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ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

SHIELDED TRANSFORMERS FOR IMPEDANCE BRIDGES

WHEN making direct impedance measurements with any kind of bridge, a shielded transformer is ordinarily used to connect either the generator or the detector to the bridge. The purpose of the transformer is to reduce or eliminate the errors in measurement which result from stray impedances between the terminals of the generator (or the detector) and ground. Although in the substitution method these errors generally cancel out of the simple bridge equations, it is desirable to make them as small as possible in order to minimize second order effects. Another less important use is the matching of impedances between the bridge and the external circuits to obtain maximum power transfer.

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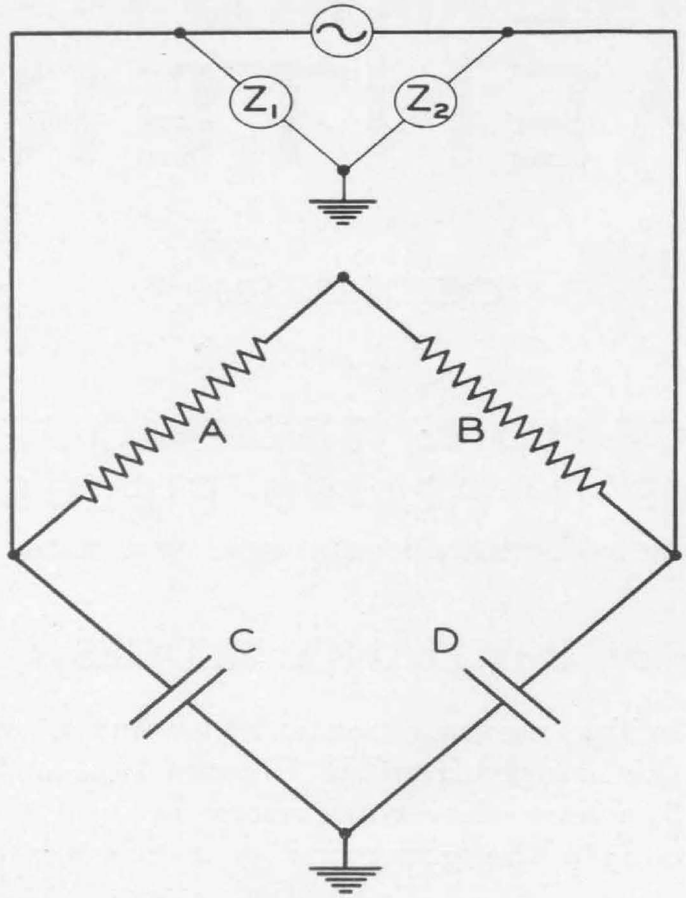
To illustrate the general application of shielded transformers in bridge measurements, let us consider the bridge circuit of Figures 1, 2, and 3, where the transformer is used to couple the generator to a grounded bridge. Figure 1 shows the generator connected directly to the bridge. Under this condition, the terminal impedances (Z_1 and Z_2) of the generator to ground are placed directly across the bridge arms *C* and *D*. These impedances are usually capacitive and have an extremely poor power factor. The resulting error in measurements of capacitance and power factor is large, since these terminal capacitances amount to several hundred micromicrofarads when an a-c operated oscillator is used, and, in addition, they are seldom balanced to ground.

The shielded transformer of Figure 2 completely eliminates these generator impedances but substitutes



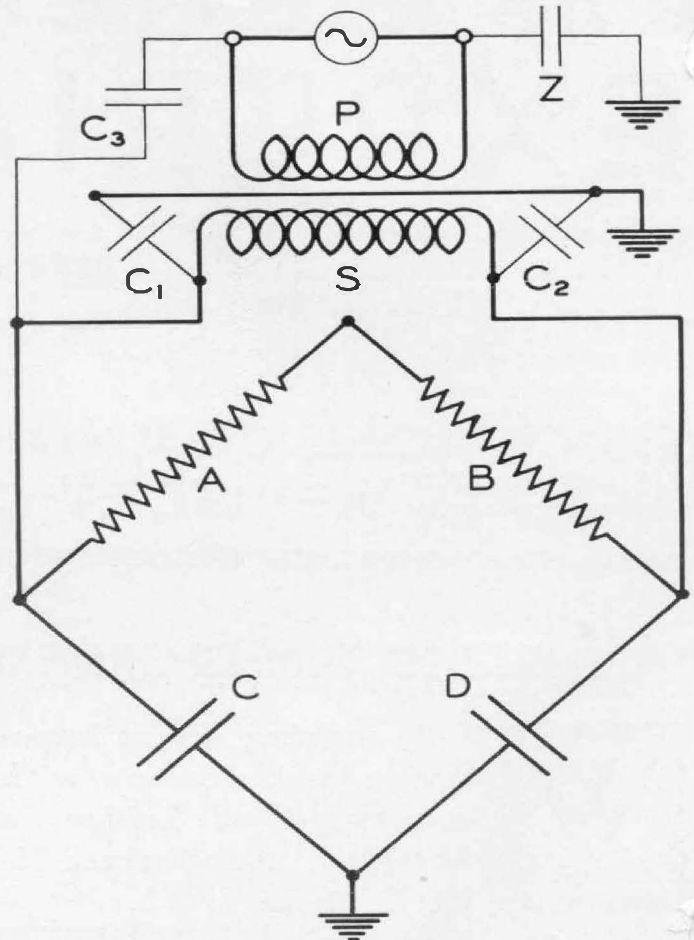


FIGURE 1 (left). Schematic circuit of a grounded bridge supplied by a generator having two unequal terminal impedances to ground

FIGURE 2 (right). Schematic diagram showing the use of a singly-shielded transformer between generator and bridge. The impedance Z represents the equivalent terminal impedance between one side of the generator and ground. For convenience in analyzing the problem, this impedance is assumed to be associated entirely with one generator terminal

in their place the terminal capacitances C_1 and C_2 of the secondary winding of the transformer to the shield. While these capacitances can be made equal, they are usually quite large, amounting to several hundred micromicrofarads and, for this reason, the singly-shielded transformer is seldom used. For equal-arm bridges the resulting error is negligible only if the terminal capacitances are equal and, in unequal-arm bridges, only when their ratio is the same as that of the ratio arms. Since it is impossible to vary the ratio of terminal capacitances as the ratio arms are changed, a doubly-shielded transformer offers the best solution to the problem.

An additional error is introduced by the presence of the capacitance C_3 between primary and secondary windings. If C_3 is appreciable compared with the impedance in the bridge arm C, a fraction of the generator voltage is applied across this arm, proportional to the ratio $\frac{C_3}{C}$, since the impedance of the power source to ground is usually much smaller than that of C_3.

Figure 3 shows the doubly-shielded transformer connected to a bridge.

Here the bridge is isolated from the load by the series combination C_5 (or C_6) and C_4 and, if C_4 is made small, the effective terminal capacitance is kept at a low value.

The requirements for a good doubly-shielded transformer are met by the Type 578 Transformer, originally described in the *Experimenter* for April, 1934.*

This transformer, which is shown schematically in Figure 3, is designed to reduce both the terminal capacitance shown in Figure 1 and the direct capacitance C_3 of Figure 2. When used with a conventional type of impedance bridge, the shield on the generator side is grounded to prevent the to-ground impedance of the generator from introducing errors into the measurement. The terminal capacitances for the winding on the bridge side then consist of C_5 (or C_6) in series with one-half the series-parallel network C_4, C_7, C_8. Each terminal capacitance is then 28 $\mu\mu$f. If the case is grounded, thus short-circuiting C_7, the terminal capacitance is increased to 40 $\mu\mu$f.

These values are sufficiently low, compared to the usual figure of several hundred micromicrofarads, to be negligible when measuring directly large capacitances or when using a substitution method with the bridge. Under other conditions, allowance can be made in the result for any error which they may cause. Since they are equal, their effect is usually negligible in equal-arm bridges.

The capacitance C_3 is only 0.2 $\mu\mu$f. Type 578 Transformers are made

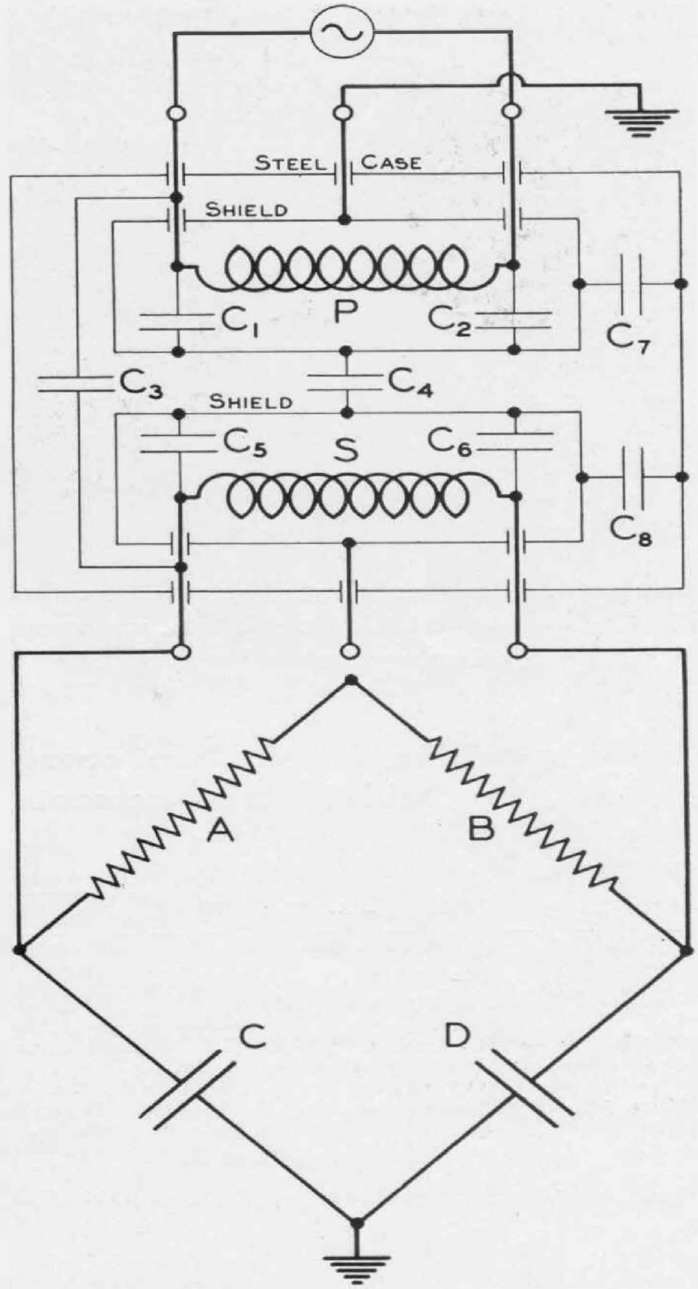


Figure 3. The grounded bridge supplied through a doubly-shielded transformer. Average values of the transformer capacitances for Type 578 Transformer are as follows:

C_1, C_2, C_5, C_6 . . . . each 200 $\mu\mu$f
C_3 . . . . 0.2 $\mu\mu$f
C_7, C_8 . . . . each 70 $\mu\mu$f
C_4 . . . . 30 $\mu\mu$f

in three models covering a total frequency range of from 20 cycles per second to 500 kc. The turns ratio for each model is 4:1, giving an impedance transfer of 16:1. Exact impe-

*R. F. Field, "A Shielded Transformer for Bridge Use," General Radio *Experimenter*, April, 1934.

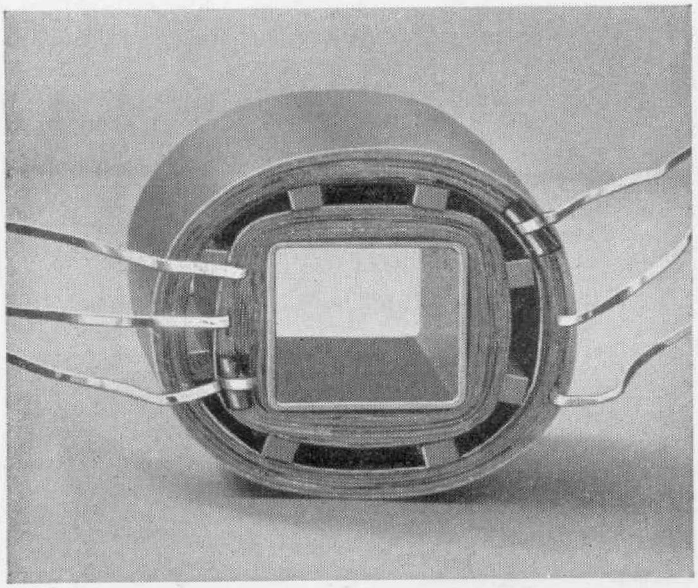


FIGURE 4. The air space between the two individually-shielded windings is the important factor in reducing terminal capacitance

dance matching is of little consequence in bridge measurements, since losses are easily compensated for by increasing either generator power or detector gain. The TYPE 578 Transformers are suitable for all impedance ratios between 1 to 16 and 16 to 1, a sufficiently wide range to cover all ordinary bridge-circuit requirements.

TYPE 578 Transformers can be used with the TYPE 293-A Impedance Bridge and, if mounted on a suitable plug-type base, in the TYPE 516-C Radio-Frequency Bridge. The range of the radio-frequency bridge can in this way be extended down to audio frequencies.

The A- and B-types can be used to step-down the 110-volt, 60-cycle, line voltage to supply a TYPE 650 Impedance Bridge.

Type	*Frequency Range**	*Impedance Range**		*Code Word*	*Price‡*
		Primary†	*Secondary†*		
578-A	50 cycles to 10 kc	50 Ω to 5K Ω	1K Ω to 100K Ω	TABLE	$15.00
578-B	20 cycles to 5 kc	60 Ω to 6K Ω	1K Ω to 120K Ω	TENOR	15.00
578-C	2 kc to 500 kc	20 Ω to 2K Ω	4K Ω to 40K Ω	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.
‡TYPE 578 Transformers mounted on plug-type bases for use in TYPE 516-C Radio-Frequency Bridge can be supplied at an increase of $5.00 over the prices shown.

REACTANCE CHARTS

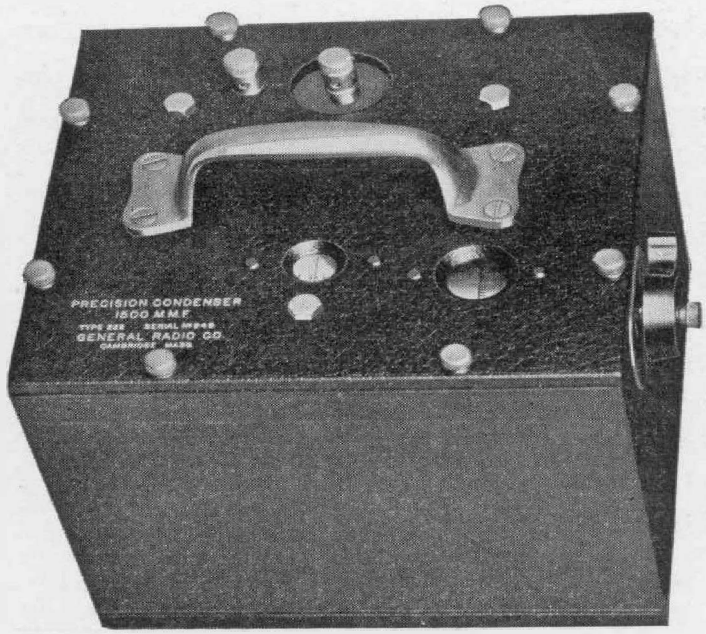
WE have available for distribution a limited number of small-scale reproductions of the reactance chart mentioned in the March, 1935, issue of the *Experimenter*. These are our standard catalog page size, 10 x 6⅝ inches, suitable for use in loose-leaf notebooks. We shall be glad to send copies to any who request them.

INCREASED ACCURACY WITH THE PRECISION CONDENSER

EXTENSIVE investigations of the stability of the TYPE 222 Precision Condenser have shown that the condenser is capable of holding a calibration made with a greater precision than has hitherto been considered feasible. The scale is sufficiently open on all models to permit settings to a considerably greater precision than is necessary for the calibration usually supplied.

The TYPE 222-L Precision Condenser is provided with a worm and 50-tooth gear, so that 25 turns of the worm are required for the 180° of rotation which lie between minimum and maximum capacitance. The drum mounted on the worm shaft has 100 divisions, each of which is about 1/16 inch long. There are then 2500 divisions, into which the capacitance increment may be divided. By estimating tenths of these divisions, the total scale length may be read to one part in 25,000. Over the middle 20 turns of the worm, the capacitance increment per turn is about 60 $\mu\mu$f, so that one worm division equals 0.6 $\mu\mu$f and 0.1 division equals 0.06 $\mu\mu$f.

The calibration chart regularly provided with each condenser gives the capacitance for each turn of the worm to an accuracy of 1 $\mu\mu$f or 0.1%, whichever is the greater. The limit of 1 $\mu\mu$f is set by the lack of a standardized technique in connecting the condenser into a measuring circuit, while the limit of 0.1% is determined by uncertainty in the value of the micromicrofarad. These two limits are equivalent for a capacitance of 1000 $\mu\mu$f. Since the stability of the condenser when carefully



handled is at least one part in 10,000, a calibration to an accuracy of 0.1 $\mu\mu$f or 0.1%, whichever is the greater, is of considerable value because it allows capacitance differences to be measured to an equal accuracy. The fact that the absolute capacitance is known only to 1 $\mu\mu$f is no detriment, because all precise bridge measurements of capacitance are made by a substitution method in which the standard is not disconnected from the circuit.

To realize this accuracy, the setting of the worm must be read to 1/5 of a worm division and the effects of backlash avoided by always approaching a setting from the same direction. Because of a slight eccentricity in the worm itself and minute irregularities in the bearings of the worm shaft, the capacitance change is not exactly linear throughout each turn of the worm. An approximately sinusoidal variation usually appears which, expressed as a capacitance, may amount to a divergence from linearity of 0.3 $\mu\mu$f. This worm variation repeats itself for each turn of the worm throughout the linear capacitance range. It is expressed as a correction which is to be applied to the value of capacitance obtained from the calibration chart by linear interpolation.

As an illustration of the use of such a calibration chart and worm correction, let it be desired to find the capacitance corresponding to a reading of 1646.8 divisions. The calibration chart in the vicinity of this setting reads as follows:

Scale Setting	*Capacitance in $\mu\mu f$*	*Capacitance Increment in $\mu\mu f$*
1400	812.2	59.3
1500	871.5	59.2
1600	930.7	59.2
1700	989.9	59.0
1800	1048.9	

The worm correction is:

Worm Divisions	*Correction in $\mu\mu f$*
0	0
10	—.1
20	—.2
30	—.2
40	—.1
50	—.1
60	0
70	0
80	0
90	0
100	0

The calibration chart gives the capacitance at 1600 divisions as 930.7 $\mu\mu$f, at 1700 divisions as 989.9 $\mu\mu$f, the corresponding capacitance increment as 59.2 $\mu\mu$f, the worm correction at 40 divisions as —0.1 $\mu\mu$f, and at 50 divisions as —0.1 $\mu\mu$f. Linear interpolation gives a value of 958.4 $\mu\mu$f for a given dial setting. Adding the worm correction of —0.1 $\mu\mu$f gives the final capacitance value of 958.3 $\mu\mu$f.

The capacitance calibration obtainable from such a calibration chart is internally consistent to an accuracy of 0.1 $\mu\mu$f or 0.1%, whichever is the greater, hence capacitance differences may be obtained to an accuracy of 0.2 $\mu\mu$f or 0.1%, whichever is the greater.

Similar calibrations may be made on other types of precision condensers with the same limits of accuracy. In the case of the Type 222-M Precision Condenser, which is already adjusted to be direct reading in capacitance difference to 1 $\mu\mu$f, the calibration takes the form of a single correction chart which gives the correction to be applied to the direct reading of the dial at every ten worm divisions.

This calibration to 0.1 $\mu\mu$f may be made at the time of purchase of a new condenser or on any precision condenser returned to our factory. In the latter case, it is advisable to have the bearings of the condenser readjusted before attempting the accurate calibration. The cost of such readjustment is usually between $5.00 and $10.00, dependent upon the amount of work necessary. Condensers made a number of years ago have only a single bearing for the worm shaft. It is not generally advisable to calibrate such condensers to 0.1 $\mu\mu$f because of their inferior stability. The price of the complete calibration for either new or old condensers is $35.00.

—Robert F. Field

RESIDUAL IMPEDANCES IN THE PRECISION CONDENSER

WHEN using a variable air condenser as a capacitance standard at radio frequencies, it is important to know the variation in effective capacitance and power factor as a function of frequency. These variations result from the presence of residual impedance and can, if neglected, cause very appreciable errors in measurements in the radio-frequency range.

The variation in effective capacitance is caused by the inductance of the condenser structure and leads. This inductance is practically constant with frequency and increases the effective capacitance of the condenser by an amount equal to $\omega^2 LC^2$.

Measurements made by means of the TYPE 516-C Radio-Frequency Bridge on TYPE 222 Precision Condensers indicate that the effective inductance of the condenser is approximately 0.06 μh. Figure 1 shows the increase in effective capacitance which this inductance causes at frequencies up to 6 megacycles. The inductance is nearly all in the supports and stator rods of the condenser and does not vary appreciably with dial setting.

At low frequencies the dielectric loss is constant with scale setting for condensers in which the field through the solid dielectric is independent of rotor position. Since the equivalent resistance varies with both frequency and scale setting and the power factor, while constant with frequency, varies with setting, a "figure of merit," $R\omega C^2$, is ordinarily used to express the magnitude of dielectric

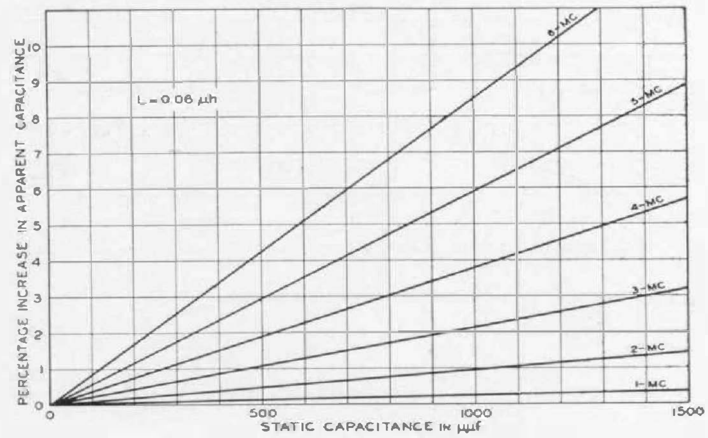


FIGURE 1. Increase in effective capacitance of a precision condenser caused by an equivalent inductance of 0.06 μh

losses. This quantity is constant with both frequency and scale setting.

In addition to the dielectric loss, there is an ohmic loss in the resistance of the metallic structure. At radio frequencies the ohmic resistance may be the controlling factor, since it increases with frequency while the dielectric-loss resistance decreases. This metallic resistance

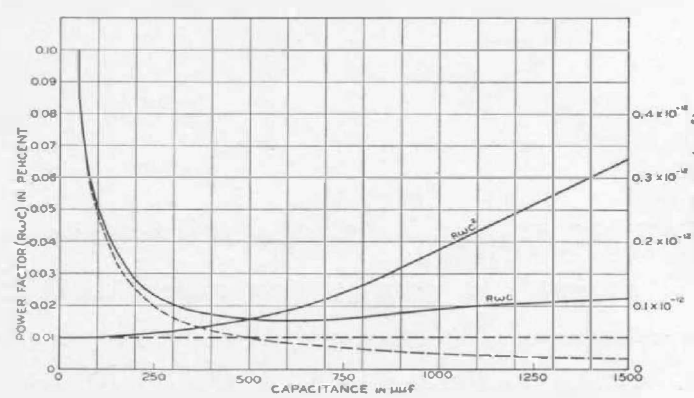


FIGURE 2. Power factor and figure of merit of a precision condenser as a function of capacitance at 1 megacycle. The full line curves are the true values obtained when dielectric loss and ohmic loss are combined. The dotted curves show these quantities when only dielectric loss is considered

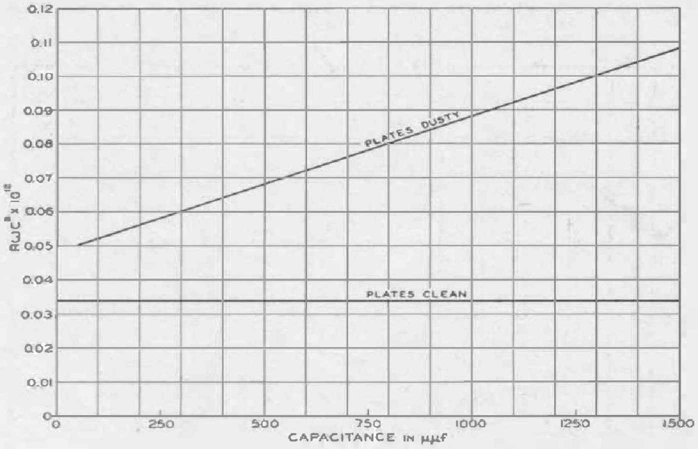


FIGURE 3. The variation in $R\omega C^2$ resulting from an accumulation of dust on the plates. The curve showing the effects of dust does not reach the "plates clean" plot at zero capacitance, because dust was removed from the solid dielectric as well as from the plates

can be measured by means of the radio-frequency bridge and is approximately 0.02 ohms at 1 megacycle. Figure 2 shows the power factor of the condenser and also $R\omega C^2$ plotted as a function of capacitance setting when both losses are combined. As a reference, plots are also given of these quantities when the metallic loss is neglected. An inspection of these curves shows that errors up to 50% may occur if the metallic loss is neglected in the measurement of the power factor of a condenser in the range below power factors of 0.05%, when the parallel substitution is used at radio frequencies. When measuring condensers of small physical size where the capacitance to ground is small, it is often possible to avoid the power factor error by using a series substitution method.

Another residual impedance, not chargeable to the condenser itself, exists if dust accumulates on the plates. The dust coating produces a loss varying with capacitance which is particularly serious when the condenser is used as the standard for measurements by the substitution method. Losses which vary with setting in either the standard or the unknown will yield erroneous results for the loss component of the unknown condenser. Figure 3 shows the variation in $R\omega C^2$ for a TYPE 222 Condenser resulting from dusty plates.

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