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Practical Methods of Testing Condensers

PART 3

By the Engineering Department, Aerovox Corporation

MEASUREMENTS AT RADIO FREQUENCIES

THE capacitance of small mica condensers is most conveniently measured with the oscillator-resonator circuit shown in Figure 1. The oscillator can be any of the customary types employing some power tube like a 45, 10, 2A3, 2A5 as triode, etc. The unit should be shielded and some provision should be made for regulating the output. A convenient frequency is 1000 kc., but other frequencies may be employed. It is desirable to use the frequency of the circuit wherein the condenser is to be used.

The oscillator is coupled to a tuned circuit consisting of a coil and variable condenser. Here precautions must be taken to prevent any coupling other than the inductive coupling, hence the presence of the shield between the coils and the can surrounding both. The coupling should be less than critical coupling to avoid the appearance of a "double hump" resulting in two tuning points. The variable condenser should be larger than the largest condenser to be measured and should be calibrated in micro-microfarads. The size of the coil should then be chosen so as to cause resonance with the variable condenser, C,

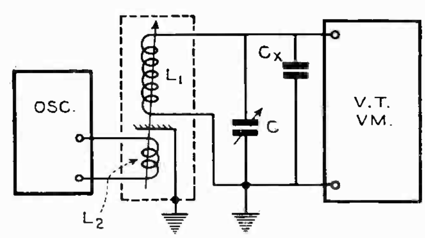


Fig. 1

nearly completely meshed. The unknown condenser is to be connected across C; it is marked Cx in Figure 1. Any type of resonance indicator may be used, such as a plate circuit detector with a milliammeter in the plate or cathode circuit, a grid-leak detector or even a diode with a meter. A meter in a grid or plate circuit of the oscillator will also serve the purpose.

The procedure is as follows: With Cx removed, tune the circuit to resonance with the oscillator and adjust the output of the oscillator to obtain a satisfactory indication on the meter. The coupling of the coils L1 and L2 may be varied, or the oscillator plate voltage might be changed. When resonance is indicated, read the setting of C and call this capacity, C1. Now connect the unknown condenser, Cx, across the variable condenser, readjust for resonance, and call the reading of the variable condenser C2. Then the unknown condenser is

$$C_x = C_1 - C_2$$

Several variations of this method are in use. Sometimes it is desirable to employ besides C another smaller variable condenser in parallel with it which is used as a vernier. This is convenient in production testing when it may be required to sort or select condensers within a definite percentage of a standard. The tuned circuit of Figure 2 is then used. Ca is a small condenser of perhaps 50 mmfd., which is calibrated in mmfd. but with zero in the center. When first adjusting the instrument, Ca is set at zero (half meshed), a standard condenser of the correct value is connected instead of Cx, and C is adjusted for exact resonance. Thereafter, other condensers can be put in the place of this standard condenser and resonance obtained by adjusting Ca. Its dial will then show immediately how many mmfd. the test condenser is high or low. Limits can be marked on the scale for rapid testing by an operator.

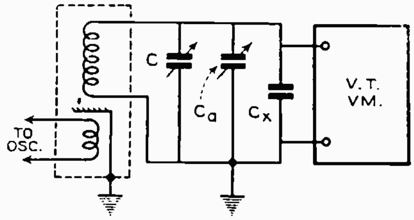


Fig. 2

Those who have used this equipment will have found that the resonance indicator or vacuum-tube voltmeter does not always show the same maximum voltage across the terminals of C and that this indication is a measure of the Q of the condenser when coil and oscillator adjustment remain the same. This provides a means of measuring Q, power factor or equivalent series resistance by a slight rearrangement of the circuit. The so-called Q-meter has had many important applications so we shall here present its theory.

Q-METER

In the case of a simple series resonant circuit, Figure 3, consisting of a coil having inductance and resistance

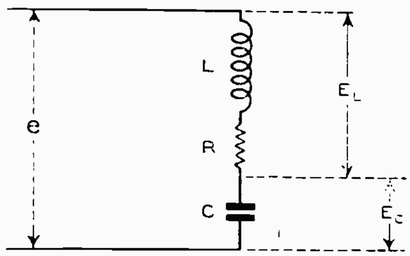


Fig. 3

and a condenser having negligible resistance, the voltage across the coil, E_L, due to an applied alternating voltage, e, at resonance is

$$E_L = e\sqrt{Q^2+1}$$

and the voltage across condenser is

$$E_C = eQ$$

In these equations Q is the Q of the coil because it was assumed that the condenser had an infinitely high Q; also, these conditions obtain at resonance only. The above equations can be simplified with a maximum error of 1% if the Q of the coil is larger than 10.

$$E_L = E_C = Qe$$

Thus the voltage across the coil or the condenser is directly proportional to the Q of the coil. It now remains to find a way of measuring the applied voltage e and the condenser voltage Ec.

MEASUREMENT OF Ec

A simple vacuum tube voltmeter with a range of 0—5 volts is satisfactory for the purpose. It should preferably be a type which places very little load on the circuit. This condition is satisfied by the plate circuit detector type or "biased detector". A recommended circuit is shown in Figure 4. A 2A6 or 75 tube is used, having the load in the cathode circuit. A voltage divider system makes it possible to buck out the steady plate current.

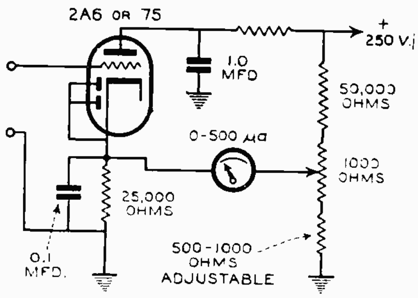


Fig. 4

The unit can be calibrated at audio frequencies (60 cycles will do) when the cathode by-pass condenser is temporarily increased to 25 mfd.

MEASUREMENT OF e

One possible method consists of coupling the oscillator to L similar to the circuit of Figure 1. The induced voltage in the coil is then given by the equation

$$e = \omega MI$$

It is thus necessary to know the mutual inductance between L1 and L2 and to measure the current in the primary. As long as M and I are known, the induced voltage is known. This voltage acts as if it were in series with L and C. The current can be measured by a thermal milliammeter while the mutual inductance can be measured on a bridge.

Note that e changes when either M or the frequency is changed even though the current may remain the same.

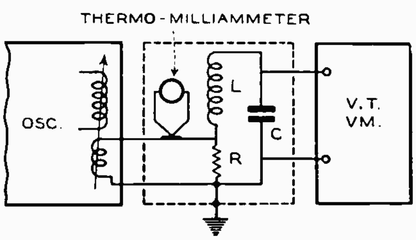


Fig. 5

A second possible method of introducing a small known voltage in the tuned circuit is shown in Figure 5. A low resistance of the order of .05 ohm is placed in series with the tuned circuit, and the oscillator terminals are connected across it while the current through this resistance is measured on a thermal milliammeter. The idea is to readjust the coupling to the oscillator for a definite reading on the meter which will be the same for all measurements. The voltage across R will then be constant and can be calculated by Ohm's Law. Knowing this voltage, the vacuum tube voltmeter, when calibrated in volts will read in proportion to Q and if a standardized value of e is always used, it can be calibrated in Q.

It is true that there is a slight inaccuracy in this method. The thermal milliammeter shows the current through R as well as the current through L and C. Usually, however, the resistance of the coil is very much larger than that of R and the error is negligible.

The resistance, R, consists of a straight piece of resistance wire the r.f. resistance of which can be calculated from the d.c. resistance by well known equations and tables prepared by the Bureau of Standards.

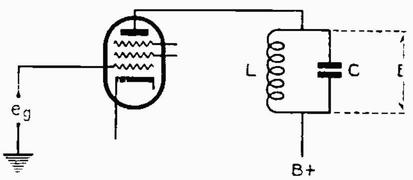


Fig. 6

A third possible method is slightly different, as shown in Figure 6. If a parallel resonant circuit is connected in the plate circuit of an r.f. pentode, the voltage appearing across the tuned circuit is proportional to the impedance at resonance, or

$$E = e_g G_m Z \qquad Z = \frac{\omega^2 L^2}{R} = Q\omega L$$

Thus, if the coil and the frequency are kept constant, E is proportional to Q.

The second method is the one usually employed; the others have been shown for the benefit of those experimentally inclined.

Q OF THE CONDENSER

Now employing the circuit of Figure 5, with the vacuum-tube voltmeter of Figure 4, it has been shown how to

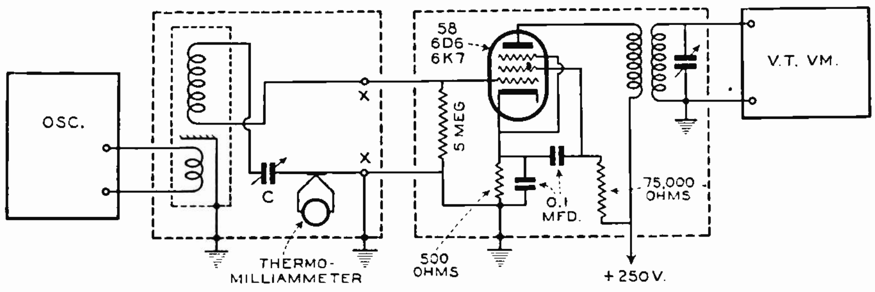


FIG. 8

find the Q of a coil when the condenser is perfect. The next problem is to find the Q of an imperfect condenser. First adjust the Q meter to resonance with a variable air-dielectric condenser, noting the Q and the condenser capacity of C1 and Q1. Then connect the unknown condenser in parallel with the tuning condenser. Readjust the tuning condenser to resonance, again find Q from the ratio E/e and read the condenser setting, giving the values C2, Q2. The constants of the condenser are then given by the equations:

$$C_x = C_1 - C_2 \text{ mmfd.}$$

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

$$\text{POWER FACTOR} = \frac{100}{Q_x} \text{ PERCENT}$$

$$R_x = \frac{1.59 \times 10^8\ C_1\ (Q_1 - Q_2)}{f\ (C_1 - C_2)^2\ Q_1 Q_2} \text{ OHMS}$$

f in kc. per sec. C_1, C_2 in mmfd.

The test can also be conducted by placing the unknown condenser in series with the variable condenser. This is especially useful for large condensers which would not permit the parallel method because retuning to resonance would become impossible. This arrangement should be connected as in Figure 7. A high resistance of about 5 to 10 meg. should be connected across the condenser so as to close the grid circuit of the tube.

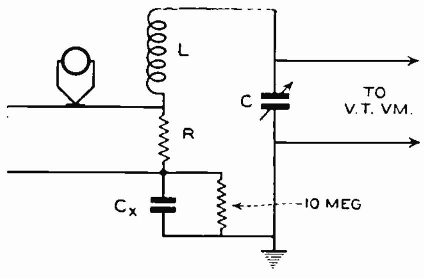


Fig. 7

Connect the condenser in place and short it with a heavy bar. Proceed as usual to read C1 and Q1 as before. Remove the shorting bar and find C2 and Q2. Then the following relations hold:

$$C_x = \frac{C_1 C_2}{C_2 - C_1} \text{ mmfd.}$$

$$R_x = \frac{1.59 \times 10^8 \left(\frac{C_1}{C_2} Q_1 - Q_2\right)}{f\ C_1 Q_1 Q_2} \text{ OHMS}$$

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

$$\text{POWER FACTOR} = \frac{100}{Q_x} \text{ PERCENT}$$

It may be found that C2 is larger than C1 which would mean that the condenser acts as an inductance at the frequency in question. The inductive reactance of the leads and the wound foils may be larger than the capacitive reactance of the condenser. The inductance is then

$$L_x = \frac{2.53 \times 10^{10} (C_1 - C_2)}{f^2\ C_1 C_2} \text{ MICROHENRIES}$$

It is not possible to measure values of Q over 2000 with the series connection. Q1 and Q2 then become so nearly alike that the measurement becomes inaccurate.

Precautions should be taken, when setting up the circuit, to prevent addition of inductance or extra capacity due to leads or proximity of the condenser to the shield.

MEASUREMENT OF R.F. IMPEDANCE

Recently the r.f. impedance of electrolytic condensers has come in for considerable attention. It can be measured in two ways; in the first method, employ the series connection described above and find the equivalent series resistance Rx from the equation. Then find the reactance Xx from

$$X_x = \frac{1.59 \times 10^8 (C_2 - C_1)}{f\ C_1 C_2} \text{ OHMS}$$

Here, (C2—C1), when negative, is to be replaced by (C1—C2), the reactance is then inductive. The value of the impedance Z is now

$$Z = \sqrt{R_x^2 + X_x^2}$$

The other way of measuring Z is by the voltmeter-ammeter method. Figure 8 shows the circuit; an oscillator is coupled to a coil in a similar way as in Figure 1. Proper shielding should be employed and the coupling should be variable. The unknown condenser is to be connected at X-X and the condenser C adjusted to resonance. The current through the condenser can then be read on the thermal milliammeter and the potential drop across it on the vacuum tube voltmeter. The impedance Z is then

$$Z = E/I \text{ OHMS}, \quad \text{Where E is in volts, I in amperes.}$$

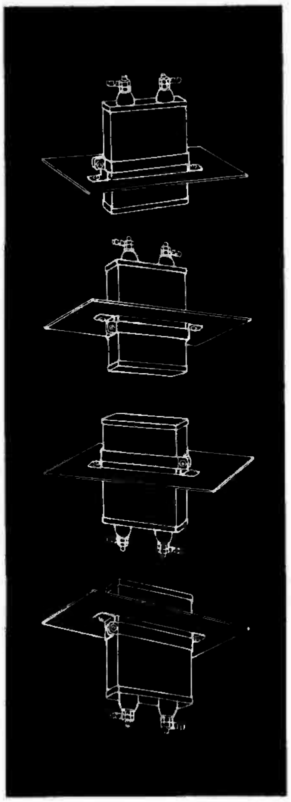
To avoid errors, the thermal meter must be on the ground side of the tuned circuit. Then the tuning condenser must be insulated from the chassis; an insulated shaft coupling and a shield should be used.

When it is desired to find whether the impedance is inductive or capacitive, short the terminals X-X, tune to resonance as indicated by the milliammeter. Insert the unknown condenser at X-X and retune to resonance. If the capacity of the tuning condenser, C, had to be increased the reactance of the condenser is capacitive; if it had to be decreased the reactance is inductive.

In this circuit the v.t. voltmeter can be the same as in Figure 4 while the r.f. amplifier is an ordinary tuned r.f. amplifier employing a 58 or 6D6 tube; the customary coupling circuit is connected between them and tuned to resonance. The combination amplifier and v.t. voltmeter is calibrated by connecting a known r.f. resistance across X-X adjusting the coupling for different readings on the thermal milliammeter and calculating the voltage.

All units must be very carefully shielded and the calibration must be made only after at least ten minutes of warming up. Thereafter a like period of warming up must be allowed before use.

A similar method has been used in the Aerovox laboratory employing a 2A5 (triode-connected) as an oscillator. The frequency was 1000 kc. and the amplifier and voltmeter tubes were a 58 and 2A6 respectively.



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