the GENERAL RADIO Experimenter

INDEX

TO GENERAL RADIO EXPERIMENTER
Volumes VI and VII, June, 1931, through May, 1933

INDEX BY TITLE

INDEX BY TYPE NUMBER

575 Piezo-Electric Oscillator
A Frequency Deviation Indicator for Transmitters (January, 1932)
A Piezo-Electric Oscillator of Improved Stability (J. K. Clapp: December, 1931)
The Wavemeter Yields (C. E. Worthen: October, 1932)

581-A Frequency Deviation Meter
A Frequency Deviation Indicator for Transmitters (January, 1932)

583-A Output Power Meter
A Power Meter with a Wide Impedance Range (J. D. Crawford: May, 1932)
A Direct-Reading Meter for Power and Impedance Measurements (November, 1932)

585 Transformer
Mixer Circuits That Work (H. H. Scott: March, 1933)

586 Power-Level Indicator
Telephone Transmission Measurements (A. E. Thiessen: August, 1932)
Inexpensive Noise-Measuring Equipment (H. H. Scott: September, 1932)

592-A Multivibrator
The Wavemeter Yields (C. E. Worthen: October, 1932)

600-A Standard-Signal Generator
Precision and Speed with the New Standard-Signal Generator (July, 1931)
Speeding Up the Standard-Signal Generator (J. D. Crawford: August, 1931)
A Linearly Modulated Oscillator (L. B. Arguimbau: August, 1931)

601-A Standard-Signal Generator
Airplane Beacons (July, 1931)
Testing Radio Receivers on the Assembly Line (A. E. Thiessen: April, 1932)

602 Decade-Resistance Boxes
Frequency Characteristics (R. F. Field: February, 1932)

603-A Standard-Signal Generator
A Standard-Signal Generator for the Medium Price Field (C. T. Burke: May, 1932)
A Signal Generator for the New Receiver Tests (A. E. Thiessen: November, 1932)

604-B Test-Signal Generator
Receiver Testing in the Ultra High-Frequency Bands (E. Karplus: February, 1933)

613-A Beat-Frequency Oscillator
A New Beat-Frequency Oscillator (C. T. Burke: May, 1932)
Pitch and Intensity Measurements with a Vacuum-Tube Oscillator (A. E. Thiessen: April-May, 1933)

616-A Heterodyne Frequency Meter
The Wavemeter Yields (C. E. Worthen: October, 1932)

619-A Heterodyne Detector
A Laboratory Heterodyne (October, 1932)

625-A Bridge
The Skeleton-Type Impedance Bridge (R. F. Field: April-May, 1933)

626-A Vacuum-Tube Voltmeter
A Vacuum-Tube Voltmeter (H. W. Lamson: November, 1931)

627-A Insulator
New Porcelain Insulator Assemblies (February, 1933)

628-A Insulator
New Porcelain Insulator Assemblies (February, 1933)

629-A Insulator
New Porcelain Insulator Assemblies (February, 1933)

630-A Insulator
New Porcelain Insulator Assemblies (February, 1933)

639-A Variable Air Condenser
A High-Voltage Two-Section Condenser (March, 1933)

642-D Volume Control
A 200,000-Ohm Gain Control (A. E. Thiessen: May, 1932)

650-A Impedance Bridge
The Convenient Measurement of C, R, and L (R. F. Field: April-May, 1933)

652 Volume Control
Volume Control in Voice Circuits (A. E. Thiessen: June, 1931)

653 Volume Controls
Mixer Controls for Dynamic and Ribbon Microphones (A. E. Thiessen: February, 1933)
Mixer Circuits That Work (H. H. Scott: March, 1933)

654-A Voltage Divider
Miscellaneous Recent Developments (May, 1932)

674 Plugs
A New Plug Group (October, 1932)
A New Plug Group (November, 1932)
Large Size Plugs and Jacks (April-May, 1933)

677-U Coil Form
New Coil Form (January, 1933)

706-A Dial
New Precision Dials (January, 1933)

756-A Condenser
A Two-Section Band-Spread Condenser (April-May, 1933)

INDEX BY AUTHOR

The GENERAL RADIO
EXPERIMENTER

VOL. VI. No. 8 JANUARY, 1932

ELECTRICAL COMMUNICATIONS TECHNIQUE
AND ITS APPLICATIONS IN ALLIED FIELDS

A UNIVERSAL BRIDGE

THERE has been a marked increase in recent years in the use of bridge methods for the measurement of impedances of all kinds. This increase has come from the greater number of quantities to be measured, from the greater range of their numerical values, and from the greater range of frequency at which the measurements must be made. The values of the magnitude range and frequency range over which measurements are desired are impressive; resistance from a microhm to a megamegohm, inductance from a millimicrohenry to a kilohenry, capacitance from a millimicromicrofarad to a millifarad; not all perhaps, but some of these at frequencies ranging from a cycle per second to a hectomegacycle per second.

A bridge is merely an instrument with which two impedances, known and unknown, may be compared. The known standard is not inherent in the bridge itself. It must be separately provided. The number and variety of these standards is large; for a single standard can rarely cover a range of a thousand to one in either direction from its own value, and that only at low frequency and low accuracy. As these rise the range of ratio drops, approaching unity for an accuracy of .01% and at a frequency of 100 kilocycles per second.

An obvious way by which the number of standards may be decreased and the accuracy of measurement increased is by the use of the various bridges in which unlike impedances may be compared, as for example, resistance and self and mutual inductance in terms of capacitance, capacitance in terms of resistance and frequency, frequency in terms of inductance and capacitance.

The TYPE 293-A Universal Bridge has been designed with considerations of this sort in mind. It provides the essentials of a bridge, variable ratio arms and a standard resistance which may be used as an added resistance to satisfy one of the conditions of balance, in such a form that all types of bridges may be constructed. These three resistances are mounted on the panel of the bridge as shown in Figure 1, with their terminals and those of an added

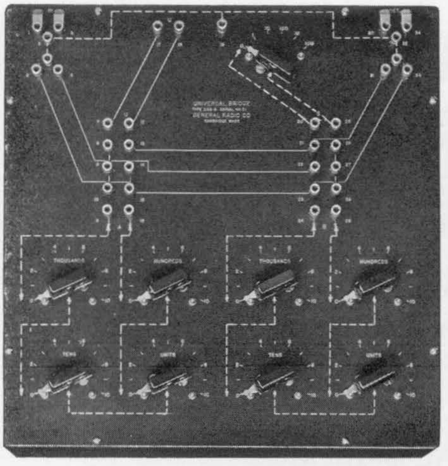


FIGURE 1. Panel view of a TYPE 293-A Universal Bridge. Dotted lines were drawn in after the photograph was taken

impedance symmetrically disposed. These four pairs of terminals may be connected to each other and to the input and output terminals placed at the upper corners of the panel through six pairs of intermediate binding posts, the actual connections being made by links which plug into the various jack-top binding posts.

The principle on which this terminal board is arranged is shown diagrammatically in Figure 2, in which the full lines represent the permanent connections. The three variable resistances together with the added impedance form the four arms of a simple Wheatstone bridge when the ten links indicated by the dotted lines are plugged in. For this four-impedance network the arrangement of the connecting links is symmetrical.

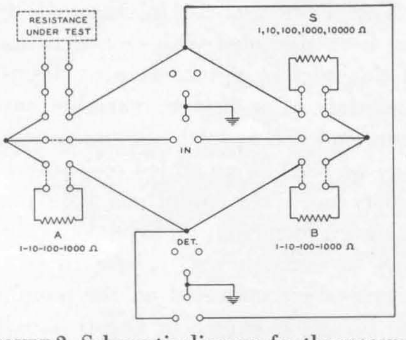


FIGURE 2. Schematic diagram for the measurement of resistance by the Wheatstone Bridge

The three kinds of bridge networks shown in Figure 3 cover practically all of the bridges used for the comparison of like and unlike impedances. The names of these bridges, together with the kinds of impedances compared on them, are given in the table. All of these bridges may be set up on the

TABLE I

Common Bridges Showing the Type of Network and the Kind of Known and Unknown Elements

Bridge	Network[1]	U[2]	S[2]
Impedance	*a*	*R* *L* *C*	*R* *L&R* *C&R*
Grover	*a*	*C* *C*	*C&R* *C&R*
Schering	*a*	*C*	*C&R*
Maxwell	*a*	*L*	*C&R*
Owen	*a*	*L*	*C&R*
Hay	*a*	*L*	*C, R&f*
Resonance	*a*	*L* *f*	*C&f* *L&C*
Wien	*a*	*C* *L* *f*	*R&f* *R&L* *C&R*
Anderson	*b*	*L*	*C&R*
Anderson-Hay	*b*	*C*	*C&R*
Campbell	*c*	*L*	*M&R*
Carey Foster	*c*	*C* *M*	*M&R* *C&R*

[1]Letters refer to the networks of Figure 3.

[2]*U* represents the unknown quantity that can be measured when the corresponding quantities in the *S* column are known. *L, M, R, C, and f* represent respectively self-inductance, mutual inductance, resistance, capacitance, and frequency.

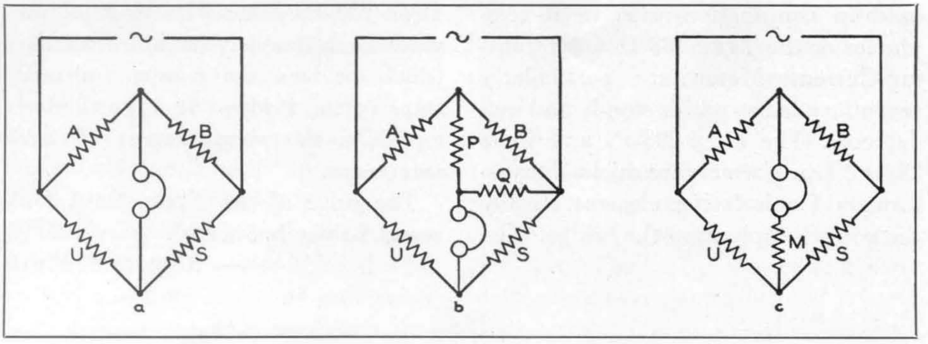


FIGURE 3. Practically all bridge networks are elaborations of these three basic circuits. The letters *a*, *b* and *c* refer to the second column of Table I

TYPE 293-A Universal Bridge by suitably placing the known and unknown impedances and the interconnecting links. The determination of their positions is facilitated by the procedure illustrated in Figure 4.

Owen's bridge, in which the inductance and resistance of an unknown inductor are measured in terms of two added capacitances and the variable resistances, has been chosen as an example.

The schematic diagram of the bridge is made and the four arms lettered cyclically *A-B-S-U* in such a manner that the three variable resistors are used to best advantage. The position of the connecting links may then be drawn on the terminal board diagram, together with the places for connecting the external impedances. Such figures for all the bridges mentioned in Table I are given in the instruction book furnished with each TYPE 293-A Universal Bridge. Blank diagrams for other bridges are also provided.

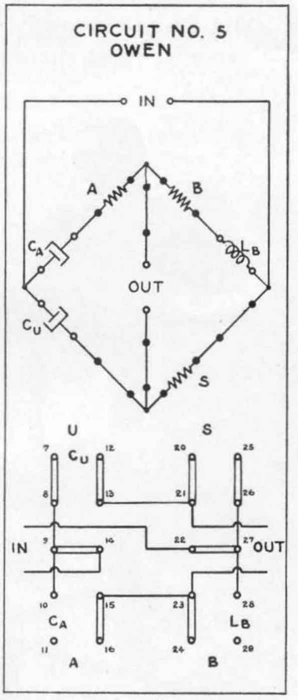


FIGURE 4

The TYPE 293-A Universal Bridge set up as an Owen Bridge

The resistors used in this bridge are the new TYPE 510 Decade-Resistance Units, having the switch contacts below the panel. The three variable resistors are shielded from each other and the whole bridge is placed in a copper-lined cabinet. Double pairs of input and output terminals are provided so that shielded transformers may be used.

The accessories required for the operation of the bridge include a power supply, null detector, and standards of impedance. Suitable instruments for these purposes are described in Catalog F. The TYPE 508-A Oscillator and the TYPE 514-A Amplifier used in conjunction with head telephones or the TYPE 488-DM Alternating-Current Meter are particularly recommended as power supply and null detector. The TYPE 293-P1 and TYPE 293-P2 Transformers are shielded transformers for isolating electrostatically the power supply from the bridge. The TYPE 293-P3 Slide-Wire Resistor provides a continuously variable resistance which bridges the lowest resistance steps in the bridge. It is particularly useful in the measurement of small reactances.

The price of the TYPE 293-A Universal Bridge is $140.00.

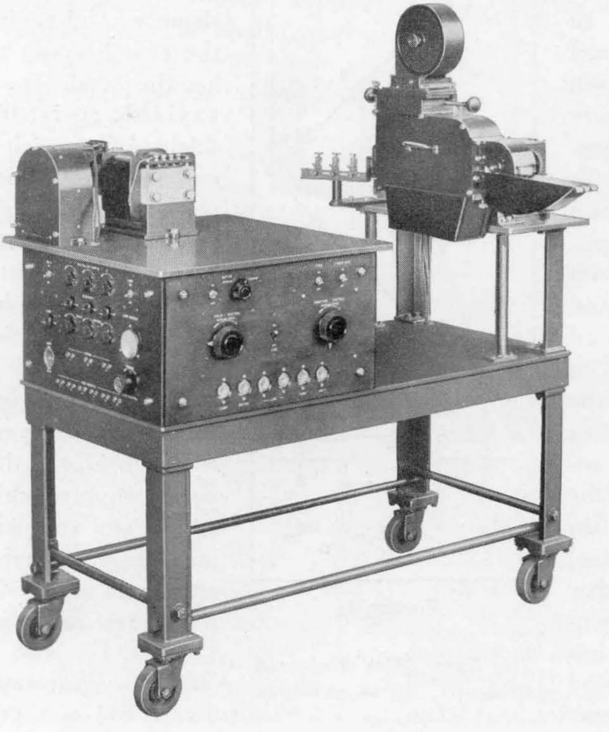
— ROBERT F. FIELD

A SELF-DEVELOPING CAMERA OSCILLOGRAPH

As an illustration of one of the many types of special equipment built by the General Radio Company, we are showing a photograph of a new self-developing string oscillograph.

This oscillograph automatically develops its own photographic records and, accordingly, is of unusual value in commercial research or in adjustment of control circuits where the results of any change must be seen at once.

The sensitized paper is fed into a constantly revolving cylinder, carried past the shutter, and then on through



A three-element camera oscillograph with the self-developing feature both developing and fixing solutions, so that the record is available within a few seconds of the time of exposure. A wide range of operating speed is available and satisfactory oscillograms can be made with paper speeds up to about 15 inches per second.

The action is controlled by a two-position lever which feeds the paper in the first position, and cuts and stops the paper in the second. A three-string harp is standard, and the camera, driving motor, light source, timing units, and controls are all mounted on a portable table.

We have available at the present time two extra oscillographs of this type, designed for operation from 110 volts, d-c. They are priced at $3000.00 each, subject to prior sale.

— H. H. Scott

A FREQUENCY DEVIATION INDICATOR FOR TRANSMITTERS

General Order No. 116 of the Federal Radio Commission, which requires radio broadcasting stations to hold their transmitter frequencies to within ±50 cycles per second of the assigned channels, places on the station frequency monitoring equipment more rigid requirements than have heretofore been necessary.

A highly stable piezo-electric oscillator for use as a monitoring standard of frequency was described by James K. Clapp in the last issue of the *Experimenter*.

While the frequency standard is the most important element of the monitoring system, General Order No. 116 requires, by implication, that an accurate means be available for comparing the frequency of the transmitter with that of the monitoring standard. Under the old 500-cycle tolerance, a zero audible beat or any audible beat note below 500 cycles was sufficient, while under the new order, the beat-frequency indicator should be accurate to within a few cycles per second.

The design of a frequency meter to operate from zero to 50 or 100 cycles per second is extremely difficult since it involves the measurement of both audio and sub-audio frequencies, and, if it actually operates down to zero, it must cover an infinite frequency range. Even if it operates only between one and 50 cycles per second, the frequency

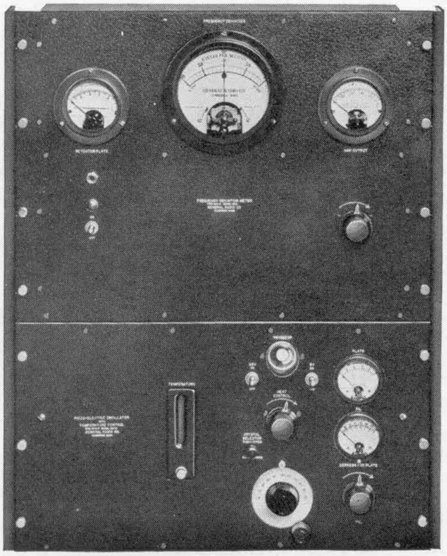


Figure 1. The frequency monitor consisting of a Type 575-D Piezo-Electric Oscillator and a Type 581-A Frequency Deviation Meter

range covered has a ratio of 50 to 1. In general, an accurate frequency meter can cover only a narrow range of frequency; and, as the range becomes smaller, the accuracy increases accordingly.

Since the problem of measuring the deviation of a radio transmitter from a known standard is concerned with the actual deviation in cycles rather than the percentage deviation, it is immaterial what actual value of beat frequency corresponds to zero deviation as long as the variations above and below this value can be measured. A practical answer, then, is to move the normal operating point up in the audio-frequency spectrum until 50-cycle deviations on either side correspond to smaller percentage changes in the audio frequency. This can be realized by using as a monitoring standard a crystal whose frequency differs from the assigned broadcast channel by, say, 1000 cycles per second. The frequency meter can then be designed to read 50 cycles per second above and below 1000. The 1000-cycle difference need not appear on the frequency indicator which can be arranged to read zero at 1000 cycles per second.

General Radio Type 581-A Frequency Deviation Meter is specifically designed to meet these requirements. It consists of a 1000-cycle frequency meter, preceded by a detector and a two-stage audio amplifier.

Voltages derived from the unmodulated master oscillator of the transmitter and from the monitoring standard are impressed on the detector and the resulting audio-frequency beat is amplified and applied to the frequency meter. The frequency indicator is a large pointer-type meter reading zero at 1000 cycles per second and indicating deviations of 100 cycles above and below this value. The scale is sufficiently open to indicate changes of one cycle per second.

The frequency meter itself is a tuned circuit arrangement, as are nearly all

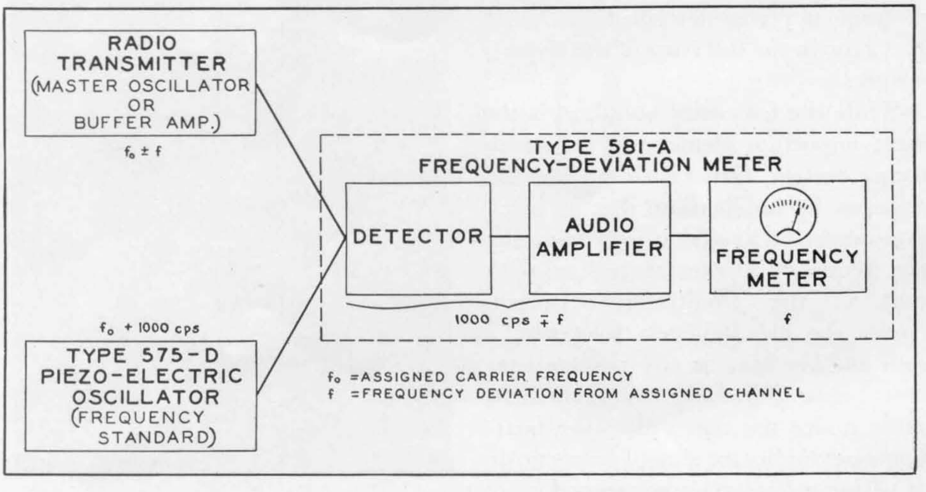


Figure 2. Schematic diagram for the frequency monitor. The "frequency standard" is operating at a frequency 1000 cps above that of the carrier. When operating 1000 cps below the carrier the beat frequency involved in the deviation meter is $(1000 \pm f)$

such instruments which cover narrow frequency ranges.

Several new features are involved which permit high accuracy to be achieved at low cost, a factor which is important if the meter is to be commercially acceptable. Another advantage lies in the fact that it indicates continuously the direction, as well as the magnitude of the frequency deviation. A glance at the meter tells the operator what adjustments he must make to bring the station to the proper frequency.

Type 581-A Frequency Deviation Meter is intended for use with the Type 575-D Piezo-Electric Oscillator. An assembly of the two instruments is shown in Figure 1.

A functional block diagram of the frequency meter assembly is shown at the right of Figure 2. A schematic diagram of the frequency meter itself is given in Figure 3. It consists of two tuned circuits, and two rectifiers connected in opposing directions. The difference of the currents from these rectifiers is indicated by a meter which is calibrated directly in cycles per second.

Figure 2 is a block diagram of the entire monitoring system. In this diagram, f_o is the assigned channel frequency and f is the deviation of the

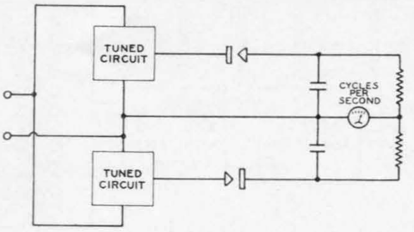


Figure 3. Schematic diagram for the frequency indicating element of the deviation meter

transmitter from that frequency. The transmitter frequency is accordingly $f_o \pm f$. The crystal oscillator operates at a frequency 1000 cycles per second above the assigned channel and its frequency may be expressed as $f_o + 1000$.

When the crystal oscillator and transmitter voltages are impressed on the detector, the resulting audio-frequency beat tone is 1000 cycles $\mp$f.*

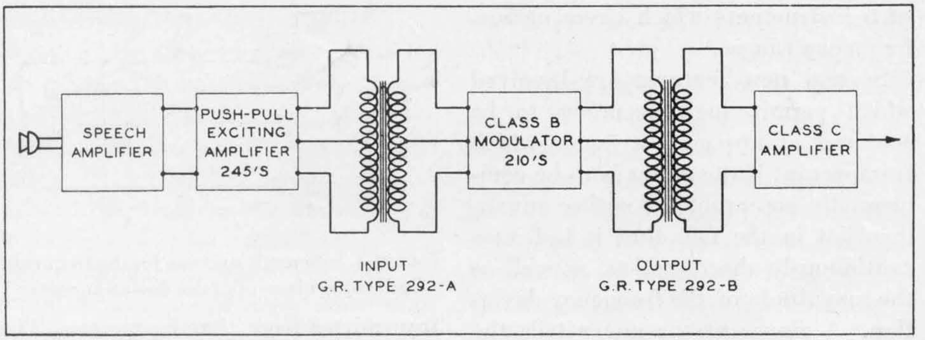
If f is zero, that is, if the transmitter is on frequency, the beat is 1000 cycles per second and the indicator is at zero. An increase in transmitter frequency produces a deflection to the right; a decrease one to the left. The scale is 200 cycles wide, that is, deviations of 100 cycles either side of zero can be read on the meter.

*The crystal frequency can, of course, be either above or below the channel frequency. The sign of the deviation indication can be reversed by reversing the leads to the frequency indicator.

THE "CLASS B" MODULATOR FOR AMATEUR PHONE TRANSMITTERS

By means of "the so-called Class B" type of amplifier, the power output from an amplifier using standard types of tubes may be greatly increased over that possible in the conventional amplifier system.

The circuit arrangement is that known as a push-pull amplifier. The



Schematic diagram for a low-power amateur phone transmitter utilizing General Radio TYPE 292 Transformers in a "Class B" Modulator

gain in power is obtained by a shift in the operating point of the tube on its characteristic so that grid current is taken. The plate current cuts off entirely in each tube during one-half of the cycle. The current in the B lead is therefore not constant, as is the case with the standard push-pull amplifier, but varies cyclically. This difference is of importance in considering power-supply design.

One of the most interesting applications of the "Class B" amplifier is in radio-phone transmitters of moderate power. By means of this circuit, tubes of the 210-type can be made to produce sufficient power for 100% modulation of 50-watt tubes.

The circuit is shown above. Two new General Radio transformers are announced for use in this circuit. One is used as an input push-pull transformer between two 245 and 210 stages and the other is used as the output transformer, coupling the "Class B" modulating amplifier to the radio-frequency amplifier.

The new transformers are: TYPE 292-A Input Transformer, price $7.00. TYPE 292-B Output Transformer, price $10.00.

The GENERAL RADIO EXPERIMENTER

VOL. VI. No. 9 FEBRUARY, 1932

ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

FREQUENCY CHARACTERISTICS

A DECADE-RESISTANCE box is composed of individual decades connected in series to the box terminals. Their arrangement and interconnections are shown in Figure 2. The result is not the pure resistance for which each separate resistor is adjusted by means of a direct-current bridge and which is indicated by the dial setting. In addition the resistors and their wiring have inductance and capacitance which may be conveniently represented by the network of Figure 3. These cause the box to have, at any frequency, a reactance and a phase angle. The resistance will vary with frequency, both because of the frequency characteristic of the network and because of skin effect or crowding of current to the surface of a solid conductor. The existence of reactance and the increase in effective resistance with frequency can be minimized by careful

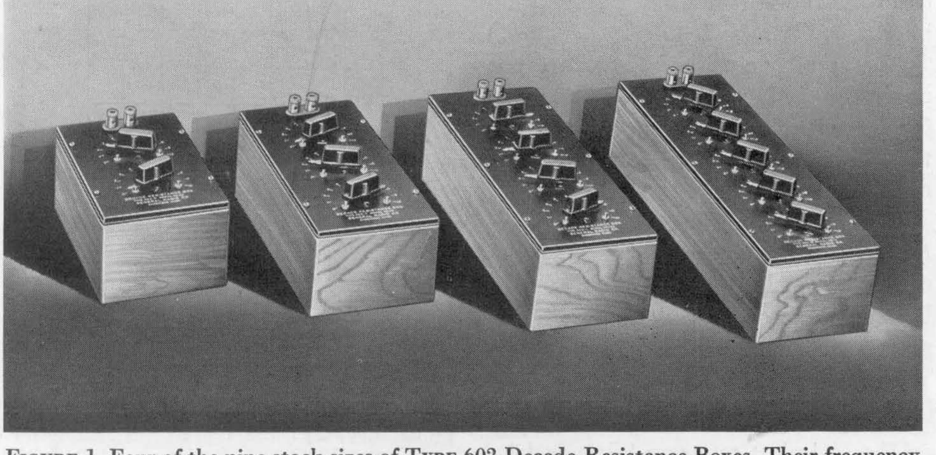


FIGURE 1. Four of the nine stock sizes of TYPE 602 Decade-Resistance Boxes. Their frequency characteristics are discussed in the accompanying article

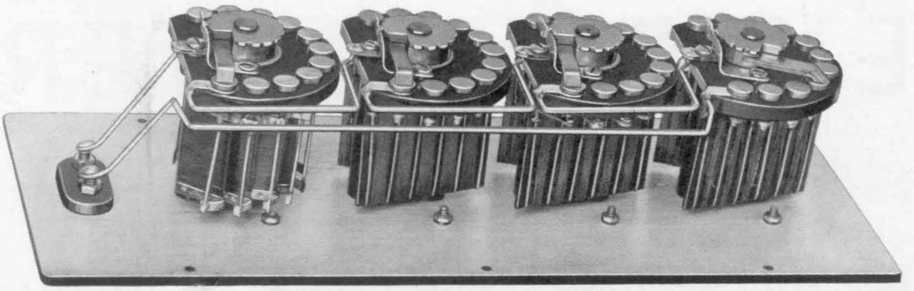


FIGURE 2. Interior of a TYPE 602-J Decade-Resistance Box. The decades are, from right to left, units, tens, hundreds, and thousands of ohms. A separate winding is used for each step

design, but they can never be eliminated. The object of all improvements in the high-frequency behavior of resistance boxes is the minimizing of these two effects.

For frequencies below 50 kilocycles the skin effect is negligible and the equivalent inductance is constant.[1]

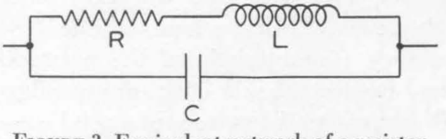


FIGURE 3. Equivalent network of a resistor

This equivalent inductance $\hat{L}$ of the network is always smaller than the series inductance L because of the shunting action of the parallel capacitance C: $\hat{L} = L - R^2C$ (1)

For small values of resistance the equivalent inductance is positive, while for larger values it is negative. The transition usually occurs in the hundreds of ohms.

Figure 4 shows the values of L and $\hat{L}$ measured at a frequency of 1 kilocycle for each of the six TYPE 510 Decade-Resistance Units. The complete boxes of Figure 1 are, essentially, assemblies of these units.

The parallel capacitance C, calculated by means of Equation (1) is about 6 $\mu\mu$f and is independent of dial setting.

The multiplicity of scales needed in Figure 4 in order to cover the wide range of values of equivalent inductance of the various decades may be reduced by using the ratio $\hat{L}/R$ of the equivalent inductance to the series resistance. This ratio has the dimensions of time and is called the time constant. When the equivalent inductance is negative, the time constant is still taken as positive, since the network is capacitive. In plotting it is

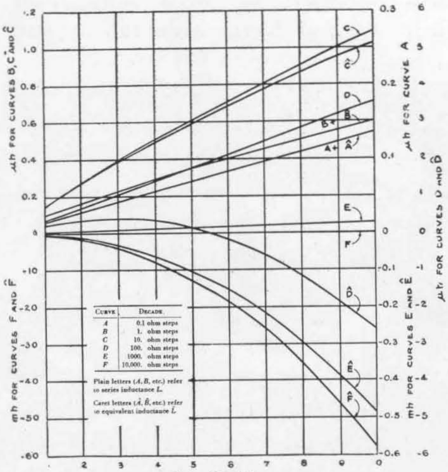


FIGURE 4. Equivalent inductance and "series inductance" as a function of dial setting for the TYPE 510 Decade-Resistance Units with their shields removed

[1]The equivalent reactance below 50 kilocycles is then $\hat{X} = \omega\hat{L}$

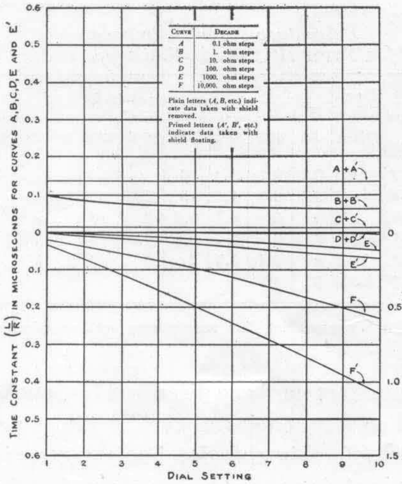


FIGURE 5. Time constant is plotted as a function of dial setting for TYPE 510 Decade-Resistance Units

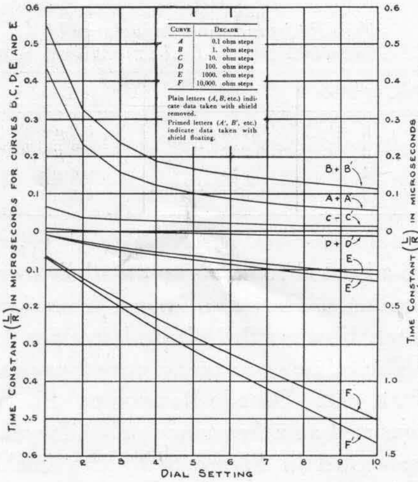


FIGURE 6. Time constant for the different decades of four-dial TYPE 602 Decade-Resistance Boxes

convenient to extend the time constant scale below the zero axis in order that the curves may be continuous.

The time constants for the TYPE 510 Decade-Resistance Units are plotted in Figure 5, both with the shield removed and with it in place but not connected, i.e., floating. The addition of a shield increases the parallel capacitance and thus affects the equivalent inductance and time constant of the larger decades by increasing the term R^2C. When the shield is connected to a terminal of the decade this capacitance is still further increased and is no longer constant for the various dial settings.

Values of these capacitances for the larger decades under the various conditions of shielding are given in Table I. The time constant for these conditions may be found by adding algebraically to the time constants given in Figure 5 that of the added capacitance.

When a number of TYPE 510 Decade-Resistance Units are assembled on a panel to form a TYPE 602 Decade-Resistance Box, the resistance and inductance of the wiring connecting the various decades and the additional capacitances of the decades increase the equivalent resistance and reactance over that of the separate units. The resistance and inductance at zero setting of two-, three-, four-, and five-dial boxes are given in Table II. These zero resistances are not included in the resistances of the various units, which

TABLE I

Parallel Capacitance in μμf of Decade Resistors

Type of Unit	Decade Ohm	Shield Connection*			
		Removed	Floating	On Zero	On Switch
510-D	100	6-6			
510-E	1000	6-6	7-7	31-17	9-16
510-F	10,000	6-6	10-10	33-21	12-18
602-J	1				
	10				
	100	18-17	21-19	41-35	53-53
	1000	17-12	19-14	27-20	63-63

*First figure is for zero setting, second figure is for maximum setting of the decade in question.

TABLE II

Zero Resistance and Inductance of Type 602 *Decade-Resistance Boxes*

No. of Dials	R	L
2	0.005 ohm	0.2 μh
3	0.007 "	0.3 μh
4	0.010 "	0.4 μh
5	0.012 "	0.5 μh

are adjusted to be correct at their own terminals. They also have a large skin effect, because the wiring is copper.

The time constants for four-dial Type 602 Decade-Resistance Boxes measured at a frequency of 1 kilocycle are shown in Figure 6 for the shield both removed and floating. The parallel capacitances are considerably larger for such a box than for a single decade and are given in Table I. They depend both on the number of decades in the box and on the position of the decade in question with reference to the other decades.

The effect on the parallel capacitance of the largest decade of connecting the shield to a terminal of the box is least when that terminal leads directly to the smallest decade. This connection however increases the resistance of the smallest decade because the resistances of the higher decades are placed in series with their capacitances to shield.

TABLE III

Percentage Error in Resistance for Type 510 *Decade-Resistance Units*

Type	Decade* Ohm	Frequency in kc 50	100	200	500	1000	2000	5000	10,000
510-A	0.1	0	0.1	0.2	1.5	5	15		
510-B	1.0	0	0	0.1	0.3	1	4	25	
510-C	10	0	0	0	0.1	0.5	2	11	
510-D	100	0	0	0	0.1	0.3	0.8	4	15
510-E	1000	0	0	0	−0.3	−1	−4	−30	
510-F	10,000	0	−0.2	−2	−6	−16			

*Percentages are for maximum setting of each decade.

TABLE IV

Percentage Error in Impedance for Type 510 *Decade-Resistance Units*

Type	Decade* Ohm	Frequency in kc 50	100	200	500	1000	2000	5000	10,000
510-A	0.1	0.2	0.7	2	15				
510-B	1	0.1	0.2	1	5	20			
510-C	10	0	0	0.1	0.2	2	10		
510-D	100	0	0	0	0.1	0.3	1	5	15
510-E	1000	0	0.1	0.5	2	6	20		
510-F	10,000	5	20						

*Percentages are for maximum setting of each decade.

This effect has been discussed by Jones.[2]

For frequencies above 50 kilocycles skin effect is the dominant factor in determining resistance except for the largest decades. Approximate values of the ratio (expressed as percentage error) of high-frequency resistance to d-c resistance of each of the Type 510 Decade-Resistors are given in Table III.

When a single decade or a number of decades are used as a voltage divider, the impedance of the different units is the factor determining the accuracy of the voltage division. Values of the ratio (expressed as percentage error) of high-frequency impedance to d-c resistance of each of the Type 510 Decade-Resistance Units are given in Table IV.

For the Type 602 Decade-Resistance Boxes the values of resistance and impedance at high frequencies are greater than for the corresponding Type 510 Decade-Resistance Units by amounts determined by the connecting wires as shown in Table II. When used in substitution methods where the change in resistance rather than its absolute value is significant, Table III still applies, except for moderate changes in the highest decades.

— Robert F. Field

[2] Jones and Josephs, *Journal of the American Chemical Society*, Vol. 50, 1928, p. 1049.

A DUPLEX SIPHON RECORDER

IN the September, 1931, issue of the *Experimenter*, we announced a high-speed chronograph. Time-interval measurements to be made with a precision of something better than 0.001 second.

The present article describes another form of chronograph for use in problems requiring a less-accurate measurement of time intervals, the maximum precision being of the order of 0.01 second. This is the TYPE 456-A Duplex Siphon Recorder, shown below.

The siphon recorder is a well-known device which, among other things, has found extensive use in the automatic recording of telegraphic code signals. Some form of writing stylus, pen or pencil, is made to move a short distance to and fro by the starting and stopping of current through an appropriate electromagnet system. This stylus traces a line upon a strip of paper moving with a suitable speed perpendicular to the motion of the stylus.

If the design of the energizing electromagnet is such that the deflecting force increases, in general, with the displacement, and if the moving member carrying the stylus operates between fixed "back" and "front" stops, then the familiar block form of trace will be produced which gives practically no indication of the waveform of the energizing current, but which affords deflection intervals proportional to the duration of the current. At slow paper speeds, these traces are rectilinear in appearance. At the higher speeds, the to-and-fro motion traces a curved line, the extent of which (along the time axis) depends upon the inertia and restoring force of the moving member. The instant at which the motion of the stylus is stopped; that is, on striking the front contact on being energized, or the rear contact on being released, can, however, be determined with a sufficient precision to permit measurements to 0.01 second at the higher paper speeds. These are the fundamental operating conditions for the TYPE 456 Duplex Siphon Recorders.

As the name implies, this instrument carries two separate and individual pens which make adjacent traces upon the ½-inch strip of "ticker" paper. This paper, obtained in 5-inch diameter rolls, is mounted on a reel housed in a drawer in the cabinet base of the instrument. The paper is threaded up through the panel and, subsequently, over a rubber-faced drum which is driven by a 110-volt universal-type motor. Driving friction is produced by a grooved tension roller pressing the paper against the drum.

TYPE 456-A Duplex Siphon Recorder with the protecting cover removed. Tape is fed from a reel in the base

While passing over the top of the drum, the paper is marked with the two traces by the pens, which, of course, move parallel to the drum axis.

The pen arms are energized by two separate closed electromagnet assemblies, the windings of which terminate in two pairs of terminal posts. The two magnet and pen assemblies may each be raised and lowered by thumb screws to adjust the contact of the pens upon the paper. Two cam arms are likewise provided for raising the pens and holding them away from the paper without disturbing the adjustment of these thumb screws. The travel of each pen arm may be controlled by an adjustable "back" screw. The restoring force of each arm may be adjusted to best meet operating conditions. Increasing this restoring force increases the speed of the moving member at a sacrifice, of course, of the sensitivity.

The pens consist merely of two fine silver tubes which are mounted on the arms by suitable spring clamps. The lower end of the pen travels over the paper, while the upper end is suspended free from contact in an ink cup which is mounted on the magnet assembly. Inks of different colors, as, for example, red and blue, may be used for each of the two traces. The flow of ink is produced by siphonic action. A small suction nozzle is provided for starting the siphons. Also, two medicine stoppers for filling the ink cups.

For maximum sensitivity, the lower ends of the pens need not actually touch the paper, the flow of the siphon being maintained by capillary attraction. Suitable inks are provided which enable the device to be kept idle in readiness for operation for at least twenty-four hours. The ink cups are readily emptied and the pens cleaned by siphoning water through them.

The shaft of the driving motor is connected to the drum shaft through a built-in reduction gear system, which is an integral part of the motor. By the use of different motors, paper speeds from 0.1 inch to 7 inches per second can be obtained. A rheostat is provided which enables the paper speed with any one motor to be varied over a ratio of about 4:1.

The standard form of pen magnets is each wound to a resistance of approximately 2400 ohms which enables the pens to be operated by a minimum current of 2 milliamperes (5 volts across the winding). A special higher resistance winding would permit operation by minimum currents between 0.5 and 1 milliampere.

The standard motor used has a gear reduction 144:1 and by means of the rheostat gives paper speeds from 0.8 inch to 3.5 inches per second. Other motors having gear reductions 72:1, 595:1, and 1120:1 are available for substituting to obtain proportional changes in paper speed.

In making time interval measurements with this chronograph it is customary to energize one pen at known time intervals such as 0.1 second, 1.0 second or any other desired value, while the other pen responds to electrical currents associated with the phenomenon to be timed. An example of such a technique was described in conjunction with the cardiotachometer in the July, 1930, issue of the *Experimenter*. Here the time intervals were one second apart and the second pen recorded each heart beat. In this manner a continuous and permanent record of the heart rate was obtained.

This same procedure may be adapted to a wide variety of problems involving timing operations as, for example, the timing of chemical phenomena, of athletic events, of vehicle speeds, of traffic distribution, of the flow of liquids and of the fall of balls in viscous media, etc.

The method used for securing the reference time intervals depends upon the particular problem at hand. One-second and one-minute intervals can readily be obtained from suitable clock mechanism, while one-second and 0.1-second intervals can be obtained from contacts operated by synchronous motors driven by 60-cps or any other regulated alternating-current sources. If the regulation of such current is not sufficiently precise for the problem, it is quite feasible to superimpose one-second intervals from an accurate clock upon a series of 0.1-second intervals from the synchronous commutator, the latter serving merely to decimate the accurate one-second intervals. The speed of the paper will be sufficiently uniform to enable one to interpolate to 0.01 second between the marked 0.1-second intervals.

The price of the Type 456-A Duplex Siphon Recorder, described above and shown in the illustration, is $190.00.

In some lines of work, it becomes desirable to provide a remote and intermittent control for this siphon recorder so that sample records may be obtained at stated intervals instead of a continuous record over a long run. For this purpose, the recorder may be fitted with two solenoids which, when not energized, release the pens from contact with the paper, and thus interrupt the flow of the ink. The driving motor may, of course, be stopped at such times, thus minimizing the amount of paper used. The Type 456-B Duplex Siphon Recorder, which is fitted with these solenoids, is priced at $225.00.

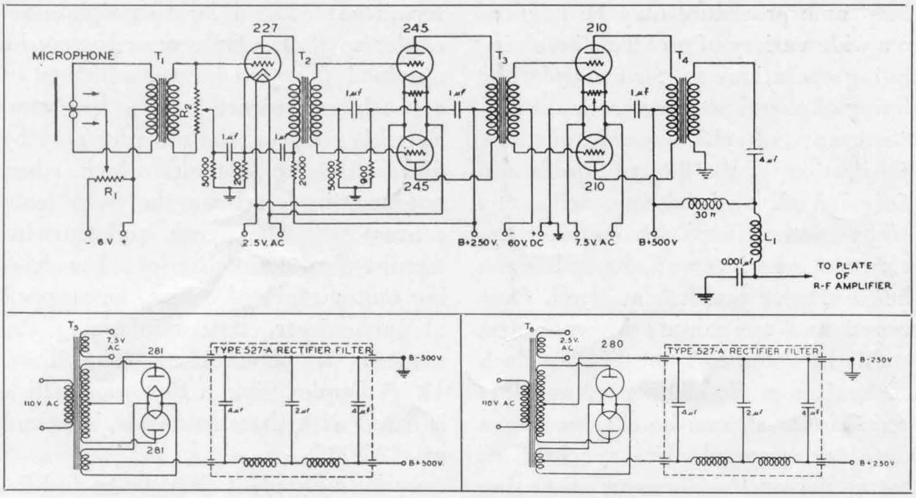
It will be evident that the to-and-fro motion of the pen arm, energized by such feeble currents, could simultaneously be used as a sensitive relay to control a considerably greater amount of electrical energy than that required to drive the arm. For such a purpose, it is quite feasible to fit one of the pen arms with suitable relay contacts. In the cardiotachometer equipment, for instance, the pen arm energized by the heart pulses is provided with such contacts through which an impulse counter is driven, thus affording a count of the total number of heart beats in any given interval, in addition to the variation in heart rate from time to time as shown by the tape records.

— Horatio W. Lamson

100% MODULATION FOR THE AMATEUR PHONE

The Class B Modulator, using transformer coupling to the radio-frequency amplifier, eliminates the high wattage tubes with the high plate voltages used in the Class A modulator system, and permits 100% modulation with relatively low power. A modulator and a speech amplifier as shown in the accompanying diagram, using only two 210-type tubes in push pull as the modulators, will easily modulate 100% some 50 watts plate input to a Class C radio-frequency amplifier.

In the diagram the microphone and speech amplifier circuits are typical of those in use in amateur modulation



*Wiring diagram for a complete speech amplifier and Class B Modulator, capable of modulating 50 watts of plate input for a Class C radio-frequency amplifier. See the Legend below.**

systems at the present time. The necessary additions are the input and output transformers of the modulator. General Radio Type 292-A and Type 292-B Transformers have been designed and built to fulfill the needs of the amateur desiring to change his modulator system to Class B.

— M. C. Hobart

Left: Type 292-A Transformer
Right: Type 292-B Transformer

*LEGEND

R_1—Type 301 Potentiometer, 200 ~	$1.00
R_2—Type 471 Potentiometer, 100,000 ~	6.00
R_3—Type 437 Center-Tap Resistor	.50
L_1—Type 379-T R-F Choke	1.25
T_1—Type 585-M Transformer (for single-button microphone)	10.00
Type 585-M2 Transformer (for double-button microphone)	10.00
T_2—Type 541-A Transformer	7.50
T_3—Type 292-A Transformer	7.00
T_4—Type 292-B Transformer	10.00
T_5—Type 565-B Full-Wave Transformer	13.50
T_6—Type 545-B Transformer	10.00
Type 527-A Rectifier Filter	17.50

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ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

THE MICHELSON VELOCITY OF LIGHT EXPERIMENT

We are indebted to Mr. E. C. Nichols of the Department of Instrument Design at the Mount Wilson Observatory, Pasadena, for the accompanying description of the latest experiment to determine the velocity of light in a vacuum.—EDITOR.

THE following is a brief description of the Michelson velocity of light experiment in vacuum. This experiment, made at the Irvine ranch near Santa Ana, California, during the period from May, 1930, to July, 1931, by A. A. Michelson of the University of Chicago, F. G. Pease of the Mount Wilson Observatory, and F. Pearson of the University of Chicago, was an endeavor to determine more accurately the velocity of light. The investigation was carried out jointly by the Mount Wilson Observatory of the Carnegie Institution of Washington and the University of Chicago.

In this experiment two systems of measurement were used: the first, that of time; the second, that of distance. In the case of the latter measurement it was felt that the direct measurement of a short base line without the additional triangulation might yield a higher order of accuracy. This was accomplished with a vacuum tube one mile long, the light traversing it eight or ten times. The base line was measured by Commander Garner of the United States Coast and Geodetic Survey. The results of this measurement have a probable error of ±0.47 mm. or one part in 3,400,000.

TIME MEASUREMENT

Two clocks were used in the time measurement. One was a ship's chronometer beating seconds on a relay and omitting every 59th second. The rate of the chronometer changed frequently, rarely remaining the same for 24 hours. The other clock was a constant-frequency oscillator of General Radio make, controlled by an oscillating quartz crystal, the period of which was increased by two multivibrators. The seconds relay and the syncro-clock of the constant-frequency oscillator were operated on a shaft driven by a unipolar motor. The unipolar motor was in turn operated by the multivibrators.

The rate of the constant-frequency oscillator was decidedly more constant than the ship's chronometer. Comparisons were made on a chronograph having two ink pens operated by relays. The chronograph was driven by a synchronous motor and had a peripheral speed of one inch per second. Time signals were also recorded on the chronograph. These signals were received from Arlington four times a day on 1700 meters.

DESCRIPTION OF APPARATUS

The mile-long three-foot diameter vacuum tube consisted of 60-foot lengths of riveted and soldered corrugated galvanized pipe No. 14 gauge, joined with rubber balloon tire inner tubes and cemented to the pipe ends with rubber cement. At each end two steel tanks were included in the tube to house the mirrors and their controls for the optical system. These tanks were fabricated from 3/8-inch steel plate and welded. They rested on base plates of the same material and were sealed with a lead wire and hydroseal; no bolts were necessary. All joints were painted with several coats of Glyptal. Not a single machined surface was necessary in the entire vacuum container, which had a volume of 40,000 cubic feet and resisted a total collapsing pressure of 53,000 tons.

The mirror mountings and their controls in the tanks were supported independently on separate concrete piers by steel columns extending up through openings in the base of the tanks. These openings were sealed off by rubber sleeves. All adjustments to the mirrors inside the tube were made with small motors operated by remote control through a motor generator Selsyn system operated from the head station at the south end of the tube. Two Kinney vacuum pumps having a total capacity of 450 cubic feet of free air per minute were used to evacuate the tube. A vacuum of 0.5 millimeters was obtained.

THE OPTICAL SYSTEM

Light from an arc lamp was imaged by a condensing lens onto a slit. The light coming through the slit passed above a small right-angle prism and onto the upper half of one of the faces of the 32-sided rotating mirror. This mirror rotated at approximately 500 revolutions per second. From the rotating mirror the light was reflected through a plane-parallel window into the tank to a diagonal flat mirror and then at right angles to a 50-foot focus concave mirror, which changed the light into a parallel beam. From the concave mirror the light passed over a 22-inch diameter flat mirror and fell upon another 22-inch flat one mile away at the north end of the tube. Thence the light was reflected nine times back and forth the length of the tube between the two 22-inch mirrors, finally emerging through the window in the tank over the same path but slightly lower and striking the lower half of the rotating mirror on a face adjacent to the one from which it was originally reflected. From this face the light was reflected into the small right-angle prism and thence onto the cross wire and was observed in the eyepiece. The single vertical cross wire was mounted in a micrometer which had divisions reading to 0.001 inch.

The rotating mirror was driven by a small compressed air turbine mounted directly on the mirror spindle.

SYSTEM OF MEASUREMENT

In the null method used, the light emerged from one face of the rotating mirror and was received on the adjacent face. As the mirror started rotating the image gradually passed from the field of view, later to reappear from the opposite side of the field as the mirror approached its proper speed. The rotating mirror was brought into synchronism with a tuning fork whose period of vibration had to be measured. The slight angle in which the return beam differed from 1/32 revolution was measured with the micrometer. The distance remained fixed. The time interval to be measured, therefore, was that during which the rotating mirror turned from one face to the next, plus or minus a small angle observed in the eyepiece.

The period of the fork was then determined by stroboscopic methods in terms of free-pendulum beats. As the rotating mirror accelerated, light from a 6-volt lamp was reflected from a small mirror on the tuning fork onto a polished face of the nut clamping the rotating mirror to its spindle. As the mirror continued to accelerate, the image from the tuning fork passed through a series of vibrating and stationary states to a final stationary state for which the beats heard between the fork and the rotating mirror ceased. At this point a second observer made a setting on the return image formed by the light traversing the tube and read off the micrometer. A reversal of the direction of rotation of the mirror eliminated any necessity for making zero readings.

In checking the tuning fork with the pendulum, light from a small lamp was focused on a narrow slit and passed into the pendulum case, whence it was reflected by a small mirror on the pendulum and focused on the edge of the tuning fork. When the fork vibrated, flashes of light from the mirror on the pendulum illuminated the fork in various positions, thus producing a series

The standard-frequency assembly used in the Michelson experiment was similar to the one shown above, except that one of the multivibrators was replaced by an amplifier for the 0.1-second pulses from the syncro-clock

of saw-tooth images. When the fork period was an exact multiple of the pendulum, the images appeared stationary. When the periods differed, the teeth appeared to travel across the field of view. The period of the fork in terms of the free pendulum could be determined from the number of flashes shown in traveling from one tooth to the next.

TRUE PERIOD OF FREE PENDULUM

The determination of the period of the free pendulum in terms of true time was done in two steps. First a comparison was made between the beats of the pendulum and a flash box, operated by the constant-frequency oscillator or by the ship's chronometer. The second comparison was made between the chronograph records of second-marks from the chronometer and the time signals from Arlington. Light from the flash box was reflected from a small fixed mirror inside the pendulum case and from a small mirror placed on the axis of the pendulum. These two reflections returned to a transparent scale in the flash box where the time of their coincidence could be observed.

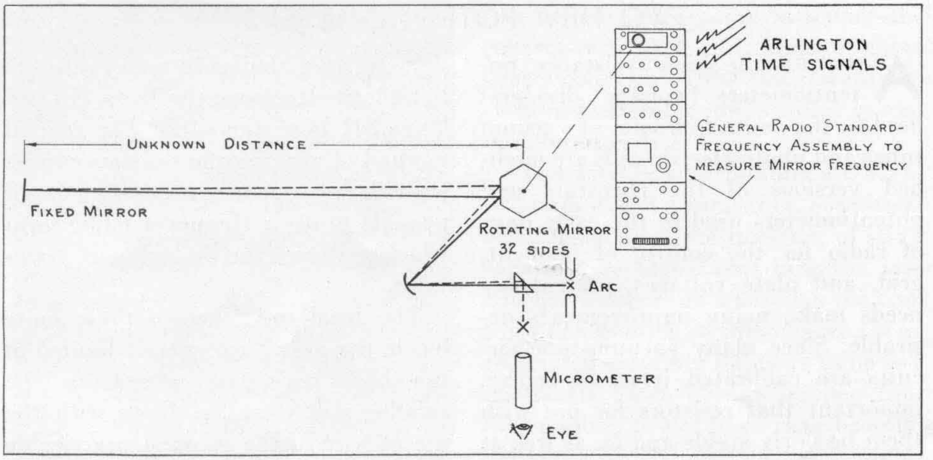
Accuracy in determining the pendulum period depended upon the precise operation of the flash box shutter. The superior performance of the General Radio Standard-Frequency Assembly in operating the shutter was a very great advantage. — E. C. NICHOLS.

THE POSSIBILITY OF USING A STANDARD-FREQUENCY ASSEMBLY TO MEASURE DISTANCE

THE experiment described by Mr. Nichols in the foregoing article should be of particular interest to everyone who has followed the development of precision frequency measurements during the past few years. The crystal-controlled standard-frequency assembly was of course designed and built primarily for measuring frequencies anywhere in the communication-frequency spectrum and its direct application to a time measuring problem serves to emphasize the identity of time and frequency.

Reduced to its lowest terms the time measuring problem in the Michelson experiment is nothing more than the determination of the rotational frequency of the rotating mirror. The use of the standard-frequency assembly to measure without intermediate steps this rotational frequency is a possibility that will suggest itself to most of us who are accustomed to think in terms of frequency rather than in terms of time. It becomes a problem of measuring a frequency of some 500 cps. with the greatest possible accuracy, say, one part in three million. If the tuning fork used in the Michelson experiment could be replaced by a frequency derived from a standard-frequency assembly, the question of determining this rotational frequency in terms of a standard time interval would be considerably simplified.

With this simplification in mind it may be of interest to consider a suggestion made several years ago by Major William Bowie of the United States



This is how the Michelson experiment might, so to speak, be inverted to measure distance in terms of the velocity of light and time. The rotational frequency of the mirror would be measured by a standard-frequency assembly, thus yielding the length of time required for the mirror to move an adjacent face into position

Coast and Geodetic Survey: that distance be measured in terms of the known velocity of light and time. A measurement of this kind would have important practical applications in geodesy where the difficulties of laying down precise base lines in mountainous countries and in archipelagoes are serious when done by present methods.

The experimental basis for such a measurement of distance was laid by an earlier experiment of Dr. Michelson when he measured the velocity of light between two stations — one located on Mount Wilson and the other on Mount San Antonio 22 miles away. The distance between these two stations was measured by the United States Coast and Geodetic Survey with a probable error of one part in 6,800,000 and the time was measured by methods somewhat similar to those just described by Mr. Nichols.

In measuring distance the experimental procedure would be reversed, and, instead of measuring the time it takes light to traverse a known distance, we would measure the time taken by light to traverse the unknown distance and then work out the distance from the known velocity of light. The compactness, portability, and high precision of a standard-frequency assembly would readily adapt it to this use since the elimination of as much bulky apparatus as possible would be desirable from the experimenter's point of view.

Some time we hope to see the experiment tried. It certainly has many interesting possibilities.

—JOHN D. CRAWFORD.

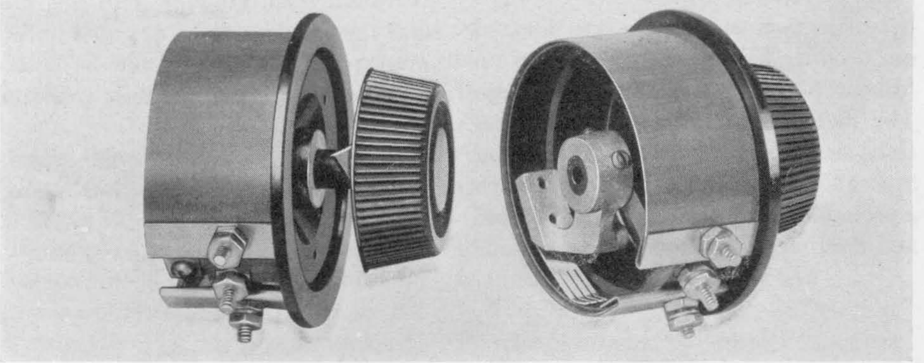
TWO NEW POTENTIOMETERS

ALTHOUGH the high resistance potentiometers (voltage dividers) used in the control circuits of vacuum tubes and photo-electric cells are modified versions of the rheostats and potentiometers used in the early days of radio for the control of filament, grid, and plate voltages, present-day needs make many improvements desirable. Since many vacuum-tube circuits are calibrated it is, of course, important that resistors for use with them be fairly stable and be as free as possible from vagaries due to changes in contact resistance, skipping, and other ills.

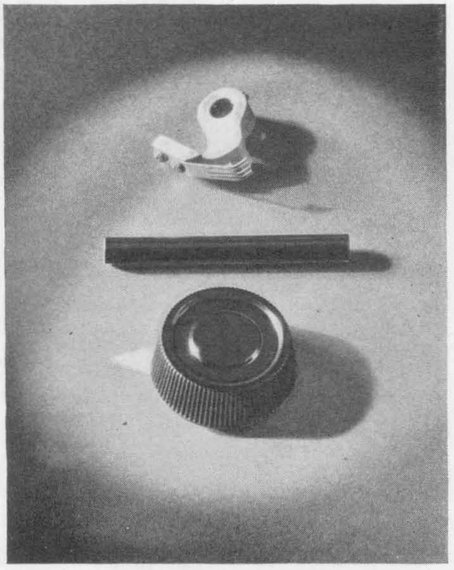
For the past several years General Radio TYPE 214 and TYPE 371 Potentiometers have met most all requirements except in high-quality, voice-frequency circuits where special logarithmic volume controls have been designed. It has been felt that some improvement could be made in controls for other circuits and the TYPE 314 and TYPE 471 Potentiometers about to be described are the result of work in this direction.

The TYPE 314 and TYPE 471 Potentiometers are similar in many respects to their predecessors, the TYPE 214 and TYPE 371 Potentiometers. The general method of winding the resistance units is similar, except that it has been found possible to use a thinner winding form which reduces the inductance somewhat.

The total resistance of these units has in the past been severely limited in the high resistance ranges by the smallness of the wire. Even with the use of wire of the greatest practicable resistivity, it has been found almost impossible to go to values much greater than 50,000 ohms even on the large size form used for the TYPE 371 Potentiometer. The small size wire causes an appreciable amount of spoilage during manufacture and even the finished product is liable to damage if handled roughly. The new units are provided with a bakelite strip which surrounds the form carrying the resistance wire. This acts as a mechanical protection and practically eliminates the possibility of damage to it during its installation in experimental equipment.



TYPE 314 Potentiometers. The fine wire used in winding the new potentiometers is protected from accidental damage by a thin strip of linen bakelite

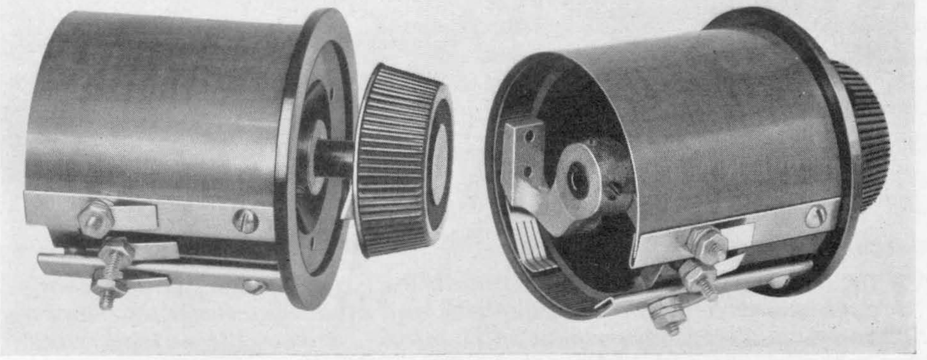


The contact arm, bakelite shaft, and large knob used in the new TYPE 314 and TYPE 471 Potentiometers

Another limitation due to the small wire size used in earlier designs was the possibility of getting imperfect contact with the slider used. The new units use a new type of slider having four fingers which bear lightly on the wire. The pressure needed to secure good contact and, therefore, the amount of wear which results is considerably reduced by this method. The four contact members also serve to reduce the contact resistance and render it more nearly constant. Thus the stability of circuits containing these units is materially improved.

Since high resistance units are likely to be used in vacuum-tube circuits of high impedance, the question of stray capacitances introduced into the system by the operator's hand on the control knob is often of importance. If an associated amplifier happens to have a substantial gain, it may happen that the coupling to the hand may be sufficient to introduce an appreciable amount of 60-cycle hum picked up from power-supply wiring in the vicinity. This effect has been practically eliminated in the new design by the use of an insulating bakelite shaft. This shaft is larger than the metal shaft used on earlier models, so that nothing has been sacrificed in the way of mechanical ruggedness by the change.

An added feature is the use of a larger knob and a non-metallic pointer. This knob is much easier to handle than the smaller one and its use is therefore worth while. The pointer has a dull white finish which eliminates the ob-



TYPE 471 Potentiometers. Contact resistance, wear, and skipping are reduced by the new four-wiper contact arm

jection to confusing reflections which were sometimes encountered when metal pointers were used in unfavorable light.

Most of these features can be seen by careful examination of the accompanying photographs. It will be noticed, of course, that the TYPE 314 and TYPE 471 Potentiometers are practically identical in design features. The difference is merely a matter of size of the form upon which the resistance wire is wound. This is the same difference that describes the old TYPE 214 and TYPE 371 Potentiometers.

The following table lists the resistance, current carrying capacity, code word, and price of each of the new units normally carried in stock.

TYPE 314 Potentiometers

Resistance	Current	Code Word	Price
200 ohms	165 milliamperes	ENATE	$4.00
600 ,,	95 ,,	ENDOW	4.00
2000 ,,	52 ,,	ENEMY	4.00
6000 ,,	30 ,,	ENJOY	4.00
20,000 ,,	16 ,,	ENROL	4.00

TYPE 471 Potentiometers

Resistance	Current	Code Word	Price
50,000 ohms	14.7 milliamperes	ERODE	$6.00
100,000 ,,	10.4 ,,	ERUPT	6.00
200,000 ,,	7.3 ,,	ESKER	6.00

TYPE 214 POTENTIOMETERS

TYPE 214 Rheostats and Potentiometers are now supplied as potentiometers only. In other words, each unit has three terminals—one connected to the sliding contact and the other two to either end of the resistor. This change is a simplification that will benefit the user, because it will make it unnecessary for him to make any changes in a unit when the direction of rotation is to be reversed.

Prices on two sizes of these units have been reduced, and all orders placed since February 8 have had the benefit of the reduction.

The following table shows the total resistance, maximum current, and prices for all of the TYPE 214 Potentiometers regularly carried in stock (for TYPE 214-B, Table Mounting as well as for TYPE 214-A, Panel Mounting). Only panel mounting models are regularly carried in stock, however.

Resistance	Current	Price	
		Old	New
0.75 ohm	4 amperes	$1.50	$1.50
2 ohms	2.5 ,,	1.50	1.50
7 ,,	1.3 ,,	1.50	1.50
20 ,,	0.75 ampere	1.50	1.50
50 ,,	500 milliamperes	1.50	1.50
100 ,,	350 ,,	1.50	1.50
200 ,,	250 ,,	1.50	1.50
400 ,,	175 ,,	1.50	1.50
1000 ,,	110 ,,	1.75	1.50
2500 ,,	70 ,,	2.00	1.50

TYPE 371 POTENTIOMETERS

Effective February 8 the prices of all stock sizes of TYPE 371 Potentiometers were reduced. These are listed on pages 28 and 126 of Catalog F and on page 12 of Bulletin 933. The linear models (TYPE 371-A) are reduced to $4.00 and the tapered model (TYPE 371-T) is reduced to $5.00.

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TESTING RADIO RECEIVERS ON THE ASSEMBLY LINE

THERE is no other single test that will give the figure of merit of a radio receiver more accurately than the measurement of its over-all sensitivity. Because it is one of the fundamental characteristics of any receiver, laboratory information on the sensitivity is usually well known. A quick comparison of the sensitivity of the sets as they progress along the final inspection line with the predetermined laboratory standards has proved to be a most satisfactory indication that their performance is acceptable.

It is almost always necessary to align the ganged variable condensers in a receiver during the final testing operation and a good radio-frequency oscillator is required for this. For superheterodynes, the alignment process must be made at frequencies both in the broadcast band and at the intermediate frequency. Since sensitivity tests must also be made, the standard-signal generator is often used as the aligning oscillator.

The General Radio Type 601-A Standard-Signal Generator has proved to be a most useful instrument for these tests. Figure 1 on the next page shows them in the final production line at the Kolster Radio Corporation's factory in Newark, New Jersey.

In order to take care of the peak production from this plant, ten test positions are necessary. Each one has its Type 601-A Standard-Signal Generator mounted upon a cabinet containing two loud-speakers (one is a stand-by in case of trouble) and an output meter. The completely assembled chassis are received in the test room from the slowly moving conveyer which has carried them down from the assembly departments. The power and loud-speaker leads are plugged in and the radio-frequency input from the standard-signal generator, working through a standard dummy antenna, is connected to the proper terminals.

Each standard-signal generator has two oscillator coils, one for the intermediate frequency and one for the broadcast band, either of which may be selected by a switch on the panel. While working at the low frequency,

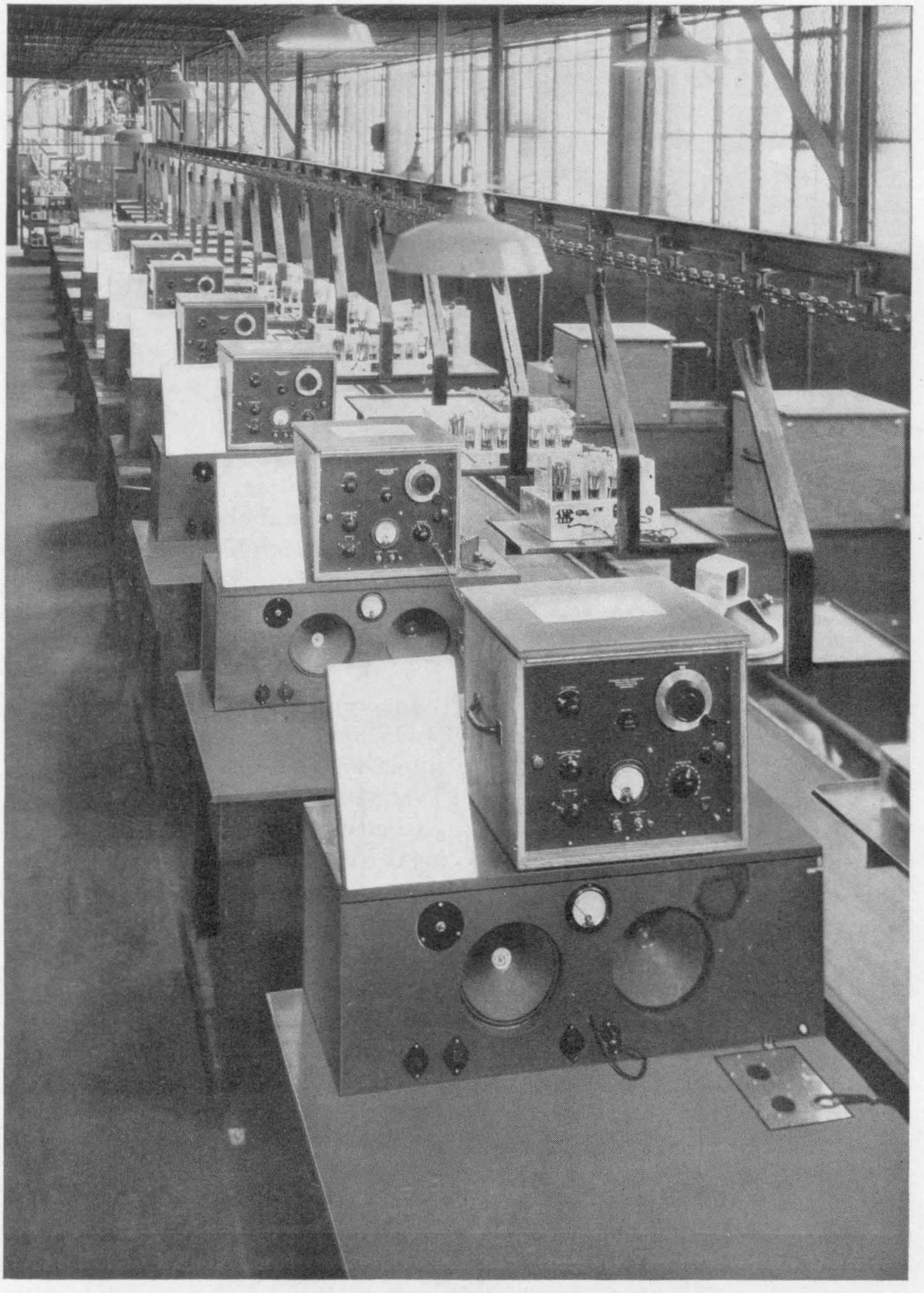


FIGURE 1. Kolster Radio Corporation's inspection room where every receiver is aligned, checked for sensitivity at several broadcast frequencies, and given a listening test. A dual-range TYPE 601-A Standard-Signal Generator is used at each of the ten test positions

the intermediate-frequency system of the receiver is lined up. After this adjustment the generator is switched to the high frequency and the general line-up of the receiver is made.

The next step is to determine the over-all sensitivity at several points in the broadcast band. These test frequencies are indicated by lines on the main tuning dial. The generator is set step-by-step to each of these frequencies, the receiver tuned to them one at a time, and the sensitivity of the receiver measured in the usual way by observing the audio-frequency output for a given signal input.

Standard output is marked on the output meter in the lower cabinet and just above it is the meter and multiplier of the standard-signal generator showing microvolts input. In this way, the operator has the whole story before him. At times, he records his observations on the charts provided and these are most useful to the production supervisor.

As a final check, a loud-speaker is turned on for a listening test.

Although the tests were originally designed for broadcast-receiver measurements, sets intended for operation at the police or aircraft frequencies could also be quickly checked by changing the coils of the standard-signal generators.

Figure 2 is a view of the rear of the Type 601-A Standard-Signal Generator with the cabinet and batteries removed. The two toroidal coils mounted on the subpanel are for the radio-frequency oscillator. They are mounted on pin jacks for interchangeability with

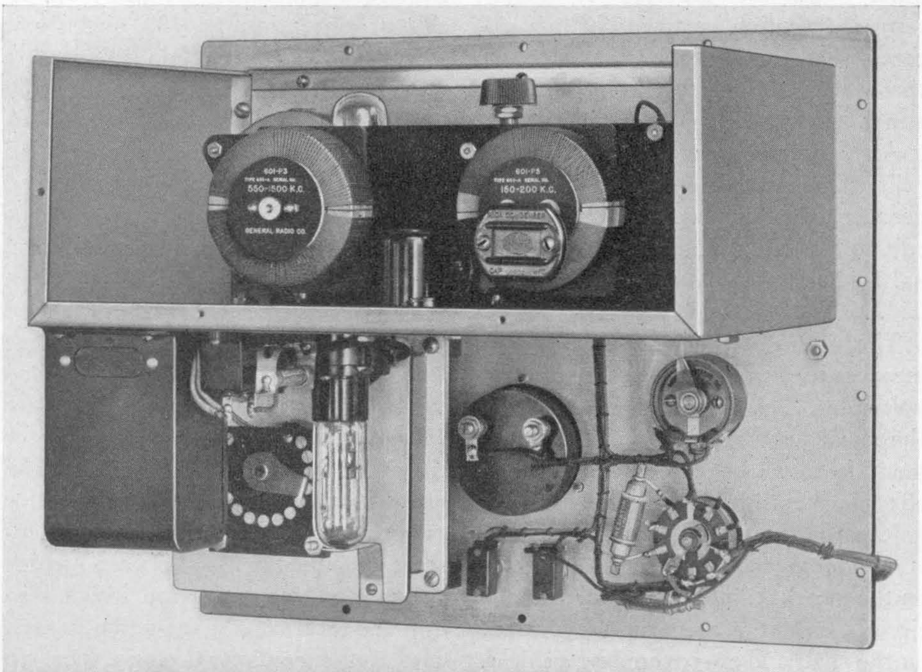


Figure 2. A view behind the panel of a Type 601-A Standard-Signal Generator. Either or both of the plug-in inductors may be replaced with others to cover special bands

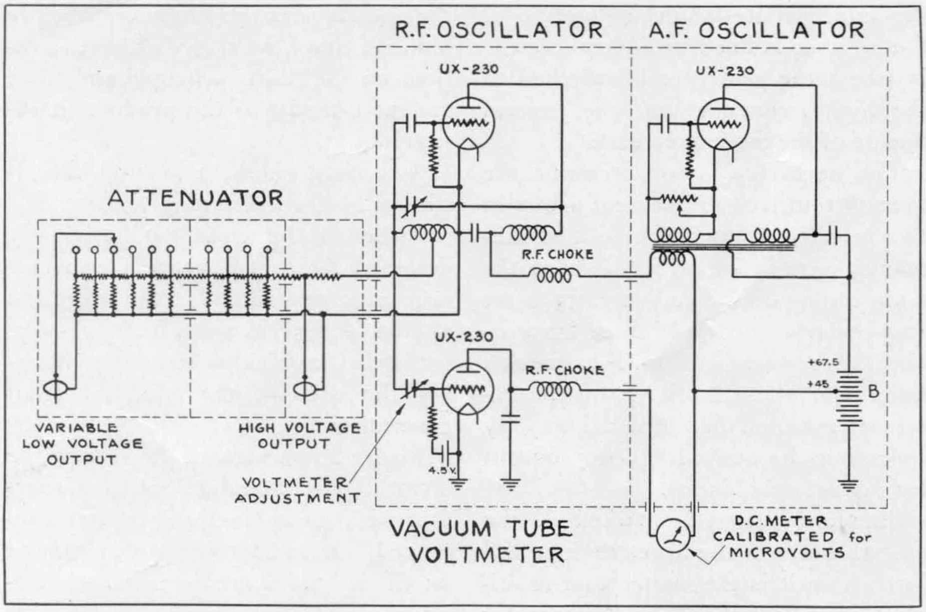


FIGURE 3. Schematic wiring diagram for a TYPE 601-A Standard-Signal Generator

other coils for different frequency ranges. Selection between them is accomplished by a four-point double-throw switch controlled from the front panel.

After some experimentation, toroidal coils were selected instead of solenoids because, although a little more difficult to build, they have so little external field that shielding is much simplified.

The radio-frequency amplitude is measured by means of a vacuum-tube voltmeter. This is a tube operating in the usual way by observing the incremental change in plate current due to changing amplitudes of radio-frequency voltage on its grid. The direct current is read by means of the micro-ammeter on the panel. All of the radio-frequency circuits except attenuator are located on the shelf and are covered by a shield.

Fastened to the under side of the shelf is the audio-frequency modulator circuit. It is a standard tuned-plate oscillator operating at 400 cycles per second with an amplitude sufficient to provide modulation at either 30 or 50 per cent. Normally, the TYPE 601-A Standard-Signal Generator is supplied with 30% modulation, but if desired General Radio can make the adjustments necessary for 50% modulation before the instrument is shipped.

The toroidal oscillator coil is tapped and a small part of the total voltage across it is led off through a shielded conductor to the attenuator. In Figure 2 the casting in back of the modulator circuit at the lower left corner of the panel houses the complete attenuator assembly. It is divided into three separate compartments between which the attenuation units are divided so that the total voltage reduction in each does not exceed 40 decibels. Due to stray admittances, it is virtually impossible to exceed this attenuation within one shield without encountering serious errors.

The whole attenuator assembly is in contact with the front panel at only one point—where the low-voltage output jack is located. This helps to reduce circulating panel currents to a point where they do not affect the measurements at high frequencies to any extent. The output voltage lead to the receiver under test is shielded and enters the attenuator through a plug and jack construction that maintains the continuity of the shield directly to the attenuator circuit.

Two output jacks are provided, one connected to the variable voltage output and the other to a fixed point on the attenuator system at a higher voltage. The former provides outputs variable in discrete steps from 1 to 20,000 microvolts. The fixed tap is at 100,000 microvolts. All of these ranges can be multiplied by a factor of 1.5 by increasing the radio-frequency oscillator amplitude to the correct point as indicated by the vacuum-tube voltmeter.

Reference to the schematic wiring diagram shown in Figure 3 will indicate the arrangement of the circuit elements.

As will be noted, the modulation voltage is introduced in series with the plate-supply battery of the radio-frequency oscillator. With this method of modulation, it is necessary to provide a highly stable high-frequency oscillator, otherwise difficulty is encountered due to frequency modulation. That is, the plate voltage applied to the radio-frequency oscillator tube, varying at an audio rate, may shift the carrier frequency by a considerable amount unless the most stable high-frequency oscillator circuits are used.

The vacuum-tube voltmeter is connected across one half of the oscillator coil in series with a very small variable condenser, which is used to adjust the reading of the voltmeter. The attenuator voltage is taken across a part of the coil.

Only one of the two radio-frequency oscillator coils is shown in the diagram for the sake of simplification. The switching between these coils is arranged so that the one that is not operating is completely detuned by shunting a large condenser across it. Thus, no reaction can occur between it and the coil in use.

In order to provide a means for checking the voltages of the various batteries without a multiplicity of meters, the micro-ammeter is connected to a multi-point switch with suitable series resistors for making direct-current-voltage measurements on the A- and B-batteries.

The General Radio Company wishes to acknowledge its indebtedness to Mr. C. E. Brigham and Mr. G. Elcock of the Kolster Radio Corporation for their kindness in supplying the photographs of their plant used in this article.—Arthur E. Thiessen

LEANING MORE HEAVILY ON THE CRYSTAL

A New Piezo-Electric Oscillator Circuit

AN oscillator with frequency determined *solely* by a quartz crystal has been the ambition of every designer and user of frequency standards. Although it is still an ideal toward which to work, such an oscillator is brought one step nearer practicability by a new circuit which makes it unnecessary for the crystal to be calibrated in the oscillator with which it is to be used. The marked improvement in frequency stability of the new system is the principal reason for the exceptional performance of the General Radio frequency monitor which so many broadcasting stations have installed to meet the 50 cycle-per-second limit laid down by the Federal Radio Commission.

All who followed closely the development of crystal oscillators during the past few years[1] will not be shocked on learning that the frequency depends on other factors besides the mechanical properties (elasticity, mass distribution, etc.) of the crystal. True enough, the crystal influence predominates but the effect of the crystal holder, the tube, and the auxiliary tuned circuits can never be ignored where even a moderate degree of accuracy in frequency is expected. Quite often these latter influence the frequency more than a big change in the temperature of the crystal.

Any vacuum-tube oscillator operates at that frequency for which the net circuit reactance is zero. In a simple tuned-plate oscillator, for example, the resulting frequency is the resonant frequency of the tuned circuit modified by the reactance introduced by the tube and the feedback system.

A complete analysis of the mechanism by which the frequency shifts to a value which makes the net reactance zero is complicated. In brief, however, it amounts to this: Anything that causes a change in the reactance of any element associated with the oscillator will result in a change in operating frequency.

The same discussion applies directly to a piezo-electric oscillator with the important difference that the principal frequency-determining element is not an electrical circuit but an electromechanical system. The crystal has its own resonance characteristic and it is always possible, in theory at least, to construct for any given crystal oscillator an equivalent electrical circuit to represent it. This equivalent circuit will have many of the reactance characteristics of an ordinary tuned circuit and the circuit will operate at a frequency for which the total reactance of the crystal and its associated equipment is zero. And so, no matter how closely a crystal may be ground to desired frequency, the frequency that results when it is operated in a circuit will be modified by the reactance characteristics of that circuit. So, also, will the operating frequency shift if changing voltages, temperature, etc., cause the reactance of tubes, coils, condensers and crystal mountings to change.

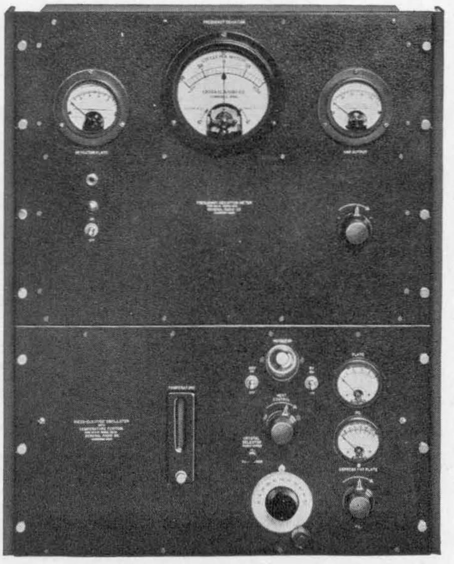
[1] See GENERAL RADIO EXPERIMENTER for February, 1930; October and November, 1930; and December, 1931.

The obvious conclusion is, therefore, that for high-precision frequency standards, the crystal, and the oscillator associated with it must be treated as a single unit when calibrations are made, and the General Radio Company has insisted that this be done wherever an accuracy better than 0.1% is required. A slightly more liberal figure could possibly be set by building the oscillators to even closer manufacturing limits, but it has not been possible to go very far in this direction without running into prohibitive expense. Transmitter manufacturers get around this by building crystal oscillators as a unit and, when replacements are required, shipping the customer a complete new assembly.

If some means could be found for operating the crystal at its own resonant frequency, the crystal could be treated as a single unit. There are very few circuits which make such operations possible because of the difficulty in securing enough feedback for the tube to drive the crystal, and, besides, there is now no practical way of determining when the resonant frequency of an oscillating crystal has been reached.

The best alternative to operating at the resonant frequency of the crystal is a circuit which will permit of an indication to show when the crystal is operating at a given condition, such as the new General Radio circuit which was described in the December, 1931, issue of the *Experimenter*.

The new circuit allows the crystal to operate much closer to its true resonant frequency than the circuits heretofore available. But what is more important, it is possible to always duplicate the original calibrating condition so long



The General Radio Frequency Monitor shown mounted on a desk-type relay rack. Its exceptional performance is due to the use of the new crystal circuit

as the constants of the oscillator circuit are of approximately the same order of magnitude as those of the calibrating circuit. By adjusting the tuning condenser of the circuit until the plate current is a minimum, the original calibrating condition can be restored. This means that the constants of the oscillator circuit can be allowed to vary over fairly wide limits (due, perhaps, to temperature and aging of the elements), but it can always be restored to normal by a readjustment of the tuning condenser. Greater reliance is placed on the crystal and less on the circuit by the new system, which is as it should be, for the crystal is inherently more stable than coils and condensers.

The fact that the new system operates at a frequency near the crystal's resonant frequency brings about an improvement in the temperature coefficient of the crystal. This is because the crystal's reactance-frequency characteristic is steeper near resonance, and for a given change in reactance caused by a change in temperature, the frequency shift required to restore the "zero reactance" condition is smaller than would ordinarily be required.

The new oscillator circuit, as was pointed out in the December *Experimenter*, has an overall frequency stability of something like ±5 parts in a million. Frequency stability (sometimes called deviation capability) is the best available index of the reliability of a frequency standard. It is the amount that the frequency will vary due to changes in temperature, tubes, etc., assuming that the changes all tend to shift the frequency in the same direction.

Frequency stability of this high order can, of course, be obtained only if the crystal is operated at a power level so low that internal heating causes no appreciable rise in its temperature. This condition is readily brought about in frequency-monitor equipment where the oscillator is inherently one of low power. Where crystals are used to stabilize high power transmitters, it is a very great temptation to operate the crystal at high power levels thus reducing the number of tubes required. The wisdom of such design is debatable and is, perhaps, not to be recommended where a high order of frequency stability is demanded. Most of the economies resulting from high power crystal operation disappear, for instance, when it becomes necessary to install very elaborate temperature-control equipment to secure anything approaching satisfactory frequency stability.

— JOHN D. CRAWFORD

WE'LL SEE YOU IN CHICAGO MAY 23-26

GENERAL RADIO will exhibit samples of all instruments developed during the past year in Chicago, May 23–26. The occasion is the sixth annual Trade Show of the Radio Manufacturers' Association held at the Stevens Hotel.

Our display will include a number of new pieces of equipment which have not yet been announced. Among them will be a precision standard-signal generator, a direct-current-operated beat-frequency oscillator, and a new vacuum-tube bridge.

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

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ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

NEW MEASURING INSTRUMENTS

OF the instruments described in the following pages of the EXPERIMENTER, three are of special interest to everyone interested in communication-frequency measurements. Both open new fields for investigation.

The vacuum-tube bridge, because it is capable of determining the dynamic characteristics of tubes over so wide a range, not only takes care of all the receiving-type tubes now in use, but will probably be able to handle all those developed for some time to come. The new circuit making possible the measurement of one characteristic without depending on other factors gives the new bridge a general utility wherever vacuum tubes are used.

The General Radio cathode-ray oscillograph is made available for obtaining the wave shape (amplitude-time characteristic) of a-c waves by the new sweep circuit. This device produces the necessary saw-tooth wave. Its frequency is controlled by the voltage being studied, hence the pattern remains stationary.

The output power meter will, of course, yield no information not previously obtainable with a decade resistance box, sensitive meter, a slide rule and a few moments of calculation. It does, however, save a considerable amount of time and equipment, and it makes easy a measurement that is often omitted because of the labor heretofore involved.

This new equipment will be on exhibition at the Trade Show of the Radio Manufacturers' Association in Chicago, May 23 to 26.

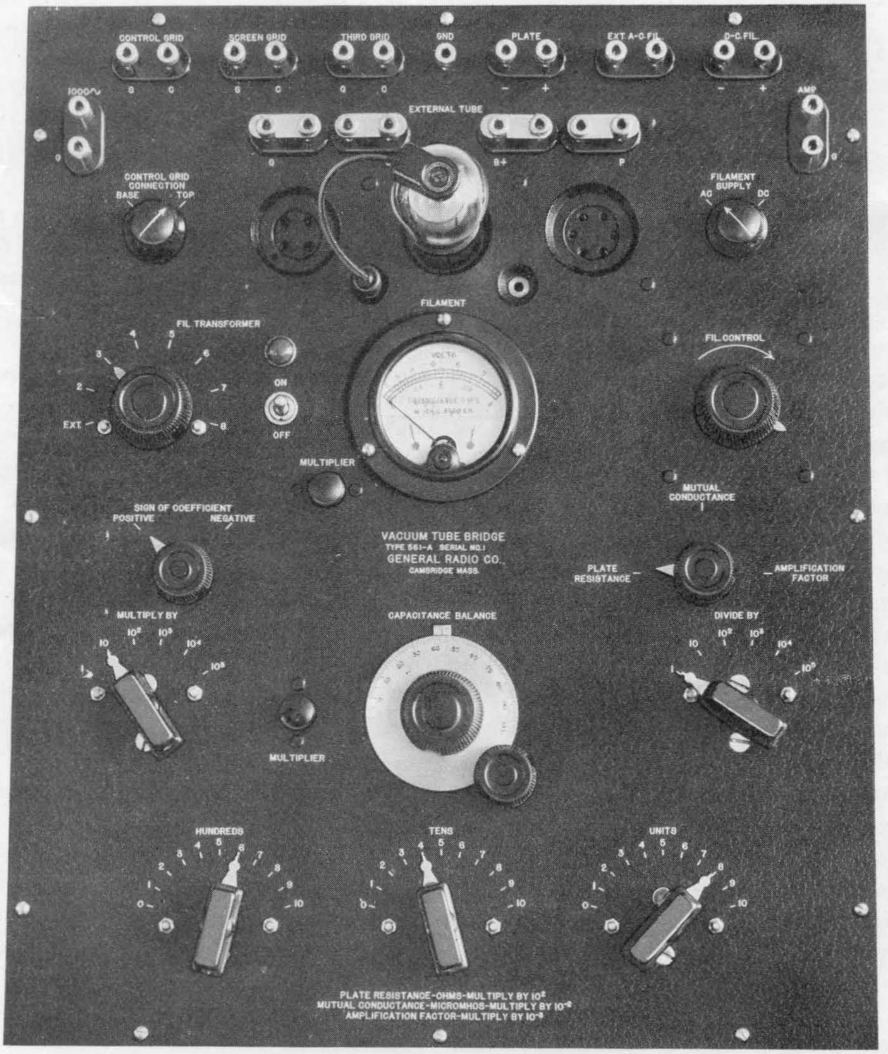
There our friends in the Chicago district, as well as the engineers of the radio industry, will have the opportunity of inspecting it.

In This Issue

A BRIDGE FOR VACUUM-TUBE MEASUREMENTS

EVER since the introduction of the screen-grid tube there has been a quite definite need for more satisfactory methods of measuring the dynamic coefficients of vacuum tubes. More recently introduced types have added fresh difficulties, so that it is now desirable to measure not only very high amplification factors and high plate resistances but also very small and very large values of transconductance.

It has seemed desirable to develop methods which could be applied without modification to the measurement



All the dynamic characteristics of all low-power tubes can be investigated for an extremely wide range of values by the TYPE 561-A Vacuum-Tube Bridge of extreme values of the tube parameters. It was felt furthermore that the new equipment should be applicable to determining any one of the three coefficients directly, so that it should never be necessary to make two measurements to obtain the quantity of interest.

In attempting to meet these severe requirements we have had to make radical changes from the old methods of measuring tube coefficients, with the result that the new equipment bears little resemblance to the conventional test apparatus.

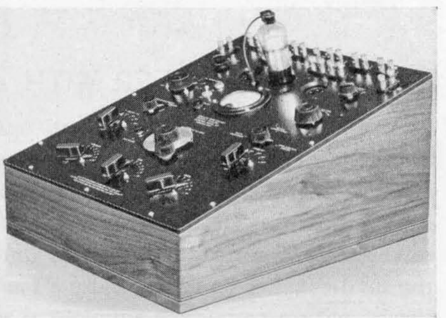
The photograph shows the panel arrangement of the new TYPE 561-A Vacuum-Tube Bridge. On the lower half of the panel, below the filament voltmeter, are located the controls of the measuring circuits. On the upper half are mounted four-, five-, and six-prong sockets, a transformer with associated controls for supplying a-c filament power, and the necessary terminals for battery connections.

No effort has been made to include a complete tube control panel with meters for measuring electrode voltages and currents. The requirements of different laboratories vary too widely in this respect to permit the construction of a generally acceptable arrangement. On the other hand a convenient means of controlling and reading the filament voltage is most important. A double-range thermal voltmeter is supplied for reading either a-c or d-c filament voltages up to 8 volts. The power transformer contained in the instrument is provided with a sufficient number of taps so that any a-c voltage in this range may be obtained without external connections.

It will be seen in the photograph that there are terminals for the supply voltages for the plate and for three grids. Provision is therefore made for the testing of the new pentodes in which the suppressor grid may be at a different potential from the cathode.

Special sockets may be plugged in when tubes having unusual bases or special base connections are to be tested. In other cases, such as in testing low-power transmitting tubes, it may be convenient to make the measurements when the tube is externally mounted with its control apparatus. The row of terminals just back of the sockets is provided for this purpose.

The measuring-circuit controls occupy the lower half of the panel. All three coefficients are determined by precisely the same procedure. The three-position switch at the right of the nameplate is turned to whichever quantity is desired, the multiplier switches are set at the appropriate value for the tube being tested, and balance is obtained by adjusting the three decade switches and the capacity-balancing condenser. At balance the decades read directly, to three significant figures, the quantity being measured.



Mounting the panel at an angle makes for easy reading when working at a table or at a laboratory bench

Negative values of all three coefficients may be measured by the same process as readily as positive values. The position of the switch at the left of the nameplate determines whether the quantity measured is positive or negative.

The multiplying and dividing switches control independent attenuators in the circuits supplying the a-c voltages on which the measurements depend. It was found necessary not only to design these circuits and their respective attenuators with particular care, but also to modify the fundamental scheme of the measurements so that the results would be independent of the ratio between the plate resistance and the plate-circuit impedance.

In a similar manner a new method of balancing capacitance currents has been adopted so that the measurements do not depend on the ratio between the plate resistance and the reactance of the stray capacitances. It has been found possible, therefore, to make accurate measurements of plate resistance when the reactance of the plate-filament capacitance is considerably less than the tube resistance.

It has not yet been possible for us to determine very closely the extreme values which can be measured with the new bridge. No difficulties have been encountered in measuring plate resistances of 20 megohms and amplification factors of several thousand. In the other direction measurements of mutual conductance down to a fraction of a micromho and of plate resistances down to 50 ohms are readily obtained. The range of the multiplier extends considerably beyond the limits given in both directions but special precautions may prove necessary to avoid external coupling between the oscillator and the amplifier if it is desired to extend further the useful operating range of the instrument. It is believed, however, that the TYPE 561-A Vacuum-Tube Bridge has a satisfactory margin over the present requirements of the vacuum-tube industry.

The necessary auxiliary equipment, in addition to the supply voltages for the plate and grids, includes a source of 1000-cps voltage, a sufficiently sensitive amplifier, and a pair of head telephones. Our TYPE 213 Audio Oscillator and TYPE 514-A Amplifier are recommended for this use.

—W. N. TUTTLE

A POWER METER WITH A WIDE IMPEDANCE RANGE

DETERMINING the power that one circuit can deliver to another is a most important communication measurement. The I.R.E. broadcast receiver tests, for instance, require that the loud-speaker be replaced by a load circuit with a resistance equal to that recommended for the output tube by its manufacturer. The receiver is then made to deliver 50 milliwatts into that load.

The introduction by General Radio of the output meter utilizing a rectifier-type voltmeter in conjunction with a constant-impedance multiplier made such power measurements considerably simpler. The output meter has had a wide acceptance in the field, in spite of

The method of using the output power meter can be seen from an inspection of the engraved scales. Full-scale deflection of meter corresponds to 50 milliwatts for a multiplier setting of "1"

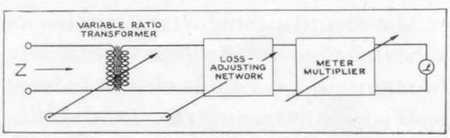
the fact that its resistance was limited to a single value: 4000 ohms at first. Later output meters for 8000 and for 20,000 ohms were made available.

Now, General Radio has developed an output meter of radically new design, in which the load resistance can be adjusted to cover a wide range, with the indicating element direct reading in milliwatts. Figure 1 shows the new TYPE 583-A Output Power Meter.

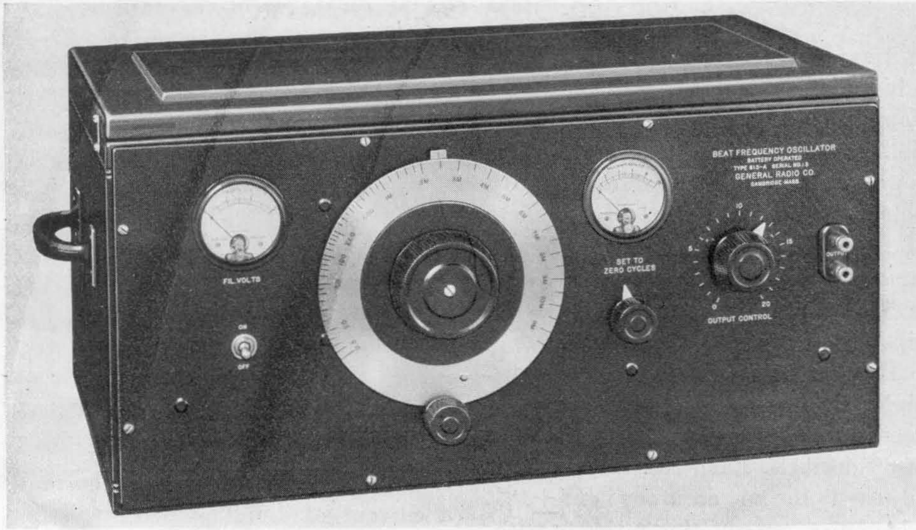
At the left are the two switches whose settings determine the resistance presented to a circuit connected across the two input terminals. The upper switch permits the selection of ten values which are approximately equally spaced on a logarithmic scale; the lower switch is an impedance multiplier. Hence, the impedance range of the instrument is from 2.5 ohms to 20,000 ohms.

At the right of the panel is a copper-oxide-rectifier voltmeter calibrated in milliwatts. Below it is the meter multiplier, which, when adjusted, makes the full-scale reading of the meter take successive values of 5, 50, 500, and 5000 milliwatts, respectively.

Obviously, the power scale can also be calibrated in decibels. This has been done, and both the meter and its multiplier carry auxiliary decibel scales



Schematic circuit diagram for the TYPE 583-A Output Power Meter



The TYPE 613-A Beat-Frequency Oscillator is operated from batteries inside the cabinet

individually calibrated and the dial individually engraved.

Some frequency drift is inevitable in a beat oscillator of any type. This arises from the fact that the output of the oscillator is obtained from the beat note between two oscillators of super-audio frequency. A change in the frequency of either oscillator will make a much larger percentage change in the beat frequency. Because of the practical impossibility of building component oscillators to be entirely free from frequency drift, some simple means of correcting for drifts must be provided. In the TYPE 613-A Beat-Frequency Oscillator a zero adjustment is furnished by means of which the two oscillators are set to zero beat when the main scale is set at zero. A milliammeter in the plate circuit serves as a beat indicator.

The instrument can be set to zero beat to within about a cycle and the scale is checked to within a cycle at all calibrated points so that the indicated frequency with the zero properly set is within two cycles at all settings of the dial.

The output has been carefully filtered so that spurious high frequencies are not present. The output characteristics may be summed up briefly as follows: Average voltage, 15 volts. The actual voltage does not depart from the average value by more than 20% over a range of 100 to 10,000 cycles. The harmonic content of the output is less than 2%. The range of calibration is 5 cycles to 10,000 cycles. The maximum power output occurs at a load of 5000 ohms and is 10 milliwatts.

The TYPE 613-A Beat-Frequency Oscillator requires three 230-type and one 231-type tubes. The battery requirements are two No. 6 dry cells and two 45-volt B blocks.

The price of the TYPE 613-A Beat-Frequency Oscillator is $210.00.

— CHARLES T. BURKE

based on a zero reference level of one milliwatt. Readings may be expressed in terms of any other reference level by adding the proper correction term.

The secret of this unusual instrument is the variable-ratio transformer shown in the accompanying schematic diagram. This transformer must be a good approach to an ideal transformer. It must respond over a frequency range of 20 to 10,000 cycles per second, and it must be so constructed that the losses are as nearly constant as possible for every one of the ratio adjustments. A compensation network operated by the ratio changing switch corrects for small differences, so that for all ordinary purposes the transformer has a constant loss. The instrument always presents a nearly resistive impedance to an external circuit.

The principal application of this instrument will, of course, be in the testing of radio receivers. It will not only serve in the standard selectivity, sensitivity, band-width, and fidelity tests, but it can also be used for measuring with fair accuracy the output of the receiver for different frequencies when once the impedance characteristic of the speaker is known.

The output power meter is also useful for determining directly the output power characteristic of any circuit as a function of load impedance. It is useful when making measurements on oscillators, amplifiers, transformers, etc. Conversely, the internal output impedance of the circuit under test can be measured by determining the load impedance for which maximum power output is secured. Other uses will probably suggest themselves to the reader.

The price of the Type 583-A Output Power Meter is $85.00.

—John D. Crawford

A NEW BEAT-FREQUENCY OSCILLATOR

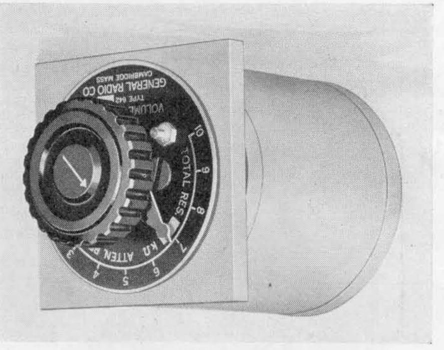
In designing the Type 613-A Beat-Frequency Oscillator, our object has been to incorporate in a battery-operated type of instrument the desirable features of good waveform, frequency stability, and an open scale which are contained in the Type 513-B Beat-Frequency Oscillator (a-c operated) brought out last year.

The distinguishing characteristics of a beat-frequency oscillator are ability to maintain a constant output voltage over a wide frequency range and ability to cover a wide range of frequency with a single control. Two oscillators are used, one of fixed frequency, the other of variable frequency. The beat note between the two oscillators is passed through a detector and amplifier and becomes the output of the oscillator.

The fact that a wide frequency range is covered by a single control necessarily presents difficulty in obtaining an open and easily read scale. In the Type 613-A Beat-Frequency Oscillator, a straight-line-frequency condenser has been used, which results in a practically logarithmic scale spread around 270° of the dial. This scale is open and easily read at all points. Each instrument is

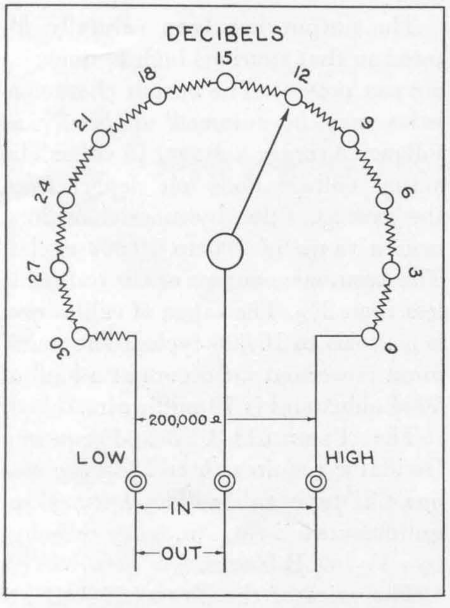
A 200,000-OHM GAIN CONTROL

In many voice amplifier circuits a high-impedance gain-control potentiometer in the grid circuit is essential. The Type 642-D Volume Control is primarily designed as a high quality unit for the various types of amplifiers of this sort. It may be used in any standard voice amplifier circuit, connected across the secondary of the input or interstage coupling units.



Each step on the Type 642-D Volume Control corresponds to an attenuation of 3 decibels

The total resistance is 200,000 ohms, divided into ten equal steps of 3 decibels, providing a total attenuation of 30 decibels. Each resistance unit is adjusted to an accuracy of $\pm 1\%$, which gives attenuation ratios to within approximately 0.1 decibel. Because of its high impedance, accuracy of calibration, and compactness, its use as a multiplier for vacuum-tube voltmeters is also recommended. Although normally used in circuits drawing no current, a current of 4 milliamperes will not cause a temperature rise sufficient to change the rated accuracy of calibration.



The extremely high impedance of this volume control makes it ideal for use across the grid circuit of an amplifier

The frequency characteristic of any reasonably non-inductive potentiometer connected to the grid of a vacuum tube depends almost entirely upon the capacitance of this circuit. The Type 642 Volume Control can be worked into a capacitance of 40 micromicrofarads with an error of not more than 0.1 decibel at 10,000 cycles per second. Since the capacity of the usual vacuum tube and its socket at the grid terminal is less than 20 micromicrofarads, a negligible error will result at 10,000 cycles per second and the rated accuracy of 0.1 decibel will hold to approximately 20,000 cycles per second.

The amount of this error is also largely dependent upon the position of the contact arm and the figures mentioned above are for the worst conditions; that is, for attenuations of 3 or 6 decibels. The error is very much less at the higher values of attenuation.

The switch arm is constructed of four-leaf spring phosphor bronze, which provides for long wear and exceptionally low electrical contact noise. The construction is similar to that employed in the precision TYPE 602 Decade-Resistance Boxes. A cam-type detent is provided. This may be removed easily if smooth action is required.

The over-all dimensions are 3$\frac{1}{16}$ inches diameter and 3$\frac{1}{6}$ inches depth behind the panel.

The price is $25.00.

Modifications of the standard unit for different impedances and attenuations per step can be arranged on special order.

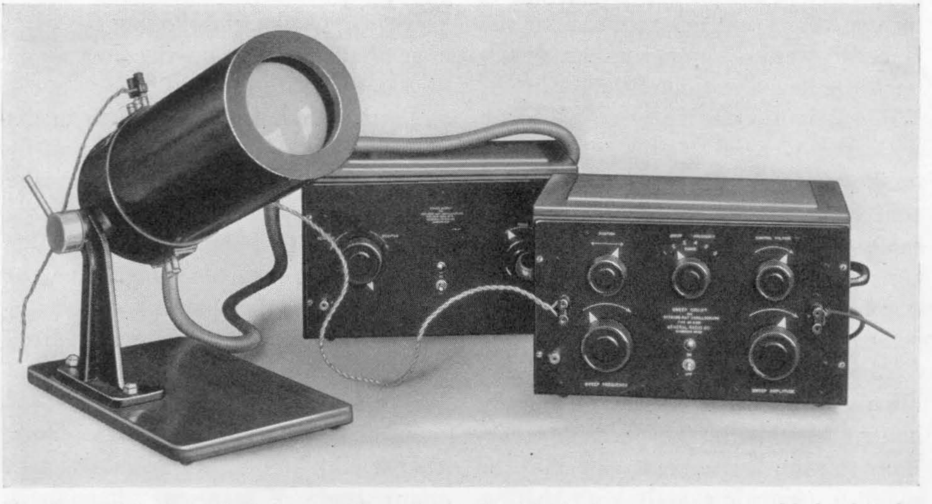
—ARTHUR E. THIESSEN

A LINEAR TIME AXIS FOR THE CATHODE-RAY OSCILLOGRAPH

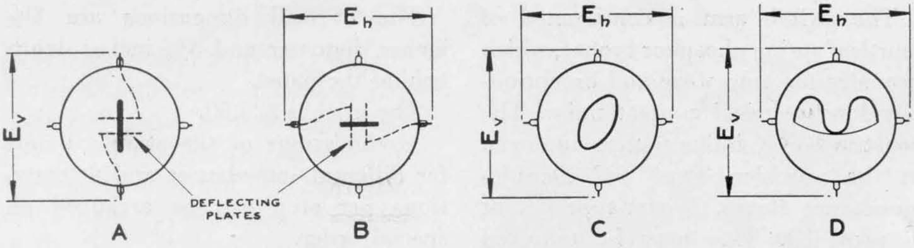
IN the past, use of the cathode-ray oscillograph has been considerably restricted due to the lack of an adequate means for obtaining the linear time axis that is necessary if wave shapes are to be observed. Although Lissajous figures are convenient in making frequency comparisons, they are in many cases entirely useless for examining the actual form of a wave.

Rotating mirrors and moving-film cameras have been used with varying degrees of success. The former, however, are limited to rather slow mirror speeds and the latter to photographic records.

The other common method for obtaining a linear time axis is the so-called sweep circuit. This consists of a means for generating a "saw-tooth" wave



The General Radio cathode-ray oscillograph. At the right is the sweep circuit and behind it the power-supply unit for the oscillograph tube



Here is what the sweep circuit does. Alternating voltages may be applied to the vertical deflecting plates (as in *A*) or to the horizontal plates (as in *B*). Pattern *C* results when E_v and E_h are applied simultaneously, the frequencies f_v and f_h being the same. If E_h is a "saw-tooth" wave derived from a sweep circuit and E_v is an alternating current wave to be examined, the wave shape of E_v appears in Pattern *D*

which, when applied to one pair of the oscillograph deflecting plates, produces a linear time axis. Commercial types of sweep circuits have, however, been restricted to operation over narrow ranges of frequency and amplitude. Furthermore, the problem of controlling the sweep circuit to keep in step with the waveform being observed, providing a stationary pattern on the oscillograph screen, has caused considerable trouble.

In order to overcome this limitation in the use of the cathode-ray oscillograph and provide a convenient means for waveform examination, the General Radio Company has developed the new Type 506 Sweep Circuit. While it is intended primarily for use with the General Radio cathode-ray oscillograph, it can also be used with similar oscillographs of other manufacture. It provides a practically linear time axis so that the waveform being observed is seen directly upon the fluorescent screen of the oscillograph.

A great advantage of this new sweep circuit is that its action may be easily controlled, that is, the periodic movement of the fluorescent spot may be made to coincide exactly with the frequency, or some submultiple of the frequency, of the wave being observed, thereby causing the pattern on the fluorescent screen to remain stationary. This makes careful examination of recurrent waveforms possible, and if desired, photographs may be taken of the patterns as they appear upon the screen.

The Type 506 Sweep Circuit has been carefully designed to provide a very high degree of control over the sweeping action. Separate adjustments are provided for changing the sweep frequency and length of sweep, as well as for regulating the amount of control voltage applied and adjusting the position of the pattern on the fluorescent screen.

Extreme care has been taken in the design of the control system so that no interference is transmitted from the sweep circuit itself back through the control circuits. Therefore, it is possible to obtain the control voltage from the same source as the observed wave without having the sweep circuit itself affect the form of the observed wave as seen upon the fluorescent screen.

The sweep circuit controls so readily that it may be used for examination of many types of transient phenomena. If a voice or music wave is impressed upon it, it will lock into control at some low frequency or its submultiple in the voice or music wave. It is, accordingly, possible to study the waveform of any sustained note or sound, as well as to see many of the transients involved.

The principle of operation of the General Radio sweep circuit is very simple, but considerable care was required in constructing suitable equipment to carry out this principle satisfactorily. The circuit is, in effect, a modified form of relaxation oscillator. A condenser is charged at a constant current until the voltage across its terminals reaches a certain predetermined value. At this point, a special mercury-vapor tube breaks down and discharges the condenser practically instantaneously. The voltage across the terminals of the condenser is applied to the horizontal deflecting plates in the cathode-ray oscillograph, thus causing the fluorescent spot to travel in one direction at a practically constant velocity and then return almost immediately to its original position.

The voltage at which the discharge tube operates is controlled by a grid in the tube. This controls the amplitude of the sweep. The rate at which the condenser charges is controlled by the current limiting tube. This controls the velocity of the sweep. By introducing a small alternating voltage in series with the direct bias on the grid of the discharge tube, the sweep circuit may be made to lock in step with an alternating voltage near its natural frequency.

The General Radio Type 506 Sweep Circuit is completely a-c operated and carefully shielded. It is mounted in a small walnut cabinet of the same size and shape as the Type 496-B Power Supply Unit for the cathode-ray oscillograph.

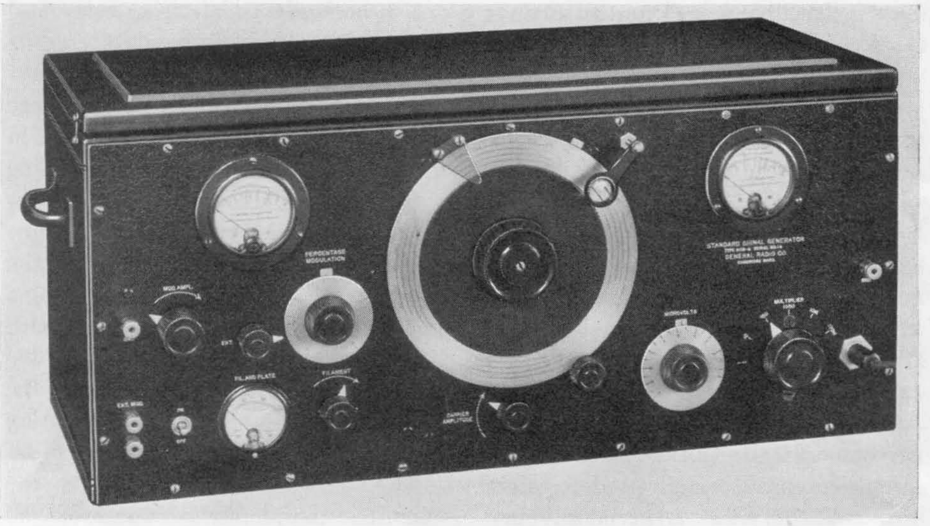
The price of the Type 506 Sweep Circuit is $160.00.—H. H. Scott

A STANDARD-SIGNAL GENERATOR FOR THE MEDIUM PRICE FIELD

The development of radio receivers for operation at high frequencies has had its corollary in a demand for a satisfactory standard-signal generator to go to very high frequencies. A careful study of the problem has indicated that generators similar in general construction to those now employed can be used with suitable design modification at frequencies as high as 15 megacycles. It is believed work at higher frequencies will require a rather different design of signal generator and attenuator system from that now used.

The General Radio Company has had under development for the last year a new signal generator designed to meet the need for dependable behavior at high frequencies. The Type 603-A Standard-Signal Generator which will be shown at the Chicago Trade Show is the result of this development. This signal generator may be used over a frequency range extending from 100 kilocycles to 15 megacycles.

Over this range its performance is well within the limits of accuracy which we have become accustomed to



The main tuning control for the TYPE 603-A Standard-Signal Generator carries a dial with 600 divisions. The microscope at its right is an aid in making close settings; the triangular index at the left is for use with calibrations filled in with pencil by the user

expect from signal generators in the broadcast-frequency range. It is capable of modulation up to 90% at broadcast and higher frequencies. Internal modulation at 400 cycles is provided and provision is made for external modulation as well.

The new standard-signal generator will be used for the usual fidelity, sensitivity, and selectivity tests on receivers throughout the very wide frequency range for which it is adapted. It is also suitable for field-strength measurements throughout this wide range, since it is semi-portable and can easily be transferred in an automobile.

The new standard-signal generator has a number of interesting design features. The shield has been so modified without increase of leakage that it is not necessary to remove any screws in order to change coils. Immediate access to the coil compartment is obtained by raising the lid on the cabinet. Space for the extension coils is also provided inside of the cabinet. Leakage around the lid is avoided by a refrigerator-door type of construction in the shielding.

An interesting new type of attenuator and shield has been evolved. The usual resistance type of attenuator has been used with a modified construction as made necessary by the much higher frequencies involved. The attenuator is enclosed in a sectionized shield which makes possible very large attenuations even at frequencies at 15 megacycles without serious errors.

The controls are shown on the front of the panel. Those at the right govern the radio-frequency circuit, those at the left the modulation circuit. The carrier frequency is controlled by a large dial with slow-motion adjustment. This dial carries an accurately engraved scale of 600 divisions, spread around 270 degrees of its circumference. The use of this dial in conjunction with a coil spread of approximately 2 to 1 in frequency makes possible direct calibration of the main frequency scale for use in selectivity and bandwidth determinations. Calibration charts are provided and they are of such size as to be read to the same accuracy as the dial scale.

Two additional convenience features will be noted on this dial: The magnifying glass over the main index greatly assists in setting and reading the scale. The secondary index, together with the space on the dial rim for extra scales, permits calibration of the instrument at special points to suit the user's requirements.

The carrier-frequency output voltage is controlled by the three adjustments in the lower right section of the panel. The carrier amplitude is adjusted, by means of the middle control, to a reference line on the right-hand meter. Maintaining this adjustment constant, the output is adjusted by means of the slide wire labeled *microvolts* and the multiplier. Continuous variation from one volt to ½ microvolt is provided. The output is taken off from the shielded plug terminals in the lower right edge of the cabinet.

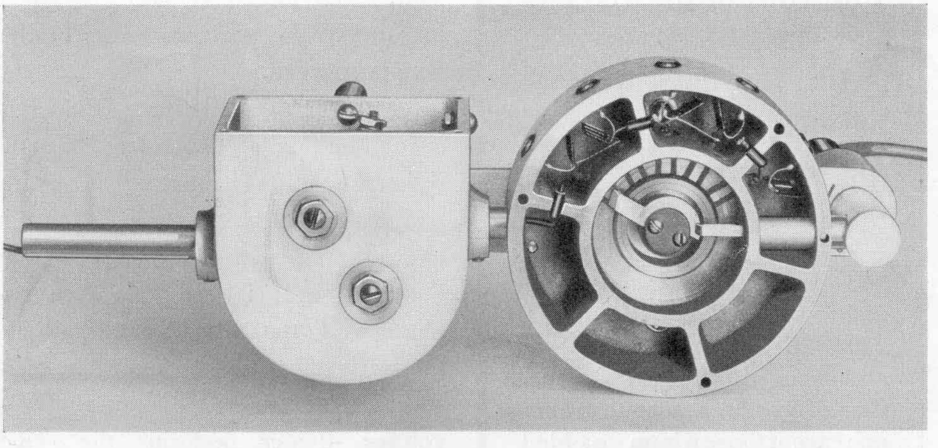
The modulation-control system is shown at the left. The meter indicates the modulation voltage and is set by means of the modulation amplitude control to a reference line. With the per cent modulation dial set at the desired modulation percentage, external modulation may be connected at the terminals indicated and controlled in the same manner.

In condensed form the performance characteristics, in the new signal generator, are as follows:

Frequency range: 100 kilocycles to 15 megacycles.

Accuracy of the output voltage at 1 microvolt: 3% in the broadcast range and below, 10% at 10 megacycles, and 12% at 15 megacycles.

The output voltage range permits continuous adjustment from



The attenuation system for the new standard-signal generator viewed from the back. The casting at the left contains the slide wire; the one at the right is the "mouse-trap-type" step-by-step attenuator

½ microvolt to one volt. Four hundred-cycle internal modulation is provided and the apparatus can be modulated with either internal or external modulation up to 90% at broadcast and higher frequencies.

The frequency modulation total swing does not exceed 200 cycles under the worst conditions in the broadcast band. At the RMA test frequencies it amounts to about 50 cycles.

The reaction of the attenuator on the carrier frequency is less than 150 cycles under all conditions.

The input impedance at the external modulation terminals is approximately 5000 ohms and a power of about 100 milliwatts is necessary to modulate the instrument to 30% throughout its range.

The radio-frequency output impedance is 10 ohms up to 10,000 microvolt setting.

The price of the Type 603 Standard-Signal Generator is $600.00. This includes the two calibrated inductors necessary for covering a frequency range of 420 to 1900 kilocycles, which includes the broadcast band.

—C. T. Burke

Return the Card

•

Please don't forget to return the card that was clipped to page 1 of your copy of the Experimenter.*

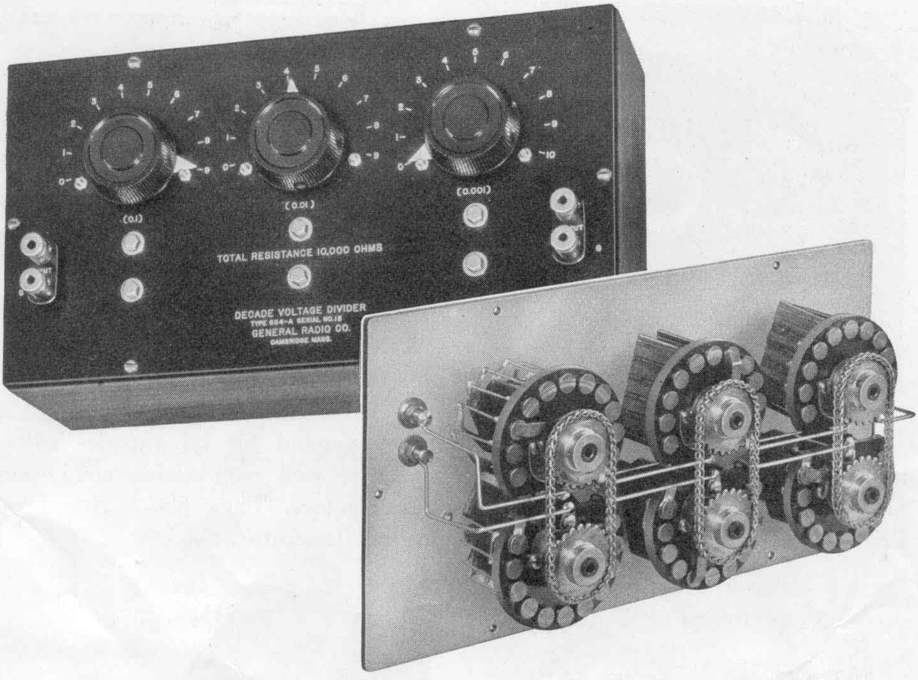
It's the only way we have of keeping our mailing list correct and up to date.

*To distribute the load on our mailing department, some cards were sent with the April issue and some with this (May) issue. Cards have been sent to everyone except those whom we added to the list after April 1, 1932.

MISCELLANEOUS RECENT DEVELOPMENTS

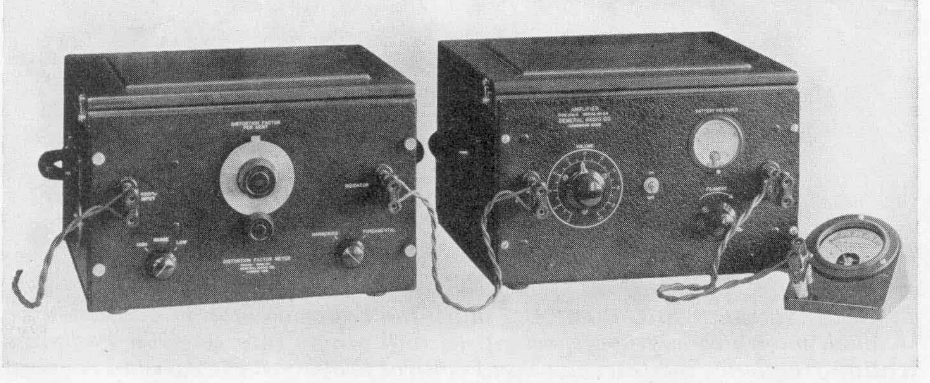
The instruments illustrated on pages 15 and 16 are all recent developments. All except the new Type 654-A Voltage Divider have been described in some of the previous issues of the Experimenter.

The Type 654-A Voltage Divider is a combination of two sets of decade resistance units connected in series with the output voltage taken off across one set. When the resistance of the "output" unit is increased, the resistance of the other unit is simultaneously decreased to maintain constant total series resistance. This voltage divider performs the same function as the older Type 554 Voltage Divider it supersedes.



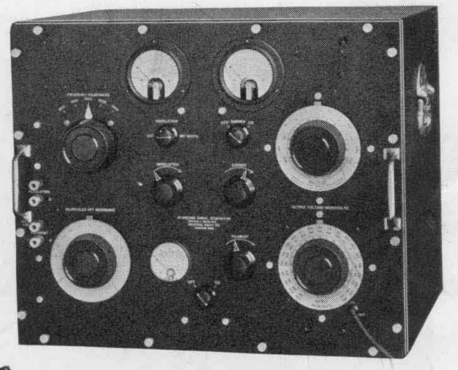
This precision voltage divider yields ratios of 0.001 to 1.000 in decade steps of 0.001. The total resistance presented by the input terminals always remains fixed at 10,000 ohms, since the resistance taken from any one unit is simultaneously added to its mate.

The price of the TYPE 654-A Decade Voltage Divider is $85.00

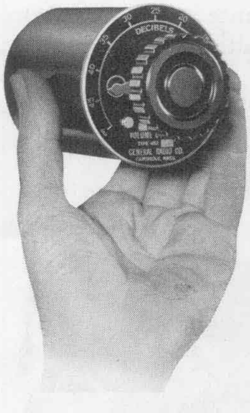


This equipment measures distortion factor. Left to right: TYPE 536-A Distortion-Factor Meter, $140.00; TYPE 514-A General-Purpose Amplifier, $70.00; and TYPE 488-HM Galvanometer, $30.00

Type 601-A Standard-Signal Generator is designed for production testing and airplane-receiver service work. Price $210.00



This standard-signal generator is recommended for laboratories where speed as well as precision are important factors. Type 600-A Standard-Signal Generator, $885.00



Freedom from noise, uniform attenuation, and low price are features of the Type 652 Volume Control. Price $12.50

Type 602 Decade-Resistance Boxes have submounted switches and are shielded against stray fields

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

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ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

WAVEFORM STUDIES WITH THE CATHODE-RAY OSCILLOGRAPH

THE absence of any appreciable inertia in a beam of fast moving electrons gives the cathode-ray oscillograph an inherent advantage over all other types for the study of waveforms involving a wide range of frequencies. However, linear frequency response does not, in itself, guarantee a useful oscillograph, and it is only recently that tube limitations have been overcome and satisfactory auxiliary equipment developed to make possible exacting study of periodic phenomena up to 50,000 or 100,000 cycles per second.

The General Radio cathode-ray oscillograph tube is of the low-voltage type, employing anode potentials of 500 to 2000 volts to accelerate the electrons emitted by the alternating-current heated filament. The arrangement of the tube elements is shown in Figures 1 and 2.

There are two pairs of electro-static deflecting plates; one to produce horizontal deflection, and the other to produce vertical deflection. If an alternating voltage is applied to either pair, the beam will be deflected rapidly so that a straight line appears upon the screen.

Obviously, some means of providing a time axis so that phenomena may be seen in their true amplitude-time relationship is most desirable. The rotating mirror has been used with vibrating-element oscillographs, and is also useful with the cathode-ray instrument. When the line produced by voltage across one pair of plates is viewed in a rotating mirror arranged with its axis parallel to the line on the fluorescent screen, the waveform may be seen, if the mirror is turning at a suitable speed.

The use of the rotating mirror with the cathode-ray oscillograph is somewhat limited in its applications since careful observation of the higher frequency phenomena to which the cathode-ray tube will respond would involve very high mirror speeds.

But probably the most serious disadvantage of the rotating mirror is its inability to keep in synchronism when the frequency shifts. Although the mirror speed may be adjusted so that a stationary pattern is obtained of the

FIGURE 1. The General Radio cathode-ray oscillograph tube. The inside of the glass at the large end is coated with a fluorescent substance on which the moving beam of electrons traces patterns

constant-frequency phenomena, any change in the frequency will cause the pattern to move. If the frequency changes appreciably, the pattern will probably move too quickly to be of any value.

Another method of obtaining a time axis is the moving-film camera. Where a photographic record of a non-recurrent phenomenon is desired, this undoubtedly is the most satisfactory equipment. The General Radio Company has perfected moving-film cameras for various uses which will operate satisfactorily at film speeds up to 15 feet per second, giving a reasonably clear representation of any phenomenon involving frequencies in the audible spectrum.

The camera is, of course, limited by mechanical and photographic factors, including maximum velocity at which the film can be driven without tearing, and the maximum film "speed" at which proper photographic records can be obtained. The latter depends to a great extent upon the optical system and the type of film or sensitized paper, as well as upon the brilliancy of the cathode-ray spot and the speed with which it moves. In this connection, it is obvious that higher frequencies will produce fainter records than lower frequencies, since the actual length of the record will be considerably greater for a given length of film, consequently reducing the amount of light to which any particular spot of the film is exposed.[1]

It is evident that some other means of visual waveform examination is desirable. Since the oscillograph is arranged with deflecting plates so that two dimensional figures may be seen upon the screen, the possibility of being able to

[1] The General Radio cathode-ray oscillograph tube is characterized by the unusual brilliance of the spot. With plate voltages of the order of 1500 to 2000 volts, the patterns on the fluorescent screen may easily be seen by a large group of persons in a lighted room. The fluorescence is unusually actinic, thus facilitating photography.

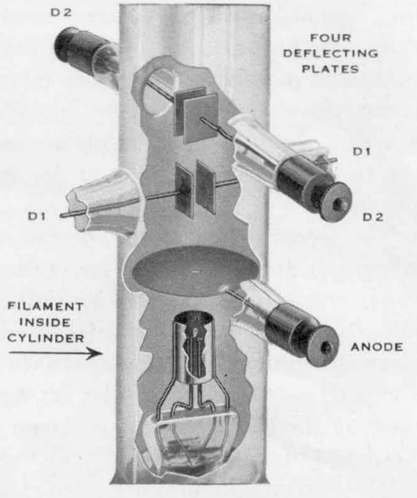


FIGURE 2. Electrode structure of the oscillograph tube. The negatively charged cylinder concentrates the electrons emitted by the filament so that practically all pass through the small hole in the anode. The beam passes between each pair of deflecting plates

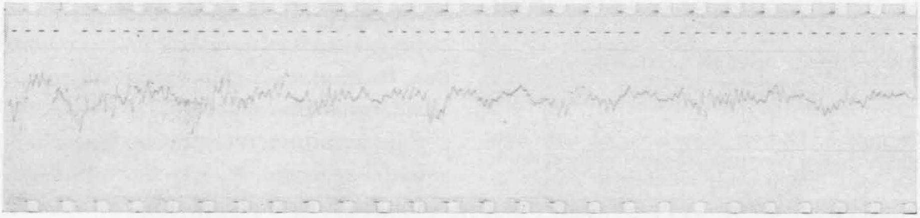


FIGURE 3. A record of speech made with sensitized paper traveling at 6¼ feet per second. Each of the dots in the line above the trace represents one millisecond. The reproduction suffers from the halftone screen required for the preparation of a printing plate, but the original is more than satisfactory for any purpose of analysis

see a waveform without the use of external mechanical equipment suggests itself.

If alternating voltages are applied simultaneously to both pairs of deflecting plates in the cathode-ray tube, Lissajou's figures will be formed, remaining stationary when one applied frequency is an exact multiple of the other. By proper interpretation of these figures, frequency comparisons can be made, but except to a skilled observer, little knowledge as to any deviation in the waveforms from a pure sinusoidal form can be gained.

This type of pattern can frequently be made more useful when the wave being observed has a high frequency compared with the other or timing wave. If, for instance, a low-frequency timing wave, say 60 cycles, is impressed across the horizontal deflecting plates, and another recurring 600 times a second is impressed on the vertical plates, a pattern will be formed upon the screen which, with a little imagination, can be visualized as the 600-cycle wave.

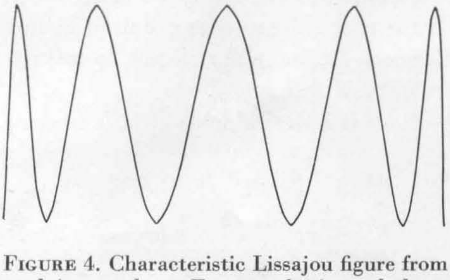


FIGURE 4. Characteristic Lissajou figure from applying a voltage E_h across horizontal plates having exactly 1/10th the frequency and twice the amplitude of the voltage E_v applied to the vertical pair. Note that the pattern near the center is an approximation to the true shape of E_v since the spot velocity due to E_h is nearly constant in this region. The "back trace" coincides with the forward sweep for this particular phase difference (90°)

If some system is used whereby the cathode-ray beam can be deflected across the screen at a constant velocity, an actual representation of any wave may be seen in linear relation with respect to time. Furthermore, if the beam can be made to traverse the screen at the desired speed, in one direction only, and then return instantaneously to its starting position, only a single representation of the waveform will be seen, whereas, with the sinusoidal timing wave previously mentioned, two views of the wave are seen, one going in each direction. The frequency at which the cathode-ray beam sweeps across the screen must, of course, coincide with the frequency of the observed wave or some submultiple of it, or the pattern will appear to move.

To provide a source of a controlled linear timing wave or "sweep," the

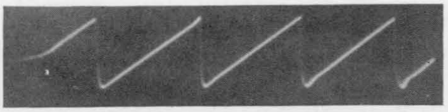


FIGURE 5. Output waveform of one TYPE 506-A Sweep Circuit as shown on the cathode-ray oscillograph using another to supply the linear time axis. Note the close approach of each trace to the ideal straight line

General Radio Company has developed the new TYPE 506-A Sweep Circuit, which was announced in last month's issue of the *Experimenter*. The sweep circuit provides a timing wave having a saw-tooth form, as shown in Figure 5 by means of a circuit which is shown diagrammatically in Figure 6.

The condenser *C* and the current limiter tube are connected in series across a source of 500 volts, d.c. Current flows in the circuit, charging the condenser, but since the current is limited to a certain maximum value, the voltage rises at a constant rate rather than exponentially, as would otherwise be the case.

Across the condenser is connected a mercury-vapor discharge tube (TYPE 506-P1). This tube is provided with a control grid so that it can be arranged to break down at any predetermined value of plate voltage. When this voltage is reached, the discharge tube flashes, discharging *C*, and reducing the voltage across its terminals to practically zero. The flash in the discharge tube is then extinguished and the condenser charges again, going through the same cycle as before.

The voltage across the condenser terminals, accordingly, has the waveform shown in Figure 5, and if the horizontal deflecting plates of the cathode-ray oscillograph are connected across the terminals of *C*, the fluorescent spot will have a periodic horizontal movement, crossing the screen at a constant velocity and then returning quickly to its original position.

The amplitude of the saw-tooth wave, that is, the horizontal length of the path traversed by the fluorescent spot, is determined by the voltage at which the discharge tube operates, which is controlled by the d.-c. bias on the grid of this tube. This bias is adjustable, so that the sweep may be long or short, as desired, and may be kept within the limits of the fluorescent screen, regardless of the anode voltage used on cathode-ray oscillograph tube.

By varying *C* and the maximum current passed by the current limiter tube, the speed at which the voltage across the condenser rises may be controlled. These two adjustments are used in the General Radio sweep circuit to adjust its natural frequency.

Since it is desirable to be able to cen-

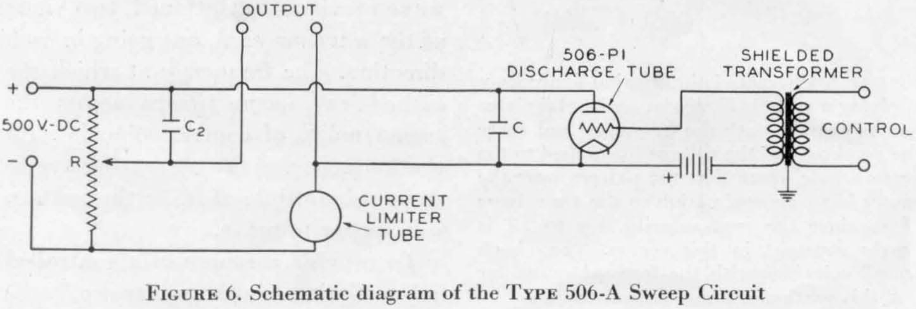


FIGURE 6. Schematic diagram of the TYPE 506-A Sweep Circuit

ter the pattern on the fluorescent screen of the oscillograph, an auxiliary position control is provided on the sweep circuit which consists of the voltage divider *R*. It will be seen from Figure 6 that the horizontal deflecting plates of the oscillograph are so connected to the sweep circuit through *R* and the C_2 that a variable direct voltage bias is impressed upon the deflecting plates in addition to the saw-tooth wave. This makes it possible to move the entire pattern horizontally in either direction on the fluorescent screen.

Probably the most important feature of the General Radio sweep circuit is the manner in which the instrument is made to synchronize with any observed recurrent phenomena. A voltage of the frequency of the observed wave, usually obtained by direct connection to the vertical deflecting plates, is impressed across the terminals marked CONTROL. A shielded transformer transmits this voltage to the grid circuit of the discharge tube. If, without the control voltage connected, the circuit is adjusted to operate at approximately the desired frequency, introduction of the source of control voltage will cause the sweeping action to synchronize exactly with the observed wave. Not only is the transformer shielded, but it is so designed that, in connection with a resistance network, it reduces to a negligible value any interference which might be transmitted from the discharge tube back through the control circuits. A volume control is also included for varying the amount of control voltage applied to the discharge tube grid so that the best operating point may be secured without the use of external equipment.

The sweep circuit is completely shielded to minimize interference, and designed so that the mercury-vapor discharge tube operates at the correct temperature. The instrument includes power-supply equipment, so that it operates entirely from the 115-volt, 60-cycle lines.

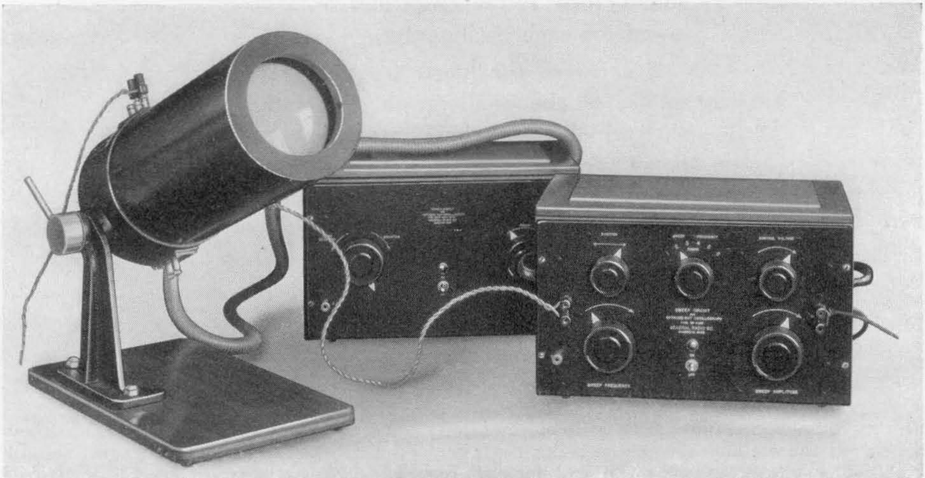
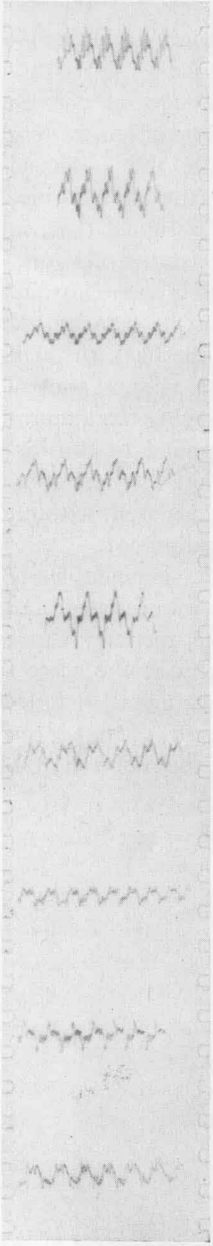


FIGURE 7. The TYPE 506-A Sweep Circuit is shown at the right of the mounted oscillograph tube and its a-c operated power supply equipment



Because of the automatic control feature of the sweep circuit, this equipment may be used for visual and photographic examination of all types of recurrent phenomena occurring at audio frequencies, as well as certain types of transients and recurring waveforms involving frequencies up to approximately 100 kc. Since the sweep circuit may be controlled by the waveform under examination, it may be made to lock in step, not only on absolutely recurrent phenomena, but on many types of phenomena involving shifts in frequency and amplitude. For instance, complex audio-frequency waves, such as are emitted by musical instruments or an orchestra, may be observed while music is being played, since a stationary pattern will be obtained on any tone which is sustained long enough for observation.

The photographs of Figure 8 were taken with a small pocket-type of camera (Ansco Memo) using 16-millimeter sensitized paper. The camera was equipped with an f/3.5 anastigmat lens, and 1/10th second exposure was allowed for each oscillogram.

Because of the linear frequency response of the oscillograph, the detail with which the various harmonic components of a sound are shown depends only upon the excellence of the microphone and amplifiers employed. The amplifying system used had an excellent frequency characteristic and no noticeable harmonic distortion.

—H. H. Scott

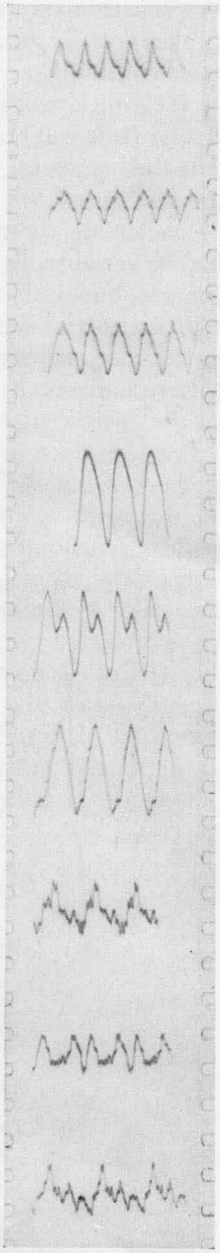


FIGURE 8. Sustained notes from a B♭ clarinet (left) and a C-melody saxophone (right) as they appear on the oscillograph screen using the TYPE 506-A Sweep Circuit. Exposure: 0.1 second for each record

VARIABLE INDUCTORS FOR BRIDGE MEASUREMENTS

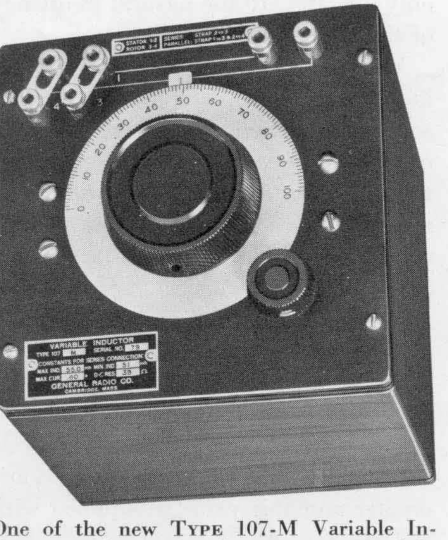
IT is a peculiarity of bridge measurements practice that, while variable (continuously adjustable) capacitance standards are almost universally used in preference to fixed standards, a general preference for fixed inductance standards over variable standards has prevailed. There are, as a matter of fact, many cases where measurement methods can be improved by the use of a continuously adjustable inductor or variometer.

The use of such an instrument permits the use of equal arm bridges for inductance measurements. Equal arm bridges have very distinct advantages, particularly at higher frequencies, over bridges where adjustable bridge arms are relied upon for a bridge balance.

The whole technique of precision capacitance measurements has been developed around equal-arm bridge substitution methods. The same technique can be adapted for inductance measurements with advantage in many cases, although variable inductance standards have not been developed to as high a degree of precision as have variable standards of capacitance. The variometer balance is of particular value where repeated measurements are made on units of approximately the same size, as this type of standard is very well adapted to a limit bridge.

A variometer for laboratory bridge work should have an inductance which will remain constant to within narrow limits over a wide frequency range. The resistance should be low. In some applications ruggedness and ability to stand large currents are important.

Undoubtedly one of the reasons why the substitution method has not been more generally adopted for inductance measurements is the limitations of the available types of laboratory variometer. The General Radio line of laboratory variometers, Type 107, has recently been rather extensively redesigned and improved with this type of application in view. The new variometers are now available in stock.



One of the new Type 107-M Variable Inductors with rotor and stator connected in parallel

The new Type 107 Variable Inductors are wound with stranded wire having individual strands separately insulated from each other in order to keep down high-frequency resistance. The coils are impregnated and baked in a high-melting-point material so that the variometers can be run 40 degrees centigrade above room temperature without damage. The mechanical arrangement of windings has been changed so as to provide a more nearly linear calibration and a new type of slow-motion dial has been provided.

In order to provide the maximum inductance range for each variometer, provision is made for connecting the coils either in series or in parallel. The rotor and stator inductances are made equal so that there is no circulating current when the coils are connected in parallel. The parallel inductance at any setting is one quarter of the series inductance at the same setting. The inductance is nearly constant over a wide frequency range and is increased by only 2% at 1/10 the natural frequency of the coil.

Values of maximum and minimum inductance and d.-c. resistance for the series connection are marked on the nameplate of each instrument. Calibrations, accurate to 1%, for the entire range of the series connection at 1000 cycles per second may be obtained at a small additional charge.

The resistance is of course a function of frequency and varies approximately with the square root of frequency. The direct-current resistance which is substantially the same as the 1000-cycle resistance is measured for each variometer and this value is supplied with the instrument. The table here lists the value of Q[1] at that frequency for which it is a maximum for each coil. These values are for the coil at full inductance setting.

All of the new variometers have a 15-watt dissipation for a 40 degree centigrade rise. At this wattage and temperature there is a 16% increase in the direct-current resistance.

The table below lists new Type 107 Variable Inductors. Ranges have been generally readjusted and a new instrument has been added so that variometers are now available for inductances from 0.005 millihenrys to 500 millihenrys. The values listed below are average values for the several ranges of variometer. The resistance given is the direct current resistance measured at room temperature. The current value is that producing 40 degree temperature rise. Maximum and minimum inductances are given for the series connection. The natural frequency for maximum setting of each variometer is given. The maximum value of Q and the frequency at which it occurs are also listed for each coil at maximum inductance setting.

Qty.	R_o	I	Lmin.	Lmax.	f_o	Q at f	
Unit	Ω	a	mh	mh	kc		kc
107-J	0.17	8.5	0.005	0.05	5000	110	400
107-K	0.7	4.0	0.05	0.5	1500	140	200
107-L	4.0	1.7	0.5	5	500	125	60
107-M	40	.60	5	50	150	65	20
107-N	64	.14	50	500	30	20	7

The price of the new Types 107-J, K, L and M Inductors is $30; that of Type 107-N is $40.

— Charles T. Burke

[1] Q is the quantity, sometimes called dissipation factor, that expresses the excellence of a given inductor when used as a tuning element. It is the ratio of reactance to resistance $\left(\frac{\omega L}{R}\right)$ at the frequency in question.

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ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

BRIDGE METHODS FOR MEASUREMENTS AT RADIO FREQUENCIES

IN the development of measuring methods simple circuits involving, so far as possible, only the units under measurement are at first used, and as experience and technique improve, more elaborate but more convenient and flexible methods are developed.

The earliest methods of measuring resistance were the voltmeter-ammeter and later the substitution methods. Bridges, which increased the sensitivity of the substitution method by introducing a differential comparison and extended its range by using ratio arms, naturally developed from the substitution method. Bridges are now universally used for direct-current and audio-frequency measurements.

In the higher frequency ranges, voltmeter-ammeter methods have been extensively used. At radio frequencies (say 100 kc. to 2 Mc.), the tuned-circuit substitution method is generally favored. In this measurement the unknown resistance is replaced in a tuned circuit by a standard which is adjusted to give the same voltage drop at constant current as the unknown. The object of the tuned circuit is to reduce the effect of reactance on the measurement.

Bridge methods have several advantages over voltmeter-ammeter and tuned-circuit substitution methods. They are not limited to narrow frequency ranges, and they grant more latitude in the choice of standards. They involve, however, the introduction of other circuit elements into the measurement and are, therefore, justly viewed with some suspicion when used under conditions where the values of the additional circuit elements are not entirely known.

The essential difficulty with measurements at high frequencies lies in the fact that the circuit elements of inductance, capacitance, and resistance cannot be individually isolated but are present together in all circuit units, and between the units themselves, as well as between units and ground. Most of the technique of alternating-current bridge methods involves the development of circuit units whose characteristics approach lumped constants and means of eliminating the effect of residuals from the measurement.

Leads, also, which are ignored at lower frequencies, may have impedances approaching in magnitude those under measurement. These problems, it should be observed, are present at 1000 cycles, although too frequently ignored. In any bridge method it is necessary to distinguish between a balance of the bridge and a balance between the unknown and standard elements. The effect of residuals is frequently such as to give a false balance involving unknown and extraneous impedances.

Bridges have been used at frequencies well above the audio-frequency range, and there is no question that with proper care bridge measurements can be used at very high frequencies.

The main difference between measurements at audio and radio frequencies is summed up in the one-thousandfold increase in series inductive reactance and the corresponding decrease in parallel capacitive reactance. This means that distributed inductance and capacitance which were entirely negligible at audio frequencies frequently have controlling influence at frequencies of the order of one megacycle.

The absence of proper standards offers as great an obstacle to high-frequency bridge methods as the difficulties inherent in the bridge circuit itself. Resistance standards usually have some reactance at high frequency, and reactance standards have resistance.

Air condensers have the smallest time constants of any impedance element and their law of variation with capacitance and frequency is known. They may be either fixed or variable. Solid dielectric mica condensers may be made which also have a small time constant varying only with frequency. Fixed straight wire resistors have very small time constants, which can be calculated provided the wire used is non-magnetic. Resistors of the bifilar, Ayrton-Perry, mica-card, and woven-tape forms also have small time constants. Their equivalent series inductances and time constants are independent of frequency over a wide range. They cannot, however, be calculated, but must be compared with the straight wire standards. Variable resistors are inferior to fixed resistors because of the added reactance of the switching mechanism. Inductors make poor radio-frequency standards, since their time constants are large and variable, depending upon skin effect and the characteristics of the iron core if one is used.

Their natural frequencies are low and variable inductors show variation of resistance with setting. They must be compared with standard condensers.

In considering bridge circuits for radio frequencies it is the natural course to select simple circuits and those having similar elements permitting a symmetrical arrangement. The equal-arm bridge should be used, although this limits the usefulness of the bridge method somewhat. It is not too difficult to make similar units having practically identical lumped and distributed constants, but to make dissimilar units in which the lumped and distributed constants bear like ratios is far more difficult. Equal resistances are normally used for the ratio arms, although capacity ratio arms can be used.

An elementary bridge circuit suitable for use at radio frequencies is shown in Fig. 1. It consists simply of the two fixed ratio arms, the shielded input transformer, and terminals for standard and unknown impedances. This diagram is, of course, exactly what would be used at audio or lower frequencies. The modifications necessary for high-frequency use lie entirely in the arrangement of parts and leads and the shielding which is required.

While this elementary bridge circuit can be reasonably well balanced at 1000 cycles, at higher frequencies a double balance is necessary in order to eliminate all factors of stray capacitance. Two methods of accomplishing this offer themselves. One is the addition of a Wagner ground circuit by means of which the capacitances to ground are first balanced before obtaining a balance of the main bridge. A second arrangement is the substitution method which is, of course, extensively used in precision measurements at 1000 cycles. In this method, the unknown and standard are placed in parallel in the same side of the bridge and balanced in the other arm by an uncalibrated condenser which must, however, possess reasonably good characteristics. The bridge is balanced once with the unknown disconnected and again with the unknown shunted across the standard. The technique is the same as that used at lower frequencies, except that greater care must be taken and it is particularly important that the arrangement of leads be unchanged for the two balance conditions. The resistance balance is obtained by adding resistance in series or parallel with

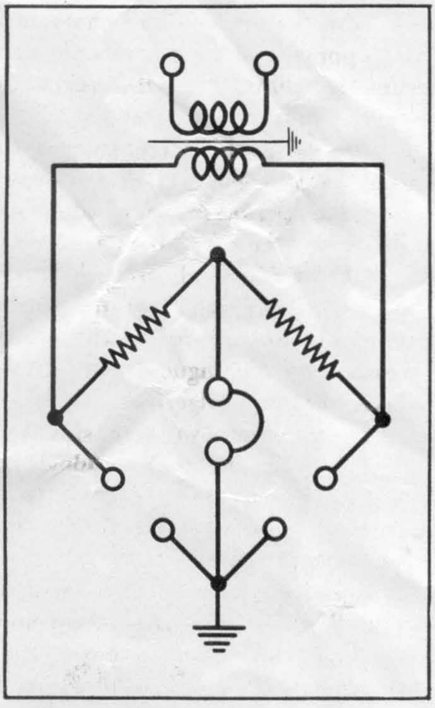


FIGURE 1. Basic bridge circuit commonly used at audio frequencies and suitable for radio-frequency work if precautions are taken

the capacitance arms. When the added resistance is changed between measurements, correction must be applied for the change in inductance of the resistance unless it can be established that this is negligible. In calculating results from the bridge measurements at high frequencies it is important to use the original bridge equations before eliminations based on orders of magnitude have been made. These equations may be easily derived or are given in most textbooks on bridges. Many of the order-of-magnitude eliminations do not hold at high frequencies.

In an endeavor to test out the practicability of bridge methods at radio frequencies, the General Radio Company has developed the TYPE 516-A

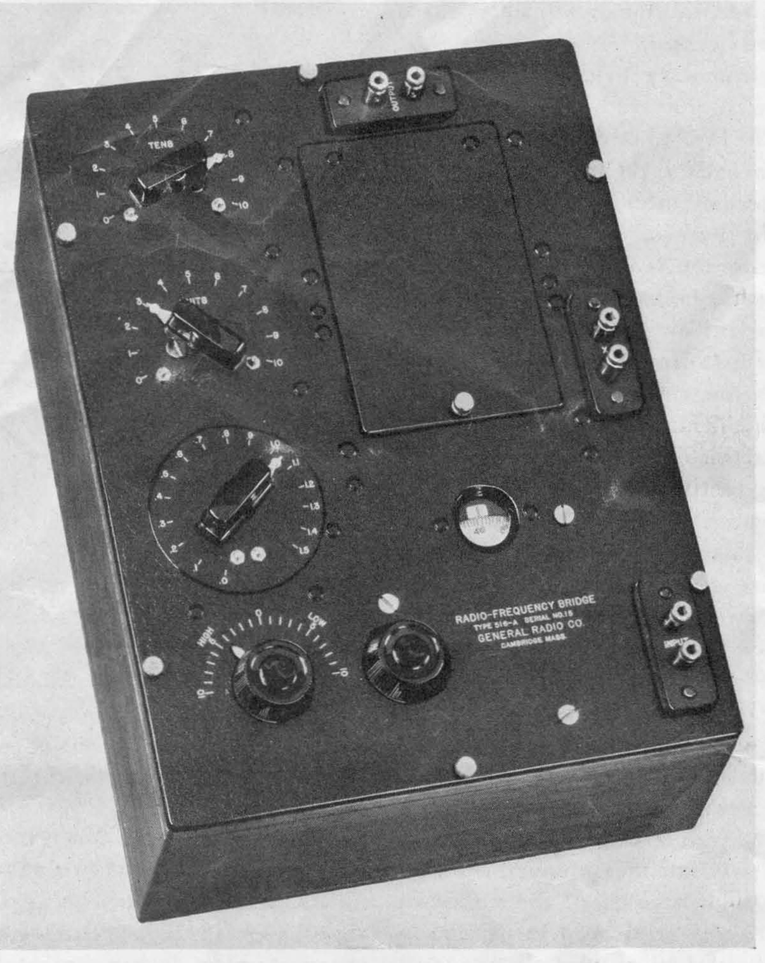


FIGURE 2. The new TYPE 516-A Radio-Frequency Bridge, an experimental instrument for the determination of reactance and resistance at high frequencies. Its use is recommended for laboratories having a considerable experience with other methods for measuring impedance

Radio-Frequency Bridge. This is illustrated in Figures 2 and 4 and the wiring diagram is shown in Figure 3.

The entire bridge is enclosed in one shield, while separate internal shields enclose the ratio arms, the balance condenser, the power-factor balance resistor, and the output transformer. The latter also contains a shield between primary and secondary.

The shielded transformer is placed in the output of the bridge, so that at balance it will have no current in it and no external field. It is an air-core transformer with concentrated windings, whose capacitances to each other and to the shield have been minimized. By a suitable choice of the number of turns the band of frequencies between 10 kc. and 5 Mc. may be covered. The ratio arms are 100 ohms each. Low-impedance elements are a requirement of high-frequency measuring circuits. These arms are wound on thin mica cards. Both transformer and ratio arms are mounted on plug-in bases so that they may be transposed or new ones inserted. The balance condenser has a capacitance of 1000 $\mu\mu$f and is provided with a slow-motion friction drive. A small vernier condenser of 15 $\mu\mu$f allows the adjustment of the total capacitance to 0.01 $\mu\mu$f. The variable resistance for power-factor balance has three dials, tens and units decades, and a non-inductive slide wire having a total resistance of one ohm and reading to 0.01 ohm. The zero inductance of this 3-dial resistance unit is only 0.2 microhenrys and the maximum inductance 1.1 microhenry. The leads from the condenser and resistor are brought to a terminal board located in a shielded compartment accessible from the front panel so that they may be connected in series or parallel or used separately.

The measurements are most easily made with a modulated carrier as a power supply and a detector and audio amplifier as a null indicator. An alternative method is to use an unmodulated oscillator, heterodyne to it, and use the rectified audio beat note as a null indication. It is essential that there be no pickup between oscillator and amplifier. Both must, therefore, be well shielded. The shielding of the oscillator must be comparable to that of a good standard-signal generator. Either the TYPE 403-D or TYPE 603-A Standard-Signal Generator is suitable.

Higher powers than are available from the signal generator will add to the sensitivity of the measurements

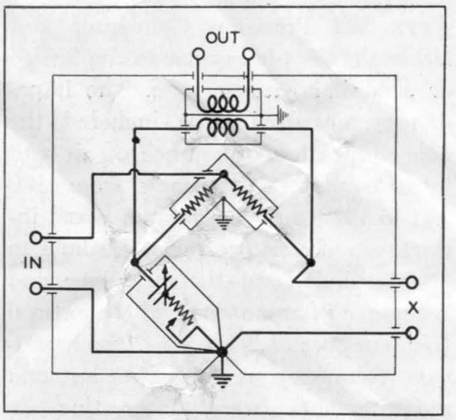


FIGURE 3. Schematic diagram of the TYPE 516-A Radio-Frequency Bridge. The heavy lines represent the bridge elements, the light line the shields

and to the speed with which the balance can be obtained. An oscillator having an output of about 25 milliwatts modulated to 50% is being developed. This instrument will maintain about one volt across the bridge at frequencies between 20 kc. and 20 Mc. It is completely shielded and uses toroidal coils, so that its external field is very small.

The most available null detector in the broadcast range is a standard receiver of good sensitivity. Commercial superheterodyne receivers having a 10-microvolt sensitivity are entirely satisfactory. Using such a receiver at full sensitivity and merely listening to the loud-speaker, the bridge can be balanced to one part in 100,000 for capacitances of the order of 1000 $\mu\mu$f and to one part in 10,000 for resistances of the order of 100 ohms. These measurements were made in an unshielded room and there was noticeable outside pickup in the receiver.

Measurements have been made with this bridge at a frequency of 1 Mc. by a substitution method, using an external

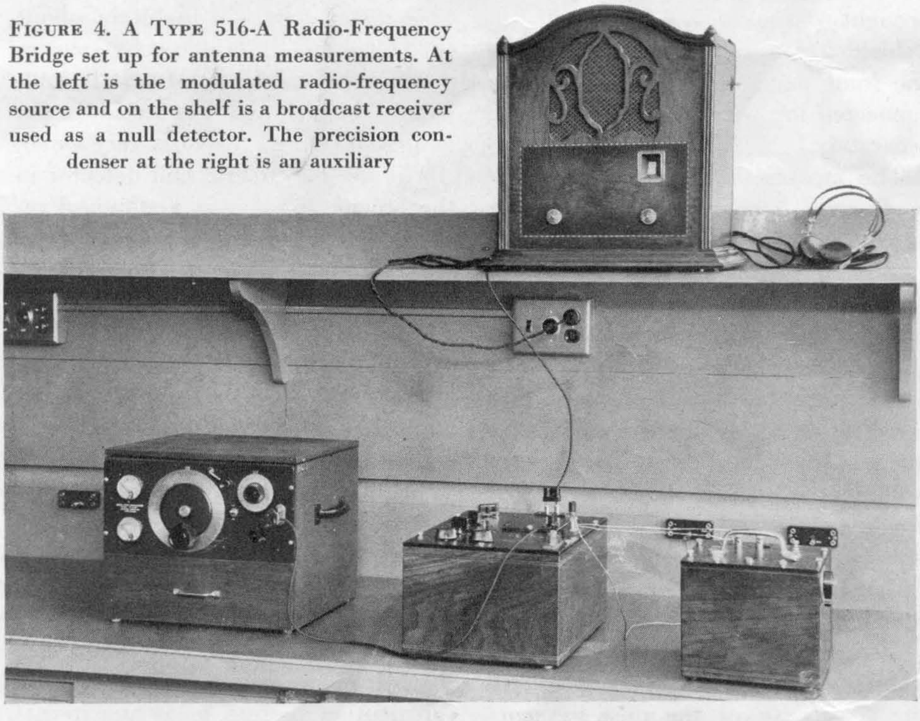
TYPE 222 Precision Condenser and either the decade resistor in the bridge or a similar external one. The impedances measured have included the capacitance and resistance of air and mica condensers, varying from 100 $\mu\mu$f to 1000 $\mu\mu$f, the resistance and inductance of resistors varying from 1 to 10,000 ohms, and the resistance and reactance of an antenna whose natural frequency was 1.2 Mc. over the broadcast frequency range. The antenna measurements were interesting in showing that the voltages induced in fairly large antennae may approach a volt in magnitude. It is, therefore, desirable that the voltage applied to the bridge be at least of this magnitude and preferably larger, so that measurements may be made at all points.

The TYPE 516-A Radio-Frequency Bridge has been developed to permit the investigation of the possibilities of bridge circuits at radio frequencies. It will not be regularly carried in our catalog because we feel that an experience in high-frequency measurements which is not possessed by the average experimenter is required in order to obtain satisfactory results with it. It will be available in stock, however, and offers an interesting and useful tool for those possessing wide experience in the technique of high-frequency measurements.

The price of the TYPE 516-A Radio-Frequency Bridge is $190.00.

— CHARLES T. BURKE

FIGURE 4. A TYPE 516-A Radio-Frequency Bridge set up for antenna measurements. At the left is the modulated radio-frequency source and on the shelf is a broadcast receiver used as a null detector. The precision condenser at the right is an auxiliary



MEASURING PENTODES WITH THE MUTUAL-CONDUCTANCE METER

THE TYPE 443 Mutual-Conductance Meter, developed several years ago for testing triodes, can be used equally well with four-element tubes. After a minor modification (which every unit in our stock now includes) both heater-type and filament type pentodes can be measured.

One of the modified mutual-conductance meters with the batteries connected for measuring a filament-type pentode is shown in Figure 1 and the corresponding circuit in Figure 2. The connecting links to the new binding posts, engraved "+" and "—", marked PENTODE SCREEN, have been installed in the left side of the panel. The cathode circuit has been broken and its two ends connected to the new posts. The screen grid of a filament-type pentode is connected to the prong corresponding to the cathode of heater-type tubes. Tests in our laboratory have shown the necessity for a source of voltage for the screen separate from that for the plate in the filament-type pentode such as the 247. The connections for the screen grid are, therefore,

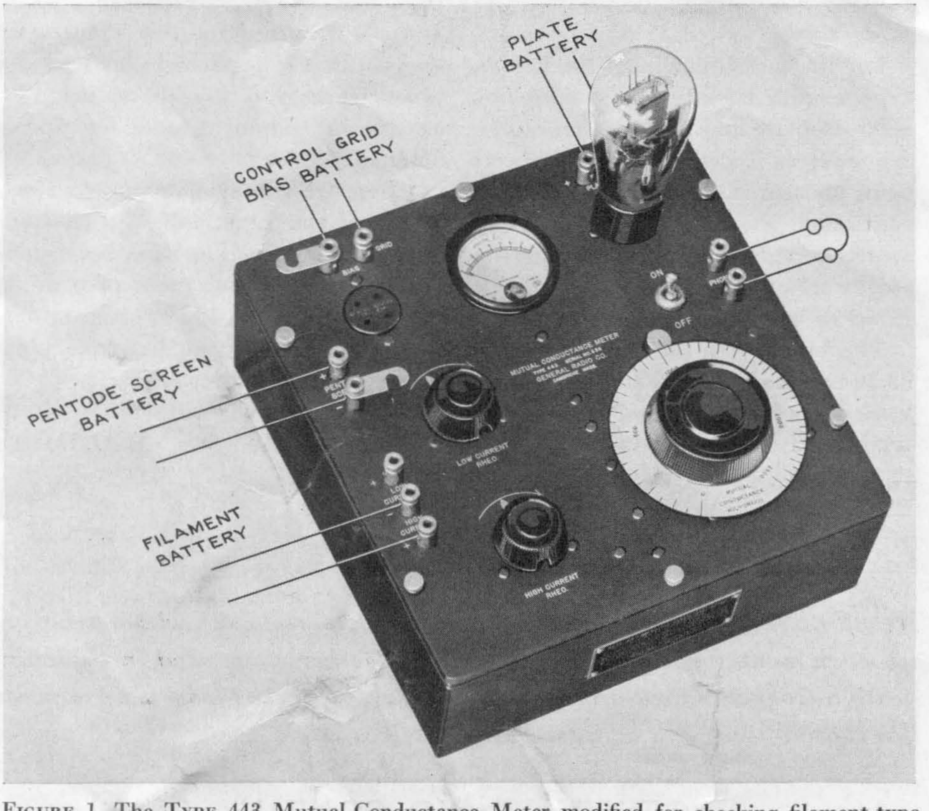


FIGURE 1. The TYPE 443 Mutual-Conductance Meter modified for checking filament-type pentodes. Connections for heater-type pentodes are the same as for screen-grid tubes; the pentode-screen terminals are closed by the link

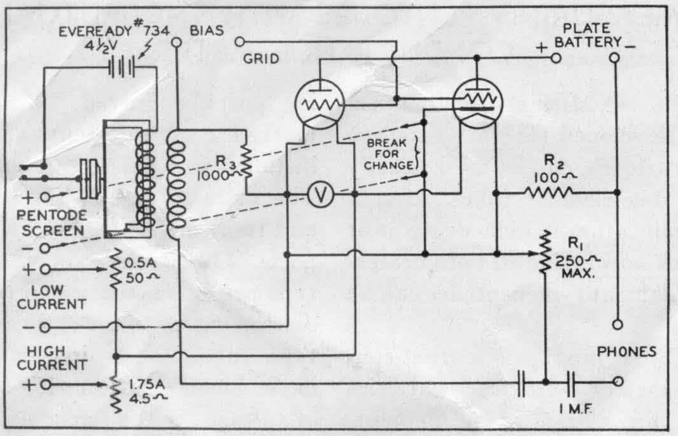


FIGURE 2. The dotted lines in this diagram show the change in wiring necessary to make the TYPE 443 Mutual Conductance Meter suitable for measuring pentodes

made to the two new binding posts.

For the measurement of the heater-type pentode tubes the connecting link is left in place and battery connections are made as if a screen-grid tube were being measured. Detailed instructions concerning this are found in the instruction book accompanying the instrument or in the General Radio *Experimenter* for July-August, 1930.

The charge for the modification is $3.20 net, and it would require about a week before return shipment could be made. If a mutual conductance meter is to be returned for this change, we suggest that it be packed very well in a wooden case to prevent damage in transit and shipment made by express prepaid.

There are still available in our stock a few of the TYPE 443 Mutual Conductance Meters that have been modified for the measurement of pentode tubes. The price is $27.00 each and immediate shipment can be made upon the receipt of an order.

— H. H. DAWES

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ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

TELEPHONE TRANSMISSION MEASUREMENTS

THE problem of measuring transmission loss over telephone lines has been greatly simplified in recent years by the development of inexpensive and simple instruments for the generation and measurement of electrical power at the usual telephone levels and frequencies.

As speech is transmitted over telephone lines the amount of power available for operating the receiver of course decreases as the distance between the transmitter and the receiver becomes greater. This decrease of amplitude follows a more or less logarithmic curve with distance, which has led to the adoption of a logarithmic unit for designating losses encountered in telephone transmission.

The unit is the decibel. It is an outgrowth of the original "mile of standard cable" which was later changed with modifications in value to transmission unit or TU, and finally to the decibel, db.

The losses that may be encountered in some of the usual telephone lines are given in the chart* following.

Line	*Loss in db per mile at 1000 cycles*
No. 12 iron wire (metallic circuit)	0.30 db
No. 12 copper wire (metallic circuit)	0.068 db
No. 24 gauge cable	2.10 db
No. 22 gauge cable	1.75 db
No. 19 gauge cable	1.20 db

These losses are given at 1000 cycles because this frequency is one of the most prominent in the voice-frequency band and is generally used when single-frequency tests are being made. Of course, all telephone systems transmit the various frequencies of the voice with different amounts of attenuation. For this reason, in order to determine the actual transmission characteristics of a given voice transmission system, tests must be made at several frequencies in the audio-frequency band, extending from about 150 to 3000 cycles, or from perhaps 50 to 5000 cycles for high quality circuits over which music and broadcast programs are to be transmitted.

However, the human ear is much more sensitive to frequencies between 800 and 1000 cycles than to any others, and commercial telephone transmitters and receivers have their best response

*B. C. Burden, *Telephony*, Oct. 10, 1931.

at these frequencies. It is because of such factors that 1000 cycles is chosen for the usual routine measurements.

FIGURE 1. This electro-mechanical oscillator operates at 1000 cycles on power from 6 volts, direct current. The output circuit is a tapped transformer

A most convenient power source for such tests is the General Radio TYPE 213-B Audio Oscillator illustrated in Figure 1. This instrument has been described in detail in a previous issue.* The important characteristics that make it particularly applicable to the question under discussion are these:

1. It is simple and rugged.

2. Its power output is ample for any of the usual tests, 50 milliwatts or almost +10 db being available.

3. Its frequency is 1000 cycles to within very close limits.

4. It has a very stable output over a period of time, making the comparison of several readings a simple matter.

5. Its power supply is very simple. Four No. 6 dry cells are ample. The direct current required is only 130 milliamperes.

Three output impedances are available: 50, 500, or 5000 ohms. The 500-ohm tap is the most suitable for the usual telephone line measurements.

The question of how to measure these audio-frequency power levels has been met with complete satisfaction with the new copper-oxide rectifier type meter.

The rectifying unit itself consists of four copper-oxide to copper junctions arranged in the form of a bridge. Junctions of this sort conduct current from copper-oxide to copper much better than in the reverse direction from copper to copper-oxide. Therefore each unit has the properties of a half-wave rectifier. The four units in the bridge arrangement give full-wave rectification with resultant increased efficiency. Alternating current applied to the bridge results in a proportional direct current in the meter circuit. Such a-c indicators are very sensitive and respond readily to the low powers encountered in telephone practice.

A special application of this meter is the General Radio TYPE 586 Power-Level Indicator illustrated in Figure 2. This instrument is calibrated directly in decibels in order to facilitate measurements in this unit without any arithmetical calculations.

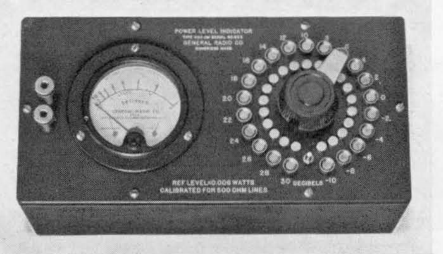


FIGURE 2. When bridged across the line, voltmeter fashion, this instrument indicates the amount of power that is being delivered to the 500-ohm line beyond the bridging point. It is direct-reading in decibels for a zero level of 6 milliwatts

*See General Radio *Experimenter* for April, 1930, copies of which can be supplied on request.

Since the impedance of the great majority of telephone lines is in the neighborhood of 500 ohms, the instrument is calibrated to read directly when used in circuits of this impedance. Six milliwatts is the zero reference level. There is a correction factor which is added or subtracted for lines of lower or higher impedance. Its value is given on a simple chart accompanying the instrument. In operation it is like any voltmeter; it is connected across the two-wire system under test and the power level read from the scale.

Two models of the instruments are available, differing only in sensitivity or range. The Type 586-A reads from −10 db to +36 db. The Type 586-C from −20 db to +36 db. Both are available for relay-rack mounting in permanent installations.

Many telephone companies maintain a regular check-up on the transmission characteristics of their lines. In this way any lines that are not satisfactory for commercial transmission are immediately detected and can be repaired before serious trouble results.

Such tests are so simple and inexpensive to make that the time expended is certainly well justified.

The 1000-cycle oscillator is connected to the pair under test at any convenient point, for instance, the main distributing frame, or the wire chief's desk. The power level at this point is read on the power-level indicator. A second power-level indicator is connected across the line at the remote point to which the test is being conducted. The difference in readings of the two indicating instruments in decibels gives the transmission loss directly.

The same test can be made on central office equipment to determine if all channels are operating properly. Cord circuits and repeat coils that become defective can be detected and located by this means before the trouble becomes sufficiently serious to interfere with satisfactory operation.

Some of the local-circuit losses that may be expected from normal equipment are given below:

Repeating coils for side circuits	0.70 db
Repeating coils for phantom circuits (two coils)	0.25 db
Magneto cord circuits	1.25 db
Common battery cord circuits	1.25 db

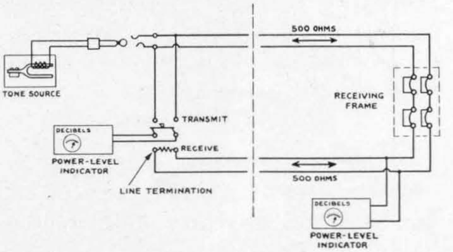


Figure 3. A convenient method of measuring line loss from one end when a duplicate pair of lines is available

Figure 3 shows a method for the measurement of long lines when two more or less similar pairs run between two distant offices. The two pairs under test are connected together at the distant end and the test equipment set up as shown. The power level at the transmitting end of the line is measured, then the switch is thrown to the receiving end and the level there measured. The difference in readings is the total loss of the loop. One-half of this value is the loss for the line in one direction only.

The maximum power level delivered by the oscillator is about +10 db and the lowest power that can be read on

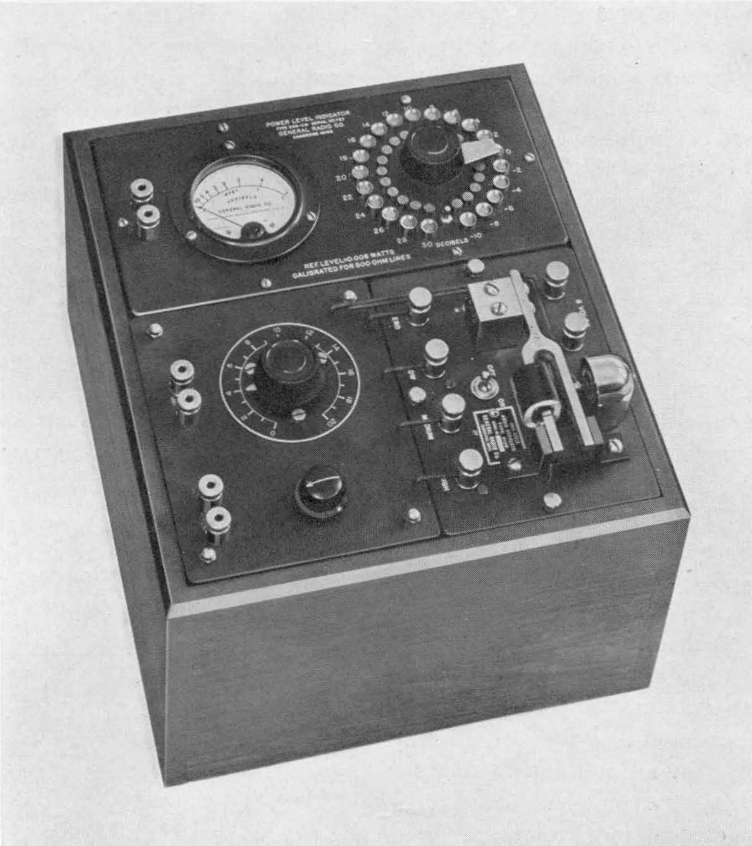


FIGURE 4. This assembly of a TYPE 213-B Audio Oscillator, a TYPE 586-CM Power-Level Indicator, and a potentiometer in a single unit makes a compact test kit for line tests. It can be made up to order, price on request

the more sensitive instrument is −20 db. Thus a total loss of about 30 db can be measured, corresponding to about 25 miles of No. 19 gauge cable, or 100 miles of No. 12 gauge iron open-wire circuit.

In order to make a check on the quality of speech and music transmission for broadcast lines, a variable frequency power source is substituted for the TYPE 213-B Oscillator. A beat-frequency oscillator such as the TYPE 613-A* is particularly recommended for this work.

The test frequency is set at a number of points from 60 to 6000 cycles and the loss at each frequency measured. A properly operating high-quality line should have a transmission loss that varies not more than 2 db to 4 db over this frequency range.

For the correct adjustment of line equalizers a test such as this is imperative.

In Figure 3 a power-level indicator is shown connected across the line at some distance from both ends of the line. This is to indicate that the power

*General Radio TYPE 613-A Beat-Frequency Oscillator. Frequency range, 10-11,000 cycles. Output power 35 milliwatts (+7.5 db). Price $210.00.

level at any chosen point on the line may be measured directly. Such tests are valuable as an adjunct to the linemen's usual tests. By such means a lineman can report to the office the exact power being delivered into a subscriber's loop for a given power supplied the line at the central office. Thus any faults in either central office or subscriber's loop equipment can be immediately uncovered by a much more precise and dependable means than by ordinary talking tests. The construction of the instrument is light and rugged enough to make it entirely suitable for such work.

Crosstalk tests can also be conducted by applying the tone source to one pair through a variable potentiometer that can be used to adjust the power level. The power-level indicator is used to monitor this level during the test. While listening on an adjacent pair, the power level is increased until the crosstalk heard in the adjacent pair under test becomes annoying. This level as read on the power-level indicator gives the information desired. On long repeater circuits levels from 0 db to +6 db are considered the maximum for safe transmission without crosstalk. Of course, on well balanced lines this level can be considerably exceeded before trouble results, and on short loops the limits are even higher.

The oscillator itself has, of course, many uses besides those mentioned above. It is widely used as:

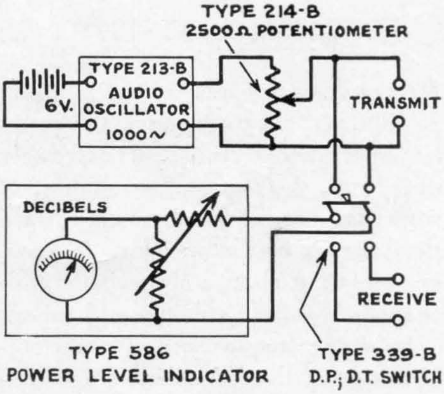


FIGURE 5. Wiring diagram for the test set shown in Figure 4

1. A tone source for use as an acoustic driver for testing telephone transmitters and similar equipment.

2. A tone source for identifying cable pairs.

3. A power source for the measurement of the gain in repeaters, public address installations, and other audio-frequency amplifiers.

Figure 4 shows a suggested arrangement for the audio oscillator, power-level indicator, and suitable auxiliary controls mounted in a cabinet for convenience and protection. The batteries for the oscillator are contained in the box, a potentiometer is provided to adjust the power output of the oscillator to any desired value, and a DPDT switch is used to transfer the indicator from TRANSMIT to RECEIVE as shown in Figure 3. A wiring diagram of such an assembly is given in Figure 5.

—ARTHUR E. THIESSEN

FREQUENCY STABILITY WITH THE SCREEN-GRID TUBE

IN the design of oscillators for use in frequency measurements, the problem of frequency stability is extremely important. A considerable amount of work has been done directed toward the design of oscillators whose frequency would not change appreciably with changes in supply voltages and tubes.

In single frequency oscillators stabilization of the frequency is not difficult. Usually a proper choice of circuit impedances is all that is necessary. It is considerably more difficult, however, to design a stable oscillator covering a frequency range of 50 to 1 with a single variable condenser.

It is generally conceded that the presence of harmonic voltages in the anode circuit of the oscillator is not conducive to frequency stability and, further, that an oscillator with good waveform is, in general, more stable than one with highly distorted plate and grid currents. An examination of the more common types of oscillator circuits indicates that the Colpitts circuit should have an advantage in this respect over other types, since the paths between plate and cathode and between grid and cathode offer low impedances to harmonics. This effectively short-circuits the harmonic voltages generated by the tube. Experimental work confirms this assumption, but, while it is better than most others, the Colpitts circuit is not inherently stable enough over wide frequency ranges to justify its use in precision apparatus unless some further stabilization is used.

It has been pointed out by Dow* that by properly proportioning the voltages applied to the plate and screen of a screen-grid tube, the oscillator frequency can be made nearly independent of changes in supply voltage. Figure 1 shows the variations in frequency resulting from grid- and plate-voltage changes in such a tube. Curve I is the change in frequency with screen voltage when the plate voltage is fixed at value B; Curve II shows the frequency change resulting from changes in plate voltage with the screen voltage held at A. Since the two curves have slopes which are approximately equal in magnitude and opposite in sign, it is evident that, if the tube is fed from a voltage divider so that normally the voltages on the screen and plate are A and B respectively, a change in total supply voltage can have no appreciable effect on the frequency. Any tendency toward a change in frequency due to a voltage change on one electrode is cancelled by an opposite change on the other.

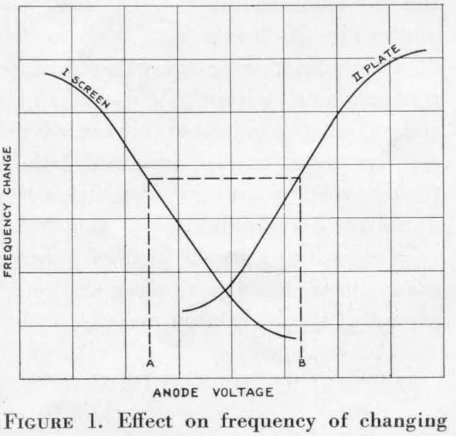


FIGURE 1. Effect on frequency of changing screen and plate voltages in an oscillator. In Curve I the plate voltage is fixed at B while the screen voltage varies; in Curve II the screen voltage is held at A and the plate voltage varies

*J. B. Dow, "A Recent Development in Vacuum-Tube Oscillator Circuits," *Proc. I.R.E.*, Dec. 1930.

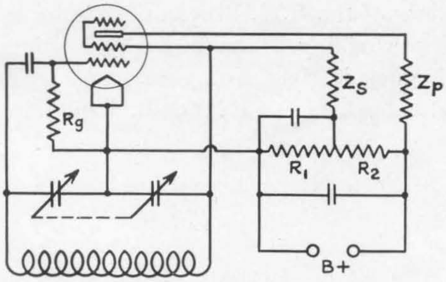


FIGURE 2. One form of voltage stabilized oscillator. The screen is used as the anode

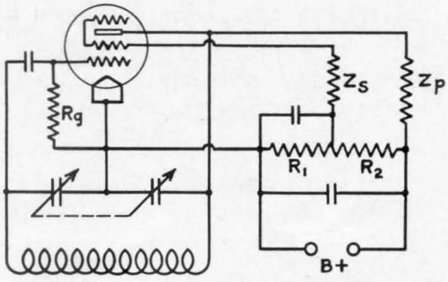


FIGURE 4. One form of voltage stabilized oscillator. The plate is used as the anode

When this stabilizing feature is applied to the Colpitts oscillator, the result is a system of unusual frequency stability. The effects of filament voltage and tube changes are greatly reduced, as well as those due to plate voltage. Figure 2 shows a simple form of this circuit. The impedances Z_s, Z_p, have some effect on the stabilization point, as does the grid leak R_g. The most stable operating point is found only by experiment, but can be located approximately by taking curves similar to those of Figure 1. Conditions differ between different types of tubes, but tubes of the same type are quite similar in operation. For optimum conditions with some tubes, the plate is at a lower potential than the screen, as shown in Figure 3.

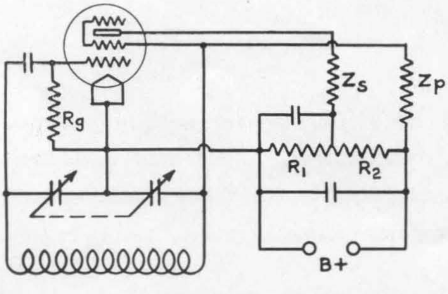


FIGURE 3. One form of voltage stabilized oscillator. Here the plate potential is lower than the screen potential

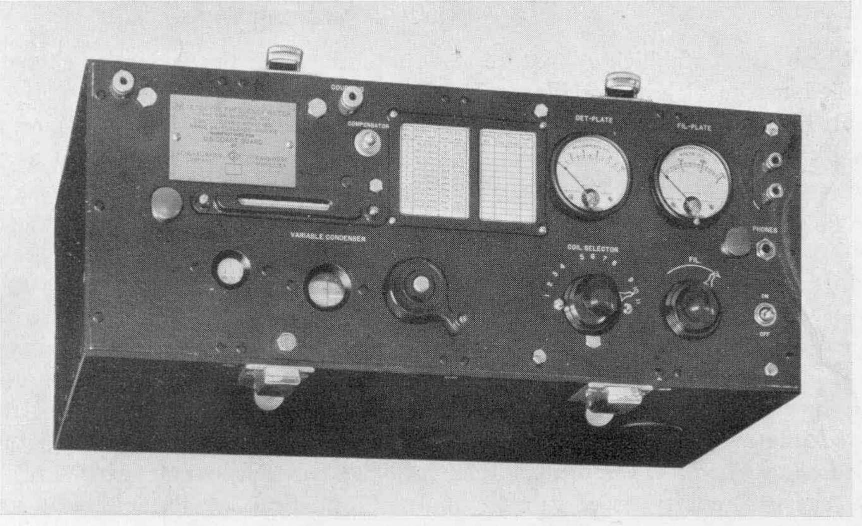
Either the plate (Figure 4) or the screen (Figure 2) may be used as the oscillator anode. When the screen is used, the plate circuit current wave is highly distorted, consisting of pulses at the oscillator frequency. Power may be drawn from this circuit at either the fundamental or a harmonic frequency without materially affecting the oscillator, particularly if the plate-screen capacity is neutralized.

The superior characteristics of the new stabilized oscillator circuit have been applied to a number of new General Radio instruments which will be announced within the next few weeks. A heterodyne-frequency meter covering all of the present commercial frequencies has been built around the new circuit. This instrument will be available in both alternating and battery-operated models, the latter being portable.

Another application of the new circuit is a linear-scale beat-frequency oscillator for measuring beats between standard harmonics and unknown frequencies. This instrument provides a means of interpolation between standard frequencies.

There has also been developed a combined oscillator and harmonic generator which is designed to take advantage of the 5-megacycle transmissions of the U. S. Bureau of Standards by providing a number of calibration frequencies based on the 5-megacycle standard. —Charles E. Worthen

A PORTABLE HETERODYNE FREQUENCY METER



A precision heterodyne frequency meter designed and manufactured by General Radio for the U. S. Coast Guard. This instrument covers a wide frequency range and employs a voltage-stabilized circuit like those described in the preceding article

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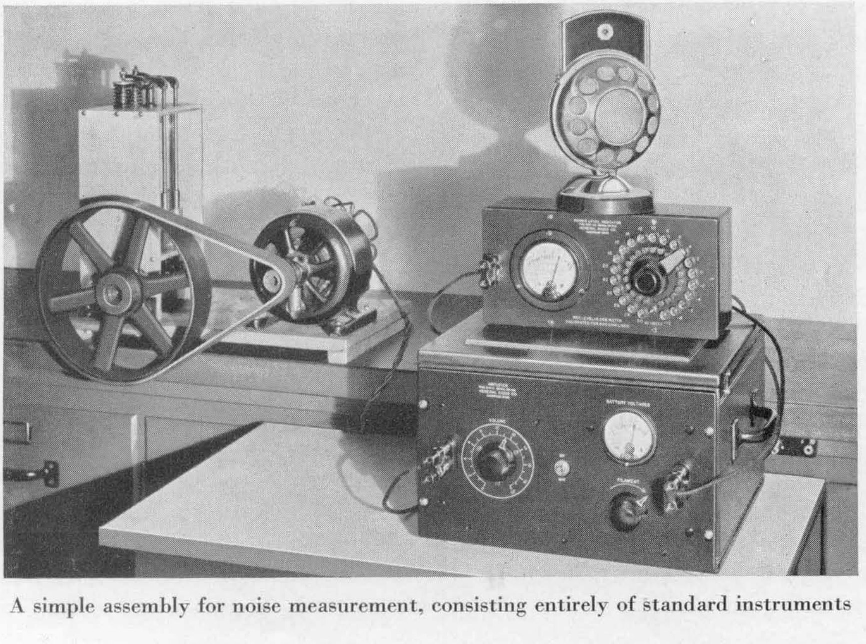
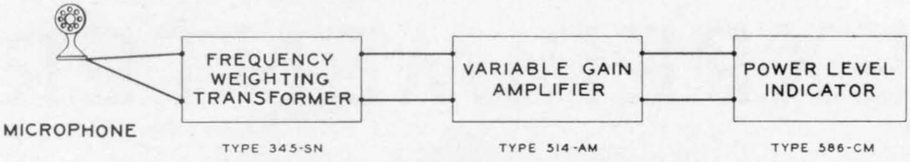
ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

INEXPENSIVE NOISE-MEASURING EQUIPMENT

MORE and more industry is realizing the fatiguing effects upon human beings of the various noises to which they are subjected, and with the realization comes the endeavor to reduce, so far as practical, all unnecessary sounds. In New York City for example, a noise commission has been making an exhaustive survey of the sources of city noise and means of its prevention. The most disturbing noises are frequently those generated by some common piece of mechanical equipment during its normal operation. Many machines, such as ventilators,



A simple assembly for noise measurement, consisting entirely of standard instruments



Noise is picked up in the microphone, weighted, and amplified. The power level indicator gives the result in decibels, referred to the background noise level, or any level chosen as reference

refrigerating systems, pumps, fans, etc., cause a constant whirring, hissing, or humming sound, which gradually works on the nervous system, causing mental fatigue.

Manufacturers of mechanical equipment are beginning to recognize the importance of quietness in their products.

An intelligent approach to the problem of noise elimination requires a means of quantitative noise measurement. Listening tests are of course of no substantial value in this work. Accordingly, various forms of noise-measuring devices have been developed in order to provide quantitative comparisons of different sounds. An extensive discussion of the problems involved in noise measurement will be found in recent issues of the *Journal of the Acoustical Society*.

The simplest form of noise-measuring set-up consists of a microphone, an amplifier, and a suitable indicator such as a vacuum-tube voltmeter or an oxide-rectifier meter. Sounds picked up by the microphone are amplified and indicated on the meter, giving a definite method of comparison. The meter should preferably be calibrated in decibels, which are the units generally used to express ratios of sound intensities. Where wide ranges of volume are to be measured, the amplifier gain should be adjustable to avoid overloading on loud noises.

In order to present a true picture of the effect of the noise on the human nervous system, the measuring system must have a frequency characteristic similar to that of the normal auditory system, *i.e.*, the low and high frequencies must be discriminated against. Some such discrimination is unavoidable in a microphone and amplifier system, but the normal loss of high and low frequencies should be accentuated.

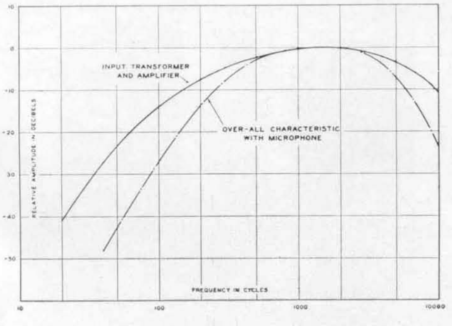
Since a flat frequency characteristic is not desired, an expensive microphone is not generally needed unless very low noise levels are to be encountered. The microphone should, however, show negligible variations with use and age and should have a residual noise level substantially below the lowest noise to be measured. The input transformer or frequency-weighting network should be so designed that its characteristic added to that of the microphone results in a close approximation to the normal ear characteristic.

A noise-measuring set of this type may be composed of several standard General Radio units. The illustration shows a system supplied to a large manufacturer of refrigerating machinery. It consists of a General Radio Type 514-AM Amplifier, a special Type 345-SN Input Transformer, a Type 586-CM Power-Level Indicator, and a microphone. The input transformer matches the microphone impedance to the amplifier and also adjusts the over-all frequency response to approximate that of the human ear. In this particular system, the input transformer is mounted in the amplifier cabinet, and the microphone receives its current from the amplifier filament battery.

The microphone is an inexpensive carbon type, since the noise levels at which it is to be used are comparatively high. The accompanying curves show the over-all frequency response of the noise-measuring system with and without the microphone. It will be noted that the over-all response of the complete system, including microphone, represents a very close approximation to the response of the normal human ear.

Although equipment of this sort is generally used to determine the decibels difference between normal noise level and noise with some machine operating, the equipment can, of course, be calibrated against any arbitrary standard desired. The threshold of hearing at 1000 cycles for an average person is frequently used as a reference level.

A convenient manner of calibrating the noise-measuring set is as follows: a 1000-cycle tone may be obtained from



The frequency characteristic of the system is made to approximate that of normal hearing

a suitable oscillator in conjunction with a loud-speaker. The observer should be so placed that he is approximately the same distance from the loud-speaker as the microphone and reasonably close to the microphone so that it may be assumed that the sound intensity reaching the observer is practically the same as that reaching the microphone. If the volume of sound from the loud-speaker is then reduced until the threshold of hearing is reached, the reading of the noise-measuring set at that point may be taken as the reference level.

With some types of microphones, the residual noise may be enough to cause an appreciable error in reading of the set at the threshold of audibility. Where very weak sounds are to be measured it is recommended that a microphone of the condenser or moving coil type be employed, but if loud noises are to be measured, the following method of calibration will be found quite satisfactory.

The oscillator used for obtaining the test tone should have a reasonably large power output and should be equipped with a calibrated volume control. If this is not the case, a suitable amplifier and attenuator may be used in conjunction with the oscillator. The loud-speaker should be reasonably linear in so far as power output is concerned, that is, doubling the power input to the speaker should double the power output. This of course means that the loud-speaker must not be overloaded. Placing the observer and microphone as mentioned before, the threshold of hearing should be obtained in the same manner and the reading of the calibrated attenuator or volume control on the oscillator or associated amplifier noted. The output of the loud-speaker should then be increased by adjusting the calibrated attenuator until a reasonably loud sound intensity is obtained. An increase of the order of 40 or 50 db is generally sufficient. It is not important that the intensity be increased by any exact amount, but only that the amount of increase be known. The reading of the noise-measuring set at that point. referred to the threshold of hearing, will equal the amount by which the output of the loud-speaker was increased.

For best results, these calibrations should be performed in an acoustically dead room or in the open air at some place where absolute quietness may be obtained. It is also advisable to perform the calibration with several individuals and use the average as a final value. — H. H. Scott

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For the convenience of those desiring to construct noise-measuring sets similar to the one described above, the following table gives the list of General Radio equipment which may be used, and the prices.

Type 514-AM Amplifier (without tubes and batteries) . . . $76.00

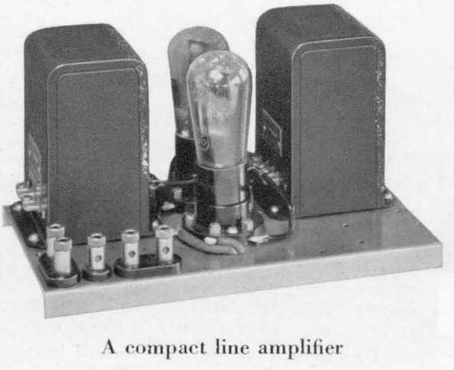
Type 586-CM Power-Level Indicator $75.00

Type 345-SN Transformer (for use in conjunction with single-button carbon microphone to obtain approximate characteristic of human ear) $15.00

If it is desired to have the special input transformer mounted within the amplifier unit and the amplifier input circuit arranged so that microphone current is obtained from the amplifier "A" battery, an additional charge of $15.00 will be made. The complete noise-measuring set as described in the foregoing article, including microphone, microphone case, suitable shielded cable connectors, and all tubes and batteries, will cost $230.00.

A BOOSTER AMPLIFIER FOR 500-OHM LINES

In modern communications systems, lines and equipment having impedances of 400 to 600 ohms are generally widely used. The high-quality transmission lines associated with radio broadcasting and sound pictures equipment generally have characteristic impedances within this range, and, accordingly, a large percentage of faders, mixers, and speech-input amplifiers have input and output impedances of approximately 500 ohms.



A compact line amplifier

Transmission lines should, of course, be operated at a volume level sufficiently high to minimize the effects of noise and crosstalk which may be picked up from nearby electrical equipment or other transmission lines. A level of +2 db is generally recommended. Increase in volume level also tends to reduce noises which may be encountered in fading and mixing equipment.

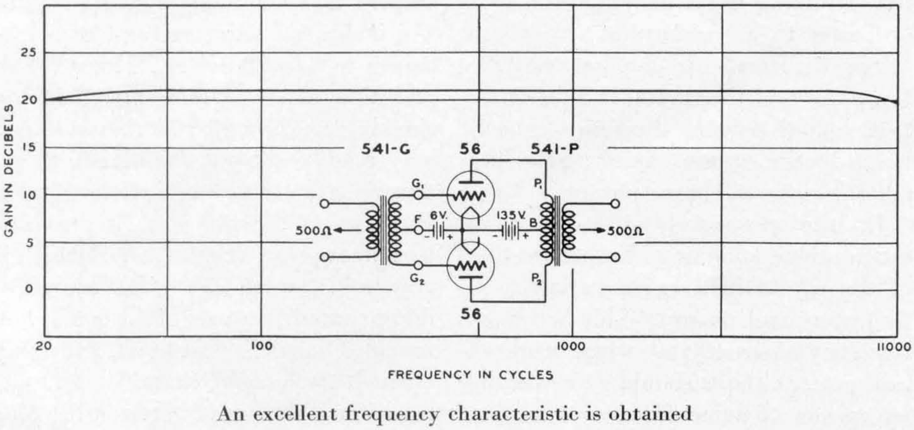
Two of the General Radio Company's new transformers, TYPE 541-G and TYPE 541-P, are finding widespread favor among engineers for use in connection with 500-ohm equipment. TYPE 541-G is a line-to-grid transformer designed for operation into either a single tube or a balanced (push pull) stage. TYPE 541-P is a plate-to-line output transformer for operation from a single amplifier tube or a balanced stage into a 500-ohm line. Using these two transformers, a line-booster amplifier may be constructed which will provide high insertion gain with an excellent frequency characteristic.

The accompanying diagram shows the circuit and frequency response of a balanced amplifier using two of the new 56-type tubes. The over-all amplification is approximately 20 db. 227-type, 230-type, or 237-type tubes may also be used, if desired, with a slight decrease (approximately 1.5 db) in gain. If a larger amount of output power is desired, 210-type tubes may be used.

—H. H. SCOTT

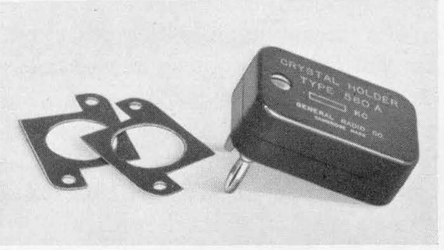
Prices on equipment used in the booster described above are as follows:

TYPE 541-G Line-to-Grid Transformer	$12.00
TYPE 541-P Plate-to-Line Transformer	$12.00
2 TYPE 438 5-Prong Sockets	.70
Special Base — Nickel-plated Brass with Binding Posts	$3.00

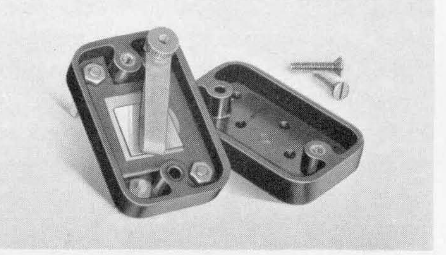


An excellent frequency characteristic is obtained

AMATEUR CRYSTAL HOLDER



The TYPE 560-A Crystal Holder assembled



The crystal is held under light pressure

The crystal is of course not included in the price of the holder

IN general, quartz-crystal holders for amateur and experimental-transmission use are constructed with two major considerations in view — frequency stability and maximum power output. In amateur operation it is generally advisable to sacrifice some frequency stability to gain in power.

The two types of holders commonly in use are the air-gap and pressure-plate types. The former are used in circuits in which frequency stability of the highest order is essential, and the latter where stability may be subordinated to power output.

The decreased air gap between the top plate and the crystal in a pressure-type holder reduces the series capacitance in the crystal circuit, affording material increase in output.

In the pressure-type holder any considerable amount of lateral motion of the crystal will cause variation in frequency and output. This "sliding" tendency of the crystal, when operated in a power circuit, should be restricted by means of some form of retention device which should limit the motion of the crystal without definitely preventing its natural oscillation.

The pressure requirements of the top plate vary with different crystals and with frequency. In some cases the weight of the top electrode alone is sufficient, while in others, pressure, supplied by a spring, is required.

The contact surfaces of both holder electrodes must be smooth and as flat as possible to insure uniform operation of the holder with different crystals.

An enclosed case is desirable to protect the crystal from dust or other foreign matter.

General Radio has designed a holder to fill the above requirements. The holder will accommodate crystals up to 1⅛ inches in diameter, and of thicknesses to 4 millimeters. Three blank retention plates of fabricated bakelite sheeting are provided so that the user may readily cut out the blanks to accommodate crystals of various shapes. Pressure on the top plate is provided by a flat spring, the tension of which is adjustable. Both electrodes are chromium plated. The case of the holder is of moulded bakelite, dust proof, and easily opened. Standard General Radio spacing of ¾ inch is used between the plug terminals. This is known as the TYPE 560-A Crystal Holder. The price is $2.25, including three fabricated bakelite retention blanks.

STANDARD-RELAY RACKS

TELEPHONE practice for a long time has been to mount equipment on racks of standard dimensions. Rack and panel dimensions have been worked out so that provision is made for instruments requiring various amounts of panel space.

The standard relay rack takes a panel width of 19 inches. The maximum allowable width of apparatus behind the panel is $17\frac{1}{2}$ inches.

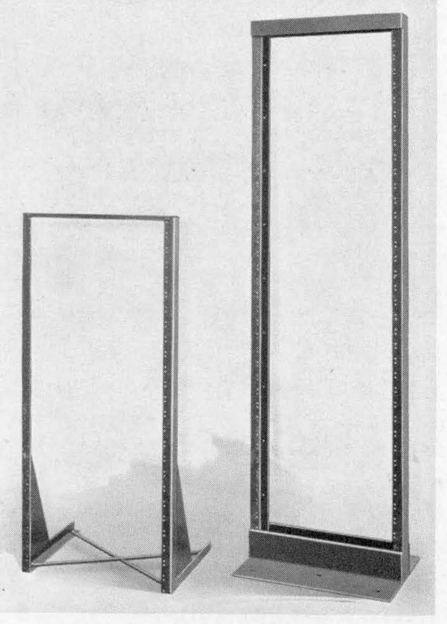
A drilling arrangement for the uprights of the rack has been worked out which permits the mounting of any size panel in any position on the rack provided certain standard panel widths and slotting arrangements are used.

The basic unit of panel width is $1\frac{3}{4}$ inches. An allowance of $\frac{1}{32}$ inch is made between panels for fitting so that the standard panel sizes are $n(1\frac{3}{4})-\frac{1}{32}$ where n is any integer.

The drilling and slotting arrangements for the panels are illustrated in the figure. Holes are tapped for 10/32 screws.

Panel slots should be laid out on the assumption that the top of the panel comes between two holes placed at $\frac{1}{2}$ inch intervals.

It is of course not necessary to slot the panel for each hole in the rack upright. The holes are at such intervals that a symmetrical arrangement of slots can be made in practically all cases. The figure illustrates the location of slots in three typical cases showing in heavy lines the positions actually slotted. General practice is to use two slots for panels up to and including five rack units ($8\frac{23}{32}$) wide, three slots for the six-unit width, and four slots for panel sizes up to eleven units.

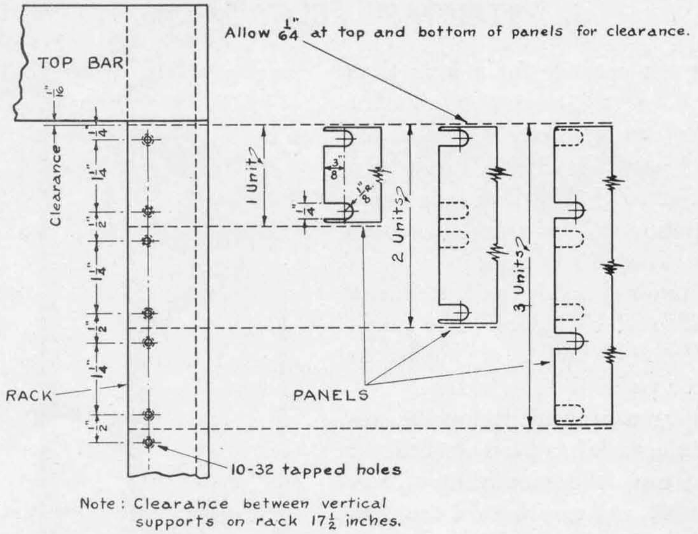


TYPE 480 Relay Racks: TYPE 480-B (*left*), TYPE 480-A (*right*)

These numbers would be modified for unusually light or unusually heavy installations.

The General Radio Company is listing two types of relay rack. One of these is a full size standard rack designed for mounting large assemblies of laboratory equipment. It contains mounting space for the equivalent of thirty-six panel units.

A smaller unit is provided for bench mounting. This is ideal for installation of laboratory assemblies consisting of several portions such as oscillators and their rectifiers. This type of rack lends itself to mounting at the back of laboratory tables to hold permanently installed equipment, thus freeing the table surface for other apparatus. The rack is also ideal for assembling of



Standard dimensions for panel cutting and drilling. Panel units are in multiples of 1¾ inches high by 19 inches wide. Maximum width of apparatus behind the panel 17½ inches

amateur-radio transmitters. This rack will mount twenty-five panel units.

Both racks are of steel frame and can be bolted to the floor or table, although this is usually not necessary. Both racks are drilled as shown in the illustration above. Holes are tapped for 10/32 panel mounting screws. Mounting screws, washers, and bridle rings for cabled wiring are supplied.

The large rack stands 63 inches from the floor and has a panel mounting space of 43¾ inches by 19 inches. The price of the large rack (Type 480-A) is $40.00; that of the smaller (Type 480-B) is $15.00.

Panels for mounting apparatus on these racks should be of ¼ or ⅛-inch aluminum depending upon the weight of the apparatus to be supported. Panels can be obtained cut to size with finished edges from the Aluminum Company of America or its local jobber.

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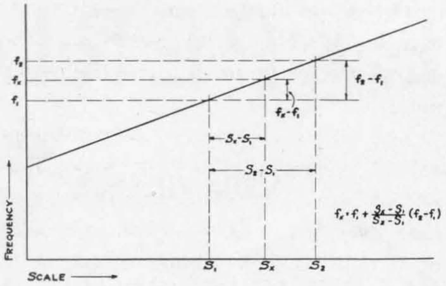
THE WAVEMETER YIELDS

THE tuned-circuit wavemeter was the first accurate radio-frequency-measuring instrument, and it is interesting that even now we measure frequency with far higher accuracies than any other quantity with which the radio engineer deals. While tuned-circuit wavemeters have been greatly refined, the accuracy of laboratory measurements, and indeed commercial requirements for frequency standards, have outstripped them. So, while the tuned-circuit type of wavemeter will still be used for many purposes—as a transfer instrument, and for measurement where an accuracy of about 0.1% is sufficient, it must yield its place as a secondary standard for really precise work, just as it was displaced by the crystal oscillator several years ago as a primary standard. Again it is a form of piezo oscillator which takes its place.

A few years ago, a wavemeter, especially one of the precision type, was regarded as a sufficiently accurate frequency standard for use on commercial channels. With the total number of stations on the air constantly growing, efficient use of the available radio channels demands that the frequency of each station deviate as little as possible from that of its assigned channel. The present regulations of the Federal Radio Commission specify frequency tolerances which are far beyond the practical limits of a calibrated tuned-circuit wavemeter.

The present frequency tolerances on channels between 1500 and 23,000 kilocycles vary from 0.02% to 0.05%. To reach accuracies of this order, measurements must be made by heterodyne methods, since the best accuracy which may be obtained commercially with the tuned-circuit wavemeter is in the vicinity of 0.1%.

The development of the piezo-electric oscillator has furnished accurate and inexpensive frequency standards. As originally developed only a single frequency and its harmonics could be obtained from a single crystal. Multivibrators opened a new range of usefulness for piezo standards by enormously increasing the number of



Illustrating method of interpolation between standard-frequency harmonics

frequencies which can be obtained from a single standard. The multivibrator extends the usefulness of the standard by providing a harmonic series whose fundamental is equal to or a sub-multiple of the frequency of the standard and is entirely controlled by it. These two instruments in combination provide a series of standard frequencies spaced at equal intervals over the radio-frequency spectrum, which can be used for frequency measurements in much the same way that milestones on a highway can be used in measuring distance.

While this type of equipment is suitable for use as a primary standard a more flexible installation is needed for commercial frequency measurements.

Frequencies which lie within a few cycles of the standard harmonics can be measured by direct comparison methods, such as listening to beats in an oscillating detector, but in order to measure frequencies between the harmonics, an additional unit is required. For this purpose, a heterodyne frequency meter is used.

The heterodyne frequency meter is a highly stable radio-frequency oscillator with a linear scale (straight-line-frequency condenser). Since this is a tuned-circuit instrument, it is subject, of course, to the usual variations in frequency due to the temperature coefficient and the effects of aging in the tuned-circuit. Its stability over short periods is extremely high and it can be used as a calibrated frequency meter of high accuracy if the calibration is periodically checked. When used with standard-frequency equipment, however, it becomes purely an interpolating device and the only factors affecting the accuracy of measurement are its precision of setting and linearity of scale, both of which are more than adequate for commercial use.

This process of interpolation may be better understood by reference to the diagram of Figure 1 which shows a plot of frequency against scale reading for the heterodyne frequency meter. By listening in a radio receiver, the heterodyne frequency meter can be successively adjusted to zero beat with the unknown frequency, the multivibrator harmonic next above the signal, and the harmonic next below the signal. This gives three scale readings, S_x, S_2, and S_1, respectively. If the frequency interval between multivibrator harmonics is 100 kilocycles, the frequency interval between f_1 and f_x is

$$\frac{S_x - S_1}{S_2 - S_1} \times 100 \text{ KC} \quad (1)$$

In other words, the frequency interval between f_1 and f_x is proportional to the corresponding fraction of the 100-kilocycle scale interval and the frequency of f_x is

$$f_1 + \frac{S_x - S_1}{S_2 - S^1} \times 100 \text{ KC} \quad (2)$$

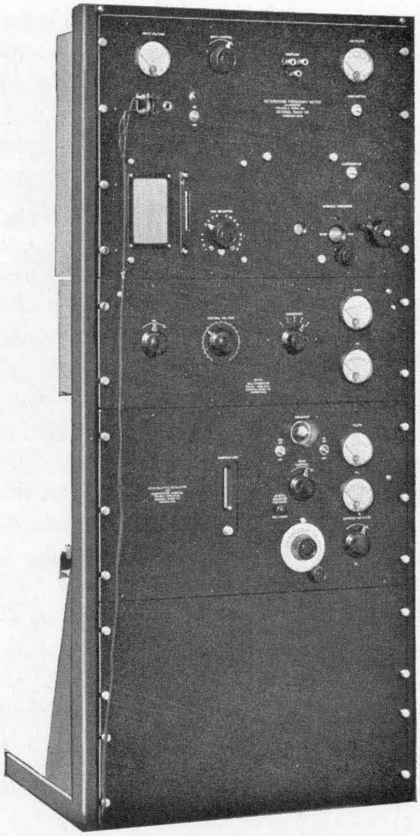
If desired, operation (1) can be carried out by means of a chart.

The frequency of the harmonic f_1 can be easily determined from the calibration of the heterodyne frequency meter.

The following analogy may be helpful in explaining the interpolation process. Suppose, for example, that a man lives in a house between the towns of A and B, and that he wishes to determine exactly how far from A his house is situated. These towns are connected by a straight highway marked by milestones. He knows that the house is between the 8th and 9th milestone from A. His problem is therefore to determine the distance between milestone number 8 and his house. Starting out from the house he paces off the distance to the 8th milestone and finds it to be exactly 440 paces. He then turns back and counts the paces from the 8th milestone to the 9th and finds there are exactly 1760. Since 1760 of his paces are equal to one mile he knows the house is 440/1760 of one mile from the 8th milestone. His house then is located 8¼ miles from A.

While the mechanics of this distance interpolation are similar to those of the frequency measurement, there remains one outstanding difference. While it took our hypothetical householder about an hour to perform his interpolation on foot, the unknown frequency can be measured on the dial of the heterodyne frequency meter in a few seconds.

The interpolation process is not limited to the fundamental frequency range of the heterodyne frequency meter. Interpolation can be made as easily at harmonics as at the fundamental. This allows measurements over a wide range of frequency to be made with an instrument whose fundamental frequency range is limited.



The secondary standard described. It consists of the following items:

TYPE 616-A Heterodyne Freq'cy Meter	$500.00
TYPE 592-A Multivibrator . .	150.00
TYPE 575-D Piezo-Electric Oscillator	215.00
TYPE 480-B Relay Rack . .	15.00
TYPE 376-J Quartz Plate (for oscillator)	85.00
TOTAL . .	$965.00

(Blank panel is not included in this price)

For use in this method of frequency measurement, the General Radio Company offers the assembly shown in Figure 2.

This assembly is capable of measuring frequencies from below 100 kc to about 30,000 kc. The overall accuracy is better than 0.01%. It is suitable for the measurement of the frequencies of transmitted and received signals and for the standardization of receivers and other calibrated apparatus.

It is particularly recommended for small communication companies engaged in furnishing a limited class of service as, for instance, airplane communication.

The piezo-electric oscillator is the same instrument used in the General Radio visual frequency monitor for broadcast stations. Its absolute accuracy with TYPE 376-J Quartz Plate is guaranteed to be within 0.002%. The multivibrator is of the type used in the General Radio Class C-21-H Standard-Frequency, a precise primary standard.

The TYPE 616-A Heterodyne Frequency Meter is a highly stable tuned-circuit oscillator using a straight-line-frequency precision condenser. It is entirely alternating-current operated and uses the voltage stabilization feature described in the August *Experimenter*. Its fundamental frequency range is from 100 to 5000 kilocycles. By using harmonic methods, it can be used to measure frequencies from 10 to 30,000 kilocycles. A detector and audio amplifier are included.

A portable, battery-operated heterodyne frequency meter is also available. This instrument, TYPE 615-A Heterodyne Frequency Meter, covers a frequency range of from 275 to 5000 kilocycles. It is similar in appearance to the model shown on page 8 of the August *Experimenter*. The portable feature is often an advantage, since the instrument can be checked in the laboratory against a frequency standard and then used for frequency measurements at points remote from the laboratory. Its price is $375.00. Substituting this instrument for the relay-rack model of Figure 2 makes the price of the complete assembly $840.00.

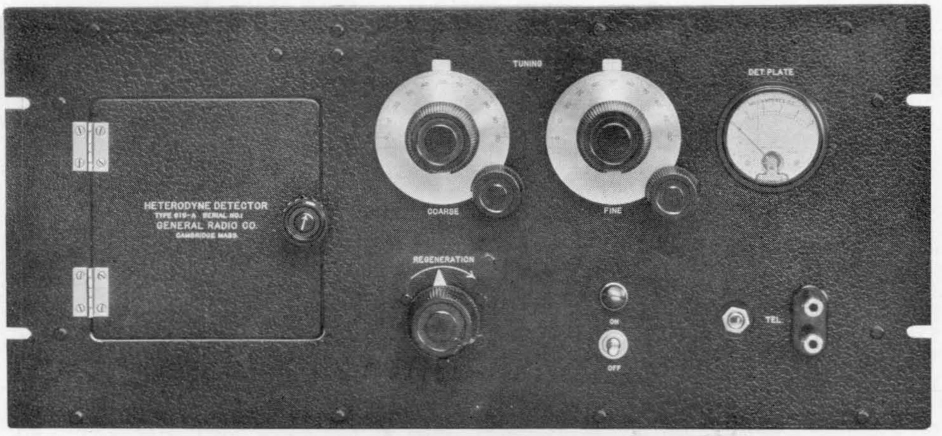
—CHARLES E. WORTHEN

A LABORATORY HETERODYNE

IN the whole range of frequencies above audibility there has not been commercially available equipment for demodulation and amplification of super-audible frequencies, yet such equipment is a necessary accessory for many types of laboratory measurements, and greatly extends the usefulness of other standard equipment. Bridge measurements, for example, can be made at frequencies above the broadcast band. In frequency measurements, a heterodyne is of course indispensable.

To be sufficiently flexible for general use, such an instrument must cover an extremely wide frequency range with a fairly uniform sensitivity. Commercial receivers are available for certain frequency bands, but no single instrument of such characteristics has been available which would cover the entire frequency band from 85 kilocycles to 20 megacycles.

The TYPE 619 Heterodyne Detector, while originally designed for use in a frequency-monitoring system, meets these conditions very well and is



Type 619-A Heterodyne Detector

entirely suitable for use as a general-purpose heterodyne.

It consists of a tuned, regenerative detector whose frequency range extends from 85 to 6000 kilocycles, and a two-stage audio amplifier. This range of frequencies is covered by the standard set of twelve coils furnished with the instrument. In addition, six extra coils are available which extend the range to 20 megacycles. A regeneration control is provided so that the detector can be used in either the oscillating or the non-oscillating condition.

This control is extremely silent in operation and no "fringe howl" or clicks are noticeable when the detector goes into oscillation.

The amplifier output transformer is designed to work into a pair of telephones.

This instrument is available in two models, one battery operated and the other designed for operation from a 110-volt, 60-cycle, alternating-current line. Both models are intended for relay-rack mounting, but can be supplied in cabinet mounting at a slight increase in cost.

The minimum-detectable signal with the battery-operated model is about 40 microvolts with a signal 30% modulated at 1000 cycles and with heterodyne reception of an unmodulated signal it is about one microvolt.

The alternating-current model has slightly higher background noise level and its sensitivity to the modulated signal is about 100 microvolts over most of the frequency range. Using beat reception with this model a signal of about 2 microvolts can be detected.

These values are for threshold sensitivity, the weakest signal which can be heard.

The price of the a-c model (Type 619-AR) is $250.00 and that of the battery model (Type 619-BR) is $225.00.

A RADIO-FREQUENCY OSCILLATOR FOR THE LABORATORY

TYPE 484 Radio-Frequency Oscillator. The drawer provides storage space for extra coils

A RADIO-FREQUENCY GENERATOR covering a wide range of frequency is often needed for laboratory measurements.

The TYPE 484-A Modulated Oscillator has been designed to fill the need for a general-purpose instrument which can be adapted to a variety of problems. Among its features are a wide frequency range, straight-line-frequency condenser, precision dial, internal modulation, output control, and low external field.

The normal frequency range is from 490 kilocycles to 40 megacycles covered with 5 plug-in inductors. Two additional inductors are also available. One spans the intermediate frequencies used in superheterodynes. The other operates at 100 kilocycles. The small change of frequency with dial setting on this coil, combined with the slow-motion dial, permits setting the oscillator with extreme precision at 100 kilocycles, in comparison with a standard.

The frequency ratio of each coil is approximately 3:1. The condenser is controlled by a TYPE 706-B, 6-inch precision dial, which has a slow-motion drive with a 3:1 reduction ratio. Its total scale length is 450 divisions and it can be set to within one-fifth division.

Modulating voltage is supplied from a 1000-cycle vacuum-tube oscillator which is included in the instrument. The modulation oscillator is a plug-in unit, and units for other frequencies are easily substituted. The percentage modulation is approximately 30%. A short-circuiting plug is provided which replaces the audio-frequency coils when it is desired to use the oscillator unmodulated.

The output is controlled by a potentiometer having an Ayrton-Perry winding. The maximum output voltage available is 2.0 volts. At the highest frequencies this drops to 0.2 volt. Over the range of any one coil the voltage varies by a ratio of approximately 1.5 to 1.

The oscillator is battery operated and uses two 230-type tubes. Batteries are self-contained.

This oscillator is a suitable power source for use with the TYPE 516-A Radio-Frequency Bridge. Other uses include resistance measurements at radio frequencies, testing receiving circuits, and determining detection characteristics of vacuum tubes.

It is an exceptionally useful instrument for experimental and demonstration use in college laboratories.

The price, less tubes, batteries, and inductors, is $125.00.

Code Word—CREST.

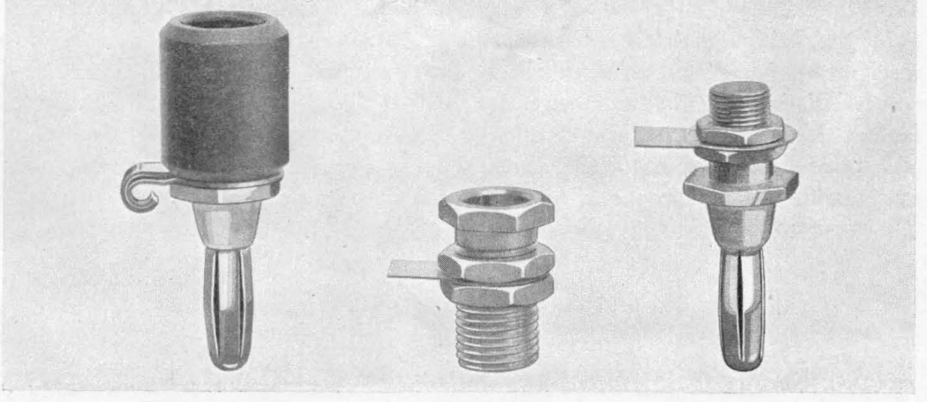
Inductors available are listed below:

Type	*Frequency Range*	*Price*	*Code Word*
484-P1	23.5 mc to 40 mc	$8.00	MODOSCBIRD
484-P2	8.9 mc to 27 mc	8.00	MODOSCDESK
484-P3	3.2 mc to 10.5 mc	8.00	MODOSCFORD
484-P4	1220 kc to 4225 kc	8.00	MODOSCGIRL
484-P5	490 kc to 1650 kc	8.00	MODOSCGOAT
484-P11	160 kc to 270 kc	8.00	MODOSCHYMN
484-P12	100 kc	8.00	MODOSCMILK
484-P21	400-cycle oscillator unit	12.00	MODOSCPALM

Weight........32 lbs.

Dimensions: 14½ deep x 12½ high x 19¾ inches long

A NEW PLUG GROUP



TYPE 674-D TYPE 674-J TYPE 674-P

THE TYPE 674 Plugs, illustrated, are similar in features and convenience to the well-known 274 type.

They are capable of carrying much heavier currents (up to 50 amperes) and have a low contact resistance.

A conical shoulder on the plug fits smoothly into a similar recess on the jack, and the main path of current is not through the plug springs.

Provision is made for attaching heavy leads to the plugs. A turned over lug is provided which clasps both the bared end of the wire and the insulated body. The latter feature removes the strain of the heavy lead from the joint.

The plugs are particularly convenient for mounting transmitting inductances. Copper tubing 5/16-inch diameter can be fitted directly into the jack end of the TYPE 674-D Plug.

A precaution should be observed in soldering to the plugs. The phosphor-bronze spring should be held with a wet cloth, otherwise the long heating necessary for soldering the large connections may damage the temper of the plug spring.

TYPE 674-P All-Metal Plug	$0.25
TYPE 674-J Jack	.35
TYPE 674-D Insulated Plug with Jack Sleeve	.50

BRIDGE MEASUREMENTS AT HIGH FREQUENCIES

THE July (1932) *Experimenter* contained an article describing a bridge suitable for measurements at radio frequencies. This article mentioned an oscillator that was being developed which would be suited for use with the TYPE 516-A Bridge. This oscillator (the TYPE 484-A) is announced in this issue of the *Experimenter*. It is shown set up for use with the high frequency bridge in Figure 4 of the July article.

In the bridge article, a broadcast receiver was suggested as a null indicator. This is probably the most satisfactory detector at broadcast frequencies, but where work is to be pursued over a wide range of frequencies above and below the broadcast range a more flexible instrument is needed. The features of the TYPE 619 Heterodyne Detector, described in this issue, recommend it for use with the TYPE 516-A Bridge. The frequency range of the heterodyne detector includes nearly all frequencies at which the bridge would be used. Its sensitivity is sufficient for good bridge balance. The following figures indicate the accuracy of balance at representative frequencies, using the TYPE 484-A Radio-Frequency Oscillator and the TYPE 619-B Heterodyne Detector. The TYPE 619-A (a-c type) has a slightly higher noise level, and less accurate balances can be obtained with it.

Frequency	*Modulated*		*Unmodulated*	
200 kc	10 $\mu\mu$f		0.15 $\mu\mu$f	0.7 ohms
1000 kc	0.5 $\mu\mu$f	0.5 ohms	0.05 $\mu\mu$f	0.025 ohms
2500 kc	0.05 $\mu\mu$f	0.03 ohms	0.005 $\mu\mu$f	0.01 ohms

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VOL. VII. No. 6 NOVEMBER, 1932

ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

A SIGNAL GENERATOR FOR THE NEW RECEIVER TESTS

THE last few years have seen some great advances in the electrical design of radio receivers, particularly since the superheterodyne principle has been so widely adopted by many manufacturers. Both the type and technique of receiver measurements have undergone many changes since then, due partly to the general improvements in receivers and partly to the additional tests necessary with superheterodynes.

In measuring broadcast receivers a new method of measurement, the so-called two signal generator test, is receiving wide acceptance. With this method, two standard-signal generators are employed, one of which delivers to the receiver, through a dummy antenna, what is termed the "desired signal." This signal is a carrier to which the receiver is tuned and represents the program that is being listened to, to the exclusion of all others. Then, in order to determine how successfully the receiver eliminates the other undesired signals, a second signal generator is set up and also connected to the receiver. Its frequency is variable over a wide range and it represents any channel which might possibly interfere with the desired signal.

The requirements for the generator of the desired signal are very simple. Only three or four test frequencies distributed in the broadcast band are necessary. The three test frequencies recommended by the I. R. E. Committee on Standardization are 600, 1000, and 1400 kilocycles. Its amplitude need be adjusted to only three standard input voltages. Those recommended by the Committee are 50, 5000, and 200,000 microvolts, representing weak, medium, and very strong signals. Modulation at about 30% at 400 cycles is desirable for preliminary adjustment of the receiver.

The interfering signal generator is necessarily more complicated. In the first place, its frequency should be variable between approximately 100 and 5000 kilocycles. Its frequency calibration should be good (incidentally, the frequency calibration of the desired signal generator does not need to be particularly precise since it can be checked against the other instrument which must be calibrated). The frequency modulation must also be reduced to a low value; and the last and most important requirement is that its output be variable between 0.5 microvolt and 1.0 volt.

The method of making the test is simple. The desired signal is set at one of the test frequencies, for instance, 600 kilocycles, and adjusted to give an output amplitude of 50 microvolts. It is modulated so that the receiver may be tuned to it; the receiver's volume control is adjusted to give the standard 50-milliwatt power output. Once tuned, the modulation is turned off so that only the carrier is applied on the desired channel. The interfering signal generator is then turned on and its frequency is varied across a considerable frequency range. In most cases this should be about 100 kilocycles on each side of the desired channel.

The average user of broadcast receivers will find that, if his set is delivering an output power of 50 milliwatts, an interfering signal having a power of 50 microwatts is objectionable. On this assumption, the amplitude of the interfering signal is adjusted as it is swept across the undesired channels until an interference test output, that is, 50 microwatts, is observed from the receiver under test for points spaced every 10 kilocycles in the interference band. A curve can be plotted indicating the amplitude of the interfering signal necessary to give the 50-microwatts interference output. During all of these tests, the percentage of modulation of the interfering signal is kept at 30% at a frequency of 400 cycles. The test may also be repeated with the amplitude of the desired signal increased from 50 to 5000 and 200,000 microvolts.

One of the problems in the design of superheterodyne receivers is to elimi-

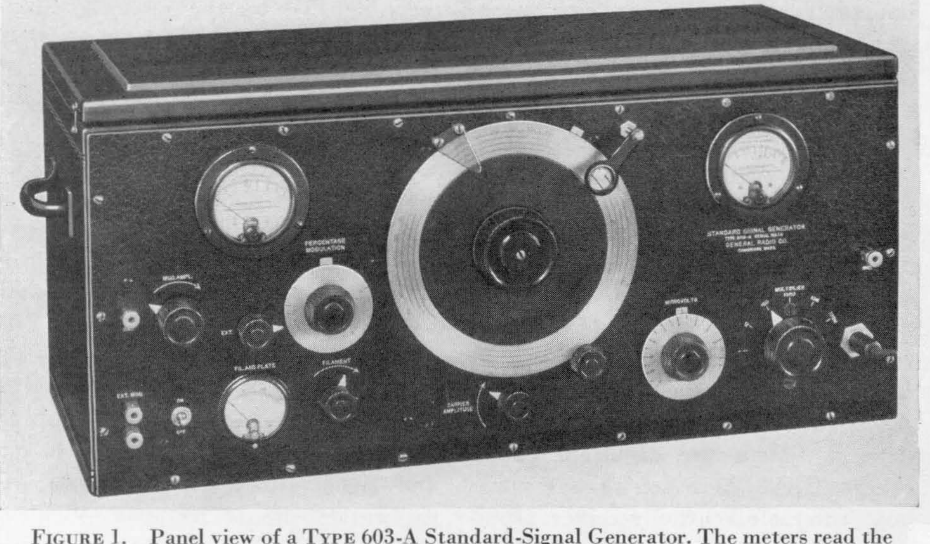


FIGURE 1. Panel view of a TYPE 603-A Standard-Signal Generator. The meters read the filament and plate voltages, modulation voltage, and carrier amplitude. Note the large frequency-control dial

nate various cross modulations which occur between the received signals and the local oscillator, particularly at the image frequency of the local oscillator. Other interference is due to direct pickup in the intermediate frequency amplifier. In order to determine the magnitude of this type of interference, a so-called "whistle interference test" is used. The tests are conducted the same as those described above, except that the interfering signal is unmodulated. Its frequency is varied across a wide band embracing the frequency of the intermediate amplifier and extending considerably above the frequency of the desired signal to include all possible points of cross modulation. In order that the audio-frequency system of the receiver shall not affect the test, a whistle when it occurs is adjusted to a frequency of approximately 400 cycles. The amplitude of the interfering signal generator is varied until the interference test output of 50 microwatts is obtained. Occasionally, it may be desirable, but it is not necessary, to vary the interfering signal by a very small amount so that the whistle frequency covers several points in the audio-frequency spectrum.

The requirements for the interfering signal generator are such that with a few additional controls it will also measure other important receiver characteristics. For instance, the over-all side-band response of a receiver can be determined by adjusting the frequency of the external audio modulation on the signal generator and noting the output-frequency characteristic of the receiver. The signal generator is set at one of the test frequencies in the broadcast band and 30% modulation at 400 cycles is applied. The gain of the receiver is adjusted so that the 50-milliwatt standard output is obtained. The audio modulation is varied from about 40 to 5000 cycles and the output power from the receiver is noted at various frequencies.

In making a test of this sort, the output load for the receiver can be either a rectifier-type meter having a resistance corresponding to the impedance into which the output tubes are designed to work, the output transformer having been removed or its secondary opened; or it may be a high-resistance output meter connected across the voice coil of the dynamic speaker. In the latter case, however, changes in the voice coil impedance due to its frequency characteristic and motional impedance will enter into the measurement. If the receiver is equipped with a tone control, the effect of this control on the frequency characteristic can also be observed.

Often it is very desirable, particularly when using pentode output tubes, to investigate the effect of various load impedances on the performance of the tubes. The General Radio Type 583-A Output Power Meter has an impedance which is variable between 2.5 and 20,000 ohms. It can be used either in place of the voice coil of the dynamic speaker or the primary of the output transformer. The difference in power delivered to varying loads for a given modulated radio-frequency input to the receiver can be noted by the various settings of the impedance switch.

With the general requirements in mind of the standard-signal generator necessary for the above tests the General Radio Company has developed the Type 603-A Standard-Signal Generator. This instrument is intended to

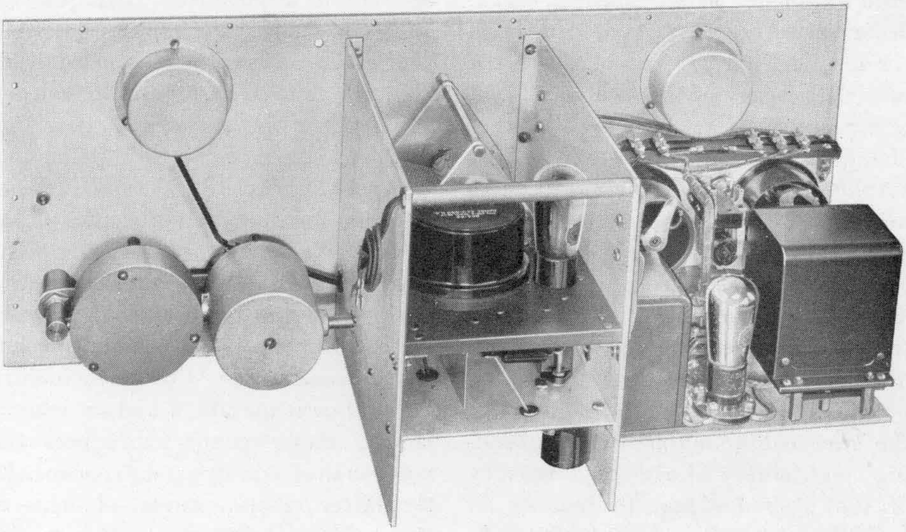


FIGURE 2. Rear view of the TYPE 603-A Standard-Signal Generator with the cabinet removed. The left-hand compartment contains the attenuator system and shielded thermocouple meter. The attenuator is divided into two sections, each housed in an aluminum casting

have the utmost flexibility. It is not restricted to the measurement of receivers in the broadcast band, but its frequency range has been extended to include most of the frequencies now in general use for radio transmission. As specifically applied to the requirements of the interfering signal generator and for the generator to be used for measuring the audio-frequency response, the TYPE 603-A Standard-Signal Generator has the following characteristics. The frequency range between 100 and 4400 kilocycles is covered by five coils. Two of these cover the broadcast band and have a combined range from 420 to 1900 kilocycles. The output voltage is continuously adjustable from 0.5 microvolt to 1.0 volt.

The ability to set and reset the carrier frequency of a standard-signal generator is of considerable importance. In order to facilitate this, a large and accurately engraved tuning dial is used. It is 8 inches in diameter and engraved around 270° of its circumference with 600 divisions. A magnifying glass is provided so that parts of a division may be read easily to improve the accuracy of setting. Fifths of a division can be very easily estimated. In the high frequency portion of the broadcast band, the coil has a range from 850 to 1900 kilocycles. The tuning dial has 600 divisions. This means a frequency change of about 1750 cycles per division for the coil span of 1050 kilocycles. Estimating fifths of divisions, the tuning can be set easily to within 350 cycles. The tuning condenser, incidentally, is straight-line frequency so that linear interpolation is possible.

The internal modulation system consists of a 400-cycle audio-frequency oscillator which delivers sufficient power for 90% modulation of the carrier. Its frequency is adjusted within ±20 cycles. The modulation percentage is continuously variable and the accuracy of calibration is such that when set for any given modulation it will be correct to within 10% of the percentage of modulation, using either internal or external modulation at 400 cycles.

The frequency characteristic of the modulation system is good and external modulation can be used with considerable accuracy over a wide frequency range. The highest audio frequency that can be used will depend upon the frequency of the carrier being modulated. The highest audio frequency that will produce an effective carrier modulation within 1 decibel of the modulation meter indication is about 1.5% of the carrier frequency. On low-frequency coils, this is the limiting factor. On higher-frequency coils, the radio-frequency filter and audio-frequency meter in the modulation circuit limit it to about 6000 cycles for an error of 1 decibel, or 10,000 cycles for an error of 2 decibels.

Very low power is required to modulate the instrument. Modulation at 30% is obtained by a power of about 60 milliwatts. The impedance at the external modulation terminals is about 5000 ohms.

The design of a flexible and accurate signal generator involves several important considerations. Two of the outstanding ones are the design of an attenuator that will operate successfully over a wide range of radio frequencies, and the reduction of stray fields to such a level that they do not enter into measurements when using the signal generator at very low output voltages. The attenuation system of the Type 603-A Standard-Signal Generator is such that essentially no measurable errors creep into its attenuation characteristics at frequencies up to and through the broadcast band. Some errors are involved in the actual direct-current calibration of the resistors and errors inherent in the direct-current d'Arsonval meter used with the thermocouples. These aggregate about 3%. At 10,000 kilocycles, the error in the attenuator becomes measurable and amounts to about 7%, which, together with the other errors mentioned above, give a total error at this frequency of perhaps 10%. At 25,000 kilocycles, all errors total to about 20%. By a careful design and layout of the oscillator and attenuator circuits, together with good shielding and use of toroidal coils in the oscillator circuit, the leakage is reduced to a point where it cannot be measured unless a highly sensitive receiver is connected directly to a multi-turn pickup coil, which is placed within a few inches of the panel of the instrument. These fields are in general so small that they do not affect measurements at 0.5 microvolt, even when using an unshielded receiver.

— A. E. Thiessen

* * * * *

The price of the Type 603-A Standard-Signal Generator is $600.00 with two calibrated coils for the frequency band from 420 to 1900 kilocycles. Additional calibrated coils for the complete frequency range of the instrument from 100 to 25,000 kilocycles are priced from $10.00 to $15.00 each, depending on the range. Calibration curves, if desired, cost $5.00 each additional.

A DIRECT-READING METER FOR POWER AND IMPEDANCE MEASUREMENTS

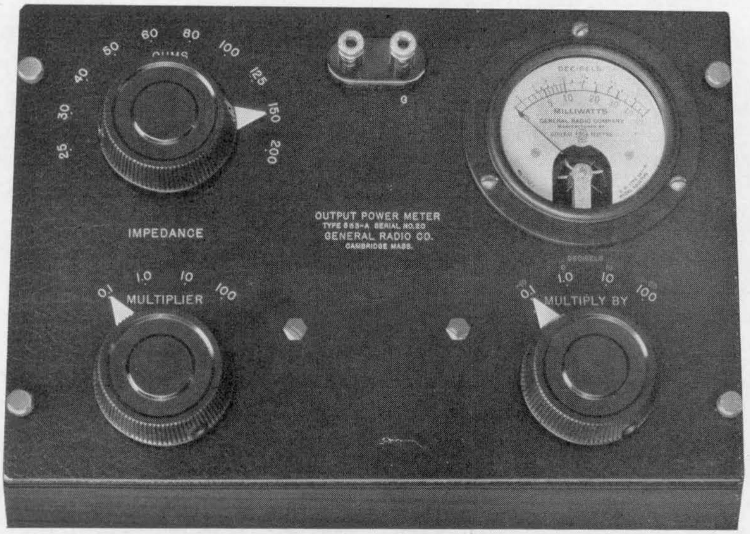


FIGURE 1. Panel view of a TYPE 583-A Output Power Meter, showing the available impedance settings and the meter scale

IT has heretofore been necessary, when power measurements were to be made over a wide range of impedance values, to use a decade resistance box and a meter to indicate current or voltage. With data so taken, the power can be calculated, and from a plot of power delivered versus load resistance, the internal impedance of the source under measurement can be determined.

This is a laborious process and in addition it consumes a good deal of time, especially when data for several such curves must be taken as the characteristics of the circuit under measurement are varied. An instrument which indicates directly power and impedance enables these measurements to be made simply and conveniently and is an extremely useful tool in the communication laboratory.

In the May, 1932, *Experimenter* the TYPE 583-A Output Power Meter which was designed for this purpose was briefly described.*

This instrument consists of a variable ratio transformer, a loss adjusting network to give constant loss at all ratios, a meter multiplier network, and a copper-oxide rectifier-type meter.

The impedance range is extremely wide, extending from 2.5 ohms to 20,000 ohms. This is a ratio of 8000:1 and more than covers all the impedance values likely to be encountered in communication measurements.

The ratio of maximum to minimum power which can be read on the meter is 5000:1, extending from one milliwatt to 5 watts. An auxiliary scale in decibels referred to a zero level of one milliwatt is also included.

The input impedance of the instru-

*John D. Crawford, "A Power Meter with a Wide Impedance Range."

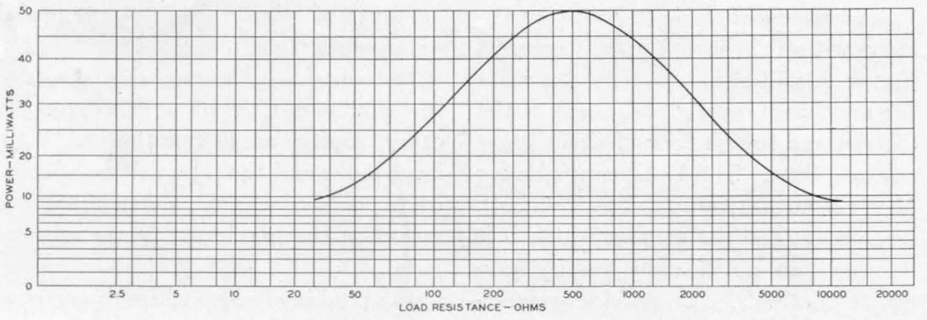


FIGURE 2. A curve of power output versus load resistance for a generator with a 500-ohm internal impedance

ment is adjustable in 40 steps spaced at approximately logarithmic intervals. This feature is of considerable importance. Figure 2 shows a plot of power output against load resistance for a device having an internal impedance of 500 ohms. The vertical lines on this plot correspond to the impedance values available in the power output meter, and these points are sufficiently close together so that the maximum power can be easily determined. Since the load impedance scale is logarithmic, the curve is symmetrical about the maximum power point. With logarithmic steps of impedance, therefore, the impedance corresponding to maximum power output can be closely estimated as the impedance switch is varied.

The vertical scale intervals of Figure 2 correspond to the angular deflection on the scale of the indicator. Since a copper-oxide voltmeter has an approximately linear scale, the scale for power calibration follows an inverse square law. This spreads out the low end of the scale allowing the meter to be read closely at low scale deflections.

Although the impedance can be varied by a ratio of 8000:1, a high accuracy of indication is obtainable over the greater portion of the useful frequency range. The error in full-scale power reading does not exceed 0.3 db between 150 and 2500 cycles per second and the average error between 30 and 5000 cycles is also not greater than 0.3 db. Since the variable-ratio transformer cannot be an "ideal" one, somewhat larger errors occur at the high and low ends of the useful frequency range. Between 20 and 10,000 cycles per second the average error is 0.6 db and the maximum error at any impedance setting at these extreme frequencies is 1.5 db.

The impedance error is also quite small over the greater portion of the frequency range. Between 150 and 3000 cycles per second this error does not exceed 7%. The average error between 30 and 5000 cycles per second is 8%. Since the accuracy of the best copper-oxide indicating element is only about 4%, these figures show that the other circuit elements are held to extremely small tolerances. At higher and lower frequencies, as might be expected, the impedance error increases, and the average error between 20 and 10,000 cycles per second is 20%. At the two extreme frequencies of 20 and 10,000 the maximum impedance error at any setting is 50%.

An analysis of these figures, particularly with reference to the curve of Figure 2, will show that they are, for the most part, negligible except at the highest and lowest frequencies.

The TYPE 583-A Output Power Meter is not intended to be a precision instrument and the uses for which it is designed do not usually justify precision methods. It combines convenience, wide range, and low price with a reasonable degree of accuracy and permits a high degree of accuracy over a somewhat smaller range.

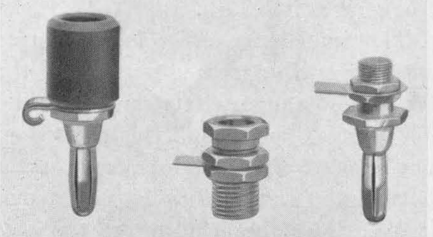
To the communication engineer the uses of this instrument are obvious. Wherever power and impedance measurements must be made: in the design and testing of filters, transformers, and other networks; in measuring the power output of vacuum tubes; in making many of the standard tests on radio receivers; its use saves a considerable amount of time hitherto spent in manipulation and in calculating results.

It is useful in determining directly the power output of a generator or other source as a function of load impedance and the internal impedance of the source can be determined by means of the maximum power output point.

In matching loudspeakers to vacuum tubes, it is often necessary to make several series of observations in order to simulate the varying impedance characteristics of the speaker. For this purpose, the TYPE 583-A Power Output Meter gives the desired results very quickly. It is sufficiently sensitive to measure directly the output of a phonograph pickup in order to determine its internal impedance and output power level.

The price of the TYPE 583-A Output Power Meter is $95.00.

A NEW PLUG GROUP



674-D 674-J 674-P

TYPE 674 PLUGS AND JACKS

The prices of the TYPE 674 Plugs and Jacks were incorrect as listed in the October issue of the *Experimenter*.

The correct prices are:

TYPE 674-P All-Metal Plug	$0.35
TYPE 674-J Jack	.25
TYPE 674-D Insulated Plug	.50

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ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

THE STROBOSCOPE

THE stroboscope consists fundamentally of a device which permits intermittent observations, either visual or photographic, of a moving object in such a manner as to reduce the speed of, or stop, the motion.

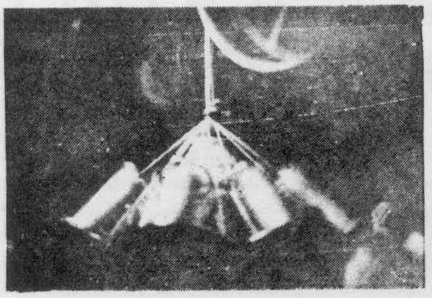
> THE quickness of the hand deceives the eye. But the eye knows a trick or two, and, aided by ingenious mechanisms, it is not deceived by the gyrations of machinery at far higher speeds than the trickster's hand achieves. Hence the stroboscope, which is not new, and the Edgerton* stroboscope, which is.
>
> Stroboscopes and their applications are described herewith. The Edgerton stroboscope on page 5.

The slow-motion picture is a familiar example of the interesting and profitable information which may be derived from a leisurely study of events which necessarily take place at a high rate of speed. The tennis player cannot slow the championship stroke to accommodate the laggard eye of the novice, but the camera can, and the motion picture camera is a stroboscope, but not all stroboscopes are cameras.

The camera shutter, operating at high speed, chops up the action into a number of small elements, so short that movement is not apparent in any one. The film can then be projected at normal speed with results that are instructive, or even backward with results that may be amusing. The function of the shutter is to exclude light from the film except for brief flashes. It seems reasonable that the same result can be obtained by shutting off the light from the object, except for brief flashes. This is the nature of the second style of stroboscope, of which the Edgerton type is the outstanding example. Obviously this type of stroboscope is well adapted for visual observations. Photography must still be used, if a non-repeated event is viewed, to store the elementary views and to release them later at a rate that the eye and mind can follow.

Consider, however, an indefatigable tennis player who repeats his stroke,

*The Edgerton Stroboscope is a development of Prof. Harold E. Edgerton, Massachusetts Institute of Technology.



Courtesy of Simplex Wire and Cable Co.

THE STROBOSCOPE STOPS MOTION

An insulation winder operating at normal speed. The carriage carrying the spools was revolving 180 r. p. m., the spools were also turning. A lower carriage turns in the opposite direction. The picture conveys an imperfect idea of the distinctness with which the operation of such machines can be observed visually. The threads and feeding mechanisms can be followed perfectly. The exposure lasted about one second, yet there is no blurring, testifying to the accuracy of flashing (unretouched)

identically, one thousand times a minute in a darkened room. If the light be flashed on him at a constant rate, exactly equal to his stroking rate, he will appear as though motionless under continuous illumination. If the flash speed be slightly slower than his stroking rate, his arm will be illuminated a little farther along in the stroke each time the light flashes and, as the eye retains the image between flashes, the madly stroking player will seem leisurely, and a single stroke can be spread over a minute if desired.

Humans, tennis playing or otherwise, cannot repeat uniform cycles at any such speed. Machines can, and wherever complicated machines are designed, built, or used, the ability to watch their operation in slow motion without photography is a boon.

The stroboscope permits stopping the motion of the machine (visually) for examination of machine or product at any part of its operating cycle while the grommets flow into the hoppers at undiminished speed. Or, perhaps, a squeaking clutch, a vibrating shaft, or a chattering valve spring stands between a new model and a waiting public—which will not wait long. A slow motion study will show the trouble, or the primary motion may be stopped and the vibrating member made as conspicuous as a mosquito-brushing hand at formal guard mount.

Sometimes the transient movement or vibration takes place at too high a speed for the eye even with the primary motion stopped. Here photography is resorted to for a second slowing down of the transient.

A little consideration of what is being done by the stroboscope is sufficient to set up the requirements of a satisfactory one.

An accurate means of timing the flash and a prompt and accurate response to the flash control are essential, otherwise the object will be viewed at irregular intervals, and vibrations not present in the object viewed will be introduced.

The flash must be of extremely short duration. Otherwise appreciable motion will take place during illumination, and blurring of detail will result.

The light must be brilliant. Otherwise the room must be made entirely dark, and details will not be seen clearly.

Stroboscope Arithmetic

Suppose that the object to be observed is executing uniformly R complete cycles of motion in unit time. Suppose further that the object is either viewed through a shutter opening for F brief, uniformly timed intervals, or is illuminated by F uniform instantaneous flashes of light in unit time. Then, if

$$R = nF \qquad (1)$$

where n is an integral number, it will be evident that each point of the object will be in exactly the same position in its cycle of motion at each observation, resulting in what we shall designate as a condition of "perfect" synchronism. Accordingly, all apparent motion of the body will be arrested, so that it will appear to be stationary at some particular phase in its cycle of motion, provided that the opening of the shutter or the flash of the lamp is of extremely short duration. If this interval of observation is of sufficient duration, the moving object, even when viewed stroboscopically, will appear blurred in outline, since each point of the body executes a perceptible amount of motion during the interval of observation.

It is further evident that the phase of the observed position of the object in its cycle of motion may be controlled at will merely by shifting the phase of the synchronous shutter or light flash with respect to the motion.

The special case of perfect synchronism, in which the frequency of motion and of observation are identical, is known as "fundamental" synchronism.

If n is greater than 1, the object will be observed only at every nth cycle of motion, so that the integrated illumination is reduced to the fractional amount $1/n$ times the illumination at fundamental synchronism.

Although any condition of perfect synchronism will completely arrest the motion, it is obviously desirable to work at the condition of fundamental synchronism.

If, on the other hand,

$$F = kR \qquad (2)$$

where k is any integral number greater than 1, then each point of the object will be visible k times per cycle of motion and will, accordingly, be observed successively at k points equally spaced, in time, throughout the cycle of motion. Such a condition, which is known as "partial" synchronism, while apparently arresting the motion of the object, is not, in general, satisfactory for visual stroboscopic observations. For example, a rotating disc having one radial line is seen as a disc with k radial lines.

A more distinct image is obtained at partial synchronism if the body is composed of mk identical parts equally spaced, in time, throughout the cycle of motion, *e. g.*, by a wheel having $P = mk$ spokes. Further, it can readily be shown that such a wheel will appear as a stationary wheel having P spokes whenever

$$PR = nF \qquad (3)$$

On the other hand, the wheel having P spokes will appear as a stationary wheel having nP spokes whenever

$$nPR = F \qquad (4)$$

Reference to equation (3) shows that there are, theoretically, an infinite number of values of R or of F for which a wheel of P spokes will be seen as a stationary wheel of P spokes. The larger the value of P, the greater will be the number of these partial synchronisms which occur within a given range of values of R or F. These facts are of importance in using the stroboscope to determine the frequency or speed of cyclic motions.

We have so far analyzed the fundamental laws of the stroboscope for conditions of exact synchronism, either partial or perfect. Consider now the case where the cyclic frequency of motion is slightly greater than an integral multiple of the frequency of observation—

$$R = nF + S \qquad (5)$$

where S is small compared to R. This means that the moving object will execute slightly more than n cycles of motion during the interval between observations so that the phase at which it is seen stroboscopically will continually advance. The object will therefore appear to move at a slow cyclic frequency of

$$S = R - nF \qquad (5a)$$

cycles in unit time and to travel in the same direction as the object is actually moving.

Conversely, if the cyclic frequency is slightly less than an integral multiple of the frequency of observation the phase at which the object is seen stroboscopically will continually recede so that the object will appear to move at a slow cyclic frequency in a direction opposite to the true motion:

$$S = nF - R \qquad (6)$$

The slow stroboscopic motion which can be obtained in this manner, and which can be adjusted to become a very small fraction of the true speed, makes the stroboscope extremely valuable in watching the cycle of motion of machinery running at speeds too high to be followed with the unaided eye.

The frequency of stroboscopic motion, S, may be made as slow as desired. On the other hand if S is increased above a certain limit the observed motion becomes intermittent and less satisfactory for purposes of visual study.

SOME STROBOSCOPE APPLICATIONS

DEVELOPMENT

An automobile manufacturer was troubled by a slight crank-shaft vibration in a new model, far too small to be observed in the rapidly revolving shaft. The stroboscope stopped the shaft motion and left the vibration which was seen and measured, although amounting to but 0.001 inch.

Automobile radio installations use a vibrating reed interruptor to obtain high voltage from the storage battery. The efficiency of these devices has been greatly increased by stroboscopic studies, revealing bending of the reed, chattering of the contacts, etc.

Other development applications: study of hunting in machinery, torsion in shafts, shaft whip, clutch slip, engagement of sprockets, cam action, behavior of loudspeakers.

PRODUCT CONTROL

The artistic effect of Andy Gump may be seriously impaired if Uncle Bim's necktie trespasses on his collar or on his chin. The proper color register with high-speed presses—for in modern plants the paper speed may approach a mile a minute—is a troublesome task. At present the register cannot be examined until the paper comes off the press, and much paper is wasted in the process of correcting the register. With the stroboscope, the sheet may be examined as though stationary while the paper rushes past. When the operator adjusts his register Uncle Bim's necktie slides gently into place and much paper and time are saved. Similarly the product of other high-speed machines can be examined and imperfections quickly spotted, and perhaps corrected, without stopping the machine.

PLANT MAINTENANCE

When machinery fails, operatives are thrown out of employment, customers wait, or trade elsewhere. Observed with the stroboscope, the machine can be followed through its cycle and the faltering element quickly spotted. Typical applications: slipping belt drives, clutches, chattering gears, hunting motors, chattering relays.

SALES

Vacuum cleaners, automobile tires, sewing machines—many consumer and industrial products operate at too high speeds for the unaided eye to judge their performance. The stroboscope is an impressive sales tool. Used at shows, exhibitions, salesmen's meetings it commands attention — drives home sales points dramatically.

POWER ENGINEERING

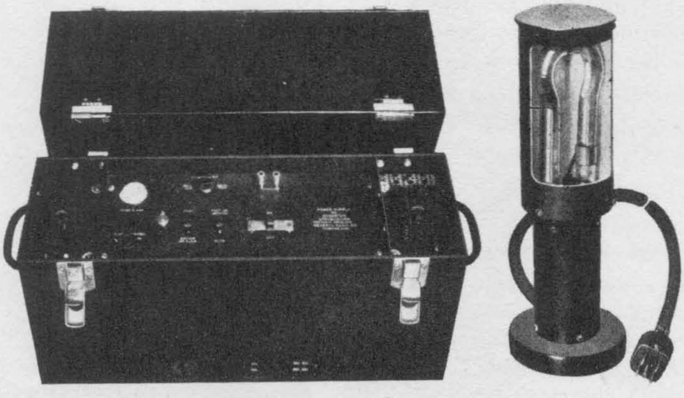
The behavior of machines and governors under sudden fluctuations in load can be observed. The stroboscope yields information as to hunting, speed of governor response, vibration, and starting characteristics. The phase of the light does not shift even with wide changes in frequency or voltage, and the supply line voltage can be used as a phase reference in making such studies on alternating-current machines.

EDUCATION

Modern education, particularly modern engineering education, explores in some degree all of the applications mentioned above, but the application of the stroboscope in the educational field only begins with them. Principles can be illustrated, phenomena observed, in the fields of mechanics, electricity, sound, and light.

THE EDGERTON STROBOSCOPE

(GENERAL RADIO TYPE 548-A)



THE EDGERTON STROBOSCOPE
Space is provided in the cover for the lamp

THE essential stroboscope requirement of a short and brilliant light flash is met in the Edgerton stroboscope by a high-intensity mercury arc lasting but five microseconds—sufficient time for an object traveling a mile per minute to move only 0.005 inch. The flash speed can be controlled accurately over the entire range ordinarily required and fundamental synchronism can be obtained up to speeds of 10,000 r.p.m.

This short, brilliant flash is obtained by discharging a capacitor across a mercury-arc tube which has the form of an inverted "U" with internal electrodes of mercury, anode and cathode, at its lower extremities.

Provision is made in the Edgerton stroboscope for flashing the light in exact synchronism with the closing of a pair of electrical contacts, by the 60-cycle supply mains (60 flashes per second), or by any external source of alternating current. The maximum speed of operation of the present equipment, which is limited by the regulation of the rectifier unit, is in excess of 150 flashes per second, so that fundamental synchronism may be obtained at all speeds from zero up to at least 10,000 r.p.m., while perfect synchronism of the second or third order will double or treble this limit.

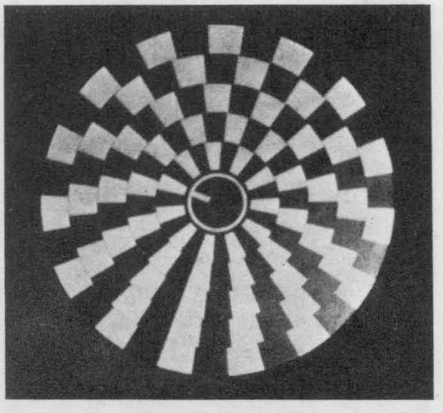
All parts of the stroboscope equipment, except the lamp and the tripping contacts, are built into a metal cabinet which constitutes the TYPE 548-A Power Supply. This is energized directly from 110-volt, 60-cycle mains and consumes a maximum power of about 0.25 kilowatt. Only three adjustable controls are required: the size of the lamp capacitor, a rheostat for controlling the intensity of the flashing voltage, and an adjustable speed contactor (if used). The cover of the cabinet is designed to store the detachable mercury-arc lamp, which is mounted in a suitable bakelite housing, and a synchronous-motor friction-driven vari-

TIMING THE FLASH

Precise and controllable timing of the flash is the essence of the stroboscope. The contactor seen consists of a constant speed synchronous motor driving a revolving commutator which makes a contact once each revolution. The flash speed is varied by sliding the driven wheel along the rack. This timer is generally used for viewing machinery in slow moton, studying vibration, hunting, relay action, etc. The position in the cycle of motion at which the flash occurs is adjusted by revolving the contactor head. Effective demonstration — a newspaper clipping on the end of a shaft can be stopped by the light and turned to the proper position for reading by the phaser. Newsprint is easily read while revolving 1800 turns a minute

able-speed contactor, TYPE 549-A, which is optional and sold separately. This contactor has a continuously adjustable range of operation from 5 to 30 flashes per second. While this gives fundamental synchronism for 300 to 1800 r.p.m., it may, of course, be used at perfect synchronisms for higher speeds. For any adjustment, the timing of this contactor is very precise and dependent only upon the frequency precision of the supply mains. The phase of the contacts may be adjusted at will by rotating the head of the contactor. If desired, the contactor mechanism may be detached from the motor drive and used, in the manner of a tachometer, against any centered, rotating shaft. This insures, of course, that the contacts will be operated in exact synchronism with the rotation of the shaft.

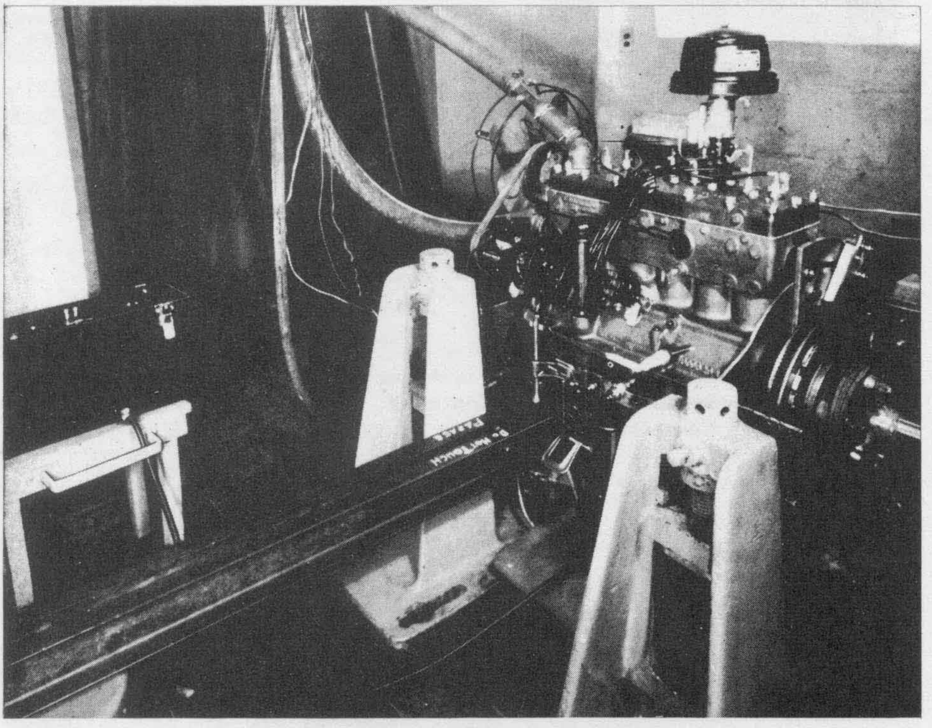
The method by which the short, brilliant flash is obtained in the Edgerton stroboscope may be analyzed with reference to the schematic wiring diagram.



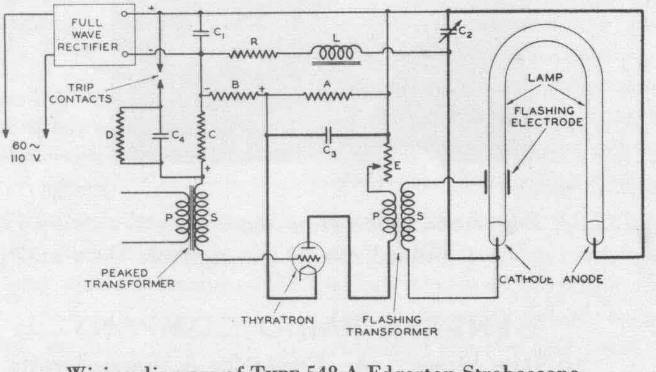
FOR SPEED MEASUREMENT

The disc was photographed under stroboscopic light at 1800 r.p.m. (fundamental synchronism). At this speed, all of the rings of squares are stopped. It will be observed that each ring has a different number of squares. As the motor speed changes (flash speed constant) different rows of squares will be stopped. A relation exists between the flash speed and motor speed which is signified by the number of squares in the stationary row (see stroboscope arithmetic, page 3)

USING THE EDGERTON STROBOSCOPE IN AUTOMOTIVE RESEARCH



Chrysler engineers measure crankshaft whip and vibration with the Edgerton Stroboscope. For an interesting description of the method, see page 75 of *Instruments* for April, 1933. Reprints can be had from General Radio Company without charge



Wiring diagram of Type 548-A Edgerton Stroboscope

TYPE 548-A EDGERTON STROBOSCOPE

The main operating limits of the stroboscope and its accessories are summarized below.

Length of flash: 5-10 microseconds.

Maximum flashing speed: 180 flashes per second. (Permitting fundamental synchronism up to 10,000 r.p.m.). Maximum photographic speed, with Type 408 camera, 60 exposures per second.

Power supply required: 50-60 cycle, 110-115 volt, 250 watt.

Dimensions: 8½ x 15½ x 24 inches.

Weight: Without contactor—56 lbs.
With contactor —66 lbs.

Performance of Type 549-A Synchronous Motor Contactor:

Maximum flashing speed: 30 flashes per second. (Corresponding to fundamental synchronisms at 1800 r.p.m.).

Minimum flashing speed: 5 flashes per second.

Type		*Code Word*	*Price*
548-A	Edgerton Stroboscope (including lamp)	MAGIC	$290.00
549-A	Synchronous Motor Contactor	MACAW	55.00
549-PI	Contactor	MADAM	25.00

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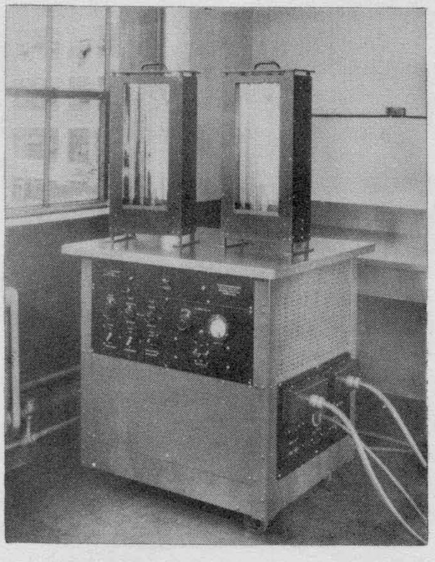

The Type 521-A Edgerton Stroboscope for service requiring greater illumination than the smaller standard model can deliver. Data and prices on request.

GENERAL RADIO COMPANY
30 State Street - Cambridge A, Massachusetts

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