THE General Radio EXPERIMENTER

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

HIGH-FREQUENCY COMPENSATION FOR AMPLIFIERS

Also

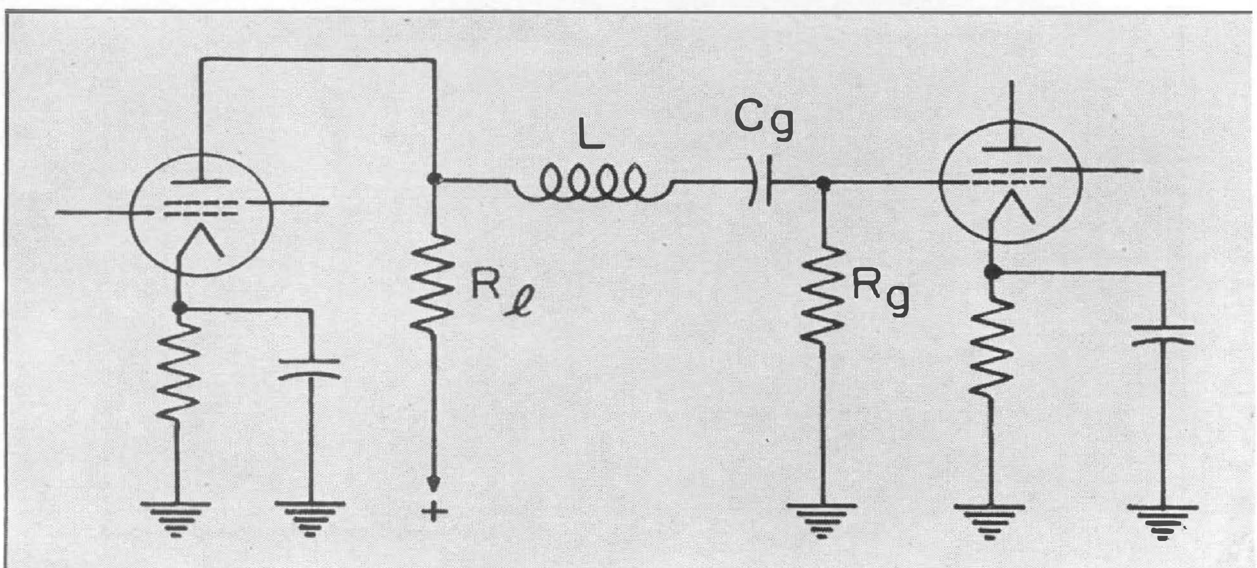
IN THIS ISSUE

● ONE OF THE MOST USEFUL TYPES of high-frequency compensation for a broadband amplifier is a series coupling inductor as shown in a typical interstage connection in Figure 1. The simplified representation of Figure 2 illustrates that this inductor, L, forms with the output capacitance of one stage, C_1, a low-pass filter. Wheeler[1] has shown that for a termination of such a filter by the image impedance of a constant-k section, best results will be obtained with a capacitance at the terminated end of one-half that at the unterminated end.

In actual practice, the termination is usually a resistor, which does not satisfy Wheeler's condition; and, while the ratio of the capacitances can be varied by locating the grid resistor and blocking condenser at one or the other end of the series coil, it is not always possible to obtain a capacitance ratio of ½ unless a capacitor is added to one end. Since

[1]Harold A. Wheeler, "Wide-Band Amplifiers for Television," *Proc. I.R.E.*, Vol. 27, No. 7, July, 1939, pp. 429–438.

Figure 1. Interstage coupling circuit with series peaking inductor.



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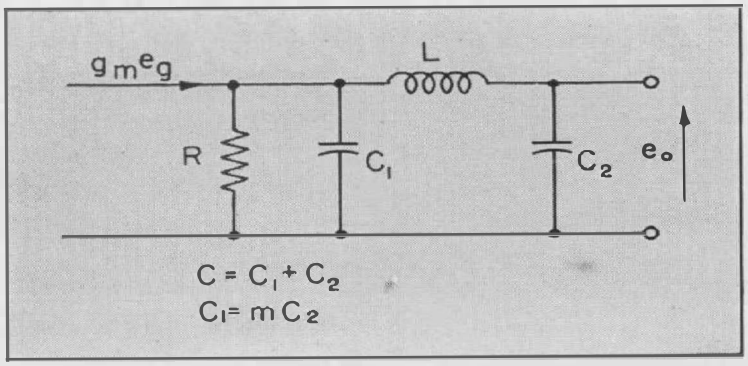

FIGURE 2. Simplified equivalent circuit of interstage coupling with low-frequency effects neglected.

the unavoidable circuit capacitances are the initial factors limiting the gain for a given band width, adding capacitance seems at first an undesirable procedure.

Since there seem to be no published data giving additional details for design, an analysis has been made of the simple four-element circuit of Figure 2, in order to determine if this ratio is necessary for uniform gain over the desired band. The present analysis has been carried through only for the amplitude characteristic. In many cases the phase characteristic is sufficiently important to require a design based on considerations of both amplitude and phase.

The circuit of Figure 2 shows C_1 as the total shunt capacitance at the terminated end of the filter, C_2 as the total shunt capacitance at the unterminated end, and R as the parallel combination of the plate load resistor, R_l, and the dynamic plate resistance of the amplifier tube. The grid resistor, R_g, is neglected as being very large compared to that parallel combination. If R_g is on the same side of the inductor as R_l, it too can be put into the parallel combination. In addition, C_1 is expressed as a fraction of C_2 in order to simplify reference to this important ratio, m.

A straightforward calculation of the circuit of Figure 2 shows that the magnitude of the ratio of grid-to-grid voltages, normalized to give unity at low frequencies, is

$$\left|\frac{g_m R e_g}{e_0}\right|^2 = \left[1 - \frac{1}{1+m}\left(\frac{L}{CR^2}\right)(\omega CR)^2\right]^2 + \left[\omega CR - \frac{m}{(1+m)^2}\left(\frac{L}{CR^2}\right)(\omega CR)^3\right]^2$$

Here one can select various values of m and observe the effect on the gain characteristic (the square root of the reciprocal of the above expression) of various values of inductance. Some representative results are shown in Figure 3. The typical curve, representing the gain

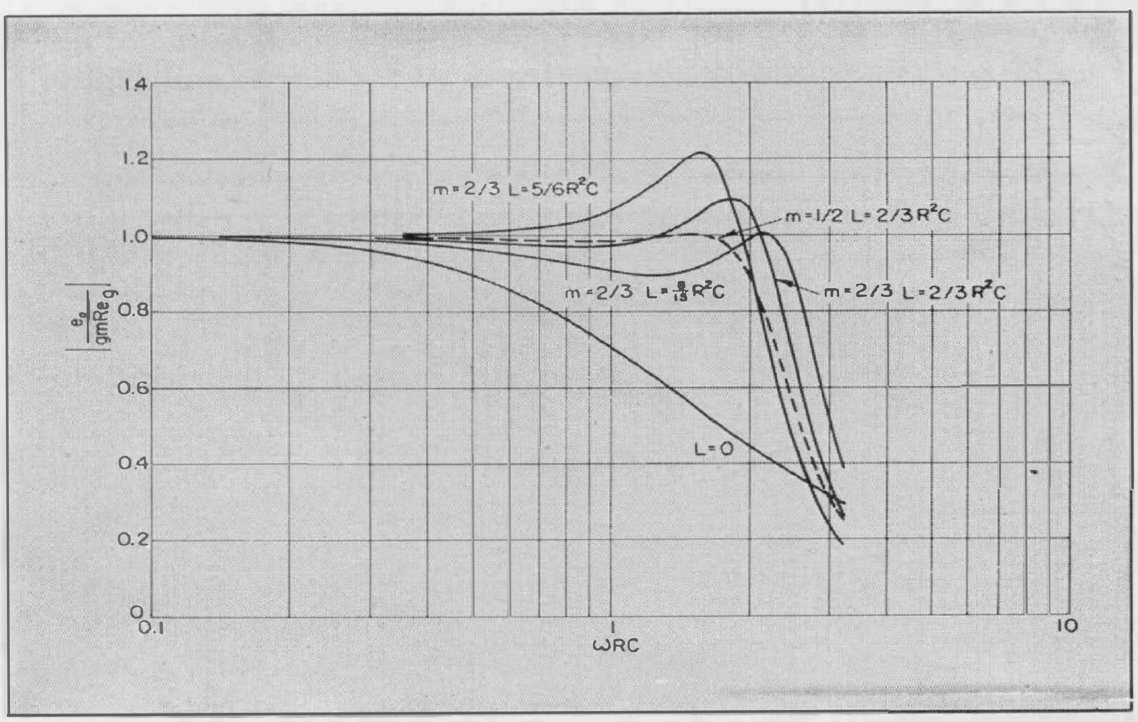

FIGURE 3. Gain characteristic of a single stage for various values of the capacitance ratio and peaking inductance.

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as a function of frequency, as the frequency is raised, shows first a sag and then a rise just before the curve drops off at cutoff.

The four solid-line curves of Figure 3 apply to the ratio of ⅔, and show the effect on the gain characteristic of increasing values of inductance. In determining which value of inductance to use, one can plot a series of this type and select one that gives the best compromise between band width and flatness. Another procedure is to set up certain requirements for the gain characteristic and on that basis determine the value of inductance. Thus if

$$L = \frac{4m(1-m)}{(1+m)} R^2C,$$

the gain rises as a maximum, after the sag, to the same gain as at low frequencies. This value of inductance corresponds to the usual one given for the ratio of ½, viz., $L = \frac{2}{3}R^2C$, and the gain characteristic for this value is shown as a dashed curve in Figure 3. The corresponding curve for $m = \frac{2}{3}$ is one with $L = \frac{8}{15}R^2C$ shown in Figure 3. However, this value of inductance is not a desirable one except for ratios in the vicinity of $m = \frac{1}{2}$. For values less than ⅓ or greater than 1, the original requirements cannot be fulfilled, so that some other basis must be used for those extremes.

One interesting condition that can be set up is based on a consideration of the derivatives of the gain with respect to frequency at zero frequency. All the gain characteristics for the present circuit have an initial horizontal slope (first derivative equal to zero at zero frequency), with a resulting flatness at low frequencies (without consideration of the effect of the C_g–R_g combination). As the frequency increases, the slope of the gain characteristic changes from horizontal, and the gain deviates from the low-frequency value. By making this change in slope as slow as possible one can obtain an improved flatness. Analytically this condition can be expressed as setting the next higher order derivatives equal to zero. Thus if

$$L = \frac{(1+m)}{2} R^2C,$$

the first three derivatives are zero at zero frequency. Furthermore, at the ⅓ point, what has been called maximal

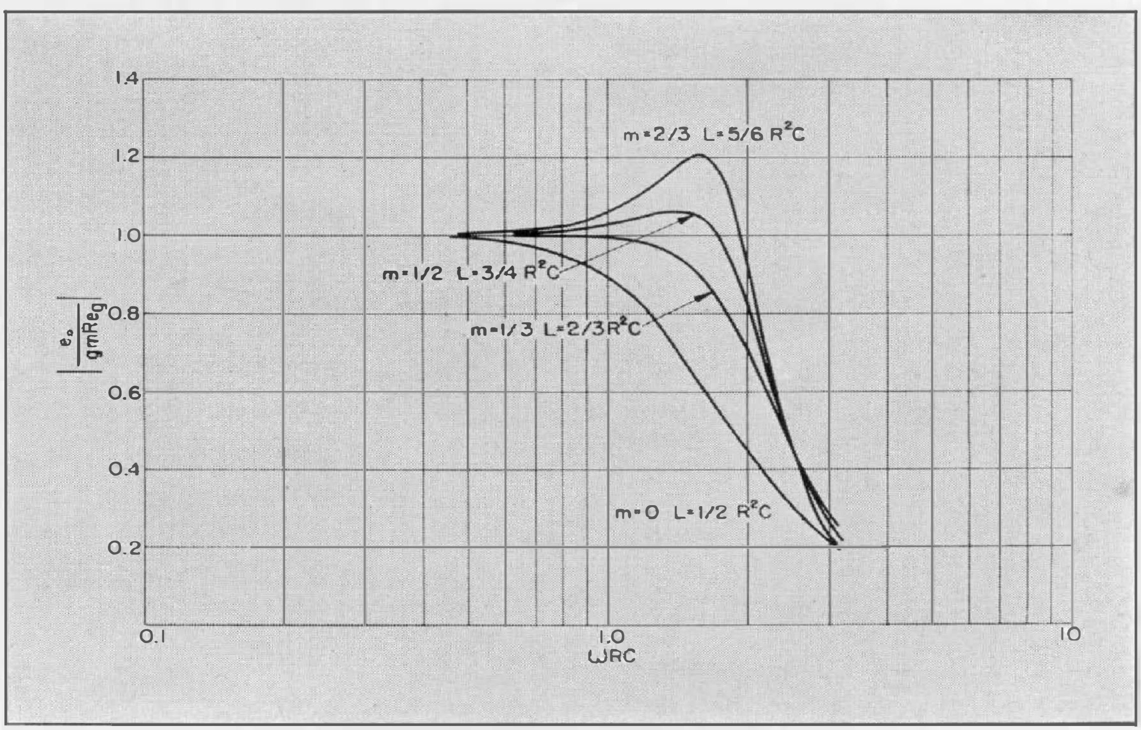

FIGURE 4. Gain characteristic of a single stage with $L = \frac{(1+m)}{2} R^2C$, the value required to make the first three derivatives of the gain with respect to frequency zero at zero frequency.

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flatness[2] is obtained, with the first five derivatives equal to zero. This value is a transition one, and the nature of the transition can be seen in Figure 4, where curves for various values of m and inductance values corresponding to the flatness condition are shown. For values of m less than ⅓, the gain decreases continually with increasing frequency, while for values greater than ⅓ the gain increases before it finally drops off at cutoff.

When it is desired to maintain the gain uniform over the band with a certain tolerance in departure, both above and below the low-frequency value, the value of required inductance is not readily expressed in terms of m. However, the possibilities can be analyzed on the basis of curves calculated by cut and try to give the maximum band width within the tolerance. If the total capacitance, C, is held constant and the ratio, m, varied, the following results are obtained when the inductance, L, is adjusted in each case for that maximum band.

From the condition of zero capacitance at the terminated end ($m = 0$), the usable band width for a given tolerance increases with increasing values of m until a value of m of ⅓ is reached. Up to this ratio no sag occurs in the frequency characteristic.

Beyond this value of ⅓ a sag in the curve will in general occur, and the usable band width continues to increase if the tolerance requirements on gain are chosen sufficiently large. Thus, as shown in Figure 5, for ±0.1 db tolerance in a single stage, a ratio of ½ gives a band width about 1⅓ times that for $m = 1/3$. For ±0.5 db tolerance a ratio of ⅔ gives about 1½ times, and a ratio of ½ gives about 1¼ times the band width[3] obtained for a ratio of ⅓. For ±0.1 db, however, a ratio of ⅔ has a band width only about 0.8 that for a ratio of ⅓.

Since, in multiple-stage amplifiers, the irregularities are multiplied by the number of stages, the tolerances must be reasonably small for a single stage. Thus a ratio greater than ½ may be undesirable unless additional means are used for compensating for the irregularities.

—Arnold Peterson

[2] V. D. Landon, "Cascade Amplifiers with Maximal Flatness," *RCA Review*, Vol. 5, No. 3, January, 1941, pp. 347–362, and Vol. 5, No. 4, April, 1941, pp. 481–498.

[3] No significant increase in band width for $m = 1/2$ is obtained for the ±0.5 db tolerance by altering the inductance from the 0.68 R^2C value shown in Figure 5.

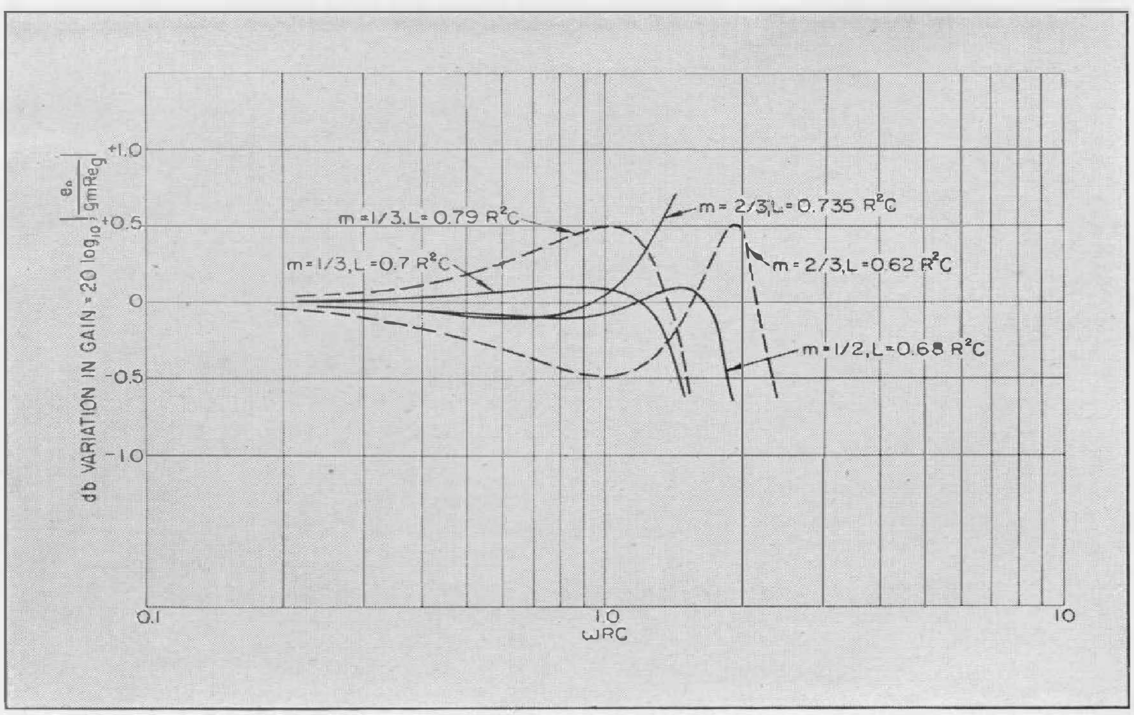

Figure 5. Gain characteristic of a single stage with L adjusted to give the maximum band within a flatness tolerance of ±0.1 db (solid-line curves) and ±0.5 db (dashed-line curves).

DYNAMIC BALANCING IN THE FIELD WITH THE AID OF A STROBOSCOPE

● **THE PROBLEM WAS** to balance a 2500 kw, 3600 rmp steam turbine. The usual field method of shifting balance weights and taking vibrometer readings on each setting was ineffective as the coasting and acceleration time of the machine was quite long. Furthermore, there was a kink in the shaft that threw in a couple that was hard to neutralize.

The erector on the job did not know where the high spot on the shaft was or which way the unbalance force moved when the shaft went through the critical and the kink threw out. Some sort of stroboscope was needed to spot this motion.

Available was a General Radio Strobotac, built so the bulb could be fired from a variably tuned firing circuit calibrated in rpm, or from a set of external contacts. This was rigged up to fire on the external contacts by making a contact that was mounted on the bearing cap. As indicated in the drawing below, a ¼″ bolt with SAE threads, a piece of sheet metal bent into an angle, and a piece of Micarta form an insulating mount.

The bolt was ground to a needle point and set to run on a machined part of the shaft just outside the bearing. The other wire from the contactor was wrapped around an ice pick and held in the center of the shaft. Numbers were painted on the shaft and the machine brought up to the critical point. The adjustable contact screwed down until the bulb started firing. The machine was then run through the critical and the shift of the high spot observed. The minimum shaft shake in the bearings was .003″ and the contacts fired the strobotac satisfactorily on .002″ separation.

Later this rig was used to check dynamic balance on a high-speed armature from a 25 kw exciter by mounting two bearings on a frame of wood scantlings and driving the armature with a light belt from a 20″ diameter by 4″ face wood pulley, chucked up in an air drill for variable speed. Checking the deflection of the scantling mount with a dial gage and weights, and then calibrating the contact, made it possible to calculate the balance weight required with fewer balancing shots.

This trick is simply a mock-up of a dynamic balancing machine, built in the field around an instrument commonly available.

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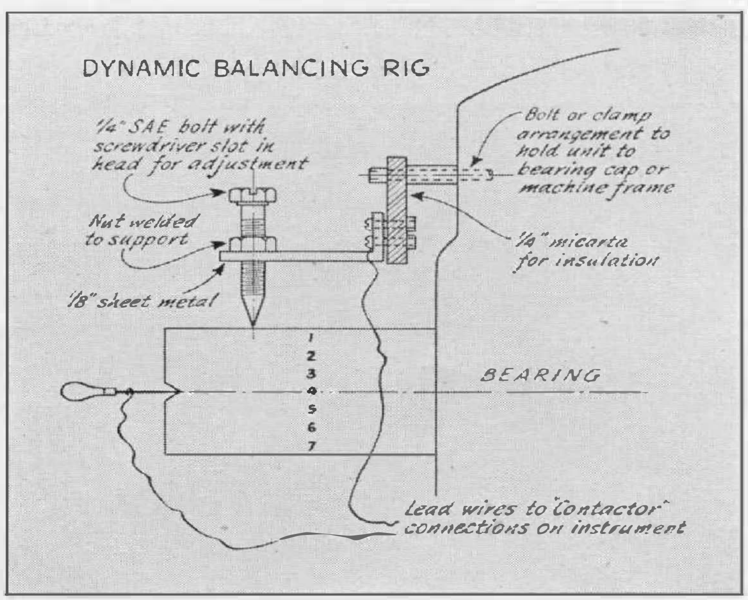
Figure 1. Diagram of arrangement and connections for dynamic balancing with the Strobotac.



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THE USE OF VARIACS* AT VOLTAGES ABOVE 230

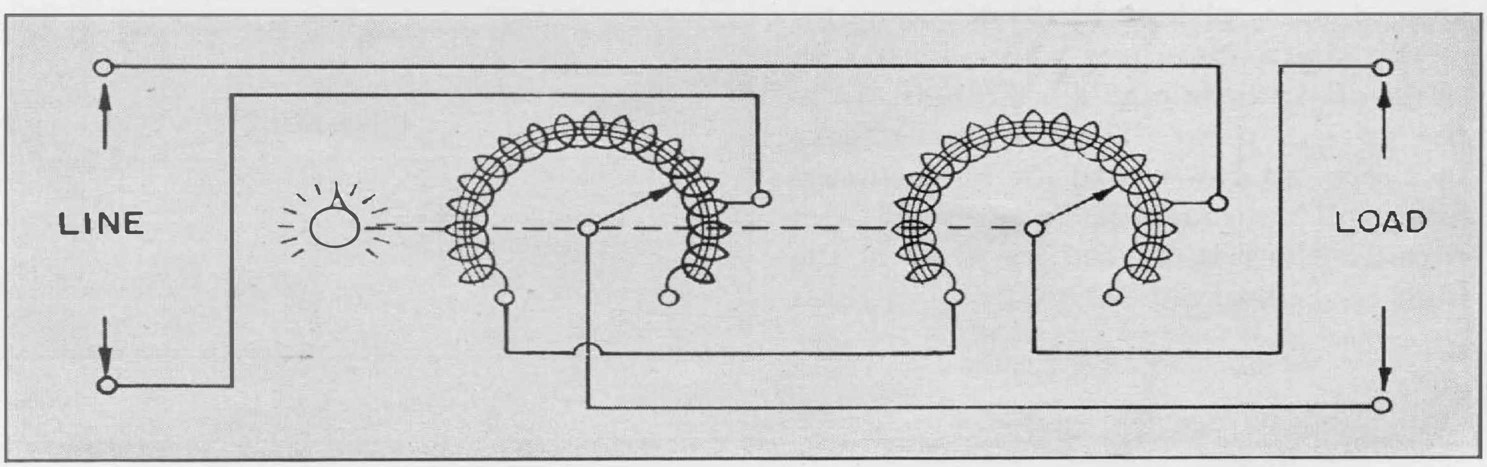
● **THE NORMAL OPERATING POTENTIAL** of TYPES 200-CUH, 200-CMH, 100-R, and 50-B Variacs is 0 to 270 volts when operated from a 230-volt, 50- or 60-cycle source, or 0 to 135 volts when operated from a 115-volt, 25-cycle source. However, it is sometimes desirable to operate equipment at a higher voltage, and, while such applications are too infrequent to justify production units, it is possible to extend the voltage range considerably by proper connections of existing units.

This extension of voltage range is made possible by the use of ganged units similar to, but differing slightly in connections from, the two ganged units normally supplied for open-delta, three-phase operation. Figure 1 illustrates this connection. When so connected the following ratings apply:

Variac Assembly	200-CUHG2	100-RG2	50-BG2
Input Volts { 50–60 cycles 25 cycles	460 230	460 230	460 230
Output Volts { 50–60 cycles 25 cycles } zero to	540 270	540 270	540 270
Rated Current, amperes	2	9	20
Maximum Current, amperes	2.5	9	31
KVA at Input Volts { 50–60 cycles 25 cycles	1.15 .575	4.14 2.07	14.26 7.13
KVA at Max. Volts { 50–60 cycles 25 cycles	1.08 .54	4.86 3.43	10.8 5.4
Net Weight, pounds	17¼	59	175
Price	$44.50	$85.00	$225.00

*Trade mark registered in U. S. A. Variacs are manufactured and sold under U. S. Patent No. 2,009,013.

FIGURE 1. Diagram of connections for high-voltage operation of a 2-gang Variac.



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MISCELLANY

● **MOST OF YOU WILL AGREE,** we think, that General Radio gives rapid service on repair work, particularly for war plants, to whom every minute of delay means a slowing down of production. Recently, however, a repair job went through our plant so fast that it left us gasping.

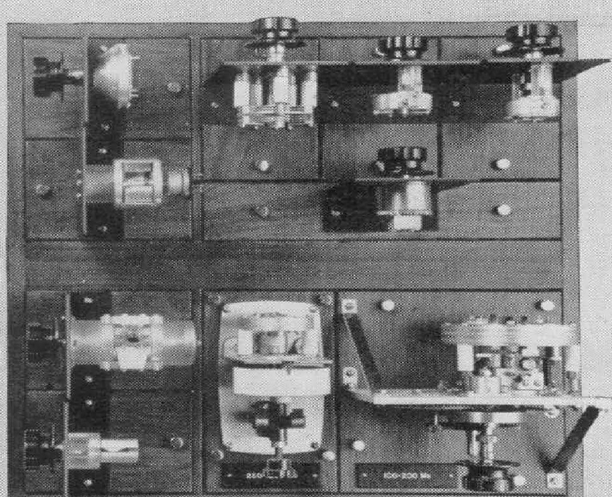
A Midwest radio manufacturer engaged in producing vital military radio equipment called us by telephone. His General Radio signal generator — a specially designed u-h-f model — had been in continuous use for over a year and was badly in need of repair and recalibration. Time was important — Army trucks were waiting outside his plant to take his products away as fast as they came off the production line. Could we do it? We could.

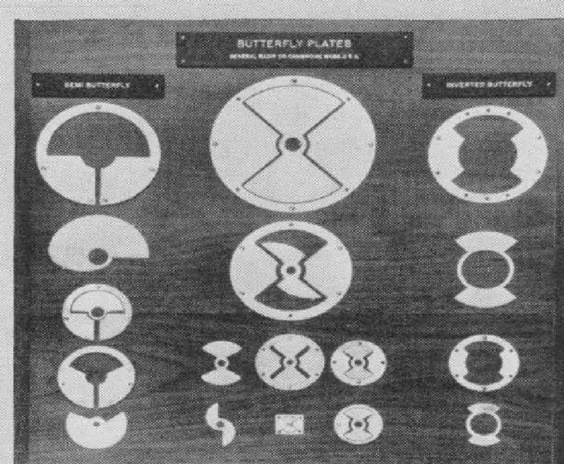
Tucking the generator under his arm, one of the manufacturer's engineers took a plane to Boston late that afternoon. At eight o'clock the next morning he was at our door. Our repair department and our standardizing laboratory went to work on the generator immediately and finished the job by late afternoon. Another plane ride and the generator was back in service the next day.

One of the things that keeps life interesting in our Service Department is the unexpected problem that turns up now and then. The latest of these concerns some output power meters rejected by the customer on the ground that some of the ranges were inoperative. The customer, we found, had drilled holes in the panel to attach his own name plates. Unfortunately he drilled right through the input transformers!

At a meeting of the Boston Section of the Institute of Radio Engineers, held January, 1945, Eduard Karplus of the General Radio Engineering Staff discussed Ultra-High Frequency Oscillators.

Mr. Karplus' paper covered the use in oscillators of the new butterfly circuits (*Experimenter*, October, 1944) as well as some newer types on which data have not yet been published. Display boards showing both butterfly plates and complete circuits were exhibited. These displays, which are shown in the accompanying photographs, were also on exhibition at the General Radio booth at the I.R.E. Winter Technical Meeting held in New York in January.





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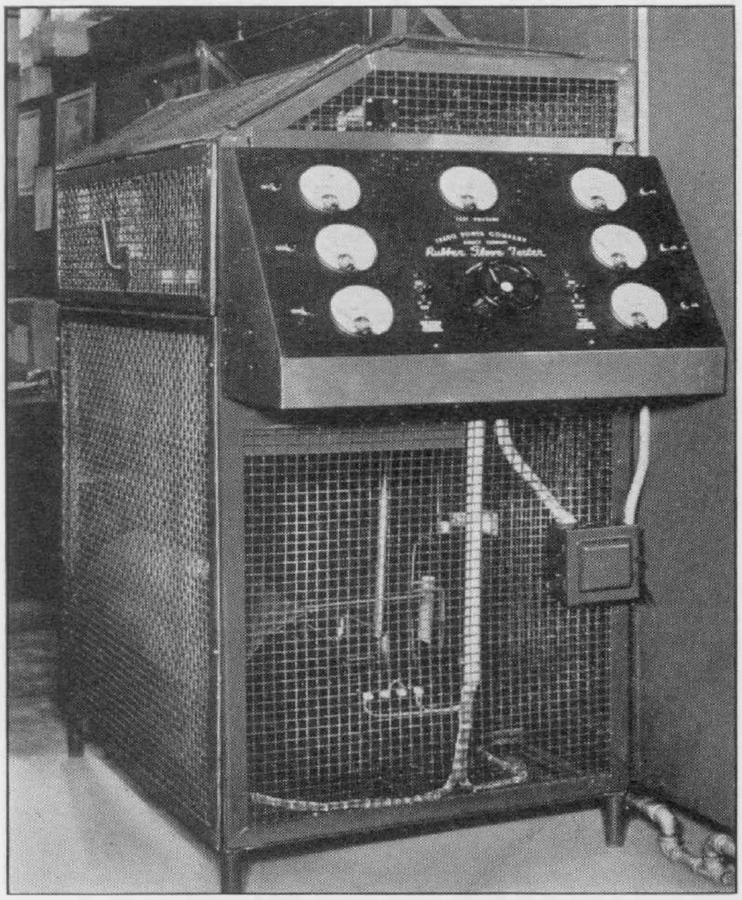

FIGURE 1. View of the rubber glove tester used by Idaho Power Company.

RUBBER GLOVE TESTER USES VARIAC

● **WHEREVER RECTIFIER POWER** supplies are used, the Variac provides a convenient method of adjusting voltage. The accompanying illustration shows a rubber glove tester designed by Mr. Leonard G. Walker of the Idaho Power Company. A Type 100-R Variac is used to vary the 240-volt a-c input to the plate supply transformer of the 15000-volt, d-c power supply. By means of the Variac, voltage is built up at the proper rate during the test cycle. Six gloves are tested simultaneously with this equipment. When a glove fails, voltage is reduced to the point where the overload relays do not trip, and the shorted unit is identified from the leakage current indicated by the corresponding milliammeter.

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GENERAL RADIO COMPANY
275 MASSACHUSETTS AVENUE
CAMBRIDGE 39 MASSACHUSETTS
TELEPHONE: TROWBRIDGE 4400

BRANCH ENGINEERING OFFICES

NEW YORK 6, NEW YORK
90 WEST STREET
TEL.—CORTLANDT 7-0850

CHICAGO 5, ILLINOIS
920 SOUTH MICHIGAN AVENUE
TEL.—WABASH 3820

LOS ANGELES 38, CALIFORNIA
1000 NORTH SEWARD STREET
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