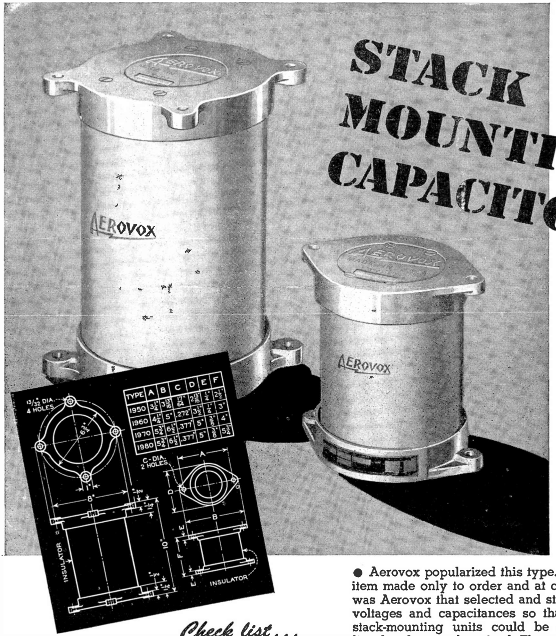
STACK MOUNTING CAPACITORS



TYPE	A	B	C	D	E	F
1950	3 1/4"	3 13/16"	17/64"	2 13/16"	1/4"	2 1/2"
1960	4 1/4"	5"	.272"	3 1/2"	1/4"	3"
1970	5 3/4"	6 1/2"	.377"	5"	3/8"	4"
1980	5 3/4"	6 1/2"	.377"	5"	3/8"	5 3/4"

Check list . . .

- ✓ Low-loss glazed ceramic case for long creepage path between terminals.
- ✓ Corona losses eliminated on inside and outside alike.
- ✓ Cast-aluminum terminal ends for low contact resistance between stacked units.
- ✓ Close-tolerance mica units equalize loading of series-connected sections
- ✓ Mica sections rigidly clamped in low-loss non-magnetic clamps and heat-treated for maximum capacitance-temperature stability.
- ✓ Mechanical design permits units to be stacked and thereby connected in series, parallel and series-parallel. Dummy units are available to support and insulate active units.
- ✓ Units may be bolted together through holes in aluminum caps.
- ✓ Standard listings; normally available without delay; at the right prices.

● Aerovox popularized this type. Originally a *special* item made only to order and at custom-built prices, it was Aerovox that selected and standardized the sizes, voltages and capacitances so that standard Aerovox stack-mounting units could be regularly produced, listed and properly priced. The rest is history.

Especially intended for various transmitting and electronic applications, these heavy-duty micas have found wide usage in military and peaceful applications alike. Such units are especially popular in heavy-duty transmitting applications such as grid, plate blocking, coupling, tank and by-pass functions. Also in carrier-current applications.

Special yesterday, *standard* today, Aerovox stack-mounting mica capacitors have contributed greatly to available quality equipment and outstanding performance.

● Literature on request . . .

AEROVOX Capacitors

INDIVIDUALLY TESTED

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Methods of Testing Solid Dielectrics

PART 2 Electrical Tests

By the Engineering Department, Aerovex Corporation

AFTER a sample plate of solid dielectric material has been prepared according to one of the methods outlined in Part I, tests may be made to determine the electrical characteristics of the material. These characteristics include insulation resistance, low- and high-frequency dielectric constant, low- and high-frequency power factor, Q at one or more radio frequencies, temperature coefficient of capacitance at audio and radio frequencies, temperature coefficient of power factor, temperature vs. current characteristics, and dielectric strength.

In some cases, certain of these tests may be omitted. A complete test program embodying measurement of each characteristic listed above, however, will serve to evaluate the material as a dielectric.

This article will discuss standard methods of measuring dielectric characteristics. While the apparatus and methods employed will be familiar to radio engineers, particularly those engaged in capacitor research and design, a few other investigators, such as physicists, chemists, and ceramists, will be introduced to these techniques for the first time.

INSULATION RESISTANCE

This is a measurement of the actual resistance offered to the passage of direct currents from one electrode plate through a thickness of the dielectric material to the opposite plate. In the test capacitor, this is the parallel resistance component.

Dielectric resistance is of a large order of magnitude. Reasonably high voltages accordingly are employed in its measurement. Common test voltages are 500 and 250 d.c. A 100-volt potential is used occasionally. For most reliable indications, an entirely non-fluctuating voltage must be employed, and batteries generally are called upon to supply this potential.

Two established methods of resistance measurement find widespread industrial use in checking high dielectric values (thousands to hundreds of thousands of megohms). They are

(1) Measurement of current flowing through a capacitor and calculation of the resistance by Ohm's Law; and

(2) Use of a direct-reading megger.

Figure 1 shows the simple circuit employed to measure leakage current. A high-voltage battery, multi-range d.c. microammeter, and test sample capacitor are connected in series. The most sensitive range of the microammeter must be 0-0.5 μa or better. A 500-v. battery is recommended. The d.c. voltmeter must

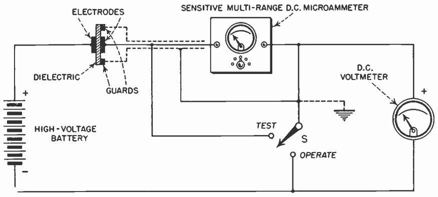

FIG.1

have a full-scale deflection equal to the battery voltage.

Switch S is arranged to short-circuit the sensitive microammeter when in the TEST position, and the d.c. voltmeter when in the OPERATE position. This switch may be a s.p.d.t. pushbutton switch arranged to cut-in the microammeter when depressed. In the TEST position of the switch, the voltmeter serves to reveal a short-circuited test sample, thus preventing damage to the microammeter. In the OPERATE position of switch S, microammeter readings may be made.

The insulation resistance value (megohms) for the dielectric sample may be found by dividing the battery voltage (volts) by the leakage current (microamperes).

$$R\ (\text{megohms}) = \frac{E\ (\text{volts})}{I\ (\text{microamperes})} \quad (1)$$

The resistance of a dielectric material often is stated in *ohms per cubic centimeter*. This is the volume resistivity (p) of the material, and is expressed by the formula: $p = RA/t$ (p is the resistance in ohms per cu. cm.; R, the material resistance measured in ohms; A, the area of the guarded electrode of the test jig in square centimeters; and t, the average thickness in centimeters of the test specimen).

Volume resistivity in ohms/cm^3 may be calculated from the voltage and current data obtained with the apparatus shown in Figure 1 by means of the equation: $p = \frac{AE}{It}$

in which E is the applied voltage (volts), I the microammeter deflection (amperes), A the area of the guarded electrode (sq. cms.), and t the average thickness of the dielectric material (cms.).

With switch S in its normal test position, the voltage across the test sample is read. Before throwing switch S to the OPERATE position, the microammeter must be switched to its highest current range. With S at OPERATE, readings then may be checked on each successively lower range, and the final reading taken on the lowest range applicable.

DIELECTRIC CONSTANT (LOW FREQUENCY)

To find dielectric constant (K), the capacitance of the prepared test sample first is measured, and the K value calculated from this measured capacitance value, area of one of the electrode plates, and thickness of the dielectric. For the low-frequency dielectric constant, capacitance is measured at 60, 120, 400, or 1000 cycles per second with a suitable capacitance bridge. For some dielectric materials, it may be desirable to check K at each of these low frequencies and to plot a curve showing variation in value.

If the thickness (t) of the dielectric is measured in inches, the capacitance (c) in mmfds., and the area (A) of one of the electrode plates in square inches, the dielectric constant may be calculated by means of the following equation:

$$K = \frac{4.45\ Ct}{A} \quad (2)$$

DIELECTRIC CONSTANT (HIGH FREQUENCY)

For many materials, it is desirable also to know the value of K at radio frequencies. The method of determination is the same as that just described for low frequencies, except that the capacitance is measured at a suitable radio frequency. Standard practice is to employ 1 megacycle for this capacitance measurement; but several K determinations may be made at frequencies as high as 20 or 30 Mc. and a plot drawn to show K variation with frequency for the dielectric material.

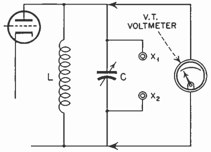

FIG. 2

The capacitance value (C) obtained by electrical measurement is somewhat higher than true capacitance determined by electrode area and spacing and dielectric constant because the electrostatic lines of force are not confined to the space between the capacitor plates but "fringes" into the surrounding space as well. Capacitance effects thus are set up between the edges of plates, as indicated by Figure 2-A. The effect of fringing is to make the dielectric constant, obtained by means of Equation (2), appear higher than it actually is.

For greatest accuracy in calculations, the capacitance C_e due to edge effects must be subtracted from the C value obtained by electrical measurement. In some applications, use of a guard electrode and shield will remove the necessity for making this correction.

When plates having unequal areas are employed in the test (which is usually the case), and one plate extends at least five times its thickness beyond the edge of the other, C_e ie. is

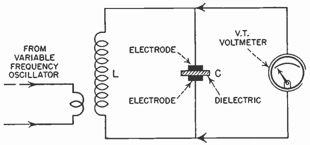

FIG. 3

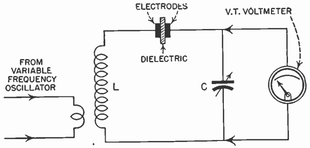

FIG. 4

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[1] ASTM Standards on Electrical Insulating Materials. Oct. 1939 p. 203

at each temperature level. Passing back through the temperature range, measurements made at the same levels as before will show retrace characteristics of the dielectric.

Permanent capacitance (dielectric constant) change may be determined by setting the chamber temperature to its original t_0 value, returning the variable-frequency oscillator, and noting difference (in mmfds) between initial and final settings of the oscillator tank capacitor.

Temperature coefficient of capacitance may be checked at low frequencies (60, 120, 400, or 1000 c.p.s.) in a similar manner. In this case, the prepared test sample is placed within a variable-temperature chamber as before, but is connected externally to a capacitance bridge. The bridge is balanced at the initial and final temperatures for C_1 and C_2 values respectively. Substitutions then are made in Equation (8) as before.

TEMPERATURE-POWER FACTOR COEFFICIENT

Temperature coefficient of power factor may be measured in a manner similar to the measurement of temperature-capacitance coefficient. The prepared test sample inside the variable-temperature chamber is connected externally to a bridge (low-frequency power factor) or to a Q-meter (high-frequency power factor). The power factor value is checked at several temperature levels over a desired range and a plot made to show variation of power factor with temperature. Measurements made back through the test range at the same points as before will reveal retrace characteristics of the dielectric material.

DIELECTRIC STRENGTH

Voltage at which the dielectric material ruptures or is punctured may be measured at a.c. or d.c. Figure 6 shows an arrangement for a.c. checking. A non-metallized plate of the dielectric material is placed between two flat-polished 1-inch-square steel blocks, A and B, which in turn are connected to the secondary winding of a high-voltage transformer. Area of the dielectric plate must be sufficiently large with respect to that of the electrode blocks to minimize surface leakage. Electrode sizes recommended by the A. S. T. M. are given in Figure 6. Small-size samples may be tested under oil.

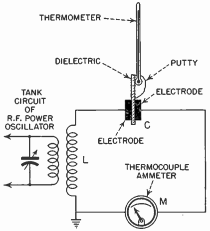

FIG. 7

A Variac, V, and 0-150-v. a.c. voltmeter, M, are included in the transformer primary circuit. Secondary voltage is determined by multiplying the reading of meter M by the transformer turns ratio.

In performing this test, the variac is adjusted slowly, increasing voltage until the dielectric is punctured. A standard rate of increase is 1000 volts per second. At breakdown, the reading (E_m) of meter M is taken.

Peak a.c. volts (E) per mil thickness required to puncture the dielectric may be determined from this Equation:

$$E = \frac{1.414\ NE_m}{t} \quad (9)$$

Where
N = transformer turns ratio
E_m = reading of primary voltmeter
t = thickness of dielectric sample (mils)

Both short-time and step-by-step dielectric strength tests are provided by the specifications of the American Society for Testing Materials.[1]

In the short-time test, the voltage must be increased from zero to breakdown at a uniform rate of rise of 500 or 1000 volts per second. The rate will be governed by the voltage-time characteristic of the dielectric material and upon the total required test time. A. S. T. M. specifications prescribe rates for particular materials.

In the step-by-step test, the initial applied voltage must be equal to 50% of the breakdown voltage determined by the short-time test. The voltage then must be increased in equal steps and held at each step for a prescribed period of time. Both the voltage increments and times for a particular dielectric material may be ascertained from A. S. T. M. specifications covering that material.

The A. S. T. M.[1] provides that five tests normally shall be made, and that five more must be made "if the average deviation from the mean exceeds 10 per cent, or if any individual test deviates more than 15 per cent from the mean." The average value of all tests is taken as the dielectric strength.

When checking d.c. voltage breakdown, a rectifier-type high-voltage power supply, rather than a simple variable-voltage transformer, will be required. Output voltage will be controlled by means of a variac connected in the transformer primary circuit, however, puncture voltage will be indicated by a high-voltage d.c. voltmeter connected across the rectifier output terminals.

R. F. TEMPERATURE-CURRENT CHARACTERISTICS

Temperature rise vs. current may be checked at radio frequencies by means of the arrangement shown in Figure 7. The prepared test sample is shielded from drafts and air currents, and is connected in series with a heavy-duty coil, L, and a thermocouple ammeter, M. Coil L is coupled to a radio-frequency *power* oscillator and is so proportioned that its inductance, together with the capacitance of the test sample, will resonate the measuring circuit to the oscillator frequency. A thermometer is secured to the dielectric face by means of putty applied to the thermometer bulb. A second thermometer indicates the ambient temperature.

The oscillator output is varied to give various measuring-circuit current levels, as indicated by meter M. After appropriate time has been allowed for the dielectric to "soak" at each current level (generally 45 to 60 minutes), temperature of the sample is read from the thermometer. The sample may be tested to destruction, a plot being made to show relation between current and temperature.

dial of variable capacitor C is graduated directly in micromicrofarads, and the v.t. voltmeter in Q units from 0 to 250 on a 0-5 v. R.M.S. scale.

Whether the test sample is in series or parallel with the circuit elements, the circuit is resonated first without the sample. (In the series circuit—Figure 4—the sample is replaced by a heavy short-circuiting bar). The capacitance setting of C at this point is recorded as C_1 and the v.t. voltmeter deflection as Q_1. The prepared test sample then is added to the circuit and variable capacitor C retuned to resonance. This second setting is recorded as C_2, and the corresponding voltmeter deflection as Q_2. The Q value may be determined by means of the applicable equation below:

(4) PARALLEL CONNECTION

$$Q = \frac{C_1 - C_2\ (Q_1 Q_2)}{C_1\ (Q_1 - Q_2)}$$

(5) SERIES CONNECTION

$$Q = \frac{C_1 - C_2\ (Q_1 Q_2)}{(C_1 Q_1) - (C_2 Q_2)}$$

LOW-FREQUENCY POWER FACTOR

Low-frequency power factor is measured at 60, 120, 400, or 1000 cycles by means of a suitable bridge. This measurement may be made at the same time and with the same bridge employed for capacitance measurement in connection with K determination.

Power factor is the ratio of equivalent series resistance of the sample to its impedance (R/Z) and is usually expressed in percent. Some commercial bridges are provided with dials graduated directly in percent power factor or dissipation factor (the two characteristics have the same numerical value for most capacitive test specimens) and are capable of rapid manipulation with somewhat reduced accuracy. Other bridges are not so equipped making it necessary to calculate power factor from bridge readings for separate reactive and resistive balances.

In experimental examination of a dielectric sample, it is desirable to check power factor at a number of low frequencies, and by means of a plot to follow variation of this characteristic with frequency.

HIGH-FREQUENCY POWER FACTOR

In a few instances, the value of power factor at radio frequencies will be required. This may be determined by means of calculations based upon Q-meter or r.f. bridge measurements.

In terms of the figure of merit, power factor is equal approximately to the reciprocal of Q:

(6)

$$\text{p.f.} = \frac{1}{Q}$$

The r.f. bridge is balanced separately for reactance (X) and resistance (R). From the two final readings obtained, power factor may be calculated:

(7)

$$\text{p.f.} = \frac{R}{\sqrt{R^2 + X^2}}$$

As in the case of low-frequency power factor, a complete experimental examination of a dielectric material will necessitate determination of h.f. power factor at a number of radio frequencies. The frequency vs. power factor characteristic then may be depicted by a graph.

TEMPERATURE-CAPACITANCE COEFFICIENT

Temperature coefficient of capacitance of the dielectric sample may be checked at radio frequencies by means of the apparatus shown in Figure 5. Here, the test sample is enclosed in a chamber in which the temperature may be varied continuously over a desired hot or cold range. The sample is connected externally to the tank circuit of a variable-frequency oscillator. R.f. output voltage from the variable-frequency oscillator is fed into an electronic mixer in which it is combined with fundamental or harmonic output voltage from a standard-frequency fixed oscillator. The beat note voltage is presented to an indicating audio frequency meter.

In testing temperature-capacitance coefficient, the variable oscillator is tuned to give zero indication on the frequency meter or some reference frequency, such as the center-scale value. This initial setting is made at room temperature, or some other convenient value (t_1). The dial attached to the variable oscillator tank capacitor reads directly in micromicrofarads, and its reading at this point is recorded as C_1. The chamber temperature then is raised or lowered by a desired amount to a new level (t_2) and the variable oscillator is retuned to restore the frequency indication to its original value. The new reading of the variable oscillator tank capacitor is recorded as C_2. Temperature coefficient of capacitance then may be determined by means of the equation:

(8)

$$\text{T.C.} = \frac{100\ (C_1 - C_2)}{(t_0 - t_1)\ C_X}\ \%$$

Where t_1 is the initial temperature, t_2 the final temperature, (both in °C) and C_X the capacitance of the prepared test sample as measured at the frequency of the variable oscillator.

The sample is permitted to "soak"

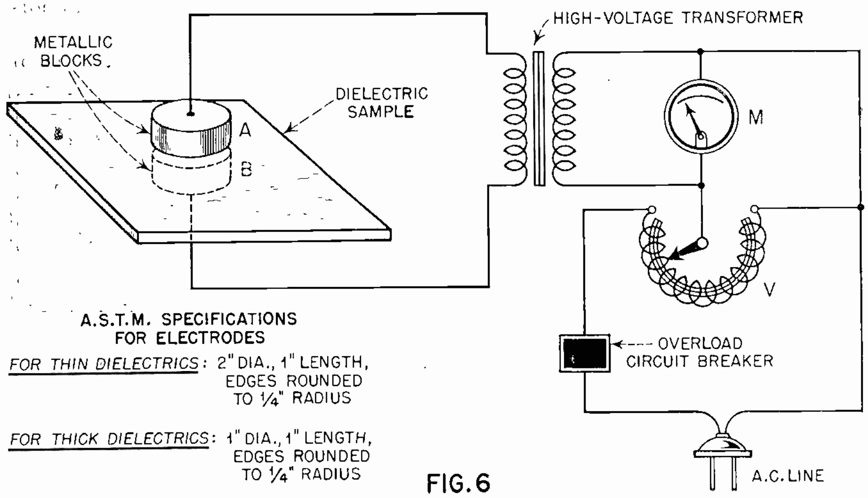

FIG. 6

equal to

$$P\left(0.195 \log \frac{1.5}{t} + 0.103\,K\right) \text{ mmfds}$$

In this formula, plate thickness (t) and the perimeter around the smaller electrode (P) are in inches. It will be noted that the dielectric constant (K) of the sample dielectric material appears in this formula. According to the American Society for Testing Materials[1], this may be the approximate value of K obtained first by ignoring C_e. But for best accuracy, "the expressions for K and for C_e may be solved algebraically or by successive substitution of trial values for K."

High-frequency dielectric constant values are calculated by means of Equation (2).

Instruments commonly employed for high-frequency capacitance measurement in connection with K determinations include Q-meters and capacitance test oscillators. Radio-frequency bridges are used occasionally.

Both oscillators and Q-meters make use of tuned L-C circuits, in shunt with which the prepared dielectric sample is connected. The tuned circuit may operate directly from the plate of an amplifier tube, as shown in Figure 2, or may receive r.f. energy by inductive or capacitive coupling.

The circuit is resonated to the oscillator frequency with the aid of the v.t. voltmeter by choosing L such that at resonance C will be set near maximum capacitance. (C is a variable unit with a capacitance-calibrated dial). The prepared test sample then is connected to terminals X_1 and X_2. The presence of the sample increases the circuit capacitance, detuning it from resonance. Capacitor C is tuned to a new setting to re-establish resonance, and the capacitance of the test sample is determined by subtracting the second setting of capacitor C from the first.

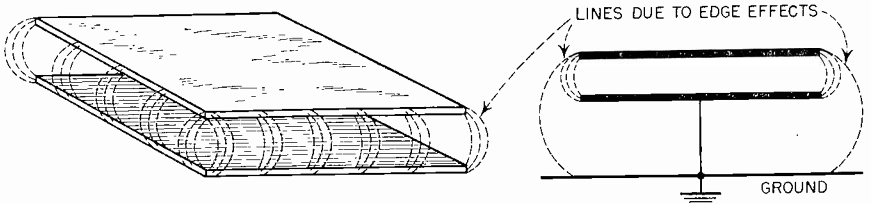

FIG. 2-A

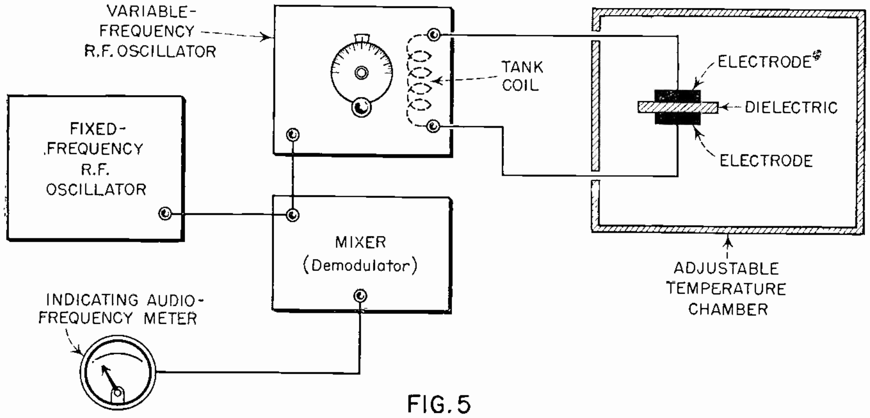

FIG. 5

Use of this method is limited to small capacitances (up to about 0.001 mfd.) by the variable capacitor maximum. Capacitances above 0.001 mfd. may be determined at radio frequencies by a comparable method illustrated in Figure 3. Here, the test sample (C) is connected in parallel with a fixed inductor (L) which, in turn, is coupled to an r.f. oscillator. The oscillator frequency is varied until peak deflection of the v.t. voltmeter indicates resonance. Capacitance of the sample then may be determined from the equation:

$$C = \frac{25{,}400}{f^2\,L} \text{ mmfds} \qquad (3)$$

Where f is in megacycles,
and L in microhenries

where f is in megacycles, and L in michrohenries.

At high frequencies, capacitor leads have appreciable reactance which opposes the series capacitive reactance of the test sample. This component can introduce an important error.

In order to minimize the effects of lead inductance, the test capacitor must be mounted as close as practicable to the terminals of the test instrument. In this way, it is often possible to make lead length negligible. When appreciable lead length is unavoidable, it will be necessary to determine the inductance of each lead and to subtract the sum of the two values from L in Equation (3). When each lead is a straight, round wire, its inductance may be calculated from the formula:

$$L = 0.00508\,l\left(2.303 \log_{10} \frac{5.08}{1.27\,d} - 0.75\right) \mu h$$

l is the length of one lead, and d its diameter.
Both dimensions are in inches.

FIGURE OF MERIT — Q

In the circuits shown in Figures 2 and 3, deflection of the v.t. voltmeter will be proportional to the figure of merit—or Q—of the tuned circuit. By maintaining the coil and variable capacitor Q high, tuned circuit Q will largely be that of the sample introduced in parallel. The reciprocal of the circuit Q will be equal approximately to the sum of the reciprocals of the variable and fixed capacitor Q values. The conventional Q-meter is a special adaptation of the basic circuit shown in Figure 2.

Q, a ratio of the reactance of the test sample to its equivalent series resistance, is very useful in evaluating the high-frequency merits of a dielectric material. At a given frequency, a high Q value indicates a good material. Q of a prepared dielectric sample may be measured with the sample in parallel with the tuning capacitor (See Figure 2) when the sample capacitance does not exceed the maximum capacitance of the tuning capacitor. When the sample capacitance exceeds the maximum tuning capacitance, the sample must be connected in series with the tuned circuit, as shown in Figure 4.

In the conventional Q-meter, the