the GENERAL RADIO Experimenter

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The GENERAL RADIO EXPERIMENTER

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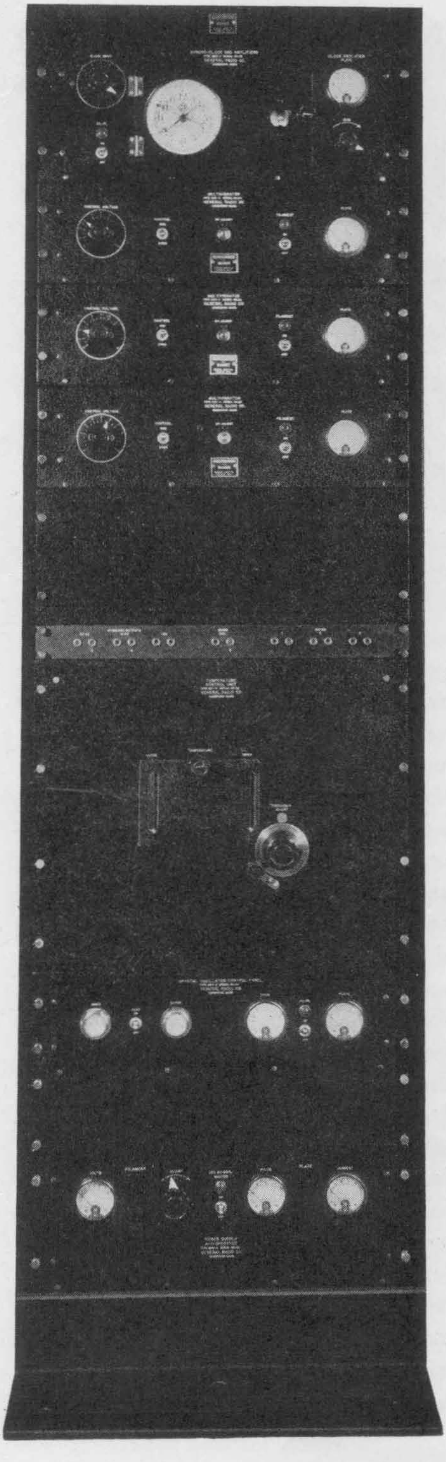
ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

RECENT DEVELOPMENTS IN FREQUENCY STANDARDS

IT is now some years since General Radio first set itself to the task of building frequency standards for the radio industry. These years have been years of achievement in the fullest sense of the word. Beginning with the wavemeter in its various stages of development, continuing through the early days of quartz crystals and culminating in the highly accurate primary standard of frequency, General Radio has, through a program of constant development, contributed much to the art of frequency measurement. The aim of this program has been to produce equipment capable of the accuracy demanded by the scientist, simple in operation, and suitable for industrial and commercial use.

The announcement by the General Radio Company of the first commercially acceptable primary standard of frequency in 1929 was an important milestone in the field of frequency standardization since it meant that this class of measurement had been lifted out of the laboratory nursing stage and made available to industry. It needed neither constant temperature room nor elaborate voltage regulating system, and was designed to operate under vibrations encountered in a factory building. This primary standard, the Class C-21-H Standard-Frequency Assembly, has found a wide use, not only in the electrical communication industry, but such fields as accurate time keeping and time measurement, the transmission of radio time signals, measurements of the velocity of rifle bullets, and of the velocity of light. Approximately thirty units are now in use in the United States and six foreign countries, operating under widely differing conditions of climate, but giving uniformly satisfactory service.

Five years' development produces considerable progress in design and manufacturing. Many improvements can be incorporated in each new lot of instruments, but eventually the point is reached where complete redesign becomes advisable.



With the advent of 1934, General Radio announces a new Class C-21-H Standard-Frequency Assembly, Series 690. While identical in its functional aspects with its predecessor, each component unit of the assembly has been redesigned and the result is a considerably higher accuracy specification and a vastly improved stability of operation. New and improved electrical circuits using modern types of vacuum tubes contribute materially to the improved accuracy and stability, while a number of features of mechanical design make the installation and operation a simple matter. The accuracy is conservatively specified as ± 5 parts in 10 million. Actually, one part in 10 million can be obtained over long periods of time.

A few of the outstanding features of this frequency standard are outlined below.

1. Piezo-Electric Oscillator

The crystal oscillator uses an electrical circuit which is a new and successful approach to the problem of making a quartz crystal oscillate at its resonant frequency. The over-all frequency stability with respect to operating parameters exceeds that obtainable with other types of oscillators. Automatic bias control assures constant amplitude and operation at small amplitude contributes materially to the frequency stability. The 50-kc quartz bar uses electrodes deposited directly on the quartz, and its mounting is designed to introduce as little damping as possible.

FIGURE 1. The new Class C-21-H Standard-Frequency Assembly

2. Multivibrators

The new multivibrators constitute a considerable improvement over previous types. The stability of control is exceptionally good, in spite of large changes in operating and control voltages. The circuit elements are adjusted at the factory before shipment and these adjustments are practically permanent, assuring correct operation when received. Three multivibrators are used operating at 50 kc, 10 kc, and 1 kc respectively.

3. Self-Starting Synchronous Clock

The synchronous-motor clock has been provided with a 60-cycle auxiliary motor for starting purposes. To bring the motor up to synchronous speed, it is only necessary to press a button on the panel.

4. Power Supply

The assembly is designed to operate from a 115-volt, 60-cycle a-c line. Two types of power supply equipment are available. One of these provides current for trickle charging lead-type storage batteries as in the previous model. The other furnishes filament and plate power directly from the line without the use of batteries.

There is no essential difference in the frequency stability obtainable from the floating-battery or from the completely a-c operated assemblies, and the choice between the two may well be based entirely upon whether or not 100 per cent continuous service is required.

With the completely a-c operated assembly, of course, a momentary failure of the power line will remove plate and filament supplies and interrupt the timing. The heat supply for

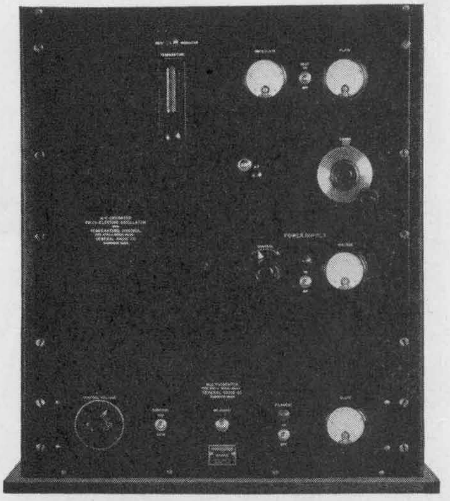


FIGURE 2. A Class C-10 Secondary Standard

the temperature-control unit will also fail, and, if the interruption lasts for more than a few minutes, the assembly will be out of service until the operating temperature of the crystal can be restored to normal. For a great many purposes, such interruptions are of no great moment, either because of an unusually reliable a-c supply or because the annoyance of interruptions in service is more than compensated by the additional cost of the floating-battery assembly and the necessary batteries.

The floating-battery assembly is the ideal installation where as close an approach as possible to continuous service is required. Both filament and plate supplies are carried by batteries and these can be chosen in sizes sufficiently large to carry the assembly for any emergency that the user cares to anticipate. Power for the temperature-control system comes directly from the a-c line, but, when it fails, relays automatically transfer the heater circuits to an "auxiliary heat reserve" which can be any independent power source that the user sees fit to install.

5. General Considerations

Complete connecting cables, vacuum tubes, spare fuses, and pilot lamps, and blank panels for filling the rack are provided. All external wiring is enclosed and connections between the panels and the cable are made by insulated plugs. The general appearance is shown in the accompanying photograph. The Class C-21-H Standard-Frequency Assembly for floating-battery operation is priced at $1,950.00; for complete a-c operation, $1,875.00.

SECONDARY STANDARDS

The improved electrical and mechanical design features employed in the primary standard have also been incorporated in an a-c model of the Class C-10 Standard-Frequency Assembly. This secondary standard of frequency consists of a Type 675-L Piezo-Electric Oscillator, a Type 692-A Multivibrator (10 kc), either a Type 676-A (50-kc) or Type 476-A (100-kc) Quartz Bar, and a Type 480-B Relay Rack.

The Type 675-L Piezo-Electric Oscillator uses the same oscillator circuit as does the primary standard just described. It includes two output amplifiers, one for supply output at the fundamental frequency, and the other for generating harmonics of the fundamental. A self-contained power supply has sufficient capacity to operate a maximum of three multivibrators. While the assembly is normally supplied with a single multivibrator, others can be added if desired.

The accuracy is ±20 parts in one million and the stability over long periods is in the vicinity of ±5 parts in one million. Power is obtained from a 115-volt, 60-cycle a-c line, and all vacuum tubes are included in the price.

Class C-10 Standard-Frequency Assembly, Series 600, with 50-kc quartz bar $595.00

Class C-10 Standard-Frequency Assembly, Series 600, with 100-kc quartz bar $565.00

—Charles E. Worthen

NEW VARIACS

A NEW SMALL SIZE; ALSO, 230-VOLT MODELS

A new type of voltage-adjusting device called the *Variac* was described in the June - July issue of the *Experimenter*. The *Variac* consists of a transformer so arranged that the voltage can be continuously adjusted in steps of about 0.4 volt. At no time is the circuit interrupted, and there is no rise in voltage between steps; that is, the *Variac* operates like a wire-wound rheostat or voltage divider.

The *Variac* possesses several important advantages over the resistance controls commonly used for voltage adjustment purposes. The change in voltage with setting of the knob is essentially linear and is practically independent of the load current. Hence the *Variac* can be used to produce any voltage between the rated voltage and zero for any load current within its range, unlike the rheostat in which control is lost as the load current approaches zero.

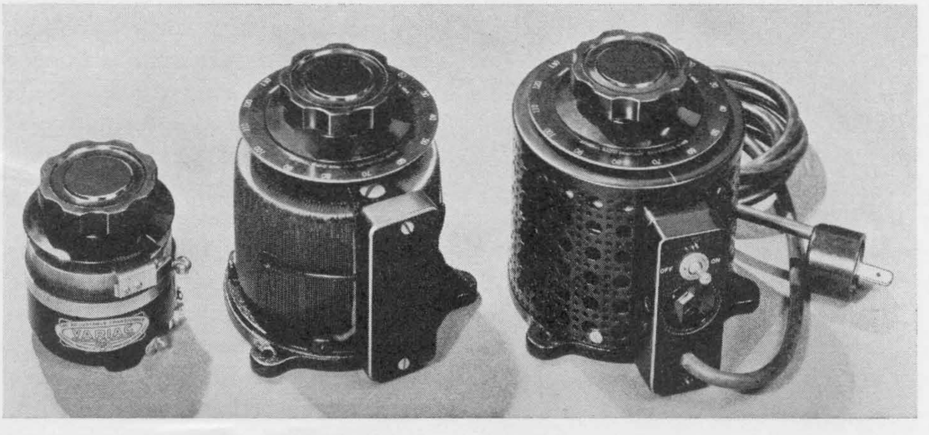
Furthermore, since series resistance is not introduced into the line as the control is varied, the voltage regulation afforded by a *Variac* is much better than with a rheostat. The high efficiency of a transformer is substituted for the necessarily inefficient resistance control.

Further development work has been done on *Variacs* for different line voltages and load current ratings. There is now available the Type 200-B *Variac*, a smaller unit designed for 115-volt service and a maximum current of 1.0 amperes. It is intended for building into other instruments requiring a smooth voltage control. Typical applications would be to vacuum-tube rectifiers whose output voltages must be adjustable under varying load conditions or to small motors requiring a speed control.

The small *Variac* is designed to give any desired voltage between 0 and full line voltage. Prices: Type 200-B *Variac* (for 115-volt line), $8.50.

The small *Variac* is suitable for mounting either on a baseboard or behind a panel like all General Radio rheostats. By removing the knob shown in the photograph, loosening the brush arm, and pushing through the shaft, the knob can be attached to the other end, thus making over the unit for behind-the-panel mounting.

The unmounted and the mounted models of the large 5-ampere *Variac*, shown at the center and right in the photograph below and described in the June-July issue of the *Experimenter*, are also available for operation from a 115-volt, 60-cycle line. It has an output-voltage range from 0 to 130 volts so that it can be used to compensate for low line voltages.



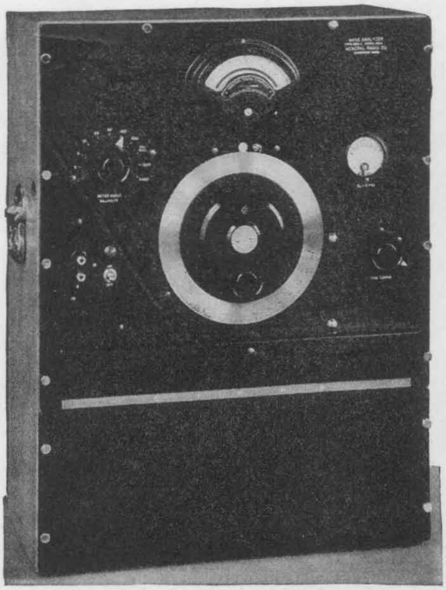
The three *Variacs*. Left to right, the Type 200-B described in the accompanying article and the Types 200-CU and 200-CM described in the *Experimenter* for last June-July

AS THE WAVE ANALYZER VIEWS THE TUNING-FORK OSCILLATOR

THE tremendous range in voltage that can be measured with the frequency-selective voltmeter known as the wave analyzer is nowhere better illustrated than in the analysis of a TYPE 213-B Audio Oscillator, shown on the opposite page. Harmonics as high as the eighth were picked off and measured even though the amplitudes got down to as little as 0.006 per cent of the fundamental voltage. The magnitude of the fundamental can be estimated for any value of load impedance by considering the curve of output in milliwatts.

The 400-cycle TYPE 213-B Audio Oscillator whose waveform characteristics are shown on the opposite page

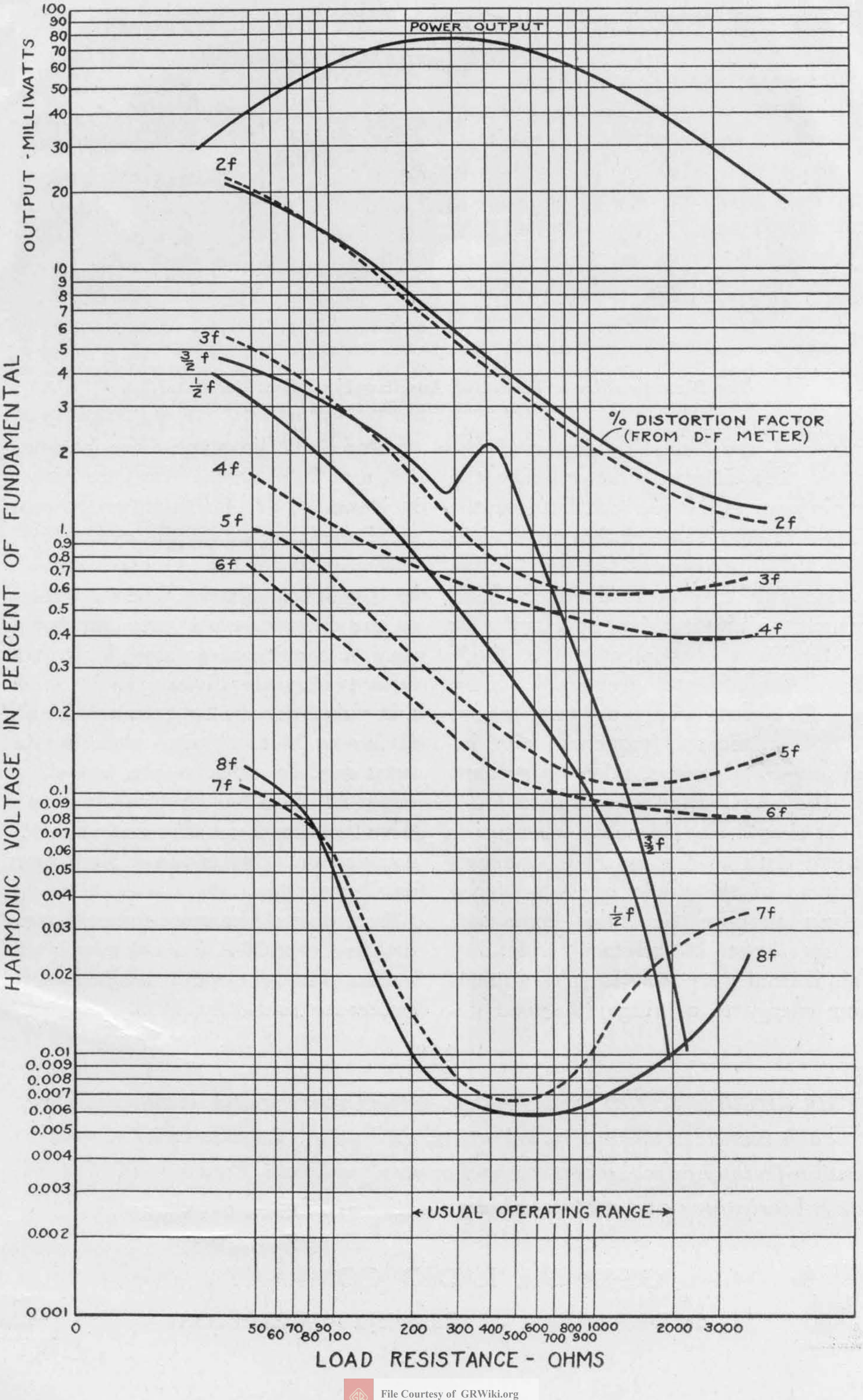
In taking these data, the straightforward simplicity of the wave analyzer was of considerable help. After the preliminary adjustments (calibration check and detector balance) were made, it was merely necessary to make one series of measurements for each value of load resistance into which the oscillator was to be worked.



The TYPE 636-A Wave Analyzer

The amplitude of the fundamental was first measured. The multiplier adjustment on the voltmeter was then changed until a deflection of 1000 divisions was obtained. The amplitude of each successive harmonic voltage was then taken, using the same multiplier setting, so that the amplitude of each harmonic expressed as a percentage of the fundamental could be read directly from the meter.

Of particular interest is the curve representing data taken with the distortion-factor meter on the same oscillator. The data agree to within ±5 per cent of the values obtained by calculation from the wave-analyzer data. The distortion-factor meter, it will be remembered, is an instrument containing filters that reads directly in


POWER OUTPUT
OUTPUT - MILLIWATTS
HARMONIC VOLTAGE IN PERCENT OF FUNDAMENTAL
% DISTORTION FACTOR
(FROM D-F METER)
2f
3f
3/2 f
1/2 f
4f
5f
6f
7f
8f
USUAL OPERATING RANGE
LOAD RESISTANCE - OHMS
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1.
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.009
0.008
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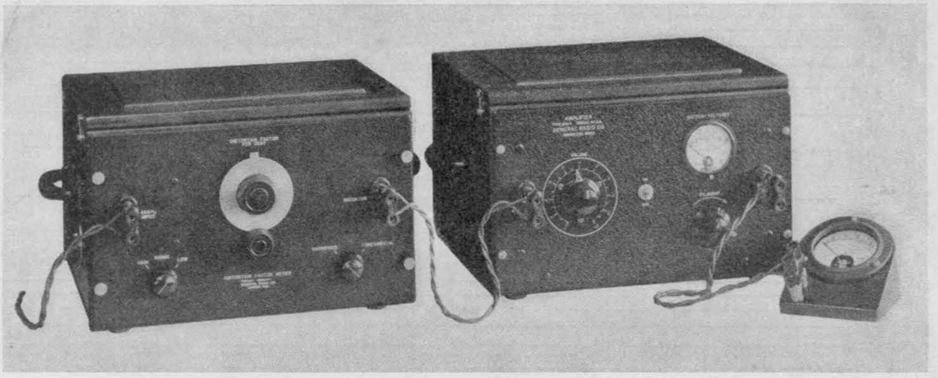

The Distortion-Factor Meter and Auxiliary Equipment for distortion measurements at 400 cycles

per cent the distortion factor of the wave, the distortion factor being the ratio (expressed in per cent) between the r-m-s value of the complex wave without the fundamental to the effective value of the fundamental alone. It is an accurate and convenient instrument for distortion measurements at a single fixed fundamental frequency. Since the filter cuts out everything above the fundamental frequency, the instrument, of course, takes no account of the contribution of energy at $f/2$.

It should also be noted when using these data as a measure of the usefulness of the audio oscillator for a given purpose that the impedance range shown is extremely wide. For all normal purposes (such as supplying energy to a bridge) the load impedance will lie somewhere between 200 and 2000 ohms. The data given, incidentally, are for the MEDIUM output impedance tap of the oscillator.

The oscillator has two other taps on its output transformer. The data given in the curves on the preceding page may be considered as applying to the other two taps by dividing by 10 to obtain values for the LOW tap and multiplying by 10 to obtain values for the HIGH tap. In other words, a load of about 30 ohms on the LOW tap would have the same harmonic content as 300 ohms on the MEDIUM tap or 3000 ohms on the HIGH tap.

Complete explanatory data concerning the TYPE 636-A Wave Analyzer will be found in the General Radio *Experimenter* for June-July, 1933.

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ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

THE MEASUREMENT OF A SMALL INDUCTANCE

IT has been known for some time that ordinary bridge measurements on the types of small inductance coils used in tuning radio-frequency receivers have been unreliable. At the same time, the commercial tolerances for these coils have been restricted, and it has become necessary to measure coils of this sort with an accuracy of considerably better than one microhenry.

A careful consideration of the bridge circuits used has revealed three sources of error—the sliding zero balance occurring when two fixed inductors having energy factors, $Q = \frac{X}{R}$, between 0.1 and 10 are compared; the variable inductance of any decade resistor added in series with either inductor; and the energy factor of the resistor in any bridge arm due to capacitance in parallel with it.

The bridge circuit shown in Figure 1 is used to measure an unknown inductor in terms of a standard inductor. Considering the quantities in the P arm as unknowns, their values are

$$L_P = \frac{B}{A} L_N$$
$$P = \frac{B}{A} N. \qquad (1)$$

If both of the inductors are fixed, one of the ratio arms, preferably the B arm, must be variable. In addition, resistance must be added in series with that inductor having the larger energy factor Q in order to provide the resistance balance. Because the resistance A appears in both balance equations, the two balances for resistance and inductance are not independent. Successive balances of resistance A and the added resistance will differ progressively and approach the correct balance point for each. The final balance is not, however, unique. It can be recognized only as the best balance in a series of approximate balances on each side of it. The amount of uncertainty introduced by this type of sliding balance point depends upon the energy factor Q of the coil. For large values of Q, the inductance balance is definite, and a consid-

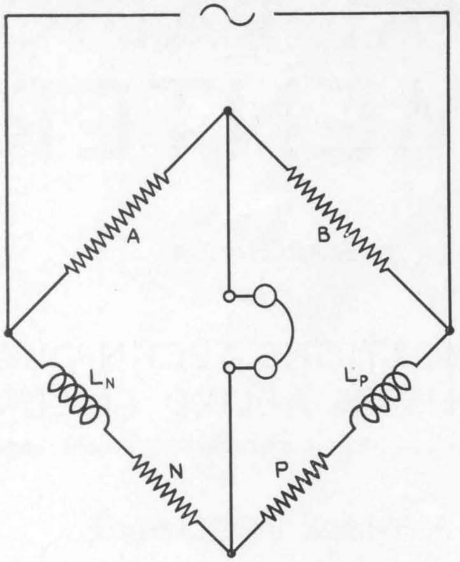


FIGURE 1. Basic bridge circuit for the measurement of inductance

erable error will appear in the resistance balance. Conversely, for values of Q less than unity, the greater uncertainty will appear in the inductance balance. Small inductors, which at radio frequencies may have energy factors approaching 100, have at a frequency of 1 kc values of Q between 0.1 and 1. Under these conditions it is quite possible for this uncertainty in the inductance balance to produce errors of a few per cent.

The two bridge balances may be made independent by the use of a small variable inductor placed in series with either inductance arm of the bridge. If the bridge is to be made direct-reading, it is preferable to place this small inductor in series with the unknown inductor. The inductance of an unknown inductor is

$$L_X = \frac{\Delta B}{A} L_N - \Delta L_P, \qquad (2)$$

where ΔB and ΔL_P represent the changes in ratio arm resistance B and inductance of the small variable inductor between the final balance of the bridge and the initial balance when the unknown terminals are shorted. By suitable calibration, the initial readings of both the variable inductor and the ratio arm B may be made zero so that the changes in their readings become their actual readings when the unknown inductor is connected in circuit.

This procedure will yield accurate results if no change in the inductance of the arm containing the added resistance occurs as the resistance is changed. In making precise measurements of inductances of less than 100 μh, however, the change in the inductance of a four-dial decade resistor can have an appreciable effect and must be taken into account.

The change in inductance of such a box from zero setting to full setting is of the order of 1 μh. The exact values for the TYPE 602 Decade-Resistance Boxes are given in the General Radio *Experimenter* for February, 1932. If this added resistance is placed in series with the small unknown inductor, the error introduced will be considerable. This error may be eliminated by the use of the TYPE 670 Compensated Decade Resistors. In these boxes, the total inductance is held at a fixed value by the use of compensating cards wound of copper wire having the same inductance as the corresponding resistance steps. Details of their construction are described in detail on page 6 of this issue. When this decade resistor is placed in the N arm, the standard in that arm may be adjusted to compensate for their inductance.

The third source of error is due to the inductance of the ratio arms and capacitance in parallel with the resistance in any arm of the bridge. Such extraneous reactances are called residuals and are shown diagrammatically in Figure 2. The terminal capacitances of the input transformer are placed across whichever pair of arms has its junction connected to ground, here the junction of the two inductance arms, because it will appear that in this position the smallest errors are introduced. The formulae applying to such a bridge are:

$$L_P = \frac{B}{A} L_N \left[1 - \frac{Q_A - Q_B + Q_{NC} - Q_{PC}}{Q_P} \right]$$

$$P = \frac{B}{A} N \left[1 + (Q_A - Q_B + Q_{NC} - Q_{PC}) Q_P \right],$$

where Q_A and Q_B are the energy factors of the A and B arms, respectively, and are of the form $Q = \frac{\omega \hat{L}}{R}$ in which $\hat{L} = L - R^2C$ as shown in Figure 3b. Q_{NC} and Q_{PC} are those parts of the energy factors of the resistances in the N and P arms due to the parallel capacitances and are of the form $Q = R\omega C$ as shown in Figure 3c. Q_N and Q_P are the energy factors of the known and unknown inductors increased by any added resistance and are of the form $Q = \frac{\omega L}{R}$ as shown in Figure 3a. The errors introduced by these residuals depend upon the same combination of Q_A, Q_B, Q_{NC}, and Q_{PC} for both resistance and inductance except that, for inductance, this term is divided by the energy factor Q_P of the unknown inductor and for resistance it is multiplied by this same Q_P. An energy factor is of appreciable magnitude only when a high resistance is combined with a large parallel capacitance. For the case of 1 kΩ

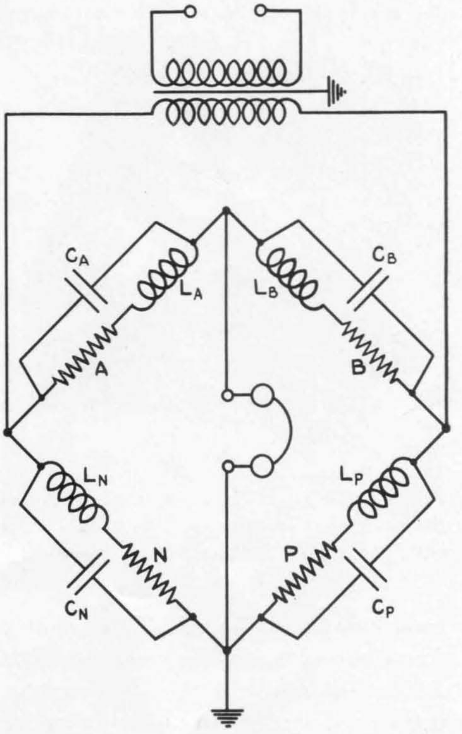


FIGURE 2. Inductance bridge circuit showing the presence of residuals

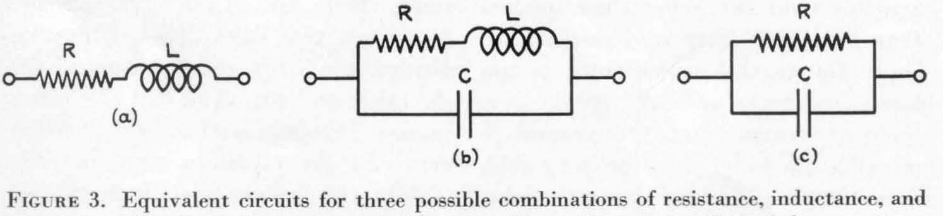


FIGURE 3. Equivalent circuits for three possible combinations of resistance, inductance, and capacitance. These relations are required for an understanding of the effect of the extraneous reactances shown in Figure 2

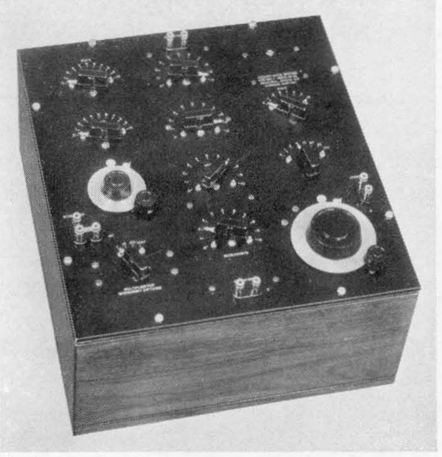


FIGURE 4. Inductance bridge making use of the principles described in this article. It is complete except for the generator and null detector

combined in parallel with 100 $\mu\mu$f at a frequency of 1 kc, the resulting Q is .0006. This would produce 0.06% error if Q_P were unity. For higher values of Q_P the error in inductance would be still smaller while the error in resistance would increase in proportion. For values of Q_P less than 1, it is the error in inductance which increases while the error in resistance remains negligible. Since it is quite possible to have a 100-μh inductor with a Q of only 0.1, errors of the order of 0.5% in inductance are possible for this case. Using a standard inductance L_N of 1 mh, resistance B is usually kept at 1 kΩ, while resistance A varies from 1 kΩ down to zero for unknown inductances of less than 1 mh. It is thus very desirable to keep the parallel capacitance across the ratio arms as small as possible. It is for this reason that the ground is placed at the junction of the two inductance arms. Terms involving the natural frequency of the inductances in the N and P arms determined by the parallel capacitances are omitted from the bridge equations because they are negligible for very small values of inductance at low frequencies. These terms become of importance only at high frequencies or in measurements of large inductances.

The three sources of error which have been previously considered—sliding zero balance, variable inductance of the added resistor, and energy factors of the bridge arms due to parallel capacitance—have been found to include all those responsible for inaccurate measurements of small inductances. When provision is made for eliminating them it should be possible to measure inductances up to 0.1 h to an accuracy of 0.1 μh or 0.1%, whichever is the larger. The upper limit of inductance, 0.1 h, is set by the use of a 1-mh standard inductor L_N, a limit of 1 kΩ for the resistances of the ratio arms, and by the fact that the accuracy of a 1-ohm decade is only 0.25%. By using larger inductance standards up to a value of 1 h, which in turn may be compared with the 1-mh standard, it should be possible to measure inductances up to 100 h to within 0.1%, and up to 1000 h to within 0.25%. If the resistance of either inductor exceeds a value of 1 kΩ the errors introduced by the parallel capacitances across the inductance arms must be considered.

When inductance measurements are made with the TYPE 193 Decade Bridge or the TYPE 293-A Universal Bridge, the TYPE 106-G Standard Inductance and the TYPE 670-FW Compensated Decade Resistor are placed in series in the standard arm and the TYPE 107-J Variable Inductor is placed in series with the unknown inductor in the X arm. The leads used in the standard arm should be twisted together loosely in order to minimize their inductance, while at the same time keeping their distributed capacitance small. The inductance of the Type 670-FW Compensated Decade Resistor is known and may be added to that of the standard inductor. The two inductors in the *X* arm should be spaced from each other and from the standard inductor so that no appreciable mutual inductance exists. Provision should be made for short-circuiting the unknown inductor without changing the position of its leads. The Type 514-A Amplifier and head telephones should be used as the null detector with its grounded terminal connected to that terminal which places the added resistance in series with the *X* arm. Any battery-operated generator such as a Type 213 Audio Oscillator or a Type 613-A Beat-Frequency Oscillator may be connected directly to the input terminals of the bridge. An a-c operated oscillator such as the Type 508-A Oscillator should be connected through a Type 293-P1 Transformer used step-down. This transformer should be used in any case if the leads from the oscillator are shielded and have large capacitance to ground. The Type 578 Shielded Transformer, having small terminal capacitances, is being developed for such use.

The greatest accuracy and ease of adjustment are usually attained with any bridge circuit when its component parts are built into a single compact instrument. A bridge embodying the features discussed above has been built on special order and is shown in Figures 4 and 5. —Robert F. Field

[A bridge of the type described is being built under Mr. Field's direction. — Editor]

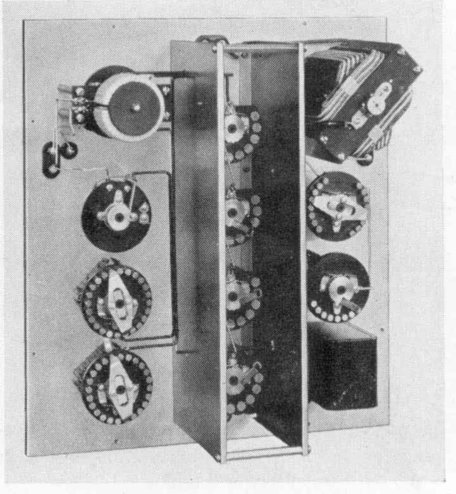


Figure 5. Behind the panel view of the inductance bridge shown in Figure 4. The arrangement of the various units is clearly shown

CONSTANT-INDUCTANCE RESISTORS

Although the residual inductance of the Type 510 Decade-Resistance Units has been reduced to a very small value by the choice of a suitable type of winding, it is still large enough to produce appreciable errors in the measurement of capacitance at radio frequencies and of a small inductance at audio frequencies. The former use was discussed in the General Radio *Experimenter* for December, 1933, in a description of the Type 516-C Radio-Frequency Bridge. The latter application is described on page 1 of this issue in connection with the design of a bridge for measuring small inductances.

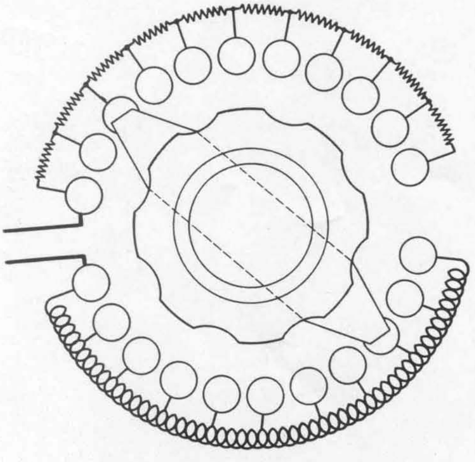


Figure 1. Schematic diagram of the inductance compensated decade resistors shown in Figures 3 and 4

Since the ideal of an inductance-free resistor is unattainable, the next best choice for a variable resistor is one in which the inductance is kept constant. This may be accomplished either by so designing the separate resistors that they all have the same inductance or by compensating for their variable inductance by introducing, at each step, sufficient inductance to keep the total inductance constant. The latter method has been adopted because it is very desirable, in switching from one value of resistance to another, that no new values be introduced during the transition.

The Type 668 Compensated Decade-Resistance Units make use of a double switch as shown in Figure 1, which connects between the decade resistors and a compensating winding of copper wire. This winding has the same inductance as the resistors but arranged in the opposite sense. In this way, as resistance is increased by a clockwise motion of the switch, the inductance of the compensating winding is reduced so that the total inductance remains constant. This method of compensation can be applied only to the smaller resistance decades because of the effect of the parallel capacitance introduced by the switch mechanism and by the windings themselves.

Any resistor may be represented by the series-parallel combination shown in Figure 2. The equivalent

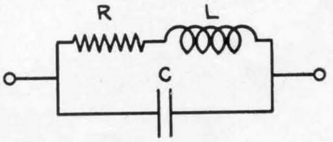


Figure 2. The behavior of any resistor can be predicted from a study of its series-parallel equivalent circuit

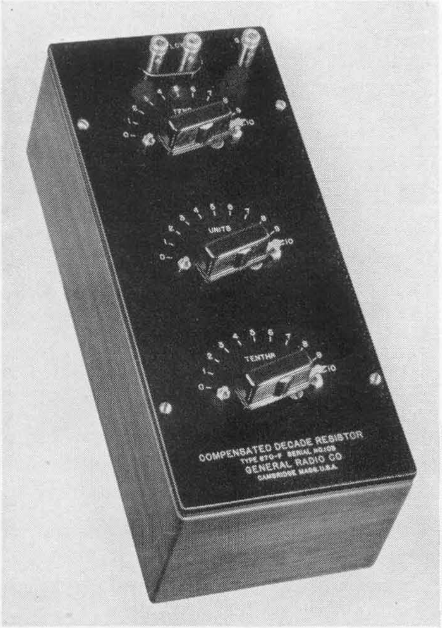


FIGURE 3. The TYPE 670-F Compensated Decade Resistor. An assembly of three TYPE 668 Decade-Resistance Units

inductance of this circuit is

$$\hat{L} = L - R^2C \qquad (1)$$

at all frequencies low compared with the natural frequency determined by the inductance and capacitance. It was shown in the General Radio *Experimenter* for February, 1932, that for the TYPE 510 Decade-Resistance Units the inductance L is proportional to resistance R and that the parallel capacitance C is approximately constant. The value of this capacitance is 6 $\mu\mu$f for a single decade, and it may be increased in a TYPE 602 Decade-Resistance Box by the multiple switches and shielding to a possible maximum of 60 $\mu\mu$f.

The form of equation (1) indicates that the equivalent inductance $\hat{L}$ will cease to increase at a certain value of resistance, will become zero when $L = R^2C$, and, for larger values of resistance, will become negative, that is, capacitive. The maximum value of inductance occurs at a resistance of about 100 ohms and reverses its sign at about the middle of the 100-ohm decade. Since it is possible to compensate for inductance variations by the method shown in Figure 1 only for an equivalent inductance increasing with resistance, this method is applicable only to the 10-ohm decade and lower.

The appearance of these compensated decades is shown in Figure 3.

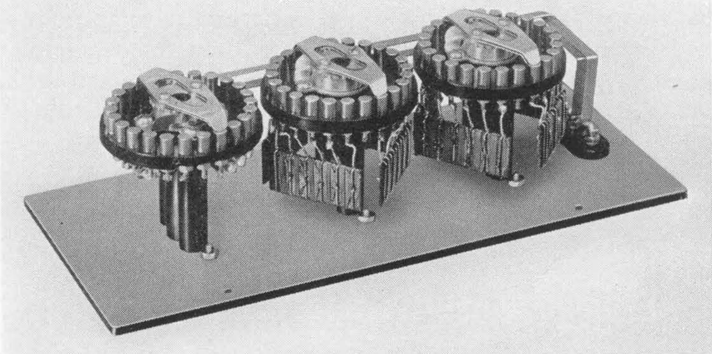


FIGURE 4. An interior view of the compensated decade resistor shown in Figure 3. In Figure 1 is shown the method by which the inductance is maintained constant for all settings of each switch

TABLE I

Data Summary for
Type 668 Compensated Decade-Resistance Units
and for Type 669 Compensated Slide-Wire Resistors

Type	*668-A*	*668-B*	*668-C*	*669-A*	*669-R*
Decade	0.1 ohm	1 ohm	10 ohms	....	....
Maximum Resistance	1 ohm	10 ohms	100 ohms	1 ohm	0.1 ohm
Time Constant	0.15 μ sec	0.03 μ sec	0.005 μ sec	0.15 μ sec	1.5 μ sec
Total Inductance	0.15 μh	0.3 μh	0.5 μh	0.15 μh	0.15 μh
Inductance Change	0.05 μh	0.05 μh	0.05 μh	0.005 μh	0.005 μh
Zero Resistance	0.005 ohm	0.020 ohm	0.015 ohm	0.045 ohm	0.020 ohm
Current for 40°C. Rise	1.6 a	0.5 a	0.16 a	1.6 a	5 a
Error	1%	0.25%	0.1%	1%	5%

The individual resistors of the tenth-ohm decade are similar to those used in the Type 510-A Decade-Resistance Unit. The cards used in the units and tens decades are smaller and thinner than those used in the Type 510-B and Type 510-C Decade-Resistance Units and were developed for use at high frequencies in the Type 516-C Radio-Frequency Bridge. Their power rating is 0.25 watt for a temperature rise of 40°C. and their inductance is considerably less than that of the corresponding Type 510 Decade-Resistance Units. The values of their time constants and total inductance at maximum setting are given in Table I. There is also given in this table the maximum change in inductance with setting due to imperfect compensation, their zero resistance, the current necessary to produce a temperature rise of 40°C., and the accuracy of adjustment. It will be noted that the total change in inductance is only 0.05 μh. Their zero resistances are larger than the switch resistances of the Type 510 Decade-Resistance Units, due to the resistance of the compensating winding. Since it is expected that the greatest use for these decades is in substitution methods, this relatively large zero resistance is not objectionable. The accuracy of adjustment given applies to the change in resistance from its zero value.

There are many uses for a variable resistor in which it is necessary to adjust its resistance value closer than 0.1 ohm and at the same time to keep its inductance constant. This may be accomplished by a slide wire compensated for inductance as shown in Figure 5. This is a developed view of a circular slide wire in which a short-circuiting arm connects from the top resistance wire to the bottom copper wire so that the inductance of the combination is independent of the position of the short-circuiting bridge. The copper wire return is placed symmetrically with respect to the two outer wires. This construction is adopted in the Type 669 Compensated Slide-

TABLE II

Data Summary for Type 670
Compensated Decade Resistors

Type	*670-F*	*670-FW*	*670-BW*
Zero Inductance	1.05 μh	1.05 μh	0.70 μh
Zero Resistance	0.045	0.085	0.050

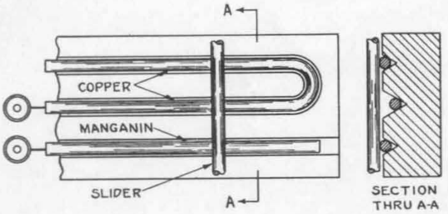


FIGURE 5. Inductance compensation as applied to slide-wire resistance units is shown schematically in this figure. The slider does not make contact with the center inductor

Wire Resistors as shown in Figure 6. There are two sizes with total resistances of 1 ohm and 0.1 ohm. In the latter, all the wires are of the same diameter. In the former, the copper wires are made of larger diameter than the manganin resistance wire in order to provide a greater wearing surface on the copper. In this case, the central copper return wire is unsymmetrically placed with respect to the two outside wires so that its inductance, with respect to them, is the same.

The various characteristics of these slide wires are given in Table I. Their constancy of inductance is such that they may be used as standards by which the inductance of other variable resistors may be measured.

The three TYPE 668 Compensated Resistance Units and the two TYPE 669 Compensated Slide-Wire Resistors are combined in three ways to form the TYPE 670 Compensated Decade Resistors. The TYPE 670-F Compensated Decade Resistor contains all three of the compensated decade resistors. The other two resistance boxes, TYPE 670-FW and TYPE 670-BW each combine one of the TYPE 669 Compensated Slide-Wire Resistors together with the next two higher compensated decades. The zero inductance and resistance of these three boxes are given in Table II.

—ROBERT F. FIELD

[Mr. Field is the designer of these new resistors.—Editor]

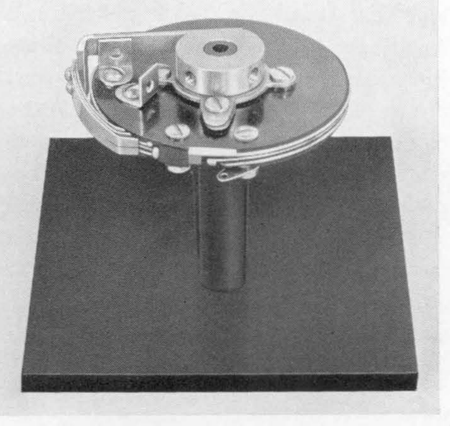


FIGURE 6. The TYPE 669 Compensated Slide-Wire Resistor. Its construction is indicated schematically in Figure 5

See Page 12 for Specifications

TAKING SLOW-MOTION MOVIES WITH AN ORDINARY MOTION-PICTURE CAMERA

All stroboscope-minded engineers are familiar with slow-motion movies in which a high-speed shutterless camera is used in conjunction with stroboscopic light, but it is not so generally known that similar pictures can be taken at normal speeds with the conventional movie camera.

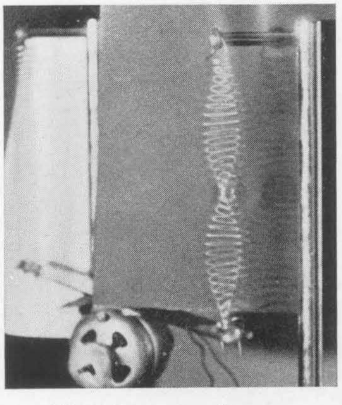
It is an almost axiomatic principle in motion-picture photography that you can photograph anything that you can see, provided, of course, that certain restrictions as to brilliancy of illumination are met. So, in theory at least, one should be able to photograph oscillatory phenomena in "slow motion" just as he views them with a stroboscope.

The hitch is, of course, that the camera shutter is closed for an appreciable part of the time, so that occasionally no flashes occur while the shutter is open. The result is a blank frame which, on projection, causes annoying flicker.

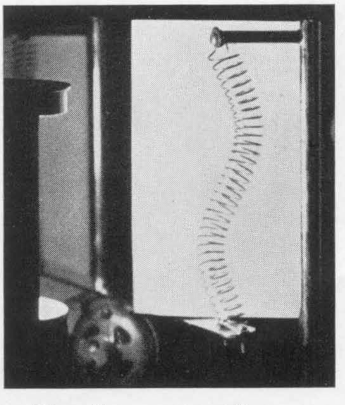
This difficulty is successfully overcome by so choosing the flashing speed of the stroboscopic light that there are at least two flashes for every frame, but, since there are 16 frames per second, this would seem to limit the application of this method to rotational speeds of 2 x 16 x 60 = 1900 revolutions per minute. Slower rotational speeds can, however, be photographed by reducing the speed of the camera sufficiently to retain the two-flashes-per-frame relationship. This is easy to do, and if, in addition, the *differential* flashing rate which determines the rapidity of the "slow motion" is reduced in proportion, the movies, when projected, will show the motion at the normal slow-motion rate.

Although this method is necessarily limited to recurrent (as distinguished from transient) phenomena, it is an excellent means of preparing pictures for demonstration purposes or for recording experimental results for future study and measurement.

—John D. Crawford

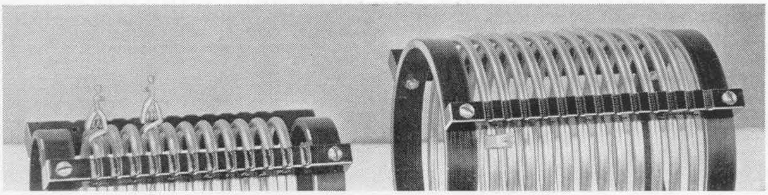


With Ordinary Light

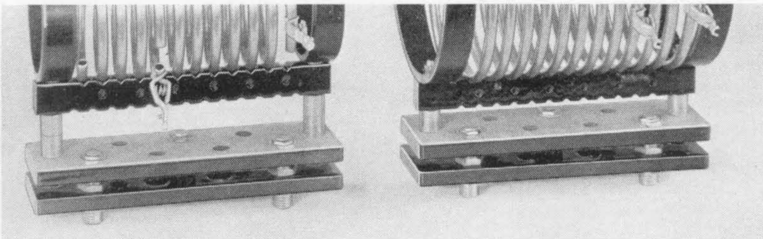


With Stroboscopic Light

One frame from a stroboscopic slow-motion movie made by the method described in the foregoing article compared with another taken with ordinary light. The Type 548-A Edgerton Stroboscope supplied plenty of illumination. (The photographs are unretouched and were taken with an ordinary 35-mm camera on super-speed panchromatic film with an $f3.5$ lens)



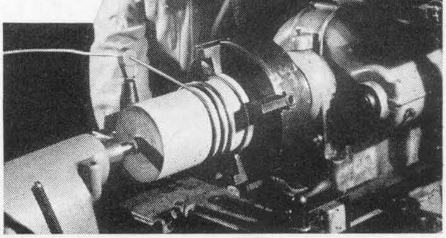
NEW INDUCTORS FOR THE POWER OSCILLATOR



ONE of the toughest mechanical jobs that the amateur or experimental laboratory constructor has is the winding of high-frequency coils for power amplifiers and oscillators. Copper tubing is the best material for such service, is extremely difficult to wind without flattening or breaking, even when the method of doing it has been carefully explained.* With care, the inexperienced mechanic can do it, but it's a long, hard job, and after he has tried it once, the amateur constructor, unless he has the patience of Job, will certainly try to buy his inductors ready-made.

The two new inductor units shown at the top of the page (at the right, TYPE 679-A; at the left TYPE 679-B) are recent additions to the General Radio line. The tubing is space-wound on a form by the method shown at right and then fitted into the ribbed porcelain supports which are held in place at both ends by bakelite rings. Each unit has a jack base fitted with three of the large-size General Radio plugs and there are holes for four more, if at some later time it is desired to add them.

It should be noted that the outer edges of the porcelain supports are also notched, so that extra coupling windings can, if desired, be added. Connections are made by copper clips, the jaws of which have been formed



This is how General Radio winds copper tubing in the manufacture of a TYPE 679-A Inductor

*See, for example, *The Radio Amateur's Handbook*, Tenth Edition, p. 88.

to fit the copper tubing. The tubing is nickel plated to eliminate the oxidation that always ruins the appearance of bare, unprotected copper. The added resistance of the nickel plating is entirely negligible, superstition to the contrary notwithstanding (in fact, it is a toss-up as to whether the nickel-plated or the oxidized-copper surface shows the greater resistance).

The essential details are given in the accompanying specifications. Both inductors were designed by J. M. Clayton in collaboration with Melville Eastham.

SPECIFICATIONS

Tubing: ¼-inch copper, nickel plated to prevent tarnish.

	Type 679-A	Type 679-B
Turns	12	7 and 4
Number of sections	1	2
Inductance (approximate)	10 μh	2 μh, 1.5 μh
Clips supplied	3	4
Type *674-P Plugs supplied*	3	3
Outside diameter of coil	5¾ in.	3¼ in.
Length, over-all	7¼ in.	7¼ in.
Height, over-all	8½ in.	6¾ in.
Depth, over-all	6½ in.	4½ in.
Net weight	3⅛ lbs.	2⅜ lbs.

Mounting: The terminal plate of each inductor is fitted with three Type 674-P Plugs so that the whole unit may be plugged into a Type 680-J Jack Base. Four additional plugs may be added to terminal plate of inductor if desired. (See illustration.)

Jack Base: This base (not included in the price of either inductor) is the counterpart of the plug base on the inductor unit. It is fitted with three Type 674-J Jacks, and four more may be added, if desired.

Prices: Type 679-A Inductor, $7.50; Type 679-B Inductor, $6.50; Type 680-A Jack Base, $1.25.

SPECIFICATIONS (Continued from page 9)

TYPE 668 COMPENSATED DECADE-RESISTANCE UNIT

Type	*Resistance*	*Code Word*	*Price*
668-A	1 ohm, total, in steps of 0.1 ohm	GABLE	$15.00
668-B	10 ohms, total, in steps of 1 ohm	GAILY	15.00
668-C	100 ohms, total, in steps of 10 ohms	GALOP	15.00

TYPE 669 COMPENSATED SLIDE-WIRE RESISTOR

Type	*Resistance*	*Code Word*	*Price*
669-A	0 to 1 ohm, continuously adjustable	GAMIN	$25.00
669-R	0 to 0.1 ohm, continuously adjustable	GAZEL	25.00

TYPE 670 COMPENSATED DECADE RESISTOR

		Dials			
Type	*Resistance*	*Decades*	*Slide Wire*	*Code Word*	*Price*
*670-BW	0 to 11 ohms, total (slide wire)	2	1	ABRID	$80.00
670-F	0 to 111 ohms, total, in steps of 0.1 ohm	3	...	ABYSS	65.00
*670-FW	0 to 111 ohms, total (slide wire)	2	1	ADOWN	75.00

*Built to order only and not carried in stock. Normal delivery, two weeks.

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ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

THE GENERAL RADIO-HAZELTINE REACTANCE METER

THE Hazeltine Corporation and associated companies have built up a completely successful testing routine for broadcast-receiver research and production involving the use of the "reactance meter." This instrument allows quick measurement of coils and condensers and quick adjustment of the "ganging" or "tracking" of receiver circuits. Many an engineer has told us that in his laboratory the reactance meter is one of his most-used instruments.

The great number of uses for the reactance meter in the radio industry has prompted the General Radio Company to manufacture this instrument under Hazeltine designs and patents. The original designs have been modified slightly, in order to incorporate improvements that have become possible since the original designs were drawn up.

The General Radio TYPE 421-A Reactance Meter consists essentially of two radio-frequency oscillators. In operation, both are set to the radio frequency at which the measurement is to be made and the unknown reactance is then connected across the tuning circuit of one of them. This oscillator is then retuned to zero beat with the first one by means of a variable condenser, the dial of which is calibrated directly in micromicrofarads. The reading of the dial, if negative, indicates directly the capacitance of the unit being measured. If the reading is positive, an inductance is indicated.

For the rapid matching of coils, etc., it is not necessary to convert this inductance reading to millihenrys or microhenrys since the micromicrofarad units may be used directly as a basis of comparison. Where a definite measure of inductance is required, it may be obtained by the simple formula $L = \frac{1}{\omega^2 \Delta C}$ in which L is the inductance in henrys, ω is 2π times the frequency at which the measurement is made, and ΔC is the capacitance difference read directly from the reactance-meter dials.

The reactance meter differs from the usual bridges used for measuring inductance and capacitance in that the

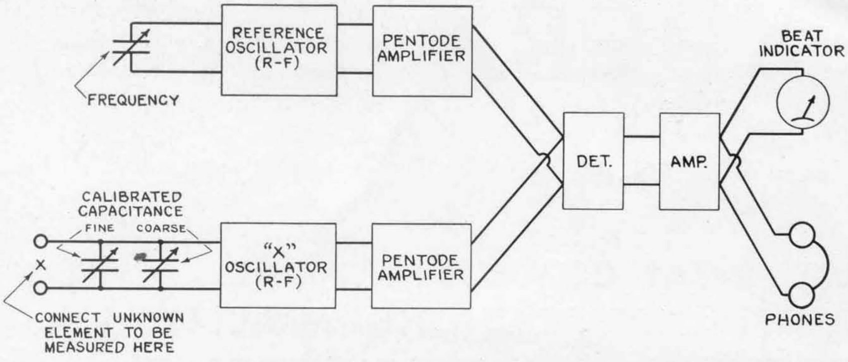

FIGURE 1. The reactance meter contains two oscillators, a calibrated condenser, and a means for indicating zero beat between the two oscillator systems

measurements are actually made at radio frequencies, thus closely approximating actual operating conditions. Furthermore, no power-factor balance is required and the indications are practically independent of power factor for most purposes. The instrument is simple to operate and direct reading for small values of capacitance. It also provides a very quick check when matching coils, condensers, etc., without the use of any computations.

What the instrument actually measures is the shunt susceptance connected to its terminals. Normal values of conductance have only small effect upon the reading. At some frequencies the reactance meter will actually function with conductances as large as 400 micromhos connected across its terminals.

The direct-reading dial on the instrument provides a range of 40 $\mu\mu$f and may be read to within 0.2 $\mu\mu$f or better. This dial controls the small condenser which is used in making most measurements. For measuring relatively large capacitances and inductances a larger condenser is provided on the meter. This condenser is supplied with a calibration curve and has a total capacitance of 2000 $\mu\mu$f. The actual range which may be covered on this large condenser depends upon the frequency at which the measurement is made, since this condenser is also used for setting to zero beat. Under the worst conditions, however, the range on this dial is equal to approximately 500 $\mu\mu$f. If desired, an external precision condenser can be used to extend the range where necessary. Extremely large capacitances or small inductances can be measured when placed in series with larger reactances, as will be described presently.

In designing the circuit for the reactance meter every effort was made to provide maximum convenience and accuracy. Aside from the direct-reading capacitance dial, and the calibration curve for the large condenser, a frequency calibration curve is supplied for each set of coils. Important frequencies in the broadcast band are calibrated directly on the frequency dial.

The visual beat-indicator meter is provided to supplement the usual telephones in setting accurately to zero beat. This meter is of the oxide-rectifier type and gives a definite indication allowing extremely accurate setting of the capacitance dials. Each of the oscillators is provided with a separate pentode amplifier, thus electrically isolating the oscillator circuits and, accordingly, minimizing any tendency for the two oscillators to pull into step as zero beat is approached. Oscillator and amplifier tubes and coils are individually shielded. The circuit has also been designed so that the operation is uniform over a wide range of frequencies and the readings of the instrument are independent of line voltage fluctuations.

It will readily be seen that the reactance meter may be used for a wide variety of measurements in the average receiver laboratory or production line. By means of this instrument, the differences between coils, condensers, etc., in the various stages of a multi-stage radio-frequency or intermediate-frequency amplifier can be immediately determined and suitable adjustments made if desired.

These measurements can generally be made without disconnecting any of the other equipment which may be connected in the circuit. For instance, let us consider a radio-frequency amplifier having four ganged condensers. Some frequency, say 1400 kilocycles, is selected for the test. With the first condenser in the gang connected across the "unknown" terminals of the reactance meter, and the receiver tuned for 1400 kilocycles, the COARSE CAPACITANCE dial is set for zero beat. The reactance meter is then disconnected from the first condenser in the gang and connected to the second condenser and retuned to zero beat by means of the FINE CAPACITANCE dial. The reading of this dial then indicates directly how much the second condenser is out of line with the first. This procedure may then be continued on each of the other condensers in the gang and with the condensers set to tune the receiver at various frequencies. For these tests the reactance meter frequency may remain unchanged. Typical results, as-

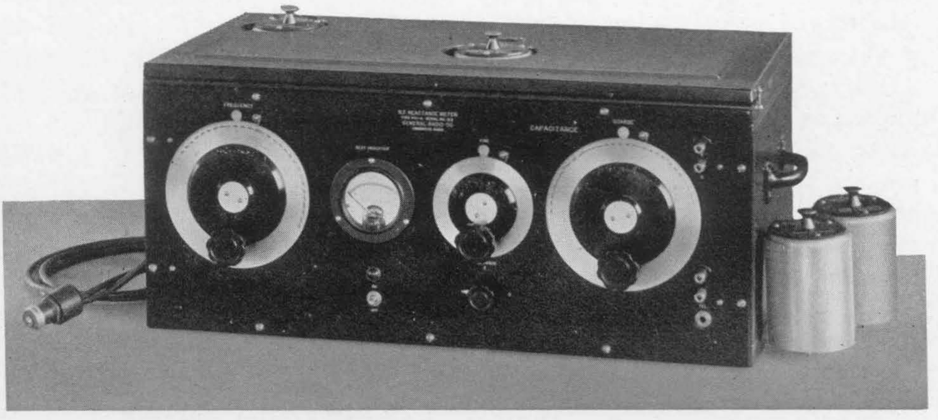

FIGURE 2. Front-of-panel view of the TYPE 421-A R. F. Reactance Meter. The dial at the left adjusts the frequency of the reference oscillator, the two at the right the "X" oscillator

suming the set to be aligned at 1400 kc on the dial, are as follows:

Approx. Receiver Tuning	*Condenser Corrections* *No. 1*	*No. 2*	*No. 3*	*No. 4*
1400 kc	0	0	0	0
1200 kc	0	+0.2 $\mu\mu$f	+0.4 $\mu\mu$f	−0.6 $\mu\mu$f
1000 kc	0	−1.4 $\mu\mu$f	−0.2 $\mu\mu$f	−0.2 $\mu\mu$f
800 kc	0	−3.4 $\mu\mu$f	+0.6 $\mu\mu$f	+0.6 $\mu\mu$f
600 kc	0	−3.0 $\mu\mu$f	+1.4 $\mu\mu$f	+1.0 $\mu\mu$f

A similar procedure may be used in checking the coils. For this purpose the tuning condensers are set at minimum capacity, thereby tuning all circuits out of the working range. In this case, however, the frequency of the reactance meter should be changed rather than the tuning condensers.

It will readily be seen that these types of measurements are invaluable in designing ganged receivers and also in checking gang condenser assemblies, matched sets of coils, etc. Charts like the above are extremely useful when made as a part of the sampling procedure to check alignment on sets taken from the production line. A similar but simplified procedure may be used for accurate alignment of completed receivers on the assembly line. In this case the trimmers are readjusted to produce zero beat.

The reactance meter is also useful in measuring the resonant frequency of choke coils, etc., since a coil measures zero reactance at its natural frequency, inductive below and capacitive above.

The capacitance of a large bypass condenser may be measured by connecting it in series with a known capacitance C within the normal range of the reactance meter. If ΔC is the difference between the readings of the reactance meter with and without the unknown in series with the condenser C, the actual capacitance of the unknown will be equal to

$$\frac{C^2}{\Delta C} - C.$$

Another frequent use of the reactance meter is to determine the inherent capacitance of a radio-frequency coil which resonates somewhere above the broadcast band. For this purpose, two frequencies are used and measurements taken with the reactance meter. If C_1 is the reading of the reactance meter at frequency f_1, and C_2 is the reading at frequency f_2, when f_2 is greater than f_1, then the actual L and C of the coil are:

$$L = \frac{1/f_1^2 - 1/f_2^2}{4\pi^2 (C_1 - C_2)}$$

$$C = \frac{f_1^2 C_1 - f_2^2 C_2}{f_2^2 - f_1^2}$$

A chart for easily obtaining L and C is provided in the instruction book.

The above illustrations do not in any way include the entire scope of the reactance meter, which can be applied to an almost unlimited number of problems. The illustrations are merely given as concrete examples of some of the more common types of measurements. Complete data for making these and many other types of measurements are supplied in the instruction book for the reactance meter.

The instrument is regularly supplied with three sets of coils, one covering the broadcast band, the others covering from 125 kc to 300 kc and from 1500 kc to 4000 kc. It is entirely operated from a source of 115-volts, 60-cycle power. All tubes are supplied.

—H. H. Scott

[The Type 421-A Reactance Meter described above is priced at $445.00, including three sets of coils.—Editor.]

A SHIELDED TRANSFORMER FOR BRIDGE-CIRCUIT USE

THE best transformer for connecting a generator to a bridge would have no direct capacitance between its primary and secondary windings and no terminal capacitances associated with its secondary winding. The existence of direct capacitance between primary and secondary allows the reflection into the bridge circuit of the terminal capacitances of the primary winding, made up in large part of the terminal capacitances of the generator itself, and applies directly to the bridge a small part of the generator voltage proportional to this direct capacitance. The existence of terminal capacitance of the secondary winding places these capacitances across the two arms of the bridge whose junction is grounded.[1]

When a bridge is used for direct measurements, the error introduced by terminal capacitances becomes negligible only when the ratio between these capacitances is the same as that between the two ratio arms. Transformers for equal-arm bridges are usually constructed in such a manner that the secondary terminal capacitances are equal. While the same practice might be followed for bridges with unequal ratio arms, it is not usually adopted. For bridges with variable ratio arms it is, of course, impossible to cause the ratio between the terminal capacitances to vary as the ratio arms are changed.

While for substitution methods the values of the terminal capacitances generally cancel out from the bridge equations, it is usually desirable to make them as small as possible. In this way, the second order effects due to the terminal capacitances and the errors introduced by the power factors of these capacitances are minimized.

Equality of the terminal capacitances may be obtained in two ways. Both depend upon the fact that either terminal capacitance of a winding is almost entirely that between the shield and the adjacent layer of the winding. To make the terminal capacitances equal, it is only necessary that the first and last layers of the winding be symmetrical with reference to the shield.

This was accomplished in the shielded transformers used in the General Radio TYPE 216 Capacity Bridge by dividing each winding into two parts and placing one coil of each winding on each of the legs of the transformer with the shield in between them, as shown in

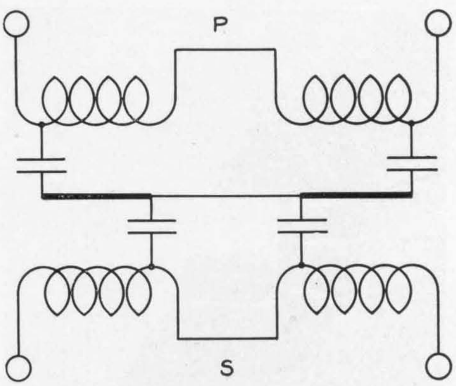

FIGURE 1. Two ways of connecting the "divided-winding" type of shielded transformer. The connection shown for the "S" winding is used on both windings of the TYPE 216 Capacity Bridge

[1]The "terminal capacitances" of a transformer winding are defined as the lumped equivalent capacitances between each of the two terminals and the shield of the distributed capacitance between the winding and the shield They are $C_{P1h'}$, $C_{P2h'}$, $C_{S1h''}$, and $C_{S2h''}$ in Figure 2. — EDITOR.

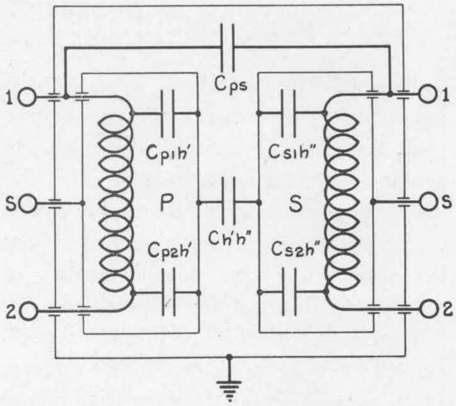

FIGURE 2. Capacitance network in the new TYPE 578-A Bridge Transformer

Figure 1. The two coils could be connected together so that the terminals of the winding nearest the shields are the terminals of the complete winding as shown for the primary winding, or they could be connected so that the terminals nearest the shields are at the junction of the two coils as shown for the secondary winding. In each case, the other terminal capacitance of each half of the winding is small. For the second case, in which the larger terminal capacitances are concentrated at the junction of the windings, the effective terminal capacitances of the coil are divided between its terminals in proportion to the voltages appearing across the two halves.

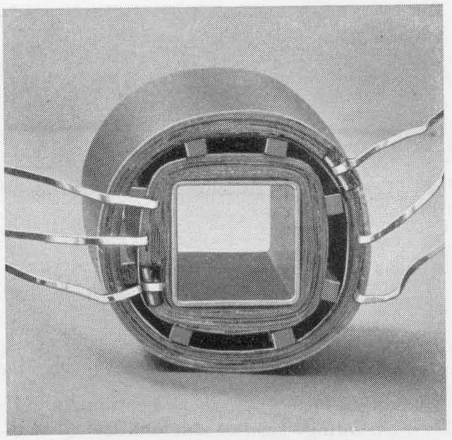

FIGURE 3. The TYPE 578-A Bridge Transformer has an air space between the two individually shielded windings

A second method by which the terminal capacitances of a coil may be made equal is illustrated in Figure 3. Two shields are provided, one at the beginning and the other at the end of the winding. The terminal capacitances are then the capacitances between the first and last layers of the winding and the adjacent shield. By making the thickness of the paper insulation between the layer and the shield proportional to the diameter of that layer, these two capacitances may be equalized. The two shields are then connected together. This method is preferable to that in which windings are placed on both legs of the transformer because it simplifies the method of winding and increases the coefficient of coupling of the transformer.

With the amount of paper that is allowable between the winding and shield, the terminal capacitances are larger than is desirable, being of the order of 200 $\mu\mu$f. The power factors of these terminal capacitances are approximately that of paper, about 1%. Both the effective terminal capacitance and its power factor can be reduced materially by surrounding both primary and secondary windings with their own shields and separating the adjacent shields by insulating spacers so that most of the capacitance between the shields is that due to air. In this manner, half the capacitance between the two shields is placed in series with each terminal capacitance so that each effective terminal capacitance is less than one-half of the capacitance between the two shields, provided that shield next to the winding is allowed to float, while the other shield is grounded. In case the shield next to the winding is connected to one of its terminals, the capacitance associated with that terminal becomes equal to the capacitance between the two shields, the other terminal capacitance being somewhat greater than the direct capacitance between the windings.

The new TYPE 578-A Bridge Transformer is made up of a primary and secondary winding shielded in the manner described above. This construction is shown in Figure 2. Representative values of its various terminal and direct capacitances are given in Table I. A copper shield placed between the iron core and the windings is grounded to the case. This effectively grounds the iron core and eliminates the necessity for grounding each separate lamination.

Aside from electrostatically isolating the generator and bridge which it connects, a transformer also serves to match the impedance of the bridge to the impedance of the generator and allow the maximum power transfer to the bridge. In the ideal transformer, the

FIGURE 4. A mounted TYPE 578-A Bridge Transformer showing the terminal plate on the 600-turn side

turns ratio of secondary to primary is the square root of the ratio of its load to the generator resistance. For this ideal case, the voltage appearing across the secondary load is one-half the generator voltage multiplied by the turns ratio. As the resistance ratio departs

TABLE I

CAPACITANCES OF TYPE 578-A BRIDGE TRANSFORMER

Direct Capacitance	Ground		Terminal Capacitance	Ground	
C_{PS}	h'	.2 μμf	$C_{P1h'}$	$h''S$	200 μμf
C_{PS}	h''	.2 μμf	$C_{P2h'}$	$h''S$	200 μμf
$C_{Ph'}$	h'', S	400 μμf	$C_{P1h''}$	S	13 μμf
$C_{Sh''}$	P, h'	400 μμf	$C_{P2h''}$	S	13 μμf
$C_{h'h''}$	P, S	30 μμf	$C_{S1h''}$	Ph'	200 μμf
$C_{Ph''}$	S	26 μμf	$C_{S2h''}$	Ph'	200 μμf
$C_{Sh'}$	P	26 μμf	$C_{S1h'}$	P	13 μμf
			$C_{S2h'}$	P	13 μμf

TABLE II

RESISTANCE RANGES OVER WHICH VOLTAGE RATIO OF A TYPE 548-A BRIDGE TRANSFORMER IS WITHIN 6DB

Connection	*Generator Resistance*	*Load Resistance*
Step-up	50 Ω to 5 kΩ	1 kΩ to 100 kΩ
Step-down	1 kΩ to 100 kΩ	50 Ω to 5 kΩ

from equality with the square of the turns ratio, the voltage ratio decreases slowly from its ideal maximum. For a departure of 4 to 1 in turns ratio or 16 to 1 in resistance ratio the voltage ratio is reduced to one-half the maximum, or 6 db. An allowable variation in voltage ratio of this magnitude is reasonable in the case of bridges for, by increasing the power of the oscillator or the amount of amplification in the detector, it is easy to make up for a 2 to 1 change in voltage. A transformer having a turns ratio of 4 to 1 which can be used either step-up or step-down is, therefore, suitable for all resistance ratios between 16 to 1 and 1 to 16. This is a sufficiently wide range to cover most of the impedances met with in generators and bridges.

The values chosen for the TYPE 578-A Bridge Transformer are such as to give a frequency range from 50 cycles to 10 kilocycles, over which the voltage ratio does not drop below one-half its maximum value, or 6 db. This variation in voltage ratio is allowable for bridge connections although it would be considered unsatisfactory for a high-quality voice circuit. For resistances varying from 50 ohms to 100 kilohms, this range may be divided as between step-up and step-down use according to Table II. For extremes in both resistance and frequency range, the effects of the two ranges are additive, so that the voltage ratio under these conditions may be ¼ the maximum value, or 12 db.

The transformer is mounted in a Model B case* with the copper shield inside the iron core grounded to the case. The terminals are brought out to six screw terminals, three on each side with the associated shield at the right, for permanent panel mounting. It may be mounted on one of the TYPE 274 Transformer-Mounting Bases for easy reversal of connections.

—ROBERT F. FIELD

*See pages 140 and 143 of Catalog G.

[The TYPE 578-A Bridge Transformer, recently developed by Mr. Field, is now available at $15.00. The code word is TABLE.

—EDITOR.]

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ELECTRICAL COMMUNICATIONS TECHNIQUE
AND ITS APPLICATIONS IN ALLIED FIELDS

HOW DIALS ARE MADE

PERHAPS the most important feature of any dial for instrument use is the scale, which must have uniform, clear, clean-cut divisions, accurately spaced. The scale may be made by several possible methods, one of which is stamping. The disadvantage of this method is that, after a few hundred scales have been produced, the die shows appreciable wear. The resulting wide scale markings plus the high initial cost of the die make this method not as satisfactory as other processes.

If a very accurate scale having a large number of fine, closely-spaced graduations is desired, the scale can be individually engraved on an automatic self-indexing engraving machine.* The precision scale thus produced has very uniform, accurately-spaced divisions, but the cost is necessarily high because of the labor involved.

Where extreme accuracy is not required and where good appearance and low cost must be combined, dials made by the "photo-etching" method are eminently satisfactory. As the name implies, the process is one in which photolithography and chemical etching are combined. Photolithography is used to print an etch-resisting coating over the surface of the dial, after which the unprotected metal is eaten away in a chemical bath.

The process is well adapted to the economical production of identical scales on a quantity basis. The details can best be understood by tracing the manufacture of a single dial, but it will be obvious that many dials can be handled as readily as a single unit.

The first essential step in the process is the making of a complete and accurate black-and-white drawing, usually to a large scale so that the subsequent reduction to actual size will minimize any small irregularities. The reduction is done in a camera having a lens carefully corrected for optical distortion, and the resulting negative is then used to make a transparent contact "positive," having black (opaque) lines on a white (transparent) background—a dial-sized replica of the original drawing.

*It is by this process that the scales on the General Radio Types 704 and 706 Precision Dials are made.

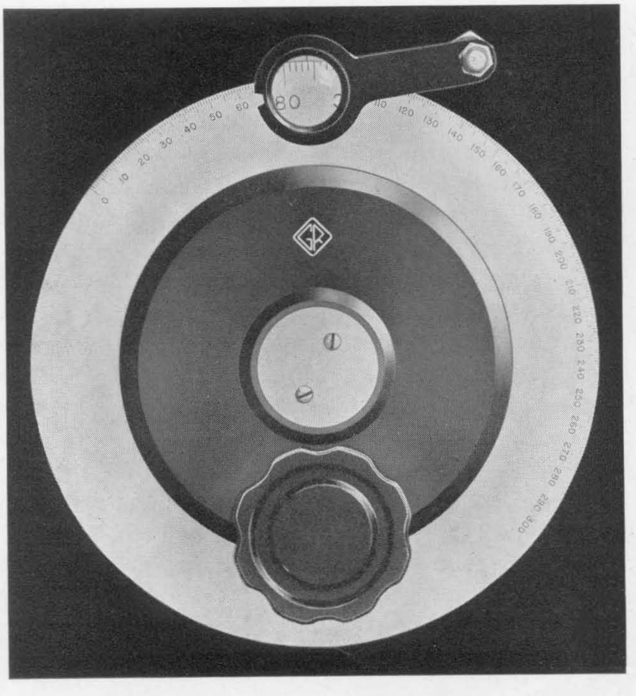
The self-indexing engraving machine which rules the scales on TYPE 704 and TYPE 706 Precision Dials

A plate of grained lithographic zinc of uniform surface is then coated with a light-sensitive solution of bichromate and albumen and carefully dried on a rotating disc at the proper temperature to produce an emulsion of uniform thickness. The zinc plate is then held in close contact with the transparent positive and exposed to intense illumination.

The exposed zinc plate is washed with a safe-etch solution and water and rolled up with lithographic ink in order to "develop" the image. The result is a zinc printing plate or "master" which takes ink wherever the positive allowed the light to strike and repels ink in the unexposed portions. The plate is placed on a flat-bed offset press which transfers the inked impression onto a rubber-covered roller or "blanket" and from that onto the actual piece of polished nickel-silver dial metal.*

After the ink has been transferred to the dial metal, the plate is then ready for etching. First it is dusted with a combination of asphaltum or dragon's blood powder and French chalk which adheres to the ink (background). The excess material is removed either by a small, soft brush or by compressed air.

*The process up to this point is simply photolithography, used for printing maps, calendars, circus posters, etc., except that the impression is made on paper or cloth instead of dial metal. Many of the small-sized General Radio instruction booklets are made by this process from typewritten originals.—EDITOR.

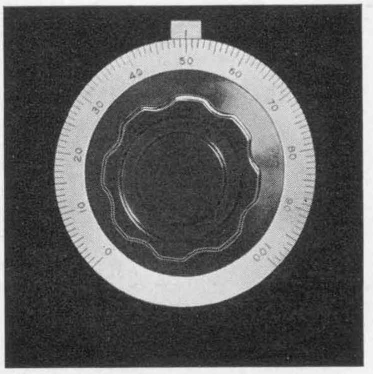


General Radio precision dials have individually engraved scales: A TYPE 706 Dial with a TYPE 519-A Dial Lens

The ink and the powder are fused and hardened by heating the sheet of metal either in an oven or over an open flame. The heating of the plate forms the acid-resist material which covers the metal where it is not desired to etch. It is especially important in the manufacture of dial scales not to apply too much heat which may distort the metal. The back of the plate is covered with asphaltum paint or other resisting material.

The etching process is purely chemical. The dial metal is hung in a solution of perchloride of iron crystals and muriatic acid which is kept constantly agitated to hasten the etching. Fifteen or twenty minutes is the usual time required for etching, but this varies with the strength of the acid, the metal of which the dials are being made, and the depth it is desired to etch. After etching is completed, the metal is dipped in cleaning chemicals and rinsed in water.

The plate, with the scales and figures etched and the background still covered with the acid-resist material, is then sprayed over the entire surface with black lacquer. After this is dry, the dial plate is immersed in a solvent



The etching process described in the accompanying article is used to make the scales on dials like this one: A TYPE 710-B, 2¾-inch dial

which removes the acid-resist material, with its coating of lacquer, leaving the polished dial metal exposed. The lacquer in the etched portions is unaffected by the solvent.

The individual dial scales are cut out and mounted on a spindle and the circular-grain finish is applied with fine emery and polishing wheels. The scales are then turned down to the exact diameter and sprayed with clear lacquer to preserve the finish. The completed dial scales are then mounted on their respective bakelite knobs and placed in stock. —MYRON T. SMITH

A NEW SWEEP CIRCUIT FOR THE ELECTRON OSCILLOGRAPH

LAST June the General Radio Company introduced the TYPE 635-A Electron Oscillograph, a small and portable type of cathode-ray oscillograph which at that time was an innovation. Although the standard TYPE 506-A Bedell Sweep Circuit* can, of course, be used to provide a linear time axis for this oscillograph, there has been considerable demand for a lower-priced unit designed mainly for use with the portable electron oscillograph.

The laboratories of the General Radio Company have, accordingly, developed a new sweep circuit known as the TYPE 655-A Bedell Sweep Circuit*

* U. S. Patent 1,707,594.

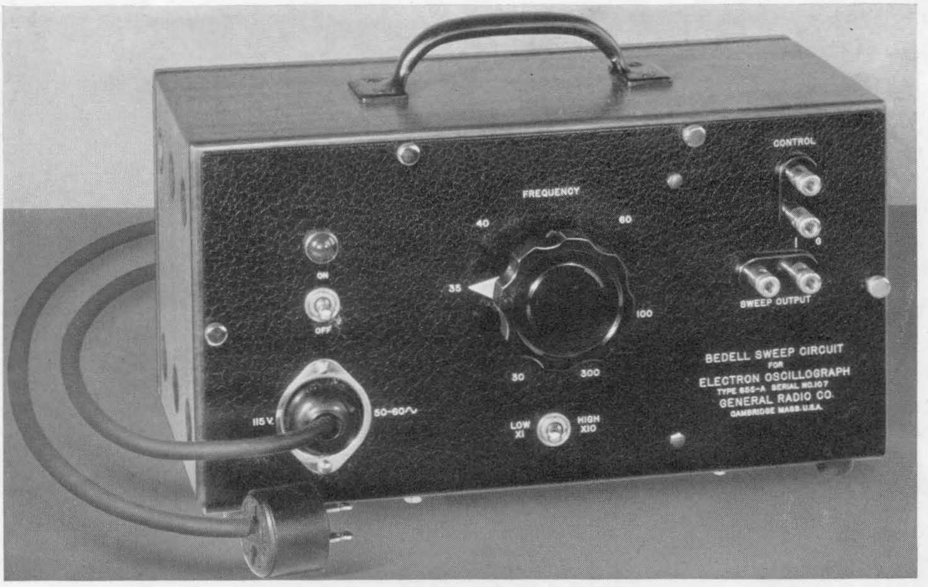


FIGURE 1. This new instrument supplies a controlled linear sweep for the General Radio TYPE 635 Electron Oscillograph

for Electron Oscillograph and intended mainly for use with the TYPE 635-A and TYPE 635-B Electron Oscillographs.* Since the new sweep circuit was intended primarily for use with a single general type of oscillograph, it has been possible to simplify it appreciably without sacrificing any of the important features which have made the TYPE 506-A Bedell Sweep Circuit so popular.

In the first place, since the sensitivity of the TYPE 635 Electron Oscillographs is not adjustable, the sweep circuit may be designed to give a definite length of sweep. For the same reason, the direct polarizing voltage which centers the pattern on the oscillograph screen may be left fixed. These factors alone make possible the elimination of two controls. It has also been possible to provide fixed synchronizing circuits in this sweep circuit which will allow control of the sweeping action for any voltage sufficient to produce a satisfactory deflection on the cathode-ray tube.

It will, accordingly, be seen that the only characteristic of the operation of the sweep circuit which must be adjustable is the frequency. In the TYPE 655-A Bedell Sweep Circuit this is accomplished by a single knob covering ranges from 30 to 300 cycles per second and from 300 to 3000 cycles per second. A double-pole switch is provided for shifting the range.

This sweeping frequency range of 30 to 3000 cycles per second was determined after a careful investigation of the uses to which cathode-ray oscillographs are generally put. We have found that the most common use for oscillographs with sweep circuits is the

*The TYPE 635-B Electron Oscillograph is a modified form of the original TYPE 635-A Electron Oscillograph and uses the RCA-906 cathode-ray oscillograph tube or its equivalent.

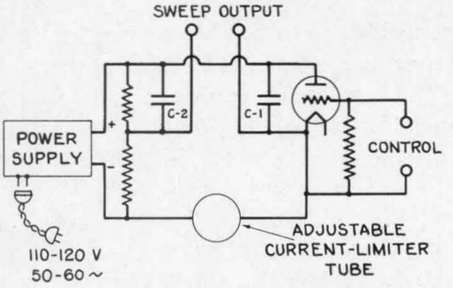


FIGURE 2. Schematic diagram for the TYPE 655-A Bedell Sweep Circuit

observation of audio-frequency waveforms in the range from 30 to 15,000 cycles per second. Another common use of the oscillograph is for observing modulated radio-frequency waves, the modulation frequency being within this same audio range and, accordingly, requiring the same sweeping frequency as for a corresponding audio-frequency waveform.

The TYPE 655-A Bedell Sweep Circuit allows observation of frequencies down to 30 cycles per second. At its upper sweeping limit of 3000 cycles per second a 15,000-cycle wave will be seen with five complete cycles across the cathode-ray screen. Similarly, 18,000- and 21,000-cycle waves, which are above the limit of audibility for most people, may be seen on the oscillograph with six and seven complete cycles, respectively, spread across the screen. For the few special occasions when extremely low sweeping frequencies are required, an external condenser may be used to extend the range.

We have also found that portable oscillographs of this type are frequently used for 60-cycle work. With the range of the TYPE 655-A Bedell Sweep Circuit either one or two cycles of a 60-cycle wave may be seen on the oscillograph.

The principle of operation of the TYPE 655-A Bedell Sweep Circuit is similar to that of the popular TYPE 506-A Bedell Sweep Circuit. Figure 2 shows the general arrangement. The condenser C-1 is charged at a constant current which is determined by the setting of the adjustable current limiter. When the voltage across this condenser reaches the breakdown value for the 885-type discharge tube, the tube flashes and discharges the condenser. The cycle then repeats itself. By introducing a small voltage of the frequency of the observed wave into the grid circuit of the discharge tube, the sweeping action may be made to synchronize with the observed wave, thus giving a steady pattern on the oscillograph screen which may be inspected carefully or photographed.

Of course, the arrangement shown in Figure 2 is not the complete wiring diagram for the instrument, which necessarily includes arrangements for providing the proper grid bias on the discharge tube, for controlling the current limiting action, etc. The sweep circuit also contains a complete a-c operated power-supply unit and a filter for minimizing interference transmitted back from the discharge tube through the control circuits.

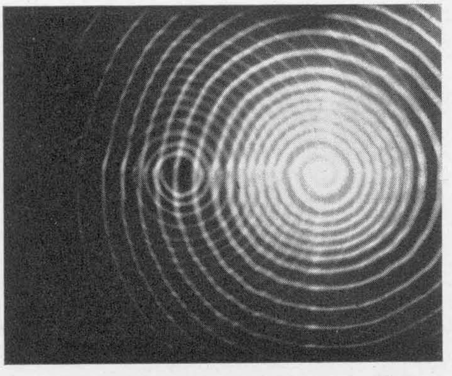
The operation of the TYPE 655-A Bedell Sweep Circuit is extremely simple. The terminal posts are so arranged on the panel that it is merely necessary to connect together corresponding posts on the oscillograph and on the sweep circuit. Only the single large frequency knob and its associated two-range switch need be adjusted, and this adjustment involves only turning the knob or setting the switch so that the desired pattern is seen on the screen. The panel of the instrument is engraved directly in approximate sweeping frequency, making it possible to set the instrument quickly to any desired value or to determine the approximate frequency of an observed waveform.

The instrument is supplied complete with a set of tubes which consist of one 885-type tube, one 58-type tube, and one 80-type tube. No batteries whatsoever are required for the operation. The instrument operates on any source of 110-120 volts, 50-60 cycles alternating current. —H. H. Scott

[The price of the new Type 655-A Bedell Sweep Circuit described in the foregoing article is $60 including tubes. The new Type 635-B Electron Oscillograph, also mentioned in the article, is priced at $80 including tubes. The sweep circuit was developed by Mr. Scott; the new oscillograph by E. Karplus.—Editor]

PHOTOGRAPHY OF TRANSIENTS WITH A CATHODE-RAY OSCILLOGRAPH*

Taking satisfactory photographs of stationary recurrent patterns appearing on the fluorescent screen of a modern cathode-ray oscillograph is a fairly simple matter inasmuch as the exposure time need be limited only by the observer's ability to maintain a stable pattern. When, however, he must record transient phenomena in which the spot sweeps only once across the screen, the "speed" of both lens and sensitive emulsion must be suited to the brilliancy of the spot and to the speed with which it moves across the screen. There is a maximum spot velocity beyond which a given spot brilliancy and a given lens-emulsion combination will fail to produce a usable record. The experimental determination of this limiting velocity is a fundamental consideration.

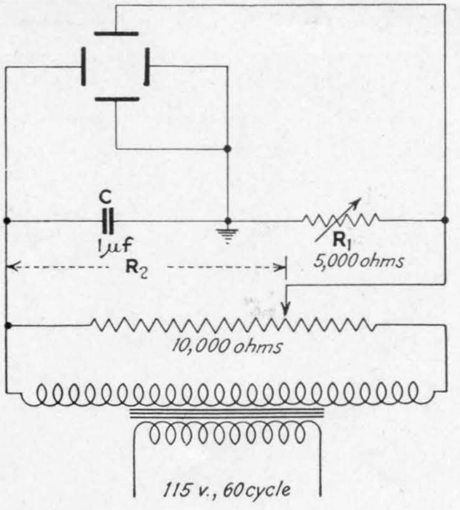


Two maximum-velocity spirals of the type described in the accompanying article. Each was taken with a different accelerating voltage on the tube

The simple method of measuring the limiting velocity described here is believed to have been the original idea of Eduard Karplus, Engineer, of the General Radio Company. It depends for its

*Reprinted from the "Notes on Electron Tubes and Circuits" section in the April, 1934, issue of *Electronics*. Copyright, 1934, McGraw-Hill Publishing Co.

operation on the fact that, when both pairs of deflecting plates are excited by equal a-c voltages of the same frequency but 90° out of phase, the circular (Lissajou) figure appears. This is traced out by the fluorescent spot which sweeps around the circle once for each cycle of the applied a-c voltage. Obviously, the velocity of the spot is proportional to the diameter of the circle, so that if its diameter is progressively increased, there will be a point beyond which a single passage of the spot fails to make an impression on the emulsion. A record of this type is shown in which the diameter of the circle was rapidly widened during the exposure so that the spot executed a spiral.



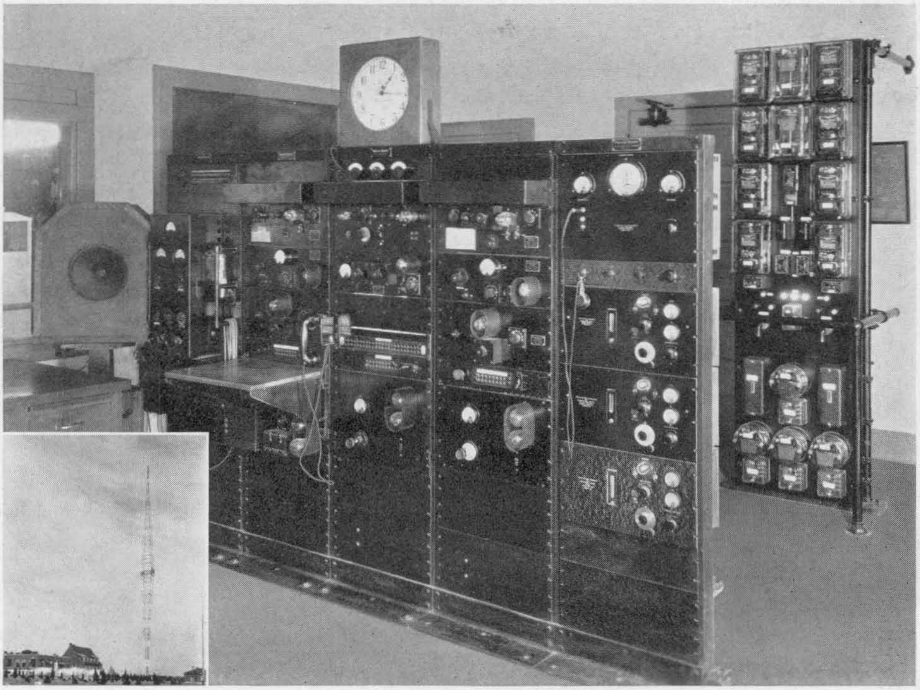
Circuit for measuring the maximum velocity of oscillograph spot that a given lens-emulsion combination will record

A convenient circuit for making the test, using the 115-volt, 60-cycle line is shown. The two quadrature voltages are taken off across C and R_1, R_1 being adjustable so that the voltages can be made equal. R_2 is a voltage divider across the line. By adjusting it, the diameter of the circular pattern can be changed at will.

The test exposure is made by decreasing R_2 until the circle is a mere spot, then the camera shutter is opened and R_2 quickly increased to a maximum. This produces a corresponding rapid increase in the diameter of the circle traced by the moving spot, which results in the spiral shown. The velocity at any point on the spiral is given by the relation $v = 2\pi rf$, where r is the distance from the center to the point in question, f is the frequency in cycles per second, and v is the velocity in linear units per second, the unit being the same as that chosen to measure r. The use of the 60-cycle line will usually give a sufficiently wide range of test velocities for cathode-ray oscillograph tubes now generally available, but greater velocities can, of course, be obtained by increasing the test frequency.

Because of the ease with which this test can be carried out, experimenters working with transients that approach the limiting velocity can easily test out each new package of emulsion stock in the same way that photographers who are trying for perfection often determine by trial the exposure required by the particular batch of printing paper being used. —John D. Crawford

CROSLEY'S WLW



RATED at 500,000 F-R-C, gold-standard watts, WLW's new plant at Mason, Ohio, has just gone on the air full time as the world's largest.

The *Experimenter* reverses the emphasis given these two photographs in the popular press to call attention to General Radio frequency monitors in the right-hand relay rack in the foreground. At the top is the frequency-deviation indicator which operates from one of the three standard-frequency oscillators below it. Three oscillators are required because this same control room is used for WSAI and W8XAL, two other Crosley channels.

Joseph A. Chambers is the Technical Supervisor.

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ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

NEW DEVELOPMENTS IN ELECTRON OSCILLOGRAPHY

FEW laboratory instruments have undergone more changes in recent years than the cathode-ray tube. All of these changes have been in the direction of longer life, lower cost, and increased simplicity of accessories, combining to produce equipment of so compact and inexpensive a nature as to open up new fields to this type of oscillography.

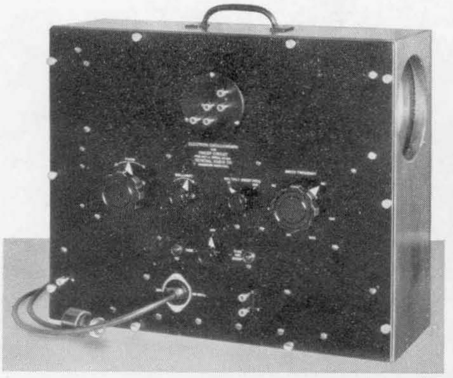
The cathode-ray type of oscillograph is, of course, old, but early tubes combined short life and high price with a complication of accessory apparatus—even including a vacuum pump in some early models—which limited the use of cathode-ray tubes to those laboratory applications where this type of oscillograph was absolutely necessary, and the tubes were almost never used outside of the laboratory.

Cheaper tubes of longer life were an early by-product of television experiments. Among the first of these to be popularized for general laboratory use was the von Ardenne tube announced with the necessary accessory apparatus by the General Radio Company. While these tubes were far more satisfactory for laboratory applications than earlier types, the cost was still relatively high in view of the tube life and the assembly left some considerable room for further refinements, although for the first time cathode-ray tubes became extensively used for general oscillography.

Further developments in this country have resulted in a line of high-vacuum tubes at greatly reduced cost which have been produced by several manufacturers. In an effort to make cathode-ray equipment further available for general testing work, the General Radio electron oscillograph was announced, which included in a single unit a cathode-ray tube and power supply.* This popular unit which could be carried about conveniently has been extensively used in schools and plants, replacing mechanical-element types of oscillograph in certain types of work.

Many types of oscillograph applications require a sweep circuit to obtain a time axis. Recent developments in tubes and circuits have permitted a

*The General Radio *Experimenter* for June-July, 1933.



The new Electron Oscillograph (TYPE 687-A) includes sweep circuit and power supply

greatly simplified type of sweep circuit, and we are now announcing the TYPE 687-A Electron Oscillograph and Sweep Circuit* which includes sweep circuit, power supply, and tube in a single portable unit entirely operated from the alternating-current line.

The significance of this development can best be appreciated by a comparison with the earlier two- and three-unit equipment which could not be conveniently carried by one person and required a great deal of setting up and connecting before the equipment was ready for use. The new apparatus is as convenient to use as a voltmeter. It requires only connection to the line and to the source of voltage which is being examined. This simplicity will undoubtedly increase the popularity of the cathode-ray tube for general oscillography. From the most complicated and inconvenient type of oscillograph it has become the simplest, most portable, and easily operated. All of these improvements are accompanied by a large reduction in cost and increase in life.

The oscillograph is ideally suited to measurements of modulation with a sinusoidal waveform. The oscillograph may also be used with a linear sweep for providing a continuous check upon modulation, since a single glance at the modulation envelope pattern will show whether or not overmodulation is taking place.

The oscillograph can be used without the sweep circuit for measuring percentage modulation by means of the familiar trapezoidal patterns. This allows an accurate measurement under steady state conditions.

The TYPE 687-A Electron Oscillograph and Sweep Circuit uses a 5-inch tube with electrostatic deflecting plates. The construction and theory of such tubes have been discussed in previous issues of the *Experimenter*.† While the linear sweep circuit is included in the equipment, switching is provided so that the instrument can be used either with or without a sweep circuit. Both pairs of deflecting plates are brought out and are available for external connections, permitting operation of either pair of plates balanced or unbalanced to ground.

The sweep circuit is of the stabilized type, which can be made to lock in step with a recurrent waveform. This feature allows careful visual study, or photographic reproduction, of recurrent audio-frequency waveforms and other phenomena.

The tube supplied as initial equipment is the General Radio TYPE 687-P1 Electron Oscillograph Tube (RCA-905 or equivalent). The impedance of the deflecting-plate circuits is about 15 micromicrofarads. The deflection sensitivity for vertical deflection is about 75 d-c volts per inch. The sensitivity

*U. S. Patent 1,707,594.

†May and June, 1932, and November, 1933.

for the horizontal deflecting plates is about 90 d-c volts per inch.

Mechanically, the equipment is assembled in a carrying case of convenient dimensions with handle, making it easily portable.

Dimensions: (Length) 19⅝″ by (width) 8¼″ by (height) 17¾″ over-all.
Weight: 37¼ pounds.
Price: $180.00, including all tubes.
Code Word: CRISP.

[NOTE: The TYPE 687-A Electron Oscillograph and Sweep Circuit was designed by H. H. Scott and E. Karplus.

—EDITOR]

NEW ACOUSTIC RESPONSE RECORDER

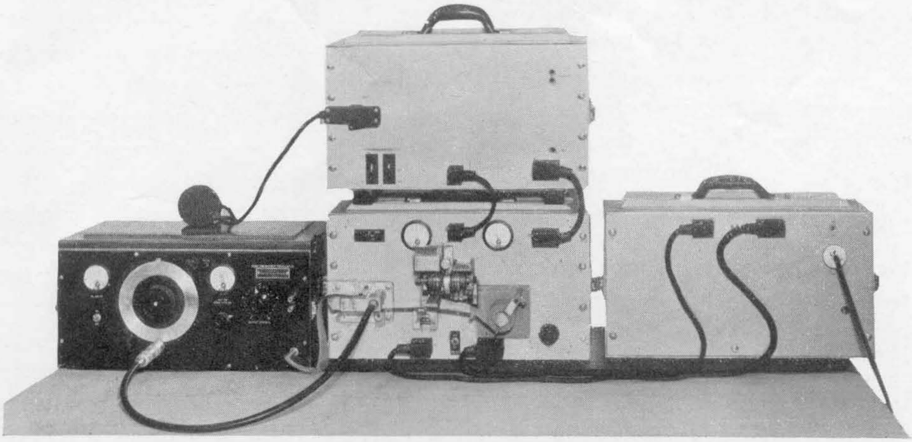


FIGURE 1. The high-speed level recorder. At the left is a General Radio TYPE 613-B Beat-Frequency Oscillator, in the center is the recording unit and its associated amplifier, and at the right a battery box

"TO supplement and augment their theoretical information, engineers have had to seek the aid of instruments. As has been the case with most work in acoustics, recent or otherwise, and because the field is a comparatively unexploited one, instruments have had to be developed especially for the purpose. One of the devices that has just become available is the high-speed level recorder,* which has already proved its value in conducting measurements of reverberation time and frequency response. Its name suggests its purpose: it automatically records sound intensity levels as they fluctuate at a point.

"Figure 1 is a photograph of the meter, designed by the Bell Telephone Laboratories, set up for synchronous operation with a beat-frequency oscillator. Excluding the oscillator, there are three separate units: the recording unit proper, its associated amplifier, and a battery box. The record is impressed on a moving waxed paper strip by a stylus which follows the changes of the sound intensity. The speed of the paper may be varied in three steps from $\frac{3}{64}$ inch per second to 3 inches per second. The stylus also may be adjusted to follow changes of intensity from 45 decibels per second to as much as 360 decibels per second. By driving

*WENTE, E. C., BEDELL, E. H., and SWARTZEL, K. D.: "A High-Speed Level Recorder for Acoustical Measurement," presented at the May, 1933, meeting of the Acoustical Society of America.

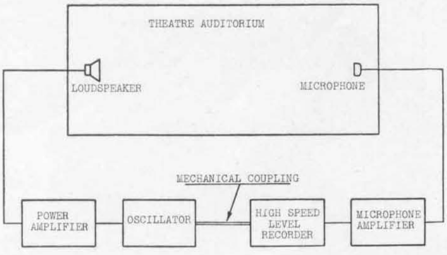


Figure 2. Schematic diagram of the acoustic response measuring equipment

the paper and the oscillator frequency control synchronously, the horizontal axis may be made proportional to the frequency instead of to the time.

"Figure 2 is a schematic drawing of the recorder as it is used for determinations of loudspeaker response in auditoriums. It is obvious that by means of such an arrangement measurements can be made expeditiously and automatically, and that, therefore, very complete information concerning the performance of a loudspeaker in a given auditorium can readily be obtained. Figure 3 is an example of such a study. The sound intensity level at a point in a theater is given as a function of the frequency from 0 to 10,000 cycles. It will be noted that the response falls off above 4000 cycles. In this

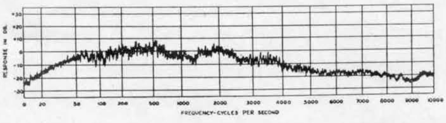


Figure 3. Typical frequency response characteristic

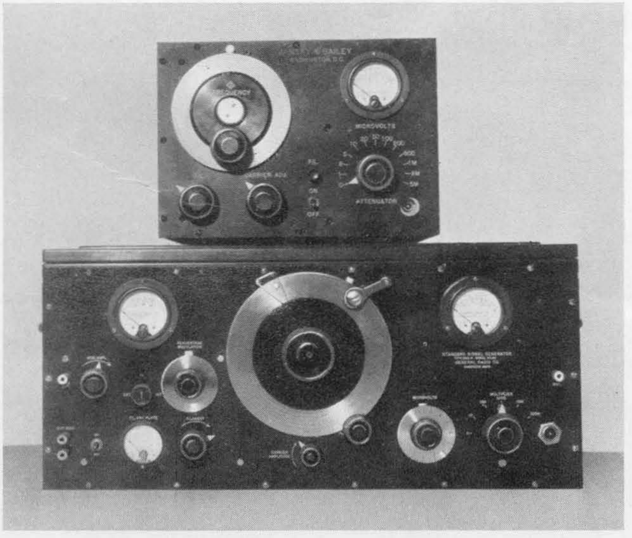
particular instance, the loudspeaker input circuits were adjusted to produce such an effect in order to avoid accentuation of the (high-frequency) surface noise very prominent in the older recordings. By conducting several such tests at representative points in a theater, valuable information concerning the distribution of sound energy, the over-all response of the system, resonances, and peculiarities of the auditorium may be ascertained."

The oscillator (at the left) is a General Radio Type 613-B Beat-Frequency Oscillator whose main tuning control is driven from the high-speed level recorder in the center by a flexible shaft.

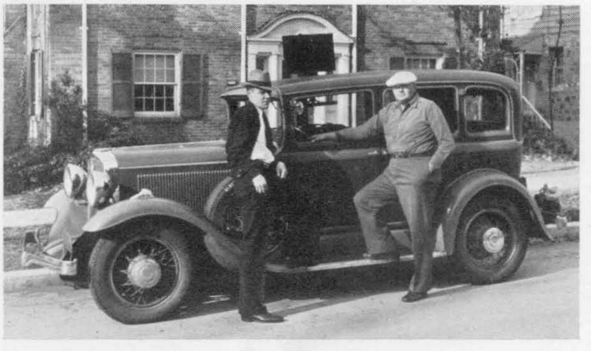
[Editor's Note—This description is from a paper "Acoustical Requirements for Wide-Range Reproduction of Sound," by S. K. Wolf of Electrical Research Products, Inc., New York, appearing in the April, 1934, issue of the *Journal* of the Society of Motion Picture Engineers. The quoted material and the three illustrations are reprinted through courtesy of the *Journal*.]

NEW YORK ENGINEERING OFFICE

In order that engineering information may be more readily available to our clients in the New York Metropolitan area we have opened an office at 90 West St., New York City. The telephone is Cortlandt 7-9382. While Mr. Myron T. Smith of our general engineering staff at Cambridge will be at the New York office a large part of the time, other engineer members of our Cambridge staff will be there from time to time. Correspondence regarding general matters should continue to be sent to Cambridge, Massachusetts.



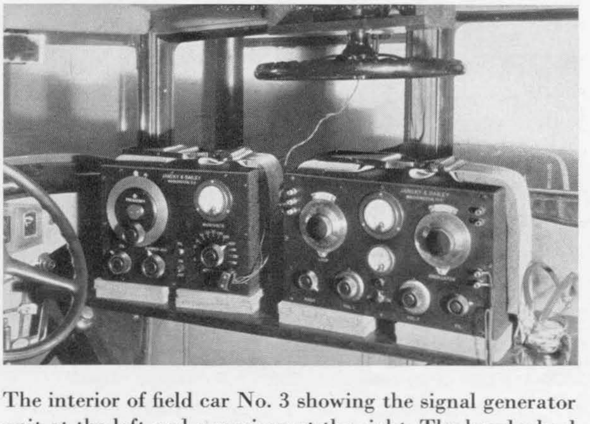
Small size standard-signal generator built by Jansky and Bailey for field intensity survey work. The calibrated attenuator is the same one used in the General Radio Type 603-A Standard-Signal Generator shown in the cabinet beneath the Jansky and Bailey unit



Jansky and Bailey field car No. 3; C. M. Jansky, Jr., at the right, M. M. Garrison at the left

"COVERAGE SERVICE A SPECIALTY"

BROADCASTING stations sell time on the air on the basis of coverage, *i.e.*, the number of listeners in the station's service area. C. M. Jansky, Jr., and S. L. Bailey, consulting engineers, operating as the firm of Jansky and Bailey, Washington, D. C., were among the first to advocate the field intensity survey as a method of putting coverage determinations on a scientific measurable basis. The accompanying photographs show some of the equipment used by Jansky and Bailey.



The interior of field car No. 3 showing the signal generator unit at the left and a receiver at the right. The hand wheel for orienting the loop is shown at the top of the photograph

ANTENNA MEASURING SET*

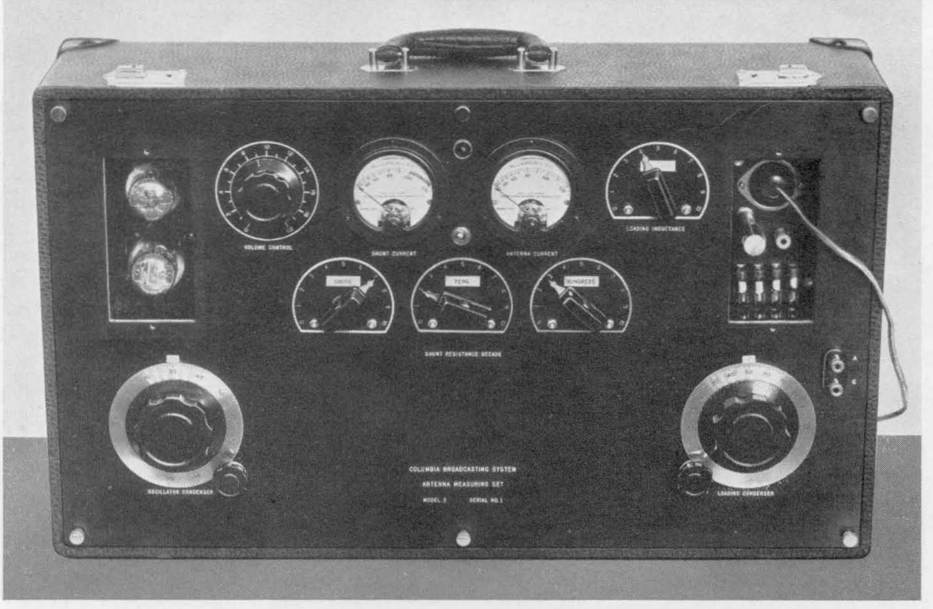


FIGURE 1. Front view of the CBS antenna measuring set

"THE impedance of the transmitting antenna and its transmission line are two of the most important constants in the equipment of a radio broadcasting station. Knowing these values, it is possible for the engineer to determine the power actually delivered to the antenna by the transmitter, the constants of the coils or condensers necessary to tune the antenna to resonance, and the proper method to follow in coupling together the antenna, the transmission line, and the transmitter. These problems must be solved during the lining-up period of a radio station.

"In the case of a low-powered transmitter, a cut and try procedure is satisfactory. But when the radio engineer is faced with the installation of a modern, high powered radio transmitter which must operate at the highest efficiency possible, the requirements are more rigid. Approximations which might be overlooked in the adjustment of a smaller transmitter would then result in the loss of many kilowatts of valuable radio-frequency power and the probability of burnout or damage to expensive equipment.

"To date there has been available no compact field equipment for use in antenna and transmission line work. Due largely to this lack of equipment, radio engineers familiar with this type of work require anywhere from two to eight weeks to properly adjust the radiating equipment of a high powered broadcast transmitter. Furthermore, if the problem is complicated by the requirements of a directive antenna system, or the reduction of harmonic radiation, longer periods of adjustment may be necessary before the station is ready for year-in and year-out operation. Therefore, engineering expenses of such work become quite appreciable.

"With the engineering of a large number of radio transmitters under the supervision of New York headquarters, the technical department of the Columbia Broadcasting System found it necessary to develop a convenient and accurate antenna measuring set.

"The set is designed to measure the impedance of any antenna from 0.1 to 0.9 wavelengths long, giving the resistive and reactive components. It may also be used to determine the characteristic impedance and the electrical length of two-wire or concentric tube radio-frequency transmission lines. And, what is probably the greatest time saver, this unit also measures the terminating impedance at the antenna end of the transmission line. All of these values must be determined to properly engineer a large broadcast installation."

The set is also designed to measure the impedance of any radio-frequency network whose resistive component does not exceed 1000 ohms. The frequency range is 500 kc to 1800 kc and the unit is a-c operated.

Mr. Lodge's article in *Radio Engineering* shows a wiring diagram and gives instructions for making measurements of resistance and reactance with the unit. The use of the equipment for measuring the surge impedance of transmission lines is also discussed.

Mr. Lodge incorporated a large number of General Radio laboratory accessories in the design of this instrument.

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*Abstract from "Antenna Measuring Set" by W. B. Lodge of the Columbia Broadcasting System appearing in *Radio Engineering* for April, 1934.

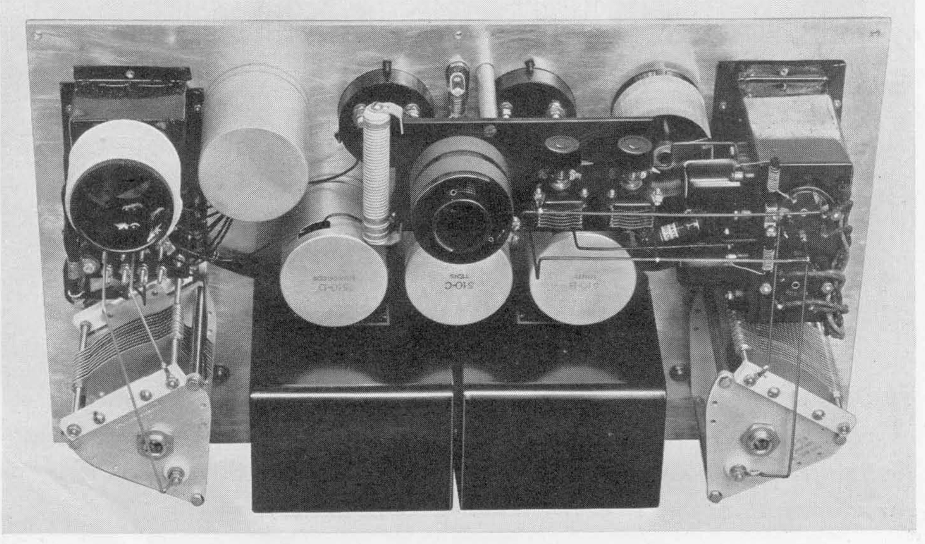
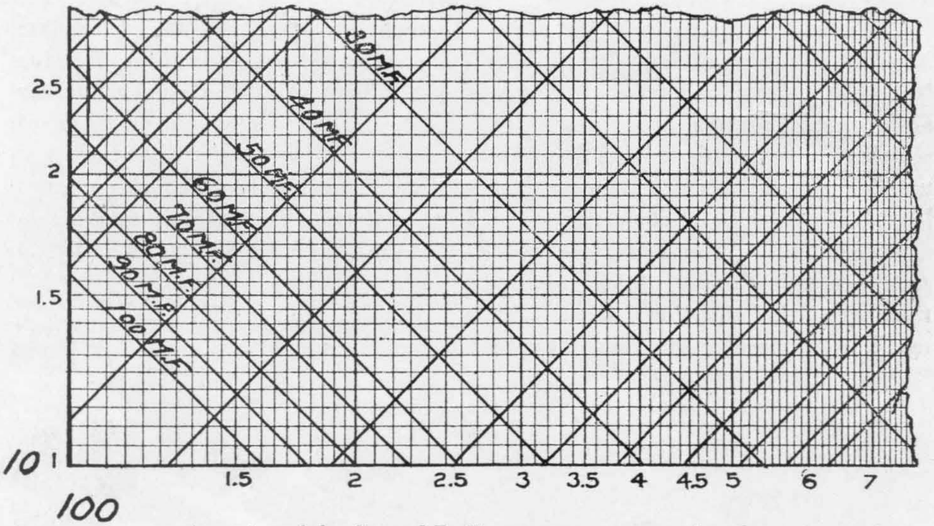


FIGURE 2. Behind the panel of the antenna measuring outfit. Note in particular the General Radio TYPE 539 Condensers, the TYPE 510 Decade-Resistance Units, and the General Radio power-transformer and rectifier-filter units

HELP IN COMPUTING REACTANCE-RESONANCE PROBLEMS

THE June, 1928, issue of the General Radio *Experimenter* included a graphical chart by means of which the reactance of a condenser or an inductor could be determined for any frequency. Separate copies of this chart were printed and there still remains a fair quantity available for distribution.

Anyone desirous of obtaining one of these charts, which is printed on a sheet of heavy bond paper 12 inches x 18 inches, can secure it by writing the Advertising Department, General Radio Company. First come first served.



A section of the General Radio reactance computation chart

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

GENERAL RADIO COMPANY

30 State Street - Cambridge A, Massachusetts

The GENERAL RADIO EXPERIMENTER

VOL. IX. Nos. 2-3 JULY-AUG., 1934

ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

IMPEDANCE MATCHING

ONE of the first and best learned lessons in communication-system design is that, to obtain the greatest possible transfer of energy from one circuit to another, the impedances of the two circuits must be matched. So straightforward is the concept that the lesson may have been overlearned. In very many cases the reason for the use of transformers as impedance-matching devices is not so much to gain in power transfer as to reduce distortion, frequency discrimination, and other common defects in voice-transmission circuits.

It is very easy to fall into the error of exaggerating the amount of reflection loss that occurs due to mismatched circuits. From the single consideration of power loss a surprising amount of mismatch can be tolerated. To arrive at a figure for reflection loss, the simplest example is the case of a resistive power source connected to a resistive load. In actual practice it is not often that pure resistances will be found in radio- or audio-frequency circuits, but in most cases the phase angle is so slight that for purposes of practical demonstration it may be considered to be zero. In Figure 1 a generator producing a voltage E_G and with an internal resistance R_G is shown connected to a load R_L. The current that will flow in the circuit is

$$I = \frac{E_G}{R_L + R_G}.$$

When $R_L = R_G$, that is, in the case where the generator and load impedances are matched, the current, $I = \frac{E}{2R_G}$, and the power in the load is

$$I^2R_L = I^2R_G = \left(\frac{E_G}{2R_G}\right)^2 R_G = \frac{E^2{}_G}{4R_G}.$$

When the impedances are not matched the current in the load $I' = \frac{E_G}{R_G + R_L}$ and the power is

$$I'^2R_L = \left(\frac{E_G}{R_G + R_L}\right)^2 R_L.$$

The ratio of the power in the load for the matched condition to the power for the mismatched condition expressed in decibels is the mismatch or the reflection loss. That is

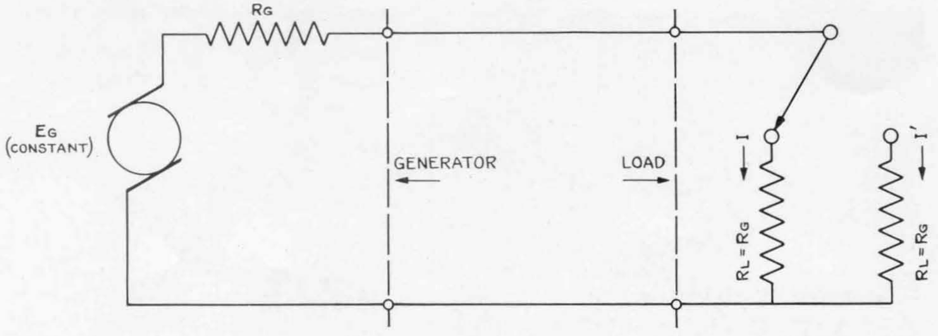


FIGURE 1. Circuit on which to base calculations of the reflection loss at a single junction

$$N_{db} = \frac{I^2 R_L}{I'^2 R_L} = 10 \log_{10} \frac{(R_G + R_L)^2}{4R_G R_L}$$

or

$$N_{db} = 20 \log_{10} \frac{R_G + R_L}{\sqrt{4R_G R_L}}.$$

From this formula can be calculated the reflection loss that occurs due to connecting together any two impedances having small phase angles. For instance, if a 5000-ohm vacuum tube were connected directly to a 500-ohm line, the impedance mismatch of 10 to 1 would calculate to cause a loss of 4.8 decibels. The losses calculated for a number of different impedance mismatches are shown in the chart in Figure 2. For phase angles of less than 45° the loss curve is practically the same, but the mismatch loss is always less when either circuit has a reactive component.*

It is obvious, therefore, that in many cases the actual power loss due to operating between mismatched impedances is not serious. If "ideal" or no-loss transformers could be realized, it would certainly be worth while to use them where every milliwatt of the available power must be utilized. However, well-designed and carefully made audio-frequency transformers of the usual types may have an inherent copper and iron loss of about 20%, or 2 decibels. When it is considered that small power transformers have efficiencies in the neighborhood of 85%, an efficiency of 80% for audio-frequency transformers is quite good in view of the many other problems involved in their design, such as frequency characteristic, freedom from distortion, etc.

The real value, however, of audio-frequency transformers and the reason why their use is so essential is to keep the circuit impedances at the correct operating values. For example, the design of a transformer to operate from a low-impedance line to the grid of an amplifier is not a simple job, and the successful operation of this sort of transformer depends upon its operation from the impedance for which it is designed. A line-to-grid transformer designed to operate from 500 ohms is apt to show frequency discrimination if operated from a line of 200-ohms impedance. Thus, a designer of a voice-input circuit finding that the output impedance of his mixer panel is 200 ohms, which has probably been determined by the

*"Transmission Networks and Wave Filters," by T. E. Shea, contains a complete discussion of this question.

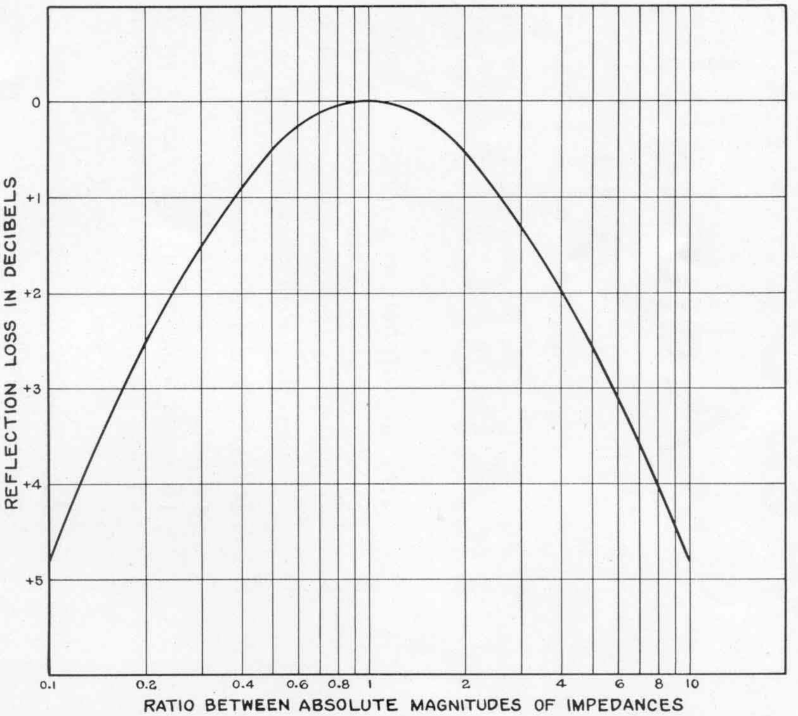
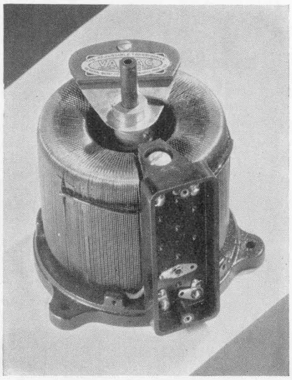


FIGURE 2. Reflection loss at a single junction in decibels as a function of the ratio between the absolute magnitudes of the two impedances. This curve is for a phase difference of 0°

microphone impedances, would certainly insert a 200- to 500-ohm transformer between the mixer and the input of his amplifier, if its input transformer were designed to operate from 500 ohms. The use of the transformer is dictated not by the consideration of the reflection loss between the 200- and the 500-ohm circuit, which is less than one decibel, but by the fact that the impedances must be kept to their correct value to maintain proper frequency characteristics.

Another example of the necessity for correct impedance matching is in the familiar case of output transformers from vacuum tubes. The distortion introduced by a three-element tube is a function, among other things, of the impedance into which it works. Ordinarily, the distortion is a minimum when the tube is worked into an impedance equal to approximately twice the plate resistance of the tube. In the case of the 2A3 tube the plate resistance is about 800 ohms and for two tubes in push-pull is 1600 ohms. The General Radio TYPE 541-D Transformer is designed to couple this system into dynamic speakers. When operating at a fixed bias potential, it is recommended that these tubes in push-pull work into 3000 ohms, which is approximately twice the plate resistance. From a consideration of the power loss due to mismatch the tubes could be worked into

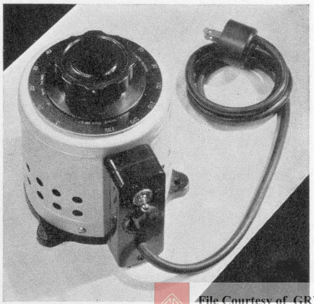


Well-Designed Adjustable AUTO-TRANSFORMER

This adjustable transformer is made by the General Radio Company and represents a striking advance both in electrical and physical design.

It is a toroidal auto-transformer whose output is varied from 0 to 130 volts (5 amp. maximum) by means of a sliding carbon brush. The input is 115 volts at 60 cycles.

From the design viewpoint the use of molded insulation, circular punched transformer laminations and the spun aluminum case are interesting. The member which carries the carb[on] brush has a fin to dissipate heat.

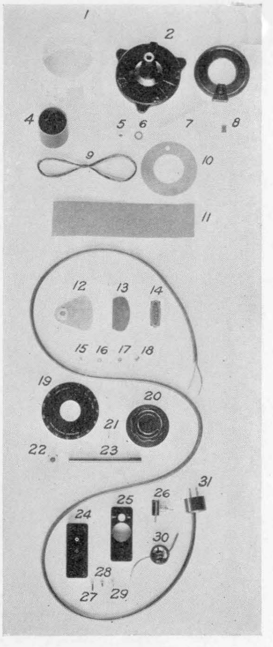


TWO views of the "Variac"; right, complete; above with enclosures removed for panel mounting. It is used for light-control and for testing household appliances and radio receivers

Materials and Parts Entering Into the Auto-Transformer

Part No.	No. Req'd	Name of Part	Material
1	1	Cover	Spun Aluminum
2	1	Mounting base	Cast iron
3	2	Winding form—end	Phenolic, molded
4	1	Winding form—tube	Phenolic, tubing
5	2	Clamping nut	Iron, cadmium plated
6	1	Lock washer	Phosphor bronze
7	1	Clamping bolt	Iron, cadmium plated
8	2	Supporting piece	Mica composition
9		Wire	Enameled copper
10	130	Lamination	Silicon steel punching
11	1	Insulating strip	Fish paper
12	1	Blade	Phosphor bronze
	1	Collar	Brass
13	1	Radiation fin	Copper, black oxidized
14	1	Label	Decalcomania transfer
15	1	Machine screw	Brass
16	1	Washer	Brass
17	1	Lock washer	Phosphor bronze
18	1	Brush holder	Brass
	1	Brush	Carbon
19	1	Dial	Photo-etched nickel silver
20	1	Knob	Phenolic, molded
21	3	Machine screws	Brass
22	2	Collar and setscrews	Brass
23	1	Shaft	Phenolic, tubing
24	1	Terminal box	Phenolic, molded
25	1	Cover	Phenolic, molded
26	1	Toggle switch	
27	2	Machine screws	Brass
28	2	Machine screws	Brass
29	4	Machine screws	Brass
30	1	Convenience outlet	
31	6 ft.	2-Conductor cord	
	1	Attachment plug	

NOTE the variety of materials used. Each has been selected for its exact suitability for the part



THE VARIAC — A "knockdown" view. This photographic parts list showing the construction of the Type 200-CM Variac was prepared by the editors of *Electrical Manufacturing* and published in their July, 1934, issue impedances varying widely from 3000 ohms, but the distortion would become a serious factor. This is one of the reasons why the selection of the correct output transformer is so important.

The impedance of ribbon and velocity microphones averages between 25 and 40 ohms. The customary volume control used with these microphones has an impedance of 50 ohms. An inspection of the chart in Figure 2 will show that the reflection loss due to coupling a 25- to 40-ohm generator and a 50-ohm load is negligible. The frequency characteristic of these microphones is not affected by such a small impedance mismatch. Therefore, it is sound practice to operate them into the regular 50-ohm mixer. If a transformer were used to couple these two circuits together, it would introduce a loss approximating 2 decibels which would be entirely unnecessary. Similarly, 500-ohm and 600-ohm lines can be connected together without trouble, unless special balancing or isolating problems are present. Impedance-matching transformers play a very important part in the circuits where these questions are serious. Generally, telephone lines are well balanced, particularly high-quality lines of the sort used to connect remote pickup points with the broadcasting studio. If these lines are connected directly to an unbalanced amplifier, which is one without a balanced and shielded input transformer, the resulting unbalance would affect the line and might introduce cross-talk. The customary cure for such a condition is to insert a 1-to-1 transformer between the line and the amplifier input transformer. The General Radio Type 585-R Transformer is an example of this. It has balanced windings and an electrostatic shield between the primary and secondary circuits so that a balanced line connected to its primary will remain balanced even though the secondary be connected to an unbalanced circuit. On short lines running around a studio or a laboratory, the question of unbalance is not usually so serious, but it is surprising the amount of pickup difficulties that have been encountered due to the fact that some part of a short link between a mixer panel and a speech amplifier or some other short local circuit is unbalanced. In the case of larger studios where several voice channels are running parallel through patch boards, relays, or other switching mechanisms, it is always considered good practice to run the wires in the form of twisted pair, shielded by flexible copper braid. This type of connector maintains a capacity balance to ground, and if well-balanced transformers are used most of the cross-talk difficulties are eliminated.

—A. E. Thiessen

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AMPLIFIERS FOR ALTERNATING-CURRENT BRIDGES

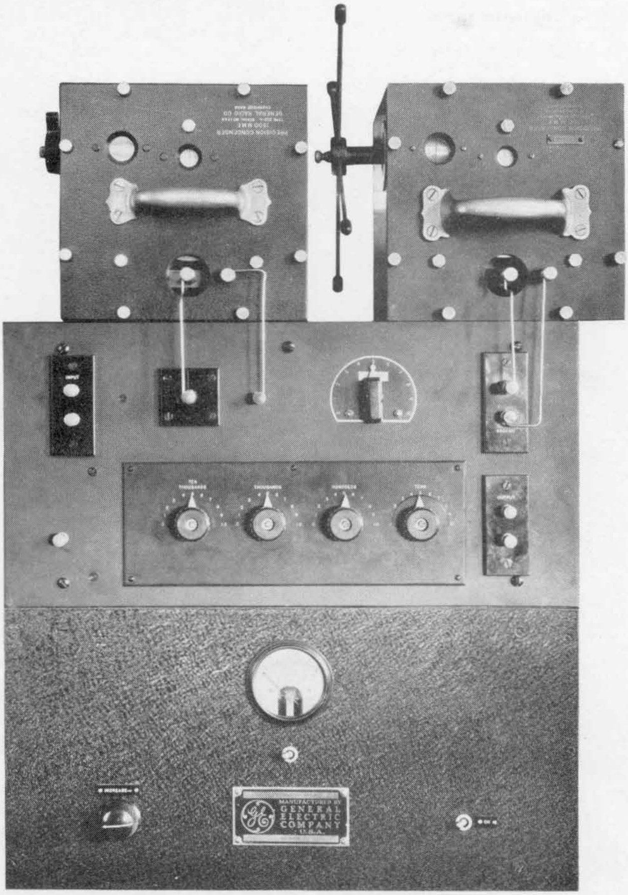

FIGURE 1. View of an audio-frequency amplifier unit with two standards (General Radio Type 222), the bridge unit in the center, and the amplifier at the bottom

Courtesy General Electric *Review*

UNDER this title W. A. Ford* and H. W. Bousman* describe two audio-frequency bridge amplifiers in the May, 1934, issue of the General Electric *Review*. After discussing the effect of stray admittances between the bridge elements and to ground, the amplifiers shown in the two accompanying photographs are described.

The complete bridge of Figure 1 has an amplifier for the detector circuit with an iron-cored input transformer between it and the bridge, an arrangement that was subject to interference induced in the transformer by power-frequency magnetic fields.

The details are given of another amplifier of high gain in which resistance-capacitance coupling between bridge and amplifier is used. This, combined with suitable multiple shielding and a self-contained galvanometer, has minimized and rendered fixed and definite many of the variable stray capaci-

*General Engineering Laboratory, General Electric Co.

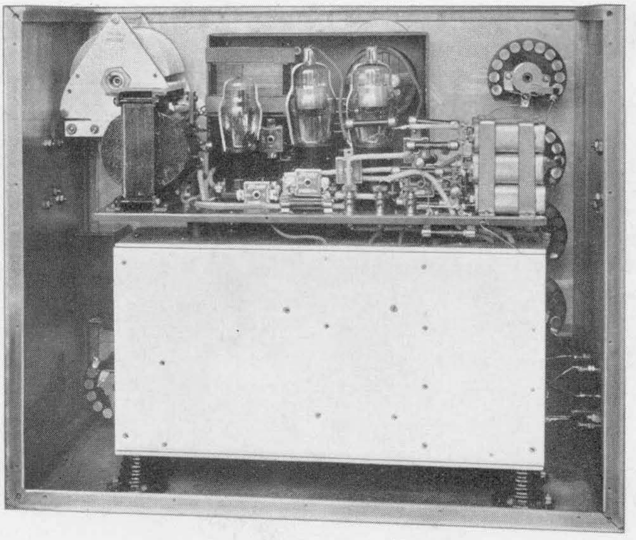

FIGURE 2. Behind the panel of a completely shielded Schering bridge. The shielded amplifier is supported on porcelain insulators inside the grounded case of the complete bridge

Courtesy General Electric *Review*

tances that often cause elusive errors in precision measurements.

Figure 2 shows the interior of a Schering bridge containing this second amplifier inside a shielded case, with the entire amplifier unit supported on porcelain insulators within the shield for the entire bridge.

Readers possessing an eye for detail will notice the liberal use of General Radio laboratory accessories, *e.g.*, TYPE 222 Precision Condensers, TYPE 539 Variable Air Condensers, TYPE 510 Decade-Resistance Units, etc.

—JOHN D. CRAWFORD

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ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

POWER FACTOR MEASUREMENTS IN OIL ANALYSIS

"SAY YES" became a familiar method of determining the end of the useful life of automobile lubricating oils as a result of an intensive advertising campaign some months ago. However satisfactory this test may have been to oil companies, public-service corporations using large quantities of insulating oils in transformers and cables require a more specific test.

Insulating oils may gradually deteriorate due either to continued operation at too high voltages or to fouling. If such a condition is neglected, breakdown with loss of service will eventually occur. In order to avoid failures of this type, some companies have adopted the "Say Yes" policy—that is, have simply changed their oil at intervals which they considered sufficient. This has resulted in a reduction in failures as well as a considerable waste of oil.

It has been determined that the deterioration of the oil is accompanied by an increase in power factor. Pure oils have power factors so closely approaching zero as to suggest that were all the impurities removed the power factor would be zero. Progressive power companies are, therefore, inaugurating routine testing of transformer and cable oils so that all oils may be removed from service before the danger point is reached, while insuring the maximum safe use of the oil. Such servicing is resulting in savings for those companies which have inaugurated them sufficient to more than pay for the service.

While it is not likely that the corner service station will install a power-factor bridge to determine the state of the lubricating oil in your crankcase in the immediate future, it is true that impurities in lubricating oil can also be detected by the power-factor method. This method of study is viewed with increasing interest by all oil technicians, and there is a growing probability that electrical tests of oil purity will become a standard part of refinery technique for all types of oils.

Measurements of this sort are among the more difficult to make because of the very low power factors which must be measured. This has resulted in a considerable study of power-factor measurements and the development of a standard measuring cell for low-power factor liquids by Professor J. C. Balsbaugh of the Massachusetts Institute of Technology. This work was carried on under the sponsorship of the National Electric Light Association.

To so fine a degree have the measurements of power factor been carried in this work that not only the effect of slight dust deposits on the condenser plates but also that of occluded gas in the plates themselves have been detected.

The General Radio Company has instituted the manufacture of cells for the measurement of dielectric constant of oils after Professor Balsbaugh's design and under his direction. There is now available the cell described in the following article. —EDITOR.

The measurement of dielectric constant and power factor of a liquid such as an oil requires the use of a test cell, an air condenser which may be filled with the liquid and whose capacitance and power factor may be measured, first when it is empty and second when it is filled with the liquid.

The ratio of the "filled" capacitance to the "empty" capacitance is the dielectric constant of the liquid. The power factor of the liquid may be determined from the values of power factor observed for the two sets of capacitance measurements.

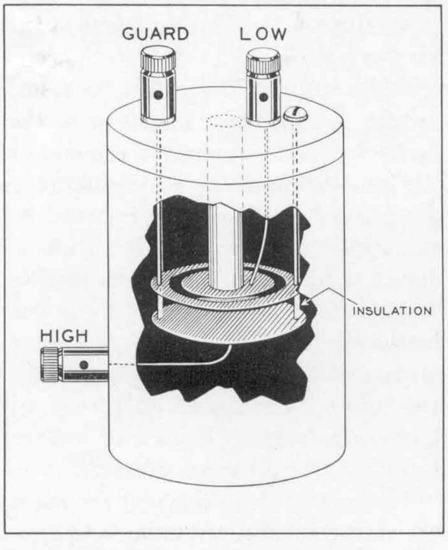

FIGURE 1. Schematic representation of a shielded 3-terminal oil cell which eliminates errors due to fringing and to losses in the dielectric supports

For rough measurements an ordinary two-terminal shielded condenser will yield satisfactory results, but there are two sources of error which make this simple cell useless for precision work. The first error is that due to fringing effects at the edges of the condenser plates. The second error is that due to the capacitance and losses introduced by the solid dielectric supports, the losses entering into both measurements. When both the power factor and capacitance of these supports are small as compared with the power factor and capacitance due to the liquid, the accuracy of the power factor determination as calculated from formulae will be satisfactory. On the other hand, for liquids with small power factors, errors due to losses in the solid dielectric supports will be relatively large and the accuracy of the final result will be unsatisfactory. Both sources of error can be eliminated by suitable design of the cell.

Except for special purposes, the two electrodes of the cell can be either parallel circular plates or concentric cylinders. In order to eliminate the effect of fringing, a guard ring can be placed around one plate, insulated from it but kept at the same potential. The second electrode is then allowed to extend for some distance past the gap between the guard ring and the guarded electrode. In this way the lines of force between the two principal electrodes of the cell are uniform over the whole surface of the smaller one.

Such an arrangement of electrodes is shown in Figure 1 but before discussing the constructional details it will be necessary to consider the capacitance network it represents.

There are three distinct capacitances involved, the direct capacitance C_{LH} between the two main electrodes and the direct capacitances C_{LG} and C_{GH} between the guard ring and each of the two main electrodes. These are related electrically as shown in Figure 2. Each of the three capacitances is called a "direct" capacitance to distinguish it from the "total" capacitance between the two corresponding terminals. The total capacitance is composed of one direct capacitance and the capacitance of the other two direct capacitances in series.*

The direct capacitance C_{LH} between the two main electrodes may be measured with a suitable bridge circuit. This usually involves the use of a Wagner ground, in which the guard ring is grounded and the low-potential electrode brought to the same potential. The magnitude of C_{LG} and C_{GH}, although entering into the preliminary adjustments of the bridge, will have no effect on the measurement of the direct capacitance C_{LH}.

*"Direct Capacitance and its Measurement," Robert F. Field, General Radio *Experimenter*, VIII, November, 1933.

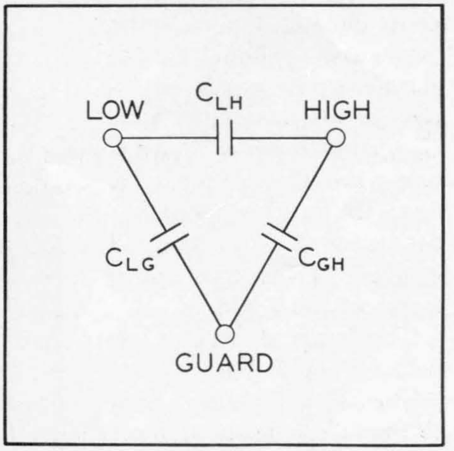

FIGURE 2. Capacitance network for a 3-terminal oil cell like the ones shown in Figures 1, 3, and 4

In a cell constructed like the one shown in Figure 1 the effect on the direct capacitance C_{LH} of the solid dielectric supports which serve to hold the electrodes in position can be eliminated by so placing these supports that they do not extend into the electric field between the main electrodes. In Figure 1, the low-potential electrode is suspended by a dielectric support, the high-potential electrode being attached by insulating spacers to the guard ring which in turn is suspended from and directly connected to the shield.

Cells using cylindrical electrodes like the one shown in Figures 3 and 4 can also be built, and in these the electrodes are most easily mounted on an axial insulating rod. Both the high-potential electrode and the guard rings are mounted on this rod and the low-potential electrode supported on insulators bridging the two guard rings.

Since, in both designs, the direct capacitance C_{LH} contains no solid dielectric, the ratio between C_{LH} when the cell is filled to C_{LH} when it is empty gives directly the dielectric constant of the liquid. For the same reason there is no dielectric loss associated with C_{LH}, and its power factor is zero when the cell is empty, hence the power factor of C_{LH}, as measured when the cell is filled, is the true power factor of the liquid.

This is strictly true at low voltages only. At voltage gradients sufficiently high to produce ionization, there are appreciable losses in the air between the plates as well as in the gas occluded in the electrodes themselves. Professor J. C. Balsbaugh* of the Massachusetts Institute of Technology has shown that the power factor due to occluded gas may be as great as 0.001% at room temperature for a potential difference across the cell of 800 volts. This power factor increases rapidly with temperature and may amount to 0.02% at 100°C. By degassing the electrodes, the power factor may be reduced to much less than 0.001% and made practically constant with temperature. The small losses in the air may be eliminated by making the cell air tight and removing the air.

The cell shown in Figures 3 and 4 is the General Radio Type 683-A Oil Cell, the arrangement of parts being due to Professor Balsbaugh. The electrodes and all the metal used for mounting them are of polished nickel and the stem, supporting rods, and container are pyrex glass. The high-potential electrode and the two guard rings are welded to nickel discs which fit tightly over the glass tubing at the center. Holes are punched in these discs to allow circulation of the liquid.

The low-potential electrode is supported midway between the two guard rings by means of the two pyrex supporting rods.

The electrode structure supported by the axial tubing is itself mounted in a two-piece pyrex container. The lower portion of the container is provided with two tubulations so that the whole cell can be evacuated and the liquid under test introduced at low pressure or in an atmosphere other than air. The joint between the two sections is ground to help maintain an air-tight seal, at the same time permitting the dismounting of the assembly for cleaning. Both the container and the electrodes can be cleaned satisfactorily by several flushings with carbon tetrachloride.

The lead wire for the high-

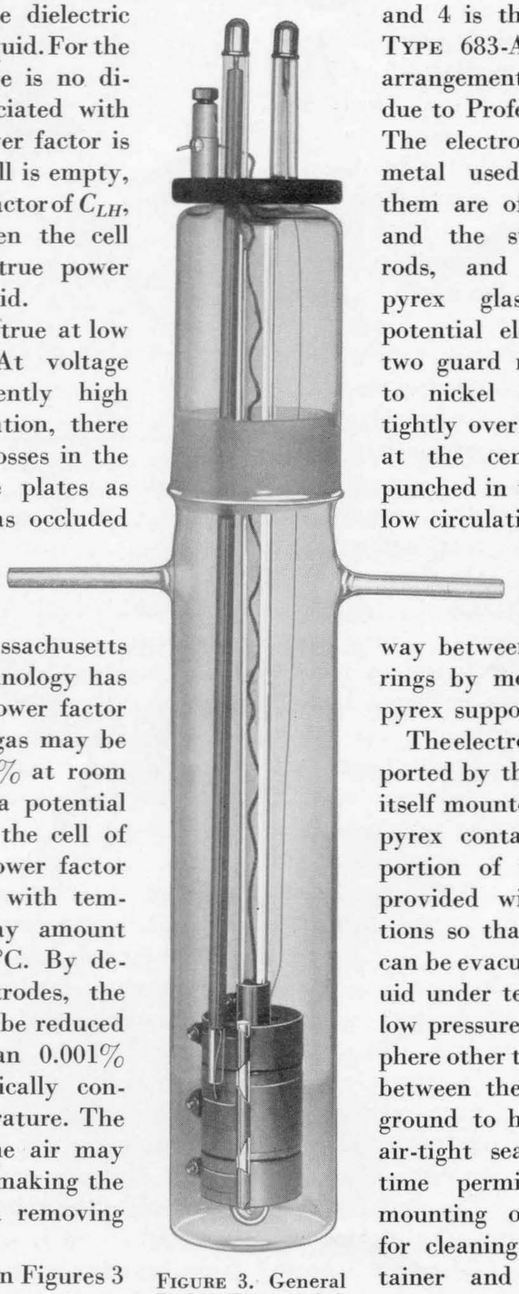

Figure 3. General Radio Type 683-A Oil Cell, a sealed glass container in which the electrode structure shown in Fig. 4 is suspended

*J. C. Balsbaugh and A. Herzenberg, "Comprehensive Theory of a Power-Factor Bridge," *Journal* of the Franklin Institute, Vol. 218, No. 1, July, 1934, pp. 49–97.

potential electrode is brought out through the central tubing in which a thermometer or a thermo-couple may be placed for measuring the temperature of the liquid. Connections to the low-potential electrode and the guard ring are brought out by nickel wires through seals in the upper section of the container. The low-potential electrode lead is shielded for its entire length. This method of bringing out the terminals increases the guard-electrode capacitances as shown in Table I.

All the nickel parts are heated in a vacuum to remove occluded gases and are then given a treatment in which the occluded gas is replaced by hydrogen. This markedly decreases the energy losses in the cell due to occluded gas.

An important feature of the General Radio oil cell is its ability to operate with a very small sample of oil. The external container has a volumetric capacity of only 200 cc. This not only provides economy of samples but it also means that the temperature-controlled water bath usually used need not be large. The over-all length of the cell is 17 inches, and the over-all width across the tabulations is approximately 8 inches. The outside diameter of the glass container is 2½ inches.

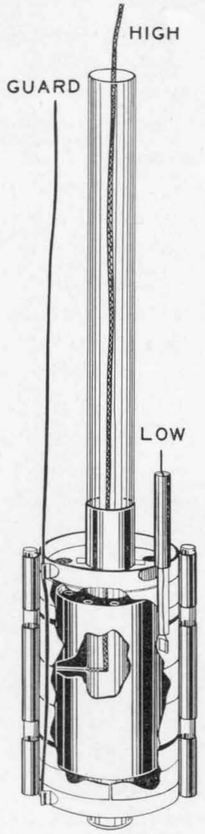

FIGURE 4. Electrode structure of the TYPE 683-A Oil Cell with the high potential electrode inside the low potential electrode and the two guard rings

The spacing between the electrodes is 5/32 of an inch, a knowledge of which enables one to calculate the voltage gradient in the sample under the test conditions employed. The direct capacitance of the measuring electrodes in air is 7 $\mu\mu$f. Values for the other capacitances are given in Table I together with values for the electrode structure only, as shown in Figure 4.

TABLE I

Direct Capacitances for TYPE 683-A Oil Cell

	C_{LH}	C_{GH}	C_{LG}
Cell complete..	7 $\mu\mu$f	12 $\mu\mu$f	23 $\mu\mu$f
Electrodes only	7 $\mu\mu$f	8 $\mu\mu$f	7 $\mu\mu$f

In use the oil cell should be surrounded by a grounded shield. The metal container for the water bath may serve, or, if a water bath is not used, tin-foil can be wrapped around the lower portion of the container and grounded so that the slight leakage over the surface of the glass will not introduce a loss in the capacitance of the measuring electrodes.

The price of the TYPE 683-A Oil Cell is $150.00, complete as shown in Figure 3. For those who wish to adapt the cell for use with existing equipment, the electrode structure itself can be obtained separately, price $125.00.

—ROBERT F. FIELD.

POWER SUPPLIES

THE problem of obtaining d-c power in amounts necessary to supply ordinary vacuum tube installations has received much attention in the last decade. At the present writing, two methods of obtaining this power are generally used, namely, rectifier-filter equipment operating from the a-c line, and wet or dry batteries. Making a choice between a power supply or a battery installation requires a careful consideration of the particular circumstances involved. In general, rectifier-filter equipment is used whenever possible to eliminate the inconvenience and expense of maintenance and replacements required in all battery installations.

There are two general types of power supplies, depending on the particular use for which they are designed. The first type consists essentially of transformer, rectifiers, and filter, with no means of changing the d-c output voltage level. The second type necessarily involves the same equipment, but in addition embodies a means of independently controlling the output level of the d-c voltage. The first type of power supply is designed usually for commercial installations where the unit is to be permanently installed to supply, say, Class A or Class B modulators. The second type, which includes the first as a special case, is a general purpose instrument, such as would be used for manifold purposes in the experimental laboratory.

TYPE 672-A Power Supply. This is one of two new power-supply units in which the output voltage is adjustable

It is not difficult to design a power supply that will yield a good regulation at a given voltage level. When a variable voltage level instrument is designed, however, care must be taken that the regulation and efficiency hold up at all voltage levels. The most obvious way to vary the voltage level of a power supply is to place a resistance in series with or a potentiometer across the output. Either one of these methods very seriously impairs the regulation and the efficiency of the power supply, and the method is of little practical use unless the power supply is to be operated at a fixed load. Placing the resistance arrangement in the primary of the plate transformer avails nothing as it is merely reflected into the secondary or high-voltage circuit. A tapped transformer may be used to secure various voltage levels, but such devices besides being inconvenient are limited in their range and afford no *continuous* voltage control.

The General Radio Company has accordingly brought forth two power supply units that incorporate the use of the Variac, a *continuously variable* auto transformer, in the primary of the plate transformer. The Variac is described in the June-July, 1933, and the January-February, 1934, issues of the *Experimenter*. The Variac operates as a linearly variable voltage device that is independent of load current. Unlike

TYPE 673-A Power Supply. Practically any voltage from zero up to the rated maximum can be obtained from the high-voltage supply circuit of this unit

the potentiometer control, there is no appreciable series or parallel resistance introduced into the line to impair efficiency and regulation. Consequently *any* voltage and current up to full load may be obtained without sacrifice in regulation or efficiency by merely manipulating the variable tap of the Variac mounted on the panel. Accomplishing the same ends with resistances would entail a great deal of bother in order to locate at the correct point in the output current and voltage region.

The filters are of the choke input type, and are carefully designed to yield a low ripple voltage and a good regulation at any particular setting of the Variac. The characteristics of the two power supply units are briefly given below.

The TYPE 672-A Power Supply Unit will deliver 45 watts at 300 volts, full load. It may be used to supply vacuum-tube circuits of any description whatsoever as long as the voltage and current ratings are not exceeded. A variable bias voltage up to 100 volts is also provided. The hum is less than 0.1% of full load voltage on either the anode or bias supplies, expressing hum as the ratio (in per cent) between the r.m.s. ripple and the d-c voltage. Hums of this order of magnitude are not objectionable in any type of circuit.

The TYPE 673-A Power Supply Unit is designed to deliver power up to 225 watts at a voltage of 1500 volts. Tube installations of any description may be supplied by this unit as long as the current and voltage ratings are not exceeded. The hum is less than 0.2% of full load voltage.

Both power supplies have panel meters that read the output current and voltage. Any ground connections may be employed and each unit is suitable for table or relay rack mounting. The ratings are given below.

	Voltage-Current Ratings				
Type	*High Voltage*	*Bias*	*Heater*	*Code Word*	*Price*
672-A	300 v at 150 ma 400 v at no load	100 v, 2 ma	45 w at 2.5 v and 6.3 v	AFOOT	**$130.00**
673-A	1500 v at 150 ma 2000 v at no load	. . . .	65 w at 10 v (center-tapped)	AGONY	**180.00**

A VARIAC FOR HIGH POWER

THE many applications which the Variac continuously adjustable transformer has found in industry have resulted in a demand for units capable of handling higher powers. The TYPE 100 Variac with a 2-kva rating is now available. This instrument is suitable for reducing voltage on devices requiring considerable power, and it is especially well adapted to problems of theater-light control.

The new Variac follows the same toroidal core construction as those earlier announced. It is supplied in an open iron frame which serves as protection against casual contact with current-carrying parts, but is not totally enclosed.

The rating of this type of device presents somewhat of a problem, since both the maximum current and maximum kva that it can handle safely are functions of the output voltage. The TYPE 100 Variac has been rated at the volt-ampere rating of the resistive load which it can carry at full (line) voltage. That is, the instrument will control at any setting a load which draws 2 kva at the rated line voltage. It should be pointed out that the Variac will not deliver 2 kva at reduced voltage settings.

The current-carrying capacity of the unit is a minimum at approximately half-voltage setting. The curve of Figure 1 shows current-carrying capacity as a function of the output voltage of the Variac. The TYPE 100 Variac is available in 115-volt and 230-volt models. Complete specifications are available on request. Price, both models, $40.00.

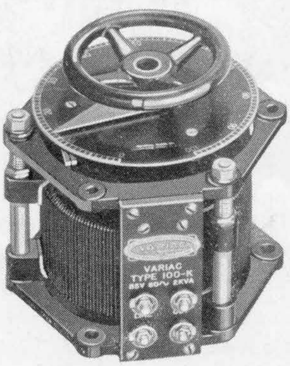

FIGURE 2. The TYPE 100-L Variac is identical with the TYPE 100-K Variac, shown above, except that the former is designed for operation on 230-volt circuits

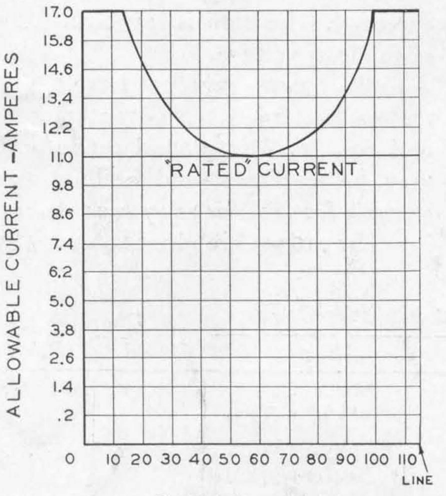

FIGURE 1. Maximum allowable current that can be drawn from a TYPE 100-K Variac plotted as a function of output voltage

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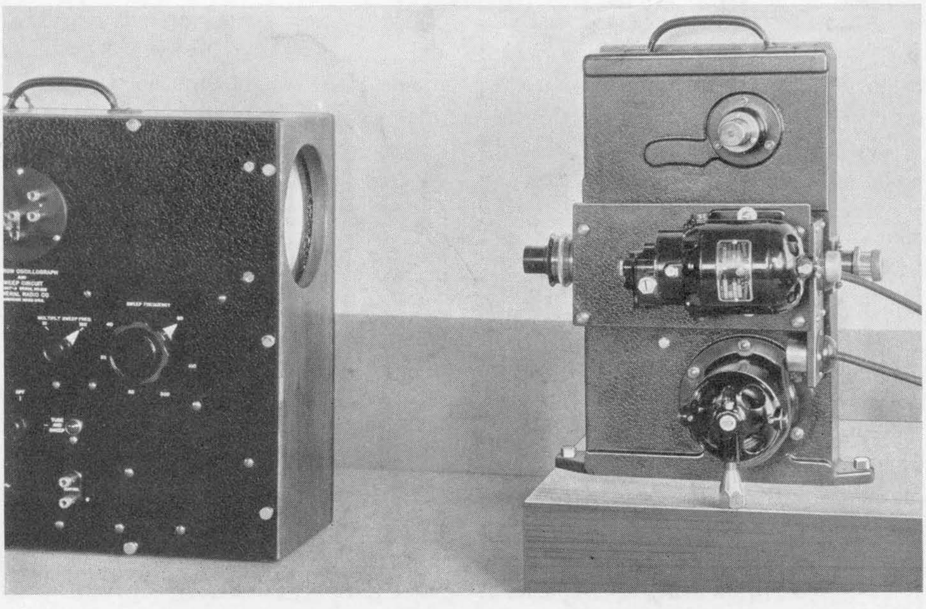
ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

A NEW MOVING-FILM CAMERA

A NEW magazine-type of camera, designed to operate over a wide range of film speeds, proves useful for all sorts of oscillographic and chronographic recording.

One of its most useful applications is in obtaining cathode-ray oscillograms of recurrent or transient phenomena, either as a continuous or an intermittent record. Recurrent phenomena, if synchronized with a sweep circuit, may be observed as a stationary picture and photographed with an ordinary "still"



The high film speeds at which the new continuous-film camera will operate make it possible to take cathode-ray oscillograms of high-frequency transients. The photograph shows the Class 651-A-E Camera Assembly and a TYPE 687-A Electron Oscillograph and Bedell Sweep Circuit camera. On the other hand, transient phenomena or recurrent phenomena which do not repeat at equally spaced intervals *must be photographed upon a continuously moving film* in order to obtain a suitable record. Examples of noise oscillograms taken with this camera unit are shown on page 3. They show how a considerable amount of resolution of high audio-frequency waveforms can be accomplished at a film speed of 32 feet per second.

Cathode-ray oscillograms are made by applying the voltage in question to the "horizontal" deflecting plates, thus producing a single straight line on the screen of the tube. The camera is set up as shown on page 1 so that the motion of the film supplies the necessary time axis perpendicular to the displacement of the cathode-ray beam. In this manner all sorts of oscillographic recording may be accomplished at audio frequencies showing elaborate detail and freedom from the distortions which might be introduced by an oscillograph employing vibrating members.

The Class 651-A-E Camera Assembly consists of a cast aluminum housing provided with two flanges for mounting it in any position. A removable slide gives access to a single compartment housing the magazine reel (capacity 100 feet), the $4\frac{3}{4}$-inch driving sprocket designed for 35-mm perforated film or paper, and the take-up reel.

The film, which is run continuously at a chosen and essentially uniform speed, is fed directly from the magazine reel over a portion of the drive sprocket and thence directly onto the take-up reel, there being no loops, as in the ordinary motion-picture camera. Idler guide rollers insure the proper lay of the film on the rim of the driving sprocket. While passing over the driving sprocket, the film is continuously exposed through a rectangular window opening extending along the film for $\frac{3}{8}$ inch and across the film for one inch between the sprocket holes. The curvature of the sprocket is small enough to permit sharp focusing over this area.

An $f/2.5$ lens of 47-mm focal length is supplied. There is an iris diaphragm but no shutter. This lens is provided with an adjustable focus covering a range of linear object-to-image ratio of from 4.0 to about 7.0, corresponding to a distance of the object from the front face of the camera of from 10.25 inches to 15.5 inches.

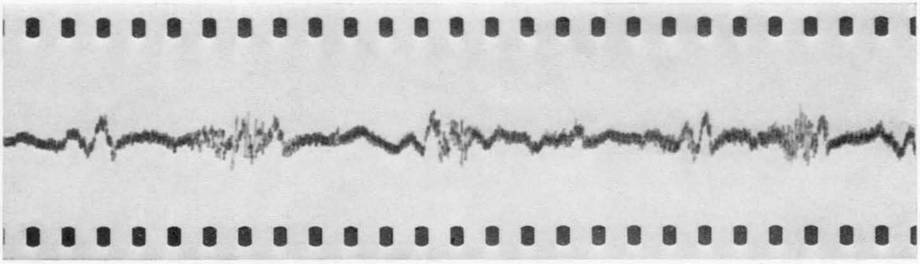
Opposite the lens mounting is located the focusing eyepiece which, by virtue of two rectangular holes in the rim of the drum sprocket, permits focusing and observation of the area of exposure.

The camera is driven by two 115-volt universal series-wound motors mounted externally on the side of the housing. One of these motors is connected directly and permanently onto shaft of the take-up reel. The other motor is connected through a self-contained 8.5-to-1 reduction gear and a universal joint to the drive sprocket. This dual-motor drive system provides a satisfactorily uniform film velocity over a wide range of speeds. The motor on the take-up reel tends to drive that reel at a speed higher than the rate of film travel over the drive sprocket and thus eliminates any slack between the sprocket and the take-up reel. The motor-driven sprocket pulls the film from the magazine reel with no slack, because of friction on the shaft of the magazine reel.

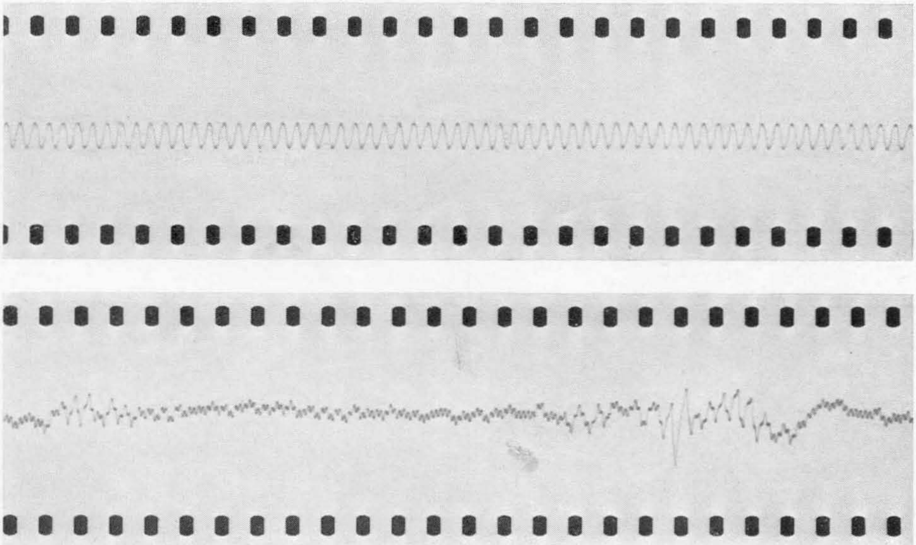
(*Continued on page 8*)

THE NEW CAMERA RECORDS HIGH-SPEED TRANSIENTS

Cathode-ray oscillograms of noise from an internal-combustion engine



An oscillogram of engine noise at a film speed in the vicinity of 8 feet per second, about the top speed for continuous-film cameras heretofore available. At this speed one cycle of a 10,000-cycle trace is a little less than 0.01 inch long



By running the film at a higher speed, resolution is markedly improved

BELOW: A 32-foot-per-second noise oscillogram from the same engine that made the record at the top of the page. An interesting blur becomes a trace that can be analyzed.

ABOVE: A 5000-cycle trace, made at a film speed duplicating that of the noise record as closely as possible. There are 13 cycles per inch, *i.e.*, 32 feet per second, just under the maximum-rated speed of the new camera

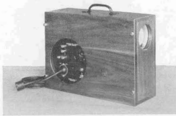
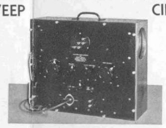
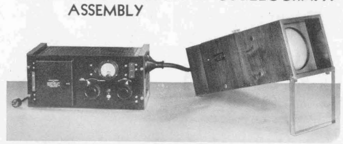
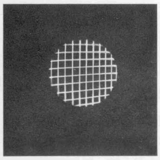
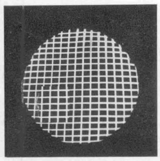
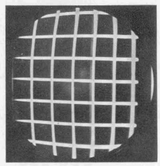
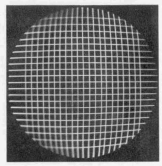
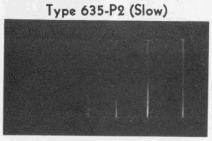
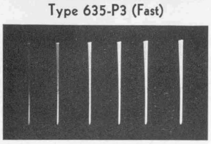
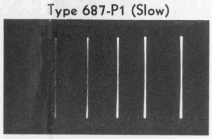
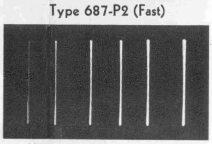
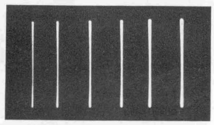
CONDITIONS

CLASS 528 Cathode-Ray Oscillograph Assembly with a TYPE 528-B Tube. Accelerating potential, 3000 volts. Lens aperture, *f*/2.5. Emulsion, Eastman No. 697 Recording Paper. Ratio between length of trace on oscillograph screen and image on film, 5 to 1

A COMPARISON BETWEEN CATHODE-RAY OSCILLOGRAPHS

CHARACTERISTICS OF EACH OF THE THREE GENERAL RADIO OSCILLOGRAPHS

Showing differences between Slow Screen and Fast-Screen Tube Equipment

	TYPE 635-B ELECTRON OSCILLOGRAPH	TYPE 687-A ELECTRON OSCILLOGRAPH and BEDELL SWEEP CIRCUIT	CLASS 528 CATHODE-RAY OSCILLOGRAPH ASSEMBLY
			
VOLTAGE SENSITIVITY and RELATIVE SCREEN DIAMETER Traces spaced 25 d-c volts apart. Both Fast and Slow-Screens have the same voltage sensitivity. *Photographs ¼ Actual Size*	ACCELERATING VOLTAGE FIXED AT 1000 V 	ACCELERATING VOLTAGE FIXED AT 1500 V 	ACCELERATING VOLTAGE ADJUSTABLE 1000 V  3000 V 
RELATIVE PHOTOGRAPHIC BRILLIANCE Each photograph shows 6 successive snapshots of a trace from a linear sweep circuit for which only the camera-diaphragm opening was changed. The *f* number for each exposure is given beneath each line. The length of trace, sweep frequency, shutter speed, and emulsion were the same for all exposures. Note the greater actinic power of the fast-screen tubes. See table, page 7.	Type 635-P2 (Slow)  Type 635-P3 (Fast)  f/22 f/16 f/11 f/8 f/5.6 f/4.5	Type 687-P1 (Slow)  Type 687-P2 (Fast)  f/22 f/16 f/11 f/8 f/5.6 f/4.5	Slow-Screen Tubes No Longer Available for This Oscillograph Type 528-B (Fast) - (3000 V)  f/22 f/16 f/11 f/8 f/5.6 f/4.5

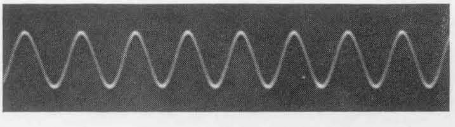
FAST-SCREEN versus SLOW-SCREEN TUBES

Since, for many readers, the data presented in the preceding two pages may be the first notice that not all tube-screens have the same characteristics, the essential difference between what we called "fast screens" and "slow screens" must be pointed out.

If one were to make a visual comparison in the same oscillograph between a fast-screen tube and a similar slow-screen tube he would notice first that the slow-screen tube produced a green pattern that appeared to be somewhat brighter than the blue pattern of the fast-screen tube. Then, if he were to compare photographic brilliancy using a camera loaded with verichrome or super-sensitive panchromatic film, he would find the fast-screen trace noticeably more actinic.

Another difference, extremely important in many high-frequency measurement applications of the cathode-ray oscillograph, appears when one attempts to take photographs with a moving-film camera. The accompanying photographs show what happened when a line on the screen produced by a 60-cycle applied voltage was spread out by swinging the camera on a pivot. The fast-screen trace is clear and sharp, but the slow-screen trace is blurred and foggy, due to the fact that in a slow-screen tube the fluorescence at any given point persists for an appreciable time after the electron beam exciting it has moved on. Where, in a fast-screen tube, fluorescence disappears in less than 25 microseconds, fluoroescence in a slow-screen tube persists for as much as 2000 times as long. The effect is very noticeable when resolving a 60-cycle trace, and it becomes increasingly bothersome as the frequency increases.

For most work around the laboratory, especially where photography is contemplated, the fast-screen tube is recommended. Its visual brilliancy, though less than the slow-screen tube, is nevertheless satisfactory for all ordinary purposes. Only when the brightest possible patterns are required (as in lecture-room demonstrations) or when persistence is an asset (as in viewing patterns with a sweep circuit adjusted for a very slow sweeping rate) should the slow-screen tube be purchased. A fast-screen tube is absolutely essential when photographs are being taken with the new Class 651-A-E Camera Assembly.



Spread-out traces from a 60-cycle voltage obtained by swinging the camera on a pivot. Fast-screen tube on the left, slow-screen tube on the right. Note the absence of blur in the fast-screen trace

FAST-SCREEN TUBES NOW STANDARD EQUIPMENT ON ALL GR OSCILLOGRAPHS — PRICE CHANGES

BECAUSE of the wider range of usefulness it affords the laboratory, all General Radio electron oscillographs are now supplied with fast-screen tubes unless specific instructions to the contrary accompany the order. Slow-speed tubes for the Class 528 Cathode-Ray Oscillograph Assembly are no longer available.

In order to determine the price of an oscillograph with a slow-screen tube, add the *replacement* price of the slow-screen tube to the price for the complete oscillograph and credit the *replacement* price of the corresponding fast-screen tube.

The following prices are now in effect:

TYPE 635-B Electron Oscillograph (with fast-screen tube) $82.00
TYPE 687-A Electron Oscillograph and Bedell Sweep Circuit (with fast-screen tube) . $184.00
*CLASS 528 Cathode-Ray Oscillograph Assembly (with fast-screen tube) $293.50

REPLACEMENT TUBES FOR CATHODE-RAY OSCILLOGRAPHS

For TYPE 635-B Electron Oscillograph

Type		*Code Word*	*Price*
635-P2	Slow-Screen Tube	CUMIN	**$18.00**
635-P3	Fast-Screen Tube	CUDDY	**20.00**

For TYPE 687-A Electron Oscillograph and Bedell Sweep Circuit

Type		*Code Word*	*Price*
687-P1	Slow-Screen Tube	ACCESSOBOY	**$40.00**
687-P2	Fast-Screen Tube	ACCESSOCAT	**44.00**

For CLASS 528 Cathode-Ray Oscillograph Assembly

Type		*Code Word*	*Price*
***528-B**	Fast-Screen Tube	CAMEL	**$78.50**

*Fast-screen tubes only are available for this oscillograph assembly.

PERFORMANCE SPECIFICATIONS FOR CATHODE-RAY TUBES

(Based on Experimental Data Like That Shown on Pages 4 and 5)

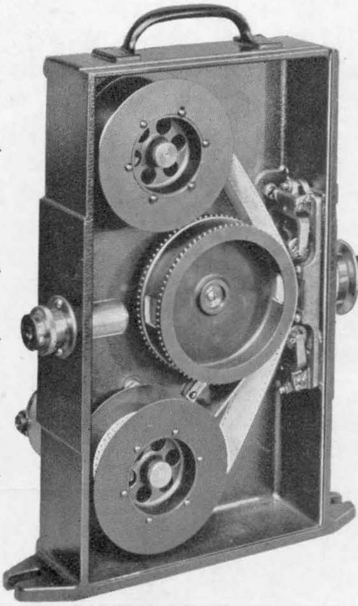
Type	*Screen Diam.*	*Fast or Slow*	*Accelerating Voltage*	*D-C Voltage Sensitivity**	*Maximum Spot Speed†*
635-P2	3 in.	Slow	1000 v	0.013 in/v	4,100 in/sec
635-P3	3 in.	Fast			11,000 in/sec
687-P1	5 in.	Slow	1500 v	0.012 in/v	6,400 in/sec
687-P2	5 in.	Fast			16,000 in/sec
528-B	7 in.	Fast	3000 v	0.0087 in/v	50,000 in/sec
			1000 v	0.0026 in/v	. . . .
			500 v	0.0013 in/v	300 in/sec

*Average for both pairs of plates.

†These values are maximum workable spot speeds S for Verichrome film, on the basis of a hypothetical aperture $f/1.0$ and with the screen at infinite distance from the lens. The maximum speed S' for any other aperture f/N and a ratio k between length of trace on screen and on the camera plate is: $S' = \frac{S}{N^2\left(\frac{1+k}{k}\right)^2}$.

A NEW MOVING-FILM CAMERA

(*Continued from page 2*)



The camera with the slide removed to show how the film is threaded. Driving sprocket and take-up reel are each driven by separate motors.

The camera is focused by viewing the object through the focusing eyepiece when the two apertures in the driving sprocket are aligned as shown. The image forms on a small piece of translucent film inserted in the gate

Film speeds may be adjusted by controlling the voltages applied to both motors simultaneously. For this purpose, the Type 100-L Variac is to be recommended when alternating current is used. At 110 volts, a film speed of approximately 15 feet per second is obtained.

Increasing the voltage momentarily to 230 volts gives a speed of 35 feet per second. Decreasing the voltage to 65 volts gives a speed of about 1 foot per second.

For film speeds under about 5 feet per second, a full magazine may be used and the camera started and stopped as often as required.

The camera is daylight loading if the film or paper has a length of black "leader" for threading. In high-speed camera work, however, leaders are seldom required because less film is lost in loading than is lost in getting up to speed. —Horatio W. Lamson

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Class 651-A-E Camera Assembly, complete with *f*/2.5, adjustable-focus lens and two motors as illustrated on page 1: *Price*, $495.00; *Code Word*, DINER.

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