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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 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

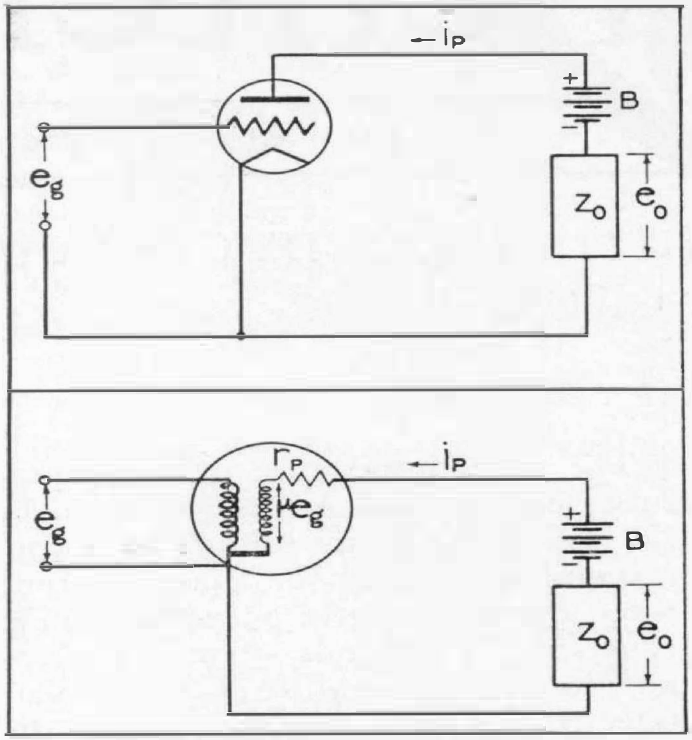

FIGURE 1. Schematic circuit for a simple vacuum tube amplifier: 1a, above; 1b, below

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

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

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* 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

$$\frac{i_pZ_o}{e_g}=g_mZ_o,$$

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.

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.

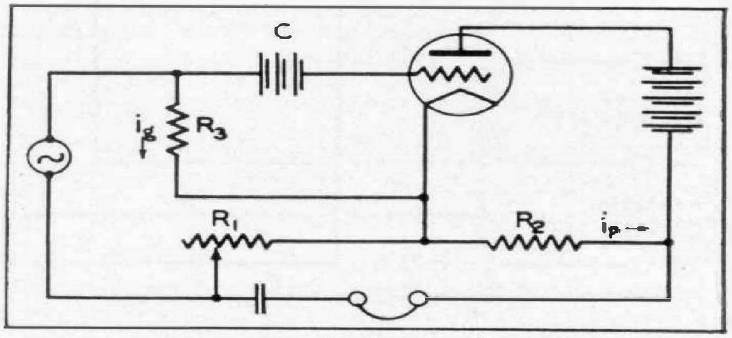

Figure 2. Functional schematic diagram of the bridge for measuring mutual conductance

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,

$$i_gR_1=i_pR_2 \text{ or } i_p=\frac{i_gR_1}{R_2}$$

and $e_g=i_gR_3$,

$$\text{hence } g_m=\frac{i_p}{e_g}=\frac{i_gR_1}{R_2}\cdot\frac{1}{i_gR_3}=\frac{R_1}{R_2\ R_3}. \qquad (2)$$

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

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

† H. J. van der Bijl, *Op. cit.*

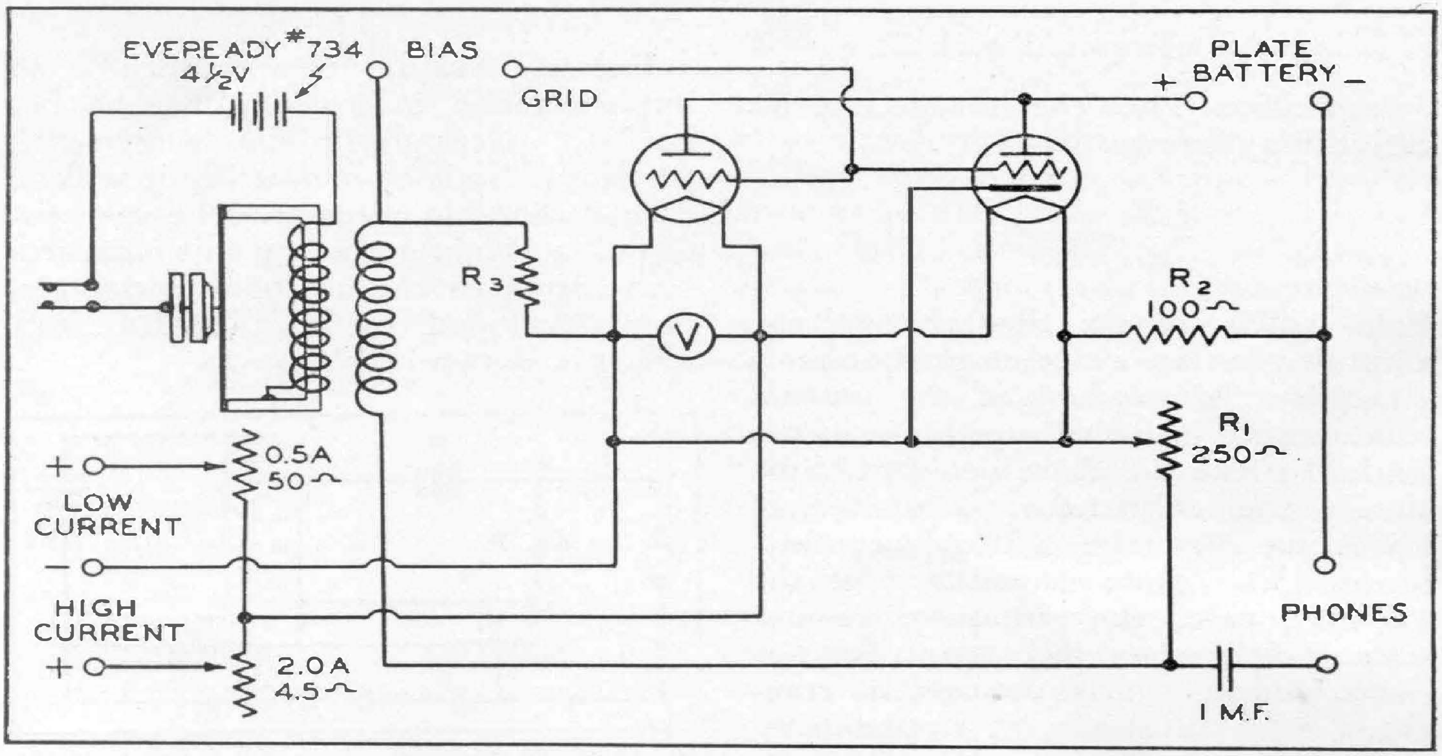

FIGURE 3. Wiring diagram for TYPE 443 Mutual-Conductance Meter. R_3 is given a value of 1000 ohms

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-

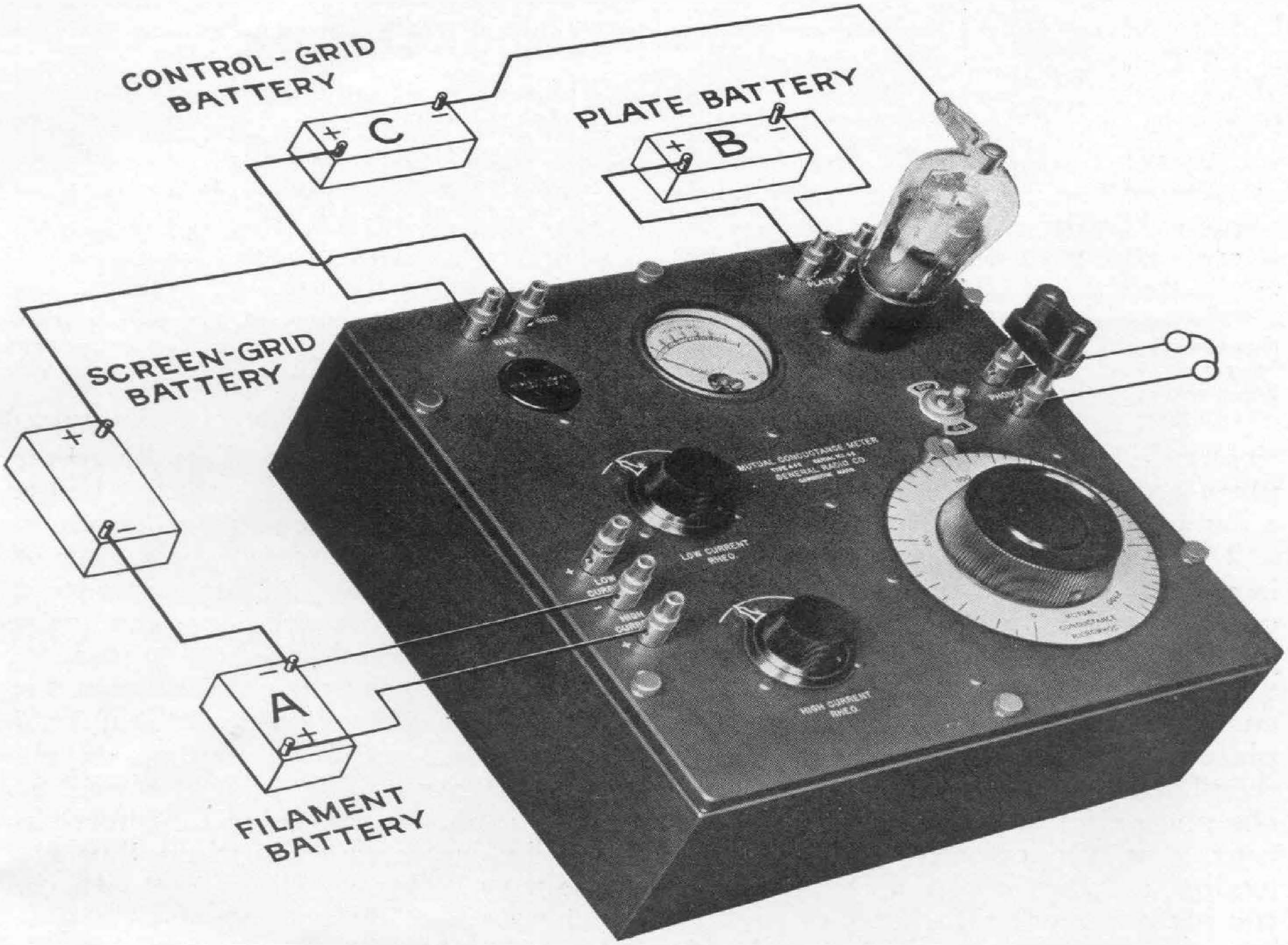

Figure 4. Type 443 Mutual-Conductance Meter showing connections for testing a 224-type screen-grid tube. The panel is engraved for triodes

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

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* 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

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

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 percent. 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 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.

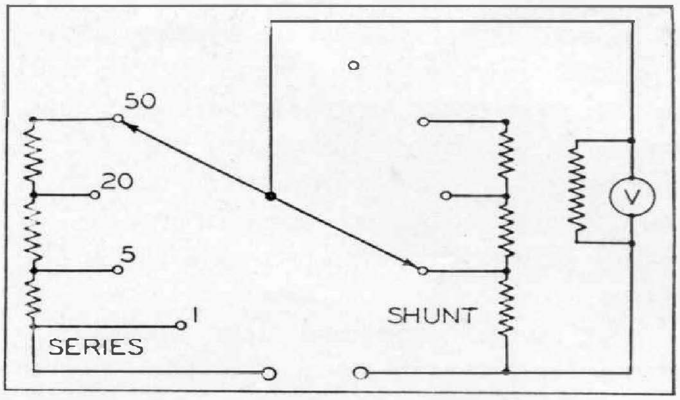

FIGURE 2. Schematic wiring diagram for the TYPE 486 Output Meter. The numerals beside each of the switch points at the left indicate the value of the multiplying factor for the voltmeter

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 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

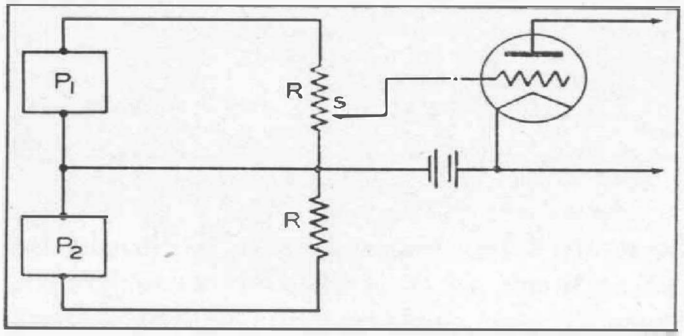

Figure 2

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

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

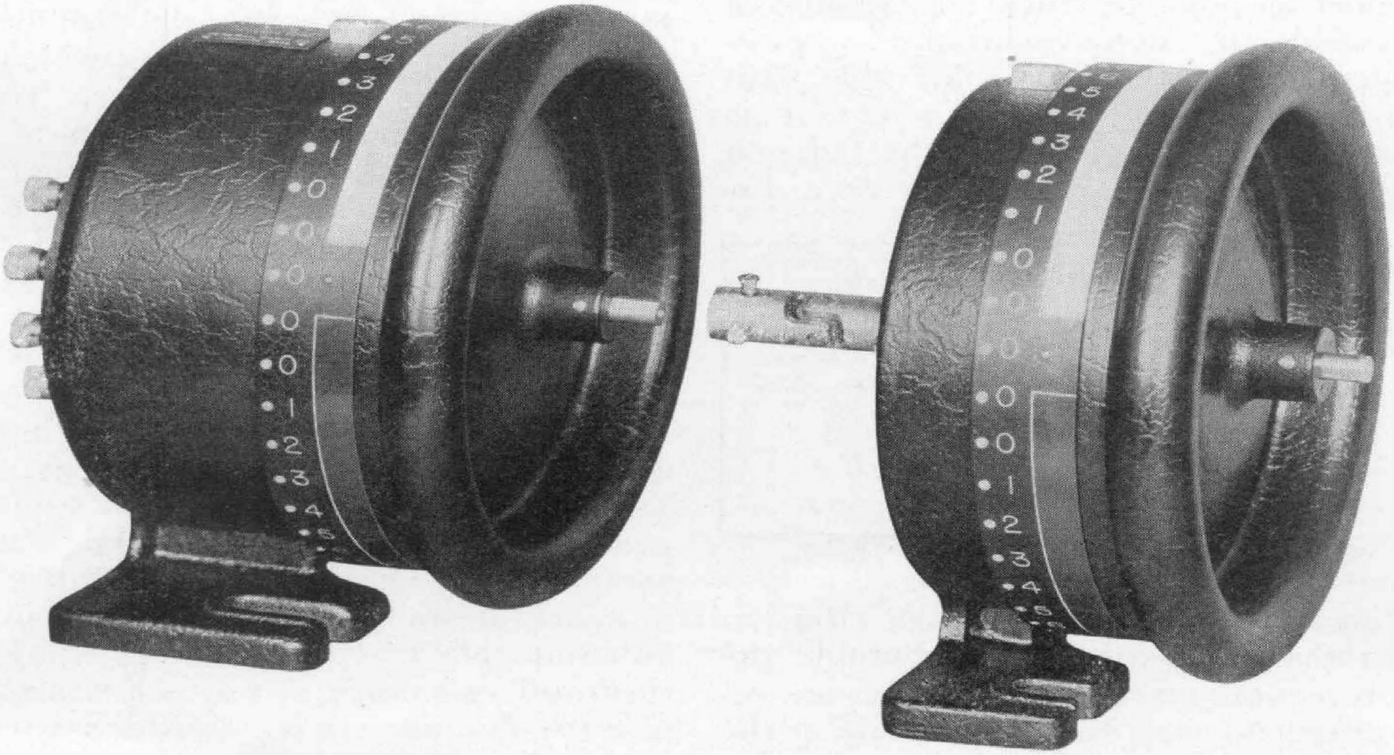

Figure 1. The General Radio Type 598 Fader. At the left is the fader proper; at the right is the "dummy" or auxiliary control. In practice the two are mechanically coupled

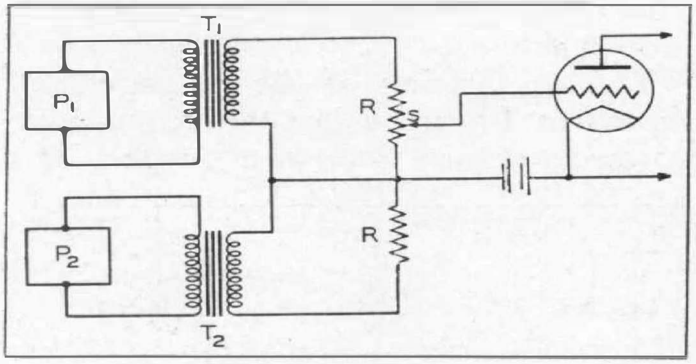

FIGURE 3

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.

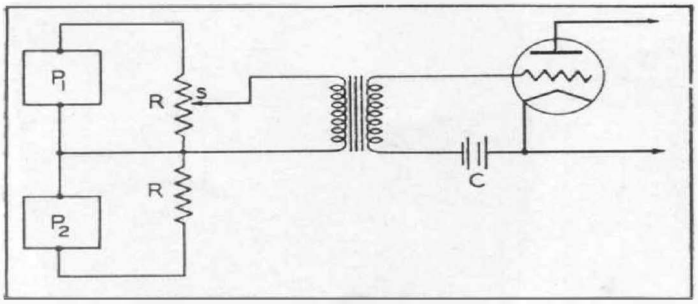

FIGURE 4

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 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.

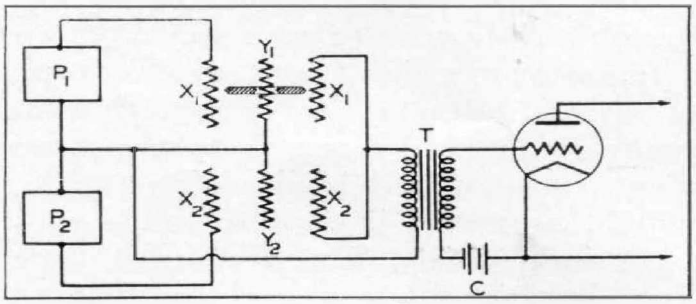

FIGURE 5

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 sufficiently 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 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.

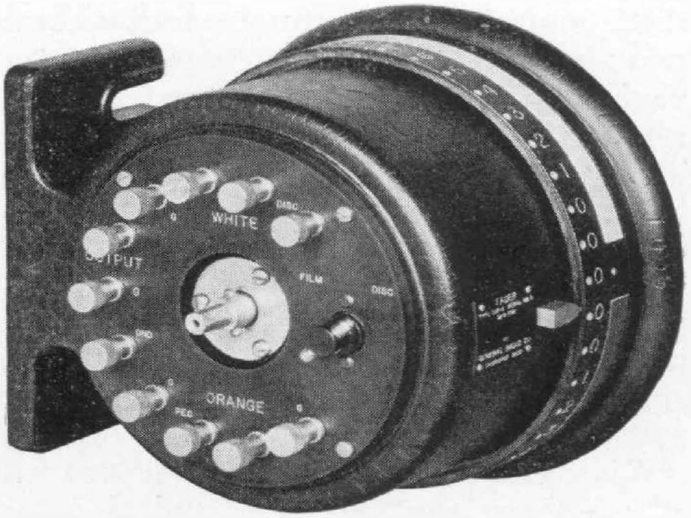

Figure 8. View of Type 598 Fader showing connection panel and selector switch for changing from film to disc track

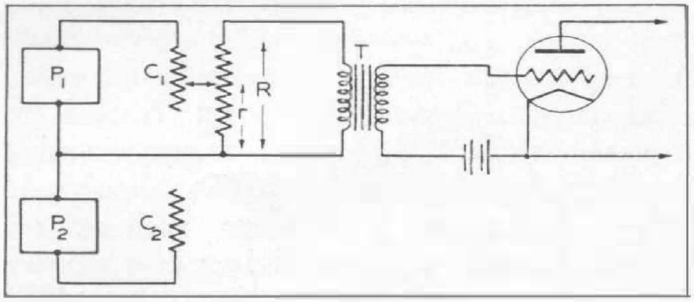

Figure 6

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

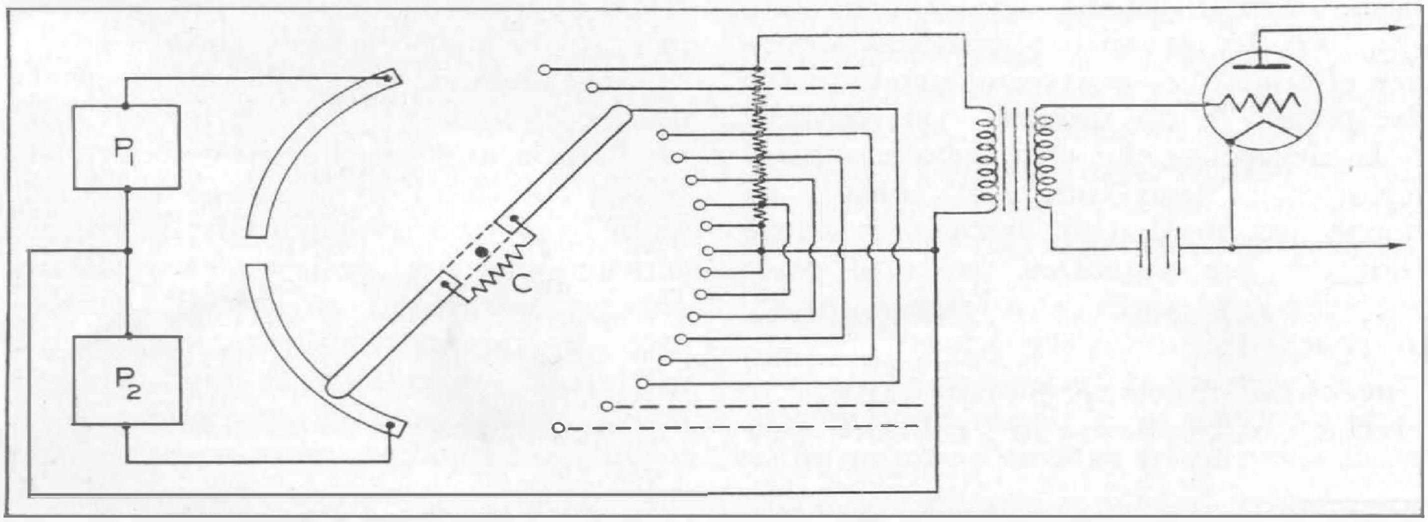

Figure 7. Schematic diagram for a fader like that shown in Figures 1 and 8. The connections for the selector switch are not shown

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.

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* *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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