

Also IN THIS ISSUE

	Page
A VISUAL BALANCE INDICATOR FOR A-C BRIDGE MEASUREMENTS	5
SHIELDED TRANSFORMERS FOR BALANCED CIRCUIT MEASUREMENTS	6

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 $0.22 \mu\mu\text{f}$, $1.07 \mu\mu\text{f}$, and $0.79 \mu\mu\text{f}$, 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 $1.19 \mu\mu\text{f}$. This is certainly not negligible when measuring capacitances of $1000 \mu\mu\text{f}$ or smaller.

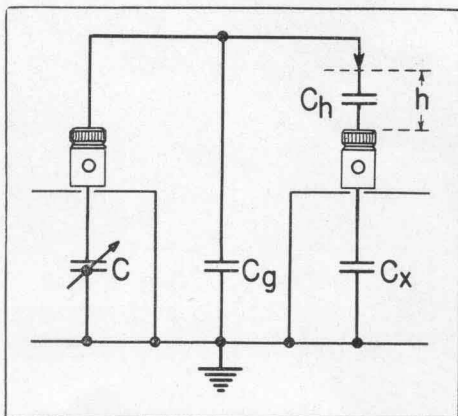


FIGURE 3. The stray capacitances C_g and C_h produce errors in the measurement of the unknown condenser C_x

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-

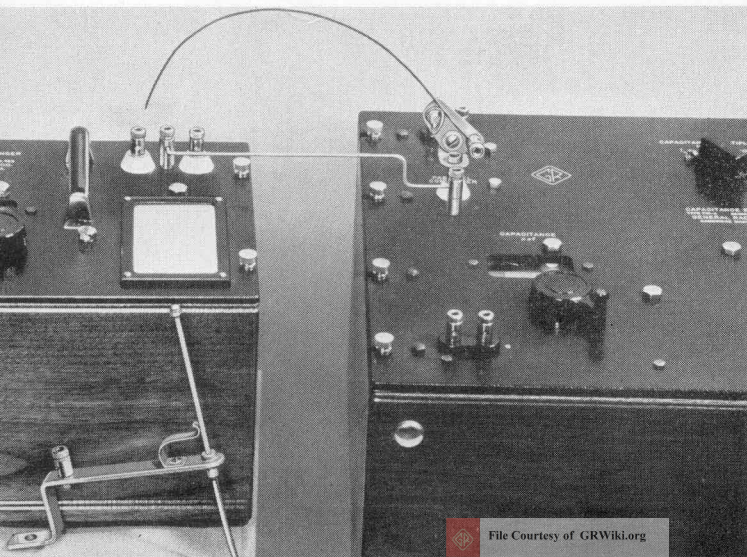


FIGURE 2. This fine wire connector, by means of which Curve A of FIGURE 5 was obtained, is used in calibrating all precision condensers in our laboratories. An older type of connector is shown leaning against the condenser cabinet, and produces a much greater error as shown in Curve B of FIGURE 5

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

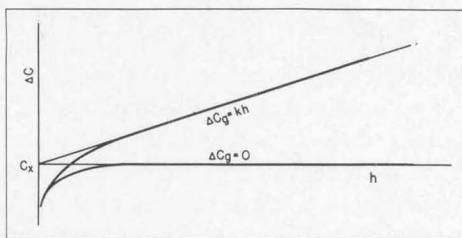


FIGURE 4. Theoretically, the measured capacitance of an air condenser plotted as a function of the distance h shown in FIGURE 3 has either a horizontal or a vertical asymptote

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 $99.13 \mu\mu\text{f}$ for the capacitance of the unknown condenser. The curve has this value for a separation h of $\frac{1}{4}$ inch. Hence, with this connector and a $\frac{1}{4}$ -inch separation, it should be possible to measure capacitance to within $\pm 0.01 \mu\mu\text{f}$. Curve *B* was obtained using the connector which is shown leaning against

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 $1\frac{3}{8}$ 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 $\frac{1}{4}$ 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 $0.01 \mu\mu\text{f}$ and to $0.02 \mu\mu\text{f}$ 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 $0.1 \mu\mu\text{f}$ is at present set as a conservative error.

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 $0.5 \mu\mu\text{f}$. There is a decrease in capacitance amounting to about $0.3 \mu\mu\text{f}$ 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 $\pm 0.01 \mu\mu\text{f}$.

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 $1 \mu\text{f}$ 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

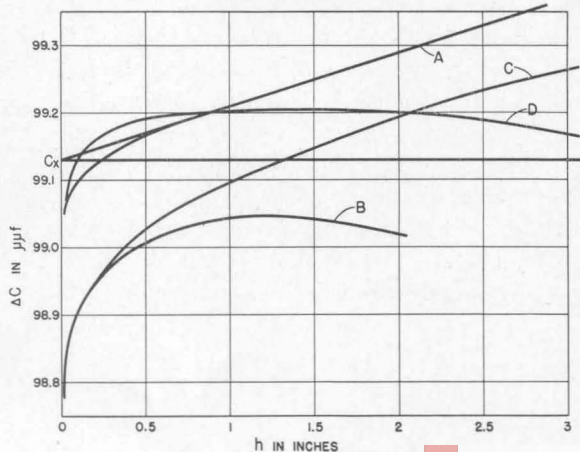


FIGURE 5. Different types and arrangements of connectors produce differently shaped plots of measured capacitance against the distance h . Curve A, taken with the fine wire connector of FIGURE 2, is the only one of the four curves which has a well-defined asymptote