the GENERAL RADIO Experimenter

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ELECTRICAL MEASUREMENTS TECHNIQUE AND ITS INDUSTRIAL APPLICATIONS

VOL. XI No. 8 JANUARY, 1937

THE MEASUREMENT OF MUTUAL INDUCTANCE

● **MUTUAL INDUCTANCE** is one of the most important properties of electrical circuits. By means of it the world's power is transmuted from generator voltage to transmission line voltage and back to the voltage suitable for our motors and electric lights. Yet the measurement of mutual inductance is of little importance as compared to measurements of self-inductance, capacitance, and resistance.

The major reason for this slighting of mutual inductance lies in the interesting fact that iron-core transformers are nearly perfect. The mutual inductance between the primary and secondary windings has so nearly its maximum value that no ordinary measurement of it could distinguish the minute difference. Such differences are of course of great importance and are measured by some characteristic of the transformer itself, the voltage regulation of a power transformer or its leakage reactance, and the frequency characteristic of an audio transformer.

The general theory of coupled circuits involves at one extreme the closely coupled iron-core transformers just mentioned and at the other extreme the loosely coupled tuned circuits of radio-frequency amplifiers, of which the neutrodyne receiver of Hazeltine is an historical example. Such loosely coupled circuits are now being used as band-pass filters at the intermediate frequency of heterodyne receivers.

Mutual inductance is unique in that it can exist only in the presence of self-inductance. An important measure of mutual inductance is its ratio to the geometric mean of the two self-inductances it connects, called the coefficient of coupling, k.

$$k = \frac{M}{\sqrt{L_1 L_2}} \qquad (1)$$

which may have any value from zero to unity. In loosely-coupled tuned circuits the resonance curve has a single peak for all values of coupling coefficient less than a so-called critical coupling.[1] A larger coupling coefficient results in a flattened top with the steepness of the sides maintained. The measurement of this small mutual inductance is of considerable importance in the adjustment of i-f filters.

Mutual inductance may be measured by using as a standard of comparison a mutual inductance, a self-inductance, or a capacitance. When the standard mutual inductance is continuously variable and of such a range that it can be made equal to the unknown mutual inductance, the Felici mutual-inductance balance is the simplest method. As

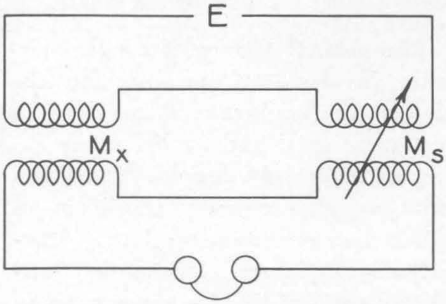


FIGURE 1. Felici mutual-inductance balance

shown in Figure 1, the primaries of both mutual inductances, unknown and standard, are connected in series to a power source. Their secondaries are also connected in series to a suitable detector, head telephones, or other a-c operated meter, in such direction that their induced voltages oppose. The standard is then varied until a balance is obtained, when

$$M_X = M_S \qquad (2)$$

The error in this measurement is essentially that of the standard, provided that the capacitive reactances between the coils of the mutual inductances are large compared with their mutual reactances and that the impedance of the detector is small.

[1] $k_C = \sqrt{D_1 D_2}$ or $\omega M_C = \sqrt{L_1 L_2}$ where D_1 and D_2 are the dissipation factors (reciprocal of storage factor Q) of primary and secondary.

TYPE 107 Variable Inductors are calibrated in such a way that the mutual inductance between their rotor and stator windings can be easily obtained from their dials calibrated in self-inductance. For a 1% full-scale accuracy of this dial calibration, the error in the mutual inductance will range from 2.5% to 10% over the portion of the scale normally used.

When the primary and secondary windings of a mutual inductance are connected in series, the self-inductance L of the pair is

$$L = L_1 + L_2 \pm 2M \qquad (3)$$

The mutual inductance M may be calculated from the two self-inductances L_a and L_o obtained with the two coils aiding and opposing (using the + and — signs before $2M$).

$$M = \tfrac{1}{4}\,(L_a' - L_o) \qquad (4)$$

For a coefficient of coupling nearly unity where L_o is very small compared to L_a, the error in the determination of M is that of L_a itself. For smaller coupling coefficients this error increases, as always happens when the difference of two nearly equal numbers enters in any

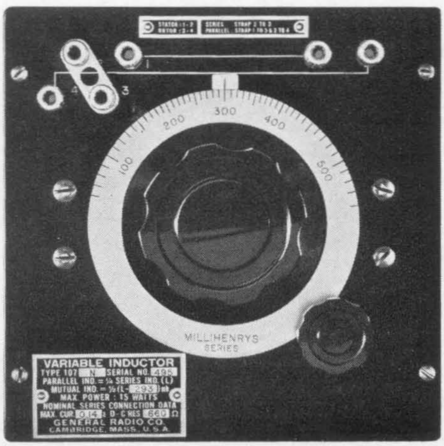


FIGURE 2. TYPE 107 Variable Inductor. Mutual inductance at any setting is one-half the difference of the scale reading and the value of self-inductance at zero mutual inductance as entered on the nameplate

formula. For example, when $K = 0.1$ and $L_1 = L_2$, the error will be increased fivefold. The measurement of self-inductance may be made on a Type 650-A Impedance Bridge with an error of 2 μh or 2% and on a Type 667-A Inductance Bridge with an error of 0.1 μh or 0.2%. The errors which occur in inductance measurements were discussed in considerable detail in the General Radio *Experimenter* for March, 1934.[1] The Type 293-A Universal Bridge may also be used with resultant errors which lie between those of the other bridges mentioned. In bridges having a decade ratio arm, from the setting of which the self-inductance is calculated, such as the Type 667-A and Type 293-A Bridges, the increase in the error as the two separate bridge balances approach one another is minimized if one ratio arm is kept fixed and the change in balance taken up by minimum changes in the other. The error is then that of the change in resistance of the decade ratio arm.

Mutual inductance may be compared with a self-inductance on the Campbell mutual-inductance bridge shown in Figure 5.

$$M = \frac{AL_P - BL_N}{A + B} \tag{5}$$

The self-inductance L_P of the winding

[1]R. F. Field, "The Measurement of a Small Inductance," General Radio *Experimenter*, Vol. VIII, No. 10, March, 1934.

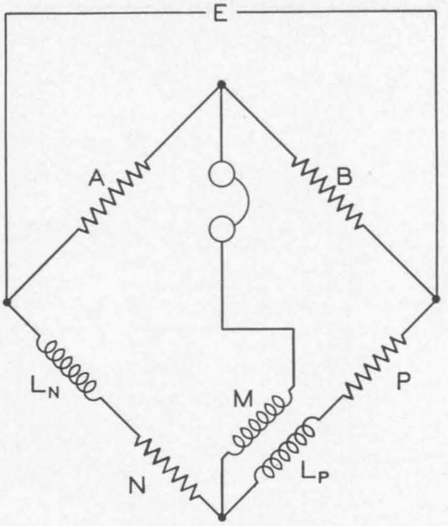


Figure 5. The Campbell Mutual-Inductance Bridge

connected into the bridge arm may be measured by removing the other winding from the detector circuit. Denoting these bridge readings by primes,

$$M = \frac{\frac{B'}{A'}A - B}{A + B} L_N \tag{6}$$

$$= \frac{B' - B}{A + B} L_N \quad \text{if } A = A' \tag{7}$$

Such measurements are easily made on the Type 667-A Inductance Bridge by connecting one winding of the mutual inductance to the unknown terminals and the other winding in series with the detector. The errors are slightly

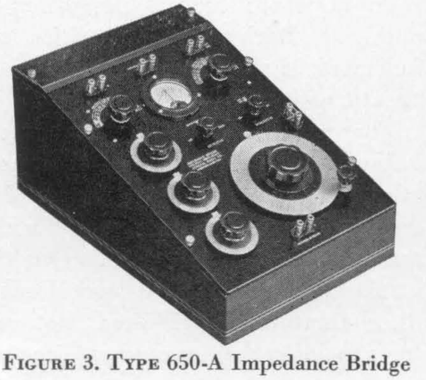


Figure 3. Type 650-A Impedance Bridge

Figure 4. Type 667-A Inductance Bridge

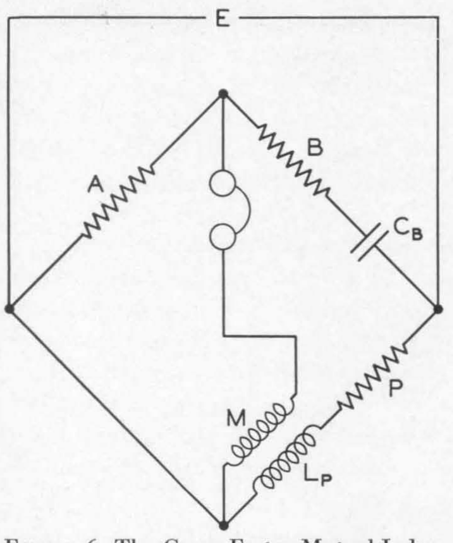


FIGURE 6. The Carey Foster Mutual-Inductance Bridge

less than for the previous case because for a given mutual inductance the difference between the two bridge settings is reduced by at least a factor of three and there is a greater chance of keeping both the bridge balances within a single decade setting lower than the highest one used.

A capacitance may be used as a standard for comparison with an unknown mutual inductance on the Carey Foster mutual-inductance bridge shown in Figure 6.

$$M = APC_B \qquad (8)$$

The resistance P includes that of the winding connected in that arm, which is somewhat difficult to obtain. This bridge circuit may be set up on the TYPE 293-A Universal Bridge, using as a capacitance standard a suitable TYPE 509 Mica Condenser.

— R. F. FIELD

NEW WAVE FILTERS

● THERE is a steady demand for wave filters offering a moderate amount of discrimination between the desired and undesired frequencies and having a moderate sharpness of cutoff. For some years the General Radio Company has been supplying TYPE 330 Filters for general-purpose laboratory use. For a number of uses, however, a sharper cutoff is required, and after a considerable period of supplying individually-designed filters for particular applications, the TYPE 830 Filter is offered as a stock item.

In discussing filter performance the quantities of interest are usually the sharpness of cutoff or, more briefly, the "sharpness," and the "discrimination" or difference between the insertion loss in decibels for the wanted and unwanted frequencies. For certain applications, peaks in the attenuation curve are important for the suppression of particular frequencies or harmonics. A filter for general application, however, should be designed so that in the valleys between the peaks the filter never gives less than a certain required attenuation. From this standpoint the height of the lowest valley measures the "discrimination," and if there is more than one valley the best design will make them all of the same height. Having defined the "discrimination" as the minimum valley height, the "sharpness" can be defined as the frequency ratio in which the discrimination is obtained. Both these quantities are indicated in the typical filter characteristic of Figure 1.

For certain applications the most important consideration is sharpness of cutoff. For other applications a wide frequency interval is available for the transition from the pass band to the attenuation region, but considerable discrimination is required between frequencies in the two regions. The conditions on the design which are necessary to obtain a sharp cutoff are very different from those which will give a large amount of discrimination. It turns out, in fact, that the greater the sharpness which is obtained by proportioning the elements in a particular configuration, the less will be the discrimination.

In the TYPE 830 Wave Filters the endeavor has been made to reach a compromise between sharpness and discrimination which will be satisfactory for a large number of applications. The insertion loss characteristic when the filter is working between constant resistance terminations is shown in Figure 2. It will be seen that the "discrimination" is slightly over 40 decibels and the "sharpness" is such that this value is reached at 1.5 times the cutoff for the low-pass types or .67 of the cutoff for the high-pass types.

High-pass and low-pass types can be used in tandem to provide a band-pass filter where the interval to be covered is one octave or more. The attenuation characteristic of such a combination is shown in Figure 3.

— W. N. TUTTLE

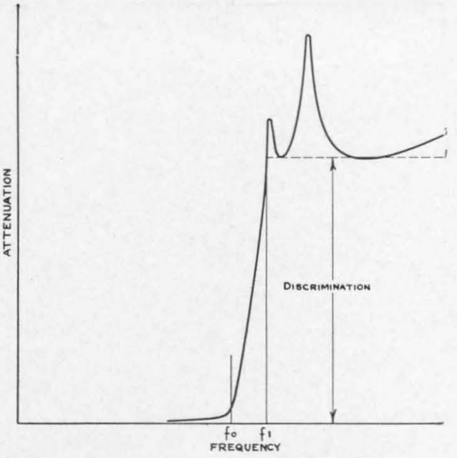
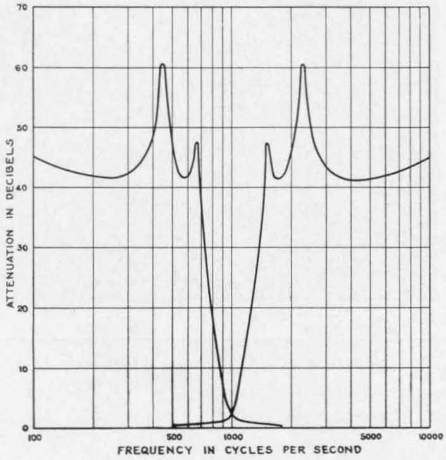


FIGURE 1. Insertion loss characteristic of a filter indicating what is meant by discrimination and sharpness. The ratio $\frac{fo}{f1}$ (or its reciprocal, depending on whether the filter is low-pass or high-pass) is a measure of sharpness

TYPE 830 Wave Filters are available in both high-pass and low-pass types. Stock models have cut-off frequencies of either 500 or 1000 cycles and image impedances of either 500 or 5000 ohms. Complete specifications are given on page 114 of Catalog J.

Type 830 Filters are manufactured and sold under patents of the American Telephone and Telegraph Company solely for utilization in research investigation, measurement, testing, instruction and development work in pure and applied science.



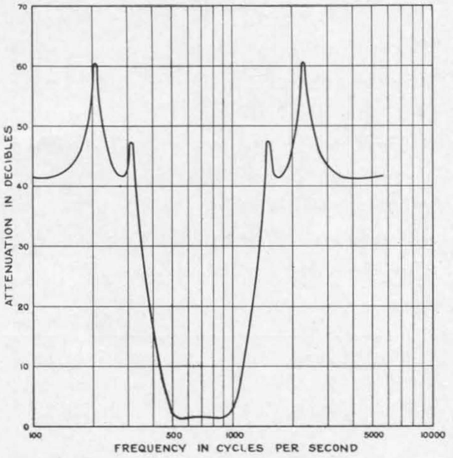
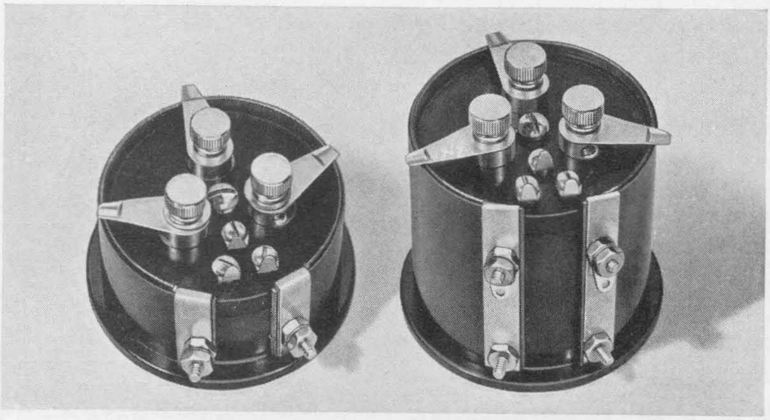


FIGURE 2 (*left*). Characteristics of 1000-cycle, low-pass and high-pass filters

FIGURE 3 (*right*). The 500-cycle, high-pass and 1000-cycle, low-pass types can be combined to form a band-pass filter covering one octave

A HANDY VOLTAGE DIVIDER



● **IN BUILDING** specialized laboratory equipment and in circuit development work, the engineer often needs an inexpensive, compact, and easily adjustable voltage divider for supplying plate and grid voltages to vacuum tubes. In several recently-developed General Radio instruments, the units shown in the accompanying photograph have been used for this purpose and have proved so useful that they are now offered for general sale.

The resistance winding and the moulded bakelite forms are identical in construction with those used in Type 471-A and Type 314-A Rheostat-Potentiometers. Three adjustable rotary contacts are provided, each covering one-third of the total resistance. Adjustments are made by loosening a thumbscrew and moving the arm to the desired position, after which the adjustment is locked by tightening the thumbscrew.

SPECIFICATIONS

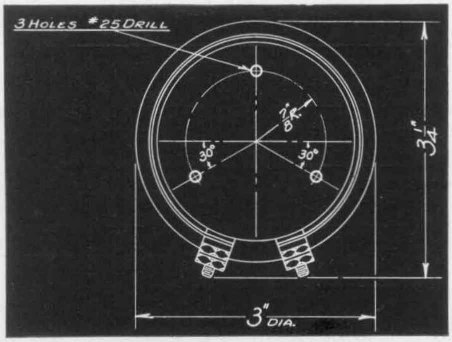
Power Dissipation: Type 154-A, 6 watts; Type 154-B, 12 watts.

Accuracy of Resistance: ± 10%.

Mounting: Standard 3-hole; see accompanying sketch.

Dimensions: Type 154-A, 3⅛ inches (maximum diameter) x 1¾ inches (height). Type 154-B, 3⅛ inches (maximum diameter) x 2⅞ inches (height).

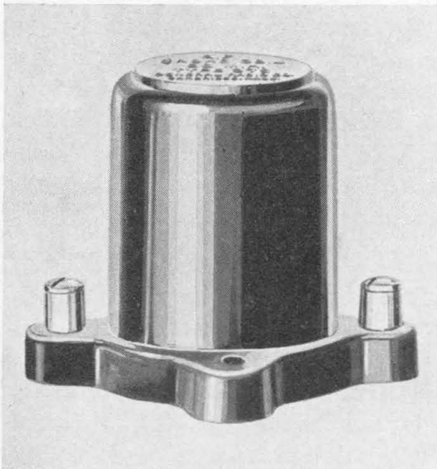
Net Weight: Type 154-A, 6 ounces; Type 154-B, 8 ounces.



Type	*Total Resistance*	*Code Word*	*Price*
154-A	5,000 Ω	DIVIDARMY	$6.50
154-A	10,000 Ω	DIVIDBOAT	6.50
154-A	20,000 Ω	DIVIDCAPE	6.50
154-B	50,000 Ω	DIVIDEYRE	8.50
154-B	100,000 Ω	DIVIDFACT	8.50
154-B	200,000 Ω	DIVIDGIRL	8.50

A WIDE-RANGE R-F CHOKE

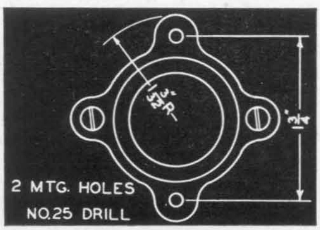
● **THE UTILITY** of most general-purpose radio-frequency chokes is limited to operation over a comparatively narrow range of frequencies. Ordinary methods of winding produce a high value of distributed capacitance, while separating the winding into several individual sections in series results in such a large number of resonant frequencies that at least one is usually located in the band where it is desired to work. The Type 119-A Radio-Frequency Choke has been designed to eliminate these faults.



The winding is composed of a large number of spiral-wound pies, each only one wire wide. By this method, the capacitance is much more uniformly distributed than with thicker pies, resulting in only one resonant point. The effective capacitance is extremely low, so that the choke is useful at fairly high radio frequencies.

The specifications for Type 119-A Radio-Frequency Choke are listed below. It will be noted that the capacitance of 2 $\mu\mu$f is extremely low for an inductance of 250 mh. These constants are practically independent of frequency and no minor resonances are found up to at least 50 megacycles.

In addition to its function as a choke, this unit has been found extremely useful as the inductance element in high-impedance low-pass filters.



SPECIFICATIONS

Inductance: 250 millihenrys.
Capacitance: 2 $\mu\mu$f.
D-C Resistance: 450 ohms.
Maximum Current: 60 milliamperes.
Dimensions: Base, 1¾ x 1¾ inches; height, 1⅞ inches, over-all.
Mounting: See sketch.
Net Weight: 3 ounces.

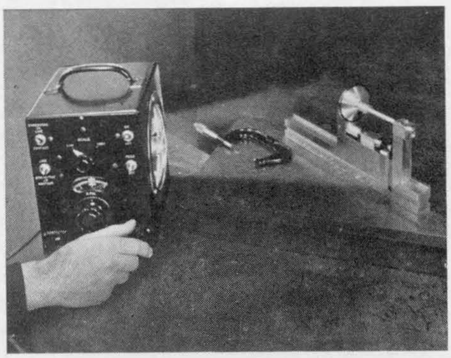
Type		*Code Word*	*Price*
119-A		IMAGE	$1.50

MISCELLANY

● **AMONG RECENT VISITORS** to the General Radio Laboratories was Dr. Georg Keinath, Director of the Instrument Laboratories of Siemens and Halske. Dr. Keinath is the author of "Die Technik Electrische Messgeräte," a well-known text on electrical measuring instruments.

● **THE "R.M.A. ENGINEER,"** published by the Engineering Division of the Radio Manufacturers' Association made its first appearance with the Fall Meeting of the IRE at Rochester. This publication, which will carry standardization reports and similar data, as well as technical articles, will be issued three times a year. Volume I, No. 1 is an achievement of which the board of editors may be proud.

● **PERIODICALLY** it becomes necessary to revise the *Experimenter* and catalog mailing list. Shortly after you receive this issue of the *Experimenter*, a post card "subscription" renewal form will reach you. The revised G-R mailing list will be made up from the returns received from these cards. In order to insure your name remaining on the list, the return card should be filled in completely and mailed promptly.



● **AN INGENIOUS** solution to a difficult problem is illustrated in the accompanying photograph.

The wheel shown in the photograph is an experimental part for a new integrator now under development in the Electrical Engineering Research Laboratory at Massachusetts Institute of Technology. The problem is to measure the friction losses. Since the shaft runs in enclosed jewel bearings, it is not accessible for speed measurement. Furthermore, the power level involved is so small as to preclude the possibility of measurement by ordinary means.

The solution devised by Dr. S. H. Caldwell and Mr. J. J. Jaeger of Massachusetts Institute of Technology is simple. A General Radio Strobotac was set at a convenient value of speed, and the disc was driven by a stream of compressed air until its speed was above that of the flashing Strobotac lamp. The disc was then allowed to coast to a standstill. Whenever its speed or a multiple of it coincided with the fundamental or a subharmonic of the Strobotac flash speed, the disc appeared to stand still momentarily. Intervals between these points were timed with a stop watch, and a speed-vs.-time curve for the complete deceleration period was plotted. From this curve and the moment of inertia, the frictional loss was easily calculated.

The GENERAL RADIO

EXPERIMENTER

ELECTRICAL MEASUREMENTS TECHNIQUE AND ITS INDUSTRIAL APPLICATIONS

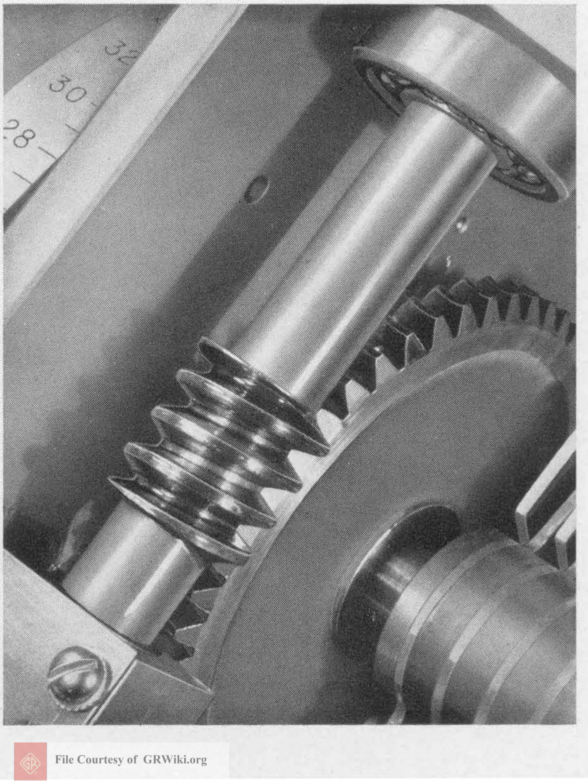
VOL. XI No. 9 FEBRUARY, 1937

BUILDING PRECISION INTO AN AIR CONDENSER

● IN TECHNICAL FIELDS, universal acceptance for a product does not depend on ballyhoo, but can result only from recognized excellence. This quality has made General Radio precision condensers the standard of capacitance for the electrical-communications industry.

The life span of the well-known TYPE 222 Precision Condenser (1919-1936) is traceable directly to the excellence of the original design plus a full utilization of advances in materials and manufacturing methods. A good condenser in 1919 because it was well ahead of current practice, it was still a good condenser in 1936 because it had kept abreast of advances in the art. The end of research and experience, however, is not to carry this process to the point of putting V-8 motors under Model-T hoods, but to point the way through better fundamental design to better products. Hence the TYPE 722*, a better precision condenser than the best 222.

*A New Precision Condenser, *Experimenter*, Vol. X, No. 8, January, 1936.



ALSO IN THIS ISSUE:

FIGURE 1. Panel view of TYPE 722-D Precision Condenser

Design is the medium of the engineer. Materials and men produce the finished instrument. The engineer's story has already been told.* Here we present briefly the manufacturing side.

MATERIALS

Choice of materials is a function of the designer, their fabrication a matter of manufacturing. Any modern product, whether a laboratory instrument or a typewriter, is made up of a surprising variety of raw materials. The TYPE 722 Precision Condenser appears at a glance to be an aluminum condenser in a wood cabinet, and indeed these are the two major constituents. In all, however, a dozen different materials are used, the proportions of the major ones being shown in Figure 2. These materials are made into over eighty *different* parts, ranging from a casting weighing 1¾ pounds to a tiny phosphor bronze spring weighing a small fraction of an ounce.

MEN AND TOOLS

The precision condenser appears to be, and is, a simple instrument, but the manufacturing, although not complicated, embraces a wide variety of operations. Fabrication of the metal alone into parts involves some forty operations performed by thirty-two men. A single workman assembles the parts into the finished instrument. Most of these operations are carried on in our own plant. A few, however, are more conveniently done outside.

Although materials and men produce the finished condenser, tools play an important part. Specially-designed jigs, dies, and forming tools are used, as well as the standard types used on lathes and milling machines. The variable air condenser is an electrical device, but the manufacturing operations which produce it are entirely mechanical. All factors affecting its stability and, in fact, all its characteristics except accuracy of calibration depend solely on mechanical considerations. Because of this, manufacturing tolerances are extremely important.

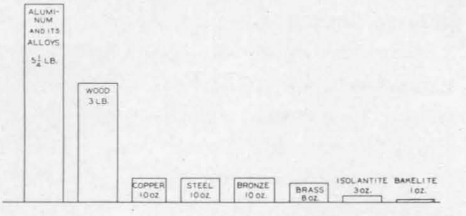


FIGURE 2. Approximate proportions of materials used in a TYPE 722-F Precision Condenser

TOLERANCES

Probably the most important of the desirable characteristics of a precision condenser are linearity, stability, and reset accuracy. Linearity of capacitance with scale setting depends on the shape and alignment of the plates, stability and reset accuracy upon freedom from both backlash and eccentricity in the moving parts. All three are a function of manufacturing tolerances. Backlash, eccentricity, and lack of alignment are matters of degree

*A New Precision Condenser, *Experimenter*, Vol. X, No. 8, January, 1936.

only, and the precision with which parts are machined to a given set of dimensions determines whether or not their magnitude is sufficient to be detected.

The accuracy with which many of the parts are machined is of the order of a few ten-thousandths of an inch. The main rotor shaft, for instance, is held to a radial tolerance of ± 0.0005 inch; its bearing surfaces to 0.0002 inch. The worm shaft, on which the worm is cut directly, has a tolerance of 0.0004 inch. The radial eccentricity of the gear is held to less than 0.002 inch. Accurate alignment of the moving parts is assured by machining and drilling the cast frame in a box jig. Even the dials receive individual attention. The main drum-type dial is engraved on a pantograph engraving machine, while the worm dial, the accuracy of which directly affects the linearity of the condenser, is engraved on a circular dividing engine to insure uniformity of its divisions.

A uniform calibration curve for the condenser requires accurate parallelism of both rotor and stator plates. These plates are stamped from full-hard aluminum and are carefully inspected for flatness and uniformity of thickness. Spacers must be cut to within 0.00025 inch.

ASSEMBLY

Care in assembly is fully as important as precision machining. No amount of precise specifications and workmanship in parts manufacture can compensate for faulty assembly. Production-line methods are not suitable; each condenser is individually assembled and adjusted by skillful, experienced workmen.

A preliminary assembly of the frame, shafts, and gears is driven by a motor for twenty minutes with the gears filled with grinding compound, after which these parts are thoroughly washed in gasoline to remove all traces of abrasive.

The stator unit is assembled in the casting with fixtures designed to preserve the parallelism of stator rods and rotor shaft Each air gap is then measured and individual plates are straight-

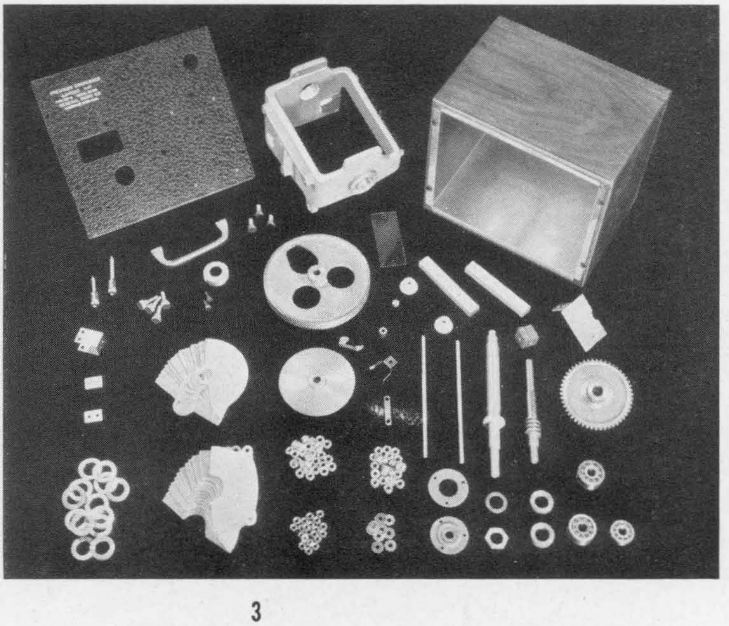


FIGURE 3. Major parts of a TYPE 722-F Precision Condenser

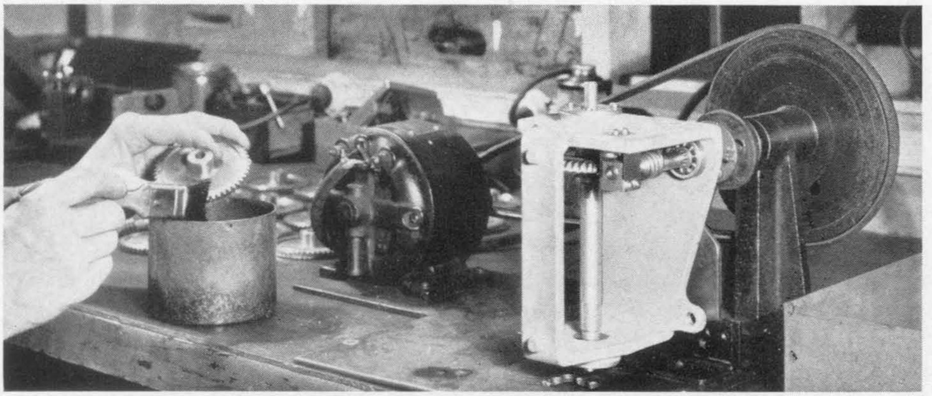


FIGURE 4. At the right is shown the motor-driven assembly for "wearing-in" the worm and gear. After this is finished, the gears must be washed in gasoline, as shown at the left, to remove the fine particles of grinding compound

ened to correct any lack of parallelism which may still exist. Straightening produces strains, and these are removed by a heating process which produces in a few hours the same amount of aging for which years would otherwise be required.

CALIBRATION

Calibration, besides converting a fine mechanical instrument into a usable standard of capacitance, places the seal of approval on all operations thus far performed. A few preliminary measure-

FIGURE 5. Assembling the rotor plates on the shaft. At the right may be seen a stator assembly and a completed condenser

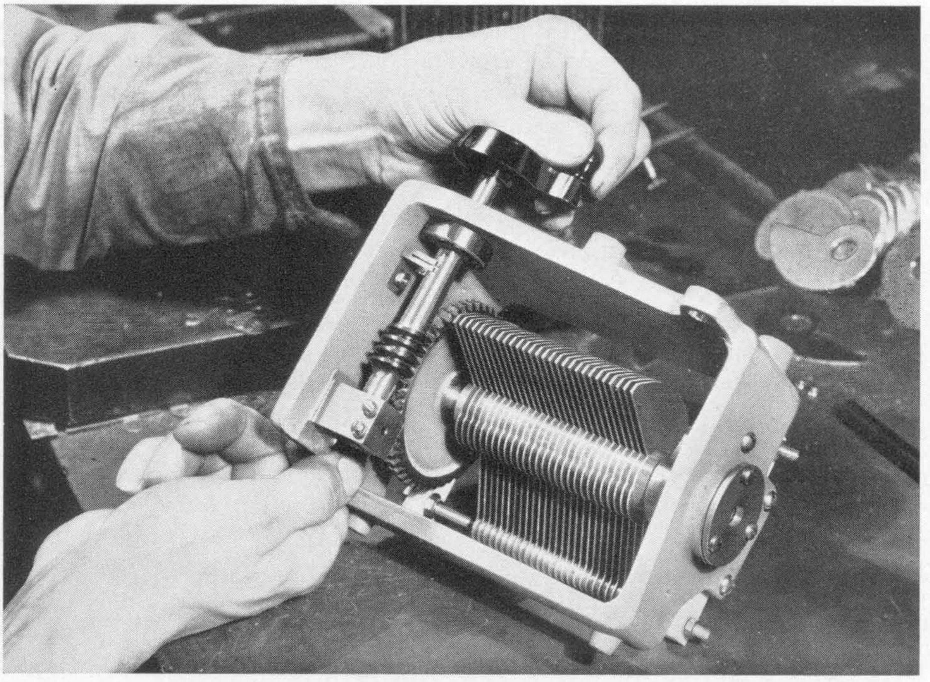


FIGURE 6. Inspecting the assembled condenser for accurate alignment of plates and smooth action of worm drive

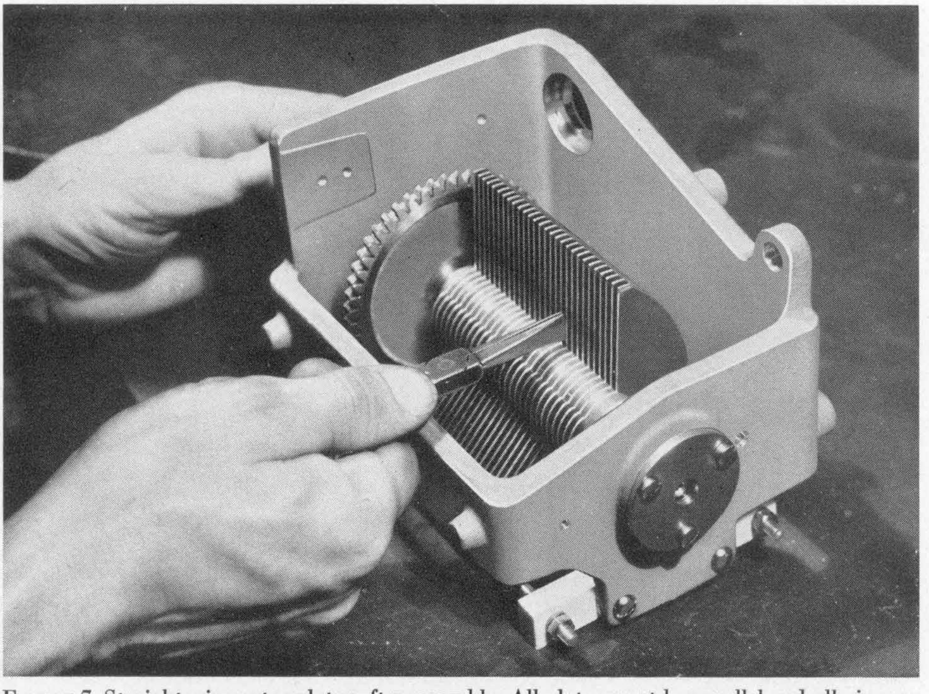


FIGURE 7. Straightening rotor plates after assembly. All plates must be parallel and all air gaps equal

ments serve to show up any lack of plate alignment or faulty manufacture which might exist. A rigid set of specifications must be completely met, or the condenser is rejected.

Calibration for the TYPE 722-F Precision Condenser consists of measurements at each of the main scale divisions. These data are supplied to the customer in the form of a table. TYPES 722-M and 722-D, being direct-reading models, require considerably more attention. Here, compensating plates are adjusted until the scale is direct reading to an accuracy considerably better than that indicated by catalog specifications. Since these adjustments require some bending of the adjusting plates, further heat treatment is necessary.

Each condenser receives at least one additional aging cycle, more if necessary. The criterion of complete aging is that the measured capacitance before and after aging shall be the same within 0.1 $\mu\mu$f.

As in the manufacturing process itself, men plus methods are necessary to produce the desired result. Calibrations are made by trained technicians, many of them engineering graduates. Methods are the result of many years' experience and a careful program of standardization. — C. E. W.

FIGURE 8. Calibrating a TYPE 722-F Precision Condenser

PRICE CHANGE—TYPE 732-A DISTORTION AND NOISE METER

● **EFFECTIVE** March 15, the price of Type 732-A Distortion and Noise Meter is $220.00. This makes the price of the complete Class 730-A Transmission Monitoring Assembly $477.00.

A DIATONIC SCALE DISC

● **THE STROBOSCOPIC DISC** shown in the illustration makes it possible to standardize the major tones of the diatonic scale in terms of A440, the pitch which is now accepted as standard. The disc is intended to be rotated at eleven revolutions per second, under which conditions ring A will be stationary when illuminated by a lamp flashing 440 times per second, and the other rings when illuminated at their respective frequencies.

Standardization in terms of any other pitch assigned to A can obviously be accomplished by changing the driving speed by the ratio of the new pitch to 440.

These discs may be found useful for purposes of instruction and demonstration, and we shall be glad to send copies to those interested.

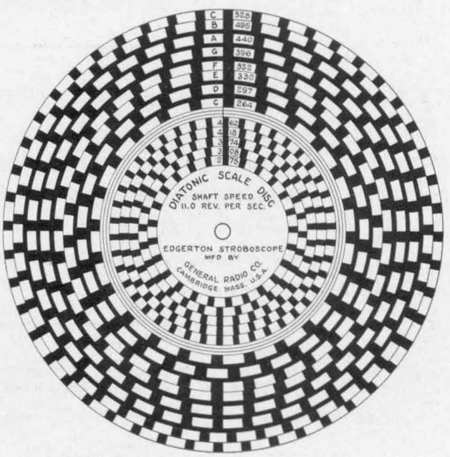
The standard speed can be obtained in a number of ways. For precise standardization, a Type 611 Syncro-Clock driven from a 440-cycle standard-frequency source* could be used. A frequency controlled power line and synchronous motor form another possible system. If an 1800 rpm motor is available, it can be fitted with a 30:11 gear train to obtain 11 rps. When using a standard pitch, whether 440 cycles or some other value, the disc can be driven from a variable-speed motor and the speed adjusted until the A ring is stationary.

The disc can be illuminated by means of a neon lamp connected to the output of a vacuum-tube amplifier. A d-c bias on the lamp is usually required to prevent flashing at double frequency. When the pitch to be measured is produced by a musical instrument, a microphone is necessary as well.

In using this disc, it should be remembered that it represents the intervals of the diatonic scale only, and not those of the tempered scale used on a piano. The tones of the latter scale are not integrally related, and cannot, therefore, be standardized on a single speed disc.

---

* H. W. Lamson, "A Simple and Precise Standard of Musical Pitch," *Journal of the Acoustical Society of America*, Vol. VII, No. 1, July, 1935.



MISCELLANY

● **MR. J. V. ARGYLE,** Technical Representative of the Canadian Marconi Company of Montreal, was a recent visitor at Cambridge. In addition to going over numerous general policy problems, Mr. Argyle discussed various technical points pertaining to our equipment that he thought would be of interest to Canadian customers. The Canadian Marconi Company is the General Radio representative for all Canada and the distribution of our products is one of the special activities of Mr. Argyle's department.

● **OTHER VISITORS** to our plant and laboratories include:

Mr. V. G. Dubenetsky and Mr. Levitin of the Central Industrial Radio Laboratory, Glavesprom, Gorki, U.S.S.R.; Mr. Jyo Yamaguchi, Engineer of the Tokyo Electric Company, Tokyo, Japan; and Mr. W. E. Moser and Mr. Edwards of the Southampton Station of Mackay Radio and Telegraph Company.

● **MR. A. E. THIESSEN** of our engineering staff leaves February 22 for a few weeks on the Pacific Coast. En route he will speak before the Physics Club of Chicago, February 23, on Stroboscopes and their applications. He also plans to present papers before the Los Angeles and San Francisco sections of the Institute of Radio Engineers. While in California, Mr. Thiessen can be reached at our 1050 Howard Street, San Francisco, or 555 So. Flower Street, Los Angeles, offices.

● **DR. W. N. TUTTLE** of our engineering staff, and Chairman of our Development Committee, sailed with Mrs. Tuttle from New York on the *S. S. Europa* on January 22 for a skiing vacation in the Austrian Alps. While on the continent, Dr. Tuttle expects to visit our French representative, Radiophon of Paris, and our Italian representative, Ing. S. Belotti & C. of Milan. Dr. Tuttle is expected to return about the middle of March.

● **A REMINDER**—Post cards to correct the *Experimenter* mailing list were mailed to *Experimenter* readers during the latter part of January. If you haven't filled in your card and mailed it, please do so immediately as the revised list is now being made up from the cards returned.

THE General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in communication-frequency measurement and control problems. When sending requests for subscriptions and address-change notices, please supply the following information: name, company name, company address, type of business company is engaged in, and title or position of individual.

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The GENERAL RADIO
EXPERIMENTER

ELECTRICAL MEASUREMENTS
TECHNIQUE AND ITS INDUSTRIAL APPLICATIONS

VOL. XI No. 10 MARCH, 1937

TUNING THE TYPE 814-A AMPLIFIER

● **WHEN** working with single-frequency voltages, particularly in bridge measurements, the elimination of harmonics and hum by means of filters is a distinct advantage. Tuning units for this purpose were mentioned in the recently-published description of the Type 814-A Amplifier* and are now available for sale. Two models are offered, one operating at 60 cycles and the other at either 400 or 1000 cycles. Nearly all low-frequency bridge measurements are made at one of these frequencies.

These filters are actually parallel resonant circuits which connect directly into the grid circuit of the last tube in

Experimenter, July-August, 1936.

Figure 1. Showing how the tuned circuit is plugged into a jack on the amplifier panel

ALSO IN THIS ISSUE: Three-Phase Voltage Control with the VARIAC . . page 4

the amplifier. This arrangement has several advantages for a general-purpose amplifier. For instance, the frequency response of the amplifier is then independent of the impedance from which it is working or into which it works, which would not be the case if ordinary filters were connected at either the input or the output. This means that the amplifier may be used interchangeably with head telephones, a-c galvanometers, or cathode-ray oscillographs without changing its selectivity characteristics. Furthermore, the filters are operating at a voltage level sufficiently high to eliminate ordinary inductive interference while, at the same time, there is little danger of strong signals in the attenuation band overloading the amplifier and thus affecting its response on wanted signals as sometimes happens when filters are used on the output. Although the filters introduce a small insertion loss, they do not, in any way, affect the maximum output voltage of the amplifier which would be undesirable in those cases where a cathode-ray oscillograph was to be used.

Figure 1 shows the characteristics of the two filter units. It will be noted that the attenuation to the second harmonic is approximately 20 db, and that higher harmonics are reduced still further. The attenuation to lower frequencies is also quite high, which is extremely desirable for the 400- and 1000-cycle filters, since this reduces the possibility of 60-cycle pickup.

Not only do the characteristics of these filters provide satisfactory discrimination against harmonics and hum, but they actually lower the total noise level of the amplifier by restricting the pass band to a small region. The TYPE 814-A Amplifier, in common with all other high-gain amplifiers, has some residual noise, caused mainly by the first tube and its associated circuits. Noises of this type cover practically the whole frequency spectrum and, accordingly, when the response of the amplifier is restricted to a narrow range, the total noise is reduced tremendously.

FIGURE 2. The TYPE 814-P3 tuned circuit. TYPE 814-P2 is similar in appearance, but is provided with a toggle switch so that either of two resonant frequencies can be used, 400 or 1000 cycles

In fact, when using either of the filters, the noise in the Type 814-A Amplifier is rendered practically inaudible. When making bridge balances this is frequently as useful as the elimination of harmonics, since it is the residual noise which often masks the threshold and makes sharp balances impossible.

These filters with the Type 814-A Amplifier provide a means for obtaining high amplification at a single-bridge frequency and with practically no background noise or interference, thus making possible an extremely sharp balance. The slight reduction in over-all gain at the bridge frequency caused by the initial insertion loss of the filter is generally quite negligible, because the gain of the amplifier is more than sufficient for most purposes. The restriction of the frequency response to a narrow band, however, improves the ease of balancing the bridge to an enormous degree.

Each of the filters is mounted in a small black crackle-finish case similar to that used on audio-frequency transformers and provided with a shielded cord and a plug which may be inserted directly in the jack on the panel of the amplifier. The Type 814-P2 is provided with a switch for shifting the response from 400 to 1000 cycles. The low price of these units and the fact that the Type 814-P2 is useful at two frequencies make their purchase desirable for all owners of the Type 814-A Amplifier. — H. H. Scott

SPECIFICATIONS

Dimensions: Area of base, 3⅝ x 4 inches; height, 4⅛ inches.

Net Weight: 4 pounds.

Type	*Frequency*	*Code Word*	*Price*
814-P2	400 and 1000 cycles	AMBLE	$17.50
814-P3	60 cycles	AMPLE	12.00

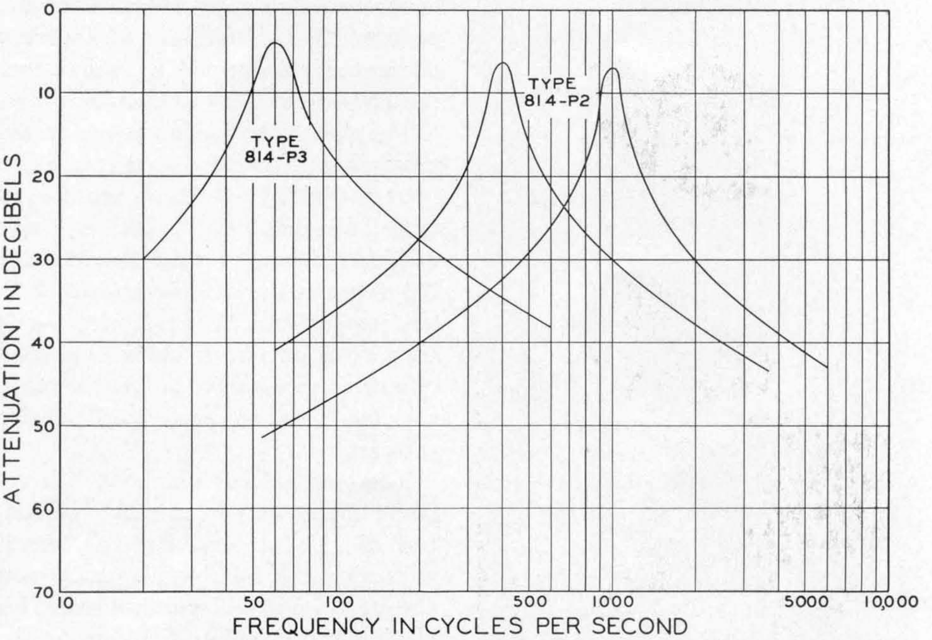


Figure 3. Frequency characteristics of both tuned circuits. Note that the Type 814-P2 is effective in removing 60-cycle hum as well as harmonics of the resonant frequency

THREE-PHASE VOLTAGE CONTROL WITH THE VARIAC

● **ALTHOUGH THE VARIAC** was designed primarily for use in single-phase circuits, it may be used equally well on three-phase systems if the *VARIACS* are ganged together for operation by a single control.

These ganged assemblies are useful in regulating the input voltage to three-phase rectifiers for the control of heating units for the starting and control of three-phase motors and for a number of other applications in which voltage adjustments on three-phase circuits are required.

One important application of the *VARIAC* control of rectifying units is in the radio broadcasting station, particularly on composite transmitters. Excessively high voltages applied to the filaments and plates of vacuum tubes materially shorten tube life. Subnormal voltages, on the other hand, markedly decrease the operating efficiency. Resistive voltage controls are not only wasteful of power but result in poor regulation, which in turn makes it impossible to realize the full capabilities of the balance of the transmitting equipment. The *VARIAC*, being primarily a non-dissipative device, permits the control of a considerable amount of power in a much smaller space than that required by resistive controls of the same power handling capacity.

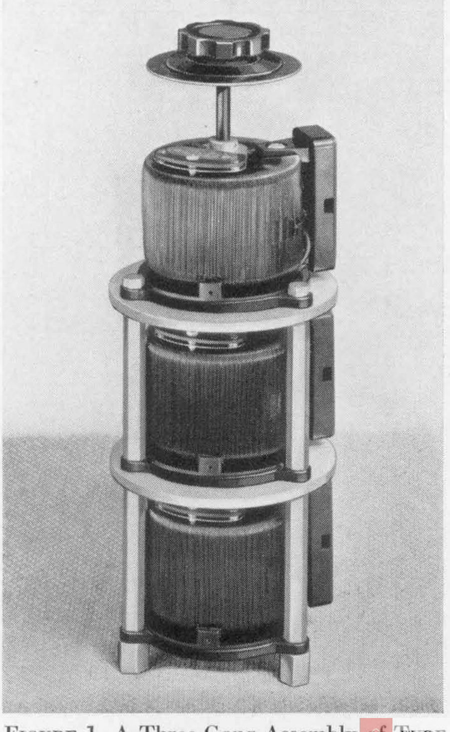


Figure 1. A Three-Gang Assembly of Type 200-CU *VARIACS*

Two- and three-gang *VARIAC* assemblies can be used on three-phase circuits in exactly the same manner as single *VARIAC* units are applied to single-phase circuits. The two most useful assemblies of *VARIAC* units are the two-gang assembly used in a delta circuit and the three-gang assembly connected in a wye. Standard Type 100 or Type 200 *VARIAC* assemblies when connected in a wye may be used to control 230-volt or 440-volt circuits.

The phase voltage of a wye-connected three-phase circuit is equal to the line voltage divided by the square root of three. Because of this the 115-volt *VARIACS* can be used to control a 230-volt three-phase line and the 230-volt models can be used on 440-volt lines. The output from such a wye-connected assembly is continuously variable between zero and full-line voltage.

The open-delta-connected three-phase circuit may be used for the control of 115-volt and 230-volt three-phase lines and for obtaining a 230-volt output from a 115-volt source. This particular connection with some of the *VARIACS* makes it possible either to raise or to lower the output voltage from the input line value, and hence makes it possible to compensate for line voltages fluctuating either above or below the desired value. The open-delta circuits listed in Figure 3 are, for most applications, the most economical means of supplying a given amount of power but make balancing to ground somewhat difficult. If a balance-to-ground is required, the wye connection is recommended.

Another combination, the closed delta, makes it possible to obtain output power and voltage characteristics which may be useful in certain special applications. It is interesting to note that, with the TYPE 200-CUH and TYPE 100-L *VARIACS* connected according to Diagrams 2 and 5, respectively, of Figure 3, an output line voltage can be obtained which is greater than the phase voltage of any *VARIAC*.

The maximum amount of power handled by the ganged *VARIAC* assemblies is in all cases equal to the square root of three, times the product of the input line voltage and the maximum output current.

Two- and three-gang assemblies of both TYPE 100 and TYPE 200 *VARIACS* can be supplied. Figures 1 and 2 illustrate the manner in which these units are assembled. When so assembled, these *VARIACS* are intended for vertical mounting only. If horizontal mounting or back-of-panel mounting is desired, it is necessary that the assembly be reinforced longitudinally so that no bending whatsoever of the shaft will occur. Any bending will, of course, result in binding of the shaft and will make the rotation of the control dial difficult. The ganged units are assembled to order and are priced as follows.

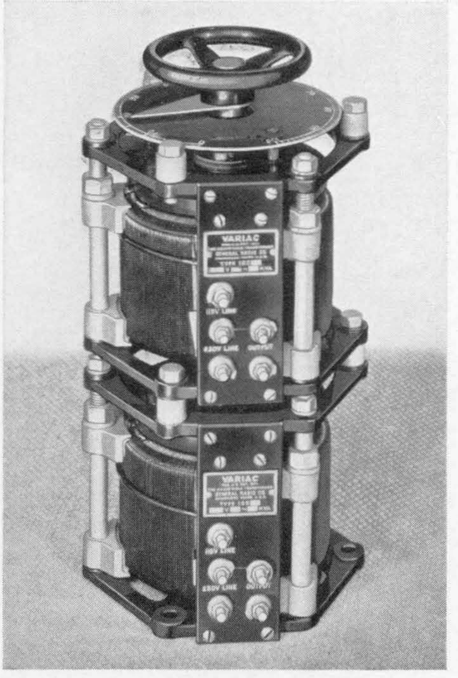


FIGURE 2. A Two-Gang Assembly of TYPE 100 *VARIACS*

The table on pages 6 and 7 lists briefly the characteristic and ratings of various combinations.

— L. E. PACKARD

Variac Type		*Price*
200-CU	Three-Gang Assembly	$ 65.00
200-CU	Two-Gang Assembly	45.00
200-CUH	Three-Gang Assembly	$77.00
200-CUH	Two-Gang Assembly	53.00
100-K or 100-L	Three-Gang Assembly	$160.00
100-K or 100-L	Two-Gang Assembly	105.00

VARIACS are manufactured and sold under U. S. Patent 2,009,013.

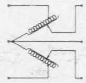
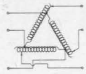
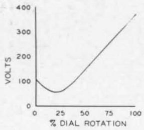
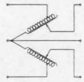
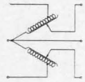
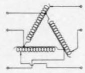
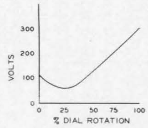
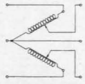
OUTPUT				INPUT					
VOLT-AMPERES		*LINE CURRENT*							
At Maximum Voltage	*At Input Voltage*	*Rated*	*Maximum*	*Line Voltage*	*3-Phase Line Voltage*	*Type of Variac*	*Number Required*	CIRCUIT	OUTPUT CHARACTERISTICS
115-VOLT CIRCUITS									
235	500	0.5	2.5	0–270	115	200–CUH	2		LINEAR
320	500	0.5	2.5	58–372	115	200–CUH	3		
1170	1500	5	7.5	0–135	115	200–CU	2		LINEAR
1600	1800	4	9	0–230	115	100–L	2		LINEAR
2000	1800	4	9	58–304	115	100–L	3		
3500	3500	15	17.5	0–115	115	100–K	2		LINEAR

FIGURE 3

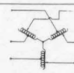
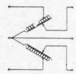
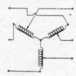
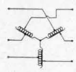
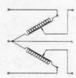
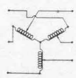
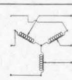
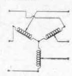
230-VOLT CIRCUITS									
430	1000	0.5	2.5	0–500	220	200–CUH	3		LINEAR
700	1000	1.5	2.5	0–270	230	200–CUH	2		LINEAR
3000	3000	5	7.5	0–230	230	200–CU	3		LINEAR
3000	3600	4	9	0–440	230	100–L	3		LINEAR
3600	3600	8	9	0–230	230	100–L	2		LINEAR
6000	6000	13	15	0–230	230	100–K	3		LINEAR
440-VOLT CIRCUITS									
1900	1900	1.5	2.5	0–440	440	200–CUH	3		LINEAR
6000	6000	7	8	0–440	440	100–L	3		LINEAR

FIGURE 3

TYPE 682-B FREQUENCY DEVIATION METER

● **Type 682-B** Frequency Deviation Meter replaces the older Type 682-A. It is similar to the old model in principle and in operation, but an input amplifier has been added. The price is $160.00, the code word, MISTY.

MISCELLANY

● **AMONG** recent visitors to General Radio: Messrs. Rosenstrom, Noren, Holstensson, Sr., and Holstensson, Jr., from Radiofabriken Luxor, Sweden; also Mr. J. F. Morrison of Bell Telephone Laboratories and Mr. J. L. Middlebrooks of Columbia Broadcasting System, both in Boston for a few days in connection with the installation of the new transmitting equipment for WEEI.

● **IRE** papers delivered: by Mr. Robert F. Field, "The Schering Bridge," at the first meeting of the new Montreal section, January 20; also by Mr. Field, "Direct-Reading Instruments," before the Buffalo Section, January 27.

● **BULLETIN 20,** entitled "The Technique of Noise Measurement" is now ready for distribution. Copies will be mailed to all purchasers of Type 759-A Sound Level Meters and to any others who are interested.

Please address requests to the Engineering Department.

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The GENERAL RADIO

EXPERIMENTER

ELECTRICAL MEASUREMENTS TECHNIQUE AND ITS INDUSTRIAL APPLICATIONS

VOL. XI No. 11 APRIL, 1937

DISTORTION MEASUREMENTS IN THE BROADCASTING STATION

● **QUALITY OF TRANSMISSION** is rapidly becoming an important factor in successful broadcasting. While program excellence and strength of signal go a long way toward determining to what station John Doe sets the dial of his 1937 receiver, he is definitely influenced by a third factor, *quality*.

Excessive audio-frequency distortion is annoying to the radio listener, and the difference between good-quality and poor-quality stations is easily distinguishable on modern receivers. Tests have indicated that a 10% total distortion is about the maximum which can be tolerated if the signal is to sound reasonably pleasant to the listener. Fortunately, it is not difficult to keep distortion well below this level in transmitting and receiving equipment.

In order to insure acceptable quality of transmission, the Federal Communications Commission has required that no broadcast transmitter shall have more than 10% combined audio-harmonic distortion when operating at a level of 85% modulation. This has been covered in paragraph (a) of the F.C.C., Rule 139, dated October 29, 1935.

During recent years, transmitter manufacturers have placed a good deal of emphasis on freedom from distortion and, as a result, transmitters are now available with distortion levels as low as 3%. Complete performance characteristics of all transmitters intended for general sale are submitted to the Commission as proof that the requirements are being met.

Holding distortion at a low figure has consequently become a problem of maintenance rather than of transmitter design. In the carefully balanced electrical circuits that make up the modern transmitter, changes in the operating biases and the characteristics of vacuum tubes, as well as the slow aging of other circuit elements, may result in excessive distortion. Proper care and maintenance are necessary to obtain best performance. Periodic tests are the obvious safeguard against excessive distortion and, when made as part of a definite maintenance routine, they add very little to the duties of the operating staff. Simple test methods and direct-reading instruments have reduced the testing time to a few seconds.

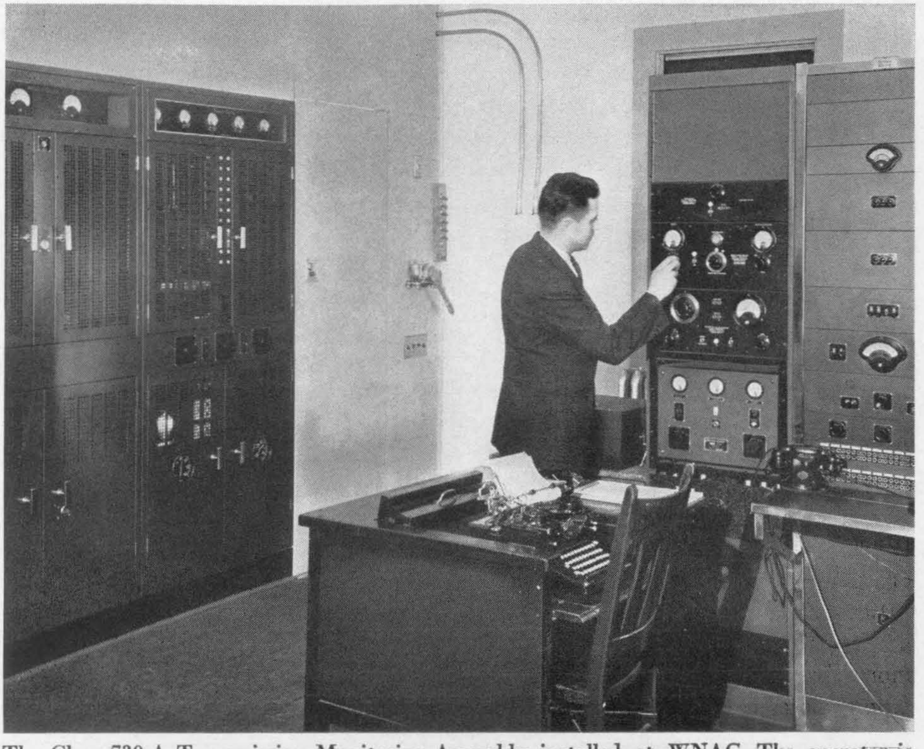
TEST METHOD

A transmitter which distorts at one audio frequency will usually do so at all frequencies, although the magnitude of harmonic components will vary with frequency in accordance with the over-all characteristics of the transmitter. A single-frequency test in the middle of the audio range, therefore, is generally accepted as an indicator of transmitter distortion. A standard test frequency of 400 cycles has been arbitrarily selected because it is commonly used in transmitter and receiver testing. Measurements made at this frequency are proof acceptable to the F.C.C. that the transmitter is operating properly as long as the combined audio-frequency distortion is less than 10% at 85% modulation.

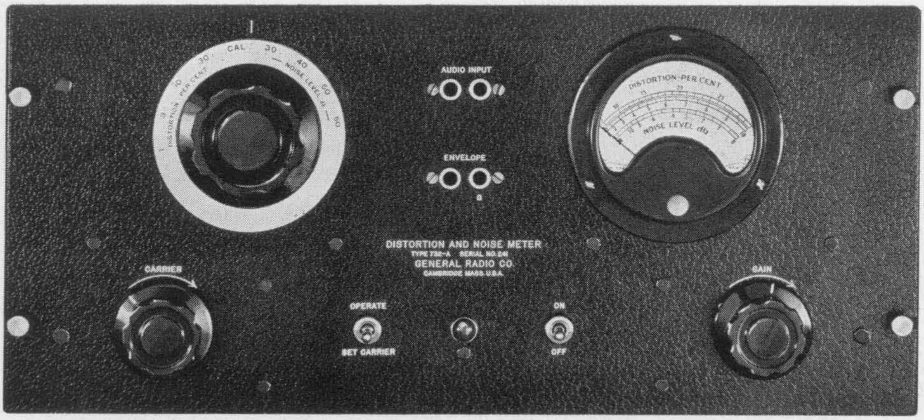
The method of test is to apply a pure sine wave at the input of the pre-amplifier or speech amplifier and to measure the total harmonic distortion placed on this sine wave by the complete transmitting system up to the antenna.

TEST INSTRUMENT

The Type 732-A Distortion and Noise Meter has been designed to measure the combined harmonic distortion at 400 cycles. In practice it is loosely coupled to the output stages of the transmitter, preferably to the antenna loading coil or one of its as-



The Class 730-A Transmission Monitoring Assembly installed at WNAC. The operator is shown using the Type 731-A Modulation Monitor. The Type 732-A Distortion and Noise Meter is just below



Panel view of the Distortion and Noise Meter. Note the open, easily-read scales. Full-scale ranges of 1%, 3%, 10%, and 30% are provided

sociated circuits. The radio-frequency energy picked up from this circuit is passed to the distortion meter which reads directly in percentage the total r-m-s distortion which is present on the audio-frequency envelope of modulated carrier.*

Measurements are made with the distortion meter simply and quickly. All that is necessary is to make an adjustment to a reference level with the tone on, and then to turn one dial to read the distortion directly on a large meter. The whole operation does not take more than ten seconds, even with inexperienced personnel.

A wide range of distortion can be measured with this instrument, the maximum distortion that can be read being 30%. The sensitivity is sufficiently sensitive to permit measurements at low distortion levels. A distortion of 1% will give a full-scale deflection on one of the measuring ranges, and distortions as low as 0.2% are easily readable.

TONE SOURCE

To generate the test tone of 400 cycles, the Type 733-A Oscillator has been designed. This is a vacuum-tube oscillator generating a nearly pure 400-cycle tone with a level sufficient for all measuring purposes. The actual distortion of this oscillator is 0.2% or less, and this amount can be neglected in most measurements. Three output impedances, 50, 500, and 5000 ohms, are provided so that almost any studio circuit can be approximately matched.

ROUTINE

In many broadcasting stations where the Type 732-A Distortion and Noise Meter is already installed, it is customary to make a routine distortion measurement at the beginning of the day's operation and at the end, and to record these readings in the station log along with the other details of the daily operations.

NOISE MEASUREMENT

Another feature of the meter which is very useful in broadcast-station maintenance is the fact that it permits the measurement of the residual noise and hum level of the system. This measurement is made by comparing the residual noise in the transmitter to a reference tone level. For example,

*The principle of operation is described by L. B. Arguimbau in the General Radio *Experimenter* for February, 1935.

after the distortion measurement has been made with a modulation percentage of, say, 85%, the test tone is turned off, and the noise meter is switched by the single control dial to another position where the meter will register the residual noise in terms of decibels below the test-tone level. In this way excessive hum or a noisy transmitter tube can be discovered immediately.

Sources of noise, whether in lines or amplifiers, can be located quickly by patching out the various amplifiers and equipment in the system until the noise disappears. The fact that the noise level is measured in decibels is most useful in evaluating the amount of noise introduced by any element in the system. This method of test is very quick and serves in emergencies to isolate any noise promptly so that it can be cleared with a minimum of interruption to the program.

No standard of background noise level has been established as yet, but in good transmitters the noise level is sometimes kept as low as 60 decibels below 85% modulation. It is not difficult to keep the noise level at least 40 decibels below the distortion test-signal level, a figure which is good enough for most practical purposes.

DISTORTION IN THE AUDIO SYSTEM

In addition to its use in measuring the over-all quality of the transmitter, the TYPE 732-A Distortion and Noise Meter has an equally important application in measurements on the audio-frequency system alone. Two audio-frequency input circuits are provided for this purpose. One of these circuits has an input impedance of 500 ohms balanced to ground, and the other an impedance of 50,000 ohms unbalanced. Both circuits are available by means of jacks in the front panel. To make distortion measurements at the 500-ohm impedance, it is necessary to have a signal with a level of about plus 1 decibel, or about 2 volts as a reference level. The exact adjustment of this input voltage level is provided for by the panel meter. Approximately 20 volts are required across a 50,000-ohm circuit. The 500-ohm input circuit is carefully balanced to ground so that the measurement can be made on balanced as well as unbalanced circuits without disturbing the circuit under measurement.

Residual noise measurements in audio-frequency circuits can also be made by the same means.

SIMPLICITY

The TYPE 732-A Distortion and Noise Meter is relay-rack mounted and alternating-current operated. It replaces earlier distortion-measuring equipment consisting of TYPE 536-A Distortion Meter, TYPE 514-AM Amplifier, and TYPE 488 Copper-Oxide Rectifier Meter. All of the essential components are self-contained in the new instrument, and no external apparatus is required except the TYPE 733-A Oscillator. This is an obvious advantage for any laboratory application and is, of course, absolutely essential in broadcast-station practice.

— ARTHUR E. THIESSEN

TYPE 732-A Distortion and Noise Meter and TYPE 733-A Oscillator are fully described on pages 111 and 112 of Catalog J.

This instrument is licensed under patents of the American Telephone and Telegraph Company solely for utilization in research, investigation, measurement, testing, instruction and development work in pure and applied science.

A 1000-CYCLE BAND-PASS FILTER

● **TYPE 830-R WAVE FILTER** is a highly selective band-pass filter, passing only a narrow band of frequencies in the vicinity of 1000 cycles per second. In order to provide maximum flexibility in application, several input and output impedances are provided. One side of the filter has two impedances, 500 and 5000 ohms; the other side has four, 50, 500, 5000, and 50,000 ohms respectively.

This arrangement makes it possible to work from either a 500-ohm line or a vacuum tube into a circuit of almost any impedance with very little impedance mismatch.

The attenuation characteristics are the same for either connection on the two-impedance side, but differ somewhat for different connections on the four-impedance side. From the plot of Figure 2, it will be seen that greatest attenuation to harmonics is obtained on the 5000-ohm output tap (this is the curve shown in Catalog J). An attenuation peak at the second harmonic occurs when the 500- and 5000-ohm taps on the four-impedance side are used. This peak is not present with the other two taps.

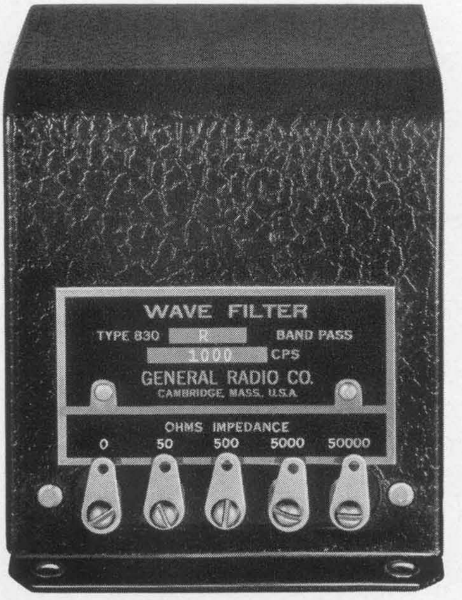


FIGURE 1. Photograph of TYPE 830-R Wave Filter, showing the arrangement of terminals

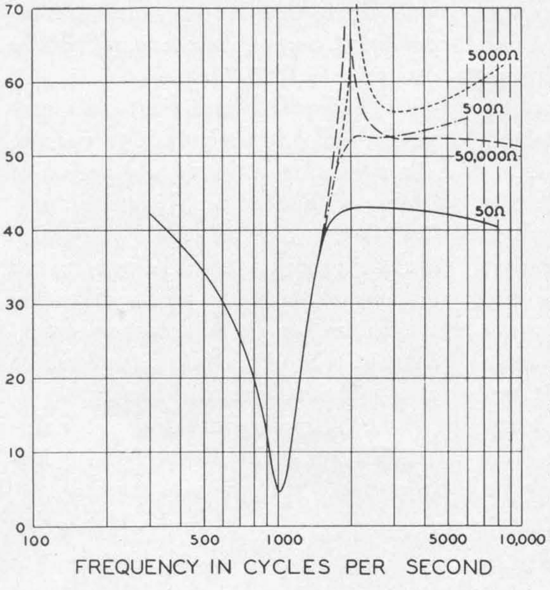


FIGURE 2. Transmission characteristics of the filter

Since either side may be used as input or output, two different connections are possible when working between 500 and 5000 ohms. From the curves of Figure 2, it is evident that somewhat better characteristics will be obtained if the 500-ohm connection is made at the two-impedance side.

The attenuation for the desired frequency is about 5 decibels, so the discrimination against harmonics is 5 db less than the actual height of the curves.

— W. N. TUTTLE

VISUAL-TYPE FREQUENCY MONITORS

A-C OPERATION FOR BATTERY MODELS

● **WE ARE STILL PREPARED** to rebuild the early battery-operated broadcast frequency monitors, converting them to a-c operated instruments. These monitors have been in service from three to five years and a complete overhauling is desirable. Many stations have had their monitors rebuilt during the past two years, and the station engineers feel that the expense involved is justified by the results obtained.

The modification of the piezo-electric oscillator into a Type 575-E includes installing a new panel and modification of the terminal strip, replacing the temperature control relay with an a-c unit, installing fusible protective links in the temperature-control circuit, replacement of the heat indicator lamp by one of the "bull's-eye" type, and such other minor changes as may be necessary.

The quartz plate will be readjusted to exact frequency, and bakelite bases will be replaced by isolantite.

The deviation meter, after modification, will be called Type 581-B and will supply the power for the Type 575-E Oscillator. The instrument will be given a complete overhauling and put in first-class electrical and operating condition.

The total charge for the modification is $155.00. The rebuilt instruments will carry the same guarantee as new equipment. The quoted price will include minor repairs not strictly a part of the reconditioning operation, but necessary major repairs will be subject to additional charge at a fair rate. The time required to do the work will be between ten days and two weeks.

When, in addition to this work, a new Type 376-L, low-temperature-coefficient, quartz plate is installed, the total price is $215.00.

The Federal Communications Commission will grant a permit to operate a broadcasting station for a period of 30 days without a visual monitor, provided it is stated that the frequency monitoring equipment is being returned to the manufacturer for modification and calibration. It is, therefore, essential that the permit be granted before the equipment is returned to us.

Before returning instruments for this modification, write to the Service Department for shipping instructions.

— H. H. Dawes

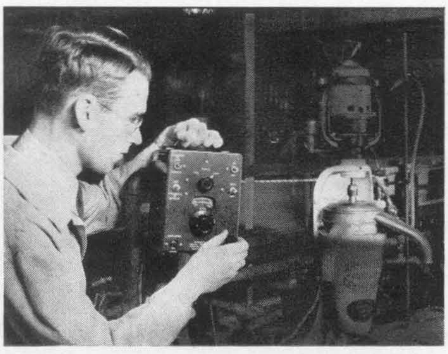
HIGH-SPEED MEASUREMENT WITH THE STROBOTAC

● **WE HAVE OFTEN BEEN ASKED** how to measure speeds outside the fundamental range of from 600 rpm to 14,400 rpm covered by the Strobotac.

Speeds of less than 600 rpm may be measured by the simple expedient of marking a single radius upon the end of the shaft to be viewed. The true speed is then the Strobotac setting to give a motionless multiple pattern divided by the number of radii seen in the pattern. Thus a cross seen on the end of a shaft at a Strobotac setting of 1000 rpm indicates a true shaft speed of 1000 divided by four, or 250 rpm. In this manner the range of the Strobotac may be extended to 600 divided by 6, or 100 rpm.

For speeds greater than 14,400 rpm, the formula is rpm $= \frac{ab}{a\text{-}b}$ where a and b are adjacent settings of the Strobotac for which a motionless image is obtained. Thus for stationary images at 8000 rpm and 12,000 rpm

$$\frac{ab}{a\text{-}b} = \frac{8000 \times 12{,}000}{4000} = 24{,}000 \text{ rpm.}$$



The Type 631-A Strobotac as used to measure the speed of a centrifuge

For higher speeds, the value of a-b becomes progressively smaller, giving increasing errors in speed determination for small errors in observation.

Take a and b at several patterns apart and multiply the answer by the number of patterns reached in going from a to b, in order to restore the accuracy of the measurement.

Thus, suppose a still image at a setting of 12,000 rpm and another, the tenth image away, at 7200 rpm. The true speed is then $10 \times \frac{12{,}000 \times 7200}{4800}$, or 180,000 rpm, as found in some types of ultra centrifuges. The Strobotac is the easiest and quickest way to measure these speeds.

Since the ratio of shaft speed to Strobotac flash rate must be a whole number, a slightly better result may still be obtained by correcting this ratio to the nearest whole number and multiplying the Strobotac dial reading by that whole number. — F. Ireland

MISCELLANY

● **GENERAL RADIO** employees have recently organized a camera and telescope club. The first meeting was enthusiastically attended by some forty people, including many, we suspect, who hadn't pushed a camera shutter for years, but were carried along by the current urge for hobby cultivation. The attendance was divided almost equally among the three divisions of still pictures, movies, and telescopes. Courses of instruction in fundamental photographic processes are planned, as well as the construction of a complete telescope.

● **THIS** is only one phase of an extensive program of out-of-hours activities promoted by General Radio's genial Dean of Education, Horatio W. Lamson. Classroom instruction in elementary electrical and radio theory has been available to our production men for several years. During the past few months a series of informal talks has been inaugurated, covering a wide range of popular and specialized subjects. Some of these, delivered by General Radio employees, serve to acquaint men with activities outside their own departments. Others have been presented by representatives from outside companies. Of these latter, two were outstanding: that by Messrs. Oleson and Lamb of the Weston Electrical Instrument Corporation on "Indicating Instruments," and that by B. W. St. Clair of the Mico Instrument Company on "Materials."

● **H. B. RICHMOND**, General Radio's treasurer, was the speaker at an Electrical Engineering Colloquium held at M. I. T. March 15 and 16. The subject: "The Operation of an Engineering and Manufacturing Organization of Moderate Size."

● **DR. W. N. TUTTLE** of our engineering staff has returned from his skiing vacation in the Alps. He reports the skiing conditions good in spite of continual blizzards. Combining business with pleasure, Dr. Tuttle visited our agents in Italy, Ing. S. Belotti and C., at Milan, as well as the National Electrotechnical Institute, Galileo Ferraris at Turin, where many General Radio instruments are installed.

THE General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in communication-frequency measurement and control problems. When sending requests for subscriptions and address-change notices, please supply the following information: name, company name, company address, type of business company is engaged in, and title or position of individual.

GENERAL RADIO COMPANY

30 STATE STREET - CAMBRIDGE A, MASSACHUSETTS

BRANCH ENGINEERING OFFICE — 90 WEST STREET, NEW YORK CITY

The GENERAL RADIO EXPERIMENTER

ELECTRICAL MEASUREMENTS
TECHNIQUE AND ITS INDUSTRIAL APPLICATIONS

VOL. XI No. 12 MAY, 1937

TYPE 726-A VACUUM-TUBE VOLTMETER

● **BECAUSE VOLTAGE MEASUREMENTS** at communication frequencies usually require a voltmeter with an input impedance so high as to have no appreciable shunting effect on the source under measurement, the vacuum-tube voltmeter is a laboratory necessity to the communication engineer. Commercially available thermionic voltmeters have in general been subject to one or more of the following defects: low sensitivity, limited voltage range, high-frequency error, and limited precision of reading at low values on the scale. The design of a voltmeter in which these defects are minimized has recently been completed, and, since it represents a new approach to the problem of a-c voltage measurements, a number of its design features are worthy of mention.

The voltmeter consists of a familiar combination — a diode-condenser rectifier circuit and a d-c amplifier. A condenser becomes charged by the rectifier

FIGURE 1. TYPE 726-A Vacuum-Tube Voltmeter

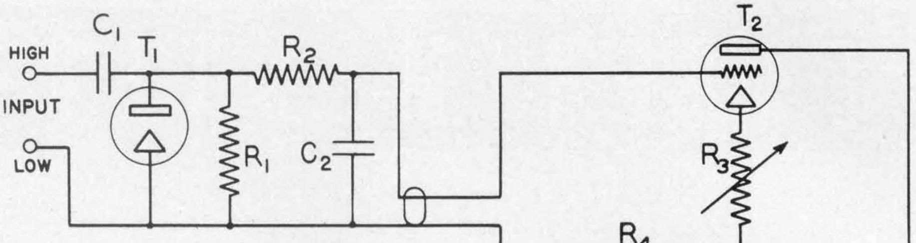
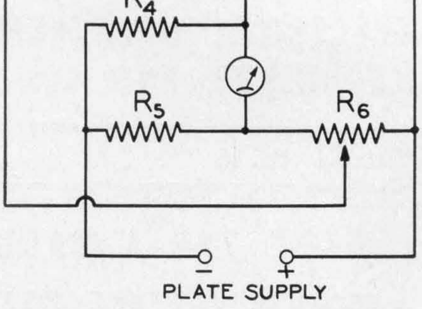


FIGURE 2. Schematic circuit diagram of the vacuum-tube voltmeter



to a voltage very closely equal to the peak value of applied alternating voltage, and the d-c amplifier and a milliammeter provide a means of measuring the voltage appearing across the condenser. There are new features in both the rectifier and amplifier circuits, however, which are very important in achieving high input impedance, permanency of calibration, and a calibration very nearly independent of the constants of the rectifier and amplifier tubes. These advantages are obtained, moreover, in an instrument covering a wide range of voltages.

THE RECTIFIER CIRCUIT

The rectifier circuit[1] is shown on the left-hand side of Figure 2. The resistances R_1 and R_2 are of high value so that they do not affect the operation of the diode T_1 and the condenser C_1 in the input loop of the circuit. If C_1 has sufficient capacitance so that no a-c voltage appears across it, its charge will build up until the voltage is equal to the peak value of the applied a-c voltage, after which time the anode will never be positive with respect to the cathode and no further rectified current can flow. When equilibrium is reached, in other words, the rectifier will approach the conducting condition only at the time of the positive peak of the applied alternating voltage. For the rest of the cycle the plate will be negative with respect to the cathode. The voltage across the diode thus consists of a negatively-biasing direct voltage in series with the applied alternating voltage, and it will be seen that the average plate potential is negative with respect to the cathode.

The purpose of R_1 is to permit the discharge of condensers C_1 and C_2 when the input voltage is reduced. This resistor is placed across the rectifier rather than across C_2, so that no direct current will flow through R_2 except when the input voltage is varied and new equilibrium conditions must be established. No correction need be made, consequently, for voltage drop across this resistor, and the entire d-c voltage is applied to the amplifier tube. This feature contributes considerably to the stability of the instrument and the permanence of its calibration.

The direct component of the voltage across the diode is equal to the peak value of the applied alternating voltage. The resistance R_2 and condenser C_2 remove the alternating component

[1] For a discussion of diode circuits, see "Crest Voltmeters" by C. H. Sharp and E. D. Doyle, Trans. A.I.E.E., 35, pp. 99-107, February, 1916.

so that only the direct component is applied to the d-c amplifier. Elaborate filtering is not necessary due to the extreme linearity of the amplifier resulting from degeneration. Unless the alternating voltage is sufficient to swing the plate current to cut-off, only a negligible amount of rectification can take place. The simple filtering arrangement shown is, therefore, entirely adequate.

THE AMPLIFIER CIRCUIT

The d-c amplifier circuit is shown in the right-hand section of Figure 2. The resistor in the cathode lead is particularly important. This provides degenerative coupling between the input and output circuits and not only accomplishes in the d-c case improvements analogous to those resulting from the use of degeneration in a-c amplification,[2] but also has other important results. Before the manner of operation is explained, the important improvements resulting from the use of degeneration in the present case will be outlined:

(a) The meter indication within very close limits is made proportional to the direct voltage introduced into the grid circuit.

(b) The sensitivity is made practically independent of the constants of the tube.

(c) The grid circuit is rendered capable of handling directly voltages hundreds of times greater than the normal cut-off bias. Hence no voltage-dividing network is required.

(d) The sensitivity can be changed for the various desired voltage ranges merely by changing the value of the cathode resistor and the value of the grid-bias voltage.

Figure 3 is a simplified diagram to illustrate the degenerative effect of the cathode resistor. If a voltage E_1 is introduced into the grid circuit, the plate current will tend to increase, causing a voltage drop E_R across the cathode resistor in opposition to the introduced voltage. The net change in grid voltage is the difference between the two. If the cathode resistor is large in value, only a very slight increase in plate current is required to develop a voltage equal to the introduced voltage. The net grid voltage, therefore, can change only slightly, and E_R must always be very nearly equal to E_1. The larger the value of the cathode resistor, the smaller must be the increment in plate current and the more nearly equal must E_R be to the introduced voltage E_1. Whenever the cathode resistor is large enough to bring about this condition, the change in plate current, indicated on the meter, will be directly proportional to the introduced voltage, and the tube constants will be of very little importance.

The same simple consideration shows that the sensitivity of the arrangement, considered as a d-c voltmeter, can be changed by varying the cathode resistor. If this resistor is increased in value ten times, only one-tenth of the change in plate current will be required

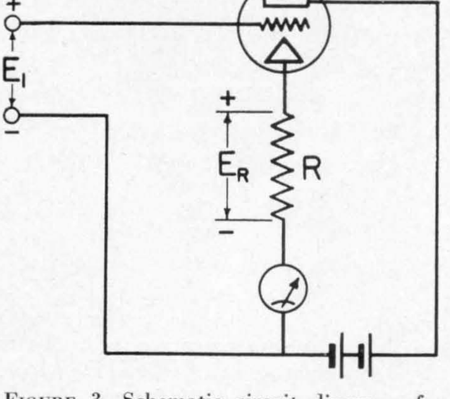


FIGURE 3. Schematic circuit diagram of a degenerative d-c amplifier

[2] See "Stabilized Feedback Amplifiers," H. S. Black, B.S.T.J. 13, pp. 1-18, January, 1934.

to develop a given opposing voltage. If the plate milliammeter has a certain full-scale sensitivity, consequently, ten times the voltage must be introduced into the grid circuit to cause full-scale deflection. For sufficiently high values of the cathode resistor, the full-scale voltage is directly proportional to the cathode resistance and depends only on this quantity and on the sensitivity of the milliammeter.

The polarity of the direct voltage developed by the rectifier circuit and applied to the d-c amplifier is such that the grid of the amplifier T_2 is made negative with respect to the cathode. This is important in preventing damage to the meter due to overload. The plate current decreases when voltage is applied and can be reduced only to zero. The maximum possible change in plate current does not greatly exceed the milliammeter full-scale current, so that serious overload is not possible, no matter what input voltage is applied. The milliammeter, of course, is connected in the circuit backwards, so that a decrease in plate current is indicated as a positive deflection.

The three resistances, R_4, R_5, and R_6 shown in Figure 2, but not in Figure 3, make it possible to balance out the initial plate current and to furnish the desired grid bias. The resistance R_3 and the position of the tap on the resistance R_3 are changed simultaneously when the range of the instrument is changed.

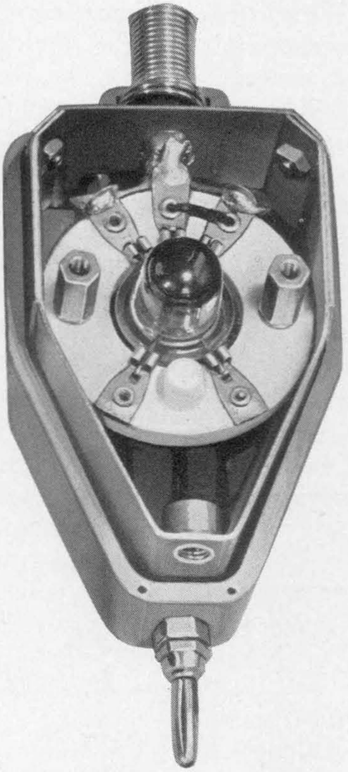


FIGURE 4. This shows the rectifier mounted in the probe with cover removed. The extremely short leads and low shunt capacitance obtained are responsible for the excellent frequency characteristic

POWER ABSORPTION

The power which must be drawn from the voltage source can readily be calculated from the known voltages appearing across the resistors R_1 and R_2. In the filter circuit R_2C_2 just considered, the entire alternating voltage appears across R_2. The same voltage appears across R_1 as appears across the rectifier, namely, the full alternating voltage in series with a direct voltage equal to its peak value. The a-c fraction of the power loss is the same which would result if R_1 and R_2 in parallel were placed directly across the voltage source. In addition, sufficient power must be drawn to supply the d-c loss in R_1 corresponding to the peak value of the a-c voltage. Short pulses of current flow through the rectifier to supply this power, so for this component of the loss the voltage source is loaded relatively heavily during a very small part of the cycle, and not at all during the rest of the cycle.

Due to the shortness and intensity of the pulses through the rectifier any resistance in the input branch reduces seriously the flow of rectified current and lowers correspondingly the meter reading. It is this reduction in meter reading due to the impedance of the voltage source, rather than the total power consumption, which is important in most applications. This effect can be made negligible only by reducing the d-c power absorbed to the lowest possible value. In the Type 721-A Vacuum-Tube Voltmeter the resistor R_1 has the value 50 megohms. About 4 megohms in series with the applied voltage is sufficient, however, to halve the voltmeter reading. From the voltage reduction standpoint the input resistance, therefore, can be said to be 4 megohms. The power absorption, however, is determined mainly by a-c losses in R_2 (10 megohms), and from this standpoint the input resistance is appreciably greater — about 6 megohms. At high frequencies other factors become important, so that the simple analysis here given is no longer applicable. These factors are discussed below.

OPERATION AT HIGH FREQUENCIES

To achieve satisfactory operation at high frequencies, the elements which make up the rectifier circuit are made as small as possible and are mounted in a separate housing at the end of a flexible cord. Probe terminals are provided so that the measuring circuit may be placed close to the voltage source. A 955-type acorn tube is used as the diode rectifier. The probe terminals can be removed to reduce still further the inductance of the input loop.

As a result of these details of con-

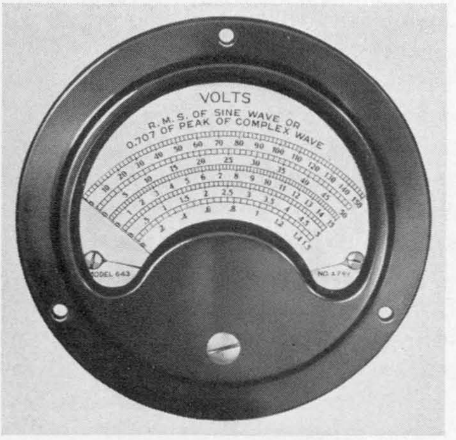


Figure 5. Five ranges of voltage are provided. It will be seen that the scales are nearly linear

struction, the resonant frequency of the input loop is about 380 megacycles, and 500 megacycles with the probe terminals removed. The frequency error in the reading is only 3 per cent at 100 megacycles.

The power consumed from the source at high frequencies is no longer determined by the values of resistances R_1 and R_2 but by the total stray capacitance across the input and the losses in this capacitance. The total capacitance is about 6 $\mu\mu$f and the power factor about 2.5 per cent, the losses occurring principally in the envelope and socket of the tube and in the material surrounding the resistance elements R_1 and R_2. It is interesting that at high frequencies the input impedance is not affected by turning on or off the heater of the diode T_1.

OTHER ADVANTAGES

By including a power-supply voltage regulator, the meter indication has been made as stable as that of a d-c instrument. Fluctuations in line voltage have no effect, nor do long period drifts which would otherwise change the reading through changes in filament temperature.

Although the diode rectifier is mounted in a probe, the probe can be mounted inside the cabinet for low-frequency measurements, if desired, and the voltage source under measurement connected directly to terminals on the panel.

The Low terminal on the panel is not connected directly to panel, but is isolated by a blocking condenser. This is convenient in measuring voltages across plate tank circuits, for instance, where the voltmeter can be grounded without damage.

The meter reads directly the r-m-s value of a sinusoidal voltage. As has been shown above, however, it is the peak value of the waveform which determines the reading. The instrument is very useful for determining the peak values of complex waveforms, these values being obtained by multiplying the reading by 1.414.

— W. N. TUTTLE

SPECIFICATIONS

Range: 0.1 to 150 volts in five ranges (1.5–5–15–50–150 volts).

Accuracy: ± 2% of full scale at all five ranges, on sinusoidal voltages.

Waveform Error: The instrument is essentially a peak voltmeter calibrated to read r-m-s values of a sine wave, or 0.707 of the peak value of a complex wave. On distorted waveforms the percentage deviation of the reading from the r-m-s value may be as large as the percentage of harmonics present.

Frequency Error: Less than 1% between 20 cycles and 50 megacycles. At 100 megacycles, the voltage indicated is about 3% larger than the voltage across the probe terminals when the tips are removed. With the tips in place the error is about 7%.

Input Impedance: About 5 megohms at low audio frequencies. Since the capacitance between input terminals at the probe is 6 μμf, the input impedance will be lower at higher frequencies. The resonant frequency of the input circuit is about 380 megacycles but can be increased to 500 megacycles by removing the plug tips of the probe.

Power Supply: 100 to 130 volts, ac, 60, 50 or 42 cycles and 200 to 260 volts, 50 cycles (see price list). The instrument incorporates a voltage regulator to compensate for supply variations over this voltage range. The power drain is less than 20 watts.

Tubes: One 955-type, one 75-type, and one 1v-type rectifier, supplied with the instrument.

Accessories: A seven-foot attachment cord, a pilot lamp, and the three tubes are supplied with the instrument.

Mounting: Black crackle-finish aluminum panel mounted in a shielded walnut cabinet.

Dimensions: (Width) 9½ x (depth) 14 x (height) 8½ inches, over-all.

Net Weight: 17½ pounds.

Type	*Power Supply* *Frequency*	*Voltage*	*Code Word*	*Price*
726-A	60 cycles	100 to 130	ALLOT	$165.00
726-A	50 cycles	200 to 260	ALTER	165.00
726-A	50 cycles	100 to 130	ABAFT	165.00
726-A	42 cycles	100 to 130	AMASS	165.00

MISCELLANY

● **ON MAY 1,** Martin A. Gilman joined the Engineering Department of the General Radio Company. Mr. Gilman receives his S.M. degree in electrical engineering from M.I.T. in June of this year.

● **ON APRIL 20,** R. F. Field spoke before the Pittsburgh section of the I.R.E. on the subject of "Direct-Reading Instruments." He plans to deliver this paper before the Indianapolis section on May 13.

● **FOR SEVERAL MONTHS,** Arnold Peterson of M.I.T. has been engaged in a research project at General Radio Company studying ultra-high-frequency oscillators. Some of the results of this project were presented by Mr. Peterson at the April 30 meeting of the International Scientific Radio Union at Washington, D. C. The title of the paper was "The Frequency Stability of Ultra-High-Frequency Oscillators." We hope to publish some of this material in a forthcoming issue of the *Experimenter*.

● **A. E. THIESSEN** returned early in April from a several weeks' visit to our Pacific Coast offices in Los Angeles and San Francisco. During this time he addressed several technical society meetings. At the February 23 meeting of the Physics Club of Chicago, Dr. Arthur H. Compton, Chairman, his subject was "Stroboscopes and High-Speed Photography."

"Direct-Reading Instruments" was the title of Mr. Thiessen's paper at the Los Angeles section, I.R.E. The talk was supplemented by a few reels of high-speed motion pictures. Douglas Kennedy is chairman of the Los Angeles section, and the speaker was introduced by W. W. Lindsay, Jr., of the Meetings and Papers Committee.

This same paper was also delivered at the San Francisco section, V. J. Freiermuth, Chairman.

The subject of "Wave Analysis" was discussed before the Electronics Club of Los Angeles, Dr. J. F. Blackburn, Chairman.

A number of invitations to address other I.R.E. sections were received, and it is regretted that the schedule did not permit the acceptance of these.

● **IN ORDER TO TEST** the performance of the Type 726-A Vacuum-Tube Voltmeter at high frequencies, it was necessary to develop an accurate method of high-frequency voltage measurement. In next month's *Experimenter*, L. B. Arguimbau will describe the high-frequency voltage standard used for these measurements.

I.R.E. HONORS GENERAL RADIO PRESIDENT

THE MEDAL OF HONOR of the Institute of Radio Engineers has been awarded to Melville Eastham, President of the General Radio Company since its founding in 1915.

This gold medal "is given in recognition of distinguished service in radio communication. It is awarded to one who has been responsible for an important advance in the science or art of radio communication. This advancement may be a single development or it may be a series of developments which in the aggregate have resulted in substantial improvements in radio communication. . . ."

Mr. Eastham has been active in radio engineering societies since the early days of wireless telegraphy, and a member of the Institute since the first year of its existence. He served as a director of the Institute for several years, and has been its treasurer since 1927. He now holds the membership grade of Fellow. As founder and president of the General Radio Company, he has contributed much to the development of instruments and methods for radio measurements.

Presentation of the medal will be made at the annual convention banquet of the Institute on May 12. The citation reads as follows:

"To Melville Eastham for his pioneer work in the field of radio measurements, his constructive influence on laboratory practice in communication engineering, and his unfailing support of the aims and ideals of the Institute."

THE General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in communication-frequency measurement and control problems. When sending requests for subscriptions and address-change notices, please supply the following information: name, company name, company address, type of business company is engaged in, and title or position of individual.

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VOLUME XII NUMBER 1 JUNE, 1937

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also

IN THIS ISSUE

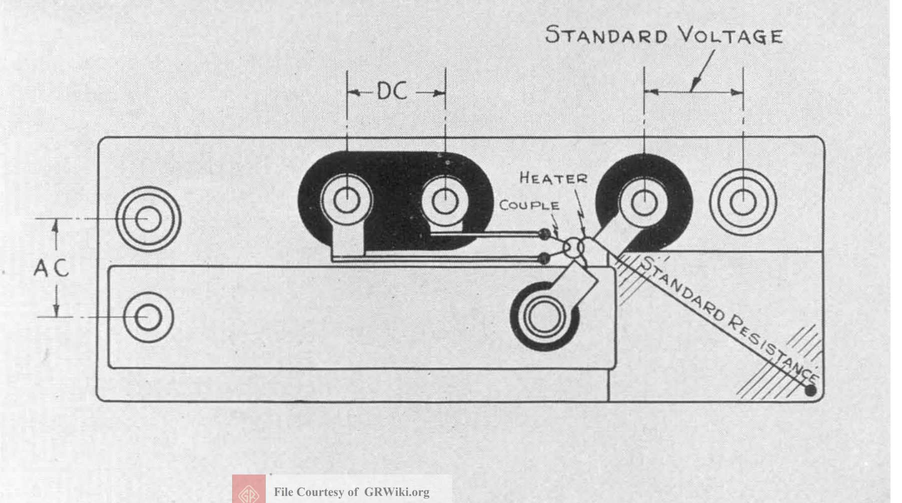
A HIGH-FREQUENCY VOLTAGE STANDARD

●**IN DESIGNING** vacuum-tube voltmeters and standard-signal generators, it is frequently necessary to have a voltage standard which is good at high frequencies. A convenient standard is the voltage drop across a standard resistor when the current through it is measured by means of a thermocouple. This arrangement can be calibrated on direct current by reference to a standard cell and, provided the frequency characteristics of the elements are known, is quite usable for high frequencies. In practice, the best solution is to design couples and resistance elements having negligible frequency error at the frequencies where it is desired to work.

A few years ago, sufficient accuracy was obtained with an Ayrton-Perry-wound resistor and an ordinary vacuum thermocouple, because

(*Continued on page 2*)

FIGURE 1. Voltage standard, making use of a ribbon resistor separated from the metal return path by 1-mil mica



accurate measurements were not required above a few megacycles. Present-day requirements are more severe, calling for measurements at much higher frequencies.

Considerable work* has recently been done on computing the characteristics of acorn-tube voltmeters and comparing the performance of different tubes with each other and with theoretical considerations.

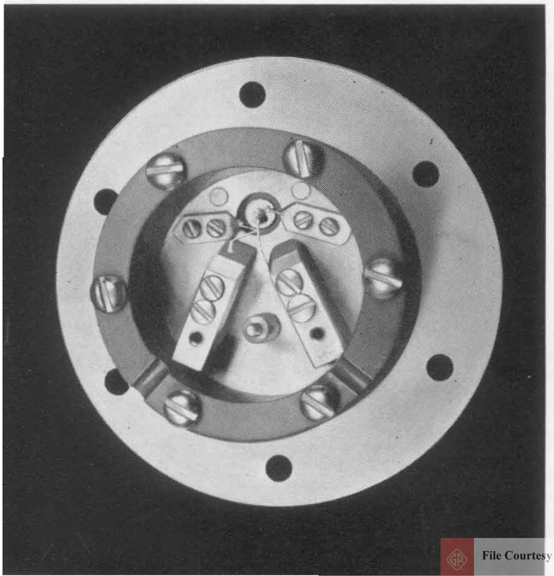
In order to obtain an independent calibration of voltage indicators, a thermovoltmeter standard for direct measurements at high frequencies has been devised at the General Radio Company.

Errors in the thermocouple-resistor system are caused by (1) skin effect and capacitance to ground in the thermocouple heater and (2) skin effect, inductance, and ground capacitance in the standard resistor.

The design of a thermocouple for use at frequencies up to hundreds of megacycles is not difficult. The heater can be made from wire of small diameter, keeping skin effect at a low value. The skin effect in a piece of manganin wire 2 mils in diameter amounts to only 1% at 100 megacycles. It is possible to draw a wire to 0.25 mils and this would have a calculated skin effect of 1% at 4000 megacycles.

*L. S. Nergaard, "Electrical Measurements at Wavelengths Less Than Two Meters," *Proc. I.R.E.*, September, 1936.

FIGURE 2. Photograph of the final model of the high-frequency voltage standard, using a 1/16-inch length of 0.0004-inch resistance wire as an impedance standard. A transparent disc covers the unit to protect the parts and to avoid errors in readings resulting from air currents



The heating effect can be measured by using a thermocouple whose junction is insulated from the heater. The insulator can be made to have a capacity of less than 0.1 $\mu\mu$f so that the capacitive current from the heater to ground can be kept negligible if the impedance from the heater to ground is kept low. Thus it appears that the current flowing in the heater of a thermocouple can be known accurately, but it is another matter to make use of this knowledge.

When a thermocouple is used for measuring voltages, an impedance standard is necessary. Probably the best impedance is a pure resistance. While this cannot be strictly realized, it may, by proper design, be approached. The circuits must be so arranged that the current flowing through the thermocouple is the same as that flowing through the standard impedance. Further, the standard voltage should be essentially equal to the voltage drop in the resistor, that is, there should be no induced emf in the leads to the standard terminals.

One arrangement made five or six years ago for testing signal generators is shown in Figure 1. The resistance unit consisted of a short length of 2-mil manganin wire rolled into a ribbon 10 mils wide and separated from a grounded slab of metal by a 1-mil sheet of mica. This rather unconventional design was used in an attempt to avoid the large inductive reactance associated with low-resistance units. The reduction was accomplished by treating the resistor as a transmission line and attempting to make $\sqrt{\frac{L}{C}}$ about equal to R. Actually, a still closer spacing would have been desirable.

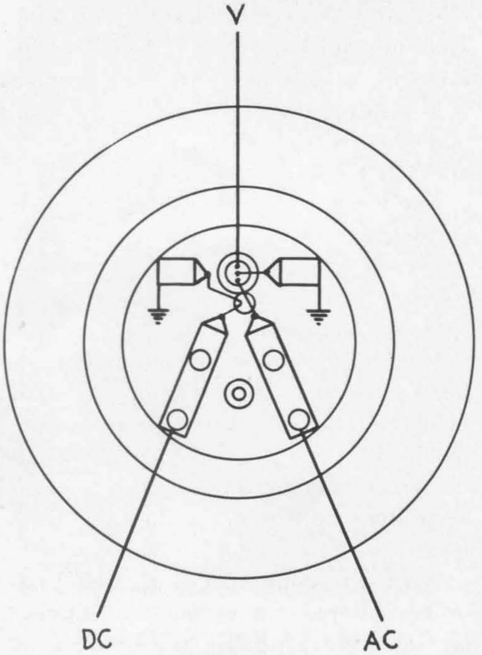


FIGURE 3. Diagram of connections for the standard of Figure 2. The return paths are through the grounded brass case

It will be noticed that the potential terminals are connected to the resistor in a manner calculated to eliminate wiring inductance in a sort of high-frequency analogue of the conventional four-terminal resistor commonly used for direct currents.

Another and more satisfactory way of decreasing the inductance (and the capacitance as well) is to decrease the necessary length by using much finer wire. Figure 2 shows a unit consisting of a piece of resistance wire 0.0004 inch in diameter, only 1⁄16 inch long, and having a resistance of about 7 ohms.

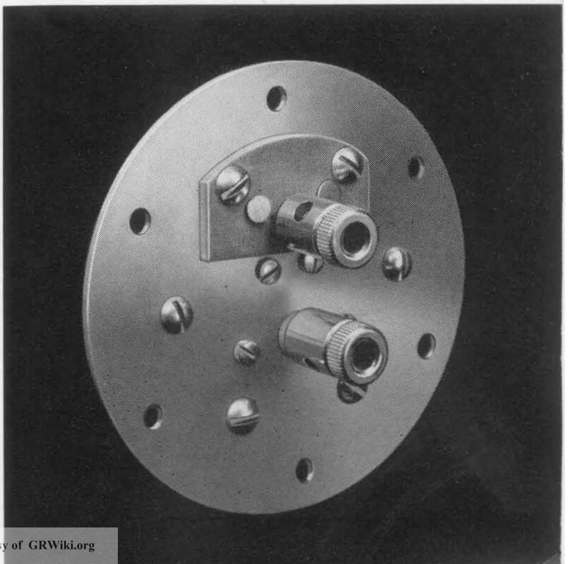
In this case, as with the resistor of Figure 1, the thermocouple heater was joined directly to the resistor in air rather than risk errors inherent in the long lead wires of the usual glass bulb construction of a vacuum couple.

The inductance of the second resistor unit is computed at about 1.6 cm (1.6×10^{-9}h) which gives an inductive reactance of 1 ohm at 100 Mc. Since this is added in quadrature to the resistance, the impedance is only increased 1%. As previously mentioned, the skin effect is entirely negligible.

Wire is now available having a diameter of 0.00025 inch. A unit of the same size as the present one, if made of such wire, would have an inductive error of 1% at 250 Mc. Another improvement over the present unit would consist in using the thermocouple heater itself as the standard resistance, taking the same precautions to minimize mutual impedance.

The voltage standard of Figure 2 has been used in measuring the error of indication as a function of frequency in the TYPE 726-A Vacuum-Tube Voltmeter and the variation of output voltage with frequency in the TYPE 605-A Standard-Signal Generator. This voltage standard in conjunction with a heterodyne method of measuring attenuation ratios provides an absolute voltage calibration for standard-signal generators. The complete system will be described in an early issue of the *Experimenter*. —L. B. ARGUIMBAU

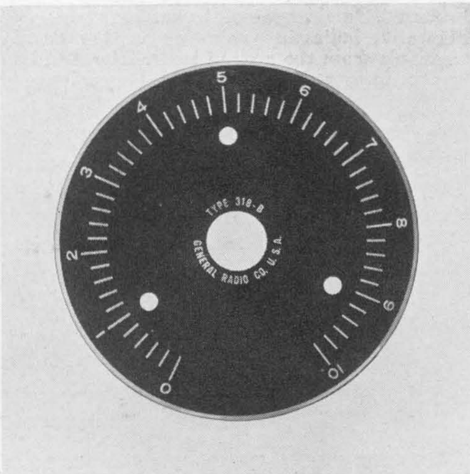
FIGURE 4. Outside view of the voltage standard of Figure 2, indicating shielding of the output terminals from the ground leads. The standard was made as a detachable unit so that it could be used in several assemblies



AT THE SILVER ANNIVERSARY CONVENTION

● **THE PHOTOGRAPH** above shows the General Radio booth at the Silver Anniversary Convention of the Institute of Radio Engineers, held in New York, May 10 to 12. A number of the newer instruments were displayed, and several members of the engineering staff were in attendance.

NEW DIAL PLATES



● **THE TYPE 318-A DIAL PLATE,** intended for use with General Radio rheostat-potentiometers, has been replaced with a new model, TYPE 318-B. The new plate has ten numbered divisions, each subdivided into five equal parts. This total of fifty divisions covers a rotational angle of 298°. The scale is photo-etched, with raised nickel-silver graduations on a flat black background. Mounting holes coincide with those of General Radio rheostat-potentiometers having a three-hole mounting.

The diameter is 3 inches and the plate is intended for use with a 1⅝-inch knob, such as TYPES 637-G, -H, -J, and -K.

Type	*Code Word*	*Price*
318-B	DEVIL	$0.35

AN IMPROVED OUTPUT METER

THE HIGH IMPEDANCE and inherent ruggedness of the copper-oxide-rectifier type voltmeter are advantages which more than offset its accuracy limitations. Because of this, the TYPE 483 Output Meter, which consists of a copper-oxide voltmeter and a resistive multiplier network for extending the range, has been widely used in laboratories where audio-frequency measurements are made.

Recent improvements in rectifier-type instruments have resulted in a meter with much better characteristics than were possible a few years ago. Using this new instrument, the General Radio Company has designed a new model of the TYPE 483 Output Meter. In addition to better electrical performance, the new TYPE 483-F Output Meter has several improved features of mechanical design. The characteristics of the instrument are discussed below.

Full-scale deflection on the indicating instrument is 2 volts. The L-type multiplying network provides full-scale ranges of 2, 4, 10, 40, 100, and 200 volts. A schematic diagram of the circuit is shown in Figure 1, a photograph of the instrument in Figure 2.

Errors in copper-oxide instruments fall into two classes: (1) errors in the voltage indication as a function of frequency, temperature, and waveform, and (2) changes in impedance as a function of voltage.

(1) ERRORS IN INDICATION

The frequency error is caused by the shunting effect of input capacitance and is not serious below 6 or 7 kilocycles. Figure 3 shows an average frequency characteristic for a number of meters as well as the maximum deviation from the average within the group tested.

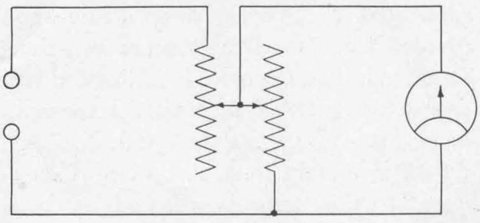


FIGURE 1. Schematic wiring diagram of the TYPE 483-F Output Meter

All copper-oxide rectifiers show temperature effects, but the new design used in the output meter has a zero temperature coefficient in the normal range of room temperatures. This is shown in Figure 5.

The indication of a copper-oxide instrument depends upon the average value

FIGURE 2. Photograph of the new output meter

of the applied voltage over a complete cycle. TYPE 483-F Output Meters are calibrated in r-m-s values on a sine-wave source. When used to measure non-sinusoidal voltages, the error in indication will depend upon the degree by which the ratio of rms to average for the applied voltage differs from that for a sine wave. Consequently, this error is affected by both magnitude and phase of harmonics.

(2) IMPEDANCE ERROR

The impedance characteristic of the copper-oxide instrument itself as a function of voltage applied is shown in Figure 4. This indicates the average impedance error which occurs on the 1 multiplier. The impedance of individual instruments may deviate from the values shown by as much as 10%.

When the multiplying network is in circuit, the error decreases and, for the 100 multiplier, the impedance is 20,000 ohms ±2%. The error in impedance increases as the multiplier setting is reduced, but, since the meter impedance error decreases with applied voltage, the minimum impedance error for a given voltage measurement will occur at the multiplier setting which gives the highest on-scale reading. In other words, with 2 volts applied, the reading should be taken at full

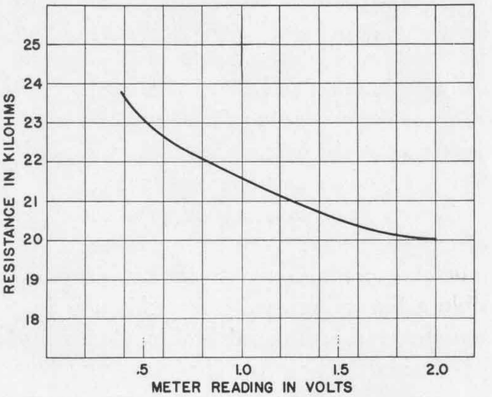
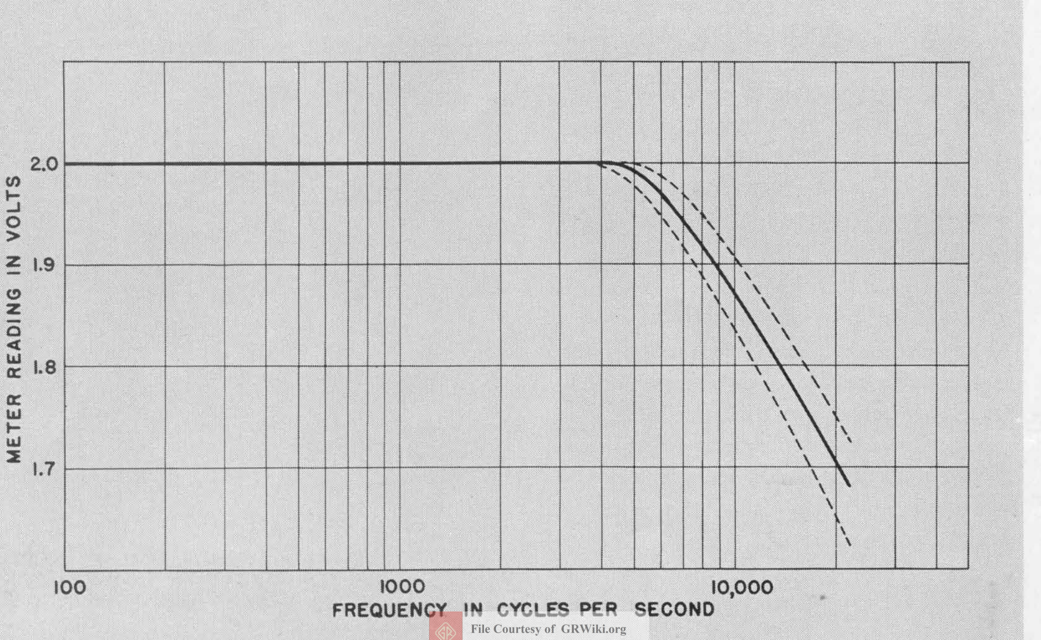


FIGURE 4. The frequency characteristic of the oxide-rectifier meter itself as a function of applied voltage. The maximum variation from the curve shown is ±10%

scale on the 1 multiplier, rather than at half-scale on the 2 multiplier.

Mechanically, improvements in the out-

FIGURE 3. Average frequency characteristic of the meter. The dotted lines show the maximum deviation from average



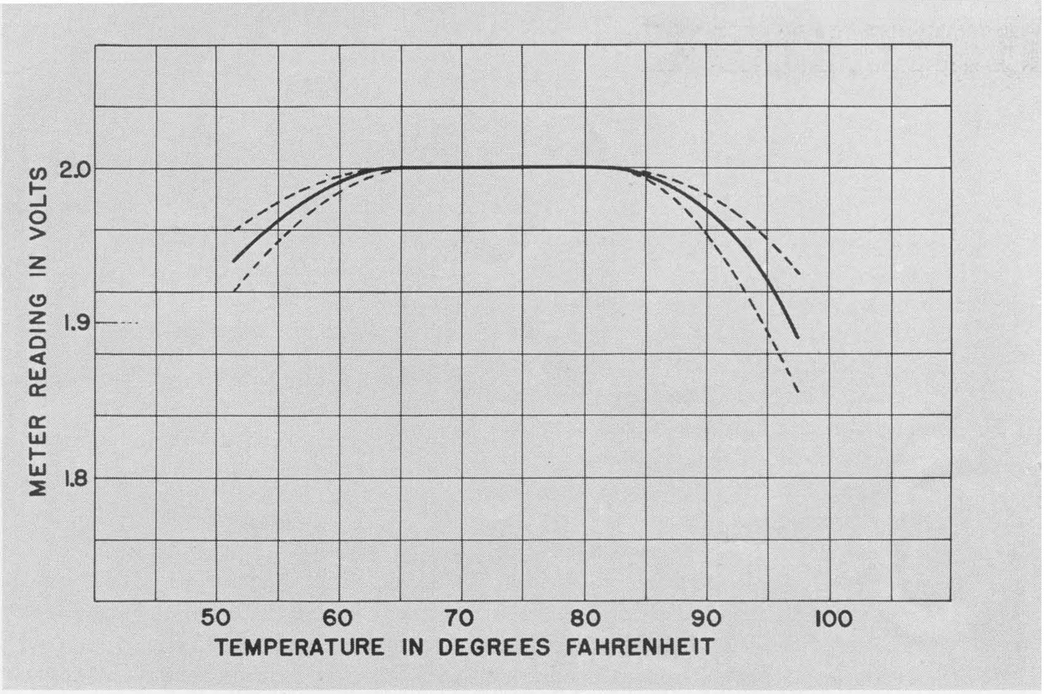


FIGURE 5. This shows the effect of temperature on the meter indication. It will be noted that in the normal room temperature range the temperature coefficient is practically zero. The dotted lines indicate the maximum deviations to be expected

put meter consist of using a TYPE 510 Switch with concealed, dustproof contacts, and mounting the assembly on an aluminum panel finished in black crackle lacquer.

From the foregoing it is evident that the TYPE 483-F Output Meter is not a precision standard of voltage. Its accuracy is, however, sufficient for most routine laboratory measurements. By far its greatest field of usefulness is in comparison measurements of various types, where the meter is used to match two voltages. Here temperature and frequency errors cancel, and even waveform errors are seldom important, because usually a single voltage source is used.

—W. G. WEBSTER

SPECIFICATIONS

Voltage Range: Below 0.5 volt to 200 volts in seven steps.

Input Impedance: Nominally 20,000 ohms.

Frequency Characteristic: See Figure 3.

Temperature Characteristic: See Figure 5.

Accuracy: ±5% of full scale, which is equivalent to ±0.1 volt multiplied by the multiplier setting. This figure holds only when frequency and temperature fall on the flat portion of the curves of Figures 3 and 5 and when the waveform of the applied voltage is sinusoidal.

Net Weight: 3 pounds, 9 ounces.

Dimensions: (Length) 9⅜ x (width) 4¼ x (height) 5¼ inches, over-all.

Type		*Code Word*	*Price*
483-F		AVOID	$54.00

This instrument is manufactured and sold under U. S. Patent No. 1,901,343.

MISCELLANY

● **THE GENERAL RADIO COMPANY** cordially invites readers of the *Experimenter* to inspect its exhibit of laboratory and industrial apparatus at the Fortieth Annual Meeting-Exhibit of the American Society for Testing Materials. The exhibition will be held June 28 through July 2 in the Astor Gallery of the Waldorf-Astoria Hotel, Park Avenue and 49th Street, New York City.

Mr. Robert Field, design engineer responsible for the development of the TYPE 516-C Radio-Frequency Bridge, the TYPE 544-B Megohm Bridge, and the TYPE 716-A Capacitance Bridge, and Mr. Frederick Ireland of the general engineering department will be in attendance at the exhibit.

Because of their particular interest to the members of the A.S.T.M., the new TYPE 716-A Capacitance and Power Factor Bridge and the new TYPE 544-B Megohm Bridge will be on display. Industrial devices such as the TYPE 548-B Stroboscope, the TYPE 631-A Strobotac, the TYPE 759-A Sound-Level Meter, and the TYPE 725-A Color Comparator will be presented for the inspection of engineers less interested in electrical measurements.

● **THE CHAIRMAN** of our Board of Directors, Mr. Henry S. Shaw, has just been honored by being elected a Fellow of the American Academy of Arts and Sciences.

● **ON MAY 21,** H. H. Scott, of the General Radio engineering staff, spoke before a joint meeting of the Detroit section of the Institute of Radio Engineers and the Engineering Society of Detroit. Also present were members of the American Society of Mechanical Engineers and the Cleveland Engineering Society. Mr. Scott's subject was "The Stroboscope and the Sound-Level Meter, Electronic Aids in the Elimination of Noise." The talk was illustrated by lantern slides and high-speed motion pictures.

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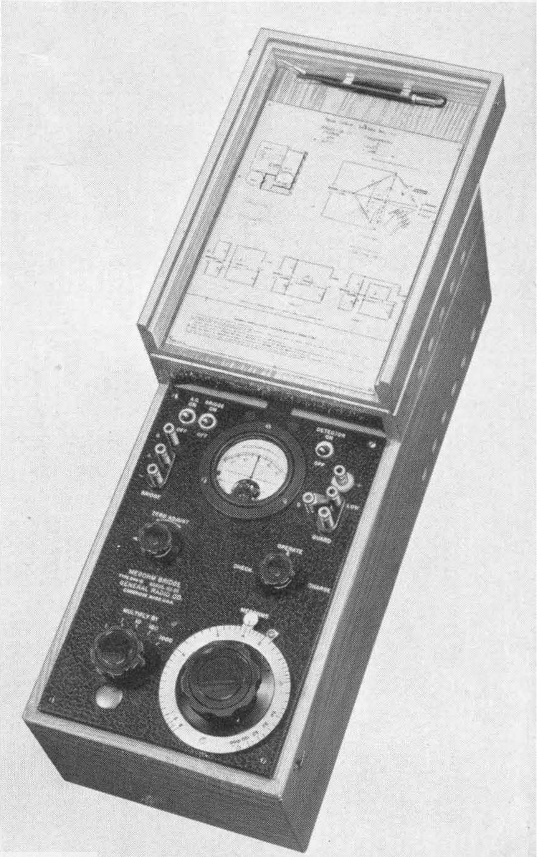
ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

THE MEGOHM BRIDGE

● **IT IS BECOMING** of increasing importance to be able to measure accurately and rapidly high resistances in the range from 1 megohm to 1,000,000 megohms. The volume resistivity of insulating materials is a fundamental property in predicting their electrical characteristics. It is particularly sensitive to small traces of moisture and so becomes a valuable measure of moisture content. When this property is used in conjunction with dielectric constant and power factor, a powerful means is offered of studying the molecular structure of complex dielectrics.

The bar to the successful use of the Wheatstone bridge in this high-resistance range is the relatively low resistance of the conventional galvanometer used to indicate bridge balance. The amount of power demanded by even a sensitive wall galvanometer is such as to make it difficult to measure resistances greater than 10 megohms. The use of a vacuum-tube voltmeter as the bridge detector completely resolves the difficulty. It is quite possible to obtain a tube which presents to the

FIGURE 1. TYPE 544-B Megohm Bridge



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REPAIRS *vs.* OBSOLESCENCE

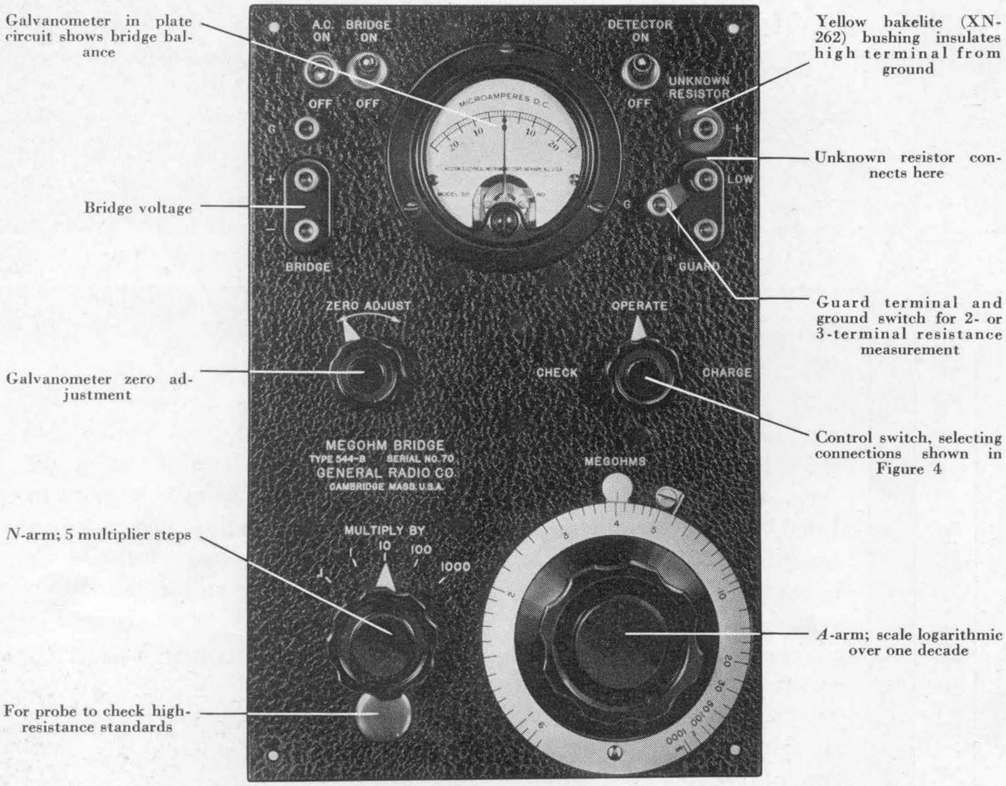


FIGURE 2. Panel view of the bridge, identifying the several controls

bridge a resistance greater than 10,000 megohms and still allows the bridge to be balanced to 0.1%, using an ordinary pointer galvanometer in its plate circuit.

AN IMPROVED MEGOHM BRIDGE

Just such a combination of Wheatstone bridge and vacuum-tube voltmeter was designed in 1933* and has been in use ever since. Two kinds of measurements have grown in importance since then — the leakage resistance of large condensers and the use of guard electrodes and three-terminal condensers — for which that bridge was not well adapted. In the TYPE 544-B Megohm Bridge, which is now announced, all the desirable features of the earlier model are retained (see Figure 1).

*R. F. Field, "Bridge + Vacuum Tube = Megohm Meter," General Radio *Experimenter*, June-July, 1933, pp. 7-9.

In addition, condensers can be measured for resistance because the voltage applied to the unknown varies only slightly during balance, and all sorts of three-terminal resistors can be connected because of the flexibility of the guard terminals and grounding system.

ACCURACY AND RANGE

The resistance reading of the bridge is taken from the settings of a five-point decade multiplier switch and a four-inch dial, having a scale which is approximately logarithmic over one decade. These appear at the bottom of the panel in Figure 2. The MEGOHMS dial is shown full size in Figure 3. The main decade is 7 inches long. Hence the scale length for the resistance range from 0.1 MΩ to 10,000 MΩ, over which the accuracy of scale reading is 2%, is 35 inches. Taking into account the errors in the other bridge arms, the accuracies of the resistance measurements are:

Range	*Error*
.1 MΩ – 100 MΩ	± 3%
100 MΩ – 1,000 MΩ	± 6%
1,000 MΩ – 10,000 MΩ	± 10%

Beyond 10,000 MΩ the error is essentially that with which the scale on the MEGOHMS dial can be read. A resistance of 1,000,000 MΩ can be detected.

THE BRIDGE CIRCUIT

The bridge is composed of the four arms *A*, *B*, *N*, *P* as shown for the OPERATE position in Figure 4, with the power applied across the arms *A* and *B* and the vacuum-tube voltmeter connected across the conjugate pairs *A*-*N* and *B*-*P*. For checking the galvanometer zero, the tube is isolated from the bridge voltage as shown in the CHECK position, with the high resistors *N* and *P* connected to the grid exactly as in the OPERATE position. The effects of any voltages, alternating or direct, in the unknown resistor *P* and of any grid current of the tube will not appear in the bridge balance because they are balanced out in the zero adjustment. There is also a CHARGE position, in which the unknown resistor *P* is placed across the arm *B*. This is valuable in measuring the resistance of large condensers.

The exact connections of the various arms are shown in the schematic wiring diagram in the center of Figure 3. Not all the standard resistors which make up the *N*-arm are wire wound. The two highest

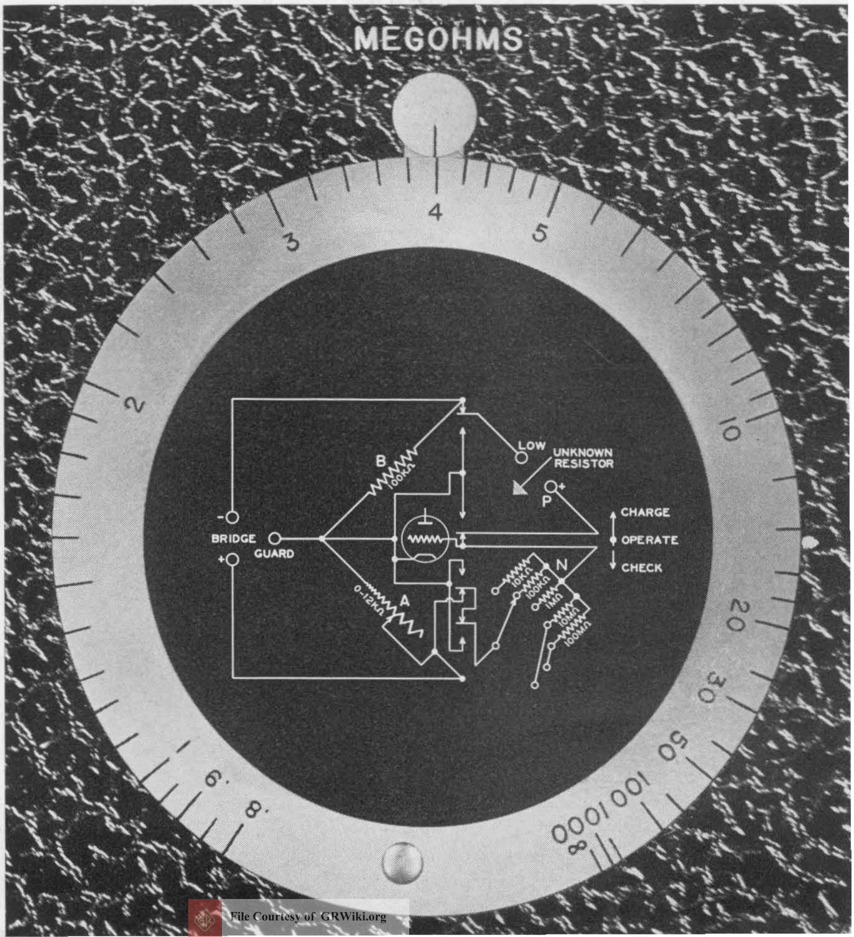


FIGURE 3. Full-size reproduction of the MEGOHMS dial, showing also the schematic wiring diagram

are of the less stable metallized-filament type. Means are provided for connecting these resistors in the *P*-arm and measuring them in terms of the wire-wound standards.

TERMINAL CONNECTIONS

All the terminals of the bridge are grouped together in the upper part of the panel (Figure 2) to allow the convenient connection of all types of resistors. For measuring all grounded resistors and most two-terminal resistors, the ground post G is connected to the Low terminal by the spring clip provided. This group includes the insulation resistance of electrical machinery such as generators, motors, and transformers, electrical equipment such as rheostats and household appliances, single conductors, cables, and condensers. For all resistors having a third terminal, which may be brought out separately or may be ground itself, this third terminal is connected to the Guard terminal as shown in Figure 6. The ground post G is connected to whichever of the two terminals, Low or Guard, is grounded. The bridge then measures the direct resistance R_D and rejects the terminal resistances R_1 and R_2. All multi-wire cables, multi-circuit transformers, and multiple terminal condensers and networks are included in this type of measurement. Guard electrodes are frequently added to simple two-terminal devices to eliminate both surface leakage and the effect of fringing in discs of insulating material. A good example of this using mercury electrodes is shown in Figure 5.

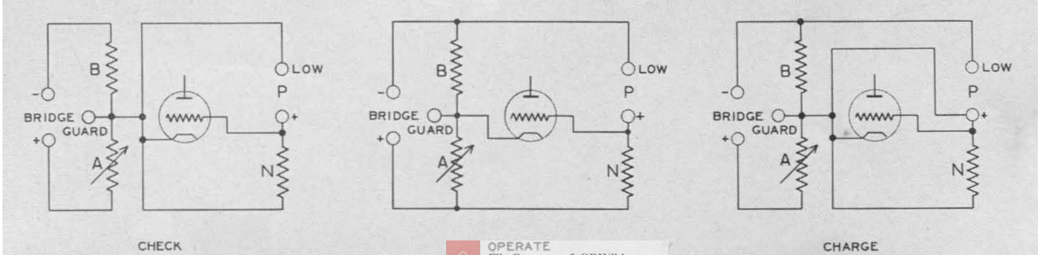
The high potential terminal and all leads connected to it are insulated with low-loss bakelite, XN-262, which even with the existing multiple paths to ground has a resistance to ground of over 1 MMΩ. The black crackle-finish on the panel is stripped from around the panel insulator so that, when the Guard terminal is grounded, there will be no leakage over it to the Low terminal.

RESISTANCE OF CONDENSERS

The leakage resistance of condensers is measured in the same manner as other resistances except when the capacitance is large, a tenth microfarad or greater. Sufficient time must then be allowed to charge the condenser, through the standard resistance in the *N*-arm, to the voltage it will have when the bridge is balanced. The time constant of this circuit, which is the product of the capacitance in microfarads and the resistance in megohms, is a convenient measure of this time interval. When this is more than a few seconds, time is saved by turning the control knob to the Charge position, as shown in Figure 4. This applies to the condenser approximately the same voltage as it will have at bridge balance.

This switch position is also useful when a condenser shows considerable dielectric absorption and therefore acquires a volume charge. After the initial adjustment, the galvanometer zero can no longer be checked in the Check position because of this volume charge. In some types of insulation, such as long cables with both rubber and paper insulation and laminated materials like the pasted mica used in high voltage generators, this volume

Figure 4. Schematic bridge diagrams for the three positions of the control knob



charge reaches huge proportions. It may require hours and sometimes days to attain equilibrium. This effect has fostered the rule of thumb of observing the resistance one minute after the application of the voltage. Any measurement taken while this volume charge is flowing is not a measurement of leakage resistance, but of charging current. There is no definite relationship between the resistance measured at an arbitrary time and the final steady state resistance. The rate of change of the instantaneous resistance is probably of more significance* than the resistance itself because it suggests by its magnitude how much greater the final insulation resistance will be. It is very easy to use the bridge for such measurements. Balance is maintained by adjustment of the MEGOHMS dial up to a given time and the setting then read at leisure. The current flowing can be easily calculated from the observed resistance and the voltage applied to the bridge. It is also possible to discharge the condenser through the standard resistance and calculate the discharge current.

EXTERNAL DECADE RESISTOR

It is possible to replace the logarithmic resistor with a five-dial TYPE 602 Decade Resistance Box when the maximum possible accuracy of balance is desired. Resistances from 10 kilohms to 10 kilomegohms can then be measured with an accuracy of about ¾%. Sets of high resistance standards can be compared over that same range to an accuracy of 0.1% provided such standards have negligible voltage coefficients.

POWER SUPPLIES

The voltage normally applied to the bridge is 90 volts, obtained from one of two power supplies mounted in back of the bridge panel, one for a-c, the other for d-c operation. Either power supply will be furnished with the bridge as listed below, while the other one may be obtained as extra equipment. In the a-c supply the bridge and tube bias voltages are stabilized against line voltage fluctuations by ballast tubes. Different tubes for the bridge detector are used for a-c and d-c operation and are furnished as part of their respective power supplies. These

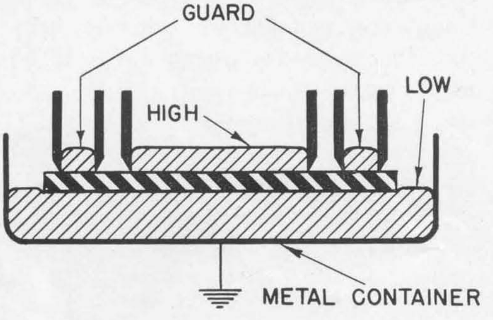
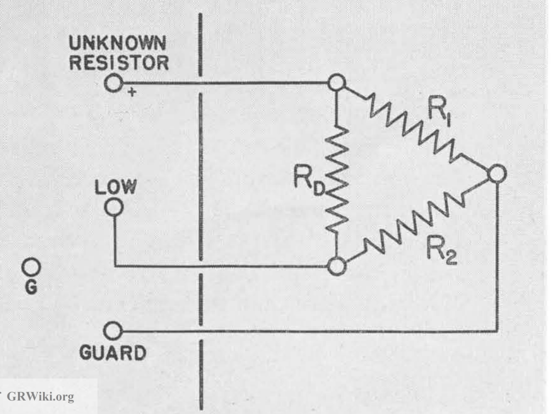


FIGURE 5. Cell for solid dielectrics, using mercury electrodes

tubes are tested for low grid current and a stock is maintained on hand. The actual voltage applied to the bridge can be measured at the BRIDGE terminals on the left of the panel. These terminals may also be used for external supply up to 500 volts. This makes it possible to study the effect of voltage on the resistance of insulation. — R. F. FIELD

FIGURE 6. Bridge connections for the measurement of direct resistance



*R. W. Wiesman, "Insulation Resistance of Armature Windings," *Electrical Engineering*, June, 1934, pp. 1010 to 1021.

TYPE 544-B MEGOHM BRIDGE

SPECIFICATIONS

Range and Accuracy: See table on page 3.

Terminals: The terminals for connecting the unknown resistor include connections for guard electrodes so that either two- or three-terminal resistors can be measured.

Power Supply: Two types of power supply are available, one using batteries, the other operating from a 115-volt, 40- to 60-cycle a-c line.

Vacuum Tubes: With battery power supply, a 1D5G detector tube is used; the a-c power supply uses a 6K7G detector, two 6X5G rectifiers, and an 874 ballast tube. All tubes are supplied with the instrument.

Mounting: Shielded oak cabinet.

Dimensions: Cabinet with cover closed, (width) 8½ x (length) 22½ x (height) 8 inches, over-all.

Net Weight: With battery power supply, 30¼ pounds; with a-c power supply, 25¼ pounds.

Type		*Code Word*	*Price*
544-B	Battery operated	ALOOF	$175.00
544-B	A-C operated	ANNOY	225.00

REPAIRS VS. OBSOLESCENCE

● **OUR SERVICE DEPARTMENT,** through which are handled all customer complaints, repairs, exchanges, and adjustments, is often called upon to repair and rebuild obsolete equipment. Experience has shown that misunderstandings between manufacturer and customer arise more often with obsolete instruments than with current models. The two major points of disagreement are (1) cost of repairs and (2) instrument performance after repairs are made.

COST

Since each instrument returned for reconditioning must receive individual attention, the work must be handled in much the same way as a special manufacturing job. Consequently, the amount of supervision required per instrument is considerably more than that necessary in regularly scheduled production. An analysis of the performance characteristics must be made as well as a schedule of mechanical repairs. All badly worn or defective parts must be replaced, resistance elements readjusted, and the remainder of the assembly thoroughly cleaned and tightened mechanically. This involves an operating check on nearly all component parts, and when these are found defective it is often difficult to find replacements, particularly if the instrument has been obsolete for any considerable period.

Parts which are of General Radio manufacture may not be in stock. While these can be made, the operation is necessarily costly because they were originally made in large quantities. Parts and materials supplied by other manufacturers may no longer be available, which necessitates finding satisfactory substitutes or making minor changes in the design of the instrument.

After all repair operations have been performed, a complete operating test and calibration must be made in our testing laboratory. Here again it is uneconomical to handle the instruments individually since all normal production work is done in quantity lots.

Electrical design and production methods are constantly improving. As a result, many labor operations performed on obsolete instruments are less efficiently performed than those on newer products. This is particularly true of such items as the Type 102 Decade-Resistance Box in which certain of the cards were wound with resistance wire having a high temperature coefficient. Readjusting resistors in these cards consumes a considerable amount of time because the wire is raised in temperature whenever a soldering iron is applied to it. The repair of these resistance boxes is often not merely a matter of readjusting a few resistors, but one of replacing most of the resistance cards in the box. Since the resistance cards represent the greater part of the original cost of the instrument, repair costs are correspondingly high.

A cost analysis of reconditioning operations on a number of obsolete instruments shows that average repair prices are approximately as follows:

Original Cost of Instrument	*Maximum Repair Charge*
Less than $50.00	75% of list price
Between $50.00 and $100	65% of list price
Between $100 and $200	50% of list price
Above $200	33% of list price

These are only approximate prices and the exact charge is, of course, dependent upon the age and the condition of the instrument. From these figures, however, it will be realized that in many instances the repair costs approach the list price of a new instrument which has replaced the model submitted for repair. Because of this it is often less expensive, or at least very little more so, if the instrument is replaced by a newer model.

PERFORMANCE OF RECONDITIONED INSTRUMENTS

In addition to the cost, the performance to be obtained from the repaired instrument should be carefully considered. It should be obvious that the maximum performance to be expected from a reconditioned instrument is only that obtainable when the instrument was originally sold. Usually this is considerably inferior to that obtainable from instruments of more recent design. In other words, a complete reconditioning of the Type 513-B Beat-Frequency Oscillator will by no means make it equal in performance to the newer Type 713-A Beat-Frequency Oscillator. As an element of the total cost of repairs, therefore, the performance to be expected from the repaired instrument is important.

If we offered for sale, at its original price of $100, a brand-new Type 102-M Decade-Resistance Box which was manufactured between 1920 and 1931, its purchase could not be justified because a Type 602-M Decade-Resistance Box, which has far better characteristics and general performance, can be purchased new for $70. Yet the cost of repairing a Type 102-M Box may be well in excess of $50.

Our Service Department will be glad to advise the user of General Radio instruments regarding both the probable cost and the desirability of reconditioning old instruments. If, after an instrument is received for repair, the costs are evidently much higher than the original estimate, a formal quotation will be submitted before work is started. — H. H. Dawes

A group of Type 636-A Wave Analyzers under test in our calibration laboratory

MISCELLANY

● **AMONG** recent visitors to our laboratories were Professor William R. Work, Head of the Electrical Engineering Department at Carnegie Institute of Technology, and Laurence E. Jermy, Editor of Machine Design.

● **IF YOU** are going away for several months this summer be sure to leave your forwarding address And Postage with your Post Office, otherwise the *Experimenters* will be returned to us with the notation "gone away — address unknown." This causes much unnecessary correspondence and delay.

The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in communication-frequency measurement and control problems. When sending requests for subscriptions and address-change notices, please supply the following information: name, company name, company address, type of business company is engaged in, and title or position of individual.

GENERAL RADIO COMPANY

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VOLUME XII NOS. 3 and 4 AUGUST-SEPT., 1937

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also

IN THIS ISSUE

A NEW INSTRUMENT AND A NEW CIRCUIT FOR COIL OR CONDENSER CHECKING

● THE REACTANCE AND RESISTANCE of coils and condensers used in modern radio receivers are frequently held to extremely close tolerances. Acceptance tests and equipment for checking these factors are important to both parts manufacturers and receiver manufacturers. Laboratory instruments of high accuracy are available for making these measurements, but their relatively high cost usually prohibits their use on the production line. The same resultant accuracy, however, can be obtained by measuring and adjust-

FIGURE 1. Two TYPE 721-A Coil Comparators arranged for testing coils at two frequenc

ing a standard coil in the laboratory and comparing others with the standard by means of simple, inexpensive instruments. Primarily for this latter purpose the General Radio TYPE 721-A Coil Comparator has been designed.

What method of measurement should be chosen if it is desired to compare, at a radio frequency, a number of production coils with a standard sample? There are available the familiar bridge methods, resonance methods, detuning methods, etc. Direct substitution can be used equally well with all of these, and any not too elaborate circuit which permits the comparison to be made readily with the desired degree of precision should be satisfactory. Bridge measurements rely on a null indication and can be made, consequently, with almost any required precision. They are difficult to set up, however, and require considerable equipment. Resonance methods, although capable of giving satisfactory results when the losses in the coil are low, frequently do not permit settings to be made sufficiently closely in other cases. Detuning methods, such as the zero-beat substitution method, likewise require, for stable and satisfactory operation, a considerable amount of equipment, and are difficult to adapt to the checking of coil losses.

A NEW CIRCUIT—ITS ADVANTAGES

A new measuring circuit has been adopted for the TYPE 721-A Coil Comparator in order to keep the simplicity of a resonance method, but with considerably increased precision of setting. This circuit, which is a bridged-T network, is shown in Figure 2. Like a bridge, it is capable of being balanced for a perfect null indication, but unlike a bridge, one side of the generator, of the detector, and of the coil under test are connected to a common grounded point. This simplifies considerably the whole arrangement, and the stray capacitance from the generator to ground, or from the detector to ground, does not have to be balanced out or otherwise compensated for. Readings are completely independent of both generator and detector impedances. The effective low impedance of the circuit, moreover, makes other effects, such as capacitance between input and output and capacitance to the operator's body, almost unnoticeable.

The conditions for balance, if the two condenser sections are approximately equal and if the coil has a reasonably high Q, are as follows:

$$L\omega = \frac{1}{(C_1 + C_2)\omega} \qquad (1)$$

$$R = \frac{R_S}{4} \qquad (2)$$

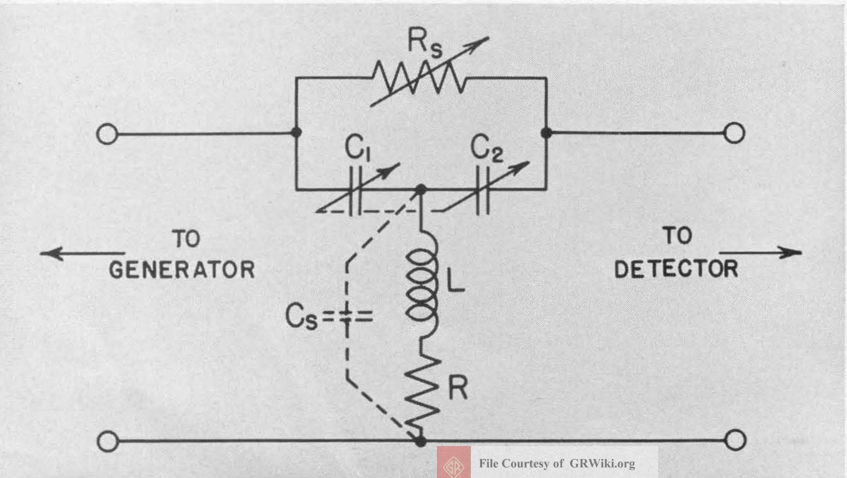


FIGURE 2. Circuit of the TYPE 721-A Coil Comparator. C_1 and C_2 are ganged and operated by a single control. L and R are the inductance and resistance of the coil under test. and C_S is the stray capacitance of the measuring circuit

In other words, the sum of the capacitance of the two sections of the tuning condenser must be sufficient to tune the coil to resonance, and the bridging resistance must be equal to four times the coil resistance. If the coil were perfect and had no losses, the bridging resistance would have to be zero and the circuit would become that of Figure 3, which shows a simple series-resonant circuit shunting the line, the coil being tuned by the two condenser sections in parallel. The circuit of Figure 2 is seen to be a series-resonant wave-trap in which losses in the coil are compensated for by splitting the condenser and inserting a bridging resistance. In this way perfect suppression of the applied voltage can be obtained regardless of coil losses.

The two condensers C_1 and C_2 are equal and are operated by a single control which determines the reactance setting. A small condenser, also in two sections, is in parallel with the main condenser and is used to show small differences in reactance in comparison measurements. The new circuit makes it possible to provide an almost ideal arrangement: a single control, with an incremental adjustment, for reactance, and an independent control for resistance.

CORRECTIONS

The simple relations which have been given for the balance condition hold, however, only when the coil has reasonably high Q. Moreover, between the junction of the two condenser sections and ground, there is usually an appreciable amount of stray capacitance which is directly in parallel with the coil and cannot be separated out in the measurement. The coil is measured, therefore, when partly tuned by this additional capacitance. The condition for the resistance balance is changed because the partly-tuned coil has a higher apparent resistance. The reactance condition is not affected, except that the stray capacitance decreases by just so much the tuning capacitance required in the two condenser sections and raises the value of the minimum tuning capacitance that can be obtained. The complete balance equations, taking account of both the coil Q and the stray capacitance, are as follows:

$$L\omega = \left(\frac{1}{1+\frac{1}{Q^2}}\right)\frac{1}{(C_1+C_2+C_S)\omega} \qquad (3)$$

$$R = \left(\frac{1}{1+\frac{1}{Q^2}}\right)\frac{R_S}{4}\left(\frac{C_1+C_2}{(C_1+C_2+C_S)}\right)^2 \qquad (4)$$

The correction for Q is seen to be generally very small. If Q is 100, the correction is only one part in 10,000. Q may be

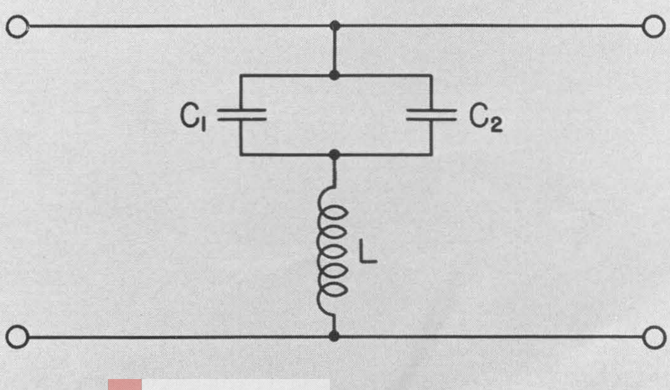


FIGURE 3. If the coil under test had no losses, the coil comparator circuit would be as shown here. This is a series tuned circuit directly across the line

as low as 10 without the correction exceeding 1%. The correction for Q will be recognized as the familiar expression for the ratio between the equivalent series reactance and the equivalent parallel reactance of a coil. The complete reactance condition (3) merely states, therefore, that the total capacitance $(C_1 + C_2 + C_S)$ must tune the coil to parallel resonance.

It is interesting that the bridging resistance has no effect whatever on the total tuning capacitance required. The total capacitance is the same as would be used under operating conditions when the coil is tuned by a parallel condenser. Since the two condenser sections C_1 and C_2 are operated together as a unit, and since the stray capacitance C_S depends only on the condenser setting, it follows that the instrument can be calibrated directly in terms of the total capacitance $(C_1 + C_2 + C_S)$ as if it were a simple condenser. Referring to the diagram, it will be seen that this can be accomplished by shorting the oscillator and detector terminals and measuring the total capacitance across the points at which the coil is to be connected.

The correction in expression (4) for the effect of the stray capacitance on the resistance measurement depends on the condenser setting alone and is independent of frequency. The bridging resistance for balance is in all cases proportional to the coil resistance, but the factor of proportionality is changed if the stray capacitance is appreciable compared with the total tuning capacitance.

PRODUCTION CHECKING OF REACTANCE

The instrument is particularly convenient for this application, since the direct measurement of L and R is less important than the ability to compare accurately a production coil with a standard sample.

In many cases a reactance check alone is all that is required. In such cases the procedure is extremely simple and straightforward. The small condenser, marked LIMITS, is set at the center-scale zero, and balance obtained for the standard coil by varying the resistance control and the control of the main condenser, marked STANDARD SETTING. The reactance setting is locked by a clamp provided, the standard coil is replaced by the production coil, and balance restored by varying the auxiliary LIMITS condenser and the resistance control. If the production coil is similar in construction to the standard, the test can almost invariably be made with sufficient precision by adjusting only the LIMITS condenser, leaving the resistance setting unaltered. In this way, an extremely rapid check can be obtained. If a meter, in place of an audible tone, is employed to indicate balance, its scale can be marked to correspond to the required limits. This arrangement may be preferable for certain applications.

Condensers can be checked as readily as coils, but it is necessary to use an external coil to obtain balance. The LIMITS dial reads directly in micro-microfarads, 1 $\mu\mu$f per division, and the scale extends from -13 $\mu\mu$f to $+13$ $\mu\mu$f. Differences can be estimated to 0.1 $\mu\mu$f.

Although it is anticipated that the single frequency test described above will be generally adopted for production checking, the circuit of the comparator lends itself particularly well to more detailed tests. For example, a convenient arrangement for checking coils at two frequencies to obtain a measure of the distributed capacitance can be made by employing two Type 721-A Coil Comparalators side by side, each with its separately-tuned detector. If the oscillator fundamental and second harmonic are used for the test frequencies, the two inputs can be connected together. It is then only necessary to shift the high-potential coil lead to test at the two frequencies and to insure that the reactance value in each case falls within the specified limits.

PRODUCTION CHECKING OF RESISTANCE

Production coils can also be checked for resistance or for Q in comparison with a standard coil. It has been shown above that for coils of the same reactance the setting of the resistance control is always directly proportional to the coil resistance. The percentage deviation in R or Q is equal in magnitude to the percentage deviation of the resistance control setting. The correction factor for the stray capacitance need be considered only for an absolute determination of R or Q. Two ranges of the resistance control are provided, reading directly 0-10 and 0-100 ohms "nominal," i.e., uncorrected, coil resistance.

DIRECT MEASUREMENTS OF R AND L

Although the Type 721-A Coil Comparator has been developed principally for production checking, it is believed that it frequently will be found valuable in the laboratory for direct measurements of reactance and resistance where precise results are not required.

The circuit makes it possible, essentially, to compare a coil with a condenser and resistor without any complications due either to the impedance of the voltage source or of the indicator employed, and it permits the comparison to be made as closely as desired. Assuming an accurate condenser calibration, the accuracy of measurement under such circumstances depends principally on how much the constants of the circuit elements vary with frequency. At high frequencies the capacitance of a condenser may differ widely from its low-frequency value, and its Q may become comparable to that of the coil. The difficulties in making a variable resistance operate satisfactorily at high frequencies are well

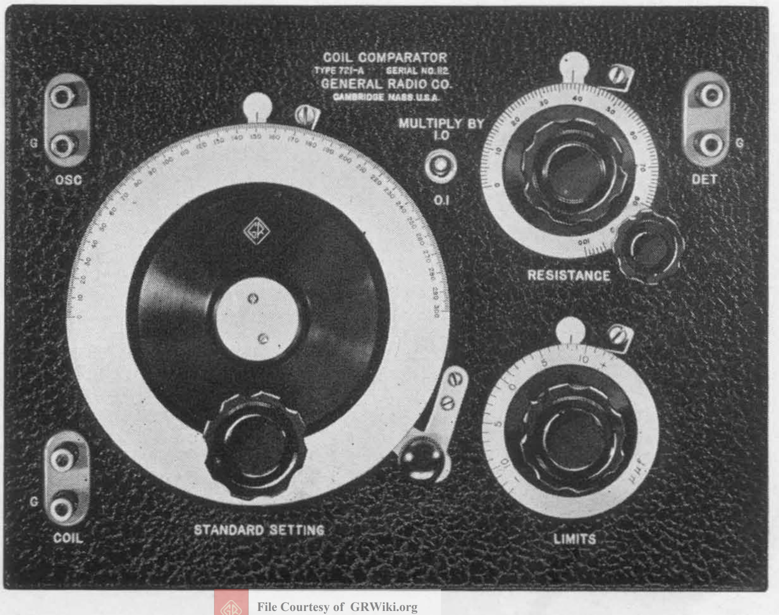


FIGURE 4. Panel view of the coil comparator. For production testing, the main dial is locked at the standard setting and deviations are read on the LIMITS dial

known. Although the TYPE 721-A Coil Comparator is not primarily intended for direct measurements, both the condenser and resistor have been designed so that high-frequency effects are reduced as much as is practicable, and the scales provided permit readings to be made with sufficient precision.

It has been shown that the stray capacitance correction for resistance depends only on the condenser setting. The condenser can be calibrated directly, therefore, once for all, not only in terms of total effective tuning capacitance, but also in terms of resistance correction factor, obtainable from the ratio of easily measured direct capacitances in accordance with equation (4). This correction curve does not vary appreciably from one instrument to another, and the average curve given in the operating instructions is sufficiently close to permit very satisfactory direct measurements of resistance. It is merely necessary to multiply the reading of the resistance control by the correction factor corresponding to the condenser setting to obtain the true series resistance of the coil.

It must be emphasized, however, that the TYPE 721-A Coil Comparator is offered principally for comparison measurements and no guarantee can be made, either with regard to frequency range or accuracy when it is used as a direct-reading instrument. It is hoped that further experience with the new circuit will make it possible to evaluate the errors which occur at high frequencies so that the advantages resulting from its inherent simplicity may be fully realized in direct measurements.

CONSTRUCTION

The condenser has the rotor and both stators insulated from the frame. Connection to the rotor is made at the center between the two sections to reduce the size of the inductive loop and improve the high-frequency performance.

The variable resistance has low residual inductance, and is capable of smooth and continuous variation. The unit employed is similar to the type used as an output potentiometer in General Radio standard-signal generators. It is wire-wound on a form of small cross-section, and the winding is of the Ayrton-Perry construction.

Two separate variable resistors are employed, controlled by the same dial, a toggle switch selecting the range desired. The dial has 100 divisions giving directly, without calibration, the "nominal" coil resistance referred to above.

AUXILIARY EQUIPMENT

The TYPE 721-A Coil Comparator is supplied without oscillator or detector, in order to permit the greatest possible flexibility and economy in the construction of test benches. A single master oscillator can be used to furnish power for several coil comparators. If a modulated oscillator is employed, a small broadcast receiver can be used for the detector and is very much less expensive than a specialized piece of test equipment. An unmodulated oscillator can be used, if preferred, with a heterodyne detector, or with a straight radio-frequency detector such as a radio receiver with an electron-ray tube tuning indicator. The oscillator should be sufficiently shielded magnetically to avoid coupling to the coil under test and should furnish, preferably, about 10 volts output, although even a standard-signal generator can frequently be used satisfactorily. A new General Radio modulated oscillator, suitable as a source of power, will be announced in the near future. — W. N. TUTTLE

SPECIFICATIONS

Tuning Capacitance: The effective tuning capacitance is adjustable between 75 μμf and 1200 μμf when the auxiliary condenser is set at zero (mid-scale). This includes a stray capacitance of 25 to 32 μμf, depending on the setting of the main condenser.

Resistance: The resistance control reads directly within 5% the "nominal" coil resistance from 0.5 Ω to 95 Ω, in two ranges. The correction for stray capacitance, however, lowers the maximum measurable coil resistance to 46 Ω when the tuning capacitance is 100 μμf, and to 85 Ω at 1000 μμf.

Inductance Range: Any coil can be tested which can be tuned to resonance at the test frequency by a capacitance between the limits given above, and which has a series resistance lying within the range specified above.

Calibration: An approximate capacitance calibration is supplied for the main dial; this is actually the average of a number of instruments and is within ±5%. The auxiliary condenser dial is direct reading in micromicrofarads and the resistance dial in ohms. A correction curve for the effects of stray capacitance is supplied.

Mounting: The instrument can be supplied in a walnut cabinet for table use, or with a metal dust cover for building into test equipment.

Accessories Required: Radio-frequency oscillator, preferably modulated for use as a power source, and a radio receiver for use as a detector.

Dimensions: Panel, 12 x 9 inches; depth behind panel, TYPE 721-AM, 9⅛ inches; TYPE 721-AR, 8¾ inches.

Net Weight: TYPE 721-AM, 12⅞ pounds; TYPE 721-AR, 8¾ pounds.

Type		*Code Word*	*Price*
721-AM	With cabinet........................	BIBLE	$85.00
721-AR	With metal dust cover................	BIGOT	80.00

In the laboratories of public utility companies where 60-cycle testing and standardization are carried on, the *VARIAC* is widely used as an easily-adjusted source of test voltage. The photograph below shows the *VARIAC* being used for this purpose in the laboratory of the Edison Company of Boston.

STANDARDIZING THE STANDARD-SIGNAL GENERATOR

● **IN A RECENT ISSUE** of the *Experimenter* a high-frequency standard of voltage was described.* One of the chief uses of this device has been the standardization of signal generator output levels at high frequencies. The following article is written to give the large number of signal generator users a brief idea of how these measurements are made. The equipment described is purely experimental; it has not been put in commercial form and is not available for sale.

A standard-signal generator usually consists of an oscillator coupled through an attenuator to output terminals. The constants of a resistive attenuator are determined at dc or at audio frequencies, those of inductive or capacitive units by computation from the physical dimensions or from audio-frequency measurements. It is possible to intercompare different types of attenuators, and a very carefully constructed unit may be used as a standard in checking cruder attenuators. It is much better, however, to use an entirely independent method.

*L. B. Arguimbau, "A High-Frequency Voltage Standard," General Radio *Experimenter*, Vol. XII, No. 1 (June, 1937).

As is well known, a detector tube with an input consisting of two frequencies superposed will give an output signal of the beat or difference frequency. If one of the signals is fairly large (e.g., 1 volt), while the other is much smaller (e.g., 1 millivolt), the amplitude of the beat frequency will be very closely proportional to the amplitude of the small input signal. This proportionality holds over a very wide range of amplitudes such as 60-80 db, so that the amplitude of the difference frequency will serve as a measure of the small input signal even when this signal is varied from 0.1 μv to 1000 μv or even 50,000 μv. This is a very useful relationship because it permits comparison to be made of the amplitudes of high-frequency signals by measuring amplitudes of low-frequency beat signals.

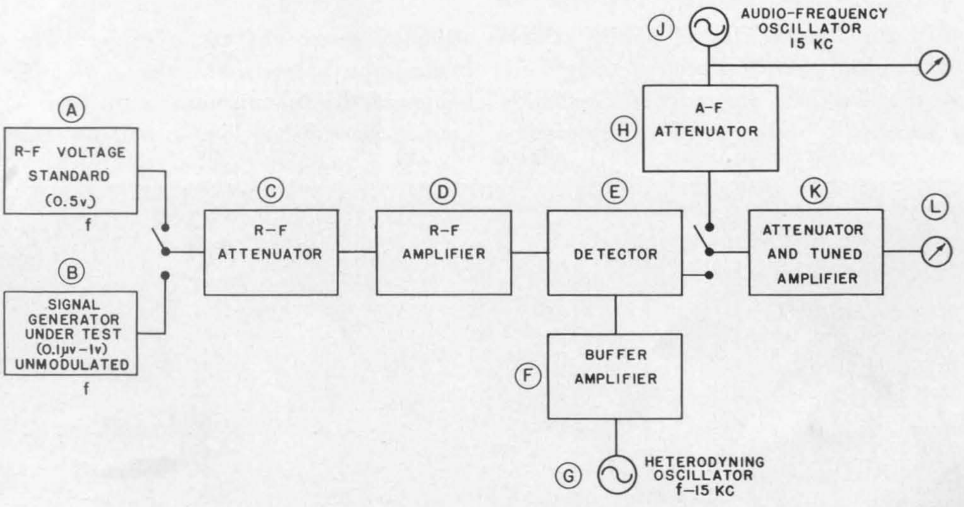


FIGURE 1. A functional diagram showing the equipment and method of measurement used to standardize signal generators

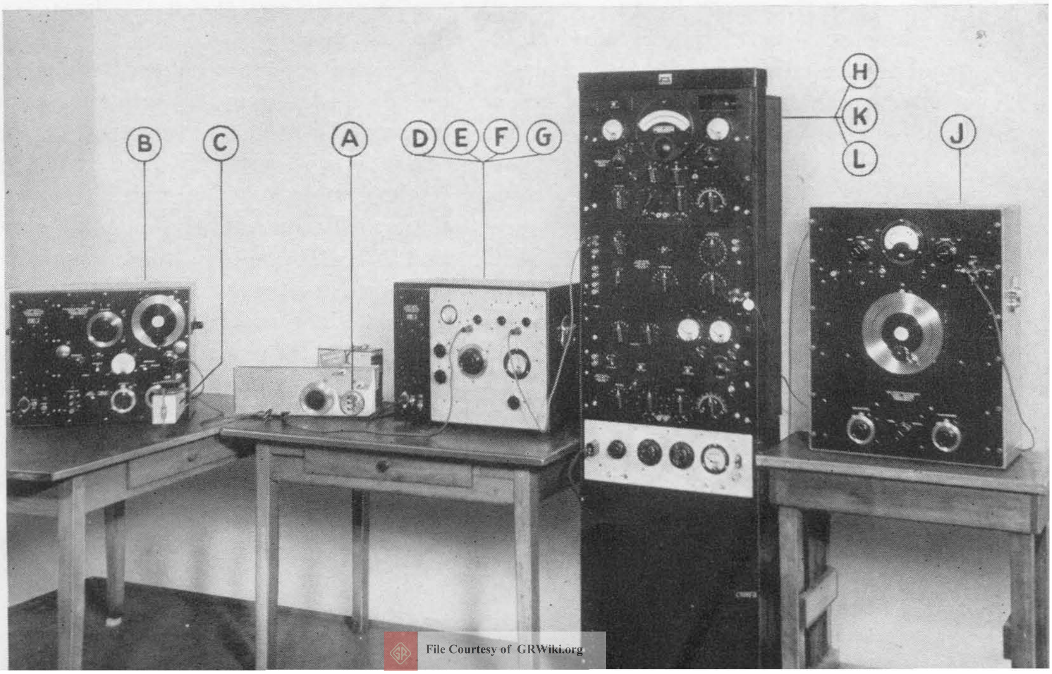
Of course precautions must be taken to make certain that the conditions outlined above are really obtained. For example, it is important that the small signal to be measured should not react on the local heterodyning oscillator. Furthermore, the detection should all occur in the detector rather than in the audio measuring circuits. It is also important that the measuring circuits should measure the beat frequency rather than 60 cycles or vacuum-tube noise of one sort or another, a requirement which makes highly selective audio-measuring circuits necessary. When these precautions have been taken, however, one has a method of comparing any voltage level with the output of the high-frequency standard previously described.

The system is shown in the functional diagram of Figure 1. Either the fixed voltage standard or the signal generator under test is connected through an attenuator to a high-frequency amplifier. The attenuator is a capacitive one of very low input capacitance and of comparatively high resonant frequency. (The construction is similar to that which was used in the TYPE 604-B Signal Generator.)* This attenuator is included chiefly to provide a high input impedance for the test circuit, although it is also used for adjusting the circuit operating level. It is removed when comparisons are made between different low levels of the same generator. As indicated in the figure, the amplified high frequency is heterodyned with another high frequency, and the low-frequency output is passed through a low-pass filter to audio-frequency measuring equipment. The audio equipment consists of a tuned circuit analyzer† built in a particularly flexible manner with gain controls in various positions; the circuit being ar-

*E. Karplus, "Receiver Testing in the Ultra High-Frequency Bands," General Radio *Experimenter*, Vol. VII, No. 9 (February, 1933).

†A. G. Landeen, "Analyzer for Complex Electric Waves," *Bell System Technical Journal*, Vol. VI, pp. 230–247 (April, 1927).

FIGURE 2. Photograph of the apparatus used at General Radio. The encircled letters correspond to those in the diagram of FIGURE 1



ranged to give a minimum of vacuum-tube noise. The comparison audio-frequency signal was provided with an attenuator of 120-db range in 0.2 db steps. Interpolation made it possible to estimate to about 0.01 db under favorable conditions.

The procedure in making the measurement is evident from the functional diagram of Figure 1. The standard voltage is applied and a reading obtained on the audio-frequency voltmeter. The unknown voltage from the generator under test is then substituted for the standard and the audio-frequency attenuator is adjusted to produce the same deflection. The difference in the attenuator settings for the two conditions then gives the difference in level between the standard and unknown voltages.

At standard broadcast frequencies, the accuracy of measurement is in the vicinity of 0.1%. At high frequencies (30 to 100 Mc), although the error in the voltage standard itself is small, differences between the internal impedance of the standard and that of the generator under measurement may lead to unpredictable errors at some frequencies because of resonant effects. In general, however, the error at high frequencies is not greater than 2% or 3%.

Two models of this equipment have been built and development has been started on a third. The first unit was built in 1930 for use in the standard broadcast band; the second, built two years later, could be used at frequencies up to 30 megacycles and it is hoped that the new unit will operate up to 100 megacycles.

— L. B. ARGUIMBAU

STANDARD FREQUENCIES FOR THE MUSICIAN

● **ON JUNE 1, 1937,** the National Bureau of Standards began a new and unique standard-frequency service. Intended for musicians, the new transmission consists of a 5-megacycle carrier modulated at 440 cycles per second, the American standard of musical pitch for A above middle C.

Experimental transmissions were given in August and September, 1936, and the interest displayed by musicians, musical organizations, and manufacturers of musical instruments was sufficient to justify their continuance as a regular standard-frequency broadcast.

Both the 440-cycle modulating frequency and the 1000-cycle frequency used on other standard-frequency transmissions are derived from a standard-frequency oscillator by means of multivibrators supplied by the General Radio Company.

Figure 1 shows how these frequencies are obtained from the standard frequency of 200 kc. A frequency of one kilocycle is produced by dividing 200 kc in three steps of 4, 5, and 10, respectively. The output of the 1-kilocycle multivibrator is filtered to obtain a pure 1000-cycle voltage which is then used to modulate a standard frequency transmitter. To produce a 440-cycle frequency, the 11th harmonic of the 1-kilocycle multivibrator is selected by means of a filter and used to control an 11-kilocycle multivibrator. Two successive reductions by factors of 5, using multivibrators of 2.2 kc and 0.44 kc, are then

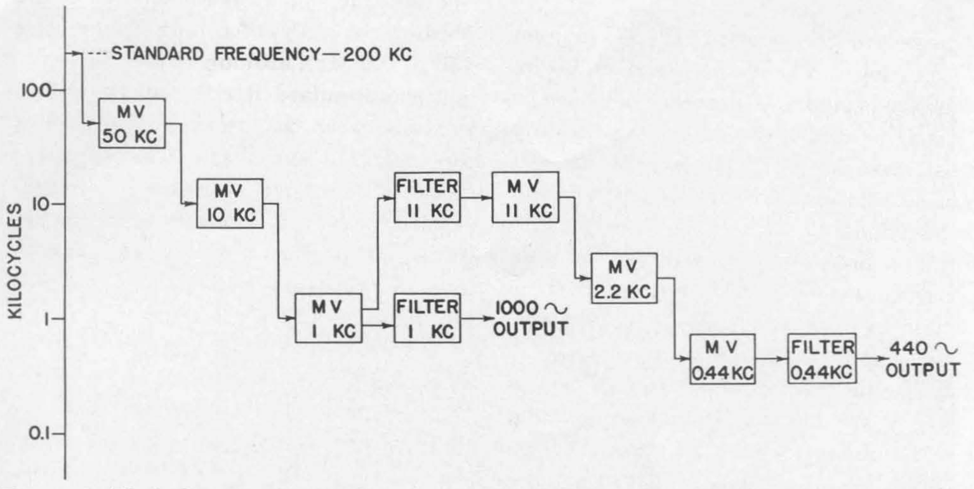


FIGURE 1. Block diagram showing how frequencies of 1000 cycles and 440 cycles are derived from a 200-kilocycle standard frequency

necessary to produce the desired 440 cycles per second. A filter is used to eliminate harmonics from the 440-cycle voltage.

The National Bureau of Standards is interested in receiving reports of methods of use or special applications of the standard frequencies.

MISCELLANY

● **AT THE SUMMER CONVENTION** of the American Institute of Electrical Engineers held at Milwaukee in June, the Best Paper Prize for 1936 in the field of theory and research was awarded to Dr. Harold E. Edgerton of M.I.T. for his paper on "High-Speed Motion Pictures" presented at the Winter Convention of the Institute in New York in January, 1936. Dr. Edgerton is the originator of the Edgerton Stroboscope and of the high-speed camera manufactured by General Radio.

● **RECENT VISITORS** at General Radio: Messrs. I-Lun Liu and Chao-Chi Cheng, radio officers of the Chinese Navy; Mr. R. L. Palmer, Laboratory Supervisor, International Business Machines, Inc.; Mr. C. G. Motwane of Eastern Electric and Engineering Company, Bombay, India.

● **MR. H. B. RICHMOND,** Treasurer of the General Radio Company, sailed with Mrs. Richmond and their two children on the *S. S. Saturnia*, on July 25, for Venice. He plans to spend several weeks in Europe and will visit a number of General Radio's foreign representatives.

● **AN APOLOGY** is due our readers for the photograph of Figure 5 in our May issue. Although diode characteristics are not linear for low values of voltage, this photo shows exactly linear meter scales. Upon investigation, we find that the meter shown was one of a lot rejected because the scales were incorrect.

● **THAT THE CURRENT** building boom has already reached General Radio is indicated in the accompanying photograph which shows a fourth floor being added to the only three-floor unit of our factory. This addition, now completed, brings our floor space to over 75,000 square feet, in three four-floor units.

● **TYPE 721-A COIL COMPARATOR** was designed by Dr. W. N. Tuttle, author of the article describing it which appears in this issue. These instruments are already in stock and immediate delivery can be made.

THE General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in communication-frequency measurement and control problems. When sending requests for subscriptions and address-change notices, please supply the following information: name, company name, company address, type of business company is engaged in, and title or position of individual.

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also IN THIS ISSUE

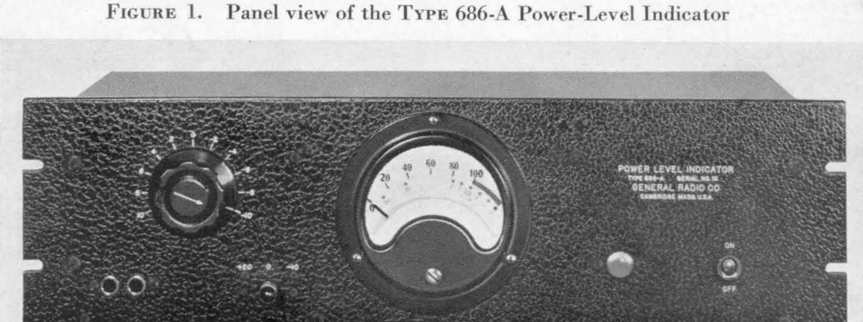
A PEAK-READING POWER-LEVEL INDICATOR FOR MONITORING BROADCAST AND SOUND RECORDING CIRCUITS

● **THE SHORTCOMINGS** of existing types of power-level indicators are matters of common knowledge to both the chief engineer and the man who "rides the gain" in the monitoring booth. Old-style, sluggish indicators, however well they may read the r-m-s average of power levels, are useless for indicating the rapid surges of power in speech and music transmission. These sudden peaks of short duration cause circuit overload with its attendant transmitter distortion and light-valve clash in sound recording. The newer high-speed meter movements, on the other hand, follow the minor level fluctuations so faithfully that the eye has difficulty in interpreting the readings, and their continued use results in eyestrain and fatigue.

The ideal meter characteristic is one having a fast upswing so that true amplitude indications are obtained on the shortest pulses of speech and music, while a slow return movement makes it possible to observe the peak amplitude and eliminates the fatiguing erratic motion characteristic of the rapid return swing.

This arrangement, used in modern broadcast modulation monitors, was originally agreed upon as a result of conferences on broadcast modulation monitors sponsored by the Federal Communications Commission. Attending the conferences were representatives of the Com-

Figure 1. Panel view of the Type 686-A Power-Level Indicator



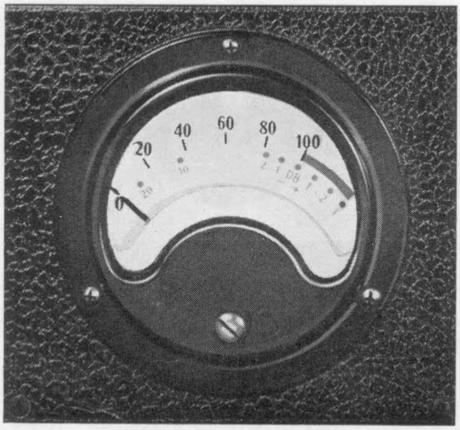


FIGURE 2. Photograph of the indicating meter. The main scale is black on a yellow background. The decibel scale is red. Two lamps behind the panel illuminate the scale

mission, the broadcasters, and leading manufacturers of radio instruments. Tests and demonstrations of different types of meter movements were made through the courtesy of Bell Telephone Laboratories in New York City. These conferences were the basis of the Federal Communications Commission specifications for modulation monitors. The desirability of this type of monitoring indication has been amply demonstrated by the modulation monitors, and this has served to emphasize the need for a similar system in audio-frequency monitoring. Among the advantages of such a system are:

(1) A more accurate indication of peaks is obtained.

(2) The meter is easy to read without eyestrain.

(3) Because it gives the same type of peak indication as does the modulation monitor, audio-frequency power-level readings can be interpreted in terms of percentage modulation and *peak readings accurately checked between the studio and the transmitter*.

(4) By adding a 0-to-100 scale like that on the percentage modulation meter, the reading of the power-level indicator can be made to coincide with that of the modulation monitor.

(5) The psychological effect is excellent in that the meter seems to show the audio wave as it sounds to the ear from a monitoring loudspeaker or headphones.

TYPE 686-A POWER-LEVEL INDICATOR*

General Radio's new TYPE 686-A Power-Level Indicator, shown in Figure 1, has the high-speed, slow-return meter movement just described. Designed to meet a set of rigid specifications for electrical performance, it registers faithfully and follows accurately the peaks occurring in speech and music. Particular attention has been given to mechanical features such as ease of reading and accessibility of tubes and other component parts.

CIRCUIT

The circuit is that of a full-wave vacuum-tube voltmeter with a linear preamplifier. Since the input impedance is resistive and constant with amplitude, no distortion is introduced into the channel across which it is connected. This impedance is greater than 15,000 ohms, resulting in an insertion loss of less than 0.15 decibel. Consequently, a negligible amount of power is absorbed from 500-ohm transmission lines.

METER

The indicator is a large high-speed Weston Model 643 Meter. The needle reaches its maximum deflection in approximately 0.15 second which means that it will respond to the shortest pulses occurring in most speech and music circuits. The mechanical damping

*This instrument has been developed in collaboration with the Columbia Broadcasting System. Their assistance in design and testing is gratefully acknowledged.

stops the swing at maximum amplitude with no appreciable overshoot, and an electrical delay circuit, composed of capacitance and resistance, allows it to return slowly toward zero. In this way the meter registers accurately each peak, but appears to "float" on the peaks without erratic movement.

The meter scale, shown in Figure 2, is printed in simple bold figures on a soft yellow background. The main scale, reading from 0 to 100, can be used to indicate per cent modulation, per cent of modulation capability, per cent utilization of channel, or percentage of any arbitrary limit. An auxiliary scale reading in decibels is also provided. The scale is illuminated from behind the panel so that it is easily read in dark monitoring booths. The upper range of the scale above 100 is colored red as a warning against small overloads.

RANGE

A wide operating range is provided. Zero decibels on the meter, which is about three-quarters of the way upscale, correspond at greatest sensitivity to an operating circuit level as low as −20 decibels. A level of −40 decibels represents a deflection of about ¼ inch and is easily readable. The maximum level is +33 decibels. The operating level of the instrument is adjustable by means of a 10-step switch in 2-decibel steps and a key-switch multiplier.

OTHER DESIGN FEATURES

No power transformers or filter choke coils are used. Therefore, the instrument cannot induce 60-cycle hum into surrounding high-gain amplifiers by inductive pickup. All tubes are easily accessible from back of relay rack. The input may be connected to a terminal board in rear or to normal-through standard double patch-cord jacks at front of panel. This feature is especially useful when the instrument, although permanently connected in one channel, is desired to check another system which cannot be patched in through the regular patchboard. The power input terminals are shown at the right of Figure 3. The attachment is designed to hold BX cable which can be wired directly to the terminals shown. —Arthur E. Thiessen

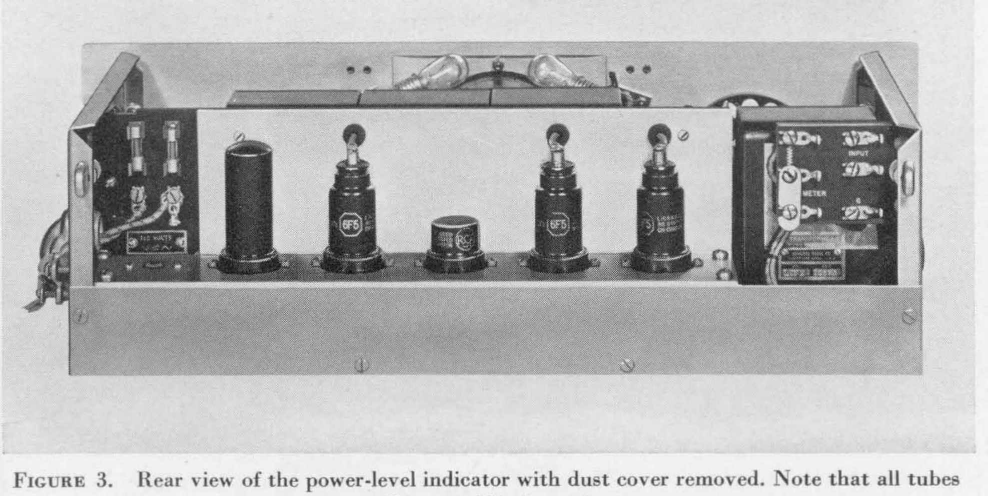


Figure 3. Rear view of the power-level indicator with dust cover removed. Note that all tubes are easily accessible from the rear

SPECIFICATIONS FOR TYPE 686-A POWER-LEVEL INDICATOR

Power-Level Range: Zero decibels on the meter scale (100 on black scale) will represent from −20 to +30 decibels, depending on attenuator setting. Total over-all calibrated range −40 to +33 decibels. All ratings are for a zero level of 6 milliwatts in a 500-ohm line. Calibration at other zero levels or for other line impedances can be supplied on order.

Frequency Characteristic: The frequency response is flat within one decibel from 60 to 10,000 cycles; within two decibels from 40 to 12,000 cycles.

Vacuum Tubes: Five all-metal tubes are used, easily accessible from back of panel:

3 — Type 6F5
1 — Type 6H6
1 — Type 25Z6

Calibration: The instrument is precalibrated at the factory, and any change resulting from tube replacements can be easily corrected by the user.

Power Supply: 115 volts alternating current, 50 to 60 cycles.

Mounting: Standard relay-rack mounting, 19 inches by 5¼ inches; depth behind panel, 8½ inches; black crackle panel finish.

Net Weight: 23½ pounds with tubes and accessories.

Type		*Code Word*	*Price*
686-A		ANGER	$195.00

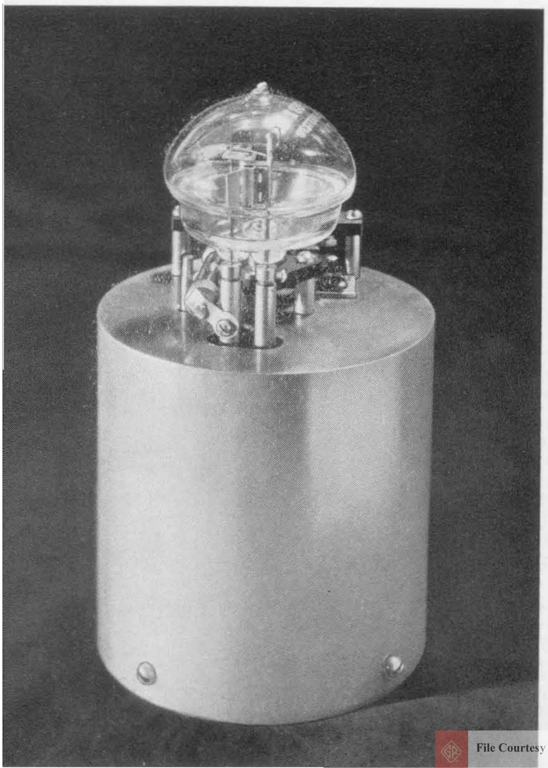
This instrument is licensed under patents of the American Telephone and Telegraph Company, solely for utilization in research, investigation, measurement, testing, instruction, and development work in pure and applied science

AN ULTRA-HIGH-FREQUENCY OSCILLATOR

• **THE WIDENING FIELD** of usefulness for ultra-high frequencies in radio communication has naturally stimulated the development of equipment for making measurements at those frequencies. Measurements of such factors as reactance, resistance, dielectric constant, permeability, and power factor are necessary both to prove the acceptability of existing designs and to provide a basis for the development of new designs and the application of new materials.

A prerequisite for measurements at any frequency is a satisfactory power source. The author, a member of the staff of the Department of Electrical Engineering at the Massachusetts Institute of Technology, has developed for this purpose the ultra-high-frequency oscillator described here. The work was a joint research project of M. I. T. and the General Radio Company.

— Editor



Vacuum-tube oscillators for operation at ultra-high frequencies have received considerable attention in the last few years. Improved vacuum tubes have permitted the use of circuits which govern the frequency of oscillation to a much greater degree than is possible at these frequencies with the older and more conventional tubes. Several tank circuits for frequency stabilization have been developed, notably the parallel-wire and coaxial transmission lines and the Kolster toroid. None of these, however, meets all the requirements for a satisfactory laboratory source. These requirements are as follows: (1) A high degree of frequency stability under varying external conditions, (2) a confined

Figure 1. The complete oscillator consisting of tank circuit and vacuum tube. The over-all height is 7 inches

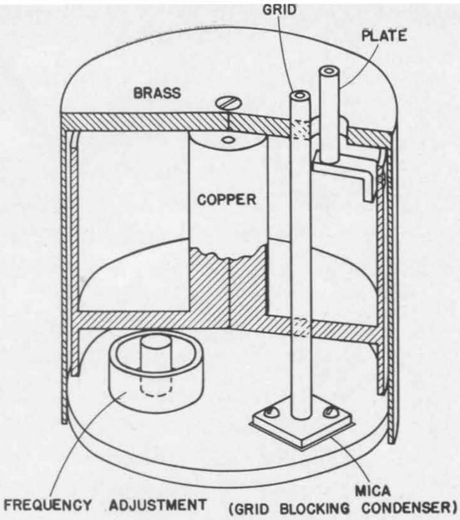


FIGURE 2. Sectional view of the tank circuit showing details of assembly

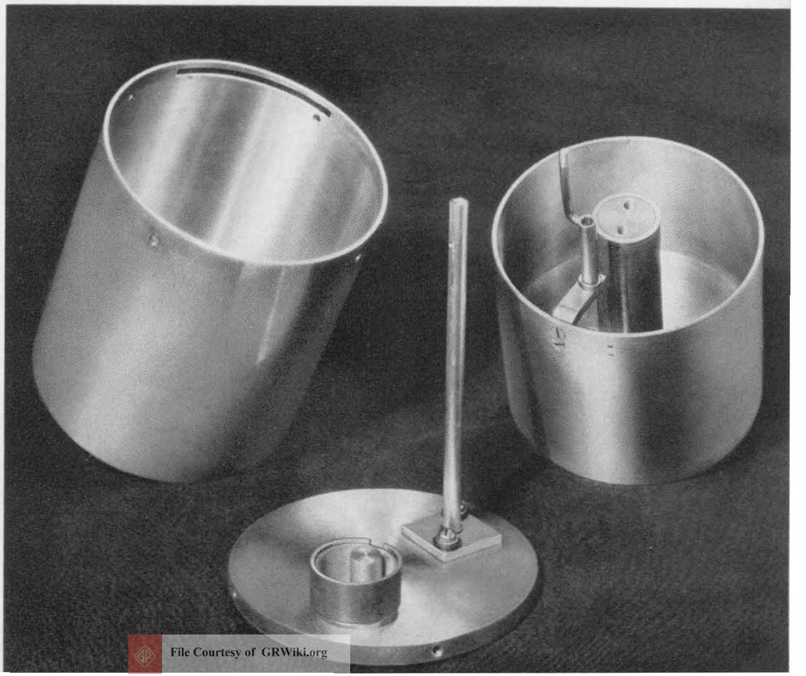
electromagnetic field, (3) ample output for use as a source for high frequency measurements, and (4) a convenient physical size. A good compromise between these conflicting requirements has been achieved in a new oscillator utilizing a vacuum tube[1] especially designed for the ultra-high frequencies coupled to a lumped concentric-element tank circuit.

This tank circuit consists of an outer containing-cylinder with a cylindrical piston-shaped insert. Referring to Figures 2 and 3, it is perhaps simplest to consider the oscillatory tank circuit as an L-C circuit, whose capacitance is that formed by the outer cylinder and the large inner copper tube, and whose inductance is that obtained by the field surrounding the inner copper rod. The dimensions of the tuned circuit are sufficiently small in comparison with the wavelength to permit its treatment as a lumped circuit.

The effectiveness of this oscillatory circuit for frequency stabilization is the result of the low losses in its component elements and of its connection to the vacuum tube in such a manner as to appear as a circuit with elements of low reactance. For the oscillator illustrated, which has an outside diameter of slightly more than 4 inches, the tank capacity is

[1]Kelly, M. J., and A. L. Samuel, "Vacuum Tubes as High Frequency Oscillators," *E. E.*, Vol. LIII, No. 11, Nov., 1934, pp. 1504-1517.

FIGURE 3. The concentric-element tank circuit taken apart. The outer brass shell is shown on the left, the inner copper cylinder on the right. The brass disc in the foreground closes the brass cylinder after the copper insert has been placed in position. The small copper cylinder, located eccentrically on a shaft passing through the disc, was used in conjunction with the large copper cylinder to form a small, variable condenser for the adjustment of the frequency to a particular value. The grid-blocking condenser made of a brass plate, separated from the brass disc by a thin mica sheet, is the support for the grid rod.



about 130 $\mu\mu$f, and the tank inductance, about 18 cm (18 x 10^{-9}h). At its operating frequency of 100 Mc the Q of the resonant circuit is approximately 2500.

The properties of this oscillator which are of interest here are the effect on the frequency of oscillation of variations in electrode voltages and other external conditions, the effect of loading, and the drift in frequency during the warming-up period.

The change in the frequency of oscillation produced by a variation in the applied plate voltage is given in Figure 4. There is also given in the same figure a similar curve obtained when the oscillator was connected to a resistive load so as to produce 4 watts output to the resistor with a plate-circuit efficiency of 20% at a plate voltage of 400 volts. The stability for the loaded condition is naturally not so good as that obtained for the oscillator unloaded because of the increased losses of the complete system, but it is much better than the stabilities of earlier types of oscillators for this frequency region[2].

Because of the method used in the measurement of these changes in frequency, these results contain no appreciable drift effect and can be considered as essentially dynamic measurements. That is, the effect of physical changes in the oscillator as a result of varying thermal conditions was minimized in order not to mask the effect of dynamic changes in the tube parameters.

A rapid variation of the applied filament voltage produced only a very small shift in the frequency. However, a slow variation in the filament voltage which permitted the thermal equilibrium of the filament to readjust itself produced a change in frequency opposite in sense to, and somewhat greater in magnitude than, that produced during the rapid variation of the plate voltage shown in Figure 4.

The ambient temperature coefficient of frequency of the oscillator has been made less than the temperature coefficient of expansion of the individual metals which are used in the tank circuit. This reduction has been accomplished by the proper utilization of the differing temperature coefficients of expansion of brass and copper to produce a tank

[2]Dennhardt, A., "Ueber Mehrrohrschaltungen fur sehr hohe Frequenzen," *Zeitschrift für Hochfrequenztechnik*, Vol. XXXV, No. 6, June, 1930, pp. 212-223.

Wenstrom, W. H., "An Experimental Study of Regenerative Ultra-Short-Wave Oscillators," *Proc. I. R. E.*, Vol. XX, January, 1932, pp. 113-130.

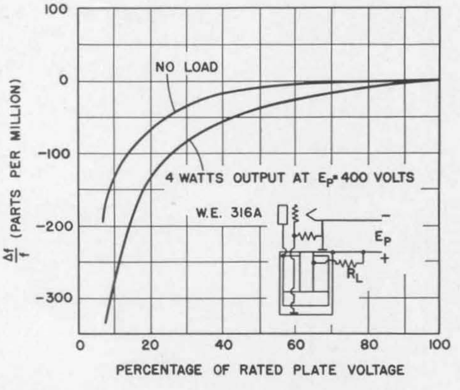


FIGURE 4. Change in frequency produced by a variation in applied plate voltage. The upper curve is taken at no load, the lower with a load of 4 watts

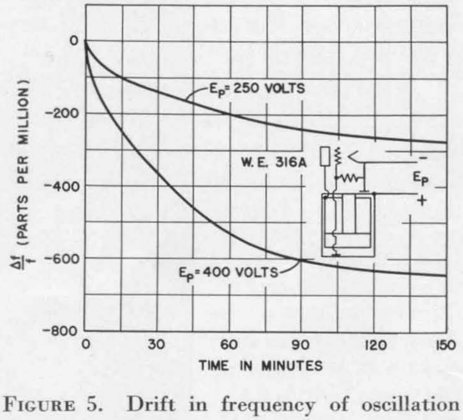


FIGURE 5. Drift in frequency of oscillation during warming-up period at plate voltages of 250 volts and 400 volts

capacitance with a negative temperature coefficient which approximately balances the positive temperature coefficient of the inductance. By this means, an ambient temperature coefficient of frequency of less than 5 parts per million per degree Centigrade is readily achieved.

The drift in frequency of oscillation during the warming-up period for the unit illustrated is given in Figure 5. This drift, which is approximately proportional to the input power to the plate circuit, is primarily a result of changes in the spacing of the tank condenser because of the temperature differential developed in the oscillator. By a change in the design of the given tank circuit, this drift can be materially reduced. However, to accomplish this reduction, the physical size should be increased, or the resultant frequency stability during varying electrode voltage conditions will be lessened. Thus, for a given application of this type of oscillator, unless compensation means are used, a design which effects the best compromise for that application should be adopted.

—Arnold Peterson

TYPE 418-G DUMMY ANTENNA

● **TENTATIVE SPECIFICATIONS** for a new standard dummy antenna for receiver testing have been adopted by the I.R.E. Standards Committee on Radio Receivers. Previously two dummy antennas were recommended to simulate the characteristics of a standard receiving antenna. One of these, intended for use between 540 and 1600 kc, consisted of a series circuit containing 200 $\mu\mu$f, 20 μh, and 25 Ω; the other, for use at higher frequencies, was a 400-ohm series resistance.

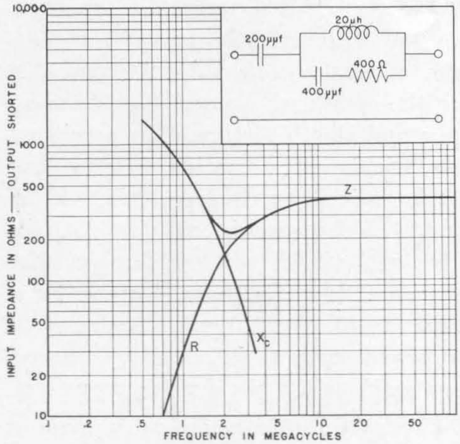


Figure 1. Resistance, reactance, and impedance characteristics of the Type 418-G Dummy Antenna

The new standard dummy antenna approximates both these characteristics. Its minimum impedance is 220 ohms, mainly resistive, at 2200 kc. The impedance approaches 400 ohms resistive at higher frequencies. The circuit constants and the impedance characteristic of the antenna are shown in Figure 1.

The new Type 418-G Dummy Antenna is designed to these specifications. It is mounted in a cylindrical metal case, with plug and jack terminals to fit the Type 605-A Standard-Signal Generator and its output cable.

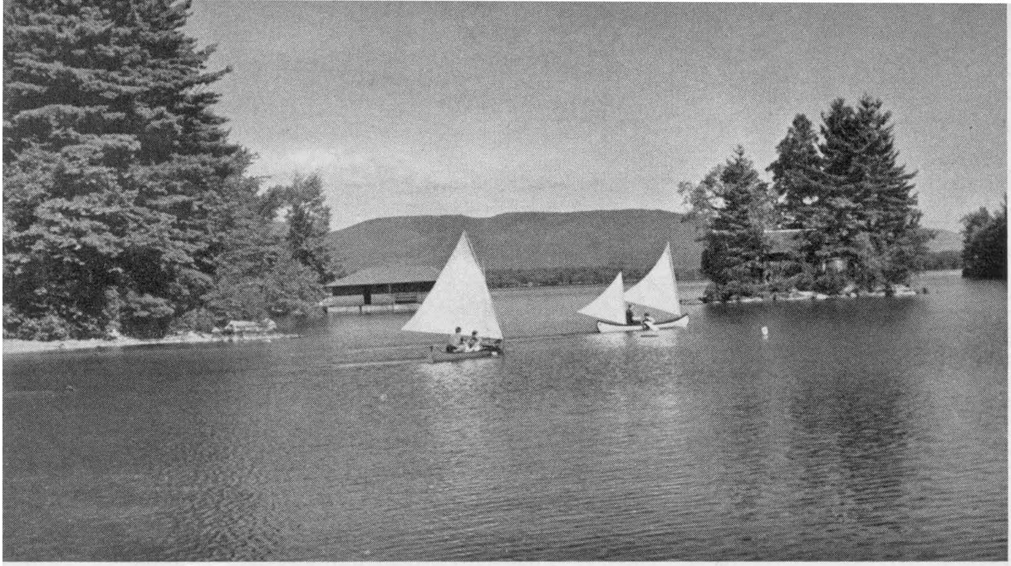
SPECIFICATIONS

Dimensions: (Length) 4⅛ x (diameter) 1⅜ inches, over-all.

Net Weight: 6 ounces.

Type	*Code Word*	*Price*
418-G	DITCH	$10.00

Figure 2. Photograph of the dummy antenna



MISCELLANY

● **THIS YEAR'S** unusually brisk season of transatlantic travel was augmented on the week-end of September 19 by the return of General Radio's treasurer and the departure of its president. Mr. Richmond, returning from several weeks in western Europe, brings a full quota of photographs, including several excellent views of our foreign sales agencies. Mr. Eastham, leaving for a vacation of about three months, plans to spend some time in eastern Europe.

● **TYPE 686-A POWER-LEVEL INDICATOR**, described in this issue of the *Experimenter*, was designed by A. E. Thiessen and Frederick Ireland.

● **IF YOU ARE ATTENDING** the Rochester Fall Meeting of the Institute of Radio Engineers, be sure to call at the General Radio booth. Measuring and test instruments for manufacturers of receivers and parts will be on display, and a staff of GR engineers will be in attendance.

● **MR. ROBERT F. FIELD** held his annual house party for GR engineers on the week-end of September 19 at Lake Winnipesaukee, New Hampshire. Nineteen attended and made full use of the available facilities for sailing, swimming, tennis, badminton, and other outdoor sports. A Saturday guest was Electronics' Editor, Keith Henney, whose Leica was much in evidence. Those familiar with Mr. Henney's prowess in the field of portraiture will be interested in the marine scene shown above. His erstwhile portrait victims at General Radio wish him all possible success in this new field.

THE General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in communication-frequency measurement and control problems. When sending requests for subscriptions and address-change notices, please supply the following information: name, company name, company address, type of business company is engaged in, and title or position of individual.

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also IN THIS ISSUE

A RADIO-FREQUENCY SOURCE FOR THE LABORATORY

● **NEARLY ALL RADIO-FREQUENCY MEASUREMENTS** require a source of radio-frequency power, and consequently the r-f oscillator is one of the most important items in the equipment of the radio laboratory. Because of the manifold applications of a general-purpose r-f oscillator, ease of operation is a primary design requirement. This feature is emphasized in the TYPE 684-A Modulated Oscillator.

The design of this new oscillator is similar in many respects to that of the TYPE 605-B Standard-Signal Generator. The master oscillator uses the same tuned circuit with its wide frequency range and direct-reading dial. The oscillator is followed by an amplifier which operates (1) as a modulator and (2) as a buffer to isolate the output circuit from the oscillator. Although this arrangement is identical with that used in the signal

FIGURE 1. Panel view of the TYPE 684-A Modulated Oscillator

generator, the output of the amplifier is considerably higher than in the signal generator because the restrictions of low output impedances and accurate voltage calibration are removed.

Other features include internal modulation at 1000 cycles, a detector for obtaining heterodyne beats when the oscillator is unmodulated, and a 1000-cycle output for audio-frequency testing. The instrument can be supplied for a-c operation with a built-in voltage regulator, or for operation from external batteries.

USES

The TYPE 684-A Modulated Oscillator provides a completely satisfactory power source for the TYPE 516-C Radio-Frequency Bridge and for the TYPE 721-A Coil Comparator. In measuring antennas and other impedances with the radio-frequency bridge, the direct-reading frequency control of this oscillator greatly reduces the time consumed in making measurements. Since the frequency calibration is good to 1%, the oscillator is quite satisfactory for approximate frequency measurements. Here both the direct-reading feature and the provision for obtaining heterodyne beats are valuable.

FREQUENCY RANGE

The range of frequencies covered by this oscillator is extremely wide, extending from high audio frequencies to the low end of the ultra-high frequency range. The normal, direct-reading range extends from 10 kilocycles to 30 megacycles. An additional range, not direct reading, is provided to cover frequencies between 30 megacycles and 50 megacycles.

The main frequency-control dial carries three scales, two of which are direct reading in frequency. The third scale is

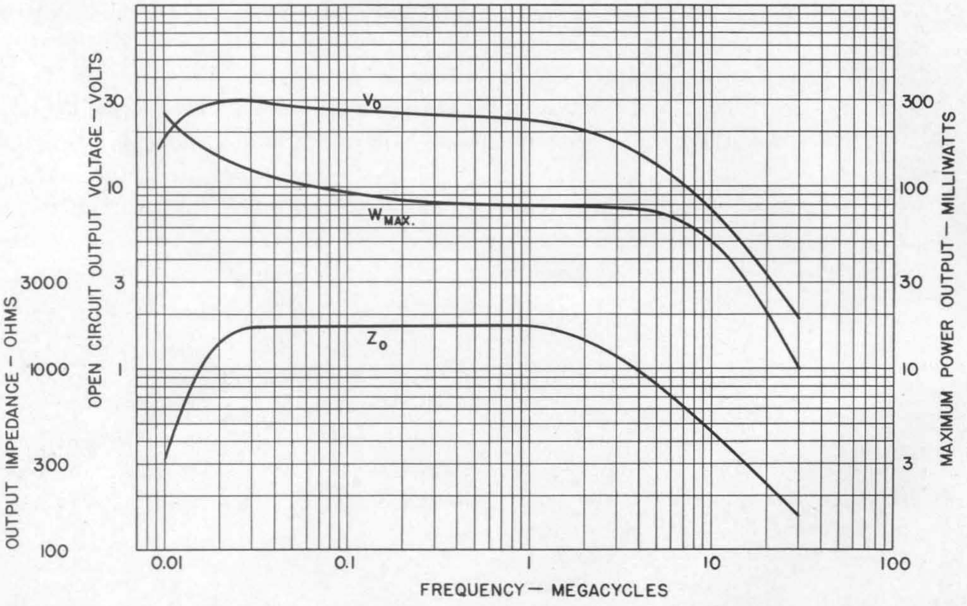

FIGURE 2. Output characteristics of the modulated oscillator. The power curve shows the maximum obtainable into a resistive load. These are average curves and do not take into account the slight differences in voltage and power which occur between the high-frequency end of one range and the low-frequency end of the next range at the same frequency

linear and is engraved in arbitrary divisions. Since the condenser plates are shaped to give a logarithmic variation of frequency with dial rotation, equal angular intervals on the dial correspond to equal percentage changes in frequency. This property is used in providing an auxiliary slow-motion dial with 125 uniform divisions, each corresponding to 0.1% change in frequency. Both dials are illustrated on page 7, under the description of the TYPE 605-B Standard-Signal Generator.

OUTPUT

Output characteristics for the TYPE 684-A Modulated Oscillator are shown in Figure 2. The output impedance is 1800 Ω (resistive) in the middle of the frequency range. At high frequencies, the impedance is lowered by the shunt capacitance of 35 μμf; at low frequencies by the shunting effect of the plate feed choke of the amplifier tube.

Radio-frequency harmonics are approximately 10% of the output voltage.

An internal 1000-cycle oscillator supplies modulating voltage to the grid of the amplifier tube for about 35% modulation, independent of the carrier frequency setting. When modulation is not desired, the 1000-cycle oscillator tube can be used to produce heterodyne beats between the r-f oscillator and any external frequency. The output of the 1000-cycle oscillator is available at a pair of terminals for audio-frequency testing.

STABILITY

Oscillator stability is excellent because of the large tuning capacitance of

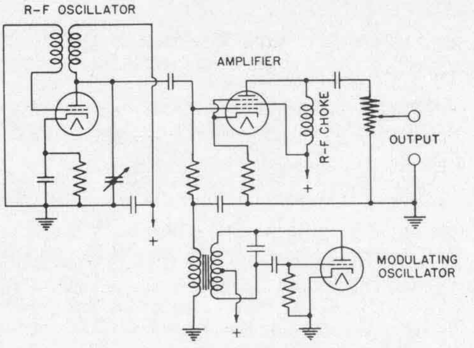

FIGURE 3. Schematic wiring diagram of TYPE 684-A Modulated Oscillator. For the sake of simplicity, power supply connections are omitted, as are the 1000-cycle output terminals and the modulation switch and its associated terminals for using the 1000-cycle oscillator tube as a detector

1400 μμf. In addition, all ordinary line voltage fluctuations are compensated for in a-c operated models by a built-in line voltage regulator. Modulation and variations in load have a negligible effect on the oscillator frequency, since an amplifier-modulator stage is used between the oscillator and the output circuit.

CIRCUIT

A schematic circuit diagram is shown in Figure 3. Power supply is omitted from this diagram for the sake of simplicity, as are the 1000-cycle output terminals.

POWER SUPPLY

The TYPE 684-A Modulated Oscillator can be supplied for operation from a 115- or 230-volt, 40-to-60-cycle, a-c line or from external batteries. In the battery model, space is provided for small plate batteries, but filament heaters are supplied by an external storage battery.

SPECIFICATIONS

Carrier Frequency Range: 9.5 kilocycles to 30 megacycles, direct reading; 30 to 50 megacycles, not direct reading.

Frequency Calibration: Direct-reading dial accurate to 1% up to 10 Mc and accurate to 2% up to 30 Mc. A correction curve is supplied for the 10-30 Mc range, yielding an accuracy of calibration of 1%. A frequency calibration curve is supplied for the 30-50 Mc range.

Open Circuit Output Voltage: 20 to 25 volts up to 2 Mc, decreasing with frequency to 1.0 volt at 30 Mc, when using the a-c supply or 225-volt battery plate supply. This output is approximately halved when using a 135-volt battery plate supply.

Output Impedance: Essentially 1800 Ω shunted by 35 μμf.

Modulation: Internal modulation of about 35% at 1000 cycles (± 5%) controlled by switch.

1000-Cycle Tone: A 1000-cycle (± 5%) voltage of 10 or 20 volts (depending on power supply) is available at the panel. The output impedance for this frequency is 20 KΩ.

Heterodyne: A heterodyne detector for checking frequencies is built into the instrument.

Tubes:
With battery supply:
One 89-type tube
Two 76-type tubes
With a-c supply:
One 5Z4-type rectifier tube
One 6F6-type tube
One 6F5-type tube
Four Type T-4½ Neon Lamps
One 89-type tube
Two 76-type tubes
All necessary tubes are furnished.

Power Supply: Either a-c operation or battery operation is possible. The a-c power supply operates from 40-60 cycle lines of 115 or 230 volts and compensates for ordinary line voltage fluctuations.

With the battery model, a battery control panel is supplied which provides filters and connections for an external 6-volt battery and for an external 225-volt "B" battery. If desired, three 45-volt "B" batteries can be installed inside the instrument.

Power Consumption:
A-C Operation: 60 watts.
Battery Operation: 6 volts, 1.2 amperes; 135 volts, 20 ma or 225 volts, 40 ma.

Shielding: Sufficient shielding has been provided to permit the use of the instrument for bridge measurements.

Mounting: The instrument is supplied for table mounting, but can be easily adapted for relay-rack mounting by removing two brackets at the ends of the panel.

Either power supply is mounted directly in the instrument.

Accessories:
Shielded Output Cable
Terminal Shield
Type 274-M Plug
One 6-foot cable for line connection with Type 684-P1 Power Supply.
One 10-foot shielded cable for battery connection with Type 684-P10 Battery Supply Panel.

Weight:
With a-c power supply: 47 pounds.
With battery supply panel: 38 pounds.

Dimensions: 19½ inches wide, 10½ inches high, 11 inches deep, over-all. Panel, 19 x 10½ inches.

Type		*Code Word*	*Price*
684-A	A-c power supply, 115 volts, 40-60 cycles	BANJO	$340.00
684-A	Battery power supply	BANDY	320.00

TYPE 449-A ADJUSTABLE ATTENUATOR

● **IT IS FREQUENTLY NECESSARY** to reduce by definitely known amounts the signal levels in broadcast speech circuits and in sound motion-picture recording channels. Such adjustments of level may also involve changes in line impedance. A convenient attenuator for making these adjustments greatly facilitates the interconnection of lines, amplifiers, and mixers, and increases the flexibility of the studio equipment. It is especially useful as an isolation network between transmitter equipment and telephone lines. The Columbia Broadcasting System, for instance, has found this type of attenuator to be very convenient.

The Type 449-A Adjustable Attenuator, which is designed specifically for this purpose, is a compact, ruggedly constructed, and accurate network which can be quickly placed and plugged into any speech or music circuit requiring level or impedance adjustment.

It consists of six separate balanced-H networks controlled by three lever-key

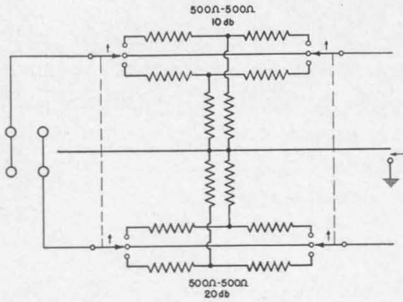

FIGURE 2. Wiring diagram of the first switch. Connections for the other two switches are similar

switches. The input network resistance is 500 ohms. The action of the first two keys inserts attenuation in 10-decibel steps between 0 and 60 decibels. The third key operates an impedance-tapering network, which in the forward position tapers the impedance from 500 ohms to 250 ohms and at the same time inserts exactly 10 decibels of attenuation. In the back position a network is inserted which tapers the impedance from 500 to 50 ohms and inserts exactly 20 decibels of loss. Either end of the network may be used as input so that high impedances may be matched to low or vice versa.

The whole assembly is mounted in a small cast-aluminum case which may be located at any convenient point in the speech circuits. It can be stowed away at the bottom of a relay rack or mounted on top of a speech amplifier or inside a monitoring loudspeaker cabinet. Its over-all dimensions are only $7\frac{1}{4}$ x $3\frac{1}{2}$ x $5\frac{1}{2}$ inches.

The base of the cast housing has two holes conveniently located so that the attenuator may be screwed to the front of a relay-rack panel for permanent mounting if desired.

Both the input and output jacks take the standard Western Electric Type 241-A Double Connector Plugs. Two pairs of jacks are provided on both the input and output so that parallel connections can be conveniently made.

The TYPE 449-A Adjustable Attenuator is sufficiently accurate for use as a standard of attenuation for checking gain of amplifiers or loss in volume controls, lines, and other networks. The resistors comprising the various networks are all wire-wound and adjusted within 0.5%. The accuracy of attenuation is

FIGURE 1. Photograph of the TYPE 449-A Adjustable Attenuator, showing the photo-etched panel. The cabinet is of cast aluminum, giving complete shielding and dust protection. Switches and jacks are of Western Electric manufacture and are the best available

within 0.1 decibel over the frequency range from 0 to 20,000 cycles. Although primarily designed for low-level circuits, the attenuator will dissipate approximately one watt in any of the six networks. Great care has been taken to make the assembly rugged to withstand any ordinary service conditions and to maintain reliable circuits in either permanent or temporary installations.

SPECIFICATIONS

Circuit: Balanced-H.

Impedance: 500 Ω in one direction, 500 Ω, 250 Ω, or 50 Ω in the other direction.

Ground: The center connection is not grounded but can be grounded to the case by the user, if desired.

Terminals: The terminal jacks take Western Electric Type 241-A Double Connector Plugs. Two pairs of jacks (parallel connected) are provided at both input and output.

Attenuation Range:
500 Ω – 500 Ω: 0 to 60 db in 10-db steps
500 Ω – 250 Ω: 10 to 70 db in 10-db steps
500 Ω – 50 Ω: 20 to 80 db in 10-db steps

Dimensions: Panel 7¼ x 3⅜ inches; depth, 5½ inches.

Net Weight: 4¼ lbs.

Type		*Code Word*	*Price*
449-A		AMISS	$70.00

IMPROVEMENTS IN THE STANDARD-SIGNAL GENERATOR

● **INEVITABLY,** slight changes in the design details of an instrument take place with each successive lot manufactured. These result not only from the suggestions supplied by the user, but also from what is usually termed "progress in the art," which includes improvements in manufacturing methods as well as in design. Minor changes, resulting in a slight improvement in operation, are seldom formally announced, but, when the sum of these reaches the point where, in the aggregate, they constitute a major change in specifications, formal recognition must be given to the fact.

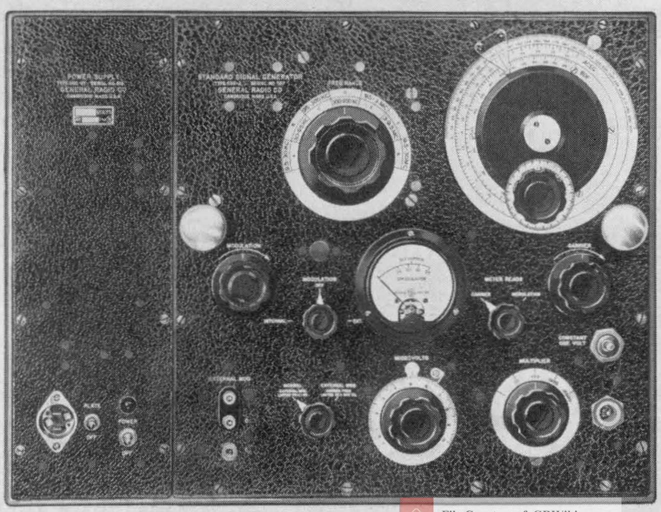

FIGURE 1. Panel view of the new TYPE 605-B Standard-Signal Generator

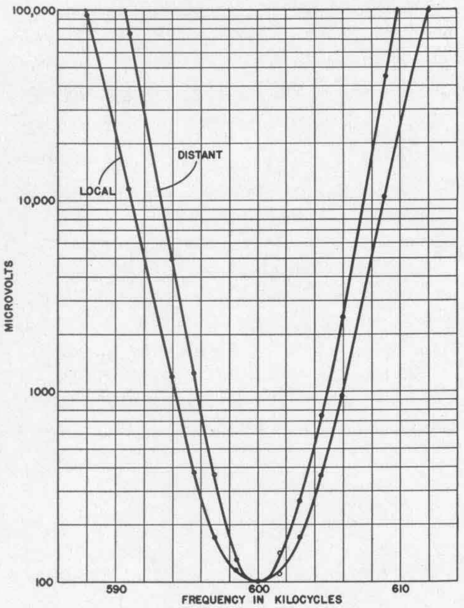

FIGURE 3. A selectivity curve for a radio receiver, taken with the TYPE 605-B Standard-Signal Generator

The TYPE 605-A Standard-Signal Generator* has reached this stage and will now be known as TYPE 605-B. Three major changes have been made:

(1) A high-frequency band has been added to cover frequencies between 30 Mc and 50 Mc. This change, which has been included in recently manufactured TYPE 605-A's, was made in response to a wide customer demand for it. These frequencies, however, are outside the normal design range of the instrument, and neither frequency range nor output can be guaranteed. The coil is added purely as a convenience for those who have a use for it. This range does not appear on the band-change dial, but is obtained by turning the switch to the position next beyond Range G. A frequency calibration for this range is included in the instruction book.

(2) A second output jack has been added, at which an output constant at one volt can be obtained. This feature was also included in later TYPE 605-A instruments, and has been found a convenience for many types of general laboratory measurements.

(3) To facilitate the taking of selectivity curves, the slow-motion dial, shown in Figure 2, has been added. This drives the main dial through a gear train, the reduction being approximately 20 : 1. The auxiliary dial carries 125 divisions, each corresponding to a frequency change of 0.1%. Adding this dial has made it necessary to redesign the air condenser which it drives. Changes in the condenser include a cast-aluminum frame and slip rings for making contact to the rotor. This latter feature, which was included on later models of the old condenser, allows more reliable contact with the rotor at high frequencies, with a consequent reduction in noise as it is rotated. Backlash of the driving gears and the rotor stack is quite small and is negligible when the dial is rotated in one direction only.

Other specifications are identical with those of TYPE 605-A. Code words and prices are unchanged.

* See General Radio *Experimenter*, June, 1936.

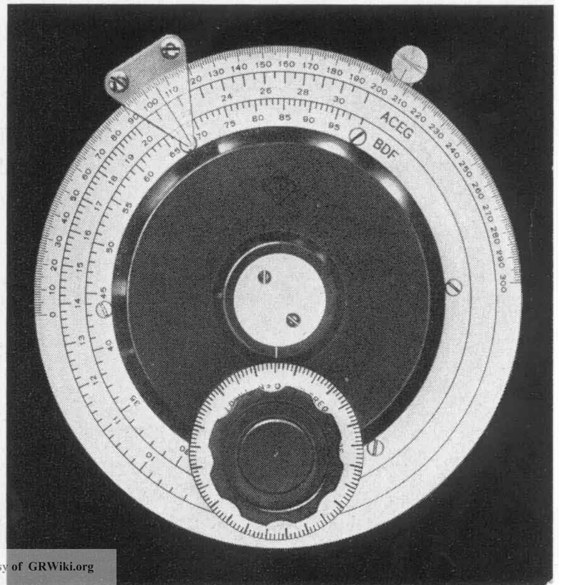

FIGURE 2. Photograph of the main and auxiliary dials. These are also used on TYPE 684-A Modulated Oscillator

REMODELING TYPE 605-A STANDARD-SIGNAL GENERATORS

● **TYPE 605-A STANDARD-SIGNAL GENERATORS** can be converted to TYPE 605-B at a price of $70.00. This includes the addition of the new condenser, gear drive, 50-megacycle coil, and 1-volt output jack. Each reconditioned generator is given a complete laboratory test after the modifications are made. If the 1-volt output jack is already installed, the price for adding the other new features is $60.00.

These prices include replacement of any parts (except vacuum tubes) which have become defective in the normal guarantee period of one year. Burned-out meters, attenuators, and other faults which are the responsibility of the user will be charged for at the usual rates.

Please communicate with our Service Department before returning instruments for remodeling.

MISCELLANY

● **TYPE 684-A MODULATED OSCILLATOR**, described in this issue, was designed by E. Karplus and A. G. Bousquet. Several engineers collaborated on the design of TYPE 449-A Adjustable Attenuator, among them P. K. McElroy, J. K. Clapp, and H. H. Hollis.

● **IN THE THIRD** annual Product Design Contest conducted by "Electrical Manufacturing" magazine, Mr. Scott was awarded a prize for his paper describing the design of the TYPE 759-A Sound-Level Meter. Five prizes, each of equal merit, were awarded to the five outstanding designs of the year. Mr. Scott's article appeared in the October issue.

● **AT THE RECENT CONVENTION** of the Society of Motion Picture Engineers in New York City, Mr. H. H. Scott delivered a paper entitled, "The Sound-Level Meter in the Motion Picture Industry."

● **ON OCTOBER 7**, Mr. A. E. Thiessen of the Engineering Department spoke before the student section of the A.I.E.E. at Lehigh University. His subject was "Direct-Reading Instruments."

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VOLUME XII NO. 7 DECEMBER, 1937

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also

IN THIS ISSUE

NOISE STEPS OUT

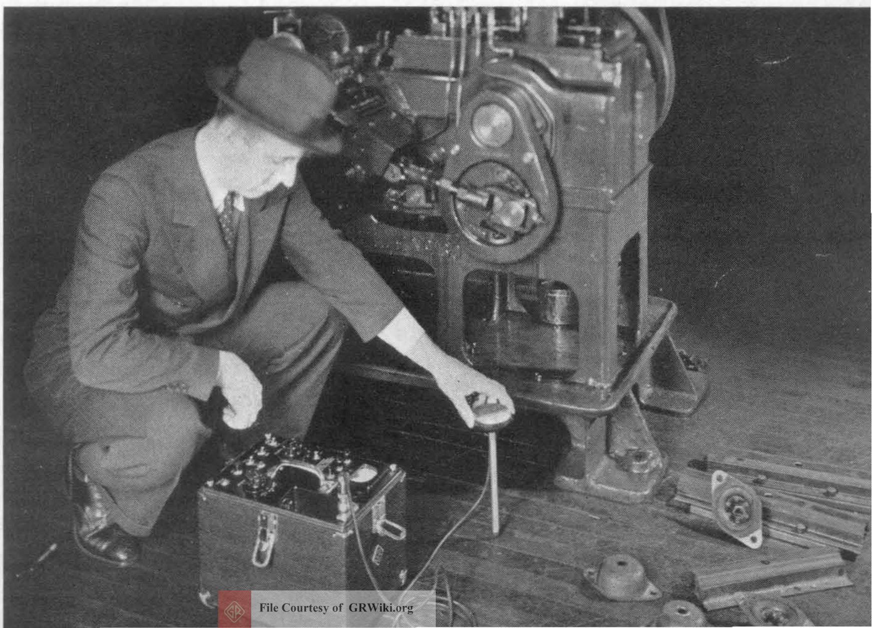
● **NOISE AND ITS REDUCTION** are receiving a rapidly increasing amount of attention from industry. A more-than-ordinary interest in the subject has been evident for some years, but, because the available information was incomplete and confusing, and because noise-measuring instruments were not standardized, industrial noise measurements seldom got out of the research laboratory and into the production department.

The adoption of the A.S.A. Standards,[1] covering terminology, methods,

[1] See "American Tentative Standards for Noise Measurement," Bulletin Z24.2–1936 and "American Tentative Standards for Sound-Level Meters for Measurement of Noise and Other Sounds," Bulletin Z24.3–1936, published by the American Standards Association.

Figure 1. The sound-level meter and vibration pickup were used very effectively in locating, and minimizing the effect of, vibration in the machine shown here

Photo, courtesy New England Screw Company



and instruments, resulted in several standardized instruments being placed on the market, all of which give identical results in the majority of applications. These standardized instruments have made it possible to use the decibel as a measure of sound level with the same confidence that one uses the volt and the ampere in measuring electrical quantities. Consequently, industry can now apply noise specifications and tests to both design and production, and is rapidly taking advantage of the opportunity.

SURVEY

The General Radio TYPE 759-A Sound-Level Meter, an accurate, portable instrument which includes even the optional features listed in the A. S. A. Standards, found immediate acceptance. A recently - completed survey[2] shows this instrument in a wide variety of applications, many of which were not contemplated when the instrument was designed.

The results of this survey have been classified and are summed up in the chart shown on the opposite page.

By referring to the diagram, it will be seen that the applications break down into three major fields and the percentage figures given represent the present distribution of the General Radio TYPE 759-A Sound-Level Meter.

1. The Appliance Field 35%
2. The Electrical and Acoustical Field................. 28%
3. The Industrial Field (which requires the vibration and sound analysis of heavy machinery)................. 21%

[2]July 1, 1937.

It is interesting to note that sound surveys in buildings, streets, and plants, the applications which one ordinarily thinks of when a noise meter is mentioned, are in the minority and involve only 10% of the total number of instruments.

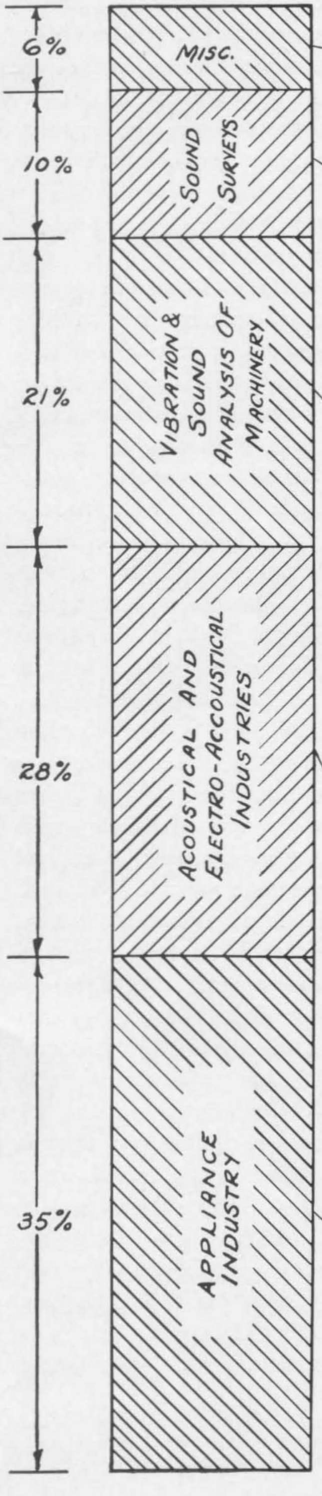
THE APPLIANCE FIELD

In the sale of household appliances, noise is a factor which is becoming of increasing importance, and it is not surprising that sound-level meters are more widely used in this industry than in any other.

The appliance industry is made up of manufacturers of such equipment as fans, small motors, vacuum cleaners, washing machines, oil burners, refrigerators, clocks, and air conditioning equipment. Since the market served is highly competitive, the salesman finds the sound-level meter invaluable as a means of proving to his customers that his products are superior. If, on the other hand, he finds his products faulty in this respect, it becomes the task of the factory engineers to design and produce quiet equipment.

The demand for convenient and accurate sound-measuring equipment comes from three different sources: first, the salesman; second, the research and development engineer; and third, the production department.

Since in this field the object is to reduce noise to the absolute minimum, the sounds to be measured are of extremely low intensity. Despite the difficulties of measuring sounds that are practically inaudible to the human ear, the General Radio TYPE 759-A Sound-Level Meter has been found entirely suitable for both laboratory and production measurements.



1. Production testing of grinding wheels.
2. Location of steam leaks.
3. Study of vibrations of aircraft fuselage, wing structures, and propellers.

1. Comparing noise level of various suburban and residential districts.
2. Measurement of office noises and effectiveness of sound installation.
3. Reducing noise of motor installations.
4. Study of office and plant noises and determination of ideal working conditions.

1. Measurements of vibration in vacuum pumps.
2. Study of the effect of mufflers on blower noises.
3. Measurement of noise produced by pneumatic drills.
4. Effect of silencing devices.
5. Measurement of high-speed transmission noise and vibration for both spur and helical gears.
6. Study of turret lathe noise.
7. Comparison of canvas and leather belt noise.
8. Study and elimination of noise in coil winding machines.
9. Production and experimental noise tests of both large and small electric motors.
10. Measurement of tractor noises.
11. With automobiles and other machinery for studying the effect of different fuels, cooling systems, manifolding, mufflers, and transmission gears.
12. Design of acoustic engine hoods.
13. Noise in automobile bodies.

1. Frequency analysis and measurement of sound patterns of foghorns and other signaling devices.
2. Measuring effectiveness of sound insulating material used in ships, automobiles, buildings, and aircraft cabins.
3. Intensity measurements and frequency analysis of aircraft noises both in flight and on ground.
4. Sound absorption measurements.
5. Electronic musical instrument research.
6. The effect of various treatments in deadening mechanical vibration.
7. Studying bank vault noises in order to determine standards governing burglar alarm systems.
8. Study of insulation values of various types of floor treatments for the reduction of impact noise.
9. For the measurement of sound distribution patterns and for frequency analysis in theaters, auditoriums, and other public address installations.
10. Measurement of noise level produced by movie projectors.
11. Frequency response for speaker combinations, radio receivers, and phonographs.
12. Susceptibility of radio to inductive interference and setting limits and standards.
13. Measurement of noise at loudspeaker of radio receivers or phonographs caused by hum and mechanical vibration — and determination of signal-to-noise ratio.
14. Measurement of reverberation time.

1. Sound and vibration analysis of air conditioning equipment.
2. Routine noise tests on new air conditioning installment.
3. For making noise studies and comparing equipment so that noise standards can be set up, governing air conditioning equipment, water pumps, refrigerators, oil burners, clocks, cream separators, horns, bells, and washing machines, fans, and other appliances.
4. Measurement and elimination of noise in postage stamp equipment meters.

FIGURE 2. This chart shows the distribution of General Radio sound-level meters in various fields of application. At the right are listed the main uses in each field

THE ACOUSTICAL AND ELECTRO-ACOUSTICAL FIELDS

In acoustics, the sound-level meter is used mainly for experiment and research. Phonograph noises, however, are measured as a production test. The radio manufacturers are using the instrument for checking the frequency response of loudspeakers, for measuring background and internal noises of radios, and for checking the susceptibility of receivers to inductive interference. Acoustical engineers are using the sound-level meter for checking frequency response and obtaining sound distribution patterns in theaters,[3] auditoriums, and out-of-door sound equipment installations. In the research laboratory the instrument is being used for the study of various types of sound-absorbing materials and determining their effectiveness in reducing sound and vibration in automobiles, buildings, ships, and aircraft cabins.

THE VIBRATION AND SOUND ANALYSIS OF HEAVY MACHINERY

The use of the sound-level meter by manufacturers of heavy machinery such as aircraft motors, automobiles, marine Diesel motors, turbines, lathes, and other machine tools is the third major field for this instrument. The automobile and aircraft manufacturers were perhaps the first to recognize its importance and, as a result of sound studies, the noise factor has become one of their strongest selling and advertising points.

In many factories the size of the equipment to be tested requires that tests be conducted in large assembly and experimental rooms where the extraneous noise level is too high to permit accurate sound measurements. It is then necessary to resort to vibration rather than sound studies. The use of a vibration-sensitive element with the sound-level meter offers a satisfactory solution to this difficulty since vibration pickups are, in general, sensitive only to vibrations produced at the point under test, and errors produced by background noises become negligible. Since the vibration pickup localizes the measurement to one point, it becomes possible, when making tests on heavy machinery such as aircraft motors, Diesel motors, and the like, to measure vibration at such points as bearings, cylinders, gears, etc., and from these localized tests a complete vibration pattern of any machine can be obtained. With this information, points of maximum strain and points at which the maximum of noise occurs can be easily located.

After locating the vibration that is causing the objectionable sound, it is often necessary to locate the source of the vibration, which is, in many instances, in some part of the machine other than the part producing the objectionable noise. Since every part in a machine has a certain definite mass and

[3] H. H. Scott and L. E. Packard, "The Sound-Level Meter in the Motion Picture Industry," presented at the Fall Convention of the Society of Motion Picture Engineers, October, 1937. This paper will be published in a forthcoming issue of the Journal of the Society of Motion Picture Engineers.

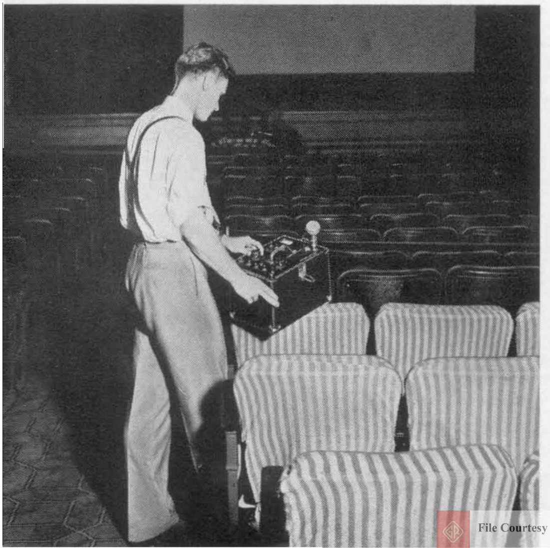


FIGURE 3. Measuring the acoustical properties of a motion picture theater with the sound-level meter

period of vibration, resonant vibrations can occur, and the cause of these resonant vibrations cannot be located by a simple vibration amplitude analysis. To cope with this problem, industrial engineers have found it desirable in studying the machine to determine both the amplitude and the frequency of each component of the complex vibration.[4] With this complete frequency and amplitude information, and knowing the speeds of the various parts of the machinery, the engineer is equipped with the necessary information for locating the ultimate source of the undesirable frequency and, hence, for bringing about its elimination.

SOUND SURVEYS AND NOISE ELIMINATION IN FACTORIES, OFFICES, ETC.

The acoustical engineer in his daily work is confronted with problems of sound insulation and reduction, and vibration elimination in buildings, offices, factories, and homes. Although basic formulae which check to a remarkable degree of precision are available for calculating the effectiveness of various sound insulating materials, no practical check on the results of acoustical treatment or sound insulation can be had without the use of accurate sound-measuring equipment. The modern acoustical engineer is not satisfied in simply trying to reduce existing noise conditions in offices, plants, and homes, but is trying, by the use of sound-measuring and vibration-measuring equipment, to locate the source of the objectionable noise or vibration and to eliminate the cause rather than its effect.

As was mentioned above in the discussion of sound measurements with heavy machinery, the scientific method of coping with noise and vibration problems is to analyze the situation, determining (1) the source of the noise, (2) the method of transmission, and (3) the manner in which the objectionable noise is excited. Having this information, a systematic procedure can be adopted for bringing about noise elimination. In many cases it has been found to be more economical to eliminate the noise at its source rather than at the point where it has been found bothersome; in others, the transmission medium has been changed; and, in still others, because of economic reasons, it has been found desirable simply to reduce the noise where it occurs. In any one case, however, to deal with the problem in the most economical manner, and to give the customer complete satisfaction, a complete survey must be made.

The uses of the sound-level meter to the acoustical engineer are (1) to obtain the information necessary to deal with the problem and (2) to demonstrate to the client the effectiveness of the treatment installed.

[4] Discussion of the TYPE 759-A Sound-Level Meter used with the TYPE 636-A Wave Analyzer and Vibration Pickup, pages 15 and 16 of Bulletin 20, entitled "The Technique of Noise Measurement," published by the General Radio Company.

FIGURE 4. The washing machine is only one of the many home appliances which the sound-level meter has helped to make quieter

THE GENERAL RADIO TYPE 759-A SOUND-LEVEL METER

The General Radio Company has taken extreme care, in the design and construction of its new Type 759-A Sound-Level Meter,[5] to insure its ability to meet all present and future demands so that it can be considered a basic sound-measuring instrument. The acceptance of the instrument by industry has proved that it is a basic instrument and that its features have met with wide approval. It furnishes instantly readings of sound intensity directly in decibels over a range of from 24 to 130 decibels, and, because of its three frequency-weighting networks, its readings are indicative of the noise actually heard by the human ear. Two features which are probably the keynote to its success are its portability and its simplicity of operation. Weighing but 23½ pounds and being small in size, it is easily carried to the point of application, and it is so simple that it can be operated by any untrained employee.

With the wide use and acceptance of sound-measuring instruments, there is an increasing demand in industry for a definite standardized procedure for making sound measurements and it is probable that within the near future this will be made available. The development of the new standards is but the first step in a series of definite specifications covering sound measurements. The Type 759-A Sound-Level Meter, being designed to meet all of the requirements of the fundamental specifications, can be expected to take care of any future demands.

—L. E. Packard

[5] For a description of the Type 759-A Sound-Level Meter, see Bulletin 20 and other publications of the General Radio Company.

BACKGROUND NOISE CORRECTIONS IN THE MEASUREMENT OF MACHINE NOISE

● **IN MANY PLANTS** soundproof rooms are either not available or not practical, and it is found necessary to make sound measurements under existing noise conditions. It is always advisable to reduce the level of extraneous noise as much as possible, but satisfactory sound measurements can usually be made, even under adverse conditions. Separate measurements are made of the background noise alone and the background plus the unknown noise. The difference of these readings is then taken and, from the chart of Figure 1, the correction in db for the background noise is determined. This correction is subtracted from the db reading obtained in the second measurement to obtain the level of the unknown noise.

Assume, for instance, that the problem is to measure the noise produced by a machine mounted in an assembly room or test room where an appreciable background noise level is present. The sound-level meter is placed in the desired test position, and a measurement is made of the general background noise without the machine running. An average measurement of the background noise in db will be sufficient although, if a widely fluctuating noise is present, it is often desirable to note the peak readings. As an example, let this reading be 72 db. The machine under test is then set in operation and, when it is operating at the desired conditions of load and speed, a second measurement is made of the total noise level. Let the result of this measurement be, say, 78 db. The difference between these two readings is then 6 db. Entering the chart of Figure 1 at 6 db, along the horizontal axis, we find the correction to be 1.25 db. This subtracted from the sound reading of 78 db gives a result of 76.75 db which is the true noise level of the machine itself.

To obtain this correction it is assumed that the power in the background noise and the power in the measured sound are added arithmetically by the sound-level meter. From the relation

$$\text{db} = 10 \log_{10} \frac{P_2}{P_1},$$

the power ratio corresponding to the 6 db difference is found to be 3.981. This means that the total noise is 3.981 times the background. The desired noise and the total noise level are therefore in the ratio of $\frac{3.981 - 1}{3.981}$ or .75, which corresponds to 1.25 db. The actual noise being measured is then 1.25 db lower than the reading of the sound-level meter.*

If actual sound-power levels corresponding to the db readings are desired, these can be calculated from the expression given above. An easier method is to refer to a set of decibel tables such as those published on pages 162 to 167 of the General Radio Company's Catalog J. A reading of 72 db, for instance, corresponds to a power ratio of 1.585×10^7. Since the reference level (corresponding to zero db) is 10^{-16} watts per square centimeter, sound-power level for 72 db is 1.585×10^{-9} watts per square centimeter.

—L. E. Packard

*A general expression for which the curve of Figure 1 can be calculated is
Error db = $\frac{1}{2}\,[d - 20 \log_{10} (2 \sinh \{0.1151\, d\})]$
where d is the difference in decibels between the two readings.

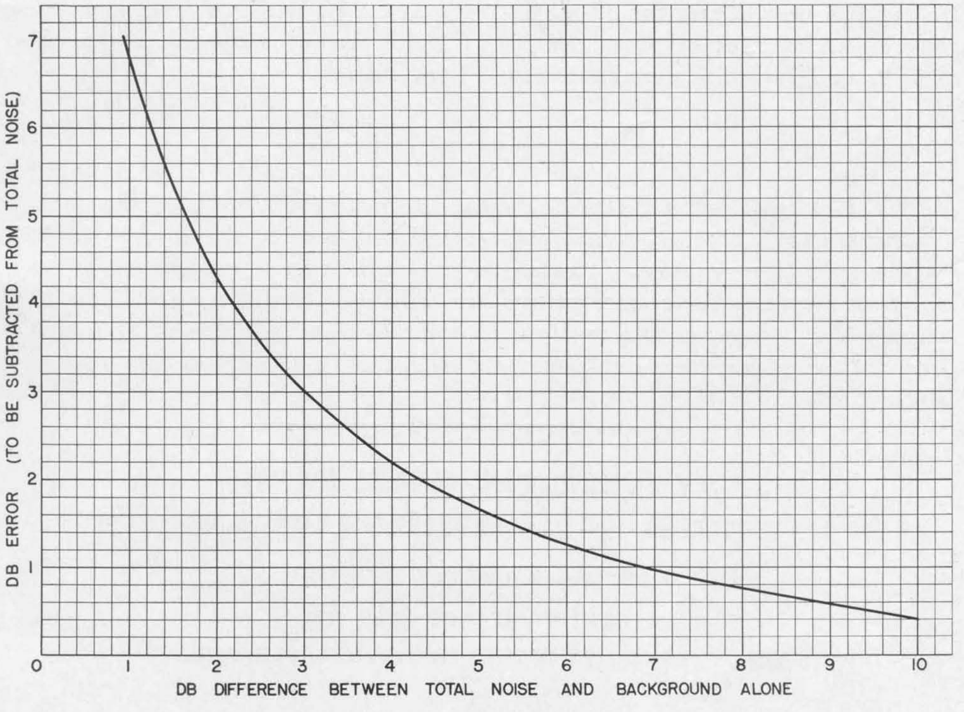


Figure 1. Background noise correction for sound-level measurements

MISCELLANY

MR. SMITH GOES TO HOLLYWOOD

To 988 General Radio customers on the Pacific Coast went, last month, cards announcing the opening of a Los Angeles engineering and sales office on December 1. Mr. Myron T. Smith, who takes over the new office, will be available for consultation concerning the application of General Radio instruments.

Mr. Smith has been in charge of our New York office since its establishment several years ago. Prior to that time he was a member of the factory engineering staff, coming to us shortly after graduation from the Massachusetts Institute of Technology with the Class of 1930.

In addition to engineering service, a stock of laboratory instruments and parts will be maintained in order to facilitate the prompt handling of orders in this area.

The address of the new office is 1000 North Seward Street, Los Angeles, and the telephone is Hollywood 6321.

MR. IRELAND TO NEW YORK

With the departure of Mr. Smith for the West Coast, Mr. Frederick Ireland takes charge of the New York office. Mr. Ireland has been a member of our engineering staff for several years, coming to us from Harvard University, where he was a member of the Class of 1933. Having spent a considerable amount of time at the New York office in the last few years, he is already well known to General Radio customers in the New York district.

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