the GENERAL® RADIO Experimenter

INDEX

TO

GENERAL RADIO EXPERIMENTER

VOLUMES XX AND XXI

June, 1945 to May, 1947

GENERAL RADIO COMPANY
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U. S. A.

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GENERAL RADIO ENLARGES PLANT

Also

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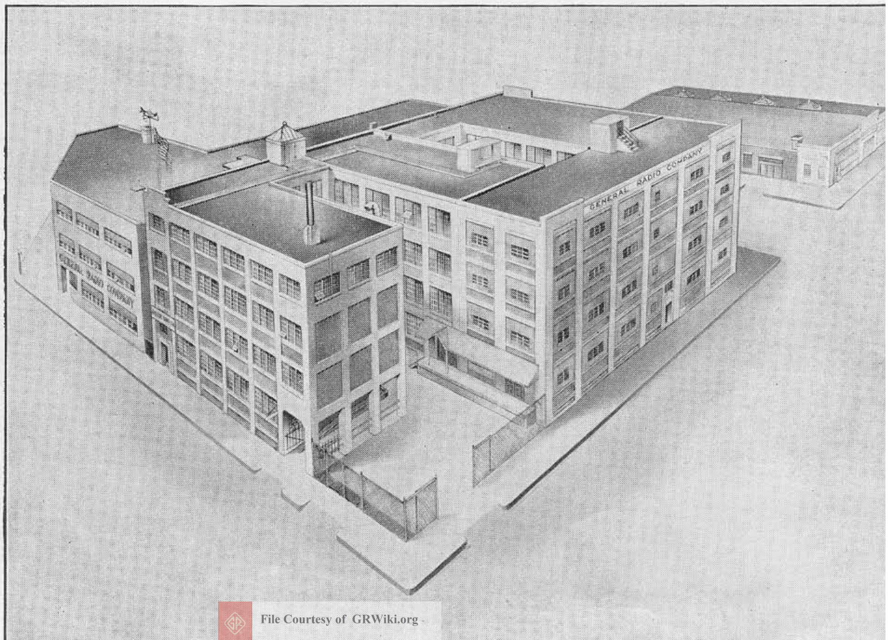
●**WORK** is progressing on a new four-story addition to the General Radio plant. This new building, located at the corner of State and Windsor Streets, Cambridge, will add approximately 30,000 square feet to the Company's manufacturing space, bringing the total plant space to 145,000 square feet. It will be used to house some of the manufacturing operations now being carried on in rented quarters and will also provide space for an increase in manufacturing capacity.

The accompanying drawing shows the plant as it will appear when construction is completed next summer. The new section is the right-hand unit of the main group.



THOSE IRON-CORED COILS AGAIN

PART II

FRINGING AT AN AIR GAP

The other improvement made since the March, 1942, article[1] comes in a better understanding of the mechanism which governs the effective permeability of a core of ferro-magnetic material with an air gap in its center leg. Reference was made to uncertainties in this respect at the middle of the text of page 3 and at the end of page 12 of the March, 1942, article. Measurements and calculations made in the meantime have indicated a method that can be used to explain the behavior of measured coils and to forecast the behavior of others.

Theory

Equation (3a) on page 8 of the March, 1942, article, which gives the approximate relationship between true and apparent permeability, can be rewritten as follows (where $\mu_t\alpha \gg 1$):

$$\frac{l}{\mu\alpha} = \frac{l}{\mu_t\alpha} + g \qquad (29)$$

This equation states that the equivalent air length of the magnetic circuit of any structure, to be used in determining the inductance of a coil thereon, is equal to the equivalent air length of the iron itself plus the length of the air gap. The equivalent air length of the iron, for instance, is equal to the actual length of the flux path in the magnetic material, divided by the product of its true permeability and the stacking factor.

Strictly, the l in the term $l/\mu_t\alpha$ of Equation (29) should be written $(l - g)$ to account for the reduction in path length in magnetic material occasioned by the gap. Actually, the complication is unwarranted, since the difference is negligible.

If Equation (29) is combined with Equation (6)[2] to replace the unknown μ by directly measurable L, the following is obtained:

$$\frac{1}{L}\left(\frac{4\pi N^2 A}{10^9}\right) = \frac{l}{\mu_t\alpha} + g \qquad (30)$$

This equation states that if the reciprocal of the measured inductance, multiplied by the proper factor determinable from constants of the structure, be plotted as abscissa against air gap as ordinate, the result should be a straight line inclined upward at 45°. It will not go through the origin, since the value of $l/\mu_t\alpha$ is finite.

Unfortunately, such a plot is not a straight line having the proper slope. It has approximately the right slope for points with very small ordinates, but soon begins to curve upward away from the 45° line as the ordinates increase. The reason for this will be shown to be the fringing at the air gap, which makes the reluctance of the gap smaller than its measured length would indicate, because of the larger equivalent *area*. Since the simple theory is easier to use if the area of the magnetic circuit is the same throughout its length, this last statement should be interpreted as saying that the equivalent *length* of the air gap is reduced by the effects of the fringing. It would be helpful to be able to calculate simply the effects of fringing.

Before that is gone into, however, one other refinement of the equation should be made. The intercept on the axis of ordinates would, by (30), represent only the value of $l/\mu_t\alpha$. Actually it always comes out larger than that value (if μ_t is assigned a representative value commonly associated with the magnetic ma-

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[1] P. K. McElroy and R. F. Field, "How Good is an Iron-Cored Coil?" *General Radio Experimenter*, March, 1942.

[2] See Part I, December, 1946, *Experimenter*.

terial in use). The difference represents the reluctance of a butt joint in the center leg which can be assigned, for convenience, an equivalent air length.

We then have the following equation, which will yield a straight-line plot:

$$\frac{1}{L}\left(\frac{4\pi N^2 A}{10^9}\right) = g' + b + \frac{l}{\mu_t \alpha} \quad (31)$$

where g' = *equivalent* length of measured air gap ($g' < g$)

and b = equivalent air length of butt joint.

Empirical information will be used which has been described in the first part hereof, namely, measurements of inductance against various air gaps. A method will be developed for calculating the effective air gap length. The fact that effective air gap lengths obtained by this method yield fairly good 45° straight lines when plotted will attest to the validity of the method for the purpose.

Effect of Fringing

This analysis was inspired by Chapter V on "Calculation of the Permeance of Flux Paths through Air between Surfaces of High-Permeability Material," of *Electromagnetic Devices*, by Herbert C. Roters, Wiley, 1941. While the whole chapter is useful in that it establishes a feeling of confidence in the methods Mr. Roters suggests, the meat for the present purpose is encompassed in Section 53 on Special Formulas for Use in the Method of "Estimating the Permeances of Probable Flux Paths." Reference will be made, by the terminology used in that section, to the various probable flux paths used in this calculation.

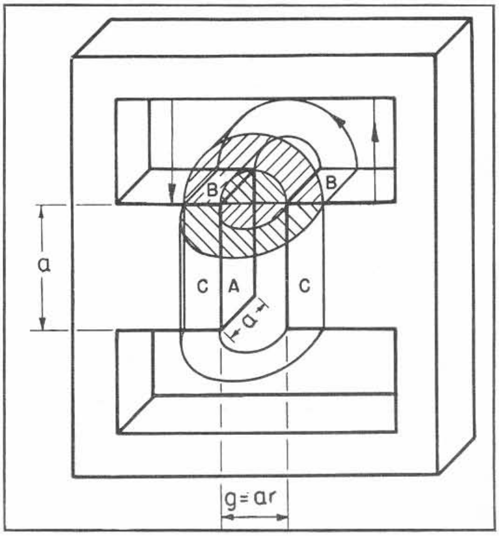
The conditions obtaining in a typical shell-type-lamination structure where there is an air gap in the center leg are covered by Figures 8 and 17 of Mr. Roters' book. Figure 8 shows the types of simple-shaped volumes which can be used to calculate the permeance of the leakage field. Figure 17 illustrates the considerations which determine the radius of the extreme boundary of the leakage flux paths. The longest leakage flux line, following a semi-circular path, cannot be any longer than twice the height of the window, since the reluctance of the path for any longer leakage line would be less if the line merely jumped over to the adjacent outside leg and back again.

Figure 14 of this article shows the situation in and around the center-leg air gap for purposes of reference. Each of the two equal dimensions of the square cross section of the center leg is denoted by a. The air gap g is replaced by ar for convenience, r being the ratio of the air gap g to the tongue width a.

There are five different kinds of flux paths to be considered. Their number and permeances are as follows:

1. There is one geometric (nonleakage) flux path between the gap faces, a rectangular prism having a base area a^2 and an altitude ar.

Figure 14. Fringing paths around a center-leg air gap.



$$\text{Permeance} = \frac{a^2}{ar} = \frac{a}{r}$$

2. There are four equal semi-circular cylindrical volumes of axial length a and diameter ar. (¶53,1.)

$$\text{Permeance} = 4 \times 0.26a = 1.04a$$

3. There are four spherical quadrants having a diameter of ar. (¶53,3.)

$$\text{Permeance} = 4 \times 0.077ar = 0.31ar$$

4. There are four half annuli having an inside diameter ar, a length a, and a thickness T given by $[a(0.446 - r/2)]$. (¶53,2.)

$$\text{Permeance} = 4 \times \frac{a}{\pi} \, ln \left(1 + \frac{2T}{ar}\right)$$

$$= 1.27a \, ln \, \frac{0.892}{r}$$

The equation for T is obtained in this way. The length of the extreme semi-circular magnetic line is $[\pi(T + ar/2)]$. Twice the window height is typically $1.4a$, as can be discerned by examining the dimensions of various GR laminations as listed in Figure 1[3]. These two values must be equal:

$$\pi \left(T + \frac{ar}{2}\right) = 1.4a \qquad (32)$$

from which $T = a \left(0.446 - \frac{r}{2}\right)$ (33)

5. There are four quadrants of spherical shells having inside diameter ar and thickness $[a(0.446 - r/2)]$. (¶53,4.)

$$\text{Permeance} = 4 \times \frac{T}{4} = a \left(0.446 - \frac{r}{2}\right)$$

If the five parallel permeances derived above are added up and the terms combined, the total estimated permeance, including leakage flux, is:

$$P = a \left[\frac{1}{r} + 1.49 - 0.19r + 1.27 \, ln \left(\frac{0.89}{r}\right)\right] \qquad (34)$$

The first term inside the bracket represents the geometric permeance, while the whole bracket represents the total. The quotient of the two (first term and whole bracket) gives the ratio between the effective gap length and the measured gap length.

$$\frac{\text{eff. gap}}{\text{meas. gap}} = \frac{\frac{1}{r}}{\left[\frac{1}{r} + 1.49 - 0.19r + 1.27 \, ln \left(\frac{0.89}{r}\right)\right]} \qquad (35)$$

By appropriate choice of different multiplying factors for the permeances listed in 1, 2, and 4, similar expressions can be obtained for the ratio of effective air gap to measured gap for other than square-center-leg cross sections. For 2 : 1 aspect ratio (stack twice as high as tongue width),

$$\frac{\text{eff. gap}}{\text{meas. gap}} = \frac{\frac{2}{r}}{\left[\frac{2}{r} + 2.01 - 0.19r + 0.905 \, ln \left(\frac{0.89}{r}\right)\right]} \qquad (36)$$

For ½ : 1 aspect ratio (gaps in outside legs of square-center-leg stack). (Note that r is ratio of gap length to width of center leg or tongue.)

$$\frac{\text{eff. gap}}{\text{meas. gap}} = \frac{\frac{1}{2r}}{\left[\frac{1}{2r} + 1.23 - 0.19r + 0.953 \, ln \left(\frac{0.89}{r}\right)\right]} \qquad (37)$$

The curves in Figure 15 include not only a center one of correction factors for a core having a square stack with a center-leg gap, but there is also an upper one labeled 2 : 1 (fringing has less effect) for a core having the center leg stacked twice as high as the tongue width and with a center-leg gap. There is likewise a lower curve labeled ½ : 1 (fringing has more effect) which represents the condition existing with equal gaps in the outer legs of a core which is stacked to a height equal to the tongue width. This curve shows why air gaps in outer legs are less effective than one in the center leg, and that the disparity increases as the gap increases.

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[3] See Part I.

The curves in Figure 15 are universally applicable to any *size* of laminations having approximately these proportions, since they have been normalized, that is, since they are plotted against the ratio of air gap to tongue width. For purposes of fringing calculations, the ratio of air gap to path length has no significance.

Two other points should be noted about these curves. First, they are not directly applicable without refiguring to so-called scrapless laminations, *since the window height in those is 0.5a.* Equation (33) will have to be different for scrapless lamination shapes, and it in turn causes changes in parts 4 and 5 of the permeance calculations.

The other point is that this analysis is apparently too simple to hold strictly for very large gaps, as will be seen on the curves to be presented subsequently. Points for large gaps depart appreciably from the straight line. This is probably partly because Equation (33) has been used to determine all four of the half annular paths in 4 above, even though the (33) limitation is active only on two of them. Likewise the (33) limitation is active throughout only part of the permeance paths calculated under 5.

Plotting the Straight Lines

Before the points representing individual measurements can be plotted to see how closely they lie on the 45° straight line of Equation (31), the data as recorded must be reworked.

To obtain the abscissa, each measured inductance must be divided into $[4\pi N^2 A/10^9]$. In this expression, N is the number of turns in the coil, and A the area in square centimeters of the center-leg cross section. This quotient has the dimensions of a length in centimeters. Since it is desired that this length come out in mils, the value of the multiplier must be divided by 2.54 centimeters per inch, and multiplied by 1000 mils per inch. Into this figure the values of inductance can then be divided.

To obtain the ordinate, the equivalent length g' of each air gap must be calculated by use of Figure 15. To use Figure 15, the ratio $r\ [= g/a]$ is necessary to enter the chart on the axis of abscissae. The curve indicates, for the particular ratio, the correction factor which must be applied. The measured air gap in mils must be multiplied by this factor, the ordinate of the curve, to get the equivalent air gap g'. In the calculations for the 746 core, the upper curve in Figure 15 marked "2 : 1" should be used. For all the other laminations, the central curve marked "square" is the proper one.

Figures 16 through 19 show for each of the four lamination shapes the distribution of the corrected empirical points about the most probable 45° straight line through them. Where both A-metal and silicon-steel laminations of a given shape were measured, two different lines are plotted, sometimes to different scales, since the A-metal intercept is so small.

Several details should be observed about these plots.

A possible reason has already been advanced for the departure of the extreme right-hand point (large air gap) from the straight line.

The first point, at zero ordinate or butt joint, is often rather badly off the curve to the right. This is probably explainable on mechanical grounds, rather than as an error in measure-

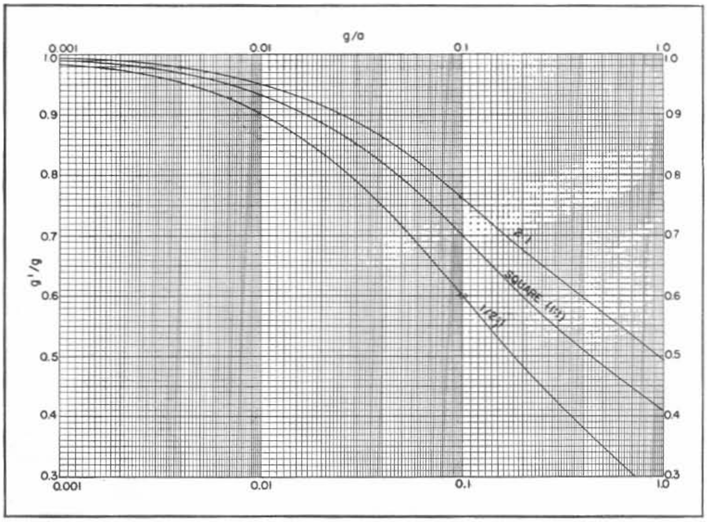

Figure 15. Ratio of effective to measured gap lengths as a function of the ratio g/a.

ment. Sloping portions of center legs of most lamination shapes are half cut off in a kick press to eliminate any center leg interleaving. If these laminations are cut off just a little too much, then when they are completely interleaved into a coil, with the outer legs touching, the joint is not truly a butt joint, but has a finite gap length. This condition is not at all unlikely to occur. Corroboration of this view is given indirectly by the fact that the first or left-hand point for the 746 A-metal plot falls on the line very well. There happens to be for this lamination a special die with a square nose on the center leg (about which more will be said later), and with a center leg which was made slightly more than half as long as the outside leg, in order to be sure that a butt joint never had a finite length.

Interpreting the Plots

The first thing to be remarked in connection with the plots is the generally small departure of the points from the 45° lines, and the fairly random distribution of the sense of deviation. Plausible explanations have been proffered for the points which deviate worst.

The first conclusion, then, is that the calculations based on Roters truly represent the extent of fringing until the air gaps are quite large in proportion, say 3/10 of the tongue width.

The intercepts on the axis of ordinates should be interpreted to learn if possible what value should be assigned to the equivalent length of a butt joint. As pointed out earlier, the intercept represents a length which is equal to $[b + (l/\mu_t\alpha)]$. The quantity $[l/\mu_t\alpha]$ is calculated for each lamination using a value of 0.96 for α, and typical values for μ_t of 470 for silicon steel and 2500 for A-metal. The table in Figure 20 lists the information deduced from the intercepts.

Column 1 lists lamination size and material.

Column 2 lists the intercepts as read from the plots.

Column 3 lists the calculated value of the equivalent air length of the ferro-magnetic material.

The length obtained by subtracting Column 3 from Column 2 is entered in the proper one of Columns 4, 5, and 6, depending on the shape of the nose on the center leg (see Figure 12 for contours). Flat-nose (Figure 12c) refers to a lamination which can be used only with an effective gap in the center leg and which has the end of the center leg perpendicular to its axis. The blunt-angled center leg (Figure 12a) is of the type where the sloping portion is not far angularly (about 13°) from the right-angled portion of the nose. The sharp-angled center leg (Figure 12b) has the sloping portion at an angle of 45°.

In the seventh column is listed the equivalent air length of the interleaved magnetic material as obtained from the measurement of inductance of the coil with fully interleaved, uncut laminations. This length can be compared with the typical calculated one in the third column. The value obtained from measurements (Column 7) will usually be seen to be larger than that obtained by calculation from ring-sample permeability value. This is because there is some reluctance in the interleaved joints which shows up as an increased effective air length. From this it may be seen that what has been called for convenience the equivalent length of a butt joint represents actually the equivalent length of a butt joint at the center leg in series with parallel interleaved joints in the outside legs.

Conclusions

Some conclusions can be drawn from Figure 20. It appears that the effective length of a butt joint is a function both of the shape of the nose and of the material of the core.

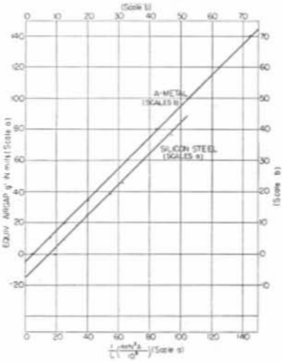
Figure 16.

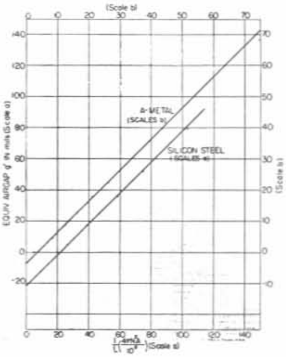
Figure 17.

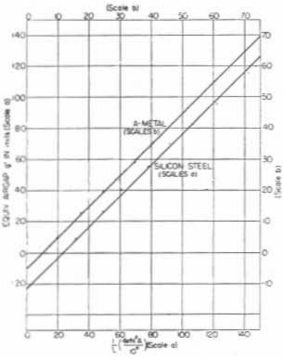
Figure 18.

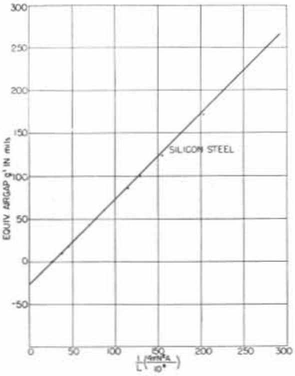

Figure 19.

LAMINATION SIZE & MAT'L	INTERCEPT mils	TYPICAL $\frac{l}{\mu_t \alpha}$	EFFECTIVE LENGTH b FOR TYPE NOSE ON CENTER LEG FLAT	BLUNT∠	SHARP∠	$\frac{1}{L}\left(\frac{4\pi N^2 A}{10^9}\right)$ FOR FULL INTERLEAVED CORE
746, AUDIO A	16	6	—	—	10	9.15
746, A-METAL	2.5	1.1	1.4	—	—	1.65
345, RT 72	21.7	10.7	—	11	—	13.2
345, A-METAL	7.2	2.0	—	5.2	—	2.1
485, RT 72	23.5	14.5	—	9	—	20.4
485, A-METAL	10.5	2.7	—	7.8	—	3.9
365, RT 72	28	18	—	10	—	17.5

Figure 20.

1. For blunt-angle-nose silicon-steel laminations, the effective lengths come out as 9, 10, and 11 mils, and for sharp-angle-nose ones, one value of 10 mils was obtained. These are all of the same order of magnitude.

2. On the other hand, blunt-angle-nose A-metal laminations gave two values of *b* of about 5 and 8 mils.

3. The only flat-nose value, of 1.4 mils, came from measurements on A-metal laminations.

The marked difference between flat-nose and angle-nose effective *b*'s was at first surprising. After consideration of the conditions in the center-leg gap, the result was less surprising. Consider the conditions at the gap with angle-nose laminations. The flat portion of the end of each lamination comes opposite to the sloping portion of the end of its mating lamination. If there were only one pair of mating laminations in the core, the air gap would be quite large, since the laminations would truly butt at only one short line, not on a surface. Actually, of course, the interleaving of the laminations in successively opposite directions gives a double gridiron type of pattern on each cross-section face. The lines of force probably do not cross from straight to sloping portion of opposite laminations of a pair but, rather, go from the straight portion of a lamination on one side to the straight portions of the two laminations adjacent on each side to the opposite mating lamination. Whatever the true mechanism, the reluctance of the joint is very high compared to what can be obtained with properly designed flat-nose laminations. The fact that there is no sensible difference in *b* for the blunt- and the sharp-angle nose is some corroboration of the supposition that very few lines of force go from flat to mating sloping faces. Otherwise, there would be a noticeable difference in values of *b* for blunt and sharp angles, because of the great difference in average air gaps in the two cases.

The fact that the blunt-angle-nose A-metal laminations had lower *b*'s is not completely understood. It should be recognized that the method pursued is not inherently an accurate one. It involves measurements of inductance of coils on ferro-magnetic cores, which are sensitive to signal level and to mechanical treatment. These measurements have to be corrected by an approximate theory, an approximate line drawn through their plotted points, an intercept read graphically, and a calculated supposititious value for equivalent air length of the magnetic structure subtracted. All of the successive steps are subject to some error. It is perhaps surprising that the agreement is as good as it is, yet there may be some demonstrable reason for the *b* to be smaller with the higher-permeability material.

There is only one value for a flat-nose core. It agrees fairly well with a figure of around 1.5 mils, which was obtained from a completely independent type of measurement, using DC instead of AC. The value is believed to be reasonable.

How to Use This Information

It is now possible to calculate with some fair expectation of accuracy a

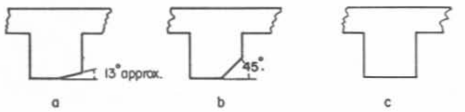

Figure 12. Types of laminations: (a) blunt-angled; (b) sharp-angled; (c) flat.

curve similar to the second curves of Figures 2 to 11[4] for some other combination of lamination dimensions and material. The inductance can be calculated from Equation (31). The effective gap length g' in that equation can be obtained by use of the curves of Figure 15. The equivalent air length b of a butt joint can be obtained by judicious use of the information in Figure 20. $[l/\mu_t\alpha]$ can be calculated from the values of the three parameters appropriate to the particular core structure. If this is done for a series of values of g', and the inductance values plotted not against g' but against g, then the desired curves can be obtained.

Thus, one can obtain A-metal curves if silicon-steel ones are already available, or one can calculate a probable curve for a completely different magnetic structure. — P. K. McElroy

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[4] See Part I.

F. C. C. APPROVAL NUMBERS FOR GENERAL RADIO BROADCAST MONITORS

After completion of type tests, the Federal Communications Commission has approved both the Type 1181-A Frequency Deviation Monitor and the Type 1931-A Modulation Monitor and has granted the following approval numbers:

Type 1931-A Amplitude-Modulation Monitor — F.C.C. Approval No. 1555.
Type 1181-A Frequency Deviation Monitor — F.C.C. Approval No. 1467.

MISCELLANY

Visitors to our plant and laboratories in the last few months include Mr. F. S. Hewitt, Director, Tele-communications Research Laboratory, University of Witwatersrand, Johannesburg, South Africa; Mr. Olle Wernholm, Electronic Research Division, Royal Institute of Technology, Stockholm, Sweden; Professor Segismundo Gerszonowicz, Head of the Department of Electrical Engineering, University of Montevideo, Uruguay; Professor J. Oskar Nielsen, Royal Technical College, Copenhagen, Denmark; Mme. Nikis and M. G. H. Bezy, Les Laboratories Radioelectriques, Paris, France; and Mr. V. A. Altovsky, Chief, High-Frequency Research Laboratory, Compagnie Francais Thomson-Houston, Paris.

THE General Radio EXPERIMENTER

VOLUME XXI No. 9 FEBRUARY, 1947

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A VERSATILE MONITOR FOR USE FROM 1.6 TO 150 MEGACYCLES

Also

IN THIS ISSUE

●**THE RAPID GROWTH** of communications in the frequency range above the standard broadcast band has created a demand for monitoring equipment that is somewhat different from the types used in most standard broadcast transmitter work. In order to produce a satisfactory monitor for this service there are many factors to be considered in addition to the strictly technical ones of circuit design and physical layout.

Monitors for these frequencies will be used by a variety of radio services such as public service companies, municipal departments, railroads, airlines, highway transportation companies, high-frequency

Figure 1. View of the TYPE 1175-A Frequency Monitor with TYPE 1176-A Frequency Meter.

broadcasting, television, and point-to-point communication. The ultimate users, therefore, will have varying degrees of technical skill, ranging from the very minimum to that of the professional radio engineer. Consequently, the monitor must be simple to operate and comparatively simple to install.

Such factors as multi-channel operation, remote monitoring, and mobile service will also influence the design; and further limitations are imposed by the wide frequency range to be covered and the different types of modulation encountered in the transmitters.

The over-all requirements for the monitor from the operating standpoint may be listed as:

1. STABILITY
2. SIMPLICITY OF OPERATION
3. MINIMUM MAINTENANCE REQUIREMENTS
4. ADEQUATE SENSITIVITY
5. EASE OF INSTALLATION
6. FLEXIBILITY

To meet these requirements, as well as the more technical ones of high-frequency monitoring, the TYPE 1175-A Frequency Monitor has been developed. When used in conjunction with the TYPE 1176-A Frequency Meter[1], this monitor provides a direct indication of frequency deviation for all types of amplitude-modulated transmitters operating at frequencies between 1.6 and 150 megacycles.

The complete monitoring assembly is in two parts, as shown in Figure 1. The TYPE 1175-A Frequency Monitor contains a crystal oscillator, a buffer amplifier, a mixer, an r-f amplifier, and an output amplifier. The transmitter carrier frequency is heterodyned with the crystal oscillator to produce a beat-frequency signal corresponding to the deviation from the assigned carrier frequency of the station. The TYPE 1176-A Frequency Meter is used to indicate the exact frequency of the heterodyne signal, or the deviation frequency in cycles per second. This instrument has six scales ranging from 200 to 60,000 cycles, full scale, in multiples of 2 and 6.

GENERAL FEATURES

Stability

Since the function of a monitor is to give a continuous check on the station frequency, stability of the instrument is of paramount importance. Low-temperature-coefficient crystals are used in a thermostatically controlled oven. Tube voltages are regulated to minimize the effect of varying line voltage. The crystal oscillator circuit[2] is one developed especially for frequency monitoring use and has excellent long-period stability.

Multi-Channel Monitoring

As many as four channels can be monitored with a single instrument, since facilities for four crystals are provided in the temperature-controlled chamber. For applications involving monitoring more than four channels, a series of these monitors can be mounted in a relay rack, and a single frequency meter arranged to be switched between monitors. While it is sometimes possible to substitute crystals in one monitor alone, this practice is not recommended owing to the inaccuracies involved in re-tuning the crystal oscillator circuit each time that a new crystal is substituted.

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[1] *General Radio Experimenter*, Vol. XX, No. 9, February, 1946.

[2] U. S. Patent No. 2,012,497.

Mobile Transmitters

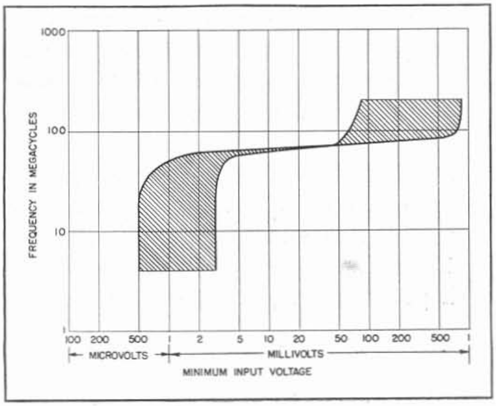
To cover the wide frequency range (1.6 to 150 Mc) with multi-channel operation, aperiodic amplifiers are used for both crystal and input buffer stages. These have sufficient sensitivity for all local monitoring applications. For mobile-transmitter monitoring, however, sufficient sensitivity must be provided to permit remote checking. In police work, for example, it is most convenient to be able to check, directly from the main control room, the transmitter frequency of an automobile located in the adjacent repair shop or cruising along a nearby street. To do this requires sensitivity approaching that of a radio receiver. For the lower frequencies, the internal wide-band amplifiers produce the desired sensitivity, and it is only necessary to connect any convenient form of antenna directly to the input terminals of the monitor. Unless there is a danger of adjacent channel interference, the antenna system need not be tuned. If there are several transmitters located in the vicinity which are within approximately 100 kc of the station frequency, a simple form of antenna tuning will eliminate any interference.

On the high-frequency channels, remote monitoring can be accomplished by the addition of a radio receiver to the monitoring system. In this case, the monitoring oscillator frequency is heterodyned with the received carrier by injecting the two signals into the receiver antenna terminals. The resulting low beat-frequency signal derived from the receiver is then measured directly on the frequency meter in the monitoring assembly. The one limitation to this system is the fact that the maximum deviation frequency that can be monitored will be determined by the bandwidth of the radio receiver's output system. Since the frequency meter requires only about 0.25 volts or more input signal, and has a 0.5-megohm impedance, it is possible to avoid this limitation by connecting directly to the second detector in the radio receiver.

Effect of Modulation

One of the most important features of the monitor is the fact that it will operate directly from an amplitude-modulated wave. This permits extreme flexibility in application, as previously noted. The circuits employed to produce this characteristic are not unlike those used in f-m receiving systems to discriminate against amplitude modulation, but with one important exception: the limiting circuits, instead of being placed in the radio frequency or i-f circuits, are in the low frequency circuits of the frequency-meter section. This arrangement is made necessary for several reasons. First of all, limiter circuits require relatively large signal amplitudes to work effectively, and these cannot be derived without tuned circuits or other complications at radio frequencies, but are quite simple to obtain at low frequencies. Secondly, placing limiters in the frequency-meter section permits operation over a wide range of signal amplitudes, since the

Figure 2. Input sensitivity of the TYPE 1175-A Frequency Monitor over the normal operating range. The shaded area indicates the normal variation to be expected.



frequency meter is not sensitive to input-signal amplitude changes over a ratio of 600:1 (0.25 — 150 volts).

While not specifically designed for television, this monitor has been successfully used to monitor television video-transmitters in the first six channels, i.e., 44 — 88 Mc.

The pulse type of amplitude modulation employed does not impair the operating characteristics of the monitor in any way.

Deviation Direction Test

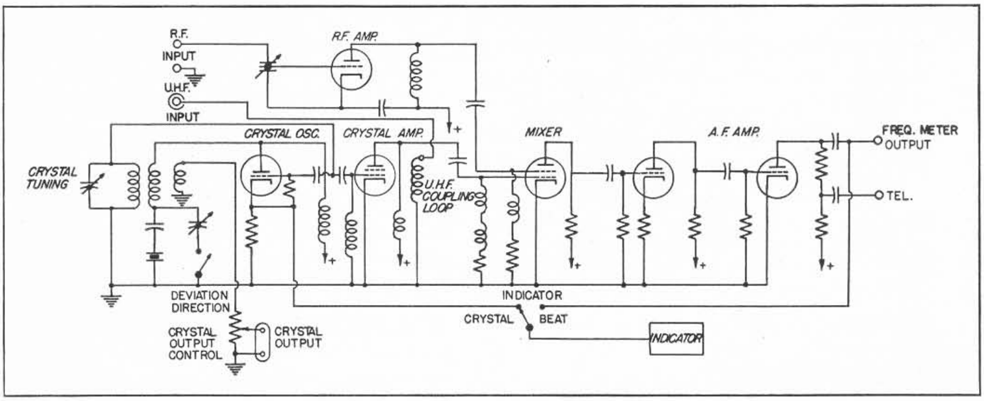
Since the crystals are operated on exact carrier frequency harmonics and are not offset, an indicator to show the sign of the transmitter deviation-frequency is provided. A push-button switch is provided on the front panel. Depressing this switch lowers the crystal-oscillator frequency by a discrete amount. The direction of the change in deviation frequency, as noted on the frequency meter, determines the sign of the deviation. If, for example, the indicated frequency increases when the button is pressed, the deviation of the transmitter is on the high side of the assigned carrier frequency. The wide range of carrier frequencies and resultant wide range of deviation frequencies make a multi-step indicator necessary. This is achieved through the use of a three-step device on the push-button. Each step shifts the monitor crystal frequency a little more than the preceding one, and the final step is adjustable. This feature is necessary to cover the wide variety of monitoring conditions encountered. For example, one channel may operate at 2 Mc with the frequency meter set on the 200-cycle range; the next at 100 Mc, 6000-cycle range; one at 150 Mc, 60,000-cycle range; and perhaps a fourth high-frequency channel at 110 Mc, whose deviation frequency happens to be rather small and hence the frequency meter has been set to, say, the 600-cycle range. In the last case, only a very small shift in the monitor crystal frequency will be required to give an observable shift in the meter indication, and the push-button should be depressed only to the first notch. Further depression of the push-button will cause the beat-frequency produced between the station carrier and monitoring crystal harmonic to go through "zero beat" and will thus result in a false movement of the indicating meter. This condition can be avoided by depressing the push-button only one step at a time until an observable shift in the meter takes place. It is also possible to determine the sign of the transmitter deviation by making a very slight shift in carrier frequency and noting the result on the frequency monitor.

Other Indicators

As a guide to normal operations of the monitor, an electron-ray tube indicates the approximate amplitude of the beat frequency produced between the monitor crystal harmonic and the transmitter carrier frequency. It can also be switched into the crystal circuit to check the oscillation condition. Telephone jacks permit aural monitoring of the deviation frequency or visual checking using an external cathode-ray oscilloscope.

Panel

In the interests of operating ease, the panel controls are identified by suitable engraved markings, thus making their function easily apparent. Such things as instruction books are often misplaced, and under these conditions the operator must rely upon memory; panel controls are therefore kept to a minimum.



Elementary schematic diagram of the TYPE 1175-A Frequency Monitor.

CIRCUIT DESIGN

Input Circuit

Figure 3 is a functional schematic of the monitor. The r-f amplifier is used to obtain maximum sensitivity for the lower range of frequencies. Above its cut-off frequency the input is coupled directly to one of the mixer-tube grids. A capacitor-type input attenuator is provided to adjust the r-f input level. Four input circuits are provided, and one is automatically selected, together with the associated crystal, by means of the panel selector switch. For simplicity, only a single one is shown here. At the highest carrier frequencies, the mixer tube will not operate efficiently, and hence another system is employed. A single u-h-f coaxial input is used for this range. It is not necessary to provide more than one common input circuit, since the possibility of interference is greatly lessened at these frequencies. Coupling is achieved electromagnetically directly to the tube envelope of the crystal amplifier tube, and the tube formerly used as a mixer now functions as an additional output amplifier.

Crystal Oscillator

The temperature-controlled crystal oven contains mounting sockets for a total of four crystals. These are relatively low frequency crystals (1.6–4.4 Mc) for maximum stability, and each is adjusted to have one of its harmonics coincide with the exact frequency of the transmitter to be monitored. The oscillator is of the tuned-grid magnetic-feedback type, and is loosely coupled to the buffer amplifier and harmonic generator. A low-impedance link-coupled circuit is brought out to panel terminals, and is provided with an attenuator. This permits a quick check to be made on receivers, tuned amplifiers, etc., using the crystal as a calibrated source of r-f.

Since the generation of crystal harmonics does not depend upon tuned circuits, multi-channel operation can be achieved without complexity. Crystal frequencies are selected to avoid possible interference between transmitters whose frequencies might fall at, or near, exact multiples of the same crystal fundamental.

— C. A. Cady

SPECIFICATIONS

Carrier Frequency Range: 1600 kc to 150 Mc.

Accuracy: With Type 376-M Quartz Plate, 0.002%.

Quartz Plate: No crystals are included in the price. See price list below. Crystals are ground to a sub-multiple of the channel frequency.

Power Supply: 105 to 125 volts, 50 to 60 cycles. By changing connections on the power transformer, the monitor can be operated from a 210- to 250-volt line.

Power Input: 75 watts, including temperature control.

Accessories Supplied: All tubes; multipoint connector; spare fuses; spare pilot lamps; power cord.

Vacuum Tubes:

1—type 6AC7
1—type 6AG7
1—type 6E5
1—type 6SN7GT
1—type 6J5
1—type 6X5
1—type 7A8
1—type 0D3/VR150

All vacuum tubes are supplied.

Panel Finishes: Standard General Radio black crackle. Certain standard grays which can be processed in quantity can be supplied at a price increase of $10.00*.

Mounting: Standard 19-inch relay-rack panel. Walnut end frames are available for adapting the instrument for table mounting. (See price list below.)

Dimensions: Panel, 19 x 7 inches; depth behind panel, 11¼ inches.

Net Weight: 22 pounds.

Type		*Code Word*	*Price*
1175-A	**Frequency Monitor**	TIPSY	**$285.00***
376-M	**Quartz Plate**	LABOR	**50.00***
ZFRI-410-P1	**End Frames for Type 1175-A**	ENDFRAMDAY	**15.00 Pair***
ZFRI-710-P5	**End Frames for Type 1175-A mounted with Type 1176-A as a single unit**	ENDFRAMGAS	**15.00 Pair***

This instrument is manufactured and sold under the following U. S. Patents:
1,967,185 2,012,497
Patents and patent applications of G. W. Pierce.
Patents of the American Telephone and Telegraph Company.

TYPE 1176-A FREQUENCY METER

A description of this instrument will be found in the *Experimenter* for February, 1946.

Type		*Code Word*	*Price*
1176-A	**Frequency Meter**	TIMID	**$230.00***

This instrument is manufactured and sold under U. S. Patent No. 2,362,503 and patents of the American Telephone and Telegraph Company.

*Add 10% to above prices.

REPRINTS AVAILABLE
ON IRON-CORED COIL ARTICLES

We shall have available shortly a reprint of the several articles on iron-cored coils that have appeared in the *Experimenter*. The pamphlet will include a cardboard *Q* template, a full-size plot of effective vs. measured air gaps and the complete text of the following articles:

L. B. Arguimbau, **"Losses in Audio-Frequency Coils,"** November, 1936.

P. K. McElroy and R. F. Field, **"How Good is an Iron-Cored Coil?"** March, 1942.

P. K. McElroy, **"Those Iron-Cored Coils Again,"** December, 1946, and January, 1947.

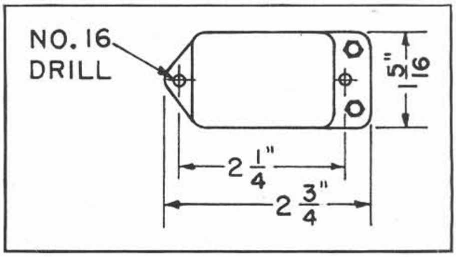
This reprint brings together for easy reference a valuable fund of information on coil design and should be a welcome addition to the engineer's technical data file.

A copy is yours for the asking.

NEW SIZES IN PRECISION FIXED RESISTORS

To complete the 1-2-5 distribution of resistance values in three decades of the resistance range covered by Type 500 resistors, three new units have been added: 20 ohms, 2,000 ohms, and 5,000 ohms. These handy resistors are excellent standards for use at audio- and low-radio frequencies. They are sealed in molded phenolic cases and are provided with both screw-type and plug-type terminals. The complete range of values is listed below, and most sizes are in stock.

All units are adjusted within 0.1%, except the 1-ohm size, which is adjusted within 0.25%.



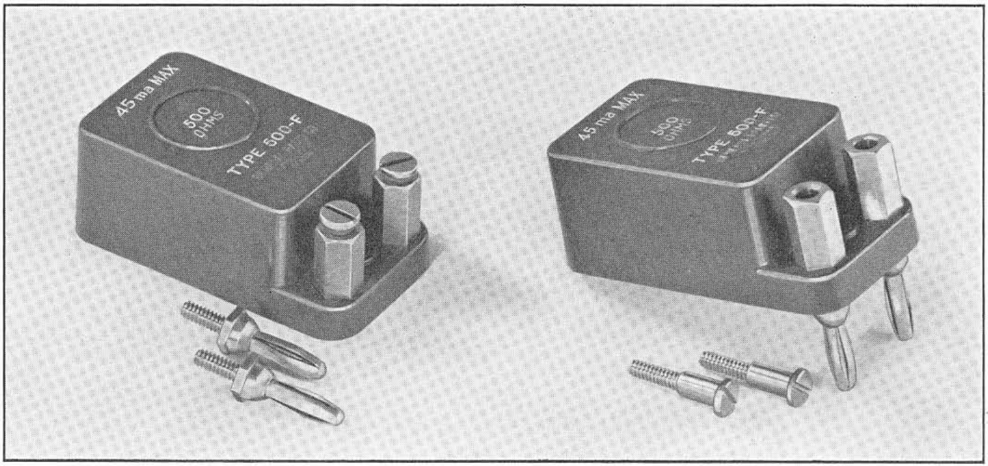
Over-all base dimensions of TYPE 500 Resistor.

SPECIFICATIONS

Type	*Resistance*	*Maximum Current*	*Code Word*	*Price*
500-A	**1 ohm**	1.0 a	RESISTBIRD	**$2.50**
500-B	**10 ohms**	310 ma	RESISTDESK	**2.50**
500-K	**20 ohms**	220 ma	RESISTFILM	**2.50**
500-C	**50 ohms**	140 ma	RESISTFORD	**2.50**
500-D	**100 ohms**	100 ma	RESISTFROG	**2.50**
500-E	**200 ohms**	70 ma	RESISTGIRL	**2.50**
500-F	**500 ohms**	45 ma	RESISTGOAT	**2.50**
500-G	**600 ohms**	40 ma	RESISTGOOD	**2.50**
500-H	**1000 ohms**	30 ma	RESISTHYMN	**2.50**
500-L	**2000 ohms**	22 ma	RESISTBELL	**2.50**
500-M	**5000 ohms**	14 ma	RESISTPIPE	**2.50**
500-J	**10,000 ohms**	10 ma	RESISTMILK	**2.50**

Add 10% to all prices listed.

View of TYPE 500 Resistor, showing how the terminals can be adapted for either screw-type or plug-in terminals.



MISCELLANY

This venerable publication is in its twenty-first year, making it a Methuselah among radio and electronic journals. Such a claim to antiquity gives us an excuse to look back in the dusty files to find out what happened in our childhood days.

Twenty years ago in the *Experimenter* — Volume 1, No. 8, February, 1927 — the feature article, "A Study of Coil Resistances at 40 Meters," by L. B. Root, described the measurement of losses in a series of single-layer coils. Results were plotted as a function of wire size and of form factor. Measurements were made on the Type 353 Radio-Frequency Measuring Set, a remote ancestor of today's precise bridges, that flourished in the laissez-faire days before residual impedances were invented.

Another article described the Type 383 Portable Capacity Bridge for measuring small capacitances, such as those between the electrodes of a vacuum tube. Tubes in those days had a maximum of three electrodes, and grid-plate capacitances were about 10 $\mu\mu f$.

Accuracy requirements were less stringent and frequency ranges more limited twenty years ago. Then as now, however, General Radio was making the radio industry's measuring equipment and GR instruments were standard in the radio laboratory.

The international aspect of General Radio's business is one from which we derive a good deal of pleasure. Contacts with businessmen in other countries are invariably stimulating, and they foster an international, rather than a strictly national, viewpoint on contemporary affairs. Most of our foreign representatives have handled General Radio products for a number of years, and with them we have built up a personal as well as a business interest. Since the war many of them have visited this country, as previously mentioned in this column. Two more that we have recently had the pleasure of welcoming back to our plant are Mr. Robert T. Ting, General Manager of the China Scientific Instrument Company, Shanghai, who have represented us for over fifteen years; and Mr. V. G. Motwane, Managing Director, Eastern Electric and Engineering Company, Bombay, our representatives in India for more than ten years.

Other recent visitors from abroad include Dr. B. J. O'Kane of the General Electric Company, Ltd., England; Mr. C. W. Goyder, Chief Engineer of the Broadcasting Department of the Government of India; Major Chen Ya-Sun, Ordnance Corps, Chinese Army; Mr. David Rich, Managing Director, Taylor Electrical Instrument Co., Ltd., Slough, Bucks, England.

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THE General Radio EXPERIMENTER

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

VOLUME XXI No. 10 MARCH, 1947

SEARCH RECEIVERS FOR RADAR COUNTERMEASURES

Also
IN THIS ISSUE

● AN ASPECT of the recent war that has received more and more widespread recognition, as hitherto classified information on equipment and techniques has been released, is the tremendously important role that was assumed by electronic devices.

The development of radar has been described in terms of equipment design and operating characteristics in many papers[1], and will, no doubt, be the subject of many more. Its direct relation to military operations, however, is a parallel story of equal fascination.

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[1] For instance: Edwin F. Schneider, "Radar," Proc. IRE., Vol. 34, No. 8, pp. 528–578, August, 1946. Lloyd J. Berkner, "Naval Airborne Radar," Proc. IRE., Vol. 34, No. 9, pp. 671–706, September, 1946.

Figure 1. Panel view of the TYPE P-540 Receiver.

The importance of radar and of electronic aids to navigation was realized very early in the war when the Battle of Britain first demonstrated, on a grand scale, the importance of aerial warfare. The RAF's gallant few, to whom so many owed so much, could never have accomplished their seemingly hopeless task of turning back the Luftwaffe had they not been alerted and controlled by an effective radar chain.

This new weapon, which helped to defeat the enemy at a critical time, soon showed, however, that it was a two-edged sword. There was, unfortunately, no monopoly of any one country on invention of electronic devices, and the Luftwaffe, repulsed in daylight warfare, soon turned to night attacks on England with the aid of electronic navigational systems that provided unpleasantly accurate blind bombing information. It became apparent very quickly indeed that a weapon of defense in the hands of the British had become a weapon of offense in the hands of the Germans and that a further defense in the form of electronic countermeasures was vitally needed. The battle lines of a war in the laboratories of the two countries therefore began to form behind the actual battle lines as first one side and then the other gained temporary supremacy in equipment and tactics.

As the imminence of involvement of the United States in the war became more and more apparent, great interest in this technical struggle led to a consideration of our own equipment needs if we were to become participants. It was the good fortune of the General Radio Company to be able to contribute one of the first developments of equipment for this new field of military endeavor.[2]

Fundamental factors in the planning of countermeasures equipment design are the immediacy of the problems and the diversity of requirements. In contrast to radar development, in which the designer poses and solves his own problem, in countermeasures development the enemy poses the problem and the designer must solve it on terms not of his own choosing. It was a consideration of the consequent need for accurate, up-to-the-minute information on enemy equipment and tactics that led the National Defense Research Committee to place its first countermeasures contract for a search receiver.

In order to establish an effective countermeasures program, it is necessary to determine, first, what equipment the enemy may have. Much information can be gathered through conventional intelligence channels, principally interrogations of prisoners, but this information is liable to be incomplete and, quite often, inaccurate. A supplementary source of information of great value is direct information obtained by seeking out enemy stations with mobile receivers that will tune to the frequencies in use and respond with sufficient faithfulness to the modulation to make possible analysis of the nature of the emitted signal. This type of information, which has been called electronic intelligence, is, at radar frequencies, collectible only within roughly optical range of the transmitter, and the equipment is therefore most suitably carried on submarines or in airplanes that can operate in enemy waters or over enemy territory.

The requirements for a search receiver for accumulating information of this kind are readily deduced from this analysis. The receiver should, first, be capable of

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[2] "Scientists Against Time," James Phinney Baxter III (Little, Brown and Company), p. 158. Chapter X of this brief official history of the Office of Scientific Research and Development is devoted to a summary of the contributions of the National Defense Research Committee to radar countermeasures.

tuning over the entire frequency spectrum within which the enemy is known to have equipment operating or in prospect. The bandwidth should be great enough to permit oscillographic analysis of modulations of various kinds, particularly short pulses. The equipment should be designed for airborne use. And, most important, the design should be flexible enough to permit rapid modification, particularly in frequency range, when changes in conditions arise.

The General Radio Company TYPE P-540 Receiver, from which many of the search receivers used in the war were derived, was designed to meet these needs. The first butterfly circuits[3] had just been developed and applied in the design of field-strength measuring equipment for the frequency range from 300 to 1000 Mc[4], and the wide tuning range of these units made feasible the design of a superheterodyne receiver having characteristics similar to those of low-frequency receivers. As early as the summer of 1941, when work was begun, it was known that the Germans were using radar frequencies between 120 and 565 Mc. The first design was therefore made to cover this frequency range with ample margins at both ends.

It was found that, with a 30 Mc intermediate frequency, the range from 75 to 1000 Mc required only two bands.

The first of these was covered with a Type 955 acorn triode in a butterfly-circuit local oscillator, tuning from 105 to 300 Mc; the second was covered with a Type 955 triode in a butterfly-circuit local oscillator tuning from 135 to 485 Mc. On the first band, mixing was done at the oscillator fundamental and yielded a tuning range from 75 to 300 Mc; on the second band, mixing was done at the second harmonic of the local oscillator and yielded a tuning range from 300 to 1000 Mc. On both bands, the antenna was tuned by butterfly circuits of appropriate range.

The need for as much flexibility in design as possible was recognized from the outset. Not only was there no guarantee that enemy frequencies outside the tuning range might not suddenly appear, but new developments were occurring at such rapid rate that there seemed good reason to suppose that frequent changes in the receiver itself might be desirable to keep it abreast of requirements. A unit-construction design was therefore chosen in which complete r-f tuning units could be plugged into a chassis that comprised the intermediate-frequency, second-detector, video-amplifier, and power-supply assemblies. Figure 1 shows the general nature of the design that was evolved for mounting in a standard ATR rack.

The basic correctness of this approach is well illustrated by the fact that, except for changes in controls and other minor modifications dictated by operational experience, no changes were made in the general chassis design throughout the war. Many substantial changes were made in tuning units, however, and improved performance obtained from receivers already in the field with newly designed units that could be inserted in place of obsolete ones.

The operating characteristics of the receivers as originally designed are now largely of historical interest and will be mentioned only as they are basic to the particular application and as they led to later improvement. The i-f bandwidth was 2 Mc, and about 90 db of i-f gain was obtained with five double-tuned overcoupled stages. This was sufficient gain to

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[3] E. Karplus, "Wide-Range Tuned Circuits and Oscillators for High Frequencies," Proc. IRE, Vol. 33, No. 7, pp. 426–441, July, 1945.

[4] E. Karplus, "Components of UHF Field Meters," *Electronics*, Vol. 19, No. 11, pp. 124–129, November, 1946.

get down into the noise level and to realize as much sensitivity as could be obtained with the r-f circuits. The r-f circuits, themselves, were elementary by modern receiver standards. No r-f amplifier was used, and the antenna and the local-oscillator tuning were separate. This simple design led to very rapid development, and models were submitted that were accepted for production within two months of the time the contract was let. The over-all sensitivity of the receiver was not extremely high, an r-f level of 5 to 15 μv generally being necessary to produce an audible signal; but it should be emphasized that sensitivity is not often important in radar-intercept work since direct signals at a given distance from a transmitter are so much stronger than signals reflected back over a path as long again to the radar receiver itself.

A few words about the subsequent history of the development of search receivers are of interest, particularly as they bring out the coordinated effort of industry. Much has been said about the interchange of information in the aircraft industry during the war. Less highly publicized has been the extent to which the same cooperation developed in the electronic industry.

By the summer of 1941 it was obvious that production facilities at the General Radio Company were going to be fully taken up by the manufacture of measuring equipment and that receiver production should be undertaken by a company better able to handle it. As a consequence, the Philco Corporation took the design and, by the spring of 1942, produced a small quantity of a Navy Bureau of Ships version of the receiver (Navy Model ARC-1). This was followed shortly afterward by a small quantity of an Air Corps version (Model SCR-587).

In the meantime the Radio Research Laboratory had been set up at Harvard University to deal directly with the development of countermeasures equipment. Intensive development work was commenced there in the spring of 1942 on an improved model, which incorporated a single-dial control of antenna tuning and local-oscillator frequency, a motor drive for sweeping any desired frequency band within the frequency range of the tuning units, improved image rejection, and an additional tuning unit to cover the frequency range from 40 to 100 Mc. This work culminated in the RRL Type D100 receiver, which was manufactured with some modifications by the Galvin Manufacturing Company for the Navy as the Type AN/APR-1 and by the Crosley Radio Corporation for the Army Air Forces as the Type AN/APR-4, large-quantity delivery beginning late in 1943.

In conjunction with this work, the General Radio Company also developed a Type P540-P3 tuning unit to cover the

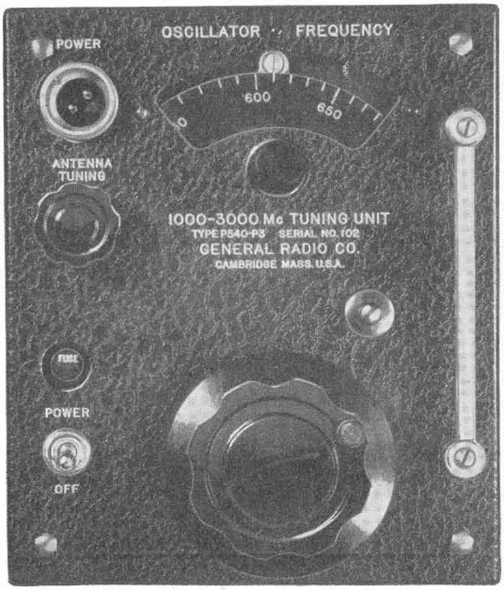


Figure 2. Panel view of the TYPE P-540-P3 Tuning Unit.

frequency range from 1000 to 3000 Mc. This tuning unit, shown in Figure 2, also used butterfly circuits. A scaled-down butterfly circuit was used for antenna tuning over the range from 1000 to 3000 Mc, and a local-oscillator butterfly circuit of more conventional dimensions for generating a fundamental frequency range of 500 to 1100 Mc with a Western Electric Type 703-A triode.

This tuning unit was produced in small quantity but was not so satisfactory as the lower-frequency units because serious difficulties were encountered with anomalous resonances in the antenna-tuning circuit. The Crosley Radio Corporation therefore undertook the development of two new tuning units using a similar local oscillator design but replacing the antenna-tuning butterfly by a tuned coaxial transmission line. The tuning of this line was ganged successfully with the oscillator drive to produce tuning units having single-dial control and frequency ranges from 1000 to 2200 Mc and 2200 to 4000 Mc.

The ultimate receiver secured from so much joint effort, therefore, covered with convenience and flexibility a frequency range from 40 to 4000 Mc, which was ultimately found to encompass all the radar frequencies used operationally by both the Germans and Japanese. It first found service in helping to spot enemy radar installations for the planning of the amphibious assault on Sicily and later found great use in the operations of the 8th Air Force over Germany and the 20th Bombing Command over Japan. Its appearance more recently among the electronic devices used at Bikini seems to indicate that advances in the art have not yet rendered it obsolete.

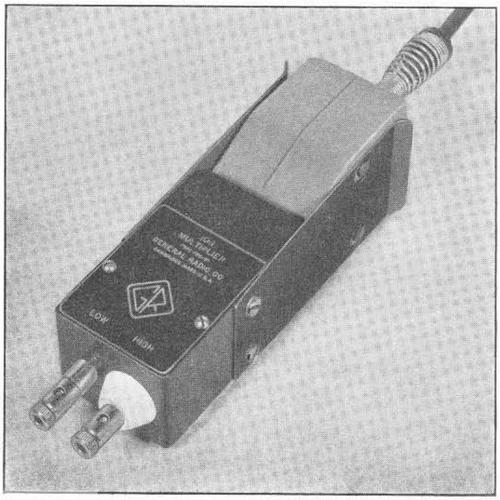
—D. B. SINCLAIR

IN STOCK—TYPE 726-P1 MULTIPLIERS

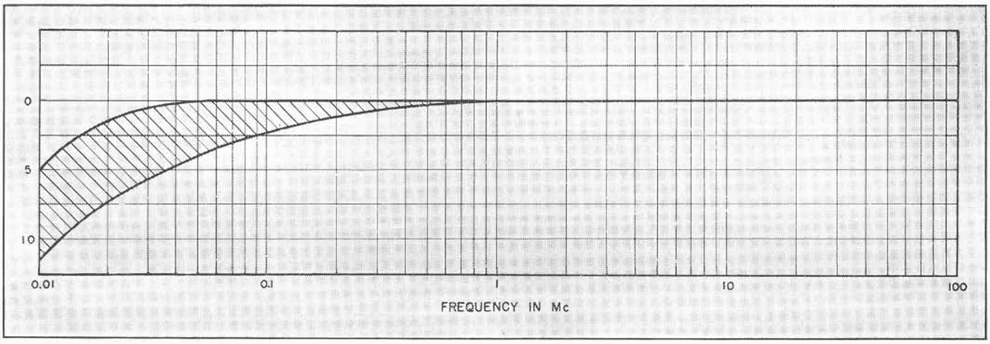
Although the TYPE 726-A Vacuum-Tube Voltmeter has been superseded by the recently announced TYPE 1800-A, thousands of the older instruments are still in use in radio and electronic laboratories. The usefulness of these can be greatly increased through the use of the TYPE 726-P1 Multiplier, which extends the voltage range of the instrument to a maximum of 1500 volts.

The multiplier is a capacitive voltage divider, which provides a 10:1 reduction between the voltage applied to the multiplier and the voltage appearing across the voltmeter terminals. The multiplier fits snugly to the voltmeter probe, adding about three inches to the effective probe length. The flanges which secure the multiplier to the probe also act as an electrostatic shield.

This useful accessory is still available and a quantity has only recently been completed in our factory. Shipment can be made from stock.



View of the TYPE 726-PI Multiplier attached to the Voltmeter probe.



Frequency characteristic of the multiplier.

SPECIFICATIONS:

Multiplier Ratio: 10 to 1, within ±1%.

Input Impedance: From 1 Mc to 100 Mc, the input impedance is effectively that of a 4.5 $\mu\mu$f condenser of less than 0.5% power factor.

Frequency Error: The frequency error is shown in the plot. No appreciable error occurs between 1 Mc and 100 Mc. The multiplier is not recommended for frequencies below 1 Mc.

Net Weight: 12 ounces.

Type		*Code Word*	*Price*
726-P1	**Multiplier**	ALOUD	**$18.00**

Add 10% to price listed above.

IMPROVEMENTS IN THE PRECISION WAVEMETER

The tuned-circuit wavemeter, long since displaced for highly precise work by crystal standards, nevertheless remains one of the most useful general-purpose instruments in the radio laboratory. This is particularly true of the Type 724 Precision Wavemeter, which has been for many years an accepted standard in the industry.

For such applications as the preliminary line-up of radio transmitters and the rapid checking of oscillator frequencies, this precision wavemeter fills a definite need in the frequency measurement field. The variable capacitor is a General Radio Type 722, specially designed for the purpose, with plates shaped to give a scale that is linear in frequency. The precision of setting is better than one part in 25,000. The plug-in coil mounting allows the coil to be rotated to obtain different degrees of coupling.

Newly developed crystal rectifiers and newly derived design formulae for inductors have made it possible to improve the performance of the wavemeter considerably. In the latest model, Type 724-B, the vacuum-tube detector has been replaced by a germanium crystal, thus eliminating the need for batteries and considerably simplifying the maintenance problem. Both selectivity and sensitivity are enhanced owing to a 2:1 improvement in the loading effect of the detector on the tuned circuit.

Selectivity and sensitivity are also greatly improved by a complete redesign of the inductors to obtain higher values of the storage factor, Q. All inductors have considerably higher Q's than formerly, with the greatest gain obtained on the 16 to 50 kilocycle coil, where the improvement is of the order of 6:1. As a result, this coil is now calibrated to the same accuracy as the others, namely, 0.25%.

SPECIFICATIONS

Frequency Range: 16 kilocycles to 50 megacycles.

Accuracy: ±0.25%.

Calibration: The calibration is supplied in the form of a table of calibrated points. Linear interpolation between these points is used to obtain settings for other frequencies.

Condenser: Precision worm-drive type similar to TYPE 722. The condenser setting is indicated on the dial and drum and is controlled from the front of the panel. There are 7500 divisions for the entire 270-degree angular rotation of the condenser rotor. The precision of setting is better than one part in 25,000. The plates are shaped to give an approximately linear variation in frequency with scale setting.

Inductors: Coils are wound on isolantite forms and enclosed in molded phenolic cases. Seven coils are used to cover a frequency range between 16 kilocycles and 50 megacycles.

Resonance Indicator: A germanium crystal rectifier is used with a microammeter to indicate resonance. The indicator is coupled to the tuned circuit through a capacitive voltage divider.

Crystal: TYPE 1N34 germanium crystal rectifier is used.

Mounting: A wooden storage case, fitted with lock and carrying handle, is furnished. This has compartments for holding the condenser, inductors, and calibration charts.

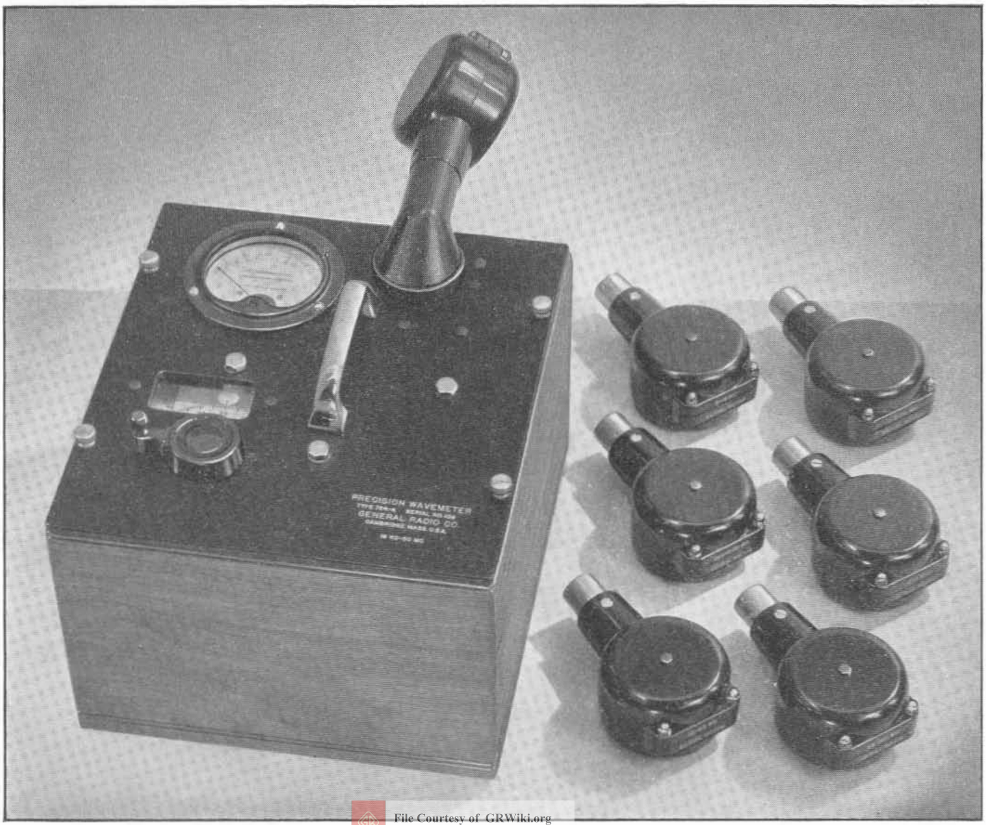
Dimensions: Carrying case, 17⅞ x 13 x 12½ inches, over-all.

Net Weight: With carrying case, 35¼ pounds; without carrying case, 20 pounds.

Type		*Code Word*	*Price*
724-B	**Precision Wavemeter**	WOMAN	**$230.00**

Add 10% to price listed above.

The TYPE 724-B Precision Wavemeter is identical in appearance with the TYPE 724-A shown here.



MISCELLANY

TWENTY YEARS AGO in the EXPERIMENTER, March, 1927 — The feature article is entitled, "A Discussion of Condenser Plate Shapes," by C. T. Burke. Three types of plates are discussed, giving linear variations in capacitance, wavelength, and frequency, respectively, and their advantages for particular uses are pointed out. Also mentioned is the fact that the straight-line-wavelength plate was first used commercially by the General Radio Company in the TYPE 124 Wavemeter, introduced in 1916.

A second article deals with the design plate supply units to achieve good regulation, and a third announces the TYPE 415 Laboratory Amplifier for use with bridges and oscillographs.

Another article, entitled "How Good is GOOD?" deals with the quality of reproduction obtainable from audio-frequency amplifiers and reproducers. It is pointed out that there is little advantage in designing amplifiers to cover a wider frequency range than can be reproduced by existing speakers.

A handy copper wire table is also published which gives the mechanical and electrical properties of wire for B and S gauges between 1 and 40.

Donald B. Sinclair, author of the article on search receivers, is Assistant Chief Engineer of the General Radio Company, where the TYPE P-540 Receiver was developed under his direction. As head of the Receiver Group of the Radio Research Laboratory, Harvard University, he supervised both the development of the D100 Receiver and its first field tests in the Mediterranean Theater of Operations.

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 address, type of business company is engaged in, and title or position of individual.

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THE General Radio EXPERIMENTER

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

VOLUME XXI No. 11 APRIL, 1947

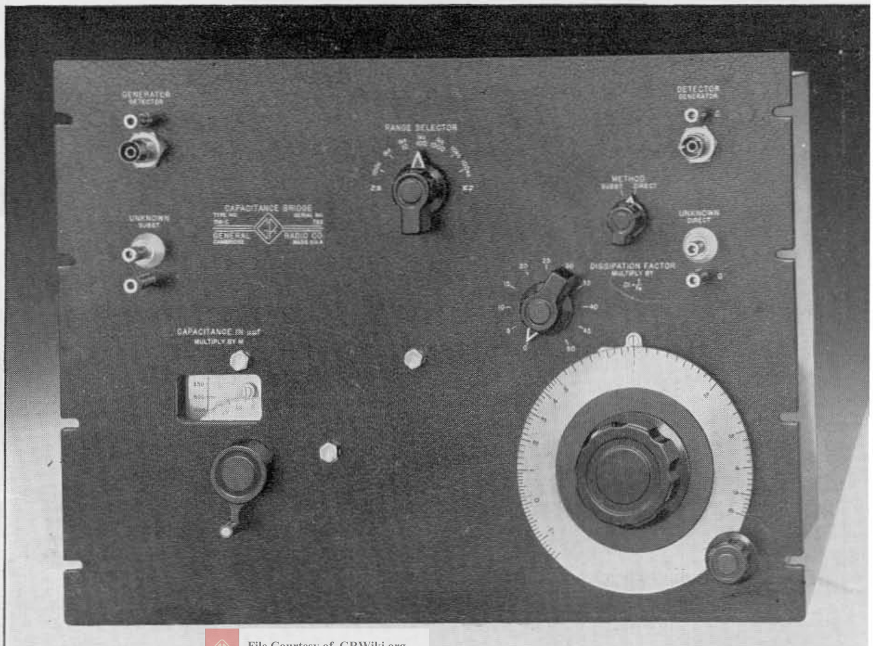
A WIDE-FREQUENCY-RANGE CAPACITANCE BRIDGE

Also

IN THIS ISSUE

● **THE CONSTANTLY** expanding spectrum of frequencies used by the radio engineer has stimulated the study of the dielectric properties of insulating materials and of the characteristics of capacitors over an ever-widening range of frequency. During the war measuring techniques were developed to keep pace with radar, pushing the upper frequency limit first to 3000 Mc with coaxial line apparatus and then to 10,000 Mc with wave-guide apparatus. The lower frequency limit of such equipment is about 200 Mc, which in turn is the upper limit of the susceptance-variation circuit. The Schering bridge and the susceptance variation circuit

Figure 1. Panel view of the Type 716-C Capacitance Bridge.



overlap, the latter extending down to 100 kc, and the former reaching at least to 10 Mc.

The Type 716-B Capacitance Bridge used the Schering bridge circuit, but has been limited to audio-frequencies within a factor of 3 below or above 1 kc. During the last four years some 25 of these bridges have been converted to Type 716-BS2 Capacitance Bridges to operate from 30 c to 300 kc for capacitance measurements up to 1000 μμf, while maintaining a capacitance range up to 1 μf at 1 kc. The new Type 716-C Capacitance Bridge, which supersedes the Type 716-B, incorporates these changes. A panel view of the new bridge is shown in Figure 1.

CIRCUIT

The circuit is that of the well-known Schering bridge, the arrangement of which is shown in Figure 2. The simplified conditions of balance are given by:

$$C_X = C_N \frac{R_A}{R_B}$$

$$D_X = R_X \omega C_X = R_A \omega C_A = Q_A$$

At any given frequency and value of R_A, the capacitor C_A can be calibrated to be direct reading in dissipation factor. The standard capacitor can be calibrated directly in micromicrofarads, and the capacitance range extended by switching the resistance R_B in decade steps. In the Type 716-C Capacitance Bridge, the capacitance C_A consists of an air capacitor and a mica decade capacitor, connected in parallel by suitable switching.

The air capacitor has a maximum capacitance of approximately 500 μμf. Connected across 20,000 ohms, this gives a maximum dissipation factor range of about 0.06 at 1000 cycles. The mica decade provides ten additional steps of 0.05 each, thus making a total range of 0.56.

The standard capacitor C_N is calibrated directly in μμf from about 100 μμf to 1100 μμf, and the total capacitance range of the bridge is extended to .011, .11, and 1.1 μf by changing the resistor R_B to 2000, 200, and 20 ohms, respectively. In order to maintain the feature of direct-reading dissipation factor, a suitable capacitor is connected in parallel with each value of R_B, to make the product $R_B C_B$ of the arm equal to the product $R_A C_{AO}$ of the arm A.

For substitution measurements of capacitance of 1000 μμf or less, the bridge is first balanced with a capacitor C_P connected in the P arm, whose capacitance is at least 100 μμf greater than that of the unknown capacitor. A second balance is obtained with the unknown capacitor connected in parallel with the standard capacitor C_N.

$$C_X = C' - C = \Delta C$$

$$D_X = \frac{C'}{C' - C}\left(R_A \omega C_A - R_A \omega C'_A\right)$$

$$= \frac{C'}{\Delta C} \Delta Q_A$$

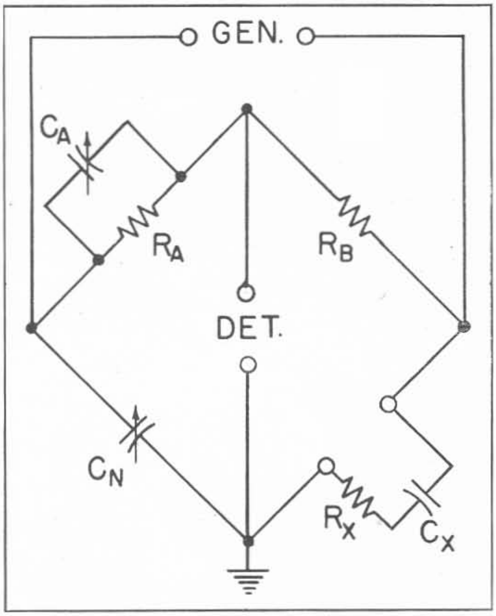


Figure 2. Elementary circuit of the Schering Bridge.

In order that the dissipation factor dial shall read up scale when the unknown capacitor is connected across the N arm, a method switch is provided, which in its substitution position, as shown in Figure 3, transfers the dissipation factor capacitors C_A to the B arm and places across the A arm a capacitance equal to twice the zero capacitance C_{AO} of the A arm.

EXTENSION OF FREQUENCY RANGE

Superficially, the problem of obtaining direct-reading scales at several different frequencies is merely that of switching the ratio-arm resistors. Although the equation of balance for capacitance is independent of frequency, that for dissipation factor is dependent on frequency in such a manner that, for a given R_AC_A combination, the range of dissipation factor is directly proportional to frequency. In order to retain the same range as the frequency is changed, it is necessary to change either R_A or C_A in inverse proportion. For several reasons, not the least of which is the obvious economic one, the change is accomplished by switching to a new value of R_A and its associated compensating capacitor. Simultaneously, of course, R_B must be switched, in order to retain the capacitance range.

The problem of satisfactory wide-frequency-range operation involves more than ratio-arm switching, however. Among the difficulties encountered are those due to

(*a*) Inductance of circuit elements and wiring.

(*b*) Leakage between primary of coupling transformer and bridge circuit.

(*c*) Insufficient transformer response at extremes of frequency range.

It is largely the limitations of (*a*) that have determined 100 kc as the highest nominal frequency for the bridge. The errors introduced by inductance vary, in general, as the square of the frequency; and, while negligible at 100 kc and with 200-ohm ratio arms, become intolerable at 1 megacycle and with 20-ohm ratio arms. These errors could be reduced to a tolerable value only by a drastic mechanical redesign of the bridge and its components, an objective not contemplated at the present time.

THE COUPLING TRANSFORMER

The principal design problem has been associated with the transformer used to couple the generator voltage to the bridge circuit. Ideally this transformer should introduce across the bridge circuit only that voltage magnetically induced in its secondary.

Actually, any transformer will have, in addition to this desired inductive coupling, capacitive and conductive

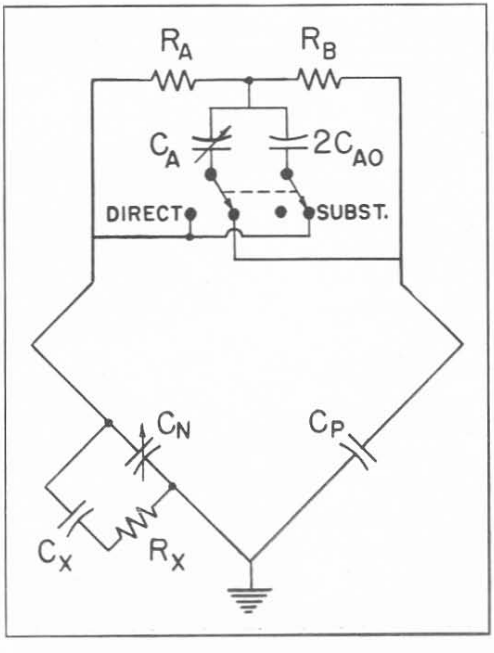


Figure 3. Method of switching from direct to substitution measurements.

couplings between the primary winding and the secondary winding and shields. Any high-impedance bridge circuit is extremely sensitive to the effects of these extraneous couplings. In the design of the transformer for this bridge, unusual precautions have been taken to shield the primary winding. The input is by way of a coaxial lead brought directly into the winding with its shield soldered to the winding shield. The latter completely encloses the primary winding except for the necessary slot, which is overlapped. Similar precautions are taken with the other shields; but nevertheless, a total residual coupling capacitance of the order of a few hundredths μμf remains, due probably to leakage through the braid of the concentric cable and fringing through the slots of the shields.

The dissipation factor of this coupling capacitance, which would supply a conductive coupling, has been reduced to a negligible value by the use of polystyrene tape for the insulation between shields. In all of the transformers used in the previous models, paper and hard rubber insulation was used and the resulting conductive coupling was sufficient to cause an error approaching 0.0005 in dissipation factor for small capacitance settings.

The effect of this coupling capacitance depends on the phase of the primary voltage across the bridge and at high frequencies is such as to produce significant errors in dissipation factor readings. To counteract this effect, a second voltage opposite in phase to the primary voltage is coupled to the bridge through a small capacitance. By proper adjustment of this coupling capacitance, the effect of the undesirable coupling is "neutralized." The problem is very similar to that encountered in the triode amplifier where grid-plate capacitance causes undesirable coupling between grid and plate circuits. The solution also is similar, as the method employed here bears a strong resemblance to the "neutralization" methods commonly employed in radio-frequency power amplifiers. The out-of-phase component of voltage is conveniently taken from the half-turn potential of the primary shield, the mid-point of which is grounded.

Maximum useful frequency range of the transformer is achieved by the use of high-permeability core material, with a one-to-one turns ratio. For the normal connection of the bridge, the one-to-one ratio means a sacrifice in sensitivity of about three to one as compared to the 716-B with its four-to-one winding ratio. On the other hand, a three-to-one *gain* in sensitivity over the 716-B is realized when the generator and detector connections are interchanged. This latter connection is frequently used at 60 cycles as it permits voltages up to 700 volts to be impressed on the unknown

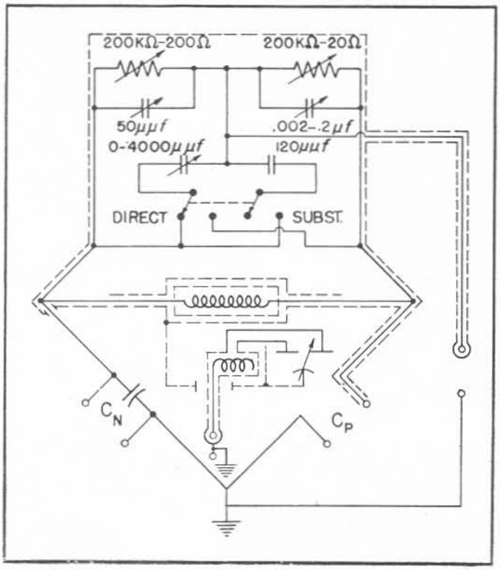


Figure 4. Schematic circuit diagram of the Type 716-C Capacitance Bridge, showing arrangement of transformer shields.

capacitance, compared to 50 volts for the normal connections. When the bridge is so connected, the transformer is operated, at balance, at zero signal level and must be protected against magnetic pickup. Such protection is provided by a case of high-permeability material which reduces pickup by more than 40 db.

The complete schematic diagram of this bridge is given in Figure 4. The transformer capacitance is placed across the *B* arm instead of the *A* arm in order to keep the zero capacitance of the ratio arms as small as possible.

ACCURACY

The same accuracy for both capaci-

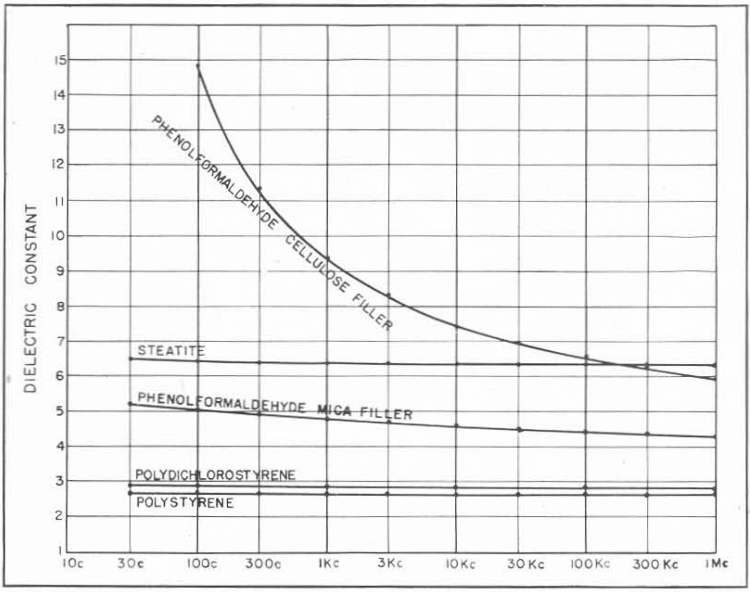
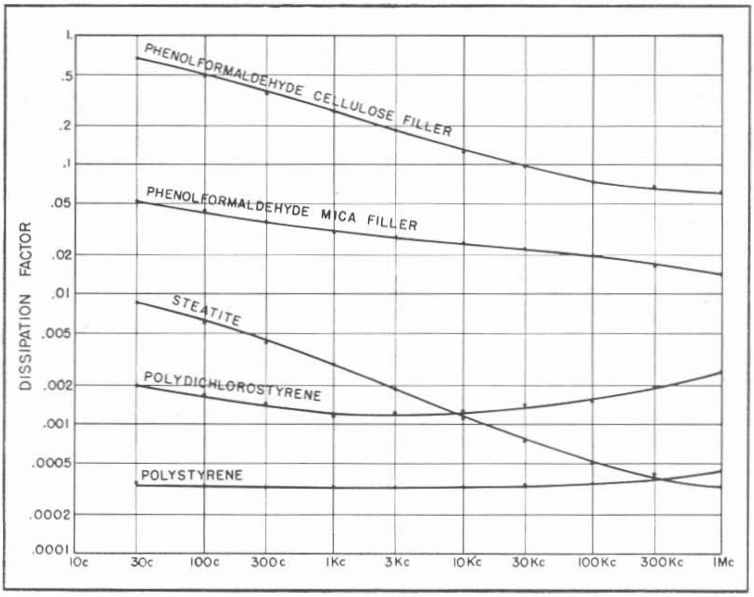


Figure 5. Typical measurements with the Type 716-C Capacitance Bridge.

(*Left*) Variation of dielectric constant with frequency for several dielectric materials.



(*Right*) Variation of dissipation factor with frequency as measured on the bridge.

tance and dissipation factor that obtained in previous models of the bridge at 1 kc, and which is stated in the specifications below, holds in the 716-C from 30 c to 300 kc, provided the bridge is always operated within a factor of 3 of its direct-reading range frequency. Substitution measurements can be made to the same accuracy up to 1 Mc provided the unknown capacitance is less than 500 $\mu\mu$f.

USES

Aside from the normal uses of the bridge in measuring any capacitor within its range for both capacitance and dissipation factor, there are many other uses for which its accuracy and wide capacitance and frequency ranges particularly adapt it. Perhaps its most important use is in the intercomparison of sets of standards, such as Type 509 Condensers. This intercomparison can be made to an accuracy of 0.02% for capacitance and 0.00005 for dissipation factor. Absolute values of capacitance have an accuracy of only 0.2% except where one or more of the standards have been certified by the National Bureau of Standards. The capacitance range of such intercomparisons can be extended with some loss in accuracy down to 1 $\mu\mu$f using special Type 722 Precision Condensers and up to 1 mf (1000 μf) using suitable groups of oil-filled paper capacitors.

Another important use of the bridge is in measuring the dielectric constant and dissipation factor of dielectric samples over the frequency range from 30 c to 1 Mc. Contained within this range are the effects of interfacial polarization at low audio-frequencies and of dipole polarization in polymers. The effect of surface water films can also be studied.

This bridge offers one of the best methods of measuring the Boella effect in high valued resistors. This effect results from the distributed capacitance occurring in such resistors. The value of this distributed capacitance and any parallel lumped capacitance is also determined. Whenever in a lower-valued resistor the effect of its series inductance outweighs that of its parallel capacitance, the value of this series inductance can be determined. In the same manner, the frequency characteristics of a large inductor or choke coil can be determined as it passes through its natural frequency and becomes capacitive.

R. F. Field
I. G. Easton

SPECIFICATIONS

Ranges: Direct Reading—capacitance, 100 $\mu\mu$f to 1 μf at 1 kc; 100 $\mu\mu$f to 1100 $\mu\mu$f at 100 c, 10 kc, and 100 kc; dissipation factor, 0.00002 to 0.56.

Substitution Method—capacitance, 0.1 $\mu\mu$f to 1000 $\mu\mu$f with internal standard; to 1 μf with external standards; dissipation factor, $0.56 \times \frac{C'}{C_x}$ where C' is the capacitance of the standard condenser and C_x that of the unknown.

Accuracy: Direct Reading — capacitance, ±0.2% or ±2 $\mu\mu$f × multiplier reading (0.2% of full scale for each range) when the dissipation factor of the unknown is less than 0.01; dissipation factor ±0.0005 or ±2% of dial reading, for values of D below 0.1.

Substitution Method—capacitance ±0.2% or ±2 $\mu\mu$f; dissipation factor, ±0.00005 or ±2% for change in dissipation factor observed, when the change is less than 0.06.

A correction chart for the precision condenser is supplied, giving scale corrections to 0.1 $\mu\mu$f at multiples of 100 $\mu\mu$f. By using these data, substitution measurements can be made to ±0.5 $\mu\mu$f.

When the dissipation factor of the unknown exceeds the limits given above, additional errors occur in both capacitance and dissipation-factor readings. Corrections are supplied, by means of which the accuracy given above can be maintained over the entire range of the bridge.

Ratio Arms: The arm across which the dissipation factor condenser is normally connected at 1 kc has a resistance of 20,000 ohms. The other arm has four values, 20,000 ohms, 2000 ohms, 200 ohms, 20 ohms, providing the four multiplying factors 1, 10, 100, 1000. Suitable condensers are placed across these arms so that the product RC is constant. At 100 c, 10 kc, and 100 kc the ratio arms are equal and have resistances of 200,000 ohms, 2000 ohms, and 200 ohms, respectively.

A switch is provided for shifting the dissipation-factor condensers to the other ratio arm when the substitution method of measurement is used, so that the dissipation-factor dial will read up-scale.

Standards: Capacitance, TYPE 722 Precision Condenser direct reading from 100 $\mu\mu$f to 1100 $\mu\mu$f; dissipation factor, TYPE 539-T Condenser with semi-logarithmic scale and decade-step condenser calibrated directly in dissipation factor.

Shielding: Ratio arms, dissipation-factor condensers, and shielded transformer are enclosed in an insulated shield. The unknown terminals are shielded so that the zero capacitance across them is not greater than 1 $\mu\mu$f. A metal dust cover and the aluminum panel form a complete external shield.

Frequency Range: All calibration adjustments are made at 1 kc and the accuracy statements above hold for operating frequencies from 30 c to 300 kc, provided the operating frequency does not differ from the range selector frequency by more than a factor of three. Dissipation-factor readings must be corrected by multiplying the dial reading by the ratio of operating frequency to the range selector frequency.

Voltage: Voltage applied at the GENERATOR terminals is fed to the bridge through a 1-to-1 shielded transformer. A maximum of 1 watt can be applied, allowing a maximum of 300 volts at 1 kc, but only 50 volts at 60 c.

Power can also be applied at the DETECTOR terminals, and the detector connected to the GENERATOR terminals.

Mounting: The bridge is supplied for mounting on a 19-inch relay rack or for cabinet mounting.

Accessories Required: Oscillator and amplifier. For audio frequencies TYPE 1301-A Oscillator and TYPE 913-B Beat-Frequency Oscillator are satisfactory power sources. TYPE 1231-A Amplifier and Null Detector is recommended for use as the detector. For aural null indications, Western Electric 1002-C Telephones can be used with the amplifier. The TYPE 707-A Cathode-Ray Null Detector can also be used as a detector for frequencies up to 2 kc.

For substitution measurements, a balancing condenser is needed. This may be either an air-dielectric model, TYPE 539-B, or a fixed mica condenser of the TYPE 505 series.

Accessories Supplied: Two TYPE 274-NE Shielded Connectors.

Dimensions: (Length) 19 x (height) 14 x (depth) 9 inches, over-all.

Net Weight: 41½ pounds, relay-rack model; 53¾ pounds, cabinet model.

Type		*Code Word*	*Price*
716-CR	**For Relay-Rack Mounting............**	BONUS	**$410.00**
716-CM	**Cabinet Mounted....................**	BOSOM	**450.00**

Add 10% to above prices.

MISCELLANY

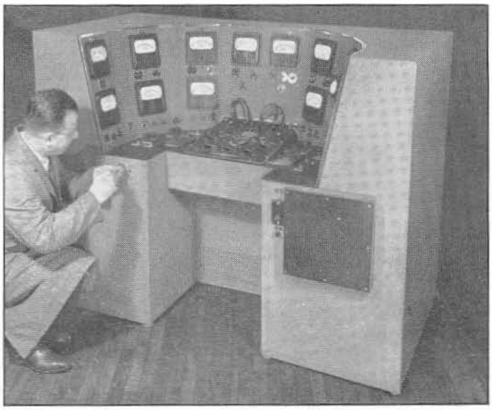
Among the recent visitors to our plant and laboratories were four from Stockholm, Sweden: Mr. Carl A. Trapp, Chief Engineer of A. B. Riffa; Mr. Tord Wikland of the Research Institute for National Defense; Mr. Gunnar Svala, Chief Research Engineer, A. B. Svenska Electronr̈or, and Mr. Carl H. Sivers of L. M. Ericcson, Tu.

The TYPE 716-C Capacitance Bridge was developed by Robert F. Field and Ivan G. Easton, the authors of the article appearing in this issue. Mr. Field is a widely known authority on impedance measurements and the properties of dielectric materials, and has contributed a number of papers on these subjects to the journals of professional societies and to the *Experimenter*. Mr. Easton, who has been intimately associated with bridge development, will also be recognized as a frequent contributor to the *Experimenter*. He is at present in charge of our New York Engineering Office.

The TYPE 413 Beat-Frequency Oscillator, which, we believe, was the first instrument of its kind to be made available commercially, was announced twenty years ago this month in the *Experimenter*. Since that time, new models have appeared every few years, each an improvement in many ways over its predecessors. A comparison of the characteristics of the TYPE 413 with those of the current model, TYPE 913-C, affords interesting proof of the progress that has been made in twenty years in the design of vacuum tubes and circuit components and in the development of circuits.

Date	*Type*	*Frequency Range*	*Open Circuit Output Volts*	*Output Power*	*Output Impedance*	*Distortion*	*Power Supply*
1927	**413**	0-10,000 cps	2 5	0.6 mw	10,000 Ω	4%	Batteries
1947	**913-C**	20-20,000 cps	25	0.3 watt	600 Ω	0.3%	A-C Line

VACUUM-TUBE TEST SET



Shown in the accompanying photograph is a laboratory test set for vacuum tubes recently developed by Sylvania Electric Products, Incorporated. For dynamic measurements of plate resistance, amplification constant, and transconductance, this test set uses the General Radio TYPE 561-D Vacuum-Tube Bridge, shown in the center of the photograph.

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THE General Radio EXPERIMENTER

VOLUME XXI No. 12 MAY, 1947

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

CONNECTION ERRORS IN CAPACITANCE MEASUREMENTS

Also

IN THIS ISSUE

• **WHEN A CAPACITOR** is connected into a circuit, some type of connecting wires must be used. These wires will have capacitances to each other and to other parts of the circuit, with the result that the capacitance actually introduced into the circuit is different from that of the capacitor alone. Even when one capacitor is substituted for another, using exactly the same leads, the capacitance of these connections may be different in the two cases, particularly if the two capacitors differ in size and shape. Such connection errors, while negligible in many cases involving large capacitances, become of importance in the measurement and intercomparison of small capacitances and of standards.

How many different types of connection capacitances are there and what are their magnitudes? An actual example will serve to illustrate them. Suppose that two Type 722 Precision Condensers are to be connected together. With their panels touching, their terminals are three inches apart. Let these terminals be connected by two No. 16 bare copper wires spaced ¾ of an inch apart (standard General Radio spacing). The wire should be bare to eliminate both the extra capacitance intro-

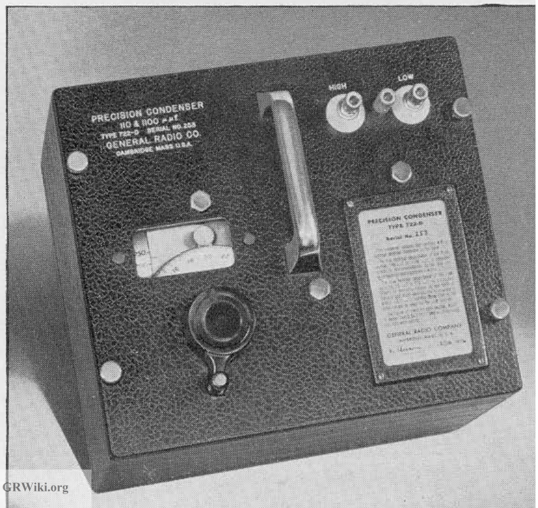

Figure 1. The accuracy to which the calibration of a Type 722-D Precision Condenser (shown at right) can be specified depends to a considerable degree upon the errors discussed in this article.

duced by the insulation, whose dielectric constant is greater than unity (3 perhaps), and the added dielectric loss in this insulation. The wire should be of small diameter because its capacitance varies as the logarithm of the ratio of its diameter to some other length, spacing of the wires, or distance to ground. Precision condensers are two-terminal capacitors with one terminal connected to the panel and shield. One of the connecting wires is, therefore, connected to the panel and to ground.

There are three types of capacitance involved: capacitance between the two wires, capacitance between the high wire and the panel, and capacitance between the high wire and ground. The calculated values of these three capacitances are 0.22 μμf, 1.07 μμf, and 0.79 μμf respectively. They are, however, by no means additive. The grounded wire shields the panel so that part of the capacitance to the panel is transferred to the grounded wire. Similarly, part of the capacitance to an infinite ground is transferred to the panel which is shielding it. The actual total capacitance is 1.19 μμf. This is certainly not negligible when measuring capacitances of 1000 μμf or smaller.

It should then be sufficient, when connecting two capacitors in parallel, to add the capacitance of the added capacitor and the connecting wires. Unfortunately, the latter, as indicated above, is not a constant for a given pair of wires, but depends greatly upon the distance of these wires to all grounded panels and hence on the size and shape of the added capacitor. It is, therefore, usual in substitution measurements to keep the leads connected to the standard capacitor with the unknown in position and with its grounded terminal already connected. The high lead is in position and just not touching the high terminal of the unknown. Such a disposition of apparatus is shown in Figure 2. Having made a sufficient measurement, such as balancing a bridge, for this condition, the unknown capacitor is connected into circuit and the second balance made. In this manner the effect of the leads is taken into account, for this should be the same in both measurements. It appears, however, that the capacitance measured depends upon the original separation of the high lead and the high terminal of the unknown.

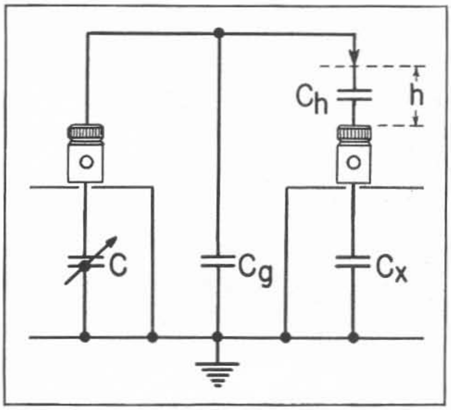

Figure 3. The stray capacitances C_g and C_h produce errors in the measurement of the unknown capacitor C_x.

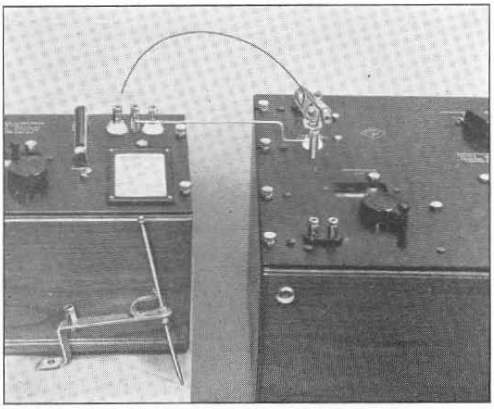

Figure 2. This fine wire connector, by means of which Curve *A* of Figure 5 was obtained, is used in calibrating all precision capacitors in our laboratories. An older type of connector is shown leaning against the capacitor cabinet and produces a much greater error as shown in Curve *B* of Figure 5.

Figure 3 illustrates the various capacitances which enter the problem. For the first measurement the high lead has a total capacitance C_g to ground and a capacitance C_h to the high terminal of the unknown capacitance C_x, both of these capacitances corresponding to a certain separation h. The total capacitance of the system is

$$C + C_g + \frac{C_h C_x}{C_h + C_x}.$$

The high lead is then brought into contact with the high terminal, making $h = 0$ and $C_h = \infty$. The standard condenser is then changed to a capacitance C' such that the total capacitance of the system is the same as before. The change in capacitance ΔC of the standard capacitor is

$$\Delta C = C_x + \Delta C_g - C_h$$

where C_h is written for $\frac{C_h C_x}{C_h + C_x}$ because in general C_h is very small compared to C_x. Other observations are then made for different distances of separation h, and the capacitance changes ΔC plotted against h, as shown in Figure 4. If in moving the high lead over the distance h, the ground capacitance C_g does not change, i.e., $\Delta C_g = 0$, the plot of ΔC against h will have a horizonal asymptote, which is the true value of C_x. Even under the most favorable conditions, there will be some change in this ground capacitance as the spacing h is changed. If the high lead is a fine wire and is kept a considerable distance from all grounded surfaces, the change in C_g will be approximately a linear function of h. The plot of ΔC will then have a slanting asymptote whose intercept is the value of C_x. The finer the wire and the greater the distance to ground, within limits, the more nearly horizontal is this asymptote. For a large wire near the grounded panels the change in C_g is such that this plot of ΔC has a maximum and changes by such a large amount that it is impossible to draw an asymptote.

Observations made with a TYPE 716-A* Capacitance Bridge on a TYPE 722-D Precision Condenser are plotted in Figure 5. Curve A was obtained with the connector shown mounted on the bridge in Figure 2. The fine steel wire is kept as far from the grounded panels as possible and is raised by means of a cam which is mounted on the triangular support. The slanting asymptote is well defined and gives a value of 99.13 μμf for the capacitance of the unknown capacitor. The curve has this value for a separation h of ¼ inch. Hence, with this connector and a ¼-inch separation, it should be possible to measure capacitance within ±0.01 μμf. Curve B was obtained using the connector which is shown leaning against the precision capacitor. Only the vertical rod moves, and its capacitance to ground should change only slowly. The supporting bar is, however, wide enough to shield the rod and cause the ground capacitance to change rapidly as the rod is raised. Hence all measured values of ΔC are low, and no asymptote can be drawn. The panel of the precision capacitor was next depressed 5 inches and

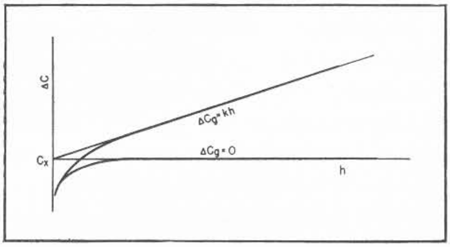

Figure 4. Theoretically, the measured capacitance of an air capacitor plotted as a function of the distance *h* shown in Figure 3 has either a horizontal or a slanting asymptote.

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* The current model is TYPE 716-C described in the April issue of the *Experimenter*.

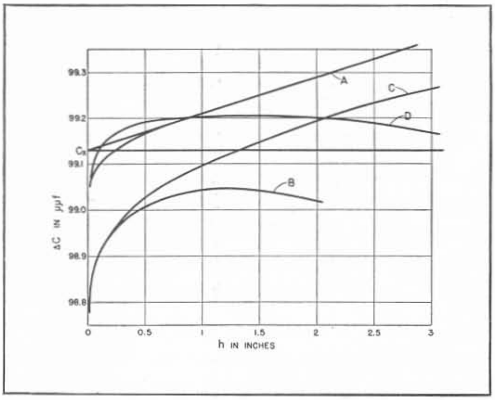


Figure 5. Different types and arrangements of connectors produce differently shaped plots of measured capacitance against the distance *h*. Curve *A*, taken with the fine wire connector of Figure 2, is the only one of the four curves which has a well-defined asymptote.

Curve *C* obtained. This shows a great improvement over Curve *B*, but the slanting asymptote is not easily defined. The critical separation *h* is 1⅜ inches. Curve *D* was obtained with No. 16 parallel wires at the same height from the panel as the hole in the terminal. There is no possibility of drawing an asymptote, and the critical separation is only 0.1 inch.

The fine wire connector is now used for all accurate capacitance measurements in the General Radio testing laboratory. The critical separation of ¼ inch is always obtained by adjustment of the height of the high terminal and the cam then used to make quick connection or disconnection. Observations can be repeated to 0.01 μμf and to 0.02 μμf even when the capacitors are removed and then reassembled. Different types of capacitors, both standard and unknown, can affect the value of the critical separation so that 0.1 μμf is at present set as a conservative error.

There are, of course, many ways of connecting capacitors in parallel so that their capacitances add with only slight error. TYPE 509 Condensers are built to be stacked one on top of another. Plugs projecting downward from the terminals fit into the jack tops of the terminals below. The plugs add a capacitance of about 0.5 μμf. The error from stacking in this way is less than 0.01 μμf.

When the power factor of a capacitor as well as its capacitance is to be measured, extra care must be taken to keep the contact resistance of the connections low. The equivalent series resistance of a capacitor varies inversely both as the capacitance and as the frequency. Even at a frequency of 1 kilocycle the resistance of a 1 μf capacitor of power factor 0.0005 is only 0.08 ohm. The use of plugs and jacks under these circumstances is questionable.

In the most precise work the capacitor is provided with a third terminal connected to guard electrodes or to the shield from which the main terminals of the capacitor are now insulated, and the bridge is provided with a guard circuit to which the extra terminal is connected. By these devices the connection capacitances and their power factors are removed from the direct measurement.

— ROBERT F. FIELD

VARIAC OVERLOAD PROTECTION

The problem of overload protection for Variac auto transformers is greatly complicated by certain inherent (and desirable) Variac characteristics. These are the ability of Variacs safely to withstand comparatively heavy overloading for short periods (as in motor starting or lamp circuit inrush) and the variation of copper loss with brush position which permits a substantial increase in allowable load currents at, or near, zero or line voltage settings.

Short-term overloads are permissible because of the thermal inertia inherent in Variacs, as in any device having appreciable mass and good thermal conductivity. The excess heat released in the overload period is quickly distributed throughout the structure and absorbed so that excessive temperatures will not be reached in a short time. This is a most important consideration for the user as it means that his Variac rating need not be increased in order to handle starting or surge conditions normally encountered.

Obviously, the use of a protective device incapable of passing safe short-term overloads would unduly limit the usefulness of a Variac. This, then, precludes the use of fuses (even "slow-blow" types) if the fullest use of the Variac is to be realized, and calls for the time-current integrating type of protector which automatically allows short-term overloads within the safe limits of Variac operation.

The variation in allowable load current poses a still more difficult problem, and one for which we have no satisfactory universal solution. If full advantage is to be taken of the maximum allowable load current, the protective device cannot be expected to function where the allowable current curve drops to a minimum. Here, then, is a condition that calls for the exercise of judgment on the part of the user, who, being familiar with the requirements to be met under his service conditions, can best decide whether to provide maximum protection at the sacrifice of increased current draw for some settings, or to sacrifice some protection in the interest of being able to obtain maximum current.

Several protective devices of the necessary time-current type are commercially available. Of these, the magnetic-trip delayed-action circuit breaker, made by the Heinemann Circuit Breaker Co., Trenton, New Jersey, seems most efficient and reliable.

Since the vast majority of Variac users do not employ protective devices, the direct incorporation of a protective device into Variacs seems uneconomical in view of the increased cost that would result.

Heinemann Breaker No. 0411TS is recommended for all present production Variacs, and may be obtained in all values of either rated or maximum current over the range required. Maximum protection to the Variac will be provided by connection of this breaker in series with the brush lead.

— GILBERT SMILEY

METER CALIBRATION WITH THE VARIAC

One of the many uses of the Variac is in supplying calibrating voltages and currents for electrical indicating instruments such as voltmeters, ammeters, and wattmeters. The accompanying diagrams show a circuit for a-c instrument calibration used by Professor R. M. Marshall of Purdue University.

The circuit of Figure 1 is used for current calibrations. The source is a 60-cycle generator, although, if ordinary line voltage variations can be tolerated, ordinary a-c lines can be used. Variac No. 1 is used to adjust the current to give full-scale reading on the instrument to be calibrated, which is connected between the ± terminal and the terminal most nearly representing the full-scale value. With Variacs No. 2 and No. 3 set at maximum, No. 1 is adjusted until the instrument reads full scale or slightly beyond. Zero deflection then corresponds to the zero settings of No. 2 and No. 3. The full range of Variac No. 2 then covers the range of the instrument from zero to full scale. Variac No. 3 changes the current 1/20th as fast as No. 2. The range and precision of control in terms of full-scale deflection are thus the same, regardless of the instrument impedances.

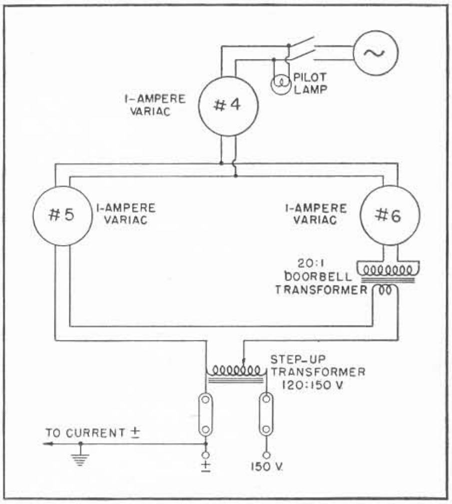


Figure 2. Circuit for potential calibrations.

Two current transformers are used so that all tests can be made in terms of a 5-ampere standard instrument. Each current transformer has several ranges. The standard instrument can be connected to one of the instrument transformers or directly in series with the meter under calibration. The transformers must be shorted as shown, if they are not connected to the standard instrument. The seven resistors are used to stabilize the circuit and to bring the current more nearly into phase with the line voltage. This arrangement gives approximately 100% power factor for wattmeter tests.

The potential circuit of Figure 2 operates in a similar manner. The two terminals provided take care of all instruments rated up to 150 volts. For higher voltages an additional transformer can be inserted at the points where links are shown. The standard instrument is connected in parallel with the instrument under test.

A grounded connection between the current and potential circuits is provided as shown in Figure 2. When a wattmeter is being tested, the potential terminal leading to the multiplier should be connected to the 150-volt terminal rather than to the + terminal, in order to avoid a high potential between the wattmeter coils.

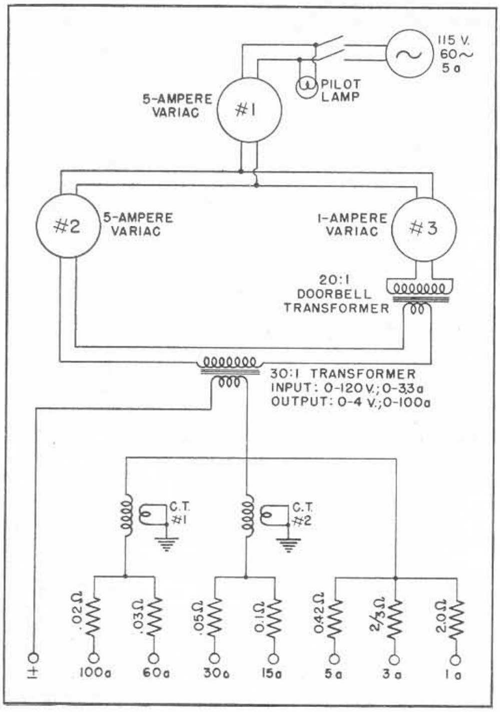


Figure 1. Circuit for current calibrations.

ASK FOR THIS TAG BEFORE RETURNING EQUIPMENT FOR REPAIR

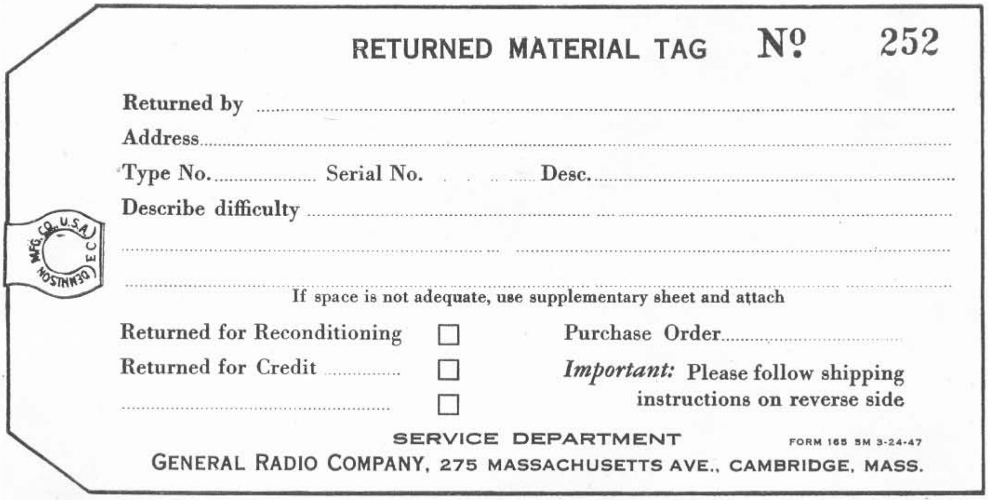
Instruments are often returned to us with purchase orders specifying "Repair." We then thoroughly recondition the instruments and recalibrate them to the same laboratory testing specifications that are used for newly manufactured equipment. Occasionally, after receiving the repaired instrument, the customer will report that the instrument still exhibits the same erratic fault or intermittent operating defect that occasioned the original return, and it is necessary to send the equipment back a second time.

To prevent this, we have been spending a greater than normal time in testing repaired instruments. Only in this way can we be sure of catching defects that would not occur in new instruments. Such a procedure, as records show, inevitably increases repair costs, and the charges billed to the customer are often as much as 10% greater than normal. Much time and money can obviously be saved if we know when the instrument is returned exactly what is wrong with it.

Consequently, we are now requesting that our new returned-material tag be attached to all returned instruments. Before returning equipment to us, please write for this tag, which gives shipping instructions and has space for describing the conditions that need correction. There will be a delay in handling returned equipment unless this tag is attached. Material returned for credit or replacement cannot be accepted unless we authorize it by issuing a returned-material tag.

Please cooperate with us in speeding up the handling of returned equipment by using this tag. The type numbers and serial numbers of the instruments to be returned should be specified when you request the returned-material tag from our Service Department.

—H. H. Dawes



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Returned by ....

Address ....

Type No. .... **Serial No.** .... **Desc.** ....

Describe difficulty ....

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If space is not adequate, use supplementary sheet and attach

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MISCELLANY

THE ARTICLE on "Connection Errors" by R. F. Field is reprinted with minor changes from the January, 1938, issue of the *Experimenter*. It has been out of print for several years, and we have had lately a considerable demand for it. This article is still timely, perhaps more so now than when originally published.

The TYPE 722 Precision Condenser is the accepted standard of capacitance for the radio and electronic industries. To realize fully its inherent accuracy, the mechanism of connection is important. The method recommended here has been used in the Standardizing Laboratory at the General Radio Company for a number of years.

Two other articles of importance to those interested in capacitance measurement and standardization will be published in the next few months. One of these will concern the accuracy of the TYPE 722 Precision Condenser, and the other will discuss the projected change from the current international values of electrical units to the new absolute values.

TECHNICAL PAPERS — "The Evaluation and Control of Noise," by Ivan G. Easton, at the Annual Safety Convention of the Greater New York Safety Council, March 27; "Measurement and Analysis of Sound and Vibration," by William R. Saylor, at the April 8 meeting of the Central Indiana Section, Instrument Society of America, at Indianapolis; "Design of an F-M Monitor," by Charles A. Cady, at the Chicago I.R.E. Conference, April 19; "Recent Developments in Instrumentation," by Ivan G. Easton, at the April 21 meeting of the Measurements Section of the A.I.E.E., Philadelphia; "Current-Time Curves in Insulation Resistance Measurement," by Robert F. Field, at the Northeastern District Meeting, A.I.E.E., Worcester, Massachusetts, April 23.

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EXPERIMENTER

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

VOLUME XXII No. 1 JUNE, 1947

INCREASED ACCURACY FOR THE PRECISION CONDENSER

Also

IN THIS ISSUE

● **LAST MONTH'S ARTICLE*** on connection errors in capacitance measurement suggests the need of a corollary article on the accuracy of calibration of the precision capacitor itself. The rating of ±1 $\mu\mu$f for all settings, while corresponding to 0.1% for 1000 $\mu\mu$f, has imposed a serious handicap on its use at low-scale settings. A recent evaluation of the sources of error and a survey of calibration records indicate that it is possible to increase materially the guaranteed accuracy of the precision condenser at settings below full scale.

The best accuracy to which calibrations can be guaranteed is 0.1%, which allows for twice as much error as the known accuracy of our standards. Our capacitance standards are evaluated in terms of measurements by the National Bureau of Standards, which are certified to 0.05%. These standards are periodically intercompared, and we have found that our measurements check those of the Bureau to about 0.02%.

Figure 1. Calibrating precision capacitors in the General Radio Standardizing Laboratory.

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*R. F. Field, "Connection Errors in Capacitance Measurement," *Experimenter*, XXI, 12, May, 1947

Such factors as temperature and aging can be expected to change the day-to-day capacitance slightly over the normal guarantee period of one year, so that 0.1% is a fair figure for the accuracy of commercial standards like the Type 722 Precision Condenser.

This tolerance of 0.1% corresponds to 1 μμf at a scale reading of 1000 μμf. The capacitance of the instrument is continuously adjustable from 1100 μμf to 100 μμf. On the Type 722-D Precision Condenser a low-capacitance section is also included, covering a 100-to-25 μμf range.

METHODS OF ASSEMBLY AND ADJUSTMENT

The rotor plates, spaced by suitable disc spacers, are clamped rigidly on a central shaft, which is mounted on ball bearings and is turned by means of a worm and gear. The stator plates with their spacers are mounted on two threaded rods which, at their ends, are supported by two steatite bars. The assembling of these plates is done in a jig in order to get all plates as nearly parallel as possible to each other and perpendicular to the axis about which the rotor turns. At each end of the stator stack there is a plate which can be moved axially in order to adjust the capacitance change per turn of the worm shaft to the scale value, such as 50 μμf for a 1000 μμf capacitor. One of these plates has its central portion removed in order to increase the capacitance per turn at the ends of the useful range, where this rate of change of capacitance naturally decreases. The other plate, while standard in shape, is faced by a rotor plate having nonradial slots extending from its edge in toward the center. Slight bending of the individual sectors will compensate for small irregularities in the rate of change of capacitance.

In the adjustment of such a capacitor, the solid adjusting plate is set to make the capacitance change for two turns of the worm shaft 100 ±0.5 μμf or better over the range from 100 to 1100 μμf, subject to the limitation that the cumulative error is also less than ±0.5 μμf. Frequently the adjusting plate must be set off from parallelism to accomplish this. The sectors of the slotted rotor plate are then bent slightly to decrease

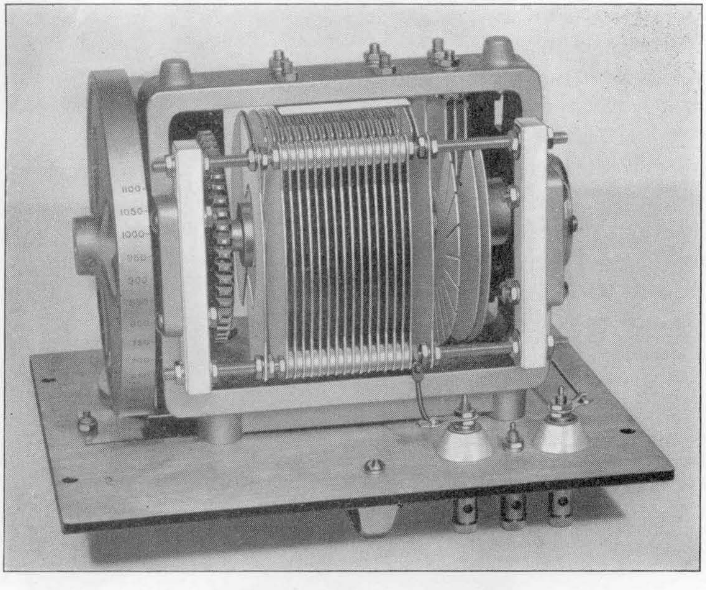
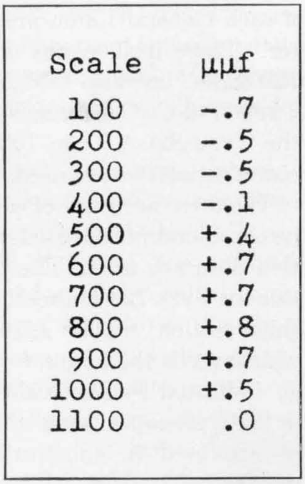


Figure 2. Interior view of a Type 722-D Precision Condenser. The slotted rotor plate for the LOW section can be seen near the right-hand end of the capacitor. The zero adjusting plate is mounted on the frame at the top.



Scale	μμf
100	-.7
200	-.5
300	-.5
400	-.1
500	+.4
600	+.7
700	+.7
800	+.8
900	+.7
1000	+.5
1100	.0

Figure 4. Correction data in this form are recorded on a card mounted on the panel of the capacitor.

the extreme variations which may occur at the ends of the range and sometimes in the center. A plot of capacitance change for every two turns of the worm shaft is shown in Figure 3.

The engraved drum and dial are mounted on their respective shafts in such positions, dictated by past experience, that the total capacitance is within a few micromicrofarads of their readings. The zero adjusting plate is then set so that the total capacitance is correctly indicated to ±0.5 μμf. The capacitor is then baked in an oven overnight to reduce any strains set up by the adjusting process. If there are any changes greater than 0.25 μμf, the capacitor is readjusted and rebaked.

The numerical results of this last measurement of capacitance are recorded as the correction error in μμf in the form given in Figure 4. A plot of these corrections is shown in Figure 3. The maximum error of 0.75 μμf is equal to that allowed the testing laboratory, which in turn is three-fourths the catalog tolerance of ±1 μμf. This particular capacitor, having the maximum allowable error, was chosen to illustrate the extremes which can occur.

ACCURACY OF CAPACITANCE READINGS

Since each complete worm turn changes the capacitance by 50 μμf, the intermediate multiples of 50 μμf will fall at the same worm positions as the 100-μμf multiples. Consequently, these points can be determined by direct interpolation to about the same accuracy as the

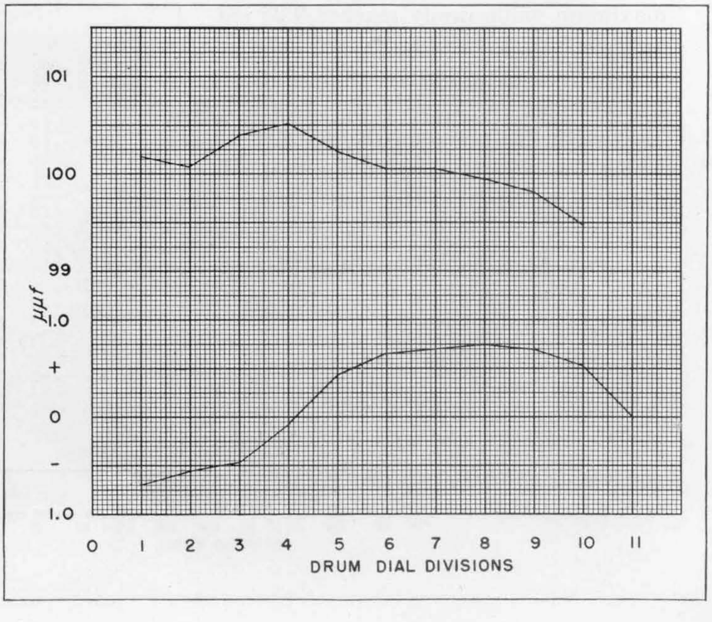


Figure 3. (Top curve) Actual change in capacitance per two worm turns for a Type 722 Precision Condenser. (Bottom curve) Cumulative error at nominal 100 μμf points. These data are recorded to the nearest tenth micromicrofarad, as shown in Figure 4, and are furnished with the capacitor for correcting the scale reading.

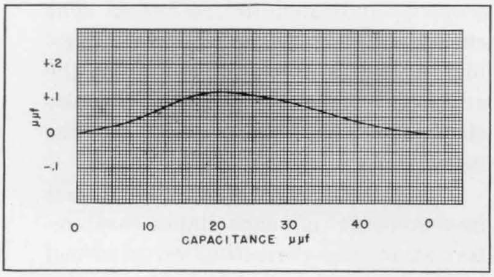


Figure 5. Worm correction for a typical Type 722 Precision Condenser.

100-μμf points. Capacitances at these points, when corrected, are accurate to ±0.1% or ±0.1 μμf, whichever is greater. Capacitance values other than multiples of 50 μμf obtained by interpolation between these corrected points cannot be as precisely determined, owing to the eccentricity of the worm.

Although the worm is cut directly on the worm shaft and considerable care is exercised in mounting the worm and gear both as to their bearings and the method of pressing the worm against the gear, a small degree of eccentricity remains. This appears as an approximately sinusoidal variation in capacitance about the average value. Its maximum value rarely reaches 0.25 μμf and controls are set up to see that this value is not exceeded. A typical worm correction curve is given in Figure 5. The particular point on the sinusoid at which the zero reading of the dial appears is entirely fortuitous. It just happens that in Figure 5 the entire correction is positive, thus giving the largest possible correction for this amount of eccentricity.

CORRECTION CHARTS

In the future, a table of corrections measured to the nearest tenth micromicrofarad will be supplied on the panel of each General Radio precision capacitor. These include not only the Type 722 series, but also bridges such as the Type 716-C Capacitance Bridge and the Type 821-A Twin-T, in which precision capacitors are used.

The rated accuracy of capacitance can be considerably increased if these correction data are used. The new specification for Type 722-D Precision Condenser (high section) will be ±0.4 μμf or 0.1%, whichever is the larger, for capacitances as indicated by the scale, and 0.5 μμf or 0.1% for capacitance differences, such as are used in substitution measurements.

The errors that make up the total are computed as follows:

Worm correction	0.25 μμf
Precision of correction	0.05 μμf
Standard tolerance	0.1 μμf
	0.4 μμf

The second item of 0.05 μμf arises from the fact that the correction is given to the nearest tenth micromicrofarad, which may differ by 0.05 μμf from the true value.

The third entry of 0.1 μμf is the stand-

Scale	0	10	20	30	40
100	-.70	-.68	-.57	-.49	-.63
150	-.65	-.57	-.41	-.33	-.48
200	-.54	-.51	-.38	-.33	-.51
250	-.57	-.52	-.40	-.32	-.43
300	-.46	-.36	-.18	-.07	-.16
350	-.21	-.16	-.01	+.10	-.05
400	-.07	+.01	+.17	+.32	+.22
450	+.24	+.35	+.52	+.61	+.50
500	+.44	+.48	+.59	+.69	+.54
550	+.52	+.59	+.73	+.85	+.69
600	+.66	+.73	+.83	+.92	+.76
650	+.67	+.71	+.83	+.91	+.76
700	+.70	+.73	+.87	+.95	+.77
750	+.72	+.78	+.90	+.99	+.81
800	+.75	+.78	+.88	+.95	+.80
850	+.75	+.82	+.93	+.97	+.79
900	+.70	+.73	+.84	+.92	+.73
950	+.65	+.66	+.76	+.80	+.61
1000	+.52	+.52	+.61	+.61	+.44
1050	+.32	+.28	+.33	+.35	+.11
1100	.00				

Figure 6. Worm correction data as furnished when a complete worm correction calibration is ordered.

ard laboratory tolerance. The accuracy of laboratory adjustment is three-fourths of the catalog specification. Hence with a 0.3-μμf laboratory error, the catalog value is 0.4 μμf.

For capacitance differences, one additional setting is involved, with its associated possible error of 0.05 μμf. To the nearest tenth, therefore, the accuracy can be specified as ±0.5 μμf. At the 100-μμf divisions, and also at the 50-μμf divisions by linear interpolation, capacitance differences can be determined with an error of ±0.2 μμf. For differences of less than 25 μμf the error decreases linearly from ±0.5 μμf to ±0.1 μμf.

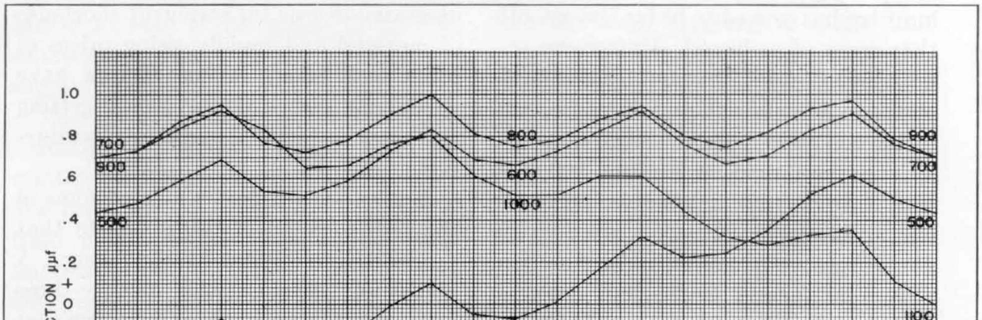
For the low section of the Type 722-D Precision Condenser (25 to 100 μμf), the correction is given to ±0.01 μμf. As a general principle, fractional errors cannot be reduced in proportion to the size of the main quantity, and consequently the specification for this section is ±0.1 μμf or 0.1% for both direct reading and differences. The slight increase of the direct-reading error to ±0.1 μμf is caused by connection errors.

As mentioned earlier, the best accuracy to which capacitance can be guaranteed is 0.1%. Consequently, if the error as specified in micromicrofarads is less than 0.1%, the specification of 0.1% governs. If the correction data are not used, the accuracy of the capacitor is ±1 μμf for direct-reading values and ± 2μμf for differences.

COMPLETE WORM CORRECTION

For those who need the greatest possible accuracy, a complete worm correction extending over the entire range of the capacitor is available. The chart takes the form shown in Figure 6. The data given are for the same capacitor as was referred to in Figures 3 and 4. Its worm correction has the maximum allowable value of 0.25 μμf, so that the maximum correction is almost 1 μμf. Since the corrections are given to 0.01 μμf, direct-reading capacitances can be easily corrected to ±0.1 μμf or ±0.1% and differences to ±0.2 μμf or ±0.1%. These data are plotted in Figure 7.

Figure 7. Complete correction curve as plotted from the data of Figure 6.



When a large number of observations must be reduced, it is sometimes easier to read the correction from a graph than from a chart.

SUMMARY

Tabulated below are the accuracy ratings of the several General Radio precision capacitors mentioned in this article.

	Direct Reading		After Correction		
Type No.	*Capacitance*	*Capacitance Differences*	*100 μμf (and 50 μμf) Multiples*	*Interpolated Points*	*Differences*
722-D High Section	±1 μμf	±2 μμf	±0.1 μμf	±0.4 μμf	0.5 μμf*
722-D Low Section	±0.2 μμf	±0.4 μμf		±0.1 μμf	0.1 μμf
722-N	±1 μμf	±2 μμf	±0.1 μμf	±0.4 μμf	±0.5 μμf*
722-M		±1 μμf	±0.1 μμf		±0.4 μμf*
716-C	±2 μμf × Multiplier	±2 μμf			±0.5 μμf*
821-A		±(0.1% + 2 μμf)			±(0.1% + 0.5 μμf)*

*For capacitances less than 25 μμf, the error decreases linearly to ±0.1 μμf.

— R. F. Field

TWO YEARS OF RECONVERSION

The road of reconversion for American industry has proved to be far less smooth than most of us hoped. Unforeseen obstacles have been frequent, particularly shortages of materials and parts, necessitating the use of circuitous detours, and, as with any road so heavily traveled, traffic jams were inevitable. One by one, however, the travelers are arriving at their goal—full peacetime production.

We at General Radio had expected that our own reconversion would be simpler than most. Since the nature of our production had changed little during the war except for the quantities required, we were able to avoid the problem of complete retooling that had to be faced by many companies. At the same time it was not possible to foresee to the necessary degree the stringent shortages of material and rapidly rising prices of parts and labor. These factors have necessarily slowed the process of getting redesigns and new designs into production.

Just two years ago*, we listed some of the new General Radio products that peacetime conditions would bring. A review of the succeeding twenty-three numbers of the *Experimenter* shows that we have not fallen far short of our goal. Seventeen new instruments have been announced, as well as three redesigns of older types. A complete list follows.

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*"Development Engineering at the General Radio Company," *Experimenter*, XX, 1, June, 1945.

Frequency Measuring Instruments

Type 720-A Heterodyne Frequency Meter July–August, 1945
Type 816-A Vacuum-Tube Precision Fork September, 1945
Type 1140-A U-H-F Wavemeter........ October, 1945
Type 1176-A Frequency Meter......... February, 1946
Type 1181-A Frequency Deviation Monitor November, 1946
Type 1175-A Frequency Monitor........ February, 1947
Type 724-B Precision Wavemeter....... March, 1947

Impedance Measuring Equipment

Type 1614-A Capacitance Bridge....... February, 1946
Type 1631-A Inductance Bridge........ February, 1946
Type 716-C Capacitance Bridge......... April, 1947
Type 1231-A Amplifier and Null Detector. March, 1946

Meters

Type 1800-A Vacuum-Tube Voltmeter..... September, 1946
Type 1802-A Crystal Galvanometer...... October, 1946
Type 1861-A Megohmmeter............ November-December, 1946

Miscellaneous

Type V-5 Variac...............May, 1946
Type V-10 Variac.......July-August, 1946
Type 1530-A Microflash.....October, 1945
Type 762-B Vibration Analyzer......... November-December, 1945
Type 1931-A Modulation Monitor....... November, 1946
Type 1261-A Power Supply............ March, 1946
Type 1260-A Variac Rectifier .... March, 1946

Other new instruments are about to go into production and others are now under development. These will first be announced in these pages.

NEW PRICE SCHEDULE

Included in the last mailing of the *Experimenter* was a new price list, which became effective on June 9, 1947. This price list supersedes all previous price lists, which should be destroyed to avoid confusion or error in ordering. In accordance with long-established policy, all prices shown in our price schedules are net, f.o.b. the factory in Cambridge, Massachusetts. If you can use additional copies of the list, we shall be glad to supply them.

The costs of manufacturing in our industry, and most others for that matter, have risen greatly since the war. We have always tried to maintain a fixed price schedule, but it has been impossible to do this during the past two years. Although the costs of manufacturing, that is, the prices of raw materials, components, wages and salaries, still continue to climb, we feel that the time is here to attempt to stabilize prices again. During the recent era of rapidly rising costs, the custom of quoting prices effective as of the date of shipment became quite general. We have always been opposed to this open price system and we still have sufficient confidence in the stability of the nation's economy to guarantee all formally quoted prices for six months. Although no change in prices is indicated in the near future, there are so many factors beyond our control that currently it does not seem practical to quote firm prices for periods longer than six months. Any customer who has placed an order where the delivery is over six months has the option of cancelling that order if any price increase is made on it.

We are glad to say at this time that the delivery situation is continually improving. Although many items are now available from stock, the delivery time required for some others is a great deal longer than we like to see it. Each month shows a general improvement in deliveries, and we look forward to the time when we can resume deliveries of almost everything from stock.

MISCELLANY

HONORS—Conferred upon Harold B. Richmond, Chairman of the Board of the General Radio Company, the honorary degree of Doctor of Engineering, at the 128th Commencement of Norwich University, for his pioneer radio service, his work on guided missiles in World War II, and his interest in engineering education. A graduate of the Massachusetts Institute of Technology, Class of 1914, Mr. Richmond has served for eleven years as a member of the Corporation of M.I.T. and is trustee of Northeastern and Norwich Universities. He has been President of the Radio Manufacturers' Association, and was recently elected Board Chairman of the Scientific Apparatus Makers of America. Joining the General Radio organization in 1919, he became Secretary in 1921, Assistant Treasurer in 1924, Treasurer in 1926, and Chairman of the Board in 1944. Mr. Richmond is a Fellow of the Institute of Radio Engineers and of the American Institute of Electrical Engineers.

TECHNICAL PAPERS — "U-H-F Measurements," by William R. Thurston of the development engineering staff, before local I.R.E. sections, at Ottawa, April 3; Toronto, April 7; London, April 8; and Montreal, April 9.

"A Very-High-Frequency Bridge for Impedance Measurements at Frequencies Between 20 and 140 Megacycles," by Robert A. Soderman of the development engineering staff, at the New England Radio Engineering Meeting, Cambridge, May 17.

VISITORS to our plant and laboratories — D. Putnam, Marconi Instruments, Ltd., St. Albans, England; C. M. Benham, Managing Director, Painton and Company, Northampton, England; A. Bergqvist and Major K. B. Genberg, Swedish Army Ordnance Department, Stockholm.

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THE General Radio EXPERIMENTER

VOLUME XXII No. 2 and No. 3 JULY-AUGUST, 1947

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A COUNTING-RATE METER FOR RADIOACTIVITY MEASUREMENTS

Also

IN THIS ISSUE

THE TYPE 1500-A Counting-Rate Meter is the first General Radio instrument developed specifically for the comparatively new, but rapidly growing, field of nuclear physics. Fundamentally, it is a frequency meter that indicates, in counts per minute, the rate at which nuclear transformations occur in a radioactive material.

In 1940 General Radio engineers, in cooperation with interested physicists at the Massachusetts Institute of Technology, designed an improved counting-rate meter.[1] Several such instruments were used on war projects, including a blood preservation program that ultimately "saved more lives than were snuffed out at Hiroshima and Nagasaki."[2] The design used in the TYPE 1500-A Counting-Rate Meter[3] is essentially the same, except that certain instabilities inherent in the original design have been eliminated in the present circuit arrangement.

The instrument is direct reading and covers the range from 5 to

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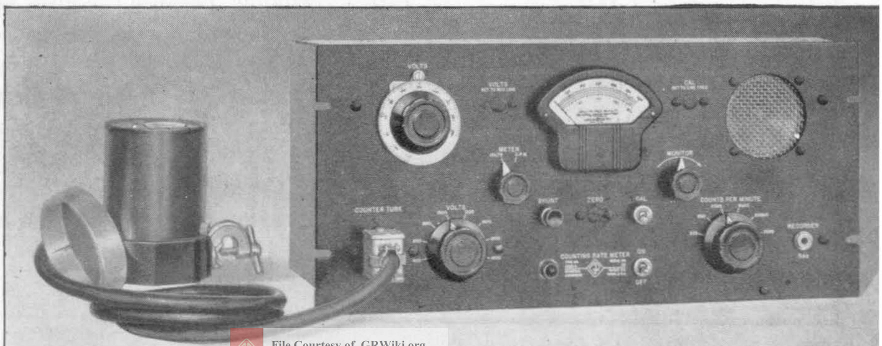
[1] A. F. Kip, A. G. Bousquet, R. D. Evans, W. N. Tuttle, *Review of Scientific Instruments*, Vol. 17, No. 9, 323-333, Sept., 1946.

[2] J. G. Gibson II and R. D. Evans, *Technology Review*, Vol. 49, No. 2, Dec., 1946.

[3] A. G. Bousquet, "Radioactivity Meter for Nuclear Research," *Electronic Industries*, Sept., 1946.

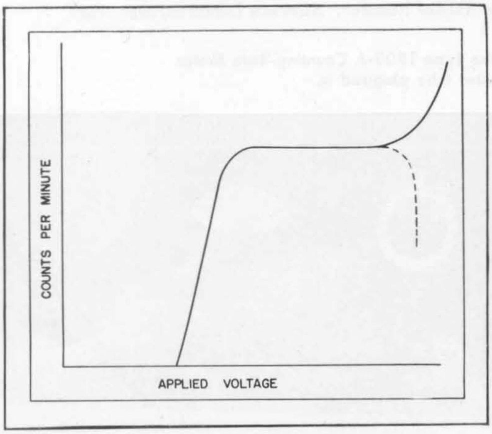
Figure 1 Panel view of the Type 1500-A Counting-Rate Meter with counter tube plugged in.



20,000 counts per minute. It includes an aural monitor, a regulated, adjustable high-voltage supply (400-2000 volts), and a quenching circuit to permit the use of either a "self-quenching" or a "non-self-quenching" Geiger-Mueller counter. The equipment is notable for its ease of operation. A major feature is provision for operating a 5-ma pen-and-ink recorder, such as the Esterline-Angus Model AW Graphic Instrument. Consequently, while data are being accumulated, the presence of an operator is not required. Results can be interpreted later from the permanent record.

The Geiger-Mueller counter tube that actuates the frequency-meter circuit is mounted, with its quenching circuit, in a probe at the end of a four-foot cable. For easy interchangeability and short leads, the instrument is designed primarily for use with a counter that has a four-prong tube base. Other designs of counters can be used, however, since connections to the socket can easily be made. Three plug-in type counter tubes are now available for use with this instrument: the Type 1500-P2 Beta-Ray Counter, the Sylvania GB-302 Beta-Ray Counter, and the General Radio Type 1500-P3 Gamma-Ray Counter.

Figure 2. Characteristic response curve of a Geiger-Mueller counter.



HOW COUNTERS OPERATE

The operating characteristics of Geiger-Mueller counter tubes differ markedly from those of other tubes familiar to the electronics engineer. Since these characteristics determine the nature of the associated circuits, a more-or-less detailed knowledge of them is necessary as an introduction to the circuit description of the counting-rate meter.

Atoms undergoing nuclear transformation radiate either particles, quanta of energy, or both. The radiation may consist of the high-speed positrons or electrons of beta radiation, alpha particles, gamma rays, X-rays, or neutrons. The radiation is detected by its primary or secondary ionizing effect on the gas in the Geiger-Mueller counter, which consists of a cylindrical metal cathode and a coaxial wire anode enclosed in a gas-filled chamber.

When the counter is designed primarily for detecting beta particles, the coaxial anode is supported at one end of the counter and a very thin "window" is placed at the other end to allow the beta particles to enter without too great a loss from absorption. The ratio of particles absorbed to the total is determined by the window density. In the Type 1500-P2 Beta-Ray Counter the window is of 1-mil (0.001-inch) aluminum-alloy foil (about 7 milligrams per square centimeter). Beta particles ionize the gas directly by collision.

Counters designed for detecting gamma radiation and fast neutrons need no window, because the glass envelope and the cathode are to a large degree transparent to these rays. Gamma rays, or photons, are flashes of electromagnetic energy which eject photo electrons from the surface of the countertube cathode in the same way that light causes the emission of electrons from a photo-sensitive surface. Soft gamma rays (X-rays) are absorbed by the gas in the counter, and ionization takes place because of the absorption process. Fast neutrons ionize the gas directly. Cosmic rays are also detected with either the gamma-ray or the beta counter.

These two conventional types of counter are not efficient detectors of alpha particles and slow neutrons. For the counting of alpha particles, an ionization chamber is ordinarily used. Counters for slow neutrons use a boron-trifluoride gas, with which the neutrons react to produce alpha particles, which, in turn, ionize the gas. These and other specialized types of counters can be easily connected to the counting-rate meter.

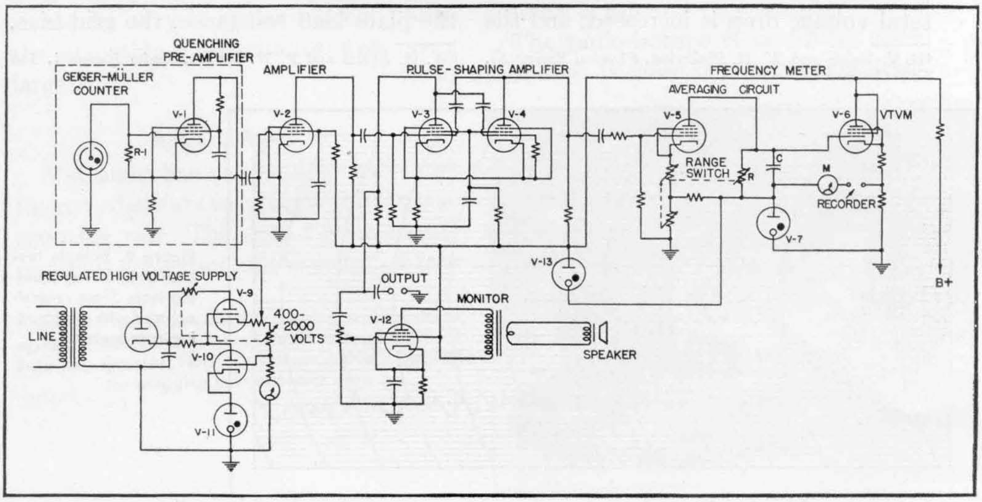
QUENCHING

When sufficient voltage is applied to the Geiger-Mueller-counter electrodes, the electron from the ionized atom is attracted to the anode and in its migration collides with other atoms of the gas and causes further ionization. As a result, there is an avalanche of electrons, which lowers the potential of the anode. This change in potential of the anode is detected by the rest of the circuit, and used as a measure of the radiation resulting from a nuclear transformation.

The positive ions travel relatively slowly to the cathode, where they may eventually cause the emission of secondary electrons. These, in turn, would be attracted to the anode and cause multiple or spurious discharges if proper precautions were not taken. In self-quenching counters a small amount of polyatomic vapor with high electron affinity is introduced into the counter. This vapor absorbs the secondary electrons, and the discharge is quenched. In non-self-quenching counters the external circuit is designed to maintain the anode potential at the low level long enough to allow the complete neutralization of the positive ions, and the discharge is quenched.

In self-quenching counters some of the molecules of the quenching vapor break down to less complex molecules each time a discharge is quenched. The life of this type of counter is consequently a function of the number of "counts" detected. It is usually about 5 x 10^8 counts, which corresponds to a three months' life at about eight hours per day operating at 10,000 counts per minute. The non-self-quenching counter

Figure 3. Functional schematic circuit diagram of the Type 1500-A Counting-Rate Meter.



is more reliable over long periods and is less affected by temperature and overvoltage.

The characteristic curve of Figure 2 shows the counter tube response as the applied voltage is varied. The discharge is properly quenched, and the response is quite constant over a fairly wide plateau for both types of counters. When the voltage is excessive, the quenching action is inadequate, and the counter will go into an uncontrolled discharge that is either intermittent as indicated by the rising characteristic due to spurious counts, or continuous as shown by the drooping characteristic with eventual abrupt failure in response.

The TYPE 1500-A Counting-Rate Meter operates with either type of counter. A quenching circuit is included, but does not impair the operation of self-quenching counters.

CIRCUIT DETAILS

As shown in Figure 3, the quenching circuit of the TYPE 1500-A Counting-Rate Meter is a modified Neher-Pickering circuit.[4] The vacuum tube V-1 normally operates at zero bias, but, when a counter discharge occurs, the voltage drop in the resistor R-1 causes the tube to operate at cut-off, and, since the impedance of the tube is increased, the total voltage drop is increased, and the voltage at the counter is maintained at a lower level for the time necessary to quench the counter discharge.

The resultant voltage pulses appearing at the cathode of V-1 are amplified and applied to a modified Eccles-Jordan pulse-shaping circuit[5] whose output pulses depend only for their time distribution on the input pulses. The positive output pulses are all identical in shape and magnitude, and when they are applied to the grid of the next tube, V-5, which is normally biased below cut-off, they cause corresponding plate current pulses to flow through the load resistor, R. A d-c voltage proportional to the average pulse rate is thus built up across the capacitor, C. For pulses spaced equally in time, the plate load voltage will assume a constant average value, but if the pulses are distributed randomly with time the voltage will fluctuate widely about the average value. The capacitor, C, smooths out these fluctuations, and its size is chosen to give a good compromise between speed of response and degree of smoothing. This capacitor, designed and built by the General Radio Company, is wound with polystyrene tape to avoid dielectric polarization errors that other dielectric materials would introduce. The ranges are varied by simultaneously changing the plate load resistance, the grid bias,

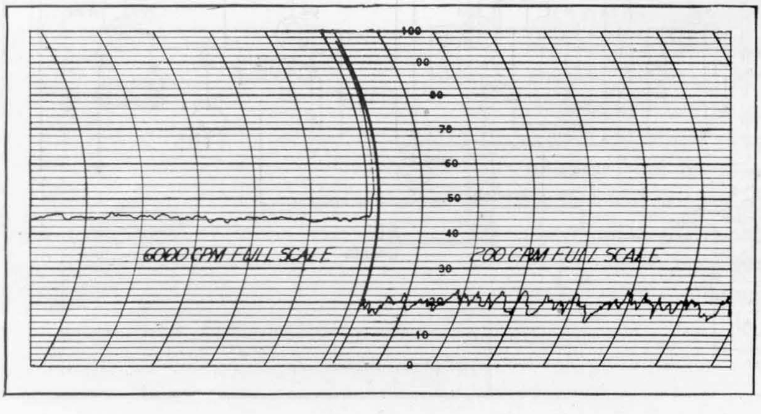


Figure 4. Sample records of beta-ray counting from 5-ma recorder, used with the counting-rate meter.

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[4] H. V. Neher and W. H. Pickering, *Physical Review* 53, 316L (1938).

[5] W. H. Eccles and F. W. Jordan, *Radio Review* 1, 143 (1919).

and the amount of degeneration in the cathode circuit of V-5. A d-c vacuum-tube voltmeter across the R-C plate load of the averaging circuit indicates the pulse rate and is calibrated in counts per minute. The full-scale ranges are 200, 600, 2,000, 6,000, and 20,000 counts per minute.

RECORDER

An Esterline-Angus 5-ma pen-and-ink recorder can be plugged in directly in series with the panel meter, and, since the calibration is linear, the recorder deflection will be proportional to the counting rate. While a recorder is not essential, its use is recommended, since, because nuclear transformations occur at random intervals, a definite time is required to obtain a minimum error in the determination of the average counting rate, no matter what the measuring method is.

A sample of the results to be expected is shown in Figure 4. The unevenness of the trace is an indication of the random time distribution of nuclear transformations. The lower the counts per minute, the more irregular the trace will be, percentage-wise, for a given running speed of the paper. Obviously, if the counting rate were only one per minute and random in time distribution, the trace would be very irregular indeed, unless the smoothing capacitance were very large.

ACCURACY

A straight line can be drawn through the recorded data to indicate the average counting rate. The accuracy to be expected is a function of the counting rate and of the recording time. After equilibrium has been established, a recording time of about one minute is required at 50 counts per minute to yield an error of less than 2 per cent in the interpretation of the results, whereas a few seconds' observation will be sufficient at the high counting rates (greater than 2000 counts per minute) to bring the error in the interpretation of the results down to a negligible value. In addition to this statistical error, the accuracy of the indicated result can be no greater than the full-scale accuracy of the meter itself. This metering accuracy is better than 3 per cent of full scale.

APPLICATIONS

Prewar radioactivity applications were numerous. During the war nuclear physics was utilized in many projects, including blood preservation, goiter diagnosis, radiotherapy, and, of course, the atomic bomb. Physicists, chemists, geologists, biologists, botanists are now applying the many newly available radio-isotopes to their particular problems. Metallurgy, power engineering, crystallography, agriculture, oil surveying, glass and plastics manufacturing, combustion engineering design, ore assaying, and turbulence research are but a few more of the fields where radioactivity is proving very useful.

The radio-isotope is useful for these purposes, because it has the same elec-

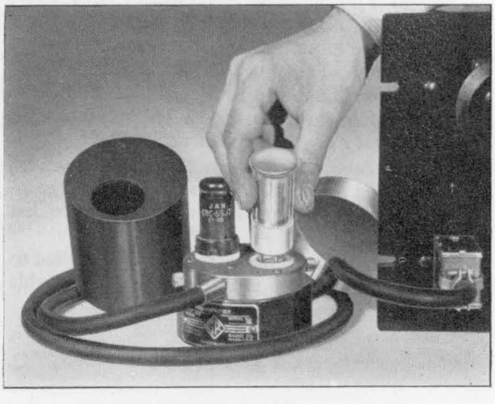

Figure 5. View of pre-amplifier and quenching circuit assembly with cover removed to show Type 1500-P2 Beta-Ray Counter. Note the convenient arrangement for plugging in the counter tube.

tron system as its stable counterpart and consequently exhibits the same chemical properties. Typical uses of these isotopes are as "tagged" elements in chemical reactions and in tracer work, and as radiation sources in radiotherapy. In these broad fields of application, it is fortunate that many of the artificially radioactive isotopes are relatively short-lived since after each experiment the slate is automatically wiped clean. Iodine 131 has a half-life of eight days; phosphorus 32, fourteen days. Carbon 14, however, is very long-lived: 5100 years elapse before its activity is halved. Some 85 radio-isotopes are now available from the Oak Ridge Isotopes Branch. Over 450 isotopes have been produced by the various particle accelerators such as the cyclotron, synchrotron, and betatron.

Biologists have learned that cells where growth is rapid are particularly sensitive to irradiation, and that cells exhibit specific absorption. Dosage of food or of medicine for a specific organ can consequently be studied readily by the tracer technique, and irradiation can be selectively applied internally. For example, radio-therapeutic doses can be administered that will get radioactive strontium to a bone tumor or radioactive iodine to the thyroid gland when local irradiation is needed. Tracer technique is proving useful in studying such problems as how light can form sugars photosynthetically from carbon dioxide and water.

The geologist has gleaned information on the age of the earth from deposits of helium and pitchblende. The mineralogist has tabulated the relative abundance of the naturally radioactive isotopes and is using the information for the ready analysis of the potassium content of salt deposits from various regions. The metallurgist is compiling valuable data concerning case-hardening, welding, alloying by tracer methods.

Cosmic radiation, plentiful at all times, provides a continuous supply of very high energy radiation. Even so, the mutations attributed to cosmic radiation are not sufficiently well controlled for the zoologist, who concentrates a radioactive beam on the Drosophila fruit fly to fathom in a short time the secrets of evolution that are otherwise disclosed only after eons of cosmic irradiation of the now human species.

Further applications of nuclear physics are daily being found. They are closely dependent on the use of electronic measuring and counting instruments.

— A. G. BOUSQUET

SPECIFICATIONS

Range: Full scale values of 200, 600, 2000, 6000, and 20,000 counts per minute are provided. The minimum rate that can be read on the meter scale is 5 counts per minute.

Accuracy: The instrument has been calibrated with a generator of equally-spaced pulses to yield an accuracy of ±3% of full scale on all ranges.

Counter Tube: Counter is not included and must be ordered separately. Both beta-ray and gamma-ray counters are available. See price list below.

Counter Circuit Voltage: The voltage applied to the counter circuit is continuously adjustable from 400 to 2000 volts. The value of the voltage is read from an eight-position switch and a calibrated dial which covers the 200-volt interval between switch points. Means are provided for standardizing the voltage so that the accuracy of the voltage readings is within ±3% of the actual value. The power supply is well regulated so that line-voltage fluctuations do not cause changes in the high-voltage supply.

Output: The output of the trigger circuit is available at rear terminals. The 400- to 2000-volt variable high-voltage supply is also available at terminals at the rear of the instrument.

Aural Monitor: A small loudspeaker is mounted on the panel for use as an aural monitor. A control, with an off position, is provided for adjusting the volume.

Power Supply: 105 to 125 volts, 50 to 60 cycles. By a simple change in connections on the power transformer, a 210- to 250-volt line can be used.

Power Input: 60 watts.

Vacuum Tubes:

5 — 6SJ7
1 — 6AG7
1 — 6X5GT/G
1 — 2X2/879
2 — 6J5
1 — 6C6
2 — 991
2 — 0C3/VR-105

Accessories Supplied: Power connection cable; plug for recorder connection; preamplifier assembly, with connection cable.

Accessories Required: Geiger Mueller counter tube. See price list below.

Mounting: The instrument is shipped with walnut end frames for table mounting. Relay-rack mounting is possible by removing the end frames.

Dimensions: Panel, 19 x 8¼ inches; depth behind panel, 13 inches.

Net Weight: 38½ pounds, including preamplifier.

Type		*Code Word*	*Price*
1500-A	**Counting Rate Meter***	WORRY	**$495.00**
1500-P2	**Beta-Ray Counter**	WORRYBETAR	**55.00**
1500-P3	**Gamma-Ray Counter**	WORRYGAMMA	**54.00**

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*U. S. Patent No. 2,374,248.

THE NEW ELECTRICAL UNITS

On January 1, 1948, the National Bureau of Standards, in cooperation with similar organizations in other countries, will introduce revised values of the units of electricity and light. This change was scheduled to go into effect in 1940, but the project was delayed by the war.

The electrical units of the present "international" system will be superseded by those of the "absolute" system, derived from the fundamental mechanical units of mass, length, and time by use of the accepted principles of electromagnetism, with the value of the permeability of space taken as unity in the centimeter-gram-second system or as 10^{-7} in the meter-kilogram-second system. Actually, all of the common electrical units fall into the m-k-s system. This revision constitutes a return to the basic principles, always recognized as desirable, of having the electrical units consistent with the fundamental mechanical units.

The international units now in use were originally intended to be exact multiples of the units of the centimeter-gram-second system, but the units were defined independently. The ampere, the ohm, and the volt were defined by reference to three physical standards — the silver voltameter, a specified column of mercury, and the Clark standard cell. The original definitions were not sufficiently specific to give the precision that eventually came to be required, with the result that the units as used differed slightly from the c-g-s system while, because of the independent definitions, the units did not satisfy Ohm's law.

This condition was recognized some forty years ago, and the units were redefined. The ohm as defined by the mercury column was retained, as was the ampere in terms of deposits of silver. The magnitude of the international volt was changed to make it consistent with the ampere and the ohm in the relationship $I=\frac{E}{R}$. This revision achieved consistency among the units, but did not correct the difference between the international system and the c-g-s system. The revision of the units to accomplish this correction was agreed upon as desirable by many scientific and engineering societies as early as twenty years ago and, since that time, plans for the change have been going forward. Absolute measurements of resistance and current have been made in various countries, and the results correlated by measurements made on the various national standards at the International Bureau of Weights and Measures.

At its meeting in Paris in October, 1946, the International Committee on Weights and Measures adopted the following relations between the mean international units and the new absolute units:

1 mean international ohm = 1.00049 abs. ohms
1 mean international volt = 1.00034 abs. volts

The mean international units are the averages of units as maintained by six countries (France, Germany, Great Britain, Japan, U. S. S. R., and U. S. A.), all of which took part in this work before the war. Each country's units differ slightly from the average, and the conversion factors for the United States will be as follows:

1 international ohm = 1.000495 abs. ohms
1 international volt = 1.00033 abs. volts
1 international ampere = 0.999835 abs. ampere
1 international henry = 1.000495 abs. henrys
1 international farad = 0.999505 abs. farad
1 international watt = 1.000165 abs. watts

To convert the values of existing standards to the new units, the present values should be multiplied by these factors.

It will be seen that for resistance, inductance, and capacitance, the magnitude of the change is 0.05 per cent. This difference is large enough so that it cannot be neglected in calibrations guaranteed to 0.1 per cent or 0.25 per cent. Consequently, during the second half of 1947, our calibrations of resistors, capacitors, and inductors will gradually be changed to the new absolute units. During 1947, the National Bureau of Standards is specifying calibrations in both systems of units, and our own standards, which are checked periodically by the Bureau, are being revalued in the new units.

All instruments listed in Catalog K, will, in the future, be calibrated in the new units and when so calibrated will carry the word "absolute" or the abbreviation "abs." on their panels. All new instruments not as yet cataloged, will be calibrated in the new units, without specific statement on their panels.

— R. F. 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 address, type of business company is engaged in, and title or position of individual.

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THE General Radio EXPERIMENTER

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

VOLUME XXII No. 4 SEPTEMBER, 1947

DR. BERANEK BECOMES GENERAL RADIO CONSULTANT ON ACOUSTICS

Also IN THIS ISSUE

•**DR. LEO L. BERANEK,** Associate Professor of Communications Engineering and Technical Director of the Acoustics Laboratory at the Massachusetts Institute of Technology, is now associated with the General Radio Company as a consultant on acoustical problems and the design of acoustical measuring equipment. He will work with a development group in the General Radio Engineering Department, headed by Dr. A. P. G. Peterson.

Dr. Beranek is a native of Cedar Rapids, Iowa. He received his B.A. degree from Cornell College in 1936, his M.S. from Harvard in 1937, and his S.D. from Harvard in 1940. After teaching physics and communications engineering at Harvard, he became Director of the Electro-Acoustics Laboratory, an OSRD project, during the war. For his work in this laboratory, he received the Biennial Award of the Acoustical Society of America in 1944. In 1945, he became director of a second war laboratory, the Systems Research Laboratory, which dealt with psycho-physical problems encountered in the combined operation of radar, radio, telephone, and plotting instruments

Bachrach

on board ships during combat. After the war he was granted a Guggenheim fellowship to study and do research in the field of acoustical materials and auditorium design.

Dr. Beranek is a member of the Editorial Board and a Fellow of the Acoustical Society of America, a Fellow of the American Physical Society, a Senior Member of the Institute of Radio Engineers, and a member of Sigma Xi. He is Chairman of the American Standards Association Sub Group Z-24B on Fundamental Acoustical Measurements, and is co-author of a book published by NDRC in 1944 entitled *"Principles of Sound Control in Airplanes."*

A FREQUENCY MONITOR FOR TELEVISION VIDEO TRANSMITTERS AND OTHER A-M SERVICES

The increasing demand for a frequency monitor for television video channels has resulted in a redesign of the Type 1175-A Frequency Monitor* to adapt it for use at frequencies up to 220 megacycles. Originally designed for a top frequency of 150 megacycles, this monitor could, with only minor changes, be made to operate satisfactorily on channels 7 to 12 of the television band, covering frequencies between 174 and 216 Mc.

For television, an increase in crystal oscillator stability to $+0.001\%$ is necessary, and this has been accomplished by changing the design of the oscillator circuit and controlling the temperature of some of the oscillator circuit elements. Provision has been made for harmonic tuning at higher frequencies, but otherwise the monitor is unchanged in its functional arrangement and operation.

The new model is now in production and will be available in two models: Type 1175-B for monitoring a maximum of four channels at frequencies between

Figure 1. Panel view of the Type 1175-B Frequency Monitor.

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*C. A. Cady, "A Versatile Monitor for Use from 1.6 to 150 Megacycles," *Experimenter*, XXI, 9, February, 1947.

1.6 and 162 megacycles; and Type 1175-BT for monitoring a single channel at frequencies up to 220 Mc.

CIRCUIT CHANGES

Crystal Oscillator

The crystal oscillator circuit is one developed in the General Radio laboratories specifically for use in monitoring where a high degree of stability and reliability is required. It differs from older types in one important respect: no tuned elements are used in the circuit except the crystal itself. The crystal operates much nearer to its true series resonant frequency than is possible in conventional circuits, and the stability achieved is correspondingly higher. Figure 3 is an elementary circuit diagram of the oscillator.

The oscillator frequency remains well within the FCC specification of 0.001% for long periods. The results of several test runs are shown in Figure 4.

Any one of the four individual crystals can be selected by means of a panel switch. Each crystal position is provided with an independent frequency-adjustment capacitor located within the crystal oven. These are accessible from within the instrument by removing the rear dust cover. The frequency of each crystal may be shifted a maximum of ±7 ppm (±0.0007%) by means of these adjustments.

The temperature control system has been improved to meet the increased stability requirements, and the operating temperature has been raised from 50° to 60°C.

Crystal Buffer Amplifier

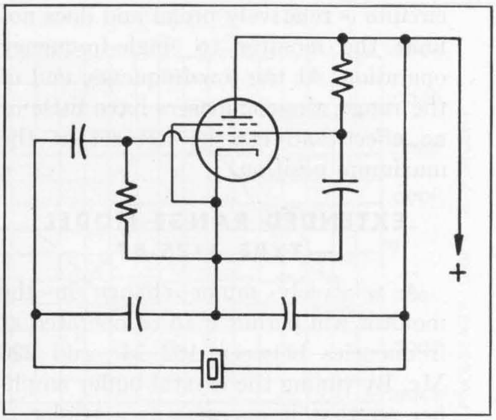


Figure 2. Elementary schematic circuit of the crystal oscillator. The crystal operates only slightly off resonance, at a frequency where its inductive reactance is equal to the reactance of the two capacitors.

Improvements have been made in the crystal buffer-amplifier stage to increase the production of harmonics, which in turn provides for more reliable operation in the high frequency ranges. Reduced coupling to the oscillator increases the frequency stability. The external Crystal Output terminals are no longer directly coupled to the crystal oscillator itself, but are now fed from the cathode of the buffer amplifier. External load impedances placed across the Crystal Output terminals do not react upon the oscillator frequency.

In order to provide for multichannel operation, with the resultant wide range in crystal frequencies, the coupling between oscillator and amplifier is aperiodic.

Mixer

The use of a miniature-type mixer tube has resulted in improved operation at frequencies above 100 Mc. With reduced lead inductances, it is possible to provide series-tuning adjustments which are effective at the higher frequencies. The coupling capacitors, which are variable silver-mica units, can be tuned to resonance and thus provide greater sensitivity. The tuning of these circuits is relatively broad and does not limit the monitor to single-frequency operation. At the low-frequency end of the range, the condensers have little or no effect and can be left set at the maximum position.

EXTENDED RANGE MODEL —TYPE 1175-BT

A relatively minor change in the monitor will permit it to be operated at frequencies between 162 Mc and 220 Mc. By tuning the crystal buffer amplifier so that it operates as a tripler, a considerable increase in over-all sensitivity results and adequate crystal-harmonics are provided for operation up to 220 Mc.

Because the tuning of the crystal buffer-amplifier can be set for only one frequency at a time, the monitor becomes essentially a single-channel device when so operated. While there is a considerable range of adjustment on the buffer-amplifier tuning, the tuning capacitor is accessible only from within the instrument.

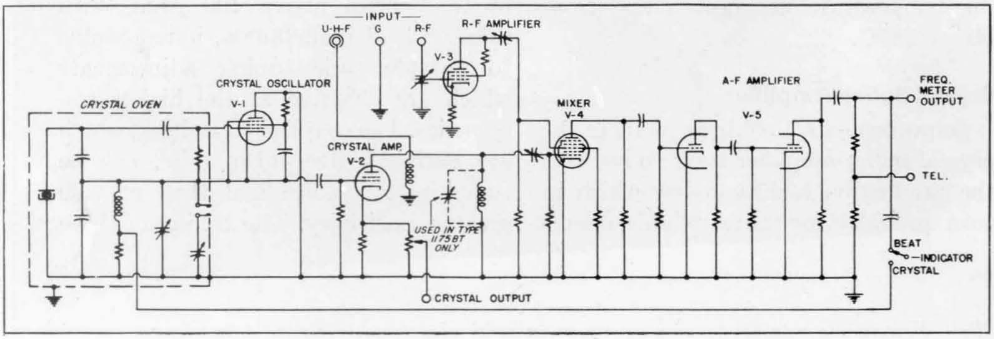
TELEVISION VIDEO TRANSMITTER MONITORING

The Type 1175-BT Frequency Monitor, used in conjunction with the Type 1176-A Frequency Meter, will provide a simple and convenient means of checking the carrier frequency of any television transmitter operating in channels No. 1 to 13 inclusive. For this use, an external plug-in filter unit is provided which eliminates the picture line-frequency of 15,750 cycles. This component of the video modulation signal must be attenuated in order to permit proper operation of the frequency meter. A low-pass filter with a 12-kc cut-off frequency accomplishes the desired result.

The monitor has a maximum operating range of ±12 kc from the assigned carrier frequency when the crystal frequency is selected for zero-beat operation and the filter unit is inserted. This is equivalent to about ±0.006% tolerance at the highest carrier frequency range and thus provides sufficient range beyond the FCC requirements of ±0.002% for television transmitters for all normal conditions. The Type 1176-A Frequency Meter should be operated on the 6-kc or 20-kc ranges (12 kc max. frequency) for television transmitters operating in the range of channels No. 7 to 13 inclusive. For television channels No. 1 to 6 inclusive, the 2-kc range of the frequency meter can be used in order to provide a more precise indication of the frequency error.

The crystal buffer-amplifier is usually tuned to a harmonic of the crystal oscillator. This is not an absolute requirement for applications in channels No. 1 to 6 inclusive, and hence the

Figure 3. Elementary schematic circuit of the complete monitor.



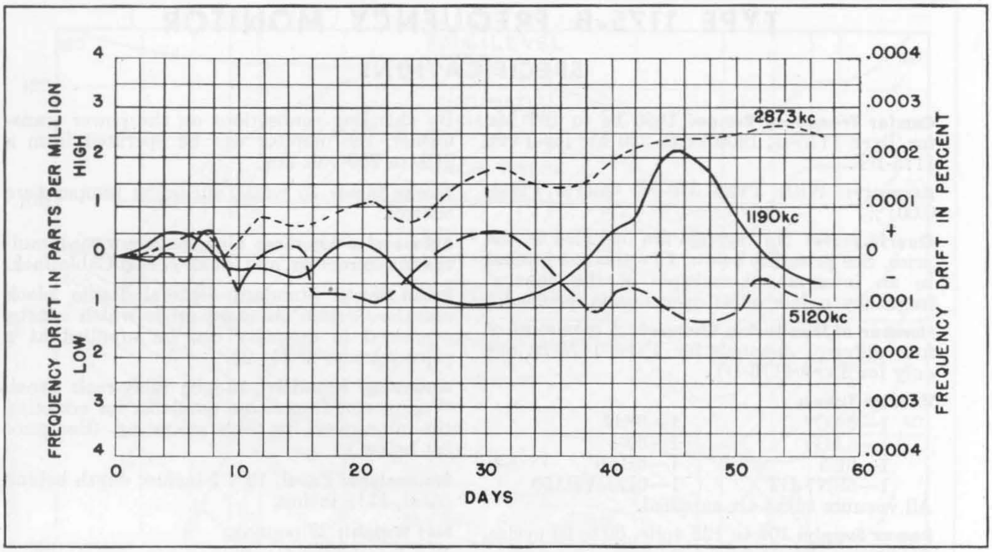


Figure 4. Actual records of crystal oscillator stability over a period of several weeks. The frequencies indicated on the plot are fundamentals. Harmonics are used for monitoring.

tuning may be omitted in order to provide multichannel monitoring, if desired. However, for operation in channels No. 7 to 13, this tuning is a definite requirement and thus limits the monitor to single-channel applications when operating in this range.

Since the crystal is normally adjusted for "zero-beat" operation, the "sign" of the frequency error from the assigned channel is determined by means of a pushbutton on the panel. Depressing this button shifts the monitor crystal oscillator by a discrete amount. The magnitude of this frequency shift is independently adjustable for each crystal position and can be set to a value commensurate with the transmitter tolerance in each case.

Offset Frequency Operation

There are certain applications that may require offset operation rather than the usual zero-beat method. For example, it may be desirable to avoid coincidence of the transmitter frequency error with that of certain modulation products present in the transmitted signal. There is also a very narrow region, within ±20 cycles of zero beat, where stable operation is not obtained because the frequency-indicating device does not have a d-c response. Most transmitters, however, never operate within this accuracy at the carrier frequencies considered, nor does the instantaneous stability approach this value.

The Type 1175-BT Frequency Monitor can be operated with an offset frequency crystal, if desired. Correct transmitter frequency would then be at center scale on the appropriate range of the Type 1176-A Frequency Meter. C. A. Cady

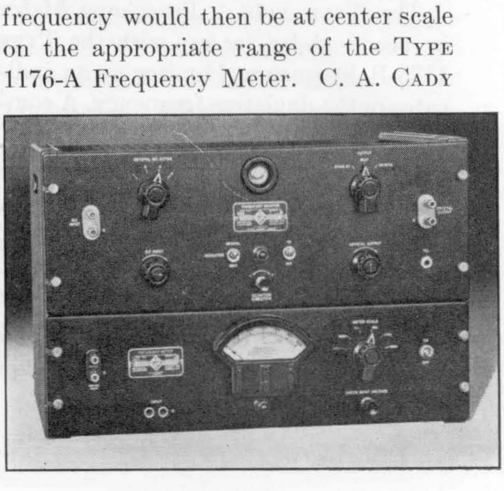


Figure 5. View of a Type 1175-B Frequency Monitor and a Type 1176-A Frequency Meter assembled in end frames.

TYPE 1175-B FREQUENCY MONITOR

SPECIFICATIONS

Carrier Frequency Range: 1600 kc to 162 Mc for Type 1175-B; 1600 kc to 220 Mc for Type 1175-BT.

Accuracy: With Type 376-M Quartz Plate, 0.001%.

Quartz Plate: No crystals are included in the price. See price list below. Crystals are ground to an integral sub-multiple of the channel frequency unless offset operation is specified.

Number of Monitoring Channels: A maximum of four different channels for Type 1175-B; one only for Type 1175-BT.

Vacuum Tubes:

- 1—6AC7
- 1—6AG7
- 1—6E5
- 1—6SN7-GT
- 1—6SJ7
- 1—6X5
- 1—6BE6
- 1—0D3/VR150

All vacuum tubes are supplied.

Power Supply: 105 to 125 volts, 50 to 60 cycles. By changing connections on the power transformer, the monitor can be operated from a 210- to 250-volt line.

Power Input: 75 watts, including temperature control.

Accessories Supplied: Line connector cord, multipoint connector, and Type 774-M Cable Jack.

Panel Finish: Standard General Radio black crackle. Certain standard grays which can be processed in quantity can be supplied at a price increase of $11.00.

Mounting: Standard 19-inch relay-rack panel. Walnut end frames are available for adapting the instrument for table mounting. (See price list below.)

Dimensions: Panel, 19 x 7 inches; depth behind panel, 11¼ inches.

Net Weight: 22 pounds.

Type		*Code Word*	*Price*
1175-B	**Frequency Monitor 1600 kc to 162 Mc**	TIPSY	**$325.00**
1175-BT	**Frequency Monitor 1600 kc to 220 Mc**	TONIC	**340.00**
376-M	**Quartz Plate**..............................	LABOR	**70.00**
ZFRI-410P-1	**End Frames for Type 1175-B (or -BT)**	ENDFRAMDAY	**16.50 pair**
ZFRI-710P-5	**End Frames for Type 1175-A mounted with Type 1176-B (or -BT) as a single unit**	ENDFRAMGAS	**17.00 pair**

This instrument is manufactured and sold under the following U. S. Patents and license agreements:

1,967,185 **2,012,497**

Patents of the American Telephone and Telegraph Company.

Patents of G. W. Pierce pertaining to piezo-electric crystals and their applications.

TYPE 1176-A FREQUENCY METER

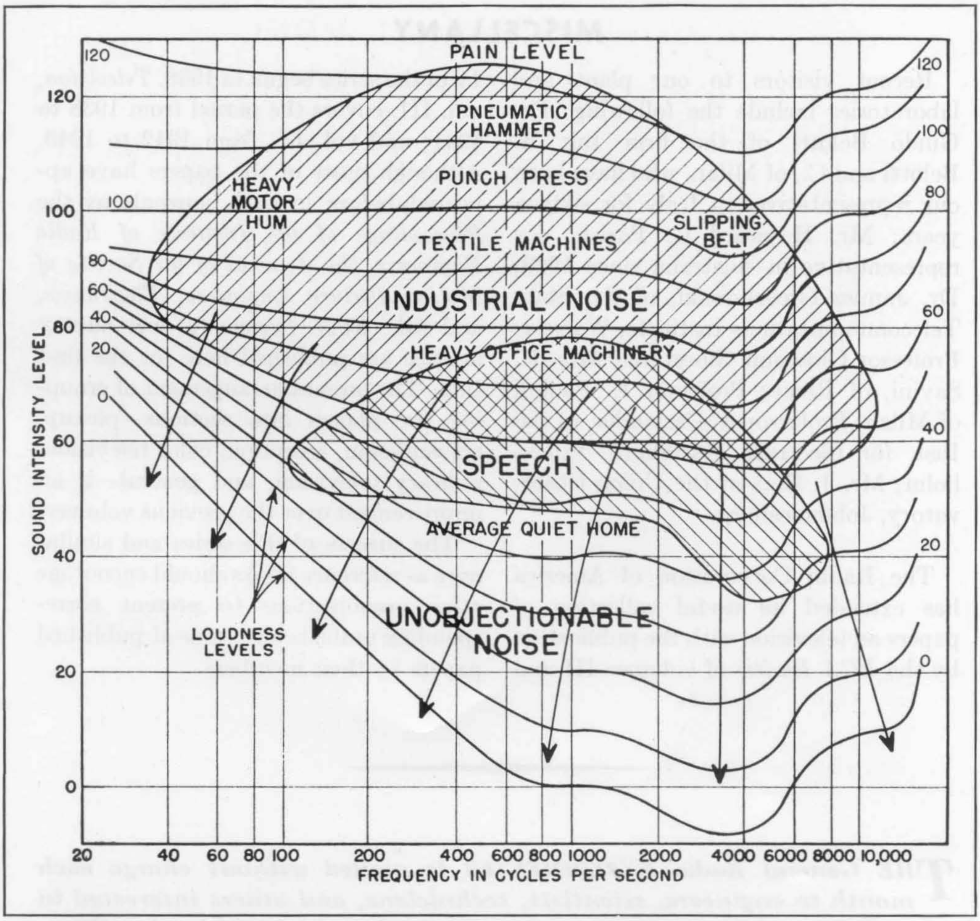
The Type 1176-A Frequency Meter is recommended for use with the Type 1175-B Frequency Monitor as an indicator of the deviation frequency. A complete description, with specifications, will be found in the *Experimenter* for February, 1946. Price and other necessary ordering information are listed below.

Type		*Code Word*	*Price*
1176-A	**Frequency Meter**	TIMID	**$265.00**
ZFRI-310P-1	**End Frames for Type 1176-A**	ENDFRAMCAT	**16.50 pair**
ZFRI-710P-5	**End Frames for Type 1176-A mounted with Type 1175-B (or -BT) as a single unit**	ENDFRAMGAS	**17.00 pair**

This instrument is manufactured and sold under the following U. S. Patents and license agreements:

2,362,503

Patents of the American Telephone and Telegraph Company.



Prepared by Dr. Howard C. Hardy, Armour Research Foundation, reprinted from *Industry and Power*, May, 1947

FREQUENCY-LOUDNESS CHART FOR INDUSTRIAL NOISE

Users of General Radio sound- and vibration-measuring instruments will be interested in an article by Howard C. Hardy, entitled "Noise and Vibration Reduction Speaks for Itself," which appeared in the May, 1947, issue of *Industry and Power*. Dr. Hardy, who is Supervisor of the Acoustics and Vibrations Section, Physics Division, Armour Research Foundation of Illinois Institute of Technology, discusses in this article the psychological aspects of industrial noise and the steps necessary for its elimination or isolation.

In the accompanying chart, which is reproduced from this article, the frequency-loudness areas for various types of industrial noise are superposed on the equal-loudness contours of the average ear, thus showing the distribution of the noise according to intensity, frequency, and loudness level as heard by the ear. The objective of noise control, the author points out, is to move the sounds in intensity and frequency in the direction of the arrows.

MISCELLANY

Recent visitors to our plant and laboratories include the following: Dr. Guido Belotti of the firm Ing. S. Belotti and C., of Milan, who have been our representatives in Italy for sixteen years; Mr. Hayward C. Parish, our representative in Australia since 1926; Dr. Janusz Groszkowski, of the State Telecommunications Institute, Warsaw; Professor Giovanni Giorgi and Mrs. R. Savini, of Rome; Professor E. Paolini of Milan; Professor A. Carlander, of the Inst. för Electrisk Mätteknik, Stockholm; Mr. J. Hers of the Union Observatory, Johannesburg.

The Radio Corporation of America has extended its useful collection of papers on television with the publication by the *RCA Review* of volumes III and IV of the series begun in 1936. *Television*, vol. III, covers the period from 1938 to 1941; and vol. IV, from 1942 to 1946. Although most of the papers have appeared before in such journals as the *Proceedings of the Institute of Radio Engineers*, the *Journal of the Society of Motion Picture Engineers*, *Electronics*, and the *RCA Review*, a few survey articles are published here for the first time. The present arrangement of grouping the papers into sections—pickup, transmission, reception, color television, military television, and general—is an improvement over the previous volumes.

The success of this series and similar ones as reference books should encourage other organizations to present corresponding unified collections of published papers by their members.

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 address, type of business company is engaged in, and title or position of individual.

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

VOLUME XXII No. 5 OCTOBER, 1947

TYPE 1170-A F-M MONITOR FOR BROADCAST AND TELEVISION SERVICES

● **WHEN GENERAL RADIO ENGINEERS** set out to design the Type 1170-A F-M Monitor, their aim was to provide, for the f-m broadcast band and for television audio channels, a monitor that would have the same high quality of performance and simplicity of operation as the monitors for the a-m band that have so long been accepted as standard by the industry.

The problem of designing an instrument of this calibre was more difficult than that of designing a-m equipment, because of the more stringent requirements set by the FCC on distortion, noise, and audio frequency range. The first step was, therefore, to determine what circuits could be adapted directly from standard a-m practice, and the second to determine what circuits were new and critical.

To generate the standard frequency, the highly stable crystal oscillator developed for the a-m frequency monitor could be used. Similarly, the modulation indicating circuits could resemble those used in the a-m modulation monitor. The requirements for distortion and noise measurement, however, as well as for adequate stability of center-frequency indication, called for a discriminator better in both

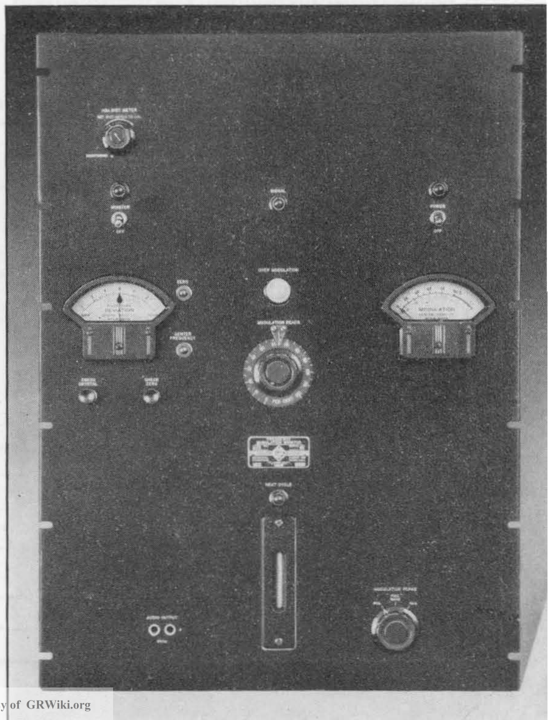


Figure 1. Panel view of the Type 1170-A F-M Monitor.

The standards of performance for f-m broadcasting are the highest that the industry has ever seen, owing primarily to the vision and unremitting effort of Major Edwin H. Armstrong. Only the use of equipment of the highest quality will insure the maintenance of these standards.

linearity and stability than the tuned-circuit type.

Tuned-circuit discriminators have been used in earlier types of monitors. They are highly sensitive and hence considerably simplify the monitor design. However, the tuned-circuit discriminator is not particularly satisfactory in either linearity or stability. It is basically a non-linear device. To approximate linearity over a 200-kc range, it must operate at an intermediate frequency of several megacycles. Slight drifts in circuit component values are troublesome, so that the center-frequency zero must be continually reset by comparison with a second crystal.

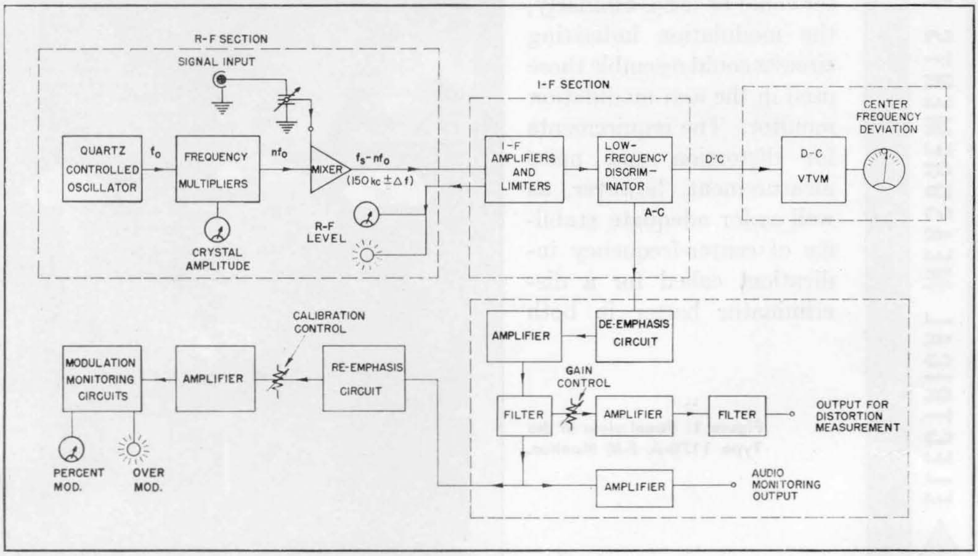
Pulse counters are inherently linear devices, and a discriminator employing this type of circuit can be made to operate linearly over a wide range with a minimum of critical circuit components and adjustments. The intermediate frequency can be low enough to achieve the stability necessary to eliminate secondary calibration adjustments.

A characteristic of the counter-type discriminator is its low sensitivity, so that it must operate at a high signal level to give a high signal-to-noise ratio. This need not be a serious limitation, however, for the desired result can be achieved quite simply, and the added circuits are notably free of critical adjustments.

Consequently, the pulse-counter type of discriminator was selected for use in the General Radio monitor. Using this discriminator, it is possible to obtain an over-all monitoring stability approaching that of the crystal oscillator, or a few parts per million.

As a result, the original design aim has been completely achieved. The new monitor gives (1) a continuous indication of center frequency without the necessity of frequency calibration checks; (2) an indication of percentage modulation (positive, negative, and full-wave) and a flashing lamp indication of overmodulation; (3) a high-fidelity output for distortion measurements—less than 0.2% distortion introduced by monitor; (4) a 600-ohm circuit for audio moni-

Figure 2. Functional block diagram of the monitor.



toring. Finally, the monitor is designed for television audio service as well as for f-m broadcasting.

The functional arrangement of the monitor is shown in Figure 2. A harmonic of a crystal oscillator beats with the incoming signal to produce an intermediate-frequency of 150 kilocycles. This beat passes through amplifiers and limiters to a counter-type discriminator. The d-c output of the discriminator provides the center-frequency indication, while the a-c output, after suitable filtering, operates the modulation indicators and furnishes a signal for distortion and noise measurements, as well as for audio monitoring.

The monitor is arranged mechanically so that the various circuits are segregated through the use of individual chassis assemblies. This makes all parts accessible and facilitates maintenance and tube replacements.

With one exception, vacuum-tube diodes are used throughout the monitor rather than crystal rectifiers. Crystals are not yet commercially available with characteristics as uniform as those of tubes. In particular, crystals exhibit a fluctuation with time in the ratio of front-to-back resistance, which precludes their use in circuits where long-period stability is desired.

The single crystal rectifier used in the monitor operates the r-f level indicator and the warning circuits, and supplies the bias on a control tube. For these functions, variations in characteristics have little effect.

CIRCUIT DETAILS OF THE MONITOR

R-F Section — The crystal oscillator circuit is one developed at the General Radio Company specifically for use in frequency monitors. It is highly stable; variations of 4% in the circuit capacitance, for instance, change the frequency by less than one part per million. The crystal has a temperature coefficient of less than two parts per million, and its temperature is maintained at 60° C. within ±0.15 degree.

The fundamental frequency of the crystal is between 1.4 and 2.2 Mc, and is so chosen that one of its harmonics, when heterodyned with the transmitter channel frequency, will produce a difference frequency of 150 kc.

The crystal oscillator is followed by an aperiodic buffer amplifier and three multiplier stages.

The tuned circuits in the multiplier stages have low Q and are operated at a high level to minimize the generation of f-m noise by phase modulation in the successive multiplier stages. A figure of 80 db below 100% modulation was chosen as a design objective for residual f-m noise. This is equivalent to a fluctuation of 7.5 cycles at the carrier frequency, or 7.5 parts in 100 million.

The 150 kc beat between crystal harmonic and transmitter frequency is produced in a pentagrid converter and is amplified by a single output stage.

For proper operation of the succeeding circuits, it is important that a specified minimum voltage be maintained, at the output of the mixer. An indicating meter is provided to measure this level. Since the voltage at this point depends on the r-f input, this device is also used as an indicator of r-f input level.

DISCRIMINATOR AND IF SECTION

Limiter Amplifier — To operate the discriminator it is necessary to generate a square-wave of constant amplitude. The 150-kc output from the r-f section passes through a diode clipper, a voltage amplifier, a second clipper, and finally drives two power tubes as limiting amplifiers.

The amplitude at the output of this amplifier is sufficient to assure a high signal-to-noise ratio and to eliminate all effects of contact potential in the discriminator diodes.

The voltage level is stabilized by regulating the plate and screen supplies of this final output stage. At this point in the circuit the signal is a square-wave of constant amplitude. The wave shape and the amplitude must be independent of frequency over a range of 150 plus and minus 100 kc in order to provide for wide modulation swings.

A control tube cuts off the gain of the amplifier tubes until sufficient input voltage has been reached to permit complete saturation of the input clipper stage. This prevents erratic indications on the meter with no input signal.

Discriminator Operation — The discriminator is shown in elementary form in Figure 3. The two diodes are connected in parallel but in opposite sense, so that the condenser is charged through the left-hand diode and discharged through the right-hand one. The time constants of the R-C circuits are made small compared to the time of one-half cycle of the intermediate frequency, so that the condenser is charged to the peak value of the square-wave and then completely discharged during alternate half cycles. The output of the discriminator, which appears across the resistor R_2 in series with the right-hand diode, consists of unidirectional pulses of constant shape and amplitude.

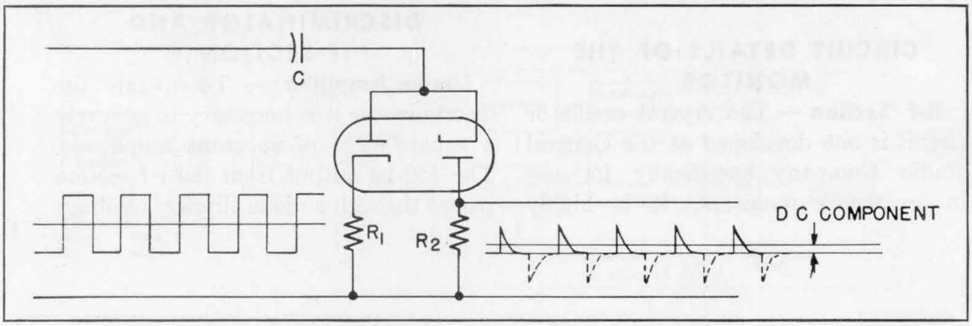
When the transmitter is unmodulated, the discriminator output has a d-c component equal to the average value of the voltage across R_2 and a series of a-c components at the pulse repetition frequency and its harmonics. The d-c component varies linearly with the transmitter frequency and consequently can be used to actuate the center-frequency indicator.

When the transmitter is frequency modulated, the pulses are "bunched up" or "spread out" when referred to a time base. The d-c component is not affected by the modulation except to the degree by which the average, or center, frequency changes under modulation.

Modulation also produces in the discriminator output a component of the modulation frequency, which is used to operate the modulation indicators and to feed the audio output circuits of the monitor.

Center Frequency Indicator — The d-c component of the discriminator output voltage is applied to a vacuum-tube voltmeter, with a bucking voltage that is independent of frequency, to operate a zero-center meter. A center-frequency shift will cause the differential voltage to change in magnitude and sign, and the

Figure 3. Elementary schematic diagram of the discriminator. The input waveform is shown at the left, the output waveform at the right.



d-c indicating meter will swing in one direction or the other by an amount proportional to the change in carrier frequency. The bucking voltage is derived from the square-wave that drives the discriminator and is proportional only to amplitude. Hence, minor variations in square-wave amplitude will affect the output of both the discriminator and the bucking circuit equally. The use of this amplitude stabilizing circuit eliminates the need for extreme regulation of the plate supply voltages as well as for precise control of all factors influencing the square-wave amplitude over its complete range of carrier swing.

AUDIO-OUTPUT SYSTEM

In order to recover the original modulation signal, the high-frequency components present in the pulse waveform are removed by means of low-pass filters.

Since the de-emphasis circuit normally employed in the audio-output channels constitutes an R-C filter with low-pass characteristics, this network can advantageously be used to couple the discriminator to the audio channels. The high series resistance helps to minimize the reactive loading effects of the external circuits upon the discriminator, and at the same time reduces the high-frequency components of the original pulse.

The resulting de-emphasized signal passes to a cathode-coupled amplifier and thence to one section of a low-pass filter. This filter section must pass without attenuation all audio frequencies up to 30 kc, the upper limit of audio measurements required by the FCC.

The second section of the filter is placed directly in the output of an amplifier, whose sole function is to drive the external distortion and noise meter. This filter section eliminates any remaining r-f components including pickup in the amplifier itself. To insure a minimum of residual distortion, the amplifier is operated at a constant low level. The input gain control can be set to give a constant output for any value of transmitter frequency swing between 6 and 100 kilocycles.

A second output, intended for local program monitoring, is obtained from a cathode-coupled amplifier with an effective output impedance of 600 ohms, unbalanced.

Modulation Metering Section

A standard pre-emphasis circuit restores the original audio-frequency characteristic for modulation measurements. This apparently roundabout method of producing the modulation signal by first de-emphasizing and then re-emphasizing has one very considerable advantage. As pointed out above, the de-emphasis circuit helps materially to eliminate the radio-frequency components of the pulse waveform. This reduces by the same degree the shielding necessary in the modulation monitoring circuits. The standard pre-emphasis circuit restores the audio-frequency components to a much greater degree than the r-f components.

An adjustable gain control is provided in the pre-amplifier circuit. This gain control permits the monitor to be calibrated for 100% modulation, with any value between the limits of 25 and 75 kc swing.

The modulation metering circuits and the overmodulation indicator circuit are nearly identical with those used in General Radio a-m monitors. The meter characteristics meet all FCC specifications. An important feature of this monitor, however, is the inclusion of a peak-to-peak, or total swing, indication, in addition to the usual positive and negative peak indications.

PERFORMANCE CHARACTERISTICS

Center-Frequency Indication — Monitoring practice in the standard a-m broadcast band has accustomed the transmitter engineer to stable center-frequency indicators. A glance at the monitor gives him a frequency indication that can be relied upon without calibration checks.

Many existing f-m monitors, however, do not have this degree of stability. Consequently, the zero reading must be checked against another crystal standard before a center-frequency reading is taken. It is customary to provide a push button on the panel for this calibration check. Such a procedure is inconvenient and time-consuming and is nearly impossible when remote indicators are used.

The Type 1170-A F-M Monitor is designed to give the same degree of stability as is customary in a-m monitors. Its over-all stability is ±4 parts per million, or about 400 cycles. A zero set is provided, which checks the electrical zero of the meter, but this need be used only once a day.

When this check is made, the accuracy of indication is bettered by a factor of two and is good to ±2 parts per million.

A glance at the meter gives the center frequency of the transmitter, even on a remote meter, and, in addition, a recorder can be operated to give a continuous record of center frequency.

To prevent erroneous on-frequency indications when the transmitter signal fails or drops below an adequate level, two warning signals are provided. The illumination of the center-frequency meter drops nearly to zero, and a pilot lamp on the panel is extinguished.

Distortion and Noise Measurements

The FCC has required the use of the standard 75 microsecond de-emphasis network in the measuring instruments. This results in a flat frequency response for the entire system between the transmitter audio input and the measuring device, and so duplicates the conditions actually obtained between studio and home receiver output. Measurements of noise and distortion are, however, referred to a given modulation percentage and frequency. The output voltage available for operation of the distortion and noise meter is thus reduced at the

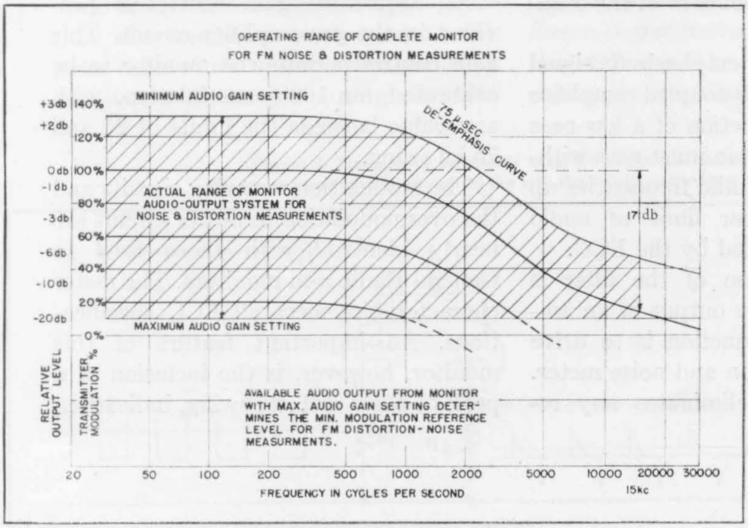


Figure 4. Operating range of the monitor for distortion and noise measurements.

high audio frequencies, and this limits the minimum percentage modulation at which distortion measurements can be made. Figure 4 shows this characteristic.

The very low distortion levels that will normally be measured in f-m transmitters impose rigid requirements on all units of the measuring system, and these include (1) the test oscillator, (2) the f-m monitor, and (3) the distortion meter. For this reason it is highly important to keep the residual distortion in any one unit as low as possible, since the minimum indicated level may equal the sum of all components in the system. Cancellation effects may reduce the indicated level below this amount, but, by the same token, readings of the transmitter distortion may be incorrect, should the level be so low as to approach the residual level of the measuring instruments.

Considerable effort was devoted toward keeping the residual audio distortion in the monitor extremely low and a figure of better than 0.2% has been achieved. When the monitor is used in conjunction with a Type 1301-A Low-Distortion Oscillator and Type 1932-A Distortion and Noise Meter, measurements can be made of f-m transmitter audio modulation distortion at values in the order of 0.5% rms distortion with a reasonable degree of accuracy.

Noise measurements in f-m systems will ordinarily be made at levels below −65 db. The residual noise level in both the f-m monitor and the noise meter is therefore of considerable importance. The combination of the Type 1170-A F-M Monitor with the Type 1932-A Distortion and Noise Meter will permit measurements to be made at levels of −75 db with accuracy.

In addition to its use in the transmitting station, this monitor is suitable for the production testing of f-m transmitters. The combination of the Type 1301-A Low-Distortion Oscillator, Type 1932-A Distortion and Noise Meter, and Type 1170-A F-M Monitor will permit transmitter type tests to be made as specified in the FCC's *Standards of Good Engineering Practice Concerning F-M Broadcast Stations*. Because of the wide range of frequencies over which this instrument will operate, and the ease of calibration adjustments, the monitor can easily be used with television aural transmitters. This flexibility of operation permits transmitter design engineers to perform type tests upon f-m transmitters of all types with a minimum of equipment.

— C. A. Cady

SPECIFICATIONS

Transmitter Frequency Range: 30 to 162 Mc with Type 1170-P1 R-F Tuning Unit; 160 to 220 Mc with Type 1170-P2 R-F Tuning Unit.

R-F Input Impedance: High impedance, with Type 774 Coaxial Connector. A capacitance attenuator is provided for adjusting the input level. The monitor can be used with standard R.M.A. transmitter monitoring output.

Input Sensitivity: 1 volt r-f, or better.

Input Level Indicators: A meter for indicating r-f input level is provided at the rear of the chassis. Signal pilot lamp and center-frequency meter pilot are illuminated when input level is adequate and are extinguished when level drops below the usable minimum.

Intermediate Frequency: 150 kc.

Discriminator: Pulse-counter type linear to better than 0.05% over a range of ±100 kc (133% modulation).

Center Frequency:

Indication: Meter is calibrated in 100-cycle divisions from −3000 to +3000 cycles per second. No zero set is necessary for each reading and no second crystal is provided.

Accuracy: Crystal frequency, when monitor is received, is within ±10 parts per million of specified channel frequency. Zero reading is adjustable over ±3000-cycle range to bring monitor into agreement with frequency-measuring service. Center frequency indication is then accurate to ±200 cycles per second.

Over-all Stability: ±400 cycles, or better, for long periods.

Percentage Modulation:

Indication: Meter is calibrated from 0 to 133%. Additional db scale is provided. Switch selects positive or negative peaks, or full-wave (peak-to-peak) indication. 100% modulation corresponds to 75 kc deviation for f-m bands. Single internal adjustment of meter circuit changes calibration to read 100% at 25 kc deviation, for television audio monitoring. Meter ballistics meet FCC requirements.

Accuracy: ±5% modulation.

Overmodulation Indicator: Lamp flashes when predetermined modulation level, as set on a dial, is exceeded. Range of dial is 0 to 120% modulation.

Output Circuits:

1. **Distortion and Noise Measurements:**

Terminals are provided for connecting a TYPE 1932-A Distortion and Noise Meter, and a gain control is provided.

Residual Distortion: Less than 0.2% at 100 kc swing (±133% modulation).

Response: 50 to 30,000 cycles per second ±½ db. Standard 75 microsecond de-emphasis circuit is included.

Maximum Output: 1.5 volts into 100,000 ohms.

Residual Noise Level: -75 db or better referred to 75 kc deviation; -65 db or better for 25 kc deviation.

Sensitivity: Full output can be obtained down to 8% of 75 kc deviation. Sensitivity varies with modulation frequency in accordance with standard de-emphasis characteristic.

2. **Audio Monitoring Output:**

Impedance: 600 ohms, unbalanced.

Output: Zero dbm at 75 kc deviation (100% modulation).

Response: 50 to 15,000 cycles per second ±¼ db.

Crystal Oscillator: General Radio high-stability circuit. Crystal is temperature-controlled at (60 ±0.15) C. Temperature coefficient of crystal is 2 parts per million per degree C, or less. Crystal oscillator output level can be read on panel meter by pressing a push-button switch. A jack is mounted at the rear of the chassis for connecting a milliammeter to check crystal oscillator plate current.

Remote Indicators: Circuits and terminals are provided for connecting the following indicators externally:

Center-frequency indicator
Percentage-modulation meter
Over-modulation lamp
600-ohm unbalanced aural monitor

Vacuum Tubes: The following tubes are used and are supplied with the monitor:

1—6AK6
1—6AB7
1—6BE6
2—2050
6—6AL5
1—6SK7
2—3-4
2—6AG7
2—6SN7-GT
1—6AG5
1—6SJ7
4—6SL7-GT
1—6AS7-G
2—6C4
1—815
2—OD3/VR150
1—6J6
1—991
1—OC3/VR105

Accessories Supplied: All tubes, coaxial connector for r-f input, power line connection cord, power supply plug.

Power Supply: 105 to 125 volts, 50 to 60 cycles. Power-transformer-primary-connections can be changed to permit operation on 210 to 250 volts.

Power Input: 300 watts.

Mounting: 19-inch relay-rack panel with dust cover.

Panel Finish: Standard General Radio black crackle lacquer. Certain standard grays that can be processed in quantity can be furnished at an extra charge of $20.00.

Dimensions: Panel, 19 x 26¼ inches; depth behind panel, 13¼ inches, over-all.

Net Weight: 88 pounds.

Type	*Description*	*Code Word*	*Price*
1170-A	**F-M Monitor**	AHEAD	**$1625.00**

(Licensed under patents of the American Telephone and Telegraph Company.)

The TYPE 1170-A F-M Monitor was developed by a group consisting of A. P. G. Peterson, C. A. Woodward, W. F. Byers, and C. A. Cady, author of the foregoing article.

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VOLUME XXII No. 6 NOVEMBER, 1947

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A WIDE-RANGE OSCILLATOR FOR AUDIO AND SUPERSONIC FREQUENCIES

Also
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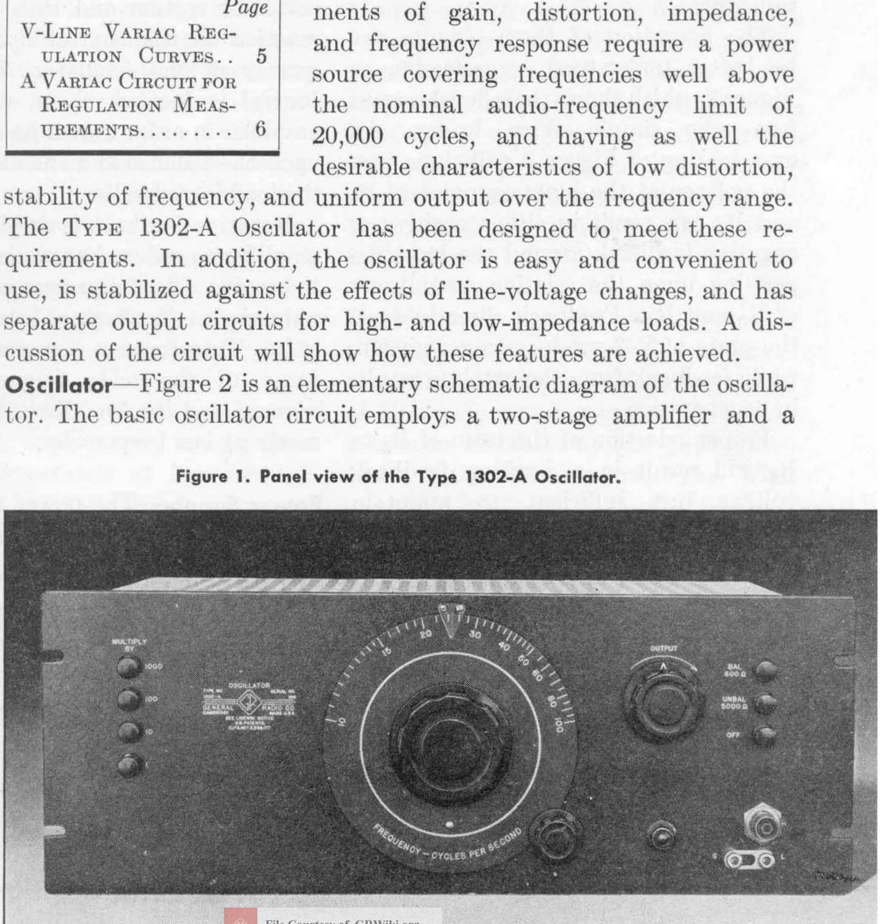
● **THE NEED** has long been apparent for a high-quality laboratory oscillator covering both audio and supersonic frequencies. Present-day laboratory measurements of gain, distortion, impedance, and frequency response require a power source covering frequencies well above the nominal audio-frequency limit of 20,000 cycles, and having as well the desirable characteristics of low distortion, stability of frequency, and uniform output over the frequency range. The TYPE 1302-A Oscillator has been designed to meet these requirements. In addition, the oscillator is easy and convenient to use, is stabilized against the effects of line-voltage changes, and has separate output circuits for high- and low-impedance loads. A discussion of the circuit will show how these features are achieved.

Oscillator—Figure 2 is an elementary schematic diagram of the oscillator. The basic oscillator circuit employs a two-stage amplifier and a

Figure 1. Panel view of the Type 1302-A Oscillator.



modified form of a Wien bridge. The output of this frequency-selective network balances to a null at one frequency and results in a negative feedback voltage at all others. Thus the amplifier has a maximum gain at the frequency at which the negative feedback voltage approaches zero. This condition can cause oscillations of the amplifier at one frequency, if a positive feedback voltage is introduced which has just sufficient amplitude to equal the losses around the loop. The amplitude of oscillation can thus be controlled by means of the positive feedback voltage, and to do this, a second set of bridge arms is added in parallel with the reactance arms of the modified Wien bridge. These additional bridge arms are resistive, but one is an incandescent lamp, which has a non-linear resistance.

The operation of these circuits can be better understood by referring to Figure 3, which shows their development from the simple Wien bridge. An examination of Figure 2 will show that the voltage at the junction point of R_3 and R_4 can result in either positive or negative feedback around the loop, depending upon the relative magnitudes of R_3 and R_4. Feedback directly from the plate of V-2 produces regeneration; while feedback from the cathode results in degeneration.

Proper selection of the ratio of R_3 to R_4 will result in a positive feedback voltage just sufficient to maintain oscillations at the normal level. An increase in e_g will cause an increase in the total bridge voltage and thus result in a current increase through R_3 and R_4. Since the resistance of R_3 varies with the current through the lamp, the ratio of R_3 to R_4 has been changed in a direction so as to reduce the magnitude of e_2. This reduction in positive feedback compensates for the increase in e_g, thus producing a-v-c action.

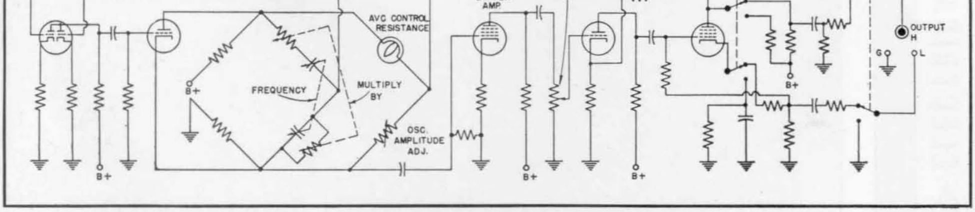
For frequency control elements, the two reactance arms of the modified Wien bridge are used. The two capacitances C_1 are ganged variable-air condensers driven by the main tuning dial; while the resistances R_2 are selected by means of the multiplier switches.

Amplifiers—A buffer amplifier is used to isolate the output control from the oscillator section and thus to prevent reaction of the control upon the frequency of the oscillator. The output control is located ahead of the final amplifier in order that it have no effect upon the balance and the magnitude of the load impedances.

Negative feedback is employed in the amplifier to reduce harmonic distortion, to provide a flat frequency response, and to minimize the effects of tube characteristics. Transformers are not used, because of the wide frequency range covered and the low distortion requirements at low frequencies.

Power Supply—The power supply employs an electronic voltage regulator,

Figure 2. Elementary schematic circuit diagram of the oscillator.



which combines the functions of plate voltage regulation and power-supply filtering. The power transformer is designed for 50- to 60-cycle operation and can be changed from 115-volt to 230-volt operation by changing taps on the transformer primary.

OPERATING CHARACTERISTICS

Frequency Range

The use of the Wien bridge as a frequency-determining circuit makes it possible to cover a wide range of frequency quickly and conveniently. The main dial is direct reading from 10 to 100 cycles, and multipliers of 1, 10, 100, and 1000 are provided.

A full decade of frequencies is covered by a 180-degree rotation of the dial. Decade changes in frequency can be obtained by depressing the panel multiplier switch. This arrangement is particularly convenient when bridge measurements are to be made over several decades of frequency.

The variable air condensers used as the frequency-controlling elements give complete freedom from the contact irregularities usually encountered with variable resistance elements. Precision fixed resistors are used to provide multiplier ranges.

Frequency Stability

For many applications, among them bridge measurements at low frequencies, it is desirable that any frequency drift be a constant percentage of the operating frequency rather than a constant number of cycles, as in a beat-frequency oscillator. Any drift occurring in the TYPE 1302-A Oscillator is of this type. The use of air condensers and precision resistors holds frequency drift to an extremely small value—not more than 0.2% per hour after a warm-up period of 10 minutes.

In measurements, one source of considerable annoyance is the erratic fluctuation of the frequency and amplitude of an oscillator, caused by sudden shifts in the power line voltage. In many industrial laboratories line voltage surges are common and occur whenever heavy intermittent loads are switched on or off in the plant. It is necessary to compensate the oscillator for transient voltage surges, as well as for the average line voltage shifts, if these effects are to be minimized. The voltage-regulated power supply in this oscillator has been designed so as to eliminate the effects of line voltage variations between the limits of 105 to 125 (210 to 250) volts.

Waveform

Bridge measurements, the measurement of the transmission characteristics of filters, distortion measurements, and a number of others require good waveform in the power source. The Wien

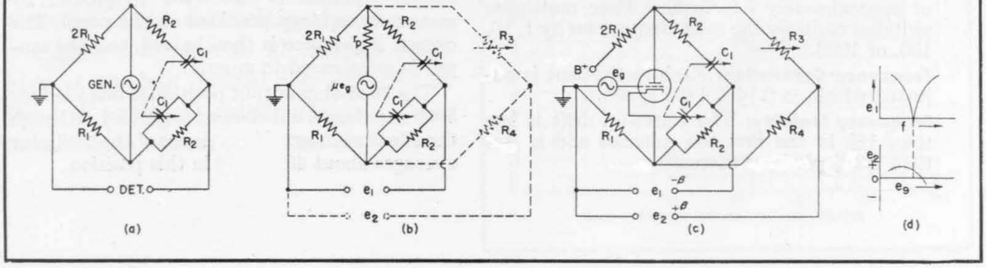


Figure 3. Development of the oscillator circuit from the basic Wien bridge; (*a*) shows the frequency-selective Wien bridge circuits; (*b*) the circuit with a second pair of arms shown dotted; (*c*) the complete oscillator feedback circuit; (*d*) amplitude and frequency characteristics of the two feedback circuits.

bridge circuit inherently suppresses harmonics, as shown in Figure 2, while the degeneration practically eliminates distortion in the amplifier. The total distortion at any frequency is less than 1%.

Output Circuit Characteristics

There are two output circuits provided: one unbalanced and designed to work into any load impedance down to 5000 ohms, and a second, balanced, output for use with a 600-ohm load. The 600-ohm balanced output may also be operated into a 300-ohm load with one side grounded. These impedances cover a sufficient range for most bridge measurements. For matching other load impedances, the Type 578 Shielded Transformers are recommended.

The output level is held constant within ±1 db over the entire frequency range by the bridge-type automatic amplitude control. Approximately 80 milliwatts into a 5000-ohm unbalanced load, or 40 milliwatts into a balanced 600-ohm load, can be obtained. Open circuit output voltages are approximately 22 and 10 volts, respectively.

The effective output impedances are: between 250 and 750 ohms for the 5000-ohm position and 550 ohms, constant, for the 600-ohm position. The 600-ohm position is intended to match into 500-ohm/600-ohm lines.

General Applications

Because of its wide frequency range and flat output voltage characteristic, this oscillator is well adapted for taking frequency response characteristics on amplifiers, telephone lines, filters, etc. Extremely rapid "spot checks," at frequencies exactly one decade apart, are possible owing to the decade switching feature. The wide frequency span, extending well into the ultrasonic range, is useful in checking the overall phase shift characteristics of audio amplifiers employing feedback circuits.

The instrument is reasonably well shielded, and the output is available through coaxial-type connectors, features which make the oscillator suitable for bridge measurements using sensitive detectors. The output terminals are arranged to be used with either Type 274 (pin-type) or Type 774 (coaxial) connectors.

The frequency range includes all frequencies at which the Type 716-C Capacitance Bridge is direct-reading, and consequently it is an excellent oscillator for use with that bridge.

—C. A. Cady

SPECIFICATIONS

Frequency Range: 10 to 100,000 cycles, in four ranges. Each range covers a decade (10-100 cycles, 100-1000 cycles, 1000-10,000 cycles, and 10,000-100,000 cycles) continuously variable.

Frequency Control: The main control dial is engraved from 10 to 100 cycles over a scale length of approximately 8¾ inches. Four multiplier switches multiply the scale frequencies by 1, 10, 100, or 1000.

Frequency Calibration: Each instrument is adjusted within ±(1½%+0.2 cycle).

Frequency Stability: The warm-up drift is less than 1% in the first ten minutes and is less than 0.2% per hour thereafter.

Output Impedance: Two output circuits are provided, balanced 600 ohms and unbalanced 5000 ohms.

The internal impedance of the 600-ohm output is constant at 550 ohms unless the LOW output terminal is connected to ground by means of the strap provided on the panel. The output impedance is then halved, and the output is unbalanced to ground.

The 5000-ohm output position is intended for 5000-ohm loads, unbalanced to ground, although the effective internal impedance of the oscillator averages about 400 ohms in this position.

Output Voltage: Approximately 20 volts open circuit on 5000-ohm output and 10 volts open circuit on 600-ohm output. The output voltage is constant within ±1.0 db over the entire frequency range.

Output Power: A maximum power output of 80 milliwatts can be obtained into an unbalanced 5000-ohm load. A maximum of 40 milliwatts can be obtained into a balanced-to-ground 600-ohm load (20 milliwatts into an unbalanced 300-ohm load).

Waveform: Harmonic content is less than 1% for all output values and at all frequencies.

A-C Hum: 5000Ω output, 24 millivolts, maximum. 600Ω output, 12 millivolts, maximum.

Terminals: Jack-top binding posts with standard ¾-inch spacing and standard General Radio TYPE 774 coaxial terminals are provided on the panel. The separate ground terminal has a strap which can be used to ground the LOW output terminal.

Mounting: The instrument is normally supplied for relay-rack mounting but can be easily adapted for table mounting by the addition of two walnut frames at the ends of the panel (see price list below).

Power Supply: 105 to 125 (or 210 to 250) volts, 50 to 60 cycles.

Total power consumption is about 90 watts.

Tubes: The following tubes are used and are all supplied with the instrument.

2—6SL7-GT	1—6V6
2—6B4-G	1—6J5
1—6AK6	1—5V4-G
1—6F6	1—0D3/VR-150

Accessories Supplied: A line connector cord, coaxial connector for output, multipoint connector, and TYPE 274-M plug.

Dimensions: (Length) 19⅜ x (height) 7½ x (depth) 14¼ inches, over-all.

Net Weight: 30 pounds.

Type		*Code Word*	*Price*
1302-A	**Oscillator**	FINAL	**$365.00**
ZFRI-412-P1	**End Frames**	ENDFRAMDIG	**16.50 Pair**

This instrument is manufactured and sold under the following U. S. Patents and license agreements:

2,173,427 **2,298,177**

Patents of the American Telephone and Telegraph Company.

V-LINE VARIAC REGULATION CURVES

Variac continuously adjustable autotransformers are extremely efficient voltage controlling devices. They have, however, a small regulation drop under load. The accompanying curves are illustrative of typical performance of the new General Radio V-line Variacs.

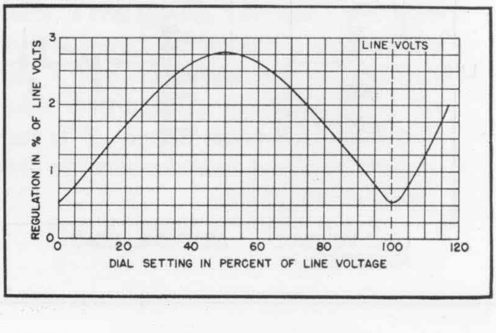
Figure 1 applies to all models operated normally *at rated load current.* Normal operation implies 115-volt supply for low voltage models and 230-volt supply for "H" models. Values are not substantially changed by the use or omission of the overvoltage feature.

Figure 2 applies to all models operated at one-half normal line voltage and one-half normal rated current. This covers such special cases as the use of an "H" model to secure 0 to 270 volts from a 115-volt line.

Regulation varies directly with load current as follows:

$$\% \text{ Reg.} = \left(\begin{array}{c}\% \text{ Reg. at}\\ \text{rated load}\end{array}\right) \times \frac{\text{actual load}}{\text{rated load}}$$

Figure 1. Percentage regulation as a function of output voltage for Variacs operated normally.



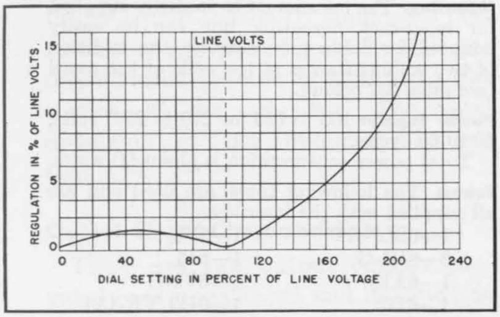


Figure 2. Percentage regulation as a function of output voltage when input voltage is one-half normal line voltage.

Where "H" models are operated at one-half rated voltage for 25 cycle applications, the regulation values of Figure 1 must be doubled, owing to the halving of the supply voltage.

Note that the normal values of Figure 1 are comparable to the regulation of any good auto-transformer, and that, at their maximum, they are but half the regulation of a conventional double wound transformer.

Values given are typical. Individual Variacs will differ slightly from these curves, but the difference will not be significant.

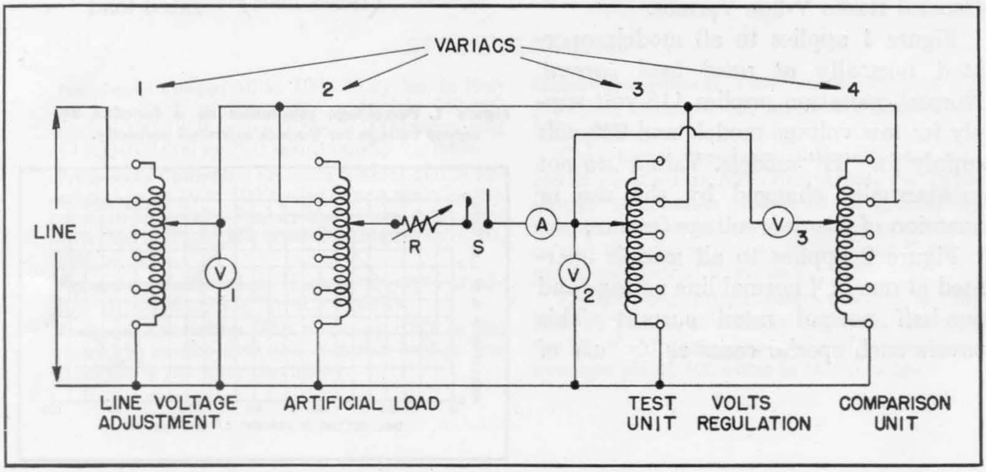
—Gilbert Smiley

A VARIAC CIRCUIT FOR REGULATION MEASUREMENTS

The typical regulation curves for the new V-line Variacs, appearing on page 5 of this issue of the *Experimenter*, were derived from measurements made by a method which differs markedly from conventional regulation measurement methods. Usually no load and full load voltages are measured, the difference being the regulation voltage drop, a satisfactory procedure where regulation is fairly large and accuracy tolerances are not close.

When, as in the case of the Variac regulation measurements on page 5, the drop is but a fraction of a volt out of one or two hundred volts, the difference in reading is so slight, and is so greatly changed by even minor fluctuations of the supply voltage during measurement, reasonable accuracies cannot be obtained by conventional methods. Obviously, a better method had to be found, a method that would read regulation voltage directly with reasonable

Figure 1. Circuit for regulation measurements.



freedom from error introduced by minor line voltage variations.

Figure 1 illustrates a circuit developed to meet these requirements, by the use of which accurate regulation measurements were easily obtained. This circuit is readily separated into functional divisions, as noted on the diagram.

Variac 1 and voltmeter, V_1, comprise the means for maintaining supply volts at an approximately correct level. Variac 1 needs be but large enough to supply the circuit losses. As an example, a V-5 (5 ampere rating) is adequate for measurement of all sizes up to V-20 (20 ampere rating).

Variac 2, resistor, R, switch, S, and ammeter, A, are "pump-back" connected to form an artificial load. While the pump-back connection is old in both principle and practice, a short description of the theory involved may be of interest to some of our readers. The circuit is based on the fact that, as long as full-load current is supplied by the transformer under test, this transformer may be considered to be fully loaded, provided only that the phase of the load current is correct. In the pump-back method, the potential difference between the loaded and loading transformers is made just sufficient to establish the desired current output from the loaded transformer. The loading transformer, Variac 2, returns to the line the power supplied by the loaded transformer, Variac 3, minus only such losses as occur in the transformers and the connecting circuit. Resistor, R, is included to facilitate close adjustment of current. Obviously, Variac 2 and resistor, R, must be capable of handling the current supplied by Variac 3. Voltmeter, V_2, indicates the output voltage of Variac 3 for each measurement point, and should be read with switch, S, open.

The novelty in the circuit is contained in the use of Variac 4 as a comparison or reference unit, and the use of voltmeter, V_3, to read regulation voltage drop directly. With the line voltage at a proper value and with Variac 3 set to a desired voltage, switch, S, is opened. Variac 4 is then adjusted until voltmeter, V_3, reads zero. Switch S is then closed and Variac 2 and resistor, R, are adjusted to the desired current reading on ammeter, A. V_3 will now read regulation voltage drop directly. Effectively, Variac 4 has been set at the no-load voltage of Variac 3 and maintains this voltage throughout the measurement. Minor fluctuations in line voltage change the voltage output of Variac 4 by exactly the same amount as they would change the no-load voltage of Variac 3, thus offsetting errors from this cause. Voltmeter, V_3, should, of course, have a scale to agree with the anticipated regulation voltage drop, which, as it is read directly, may be determined with satisfactory accuracy.

A voltage-divider, "potentiometer," may be substituted for Variac 4 if measurements are not to exceed line voltage. When, as with Variacs which have an overvoltage feature or with step-up transformers, measurements must be made at values exceeding line voltage, a Variac in this position enables the method to be applied.

Voltmeters, V_2 and V_3, should have sufficiently high impedance to be a negligible load on their respective circuits. TYPE 1800-A Vacuum Tube Voltmeters were used to obtain the data for the V line regulation curves. Multiple scale instruments, particularly in the case of V_3, permit closer reading of both zero adjustments and measured values.

— GILBERT SMILEY

MISCELLANY

Melville Eastham

Arthur E. Thiessen

HONORS—Certificates of Commendation have been awarded by the Navy Department, Bureau of Ships, to Melville Eastham, Chief Engineer, and Arthur E. Thiessen, Vice-President of the General Radio Company, for their contributions to the successful prosecution of the war.

The award to Mr. Eastham was made for his "outstanding leadership, vision, and perseverance, as Director of the Loran Development, Radiation Laboratory, in the development of the Loran system from its inception to its culmination as an operating system."

Mr. Thiessen's certificate was awarded for his "outstanding cooperation in the rapid expansion of the facilities of the General Radio Company from peacetime manufacture to wartime production of large quantities of superior quality electronics test equipment."

Technical Papers — presented by R. A. Soderman of the Development Engineering Staff: "U-H-F Measurements," Seattle Section, I.R.E., September 17; "A V-H-F Bridge for Impedance Measurements at Frequencies Between 20 and 140 Mc," Portland Section, I.R.E., September 18, and at the West Coast Convention, I.R.E., September 25; both papers at Los Angeles before the Electronics Section, A.I.E.E., September 30, and the San Diego Section, I.R.E., October 1.

— presented by W. R. Thurston of the Development Engineering Staff: "U-H-F Measurements" at the October 21 meeting of the U.R.S.I. at Washington, D. C.; "Coaxial Elements and Connectors" at the National Electronics Conference, Chicago, November 3.

Recent visitors to our laboratories: B. V. Baliga, M. L. Sastry, and N. N. Pai, of All-India Radio, New Delhi; C. J. Gorter, Director, Kamerlingh Onnes Laboratory, University of Leyden; and J. Hers, Union Observatory, Johannesburg.

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

V-20 SERIES VARIACS — NEW, STANDARD MODELS REPLACE 100 SERIES — RATINGS INCREASED

Also

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● THE TREND towards increased watts per pound already noticed in the previously announced V-5 and V-10 Series Variacs* is even more pronounced in the V-20 Series. Where the V-10MT delivers 112 per cent more power per pound than the 100-Q, the V-20M (a cased model) delivers 143 per cent more power per pound than the 100-Q. Once again the use of new materials and design formulae have made possible a marked improvement.

Ratings of V-20 Series Variacs double those of the V-10 Series, just as the latter doubled V-5 ratings. V-20 is rated at 20 amperes, with a 30-ampere maximum. V-20H rates at 8 amperes; 10 amperes maximum. These ratings necessitate a departure from the terminal practice of the previously announced V-5's and V-10's. Heavier, barriered terminals are provided in a box designed for BX or conduit attachment, since V-20 capacities exceed those of ordinary plugs, cords, and outlets (Figure 2).

V-20's, nevertheless, bear a marked resemblance to V-5's and V-10's, being designed on the same general principles. The two brushes are of the new unit con-

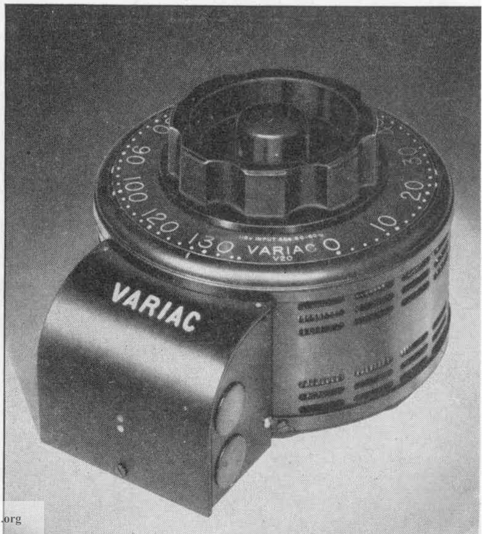

Figure 1. View of the Type V-20M Variac.

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*Gilbert Smiley, "V-5 Series Variacs — New, Improved Models Replace 200-C Series," *General Radio Experimenter*, May, 1946; "V-10 Series Variacs—New, Standard Models, Intermediate Between 200-C and 100 Series," *General Radio Experimenter*, July-August, 1946.

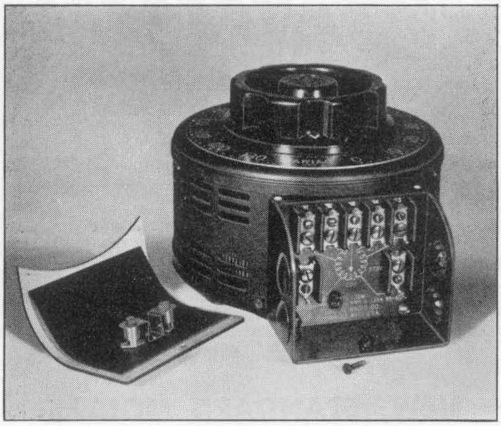


Figure 2. View of the V-20M with terminal box cover removed. Note the spare set of brushes attached to the cover.

struction, and, in addition, spare brushes are mounted in the terminal box. The case may be removed by loosening two screws; the terminal cover by one. Low-loss scroll core construction is standard. Aluminum base, dial, and enclosing parts contribute strength with light weight.

The control knob is a newly designed combination knob and handwheel, which is greatly improved in both appearance and utility over the earlier handwheel.

Rounded contours and compressible rubber feet minimize damage to adjacent objects. Corrosion-resistant materials with a durable baked finish preserve appearance. Every effort has been made to incorporate in V-20 Series Variacs all possible convenience, reliability, and efficiency.

Like the V-10's, V-20's are wound on a new concentric toroidal winding machine with great gains in both winding speed and accuracy. The V-20 winder, like the V-10 winding machine, was produced from our own designs in our own tool room. Figure 3 shows a winding in process.

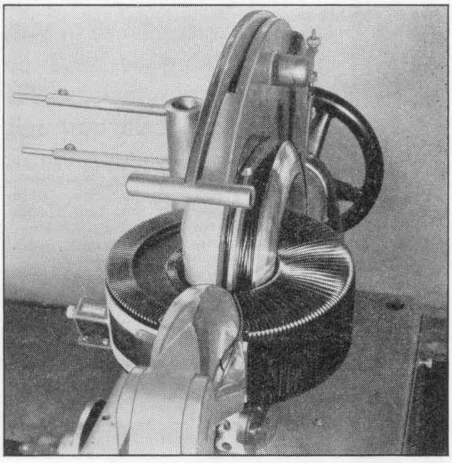
Since the outstanding feature of the V-20 is its truly remarkable output per pound of weight, some further expansion of this subject seems warranted. Thirty amperes at 115 volts is 3.45 KVA, the V-20 rating. Completely cased, the V-20 weighs but 20¾ pounds. One V-20 in single-phase service will deliver .166 KVA per pound. Contrast this figure with a tabulation of older models:

Variac	*KVA/lb.*	*V-20 Gain*
200-CM	.0908	83%
100-Q	.0684	143%

When standard Variacs, V-20's included, are operated in a three-phase wye connection, the power output is still further increased because the overvoltage portion of the winding allows the units to be operated at double their normal single-phase line voltage. Three V-20M units in a three-phase wye deliver 12 KVA, corresponding to 0.192 KVA per pound.

Open delta (Figure 5) and overvoltage circuits (Figure 6) do not increase KVA per pound but do extend usefulness. Figure 6 is especially interesting in

Figure 3. A V-20 winding in process.



that two V-20's so connected will deliver 0–270 volts from a 230-volt line at *20* amperes rated, whereas two V-20H's in parallel would cover the same range at but 16 amperes rated. Two V-20H's connected according to Figure 6 will cover 0–540 volts from a 460-volt line at 8 amperes rated.

Figure 9 shows a V-20 used with a supplementary transformer to cover a limited voltage range. Suppose, for example, that a range of 0–10 volts is required. The ratio of the supplementary transformer is 115/10 =11.5. Since current is in inverse ratio to voltage, the current step-up is 11.5/1. Thus, with the supplementary transformer, the V-20 will supply 20 ×11.5 =230 amperes over the 0–10-volt range. Furthermore, the entire Variac range will be used in going from zero to ten volts, finer adjustment of load is possible, and wear is distributed evenly over the Variac winding.

Figure 10 shows a V-20 and supplementary transformer operated to secure line-voltage regulation. As shown, the range is from 105 to 125 volts, with 115 volts out. The transformer ratio is 5.75/1. The available current is

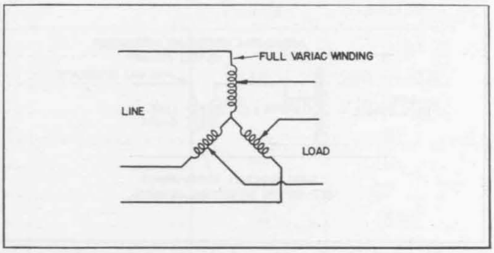


Figure 4. Three-ganged Variacs in a wye connection. Line voltage can be double the normal single-phase line voltage of the Variac.

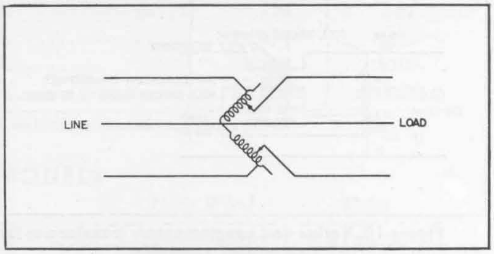


Figure 5. The open delta, a convenient three-phase connection using only two Variacs.

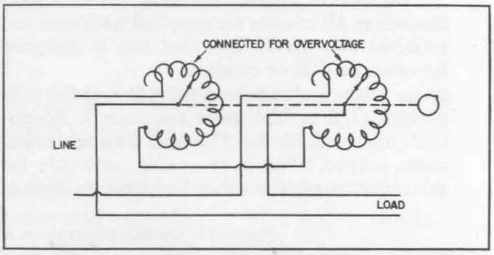


Figure 6. Two Variacs in series with single control can be operated at double the voltage of a single unit.

Figure 7. The new Type V-20M shown beside its predecessor, Type 100-Q. Delivering 66% more power, the V-20 is much smaller.

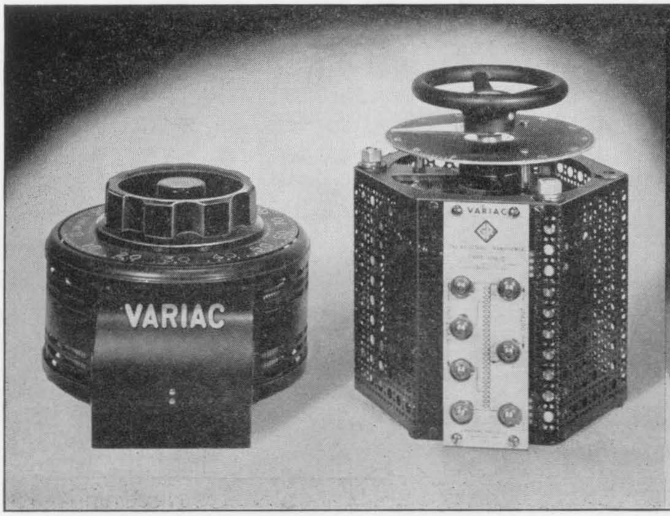


Figure 8. A three-gang assembly of V-20 Variacs.

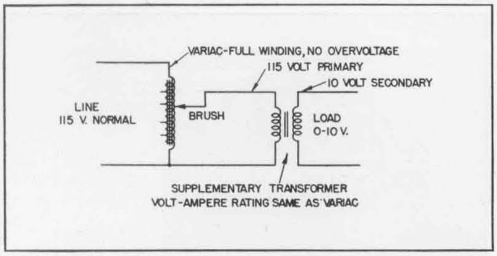


Figure 9. Connections of Variac and supplementary step-down transformer.

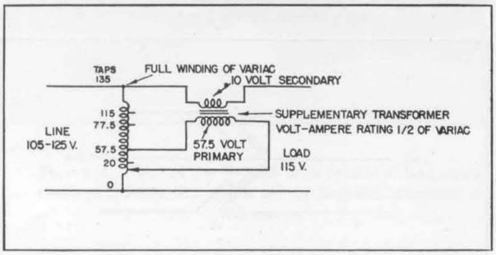


Figure 10. Variac and supplementary transformer for line voltage correction.

115 amperes (5.75 ×20), yielding a KVA capacity of 13.2 over the entire regulation range. Note again that regulation is close and that wear is reduced by working the whole Variac winding. When the brush is below the tap, voltage is subtracted from the line voltage; when above, added to it.

Thus in Figures 9 and 10 are shown ways of still further increasing the effectiveness of the V-20's high output. These supplementary transformer circuits are equally effective with all new Variacs having taps 6 and 7 to permit the use of the circuit of Figure 10.

—Gilbert Smiley

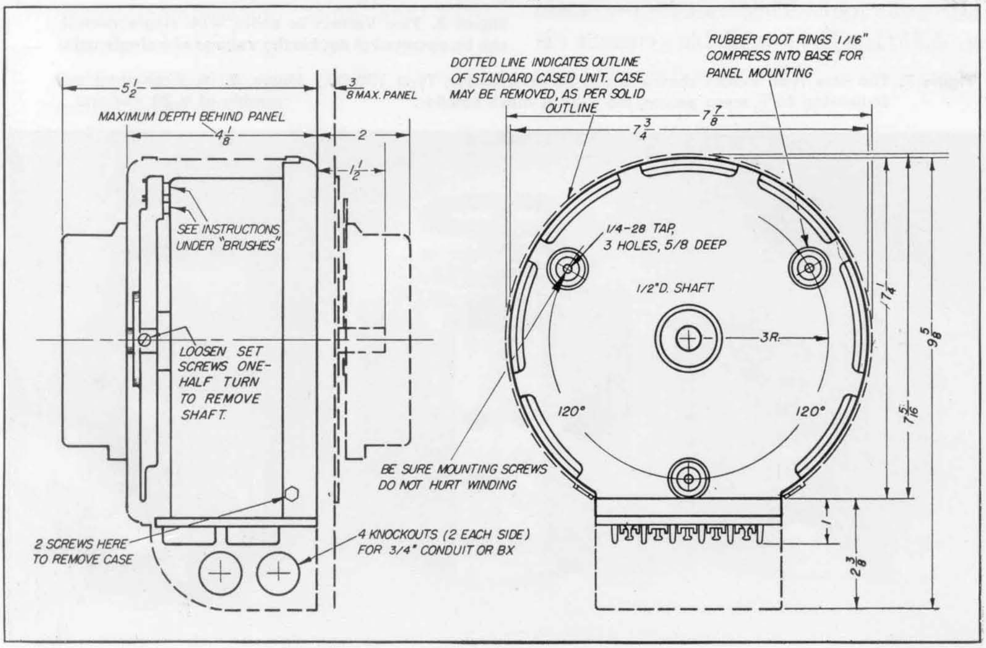
SPECIFICATIONS

Mounting: All models are supplied with case and terminal box cover. Terminal box is designed for use with BX or conduit.

Dials: Dials are engraved for overvoltage connection (135 or 270 volts maximum). Special dials are available for 115- and 230-volt maximum output. Dial is reversible, one side for table mounting, the other for panel mounting.

Current Ratings: In the following table, *Rated Current* is the current that can be safely drawn at any dial position and is determined by the loss in the winding; maximum current can be safely drawn at voltages close to input line voltage or at low output voltages and is determined by brush loss. A load drawing maximum current at line voltage will not overload the Variac at lower voltages.

Figure 11. Outline dimensions of Types V-20M and V-20HM Variacs.



Type	*V-20M*	*V-20HM*
Load Rating (KVA)	3.45	2.3*
Input Voltage	115	230 *or* 115
Output Voltage (Zero to)	115 *or* 135	270 *or* 230
Rated Current (Amperes)	20	8*
Maximum Current (Amperes)	30	10
No-Load Loss ∽ 60 (Watts)	27	27
Over-all Height for Table Mounting (Inches)	5½	5½
Maximum Panel Thickness (Inches)	⅜	⅜
Depth behind Panel (Inches)	4⅛	4⅛
Diameter of Variac Cylinder (Inches)	7⅞	7⅞
Add for Terminal Box (Inches)	1¾	1¾
Net Weight (Pounds)	22¾	21½
Code Word	JEWEL	JIMMY
Price	**$55.00**	**$55.00**

*With 115-volt input applied across half the winding, rating is reduced to one-half the value shown.

GANGED MODELS

Type	*Description*	*Code Word*	*Price*
V-20-G2	**2-Gang Type V-20**	JEWELGANDU	**$126.00**
V-20-G3	**3-Gang Type V-20**	JEWELGANTY	**182.00**
V-20H-G2	**2-Gang Type V-20H**	JIMMYGANDU	**126.00**
V-20H-G3	**3-Gang Type V-20H**	JIMMYGANTY	**182.00**

AUDIO-FREQUENCY DISTORTION AND NOISE MEASUREMENTS

Just before the war, when the requirements of national defense began to take up more and more of our facilities, it became necessary to discontinue the manufacture of some instruments because they were used primarily for civilian purposes. Among these was the Type 732-B Distortion and Noise Meter and the Type 732-P1 Range Extension Filter. These very popular instruments had found wide use throughout the broadcast industry, both here and abroad, and in a great number of sound recording and motion picture studios.

Particularly for the broadcast and communications laboratory applications, a new type of distortion and noise meter* was developed just after the war and introduced in 1946. It makes possible the measurement of harmonic content of any fundamental frequency in the band from 15 to 15,000 cycles with harmonics up to 45,000 cycles.

There are some applications, however, where a sharply selective tuning element is not desirable. This is particularly true when making distortion measurements of sound on film or on disk recordings where the fundamental frequency is not constant. Variations in the fundamental frequency, such as "wows" and other irregularities, will cause detuning of the highly selective single-frequency R-C filter used in the Type 1932-A Distortion and Noise Meter. This difficulty is completely overcome with the Type 732-B Distortion and Noise Meter. It is equipped with a 400-cycle high-pass

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*Type 1932-A Distortion and Noise Meter.

L-C filter, so that measurements of the harmonic content of a 400-cycle signal can be rapidly made. If the 400-cycle signal is somewhat unsteady, the accuracy of the measurement is not affected, because of the width of the pass band. As an auxiliary unit for use with the distortion meter, the TYPE 732-P1 Range Extension Filters are available, so that distortion measurements at additional fundamental frequencies of 50, 100, 1000, 5000, and 7500 cycles can be made.

The simplicity of this distortion meter and its speed of operation make it a most useful instrument for production tests on radio transmitters and receivers. Among the measurements that can be made with this instrument are: (1) Signal-to-noise ratio; (2) distortion vs. power, r-f level, frequency, and percentage modulation; (3) audio frequency response; (4) noise vs. carrier level; and (5) hum modulation and hum level. Other measurements that can be made on receivers include (1) distortion and noise as a function of audio output; (2) whistle output at 2nd and 3rd har-

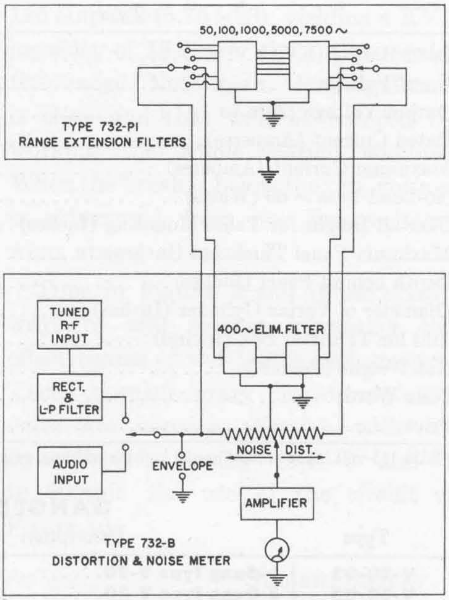


Figure 2. Functional block diagram showing connections between the distortion and noise meter and the range- extension filters.

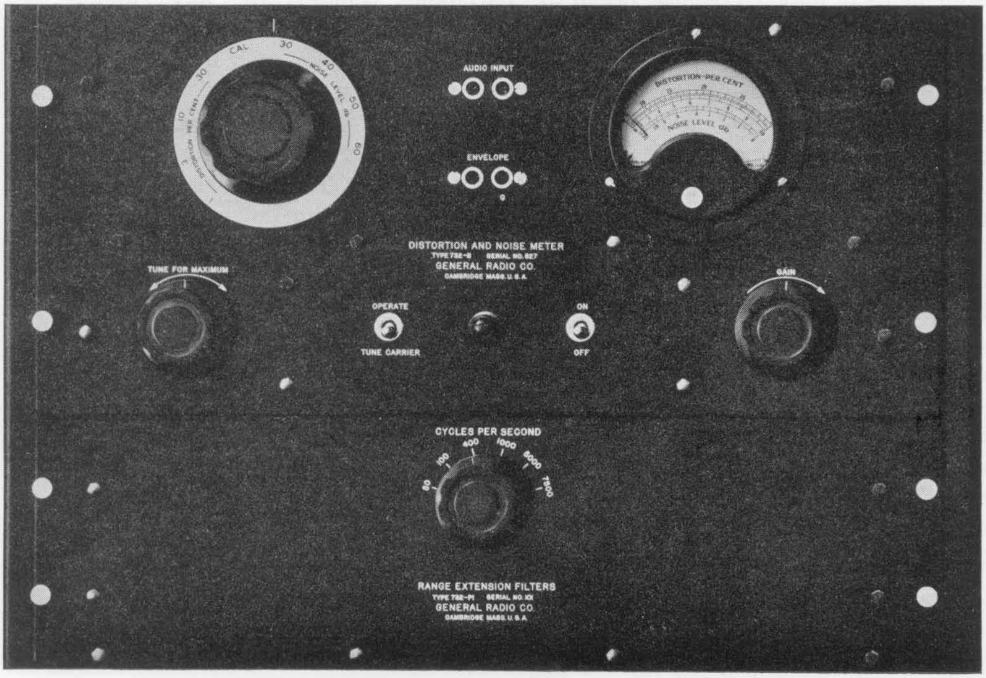


Figure 1. Panel view of the Type 732-B Distortion and Noise Meter with Type 732-P1 Range-Extension Filters.

monics of the intermediate frequency; and (3) two-signal cross talk.

There has been a steady and continuing demand for the Type 732-B Distortion and Noise Meter with the Range Extension Filter, and we have been glad to meet it by the resumption of production at this time. *Deliveries can be made promptly.* Detailed specifications are given below. — A. E. Thiessen

SPECIFICATIONS FOR TYPE 732-B DISTORTION AND NOISE METER

Distortion Range: Distortion is read directly from a large meter. Full-scale values of 30%, 10%, 3%, and 1% are provided, and are selected by a multiplier switch. The range for carrier-noise measurement is from 30 to 70 db below 100% modulation or 65 db below an audio-frequency signal of zero level.

Input: A tunable r-f input circuit and a 500-ohm audio-frequency input circuit are provided.

Audio-Frequency Range: 380 to 420 cycles for distortion measurements; 30 to 24,000 cycles for noise or hum measurements. For extending the distortion measurements range, see Type 732-P1 Range-Extension Filters.

Carrier Frequency Range: The Type 732-B Distortion and Noise Meter is designed to operate at any carrier frequency between 0.5 and 60 megacycles. This range is covered by two coils. A single coil (either for the 0.5- to 8-Mc range or for the 3- to 60-Mc range) is supplied with the instrument unless both coils are specifically ordered. The coils are readily interchanged. (See price list.)

Accuracy: The over-all accuracy of measurement of each distortion range is better than ±5% of full scale ±0.1% distortion.

Meter: A Weston Model 643 Meter, calibrated directly in per cent distortion and decibels noise level, is provided. Zero adjustment of the meter is made by a knob projecting from the meter face.

Controls: A carrier control is provided for tuning the input circuit of the instrument to resonance with the carrier. A switch is provided for selecting the proper distortion or noise range. An amplifier gain control and an ON-OFF switch with pilot lamp are also provided.

Vacuum Tubes: One 37, two 6C6, one 1-V, and one 84 are supplied.

Other Accessories Supplied: Spare fuses and pilot lamps. Two dummy plugs to be used if the Type 732-P1 Range-Extension Filters are not connected. One carrier input coil.

Terminals: In addition to the radio-frequency input binding posts at the rear, two normal-through Western Electric output double jacks are provided on the panel, one at high impedance for the modulated envelope from the rectifier, and one at 500 ohms for use in audio-frequency testing.

Power Supply: 115 or 230 volts, 40 to 60 cycles.

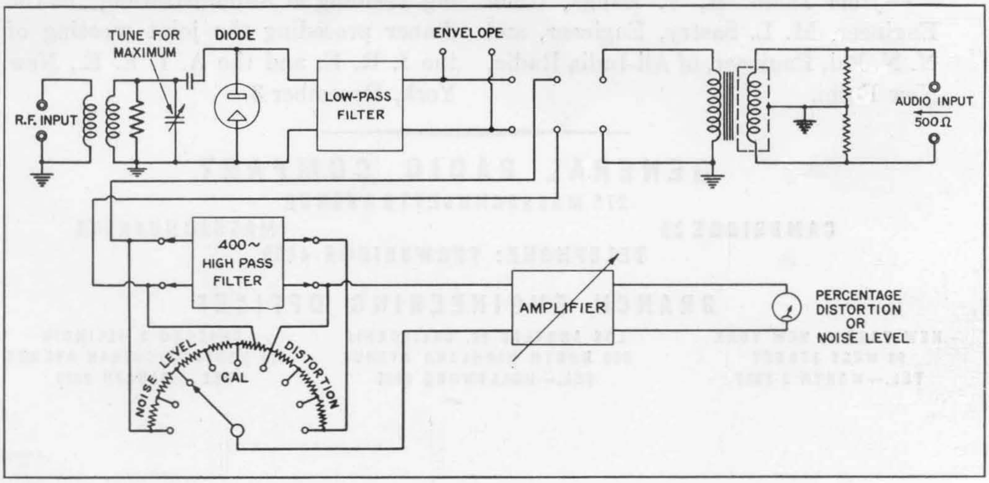
Mounting: The instrument is relay-rack mounted. The panel is aluminum with the standard General Radio black-crackle lacquer finish.

Dimensions: Panel, 19 x 8¾ inches; depth behind panel, 12 inches.

Net Weight: 40 pounds.

Type	*Description*	*Code Word*	*Price*
732-B	**Equipped for 0.5- to 8-Mc Carrier Range**	EXPEL	**$374.00**
732-B	**Equipped for 3- to 60-Mc Carrier Range**	EQUAL	**374.00**
732-P6	**Extra Coils for 3- to 60-Mc Carrier Range**	CYNIC	**16.50**
732-P5	**Extra Coils for 0.5- to 8-Mc Carrier Range**	CULER	**16.50**

Figure 4. Functional schematic diagram of the Type 732-B Distortion and Noise Meter.



SPECIFICATIONS FOR TYPE 732-P1 RANGE-EXTENSION FILTERS

Audio-Frequency Range: 50, 100, 1000, 5000, and 7500 cycles. Flat band width ±5%.

Accuracy: At distortions greater than 0.5%, the error is less than 10% of the true value ±0.15% distortion.

Accessories: Two shielded cables are supplied for connecting the TYPE 732-P1 Range Extension Filters to a TYPE 732-B Distortion and Noise Meter.

Test Voltage: The TYPE 1301-A Low-Distortion Oscillator is recommended as the source of test voltage.

Controls: A single control is provided for selecting the proper filter.

Mounting: The instrument is relay-rack mounted. The panel is aluminum with the standard General Radio black-crackle lacquer finish.

Dimensions: Panel, 19 x 5¼ inches; depth behind panel, 12 inches.

Net Weight: 25 pounds.

Type	*Description*	*Code Word*	*Price*
732-P1	**Range-Extension Filters**	ESSAY	**$209.00**

MISCELLANY

Recent Visitors to General Radio

—*from Holland:* Dr. C. E. Maitland, General Board of Management, and Dr. R. M. M. Obermann, Chief Engineer, Instrument Laboratory, State Board of Post and Telegraph Service; Willem A. Van Waasdijk, Chief Engineer, Radio Division, Van Der Heem, N.V., The Hague; F. C. L. Van Vugt, E. Wieringa, M. Vader, and H. Landeweer, of N. V. De Bataafsche Petroleum Mij., The Hague.

—*from Switzerland:* Dr. Karl Berger, Lecturer of High Voltage Engineering, Swiss Federal Institute of Technology, Zurich.

—*from Norway:* Erik Julsrud, Engineer, Broadcasting Dept., Norwegian Telegraph Administration, Oslo.

—*from India:* B. V. Baliga, Chief Engineer, M. L. Sastry, Engineer, and N. N. Pai, Engineer, of All-India Radio, New Delhi.

—*from England:* Dr. A. J. Biggs, of the Research Laboratories of General Electric Company, Ltd., Wembley, and C. H. Crocker, Development Laboratories, General Electric Company, Ltd., Coventry.

Papers Presented

— by W. N. Tuttle, Development Engineering, "Thyratron Control of A-C Motors," at the National Electronics Conference, November 5.

— by R. A. Soderman, Development Engineering, "A V-H-F Bridge for Impedance Measurements at Frequencies between 20 and 140 Mc," at the Rochester Fall Meeting, November 19.

— by H. B. Richmond, Chairman of the Board, "The Value of an Engineering Training in Administration," at the dinner preceding the joint meeting of the I. R. E. and the A. I. E. E., New York, December 3.

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