured, the coupling coils of the wavemeter and of the measured circuit are, in effect, the primary and secondary windings of a transformer. The impedance of the wavemeter circuit is reflected into the oscillator circuit by "transformer action," the magnitude of the reaction depending upon the value of coupling between the two circuits. For close coupling the reflected impedance may be large enough to materially modify the effective impedance of the oscillator circuit. It should, therefore, be apparent that when a wavemeter is coupled to an uncontrolled vacuum-tube circuit,* the wavemeter may react upon the oscillator and change its frequency.

When the wavemeter is in resonance, the impedance reflected into the oscillator is non-reactive and little damage is done because pure resistance introduced into an oscillator circuit causes a frequency change that is entirely negligible. If the wavemeter be out of resonance, the reflected impedance has an appreciable reactive component which alters the reactance of the oscillator circuit, and consequently alters the frequency of the oscillator.

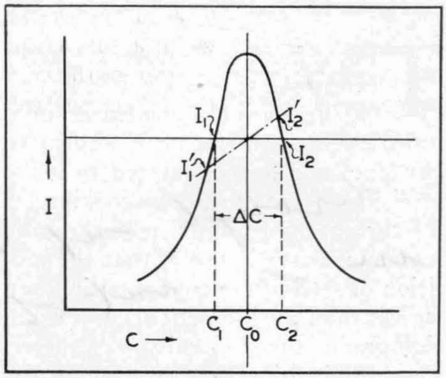

FIGURE 2. Typical resonance curve showing the operation of the incremental capacity method

The reactance reflected into the oscillator circuit depends upon the amount by which the wavemeter is detuned, for a given value of coupling. The de-tuning is dependent upon the ratio of the incremental condenser,

*One whose frequency is determined by the reactance of the tuned circuit, in other words.

ΔC, to the variable condenser C. As the value of C is changed in adjusting the wavemeter over its range, the reaction of the wavemeter on the oscillator also varies. By choice of the value of coupling employed with each setting of the wavemeter, the reaction may be kept at a small and practically constant value.

The precision with which readings may be taken with a wavemeter fitted with this incremental condenser is remarkably high, of the order of one part in 20,000. This means that an oscillator could be set to within 1000 cycles of a desired frequency in the vicinity of 20,000 kilocycles, or 15 meters. The absolute accuracy of the wavemeter involves such factors as the permanence of construction of the coils and variable condenser and the changes in the constants of the circuit with temperature.

It must be borne in mind that the rating of the oscillator has nothing to do with the shift in frequency that will be caused by improper handling of the wavemeter. If the wavemeter is coupled to 5-watt and 1000-watt oscillators having identical tuning characteristics, then the wavemeter will cause the same shift in frequency in both for the same values of wavemeter-oscillator coupling.

For this reason, the push-button type of wavemeter must be used with care and the coupling kept as small as possible. Ordinarily no difficulty is encountered when measuring the frequency of a transmitter if the wavemeter be coupled to the power amplifier following any form of master-oscillator.

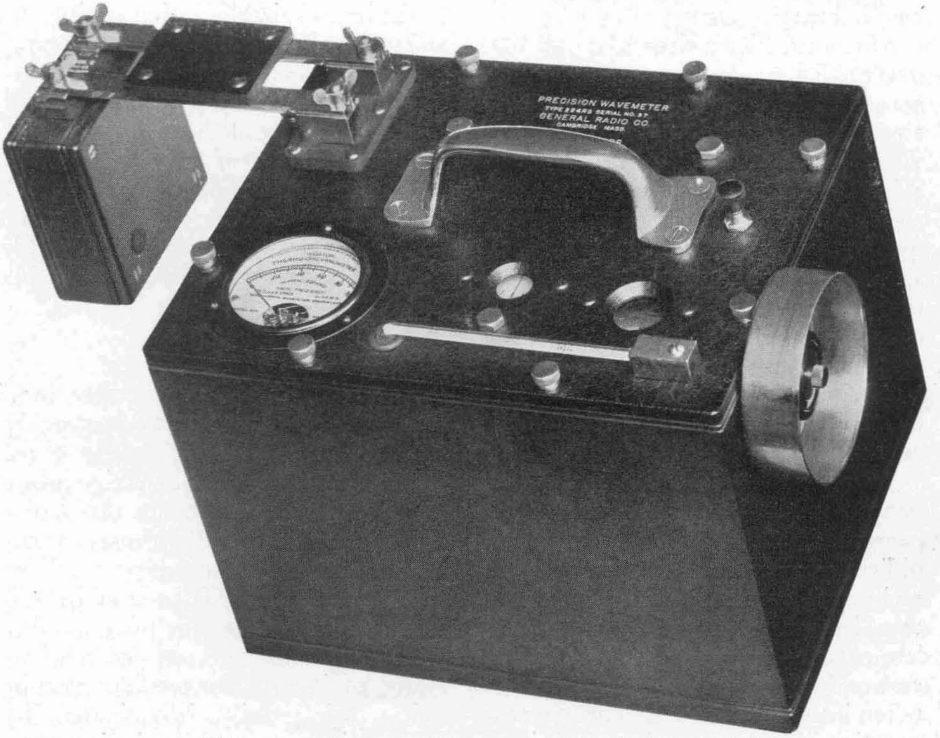

FIGURE 3. A special TYPE 224-R Precision Wavemeter equipped with a push-button switch

A Radio-Frequency Driver for the Service Laboratory

By Charles T. Burke

THE service laboratory which specializes in the maintenance and repair of radio receivers finds itself in a position very much like that of the automobile garage. Present-day receivers are almost as complex as automobiles and it requires the same high type of work to service both. There was a time when anyone owning a few wrenches and a tire pump could set himself up as an automobile service station, but that day is gone. Garages equipped with many kinds of special tools are able to perform work so much cheaper that the man without equipment must often charge less than his cost in order to compete.

There was also a time when all that one needed to service a radio receiver was to possess a working knowledge of two or three popular circuits and an ability to handle a screwdriver and a soldering iron. Only the simplest of tools were required. The radio-frequency section of most receivers consisted of a relatively simple set of tuning controls which operated the detector tube; or, if there were radio-frequency amplifiers, each one had its own control. Troubles were easy to localize when one could get at all the connections.

The modern radio receiver with ganged tuning controls and chassis construction presents a much more difficult service problem. Ganged controls and concealed wiring make it troublesome in many cases to use obsolete cut-and-try methods. Besides, the cost of doing service work must now be taken into consideration. The owner of a radio set looks upon it as a finished instrument installed in his home to give him entertainment. From his point of view, it should be as foolproof a device as the phonograph or the automobile, and he will not pay for the expense of tearing down his set whenever minor troubles develop.

There are now available on the market instruments for making service tests which not only make it possible to do more work in less time, but also to do a materially better job of it. Whether or not the service man will equip himself with good instruments or depend upon cut-and-try methods is a question that he must settle for himself, purely on a basis of cost. If one service man in a given locality makes use of the best available testing equipment and is enabled thereby to do better work at a lower cost than his competitor, the competitor will be forced to adopt similar methods or else go out of business. Many of these helps the service man may construct for himself, but here again, he must decide whether he has saved anything by building his own after allowing for the cost of his time.

II

The troubles that may arise in a modern radio receiver may be roughly classified into the following three groups: (a) those due to defective tubes, (b) those due to defects in the audio-amplifier system, and (c) those that appear in the radio-frequency amplifier and detector units. Tube troubles will be disclosed by any one of a number of testing units now on the market; many audio-amplifier troubles may be quite satisfactorily investigated by simple direct-current continuity tests. For making checks upon the radio-frequency system, however, the fundamental testing device that must be used is a modulated radio-frequency oscillator, for furnishing a test signal at one or more points in the broadcast band.

When neutralizing, when adjusting trimming condensers, when aligning gang tuning controls, when making general radio-frequency continuity tests, and when making any one of a number of other investigations in the absence of a reliable signal from several different broadcasting stations, a test oscillator is an absolute necessity if an intelligent test is to be made. Since practically every one of the new receivers uses a complicated radio-frequency amplifier, the importance of a radio-frequency driving circuit for the service laboratory needs no further emphasis.

III

To meet the demand for a general-purpose driving oscillator, the General Radio Company has developed its Type 360 Test Oscillator shown in Figure 1. This instrument consists of a modulated radio-frequency oscillator

Figure 1. The Type 360 Test Oscillator

which will operate at any point in the broadcast band (550 to 1500 kilocycles)

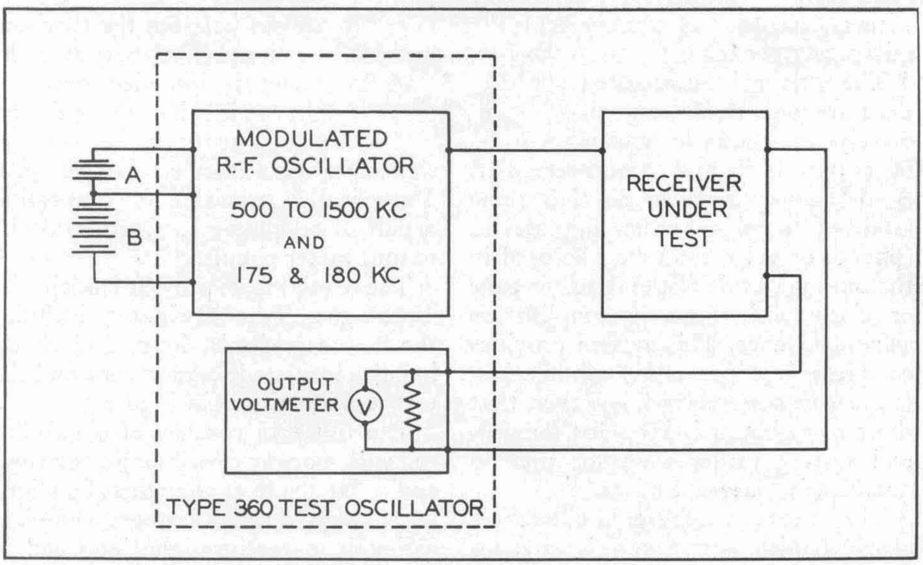

Figure 2. Functional schematic diagram for the Type 360 Test Oscillator

and in addition, it delivers a signal at 175 and 180 kilocycles for making tests upon the intermediate-frequency stages of superheterodyne receivers.

The frequency of the test oscillator in the broadcast band is adjusted by means of a variable condenser whose dial is calibrated directly in frequency (kilocycles) with an accuracy of 2 per cent. This makes it possible to know in which part of the broadcast band the test is being made. It also makes possible the approximate calibration of a receiver.

The two test frequencies at 175 and at 180 kilocycles are made available by a selector switch, which takes care of the necessary changes in the tuned circuits. A small variable condenser which permits varying the oscillator frequency over a band of about 4 kilocycles on each side of the specified channel is included in the circuit. The channel frequency is adjusted by the General Radio Company to the specified value with an accuracy of plus or minus 0.25 per cent.

FIGURE 3. Novel test tool for use with the TYPE 360 Test Oscillator

The driver is modulated at a frequency of approximately 800 cycles by means of a grid leak and condenser. This is, of course, supplied so that some kind of a signal-indicating device (phones or voltmeter) may be used in the output circuit of the detector tube or of the audio-frequency amplifier to show resonance. This system provides complete (100 per cent.) modulation. It must be remembered, however, that the test oscillator is intended for general testing rather than for making quantitative measurements.

The TYPE 360 Test Oscillator is provided with an output voltmeter for showing when an adjustment on the receiver results in a maximum output. The output voltmeter is the same one that is used in the TYPE 486 Output Meter which was described in the July–August issue of the General Radio *Experimenter*. It consists of a direct-current micro-ammeter in conjunction with a double-wave rectifier of special design. This type of instrument has considerable value in alternating-current measurements, since it permits the building of low-range instruments of high resistance.

The output device is brought to pin-jacks on the panel for connection to the output circuit of the radio receiver under test. A resistance network which offers an impedance of 4000 ohms is provided for use with the voltmeter when testing a receiver designed for use with a high-impedance (cone-type) speaker. The voltmeter is connected directly across a low-impedance (dynamic) type of speaker, and a selector switch is provided to choose between the two connections. The output voltmeter is intended only for the indication of optimum adjustment and is not designed for quantitative measurements. There is also provision for connecting a pair of telephone receivers into the output meter circuit.

The equipment provided with the TYPE 360 Test Oscillator includes the necessary leads, long- and short-handled insulated screwdrivers, and the test tool illustrated in Figure 3.

The test tool consists of a bakelite rod with a heavy closed loop at one end and a flat spade at the other. In aligning a stage of radio-frequency amplification in a receiver, the loop end is brought into the field of the coil, the closed loop acting as a short-circuited turn to reduce the inductance of the coil. Should this test cause an increase in signal strength, the trimming capacity in the stage should be decreased.

The flat end of the tool is intended to be brought near the tuning condenser of the stage being tested, the resulting stray capacity to the tool increasing the effective capacity of the tuning condenser. A decrease in signal strength indicates that the tuning capacity for the stage is either correct or too large; an increase in signal strength indicates that the tuning capacity is too small. This method of test, which is suitable for all receivers where the parts are sufficiently accessible, greatly facilitates the task of aligning the receiver, since it shows exactly how the trimming condenser should be adjusted.

The TYPE 360 Test Oscillator employs one 112-type tube which requires a 6-volt storage battery and 45 volts of plate battery to operate it. The necessary connection leads are provided. A hand-hole covered by a metal plate is located in the base of the cabinet so that the tube may be inserted without removing the panel. There is a small pilot light to show when the filament of the oscillator tube is lighted.

The test oscillator is coupled to the receiver under test by a single lead-wire provided with the instrument. It is intended that it shall be placed far enough away from the receiver to minimize spurious couplings, even though the receiver be poorly shielded.

IV

Last year, it will be remembered, the General Radio Company built a test oscillator particularly for use in making adjustments upon the Radiola superheterodyne receivers. There was a test signal at 180 kilocycles and one at either end of the broadcast band. This instrument is now obsolete, its place having been taken by the TYPE 360 Test Oscillator. Although it is similar in many ways to the old one, the new test oscillator is distinctly a general-purpose testing device for use with any kind of receiver whose radio-frequency amplifiers are tuned to frequencies within the oscillator's working range.

The price of the TYPE 360 Test Oscillator is $110.00, its size is 10¾ inches by 10¾ inches by 7 inches, its weight is 11½ pounds, and the code word is OVATE.

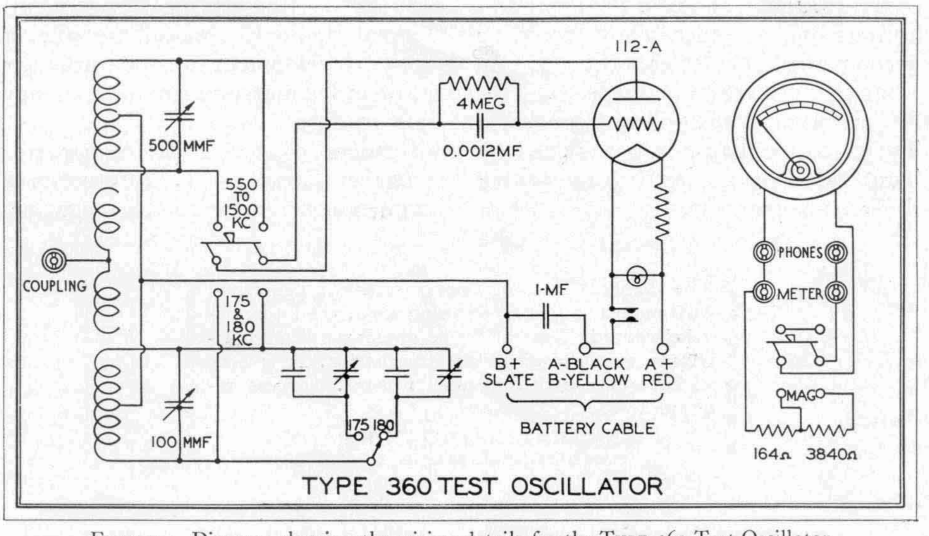

FIGURE 4. Diagram showing the wiring details for the TYPE 360 Test Oscillator

MISCELLANY

By THE EDITOR

ENCLOSED with this issue of the *Experimenter* is a postal card upon which you are asked to report to us whether or not your name and address appear correctly on our stencils. The card will also give you an opportunity to indicate whether you wish to continue on the mailing list.

Please print or typewrite your entries on the card and return it promptly in order to insure your receiving the October issue. Our new mailing list will be made up from the returned cards.

* * * *

This year's superheterodyne receivers have intermediate-frequency amplifiers tuned to 175 kilocycles; last year's models operated at 180 kilocycles. The General Radio TYPE 320 Test Oscillator (no longer manufactured) may be modified to supply the new test frequency. There is a charge of $8.50 net for this service, which may be performed only at our factory.

Instruments returned for modification should be carefully packed, shipped express *prepaid*, and bear the name and address of the sender. They should be accompanied by a letter stating exactly what changes are to be made.

This repair work will not convert a TYPE 320 Oscillator into a TYPE 360 Test Oscillator; the latter is an entirely different instrument.

The General Radio Company takes pleasure in announcing that on September 3 Arthur G. Bousquet joined its Engineering Department. Since his graduation from the course in electrical engineering at Tufts College with the Class of 1928, he has been with the Bell Telephone Laboratories, Inc., in the Apparatus Development Department.

CONTRIBUTORS

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

JAMES K. CLAPP, S.B., Massachusetts Institute of Technology, 1923; S.M., 1926. ‹‹ Marconi Wireless Telegraph Company, 1914–16. ‹‹ United States Navy, 1917–19, foreign service 1918–19. ‹‹ Radio Corporation of America 1920, also 1922–23. ‹‹ Instructor in electrical communications, Massachusetts Institute of Technology, 1923–28. ‹‹ Engineering Department, General Radio Company, specializing in the development of apparatus for the precision measurement of frequency 1928 to date.

Readers of the *Experimenter* will recognize CHARLES T. BURKE as a previous contributor to the magazine.

The General Radio *Experimenter* is published each month to furnish descriptions of the latest developments in General Radio apparatus and to distribute useful engineering information. It is sent without charge to interested persons. Address requests to the

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A Low-Frequency Oscillator

By L. B. Arguimbau

RECENTLY the increased attention paid to the operation of broadcast circuits at the lowest audible frequencies has created a demand for measuring equipment to cover this range. With this in view the General Radio Company has extended the frequency range of its Type 377 Low-Frequency Oscillator to include all frequencies lying between 25 cycles and 70,000 cycles.

At the same time that this change was contemplated it was thought desirable to design the new oscillator for use with one particular type of tube to operate under fixed battery conditions. In the Type 377 Low-Frequency Oscillator the choice of tubes and their operating points was left to the user for the added flexibility thereby obtained. In many cases, however, the general recommendations given were not followed; high-power tubes were used with incorrect operating conditions, and the oscillator was seriously overloaded with resultant distortion. It was believed that this situation could best be avoided by settling on definite operating conditions, providing an instrument with the power level best adapted to the average user, and employing additional amplification if needed in special cases.

Before going into a discussion of the characteristics of the new Type 377-B Low-Frequency Oscillator, it may be of interest to outline briefly the theory of its operation so that the necessity for certain adjustments may be better appreciated.

Consider the amplifier circuit shown in Figure 1. In accordance with the usual tube theory, a small sinusoidal voltage e_g applied to the grid will be amplified in the customary way, giving rise to a slightly distorted plate-current wave. Most of the higher harmonics are filtered out in the tuned circuit so that the voltage e_s across the transformer secondary will be essentially sinusoidal. If the resistance R is properly chosen, this secondary voltage can be made exactly equal to the applied grid voltage. When this has been done, we may connect the circuit as shown in Figure 2, and oscillations will be sustained. The departure of the grid voltage from a sine wave depends upon the magnitude of the swing and operating point and also upon the selectivity of the tuned circuit. Just as in the usual amplifier theory, the least distortion will be present when the grid-voltage-plate-current characteristic of the tube is essentially straight.

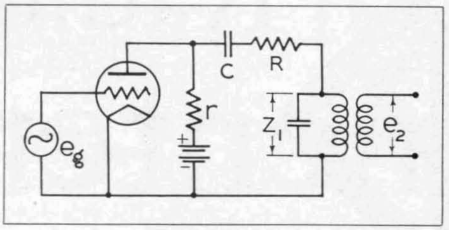

FIGURE 1. Vacuum-tube amplifier with input voltage e_g and output voltage e_2

It has been found that the grid current in an oscillator tube provides a remarkably simple and accurate means for estimating the amplitude of oscillation. For a given grid current, we can say that the grid swing has a definite value, regardless of the characteristic of the coil and the frequency chosen. Hence, if *R* is adjusted to give a predetermined grid current, the grid will be operating at a given swing, a consideration of prime importance when the signal is to supply an amplifier tube.

For those who may be interested, a brief sketch of the details is given in Appendix A. The important point to be noticed is the close analogy between an oscillator of this type and a tuned amplifier. Further application of this analogy can be made to account exactly for the waveform obtained and for the variation of frequency with operating point, but this is too involved to be of interest.

The circuit finally adopted for the TYPE 377-B Low-Frequency Oscillator is shown schematically in Figure 5 where it will be noticed that this follows the outline given above. An adjustable 100,000-ohm rheostat *R* is used as a feed-back resistance and it should be adjusted to give a grid current of 30 micro-amperes (as indicated on a 0–200 micro-ampere meter mounted on the panel). The 50,000-ohm plate-supply resistance *r* provides a good coupling device and at the same time limits the oscillator plate current to about 2 milliamperes. In Figure 3 a tuned-plate oscillator is shown. In practice it was found desirable to use a Hartley circuit for the lower end of the range, using the tuned-plate circuit at higher frequencies.

It will be noticed that the output power is taken off across a slide-wire potentiometer in the plate circuit of the last tube. This was done for two reasons: to prevent interaction with the oscillator tube and to prevent the waveform from varying excessively with the output setting. It should be noticed that this arrangement makes the effective output impedance of the oscillator depend upon the potentiometer setting. In a few isolated cases (such as measurements on harmonic production in non-linear circuits) this is undesirable, but for all ordinary purposes it causes no difficulty. Measurements on harmonic production and allied phenomena require special precautions, and no ordinary coupling device should be used without a careful consideration of its effect on the circuit being studied. In all measurements on linear circuits where the effect of harmonic flow is of no interest, the impedance of the generator tube need not be considered; by proper connections, any source impedance from zero to an arbitrarily large value can be simulated. This matter is treated at length in the November issue of the *Experimenter*.

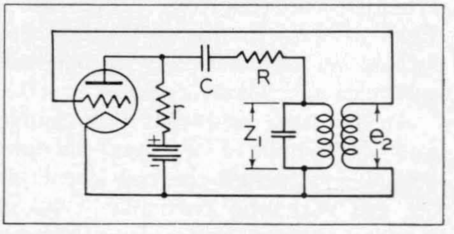

FIGURE 2. The amplifier of Figure 1 becomes an oscillator when its input voltage is supplied by the output circuit

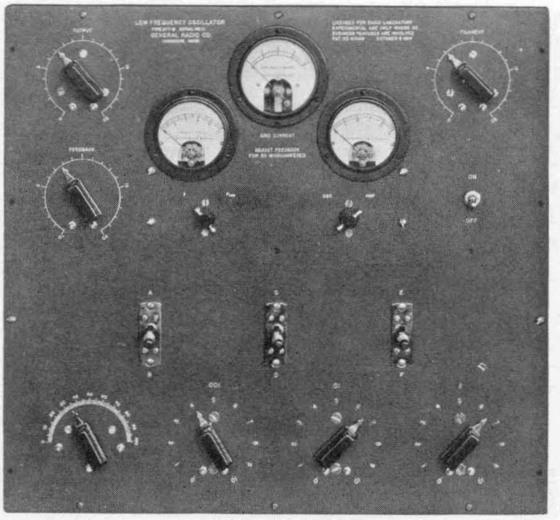

Figure 3. Front of panel view of Type 377-B Low-Frequency Oscillator. It is mounted in a heavy hinged-back cabinet

Recognizing that the needs of different users will vary somewhat, provision has been made for using either one or two amplifier tubes. If only a small amount of power is needed and it is desired to reduce battery drain to a minimum, only one tube need be used; the total plate current will then be about 10 milliamperes. Without any change in the circuit, a second tube may be added in parallel; in this case, the plate current will then be about 16 milliamperes. Typical output characteristics for these two cases are shown in Figure 6.

A series of measurements has been made with a harmonic analyzer to determine the dependence of waveform on operating conditions. These measurements show that the voltage wave given by the oscillator tube itself contains no harmonic having an amplitude larger than 0.5 per cent. of the fundamental. On the other hand, the amplifier has been designed to deliver the maximum amount of power con-

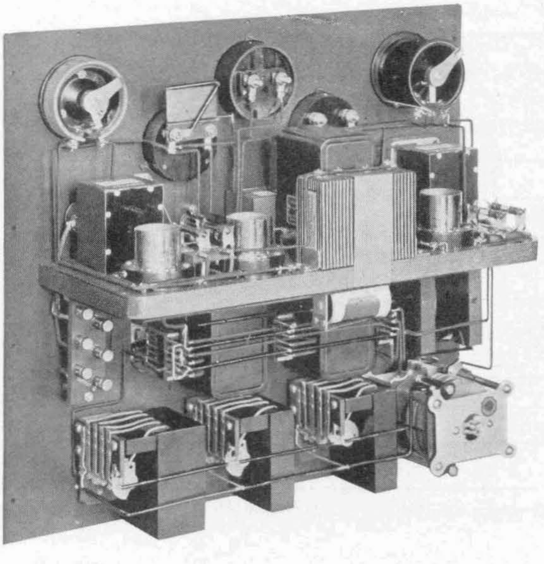

Figure 4. This photograph shows the internal construction of the Type 377-B Low-Frequency Oscillator

sistent with the usual requirements on waveform. Harmonics introduced by the amplifier may amount to 3 per cent. of the fundamental. If much better waveform is required, it is necessary to reduce the signal level at which the last stage is operating. This may be accomplished by substituting a 1.0 megohm resistance for the 0.5 megohm unit in the place marked A in Figure 5. This change reduces the harmonics to 1.0 per cent. of the fundamental, if the load resistance is not less than 8000 ohms.

The adjustment of the feed-back resistance for constant grid current helps to minimize the changes in frequency due to operating condition. Measurements on one particular oscillator showed that for frequencies in the neighborhood of 40 cycles, changes in plate battery amounting to 25 per cent. made a change in frequency of less than 0.1 per cent. when the feed-back was readjusted to give 30 micro-amperes. If no adjustment was made, the departure was less than 0.3 per cent. If the grid current was allowed to depart by 10 micro-amperes from the rated value, the frequency drift was not more than 0.3 per cent. Changing the oscillator tube gave rise to similar differences. At 25 cycles the changes were about twice as large as those mentioned (i.e., a maximum of about one-tenth of a cycle).

These figures refer to frequency changes covered by tubes and operating points. Ageing effects may be larger but they should never exceed 3 per cent.

APPENDIX A

Consider the amplifier circuit shown in Figure 1. Assume a sinusoidal voltage e_g impressed on the grid. When this swing is very small, we may treat the circuit in accordance with the usual tube theory, considering the tube as a sinusoidal generator μe_g in series with a resistance r_p, the internal plate impedance of the tube. Neglecting the effect of the shunt resistance r and the condenser C* we may write for

* By the use of Thévenin's Theorem we may eliminate the effect of the parallel resistance r and the condenser C by making the substitutions,

$$\mu' = \left(\frac{1}{1+\frac{r_p}{r}}\right)\mu \text{ and } r_p' = \left(\frac{1}{1+\frac{r_p}{r}}\right)r_p - j\frac{1}{\omega C},$$

using these new quantities in place of μ and r_p. It will be noticed that this has little effect when

$$r_p << r \text{ and } \frac{1}{\omega C} << r.$$

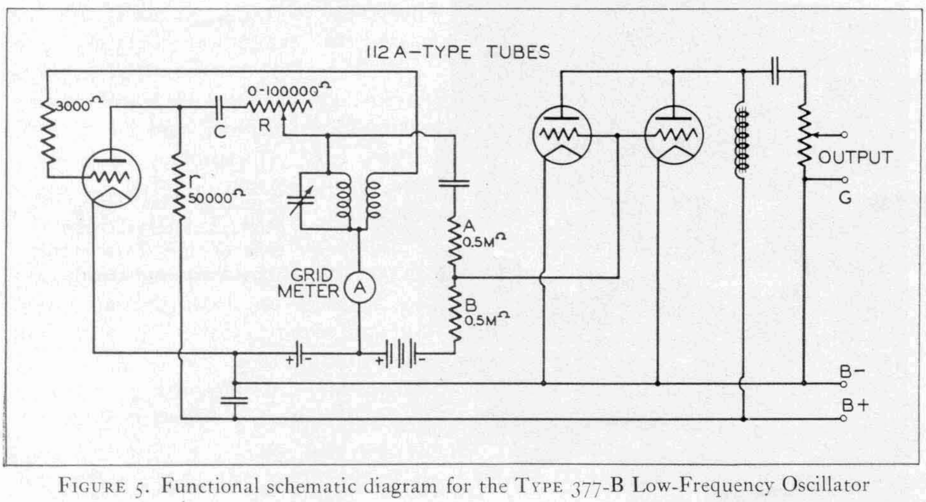

FIGURE 5. Functional schematic diagram for the TYPE 377-B Low-Frequency Oscillator

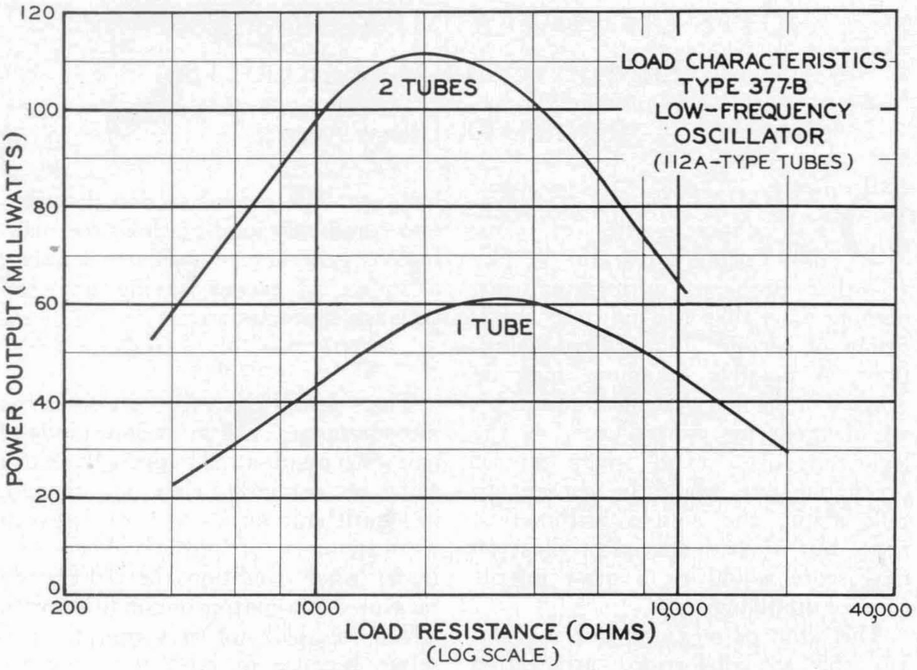

FIGURE 6. Power output of the oscillator as a function of load resistance

the magnitude of the voltage across the secondary,

$$e_2 = \frac{n_2}{n_1} \cdot \frac{Z_1}{r_p + R + Z_1} \cdot \mu e_g. \qquad (1)$$

Z_1 is the impedance of the parallel circuit, and $\frac{n_2}{n_1}$ is the turns ratio of the transformer. Even though some distortion is produced by variations in plate resistance introducing harmonics in the plate current, the voltage across the tuned circuit Z_1 will be very nearly sinusoidal. (Actually, the harmonics at this point can be kept below 0.5 per cent.) It is to be noted that for a given tuned circuit and tubes (i.e., given Z_1 and r_p), the secondary voltage can be regarded as a function of the coupling resistance R. In particular, if Z_1 is sufficiently high we can choose R in such a manner that the secondary voltage e_2 is equal to the applied grid voltage e_g. When this has been done we may rewrite (1):

$$r_p + R = \left(\mu \frac{n_2}{n_1} - 1\right) Z_1.$$

Actually, of course, this is not the whole story. In practice the amplitude will adjust itself until the dynamic plate impedance satisfies the above equation. By properly choosing R, however, we can select any such equilibrium position, thereby fixing the amplitude. The flow of harmonics out-of-phase with the fundamental will introduce a reactive component in the plate impedance and cause the frequency to assume such a value as to give an equal and opposite phase shift in the tuned circuit. This phase shift will be obtained in the case of a sharply resonant circuit by a much smaller percentage change in frequency than is the case in a broadly tuned circuit.

The commercial data for the TYPE 337-B Low-Frequency Oscillator are the same as for the old design. Price, also, remains unchanged.

Notes on Power Measurement in Communication Circuits

By John D. Crawford

DETERMINING the transmission characteristics of communications apparatus is, like all other problems in measurement, nothing more than the judicious application of certain standardized definitions. A possible difference may be claimed in the fact that these quantities are defined, for convenience, as the logarithm of a ratio where almost every one else would be content to talk about the simple arithmetical ratio. But to claim special privilege on that score would be a most puerile form of quibbling.

This kind of measurement is, after all, the straightforward application of engineering principles. It has a technique and a system of definition that are peculiar to itself, but so has every specialized business. Yet, when for the first time one is confronted with the practical aspects of finding out how the amount of power obtainable from a system is affected by changes in the circuit conditions, there is, seemingly, an instinctive tendency toward confusion.

The principal difficulties appear because standardized definitions have not been readily available. One has had to rely on piecemeal information, and it is little wonder that there should be confusion when one finds himself unable to uncover satisfactory definitions and criticize methods.

We have, therefore, prepared these notes for the purpose of discussing some of the difficulties. The first section shows that an error may be involved in blindly assuming that voltage or current ratios may be substituted for power ratios when measuring attenuation, gain, transmission loss, etc. The second section describes two commonly-used methods for making *any* generator or oscillator simulate a source of power having any impedance characteristic.

I

The definitions for transmission measurements such as various kinds of gain, attenuation, and losses have one thing in common: they all express, in logarithmic form, the ratio between two amounts of power. When and under what condition the powers are measured is a matter of definition with which we shall not now concern ourselves because we wish to emphasize the generality of the following remarks.

First, consider the equation defining the decibel in terms of the power ratio, understanding, meanwhile, that our emphasis upon *power ratio* is necessary because the measured quantities deal with power, not because one unit has been arbitrarily defined that way. We say that any two amounts of power — W_1 and W_2 in Figure 1, for example — differ by N decibels where

$$N = 10 \log_{10} \frac{W_1}{W_2}. \qquad (1)$$

Now the equations linking the voltage, current, and power in a power-absorbing circuit are:

$$W = \frac{E^2 k}{Z} \text{ and } W = I^2 Z k = I^2 R, \qquad (2)$$

where W = absorbed power
E = voltage drop
Z = impedance
k = power factor
I = current
R = effective resistance.

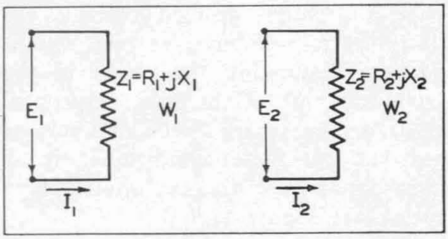

FIGURE 1

Applying (2) to (1) we find (*a*) that using currents,

$$N = 10 \log_{10} \frac{I_1^2 R_1}{I_2^2 R_2}$$

$$= 20 \log_{10} \frac{I_1}{I_2} + 10 \log_{10} \frac{R_1}{R_2}, \quad (3a)$$

and that (*b*) using voltages,

$$N = 10 \log_{10} \frac{E_1^2 Z_2 k_1}{E_2^2 Z_1 k_2} = 20 \log_{10} \frac{E_1}{E_2}$$

$$+ 10 \log_{10} \frac{Z_2}{Z_1} + 10 \log_{10} \frac{k_1}{k_2}. \quad (3b)$$

This may be summarized in the following simple statement: When measuring ratios between currents and between voltages for expressing these transmission characteristics, both the nature and the magnitude of the impedances must be taken into account.

In other words, if you measure the currents, you must know the effective resistances; if you measure the voltages, you must know both the effective resistances and the reactances of the circuits with which you are working. If the current or voltage ratios are measured without taking into account the impedance conditions, current ratio measurements will produce an error of $10 \log_{10} \frac{R_1}{R_2}$ decibels, and voltage ratio measurements will yield an error of $10 \log_{10} \frac{Z_2}{Z_1} + 10 \log_{10} \frac{k_1}{k_2}$ decibels. In this connection it is worth noting that the impedance relations to be satisfied are not necessarily the same as those implied by the phrases "equal impedances" or "matched impedances" when specifying the conditions for maximum energy transfer or for the elimination of reflection losses.

In order to anticipate protests from readers who can, in effect, quote Scripture to prove that the quantities we have been discussing are based upon voltage or current ratios, allow us to make the following remarks:

In recognized text books the use of voltage and current ratios is an alternative to the use of the power ratio, and the impedance conditions are implied even if they are not stated in so many words. Most of the classical theory of transmission lines and networks is built up and taught on the long-line basis: that is to say that a transmission line, infinite in length and with uniformly distributed constants, is broken up into sections and the behavior of each section studied. The impedance at any junction between recurrent sections looking down the line toward the receiving end is the same as the impedance looking into the same section at the preceding junction. Since the impedances are the same, the current ratios and the voltage ratios are equivalent to the power ratio. Because this ratio of input to output power happens to be the power ratio of greatest interest, it is natural that the voltage and current ratios should be substituted. Here, the impedance conditions are *implied.*

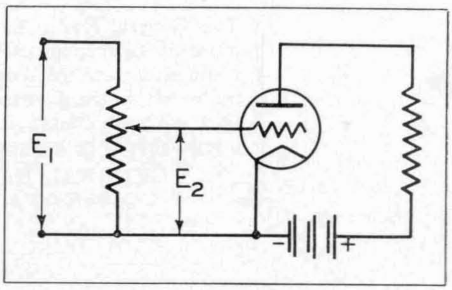

FIGURE 2

Another instance where the impedance conditions are implied is that where one of the loads is the high-impedance input circuit of a vacuum tube. Since the vacuum tube is, to a first approximation at least, a voltage-operated device, the power it absorbs bears no particular relation to the power it delivers. If, however, the power in the output circuit of the tube is measured and compared with the power delivered to the same circuit with a different applied voltage, the power ratio will have its true significance. Presumably the power in the output circuit of the tube is proportional to the square of the grid voltage and under these conditions, it is perfectly proper to use the voltage ratios (see Figure 2).

The second part of "Notes on Power Measurement in Communication Circuits" will appear in the November issue of the Experimenter.

MISCELLANY

By THE EDITOR

THE General Radio Company takes pleasure in welcoming Robert F. Field, who joined its staff on October 1. Mr. Field received his A.B. from Brown University in 1906 and his A.M. the following year. He taught physics and electrical engineering there until 1915, leaving to take work at Harvard University, where he was awarded an A.M. in 1916. From 1918 until the present, he has been teaching at the Cruft Laboratory which offers courses common to both the Engineering School and the Department of Physics at Harvard University. As Assistant Professor of Applied Physics, he taught courses in communication engineering, specializing in electrical measurements.

With the General Radio Company, Mr. Field will undertake development work on bridges and fundamental standards of resistance, inductance and capacitance, particularly at high frequencies. He will also study the applications of electrical measurements to bio-physical problems.

CONTRIBUTORS

Both contributors to this issue of the General Radio *Experimenter* are members of the General Radio Company's Engineering Department.

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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The General Radio Experimenter

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Notes on Power Measurement in Communication Circuits*

By John D. Crawford

II

ANOTHER communication measurement problem makes its appearance when it is desired to determine experimentally how much power a given power source is capable of delivering to a specified load or sink. So long as the source itself is available for test, it is merely necessary to set up the equipment and make the measurements. If, however, the source is not available, some means must be found of simulating it. At least two methods for doing the job are available, and we propose to describe them. Both are perfectly general: the "source" may be a vacuum-tube oscillator or a microphone or an incoming transmission line; the "load" may be a loud-speaker or an attenuation network or an outgoing transmission line. There are only two restrictions: the "source" must supply a sinusoidal voltage, and the impedance of the "load" must not depend upon the current in it.

A generalized statement about networks called Thévenin's Theorem gives directly one of the methods for setting up a simulating source. We shall defer stating it until later because it will simplify matters to set up a specific hypothetical problem, follow through its solution, and with that as a basis, state the general law. Our discussion must be understood to be an attempt

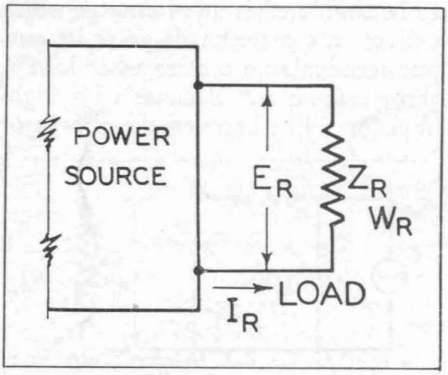

Figure 3

to show that Thévenin's Theorem is plausible without trying to prove it.

Consider, for example, the load circuit shown in Figure 3. Its impedance at a given frequency is Z_R; the voltage drop, current, and absorbed power which correspond to Z_R are, respectively, E_R, I_R, and W_R. Inasmuch as Z_R is assumed to be independent of

* This is the second part of an article begun in the October issue of the *Experimenter*. Although complete in itself, this section depends upon the introduction preceding Part I.

I_R, we can make the obvious statement that for any value of Z_R, W_R will depend only upon the magnitude of E_R (or of I_R, since E and I are linked by Ohm's Law).

Now suppose that we want to determine experimentally how much power the load will absorb at different frequencies from a given power source which is not available for the tests. What must we do in order to set up a simulating source? We have just seen that the only way a source can affect W_R is to change E_R. Therefore, all we need do to simulate the given source is to make sure that, no matter what value Z_R may assume (as a result of changing the test frequency, for example), E_R for the simulating source is the same as E_R for the source itself. In other words, no power measurements on the load could tell us which of two sources was supplying power if the terminal voltages (E_R) of each were the same.

Let us also assume that the source to be simulated is an alternator which delivers a constant voltage at its output terminals no matter what load is thrown upon it.* Because of a high-impedance line between the alternator

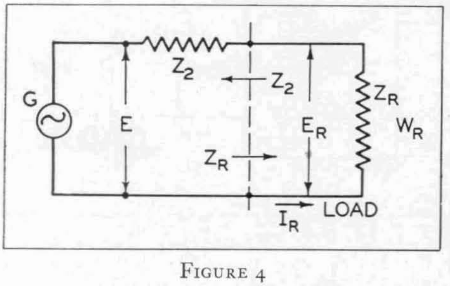

FIGURE 4

and its load terminals, the voltage at the load terminals depends upon the size of the load. This condition is represented in Figure 4, where E is the voltage of the alternator, G, and Z_2 is the

*An oscillator which could do exactly that would be a curiosity, having, as we shall point out later, a negligible "internal impedance."

impedance of the line. E_R is therefore always less than E by E_2, the voltage drop in Z_2. In other words, W_R depends upon Z_2.

From what has gone before, Z_2 may be considered a part of a new load, Z'_R, having an impedance of Z_2+Z_R. The power delivered to this new load will, as before, be fixed if the voltage drop across it is fixed. The generator, G, delivers constant voltage under all conditions of load, a fact which enables us to build a simulating source. Since the load cannot distinguish between one generator and another if the impressed voltages are the same, we can take any generator, maintain its terminal voltage equal to E by manual adjustment, and the power delivered to Z'_R will be the same for both the actual and the simulating sources. Furthermore, the voltage drop in Z_2 will be the same under both conditions, and the power delivered to Z_R will be the same as though it were connected, to the original source. Therefore, we have shown that any generator connected in series with an impedance equal to Z_2 will simulate this particular source, if the voltage at the generator terminals is maintained constant and equal to E.

From the foregoing discussion we may conclude that the presence of Z_2, the internal impedance for the given power source, is the reason why changes in the magnitude of Z_R affect the terminal voltage E_R. If Z_2 is equal to zero, E_R would be constant and equal to E, the open-circuit voltage of the source; but if Z_2 is not zero, then every decrease in the magnitude of Z_R causes E_R to be less than E by the voltage drop in $Z_2 = I_R Z_2$. Furthermore, any generator or any source behaves as though it had no internal impedance if its terminal voltage is maintained constant.

Suppose that G were not a constant-voltage generator, or, in other words,

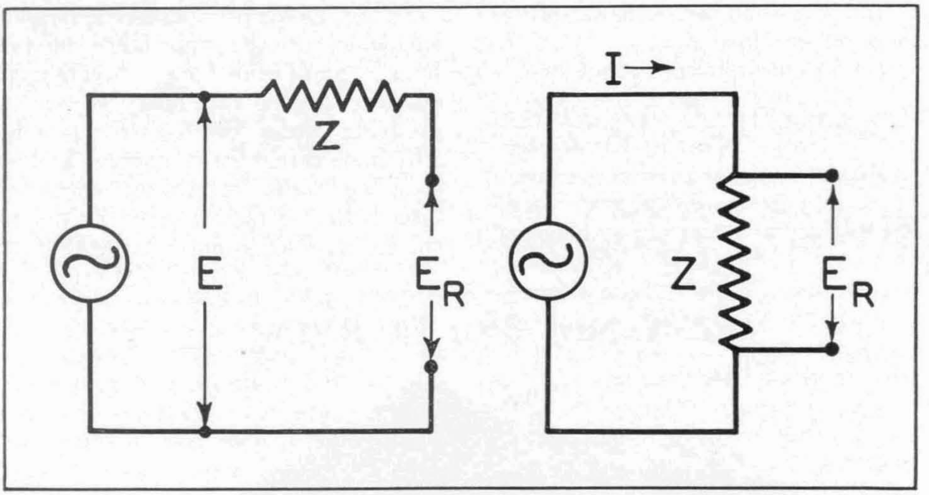

FIGURE 5. Two methods for simulating a power source when its open-circuit voltage $E = IZ$ and its internal impedance Z are known. LEFT: Constant-voltage method. RIGHT: Constant-current method

suppose that its terminal voltage E depended upon the amount of current taken by the load. This would, of course, indicate that somewhere ahead of its output terminals there existed an appreciable impedance. To simulate this new source we would proceed exactly as before: maintain the simulating-generator voltage constant and equal to the open-circuit voltage of the source and connect in series with it an impedance equal to $Z_G + Z_2$, the sum of the internal impedance of G and the impedance of the intervening connecting wires.

It is now time to discard all of our labored attempts at a simple and orderly development to state the general law about which we spoke at the beginning of this section. It is a corollary of Thévenin's Theorem, a theorem that is capable of a formal proof with which we shall not concern ourselves here. Thévenin's Theorem permits us to state that *any* power source can be simulated (Figure 5) by a generator with a terminal voltage E connected in series with an impedance Z; E being equal to the no-load or open-circuit voltage of the source and Z being equal to the impedance of the source *as seen from its output terminals*. This can be verified experimentally for a simple source like the one we have been discussing by connecting an oscillator to a load of adjustable but known impedance and observing its terminal voltage as a function of delivered power or of load impedance or of current. Errors due to bad waveform and overloading in the oscillator must not be allowed to enter.

The diagram at the right in Figure 5 shows the second simulating method and although it does not follow directly from Thévenin's Theorem, it can be shown to be entirely consistent with it. In the second method, constant current is maintained through the parallel circuit formed by Z, the impedance of the simulating source, and the load impedance; the constant current being such as to make the no-load voltage drop across the simulating impedance equivalent to the no-load voltage of the power source. If we can show that for any value of Z_R the voltage E_R is the same for both the constant-current and the constant-voltage methods, the two are equivalent.

Imagine that both circuits are terminated in a load Z_R:

(a) for constant-voltage method,

$$E_R = I_R Z_R = \left(\frac{E}{Z+Z_R}\right) Z_R = \frac{EZ_R}{Z+Z_R};$$

(b) for constant-current method,

$$E_R = I\left(\frac{Z_R Z}{Z+Z_R}\right) = \frac{E}{Z}\left(\frac{Z_R Z}{Z+Z_R}\right) = \frac{EZ_R}{Z+Z_R}.$$

If the voltage of the source is non-sinusoidal or the impedance of the load is non-linear (i.e., a function of current), special care must be used in applying these simulating methods. The same care must be exercised when studying transient effects, since our discussion has been tacitly limited to the steady-state condition.

A NON-POLAR RELAY

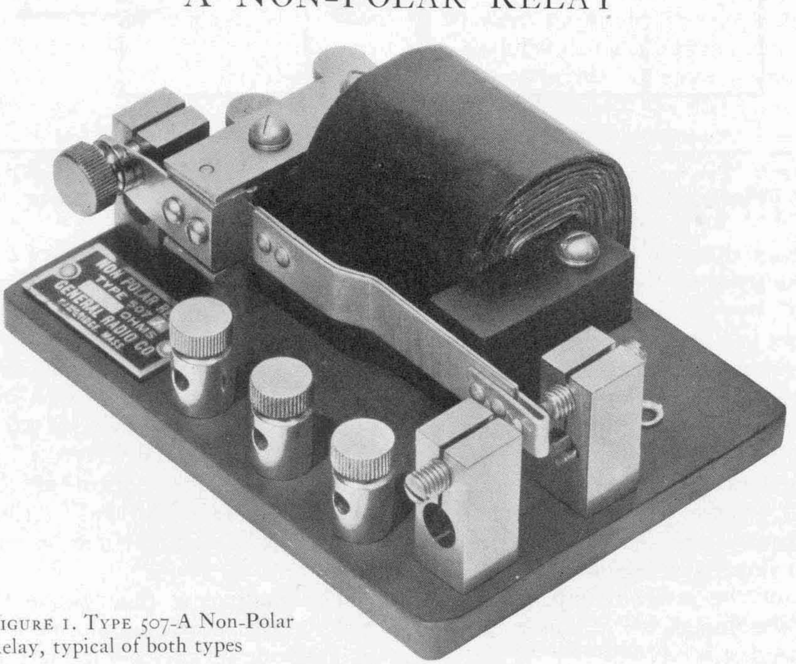

FIGURE 1. TYPE 507-A Non-Polar Relay, typical of both types

AS their names indicate, the new TYPE 507 Non-Polar Relays contain an armature that is not permanently magnetized. They do not, therefore, distinguish between the two directions of current as does the TYPE 481 Low-Current Relay.* Their principal use is in cases where contacts of low current-carrying capacity must control heavier currents, as in the TYPE 547-A Temperature-Control Box.

There are two of the new Non-Polar Relays, bearing the type numbers 507-A and 507-B, respectively. Their specifications are as follows, currents given corresponding to positive operation in either vertical or horizontal positions:

TYPE 507-A Non-Polar Relay. Current to close, 10 mla. Current to open, 6 mla. Resistance (±5%), 250 ohms. Code Word, NITRE. Price $12.00.

TYPE 507-B Non-Polar Relay. Current to close, 2 mla. Current to open, 1 mla. Resistance (±5%), 4000 ohms. Code Word, NOBLE. Price $15.00.

*C. T. Burke, "A New Relay," *General Radio Experimenter*, III, February, 1929.

Temperature Control for Piezo-Electric Oscillators

QUARTZ plates for use as standards of frequency in piezo-electric oscillators must be kept under temperature control if constancy of frequency is to be expected. It is impossible to make a general statement about the frequency of such an oscillator as a function of the temperature of the plate, because the frequency-temperature coefficient varies considerably with the way the plate is cut. Even among plates of the same "cut" taken from the same mother crystal, the coefficients are not alike. It is, however, safe to say that the frequency variations per Centigrade degree will average about 30 parts in a million with a possibility of its being as great as 75 or 100 parts in a million. The necessity for temperature control where precision frequency standards are to be maintained is obvious.

On the question of temperature-control methods there are different points of view taken by two groups. One says: standardize on a definite operating temperature, maintain it as closely as possible, and specify the operating frequency of the quartz plate at that temperature. The other group says: standardize on a nominal operating temperature *near* which the temperature is to be maintained, and rely upon making adjustments in the frequency of the plate by changes in its temperature. Control equipment to meet the specifications of both groups should reduce variations in temperature to the same minimum, but the second group requires, in addition, a thermo-regulator that can be readily adjusted to any value in the neighborhood of the standard temperature.

The General Radio Company holds that with plates for frequency standards,* the temperature should be kept constant and all adjustments of frequency made by the use of an adjustable air-gap in the plate holder or by changes in the circuit constants of the oscillator itself. This attitude has much to recommend it from the point of view of both the manufacturer and the user of high-precision quartz plates, for it simplifies the problem of constructing suitable temperature-control boxes and makes for interchangeability of one plate with another. It has an important bearing upon the cost of adjusting quartz plates, since the extra time and labor involved in calibrating one plate at 51.7 degrees and the next at 48.3 degrees (for example) is considerable. The General Radio Company has established 50.0 degrees Centigrade as its operating temperature for standard quartz plates, a value which is in accord with those established by other American laboratories, civil and military. This temperature is high enough to make possible the operation of temperature-control equipment in the tropics without heat absorbers (refrigeration).

When it became apparent two years ago that quartz plates of high precision would be in demand, the General Radio Company investigated the temperature-control equipment that was already on the market with a view to adapting it to meet the following requirements: (*a*) ability to maintain the temperature to within one- or two-tenths of a Centigrade degree over a fairly wide variation in room temperature; (*b*) absence of circulating air and

* As distinguished from their use as controls in oscillators where a maximum power output is one of the first considerations. All General Radio quartz plates are intended for use only in low-powered oscillators.

oil baths; (*c*) compactness; and (*d*) ease with which modifications for electrical connections could be made.

It may be of interest to note that the range of permissible variations in room temperature is a most important feature of any temperature-control unit. Yet, strangely enough, it is one of the specifications that is often overlooked. A box which would control the temperature to within one degree when the room-temperature variations were limited to two degrees might show an entirely different characteristic if the room temperature were allowed to change with the weather.

No commercial unit that met all of the requirements being available, a development program was begun which has extended over an entire year, ending with the design of the TYPE 547-A and the TYPE 547-B Temperature-Control Boxes shown in Figures 1 and 2. They are of the same construction, differing only in the type of thermoregulators employed.

Both boxes are encased in walnut cabinets within which are arranged (in order): a balsa wood insulating layer, the heaters, an aluminum distributing layer, an asbestos pressboard attenuation layer, and a second casing of aluminum which forms the temperature-controlled chamber. The inner space is 4 inches by 4 inches by 3⅝ inches deep, and in it are two sets of terminal blocks into which two TYPE 376 Quartz Plates may be plugged. A switch on the front of the bakelite panel allows a selection to be made. The heaters are placed on all six faces of the outer aluminum casing, the aluminum tending to equalize the temperature over the surfaces and reduce the temperature gradient inside the controlled chamber. Heater current is supplied from any 110-volt main, either alternating- or direct-current.

Of special interest to those desiring temperature-control for use with General Radio piezo-electric oscillators is the fact that the TYPE 547 Temperature-Control Boxes are intended to be mounted on top of them. The cabinet size is the same as that of the TYPE 275 Piezo-Electric Oscillator and a special

FIGURE 1. TYPE 547-A Temperature-Control Box

connecting bar is available for linking the two units. A slight modification in the TYPE 375 Station Piezo-Electric Oscillator adapts it for use with the new units in the same manner.

On the front of the bakelite panel are mounted rheostats for controlling the amount of power delivered to the heaters. Depending upon their adjustment, the power delivered to the unit will range between 41 and 71 watts.

The TYPE 547-A Temperature-Control Box utilizes a mercury-type of thermo-regulator which may be adjusted to operate at any temperature between 40 degrees and 60 degrees Centigrade. Once the regulator has been adjusted, the temperature of the air inside the chamber is held to within ±0.1 degree Centigrade for a variation in room temperature of ±20 degrees Centigrade (±11 degrees Fahrenheit). This temperature variation in a quartz plate will keep the frequency of a piezo-electric oscillator within limits satisfactory for practically all purposes. The thermo-regulator operates the heater circuit through the relay shown on the front of the panel, a six-volt battery being required.

Once the thermo-regulator in the TYPE 547-A Temperature-Control Box has been adjusted to the desired value, the operating temperature cannot be changed without removing it from the inside of the box. Sometimes, as we have previously mentioned, it is desired to adjust the operating temperature while the unit is in operation. At a sacrifice in the degree of constancy with which the temperature is maintained, the TYPE 547-B Temperature-Control Box has been made available.

It makes use of a bi-metallic thermoregulator that depends for its operation upon the unequal temperature-coefficients of two strips of metal. It is rugged enough so that it controls the heater current directly without the necessity for a relay, which, of course, eliminates the need for the six-volt supply.

The temperature may be adjusted to any value between 40 degrees and 60 degrees Centigrade, and the air within the chamber will remain within ±1.0 degree Centigrade for a room temperature variation of ±20 degrees Centigrade (±11 degrees Fahrenheit). This unit is recommended for use only where the ability to change the temperature while the unit is in operation is of importance.

Both units are primarily intended for operation near 50 degrees Centigrade where the room temperature

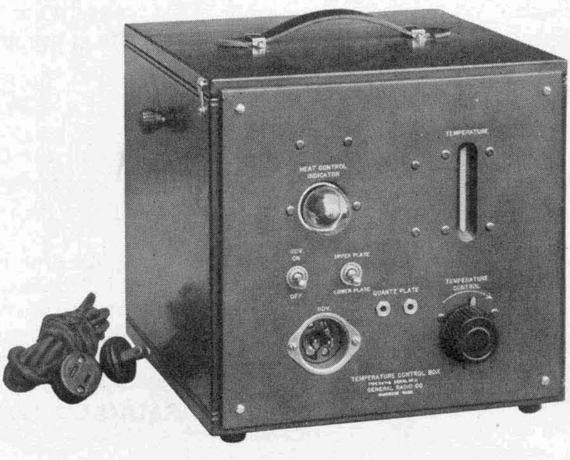

FIGURE 2. TYPE 547-B Temperature-Control Box

variations occur around a mean of 20 degrees Centigrade. Inspection of the above specifications might lead one to expect that good control of temperature might be obtained for an operating temperature of 40 degrees and a room temperature of 40 degrees. That control could be had under this condition is improbable, and in localities where the temperature of the room might rise to 40 degrees Centigrade, the operating temperature should be kept higher, 50 degrees, if possible.

The commercial data on these instruments are as follows:

TYPE 547-A Temperature-Control Box. Code Word, BURLY. Price $150.00.

TYPE 547-B Temperature-Control Box. Code Word, BUXOM. Price $140.00.

They will be ready for delivery on November 15.

MISCELLANY

By THE EDITOR

WITH the September issue of the *Experimenter* we enclosed a card which readers were asked to return if they wished to continue on the mailing list. Although the percentage of returned cards has been large, we feel that there are still some interested readers who have neglected to return them. If it is your intention to return the card, please do so at once.

None of the changes requested on returned cards have been made, and no names have as yet been dropped from the list because no card was returned. It may be of interest here to state that on the average of one card in every four calls for a change in the address stencil.

Should you have mislaid your return card, a letter or a postal card with the following information will replace it:

(a) Your name and mailing address (printed for the sake of legibility)

(b) Your business affiliation

(c) The kind of business in which your firm is engaged

(d) Your position

(e) The technical field in which you are particularly interested.

If you can return the address label from the *Experimenter* mailing envelope, so much the better, inasmuch as our files are arranged alphabetically.

These cards were sent out for the purpose of correcting our mailing list and of removing from it those persons who are no longer interested in reading the General Radio *Experimenter*. The additional information about each reader is being used to analyze the circulation so that the editor may know the different classes of readers for whom he is preparing material.

CONTRIBUTORS

All the material for this issue of the *Experimenter* has been contributed by The Editor.

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The General Radio Experimenter

VOL. IV, NO. 7 — DECEMBER, 1929

TELEVISION: A COMPARISON WITH OTHER KINDS OF ELECTRICAL COMMUNICATION

By J. W. HORTON

TODAY, through the universal use of systems of electrical transmission, information may be conveyed in a negligible time between individuals separated by a distance restricted only by the dimensions of the earth. It is difficult for us to realize that until the time of Morse and his electric telegraph the instantaneous transfer of intelligence was confined within the limits of human vision. The potentialities arising from our ability to control an electric current at one place, to transmit it to some distant place, and to recognize there the effects of the initial control cannot be evaluated.

The fundamental principle underlying the telegraph, the telephone, picture transmission systems, and television is this: Complex electric waves, controlled at the sending station by the sound or image being sent, are used at the receiving station to actuate devices which reproduce the sound or the image. In television one does not see the person at the other end of the line, nor in telephony does one hear his voice. In one, the distant person is represented by an image reproduced by an optical system; in the other, his voice is represented by sounds reproduced by an acoustical system. The only thing ever transmitted is an electric wave.

The first step in the development of the art of electrical communication was taken thousands of years ago when man first devised symbols to represent ideas. These symbols were not adapted to electrical transmission. It was necessary, therefore, for Morse, in order to utilize his electric telegraph equipment, to modify the system of symbols (our alphabet) so that they were readily identified with the characteristics of an electric wave.

This brings us at once to an important fact: The distinguishing characteristic of an information-conveying electrical wave is the variation in its intensity with time. To be more specific, the intensity is a single-valued function of time; that is to say, it varies from instant to instant, and for any given instant there is one and only one corresponding value of intensity. In order to conform to this requirement of the electrical signal wave, the Morse code is likewise a single-valued function of time.

The information contained in the sounds we hear may also be completely represented in terms of a quantity which has different values for different times. Specifically, a sound may be described in terms of the variation in air pressure with time. To obtain the telephone, therefore, it was only necessary to provide terminal apparatus capable of following these exceedingly complex variations with sufficient accuracy and a channel capable of transmitting the corresponding electric wave.

When we attempt to extend electrical-communication methods to include visual information, we find that we have to deal with anything but a single-valued function of time. In a still picture the information may be described as a function of area only. This fundamental fact was recognized early in the history of electrical communication, and means have been devised for translating pictures into terms of a time variable. By means of scanning and distributing devices, information regarding the tone value of each elementary area of a picture may be transmitted individually over a single channel, the several areas being successively dealt with in a predetermined order and at a definite rate.

It is further necessary to provide for recording this information in order that the time factor may be eliminated and the information restored to its original form as a function of area only. In still-picture transmission, photographic methods are employed for making a permanent record. The result is a single picture, differing but little in appearance from an ordinary photograph. In television the record is made, not on a photographically-sensitive surface, but on the retina of the eye. It is necessary, therefore, to complete the transmission of a single image in a time so short that it is retained by the retina as a complete picture. Furthermore, in order to convey information as to any motion which may take place in the original object, it is necessary that a series of images be reproduced in rapid succession. Experience has shown that the transmission of approximately twenty images per second satisfies both of these conditions.

When our eyes bring us information as a result of visual observations it is conveyed from the retina to the brain by a very considerable number of nerves, each carrying a separate message. In comparison with the speed with which an electric current may change its intensity, these nerves, in spite of their reputation to the contrary, are extremely sluggish. If we work our electrical system at the speed required for television it will convey in succession the messages representing the several picture elements, and it will distribute them to their respective nerve channels as rapidly as the nerves are capable of receiving them. In this respect television and the multiplex telegraph are amazingly alike. In both, one trunk circuit brings in information as fast as several local circuits, working simultaneously, can absorb it.

These considerations emphasize the fact that the *rate* at which information is transmitted is of very great significance in electrical communication. Inasmuch as it has been necessary, in order to effect their transmission, to reduce various forms of information to common terms, namely, those of time variation, we have at once a convenient basis for comparing them. It is desirable to do this in order to form an estimate of the relative magnitudes of the burdens imposed on the channel when it is used to transmit information in one form or another.

In the case of a single picture, it is apparent that the total amount of information is proportional to the number of individual elementary areas recognized. For example, if a picture of some given scene is printed from a halftone photo-engraving, the amount of information conveyed by the reproduction depends upon the total number of "halftone dots" used and not on the area of the picture. A fine magazine halftone may easily include more information in an area one inch square than a coarse newsprint illustration in an area two inches square.

If the elementary areas of a picture as it is scanned for transmission alternate between dark and light, the number of cyclic variations of light intensity will be half the number of picture elements. The maximum frequency in the electric signal wave will, in turn, be equal to the maximum number of cyclic variations in the picture divided by the time required for its transmission. It is thus apparent that the greater the number of elementary areas separately recognized in a given time, the higher will be the maximum frequency required to transmit the image. It may be shown that the electric wave contains also a component of zero frequency.* Hence, the *frequency range* occupied by the signal is determined by (*a*) the number of picture elements and (*b*) by the time of transmission.

This is a special case of a fundamental law of communication, which states that the rate at which information may be transmitted over a given channel is proportional to the frequency range which that channel can accommodate. This concept is treated at some length in a paper presented at the Volta Centenary in Geneva by Mr. R. V. L. Hartley of the Bell Telephone Laboratories.† It may be employed in evaluating amounts of information by relating them to the product of the frequency range and the time of transmission.

To compare the amount of visible and audible information it will be necessary to make some assumptions

* J. W. Horton, "Transmission of Pictures and Images," *Proceedings of the I. R. E.*, September, 1929, p. 1547. This is an abstract of that paper.

† R. V. L. Hartley, "Transmission of Information," *Bell System Technical Journal*, July, 1928, p. 535.

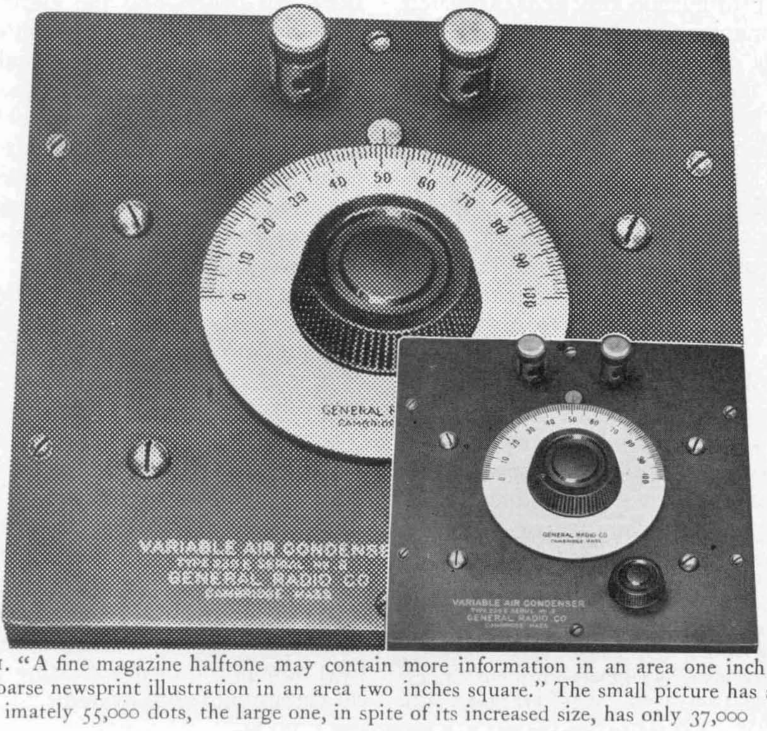

FIGURE 1. "A fine magazine halftone may contain more information in an area one inch square than a coarse newsprint illustration in an area two inches square." The small picture has approximately 55,000 dots, the large one, in spite of its increased size, has only 37,000

as to the degree of fidelity to be secured in the reproduction of each. Regardless of the detailed method by which the transmission of a single picture or image is effected, the reproduced copy will have a structure of some sort. In order for this to be negligible on normal inspection, as of ordinary photographs, it is essential to employ no less than 10,000 elementary areas for each square inch of picture surface.* This gives us a frequency range of 5000 cycles per square inch.

In the case of speech, it has been found that acceptable reproduction may be secured through a frequency range of less than 3500 cycles per second. This range is, of course, to a considerable extent independent of the rate at which the words are spoken. If we speak slowly, therefore, we are not utilizing the communication channel to its fullest advantage. To determine the normal relation between frequency range and the rate at which verbal information may be transmitted, let us imagine that a phonograph record is made of speech at the usual rate of about 100 words per minute. If this record is played back so that the words are reproduced at the rate of one per second, we find that the frequency range has been reduced to approximately 2000 cycles per second. Thus, one square inch of picture may be said to be roughly equivalent as an amount of information to 2.5 spoken words.

To obtain moderately satisfactory reproduction of a small picture, such as one 4 inches by 5 inches square, it is necessary to employ communication facilities — i.e., frequency range multiplied by the time they are used — equal in value to those required for 50 spoken words.

By means of further assumptions of a similar nature, we may arrive at the conclusion that the ratio of the amount of information received in a given time by our eyes, to that received by our ears, is somewhere in the neighborhood of 200 to 1. It must be emphasized that this merely indicates an order of magnitude, and that it depends entirely on some rather arbitrary assumptions. That the ratio is fairly high is evidenced by the fact that in the talking motion pictures, the sound-on-film record has required an almost negligible sacrifice in the space formerly allotted to the visual record alone.

These considerations are largely independent of the method used for reproducing the copy of the original picture or scene. It is to be expected that the attention now being directed to television will result in the development of entirely practicable means for effecting the required scanning operations, for controlling the electric current, and for reproducing the desired image at the receiving terminal. Such devices will not in themselves be the complete solution to the problem of television. It will also be necessary to provide communication channels having many times greater information-carrying capacity than those now generally available.

From this it follows that the future of television is largely a question of economics. We may recall in this connection that the biggest obstacle which Morse had to overcome before he could transmit a telegram to any distance was that of raising funds to build his line. In other words, it is the communication channel for which we pay when we employ electrical communication facilities. Let us not ignore the fact that the burden imposed on this channel by television is many times greater than that now borne in our existing electrical communications systems.

* The halftone engravings ordinarily used in the *Experimenter* have about 18,000 "dots" or elementary areas per square inch; in a newspaper, from 4200 to 7200 "dots" per square inch.

GAIN IN AMPLIFIERS AND OTHER NETWORKS

By ARTHUR E. THIESSEN

NEARLY everyone who has worked with transmission circuits has had at least a few occasions to use the much-abused terms, amplification and attenuation — or, simply, gain and loss — to identify the behavior of some particular circuit element such as an amplifier or an attenuation network. The purpose of the following is to define just what is meant by the familiar terms, gain and loss. Since loss is negative gain, by confining a discussion to gain alone the wording of definitions is simplified without in any way changing the meaning. Because the performance characteristics of most networks encountered in communication circuits are, for most practical purposes, the same when working between non-reactive and reactive circuits and because calculation and measurements are much simplified by so doing, we will consider all of the circuit elements to be non-reactive.

Gain always refers to the amount of power transferred across a junction from a generator or other power source to a load. In Figure 2a, a power source consisting of a source of voltage E_G in series with resistance R_G is shown connected directly to a load of resistance R_R. With a given source and load, there will always be a definite amount of power, determined by these constants, delivered across the junction *JJ'* and dissipated in the load. If the junction is opened and an amplifier put in, there will be an increase of power in the load. The ratio of the load power when the amplifier is in the circuit to the load power when the load is connected directly to the generator is called the "insertion gain" — or, sometimes, "transmission gain." The power in the load when it is connected directly to the generator is called the reference power or reference condition. However, as we usually speak of gain, we mean a special case in which we take for the reference condition the case when all of the *available* generator power is transferred to the load. Thus, gain, as we ordinarily understand it, is the ratio of the load power when the amplifier is inserted at the junction to the load power when the load is so connected to the generator that it absorbs all of the *available* generator power. This is the condition for maximum power transfer across the junction,* which will be shown to occur when the load resistance equals the generator resistance.

In Figure 2a, let I_R be the current in the load R_R

$$I_R = \frac{E_G}{R_G + R_R},$$

and let W_R be the power in the load

$$W_R = I^2 R_R = \frac{E_G^2}{(R_G + R_R)^2} \cdot R_R.$$

Then differentiate W_R with respect to R_R to find the value of R_R for maximum W_R:

$$\frac{dW_R}{dR_R} = \frac{E_G^2}{(R_G + R_R)^2} - 2E_G^2 R_R (R_G + R_R)^{-3}$$

When W_R is a maximum, $\frac{dW_R}{dR_R} = 0$, and

$$\frac{E_G^2}{(R_G + R_R)^2} = \frac{2E_G^2 R_R}{(R_G + R_R)^3},$$

$$R_G + R_R = 2R_R \text{ and } R_R = R_G.$$

This means, of course, that in order to determine the reference condition for gain measurement, the load resistance

* See footnote, page 7.

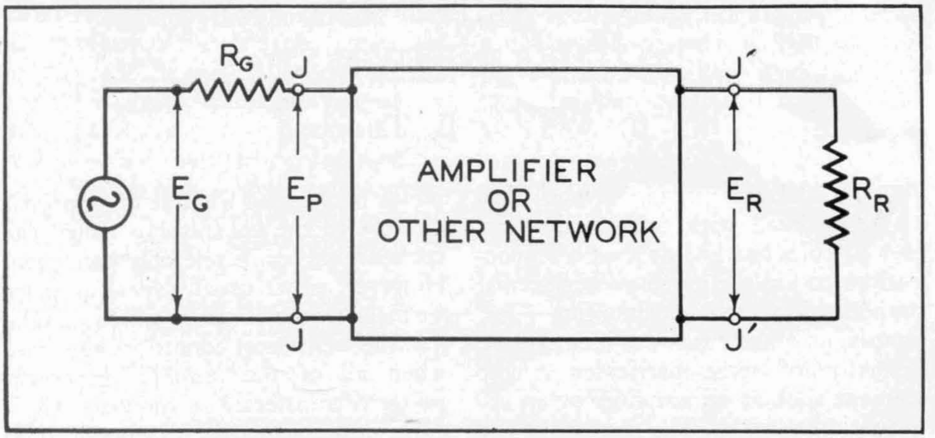

FIGURE 1. The gain resulting from inserting an amplifier or other network at the junction *JJ′* is the ratio between the resulting load power (power dissipated in R_R) and some *reference power* corresponding to a specified *reference* condition

must be equal to the generator resistance. If they are unequal, as is often the case, an impedance-matching device might be employed. An ideal device for this purpose is illustrated in Figure 2b. This is called an impedance-matching-transformer. It is one in which no power loss would occur and in which the apparent resistance of the primary is equal to the resistance of the generator when the secondary is connected to the load. Perfect matching would thus be obtained between the generator and the primary of the ideal transformer; therefore, all of the available generator power would be transferred across the junction from the generator to the transformer. Since there is no gain or loss of power in the ideal transformer, all of the power in its primary is delivered to the load. In other words, the ratio of the power output to the power input is unity in an ideal transformer. This is the reference condition that is used for the measurement of gain.

If we were to remove the theoretical ideal transformer and put the amplifier in its place, some increase of power in R_R should occur. The gain is the ratio of the load power realized with the amplifier in the circuit to the load power which would have existed at the reference condition. This is the same as saying that the gain of the amplifier is the ratio of its power output to the *available* power input.

This ratio is usually expressed in logarithmic units:* the gain in decibels N being equal to ten times the common logarithm of the power ratio:

$$N = 10 \log_{10} \frac{\text{Output Power}}{\text{Available Power}}.$$

Since we can never actually have an ideal impedance-matching transformer, some means must be employed for determining the available power in order to fix the reference condition. Refer again to Figure 2b. The ideal transformer, by definition, has primary and secondary impedances which match R_G and R_R, respectively.

Then $E_P = \frac{1}{2} E_G$,

and the power available at the input to the ideal transformer is

$$\frac{E_P^2}{R_G} = \frac{E_G^2}{4R_G},$$

* J. W. Horton, "Units of Electrical Transmission," *General Radio Experimenter*, III, January, 1929.

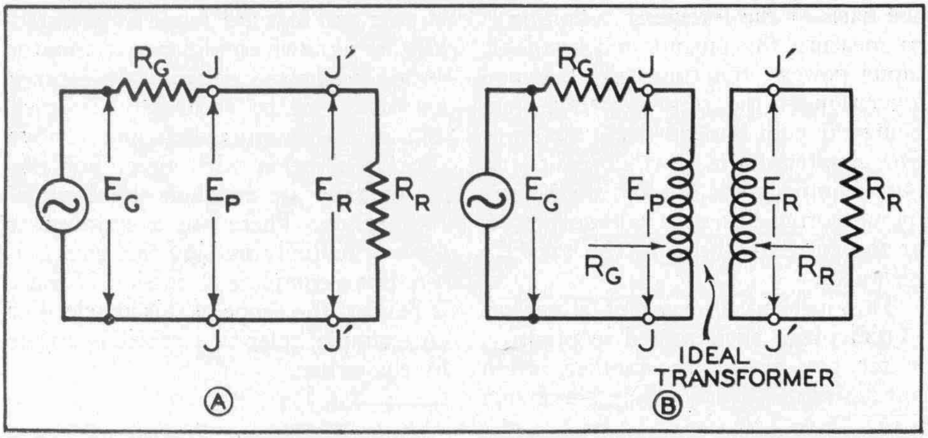

Figure 2. In general, the reference power for gain determinations is the load power when source and load are directly connected (as in *A*), but for gain as defined in the accompanying article an additional condition is imposed: R_G must be equal to R_R. The reference power may be obtained: (*1*) by use of an ideal impedance-matching transformer as in *B* or (*2*) by computing $\frac{E_G^2}{4R_G}$.

which simply means that one-half of the power generated in the power source is available at the terminals of the output load under this reference condition. This is equivalent to determining it by means of an ideal transformer.

Sometimes all of the power that a given generator is capable of delivering is not *available* for use in operating any single amplifier. Suppose, as a specific example of this, it is necessary to shunt a monitoring amplifier across a telephone line. The input transformer of such an amplifier would be designed to have an impedance large enough so that it could be bridged across the line without drawing more than a certain allowable amount of power. However, regardless of its input impedance, it still draws some power from the line. This power is the *available power*, the power that must be used as reference condition when calculating the gain of the amplifier.*

If the grid of the first amplifier tube were connected directly to the line, the power absorbed would be, of course, very small, although the power delivered by the amplifier might still be quite large. In this case, the gain would be very great, but the definition would still hold.

In designing an amplifying or an attenuating network to work between a given generator and load, the input and output circuits of the network should match the two impedances respectively for the maximum efficiency. Often, however, this is impossible or impractical. It should be remembered that any loss caused by such mismatching is entirely chargeable to the network.

The most direct method of determining the gain or loss of a network on

*Editor's Note.—This statement means that if the *maximum* amount of *power* the source is capable of delivering $\left(=\frac{E_G^2}{4R_G}\right)$ is not *available* for use in the amplifier or network being considered, the previous remark about the "condition for maximum power transfer across the junction" must be interpreted with care. If *maximum* power is not *available* the network must be considered for both calculation and measurement purposes as working out of a new source whose *maximum* power is equal to the *available* power. In other words, E_G for the new source is the same as E_G for the old one, but the new R_G is given by the relation

$$R_G\,(new) = \frac{E_G^2}{(Available\ Power) \times 4}.$$

the basis of the foregoing definition is to measure the output and available input powers, ten times the common logarithm of the ratio between them being the gain in decibels. If we know the characteristics of the input and output impedances, we find the powers by measuring either the voltages across, or the currents through, the two impedances.*

This method, because of a variety of difficulties encountered in practice, is for one reason or another, often not desirable. Nearly all measurements of gain and loss are made by comparing the unknown amplifier or attenuator with a calibrated network. Resistance networks can be accurately designed and once constructed do not change their calibration with time. For this reason they are excellent standards of comparison. There are a number of ways of actually making this comparison, but a complete discussion of these is beyond the scope of this article. For an example, refer to a previous article by the writer.†

* John D. Crawford, "Notes on Power Measurement in Communication Circuits," *General Radio Experimenter*, IV, October, 1929.

† Arthur E. Thiessen, "Production Testing of Audio-Frequency Amplifiers," *General Radio Experimenter*, IV, June, 1929.

MISCELLANY

By THE EDITOR

THE line of TYPE 376 Quartz Plates manufactured by the General Radio Company has been completely reclassified. New prices are in effect and a new high-precision class for use with temperature control has been made available. A complete description of the TYPE 376 Quartz Plates will be published in the next issue of the *Experimenter*.

* * * *

When we described the new TYPE 547 Temperature-Control Boxes in the November issue of the *Experimenter*, we interchanged the Centigrade and the Fahrenheit values for the allowable variation in room temperature. Control will, of course, be obtained over a room-temperature variation of 11 degrees C. or 20 degrees F.

We hereby tender our thanks to those readers who were good enough to call our attention to the error and hope that none of the others were misled by it.

CONTRIBUTORS

J. W. HORTON has been Chief Engineer of the General Radio Company since October, 1928. For the twelve years preceding he was with the Bell Telephone Laboratories where he obtained the information upon which this article is based.

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