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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also IN THIS ISSUE

CONNECTION ERRORS IN CAPACITANCE MEASUREMENTS

● **WHEN A CONDENSER** 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 condenser alone. Even when one condenser 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 condensers 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 $\frac{3}{4}$ of an inch apart (standard General Radio spacing). The wire should be bare to eliminate both the extra capacitance intro-

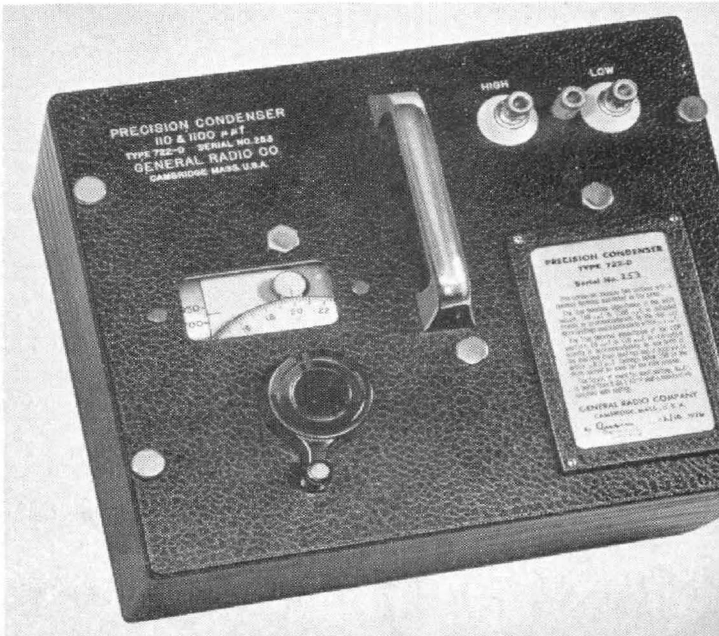


Figure 1. The accuracy to which the calibration of a Type 722-D Precision Condenser (shown at right) can be specified depends to a considerable degree upon the errors discussed in this article

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 condensers 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 $\mu\mu$f, 1.07 $\mu\mu$f, and 0.79 $\mu\mu$f, 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 $\mu\mu$f. This is certainly not negligible when measuring capacitances of 1000 $\mu\mu$f or smaller.

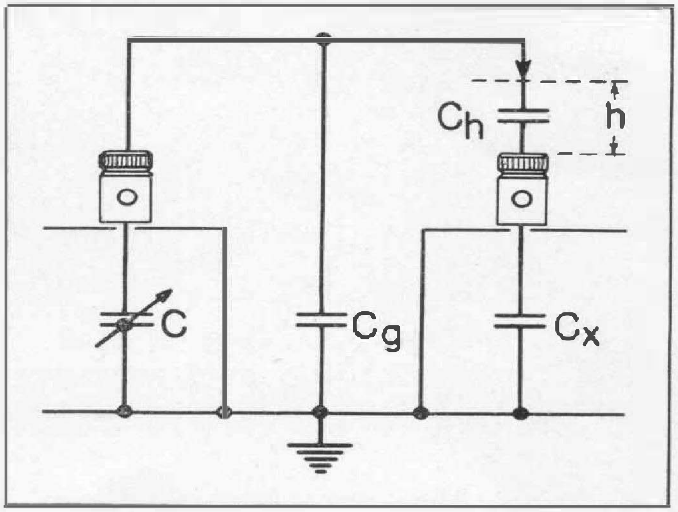


FIGURE 3. The stray capacitances C_g and C_h produce errors in the measurement of the unknown condenser C_x

It should then be sufficient, when connecting two condensers in parallel, to add the capacitance of the added condenser 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 condenser. It is, therefore, usual in substitution measurements to keep the leads connected to the standard condenser 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 ap-

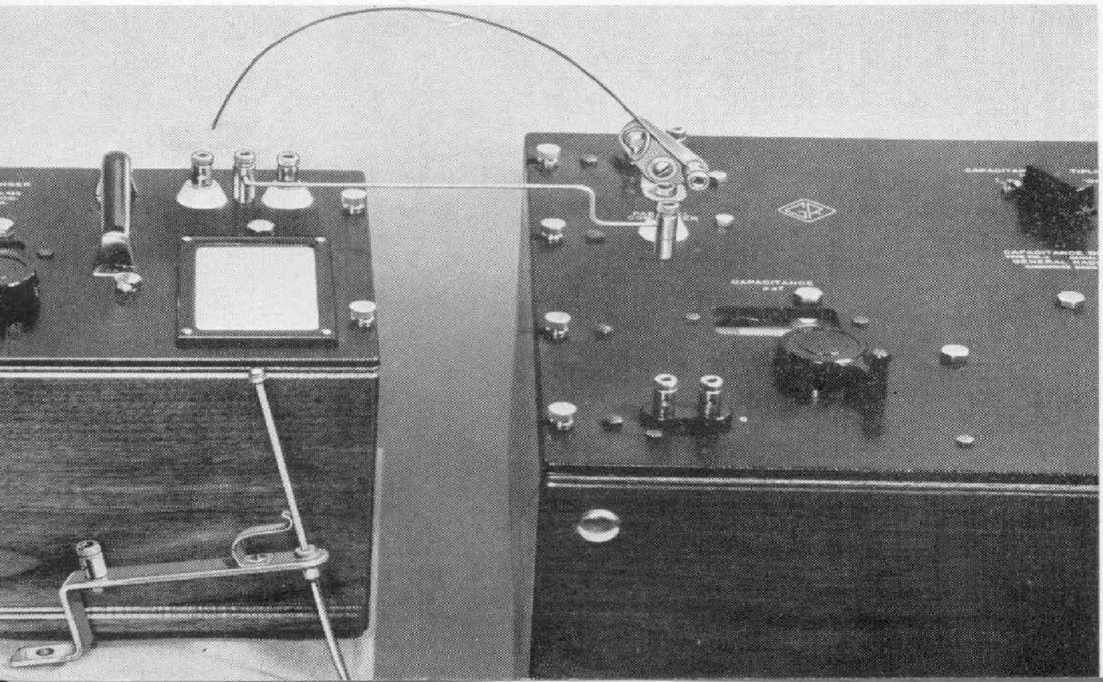


FIGURE 2. This fine wire connector, by means of which Curve *A* of FIGURE 5 was obtained, is used in calibrating all precision condensers in our laboratories. An older type of connector is shown leaning against the condenser cabinet, and produces a much greater error as shown in Curve *B* of FIGURE 5

paratus is shown in Figure 2. Having made a sufficient measurement, such as balancing a bridge, for this condition, the unknown condenser 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 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 condenser 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 horizontal 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 condenser. 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 to within ±0.01 μμf. Curve *B* was obtained using the connector which is shown leaning against

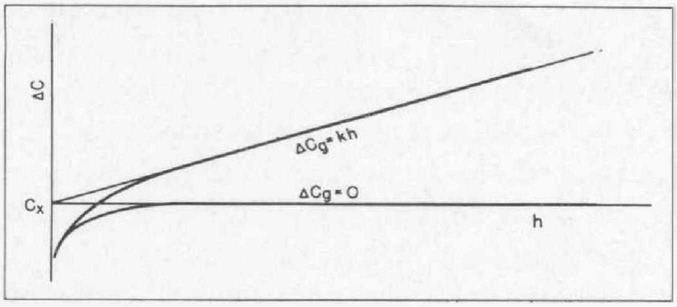


FIGURE 4. Theoretically, the measured capacitance of an air condenser plotted as a function of the distance *h* shown in FIGURE 3 has either a horizontal or a vertical asymptote

the precision condenser. 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 condenser was next depressed 5 inches and 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 condensers are removed and then reassembled. Different types of condensers, 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.

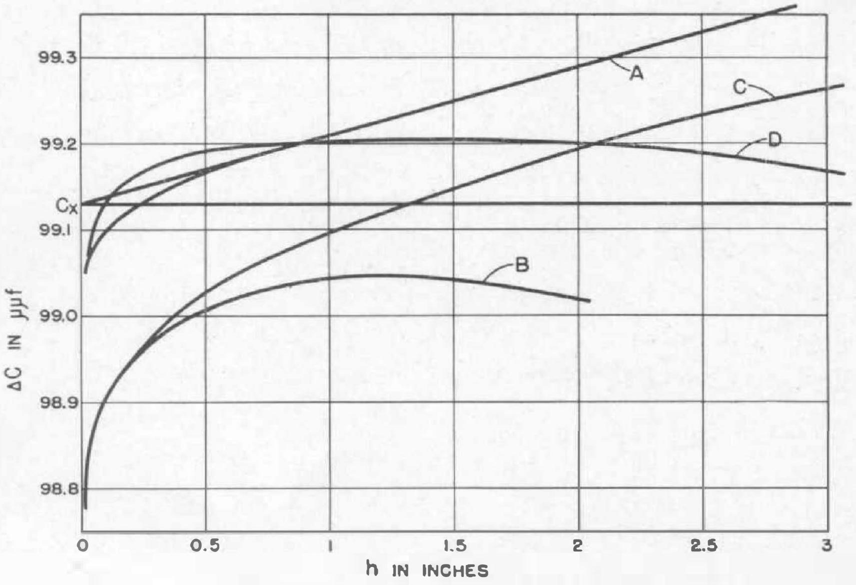


Figure 5. Different types and arrangements of connectors produce differently shaped plots of measured capacitance against the distance h. Curve A, taken with the fine wire connector of **Figure 2**, is the only one of the four curves which has a well-defined asymptote

There are, of course, many ways of connecting condensers 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. There is a decrease in capacitance amounting to about 0.3 μμf when similar units are placed below and above. These condensers are, therefore, most accurately measured by using two dummy cases between which they are always placed. The error of measurement is ±0.01 μμf.

When the power factor of a condenser, 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 condenser varies inversely both as the capacitance and as the frequency. Even at a frequency of 1 kilocycle the resistance of a 1 μf condenser 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 condenser is provided with a third terminal connected to guard electrodes or to the shield from which the main terminals of the condenser 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

A VISUAL BALANCE INDICATOR FOR A-C BRIDGE MEASUREMENTS

● **THE PRECISION OF BALANCE** of a-c bridges is a direct function of the sensitivity of the null indicator. At a frequency of 1000 cycles, where most electrical communications measurements are made, magnetic head telephones, by virtue of their mechanical resonance, have adequate sensitivity when used with an amplifier. For commercial power frequencies and for the higher audio range, however, headphones are not suitable, being limited by their own lack of sensitivity as well as that of the ear. For these frequencies, a visual indicator is desirable.

The copper-oxide-rectifier meter in conjunction with an amplifier provides adequate sensitivity and is convenient to use. To facilitate the use of this visual indicator, the Type 814-AR Amplifier (a relay-rack model) is provided with space for mounting a standard-size meter. This amplifier, in conjunction with a copper-oxide meter, is an excellent detector for 60-cycle measurements.

The meter, mounted on the amplifier panel, is shown in Figure 1. Space behind the meter is used for batteries.

This meter is also used in the Type 483-F Output Meter*. Its impedance is 20,000 ohms and its frequency characteristic is considerably better than any previously obtainable. Two volts are required for full-scale deflection, and the smallest scale division is 0.1 volt. A deflection of one-quarter division, or 0.025 volt, is easily detected.

About 4 microvolts applied to the amplifier input will give this deflection on the meter. With 10 volts applied to the Type 716-A Capacitance Bridge, this means that capacitance and power factor can be balanced to a few millionths.

The sensitivity of the meter is essentially constant up to 10 kilocycles and about equivalent to that of head telephones at 10 kilocycles and 100 cycles. Head telephones at low frequencies, however, tend to emphasize harmonics because of mechanical resonance effects, and, at frequencies as low as 60 cycles, there is always the possibility that the ear will re-combine harmonics to produce the fundamental.

**Experimenter*, June, 1937.

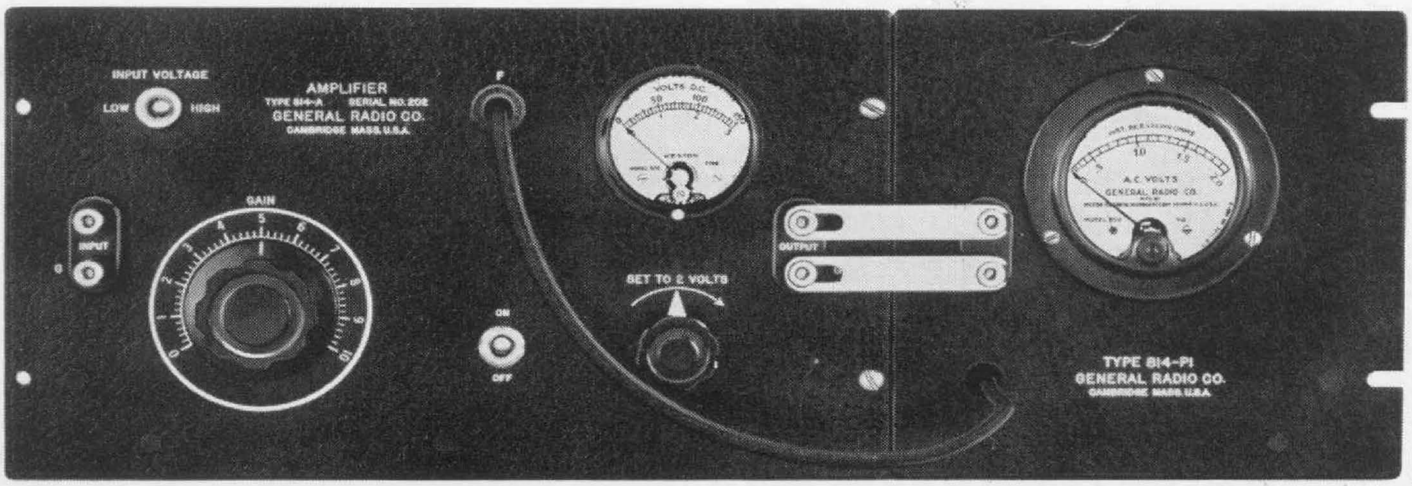


FIGURE 1. The TYPE 814-AR Amplifier with meter and filter. The filter can be mounted at the rear of the instrument, and is connected to the panel jack through a hole in the panel

Sharpness of balance with either meter or headphones is greatly increased by the use of a filter to exclude harmonics. Type 814-P Tuned Circuits* have been designed for this purpose and can be connected in the grid circuit of the last amplifier tube by plugging into a jack on the amplifier panel. These circuits are stocked in two models, one operating at 1000 cycles and 400 cycles, and the other tuned to 60 cycles. Other single-frequency and multiple-frequency units can be built to order.

**Experimenter*, March, 1937.

Type	*Description*	*Code Word*	*Price*
814-AR	Amplifier	ALONE	$97.50
814-P2	Tuned Circuit — 400 and 1000 cycles	AMBLE	17.50
814-P3	Tuned Circuit — 60 cycles	AMPLE	12.00
488-D1	Rectifier Meter	OURMETSEAT	30.00

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

SHIELDED TRANSFORMERS FOR BALANCED CIRCUIT MEASUREMENTS

● **ONE OF OUR RECENT** routine measurement problems required a balanced power source at several hundred kilocycles. To obtain this, a shielded transformer operating at these frequencies was necessary. Type 578 Transformers were tried, and proved to be excellent for the purpose. These transformers were originally designed for use with impedance bridges and were described in the *Experimenter* for April, 1934 and October, 1935.

Two shields are used on the Type 578 Transformer so that it can be used in either direction. The shields completely surround each winding and make the terminal capacitances equal. This double shielding also reduces the magnitude of the terminal capacitances, which is desirable for work at high frequencies in order to avoid too great a shunting effect on the secondary load impedances.

Figure 2 shows the Type 578 Transformer as the coupling device between an unbalanced and a balanced system. The capacitances which must be equal (or of negligible magnitude) are C_1 and C_2. Each of these consists of the terminal capacitance of the winding to shield in series with one-half the shield-to-shield capacitance. The magnitude of C_1 and C_2 is about 40 $\mu\mu f$ each and they do not differ by more than 3 $\mu\mu f$.

Figure 1.
The Type 578 Transformer

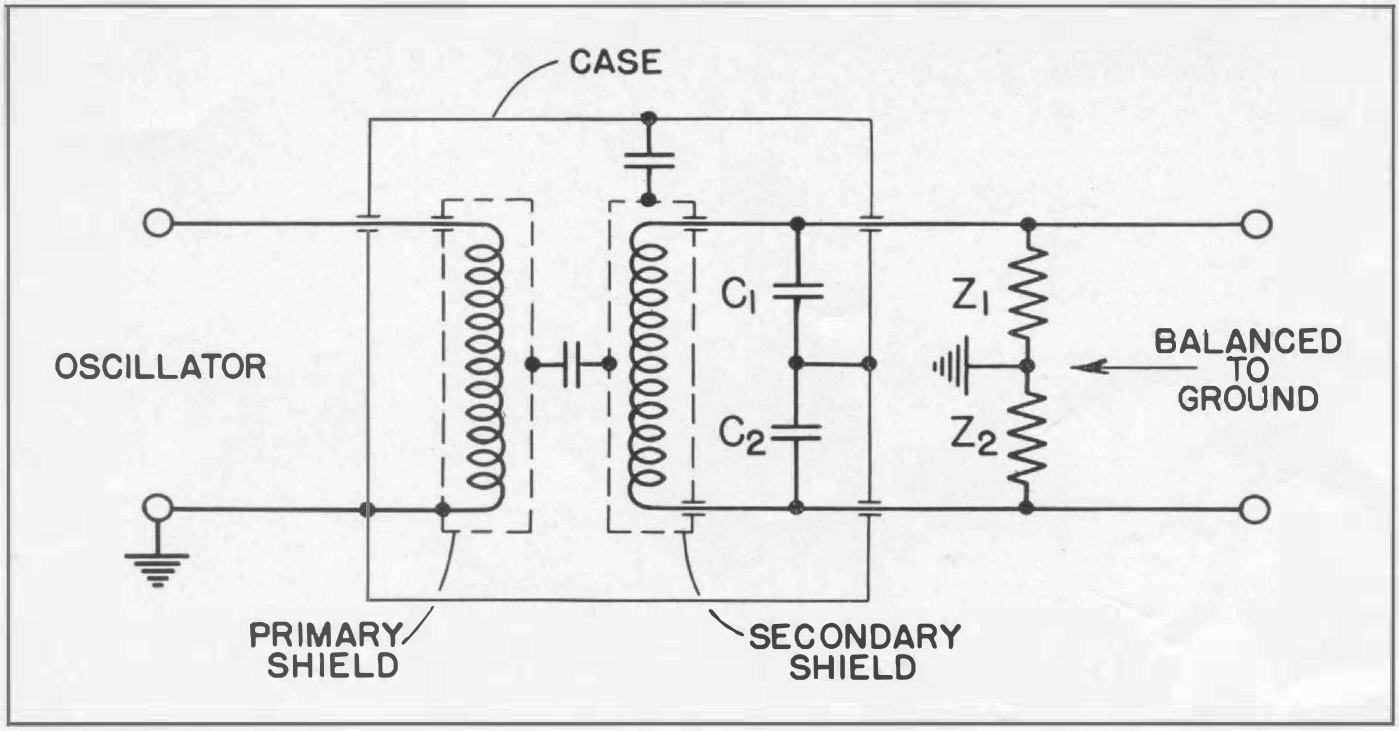


FIGURE 2. This diagram shows the shielding arrangement and the capacitances which are associated with each terminal. For the connection shown, C_1 and C_2 are about 40 $\mu\mu$f each. Note that the transformer windings are not center-tapped

With Z_1 and Z_2 each equal to 3000 ohms resistive, the unbalance caused by the maximum inequality of transformer terminal capacitances is, at 0.5 megacycle, about 1.5% in impedance and 2° in phase. At lower frequencies and with lower values of Z_1 and Z_2, the unbalance is, of course, correspondingly less. At audio and low radio frequencies and with 500-ohm circuits, little, if any, unbalance will be noticed.

When the transformer is used to obtain a balanced source for measurements of gain or attenuation, the magnitude of Z_1 and Z_2 is not important since the voltages across them are usually held constant to simulate a zero-impedance generator.

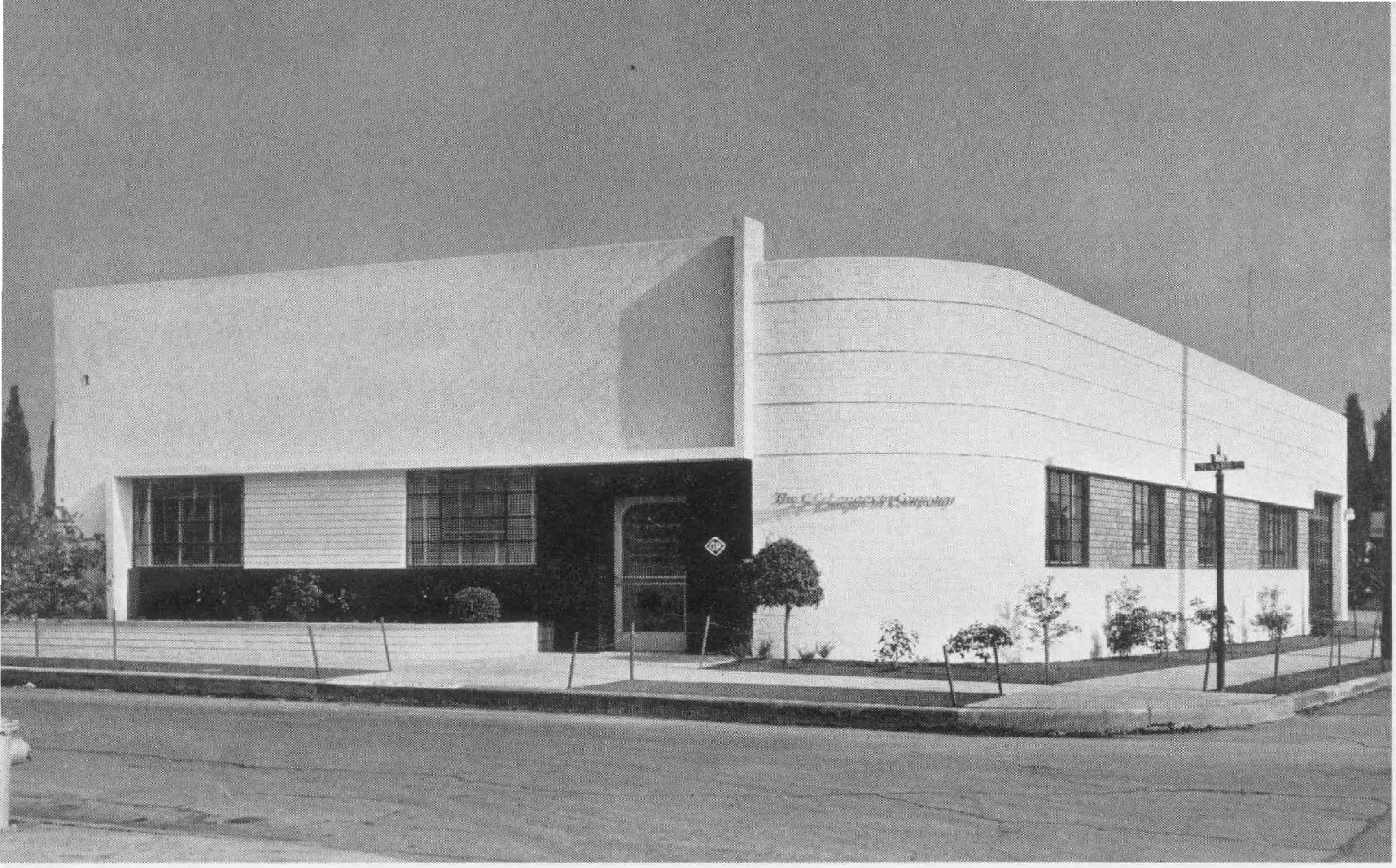
When a vacuum-tube voltmeter is used to measure equal voltages across Z_1 and Z_2, even order harmonics in the voltage wave can produce unequal voltage readings if the voltmeter is not a true square-law device. To avoid this, it is desirable to use a filter between generator and transformer.

Three models of this transformer are available, covering an effective frequency range of 20 cycles to 0.5 megacycle. — W. G. WEBSTER

Type	Frequency Range*	Impedance Range* Primary	Impedance Range* Secondary†	Code Word	Price
578-A	50 cycles to 10 kc	50 Ω to 5 KΩ	1 KΩ to 100 KΩ	TABLE	$15.00
578-B	20 cycles to 5 kc	60 Ω to 6 KΩ	1 KΩ to 120 KΩ	TENOR	15.00
578-C	2 kc to 500 kc	20 Ω to 2 KΩ	4 KΩ to 40 KΩ	TEPID	15.00

*Range for voltage transfer within 6 db of maximum value. At extreme ends of both impedance and frequency ranges, the combined loss may be 12 db.

†The low impedance winding is considered to be the primary.



Of modern architecture in keeping with its general surroundings is our new Hollywood office at 1000 North Seward Street. We share the occupancy of this building with the C. C. Langevin Company, who for nearly a decade and a half have represented us on the Pacific Coast. The specialization of the Langevin organization in sound work and the diversification of our own activities made separation of the two organizations advisable. The pangs of parting were greatly softened by the arrangement which makes Mr. Langevin our genial landlord.

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GENERAL RADIO COMPANY
30 STATE STREET - CAMBRIDGE A, MASSACHUSETTS

BRANCH ENGINEERING OFFICES
90 WEST STREET, NEW YORK CITY
1000 NORTH SEWARD STREET, LOS ANGELES, CALIFORNIA

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