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Determining Capacitor Inductance

By the Engineering Department, Aerovox Corporation

THE INHERENT INDUCTANCE of a capacitor structure acts in series with the capacitance to form a resonant circuit. This inductive component is of low magnitude, usually less than 1 μh. in the small-dimensioned capacitors employed in radio receiver and test equipment circuits, but its effect upon circuit operation becomes more pronounced as the operating frequency is increased. (A 2-inch length of No. 20 wire, for example, has a reactance value of 30.6 ohms at 100 Mc.) Circuit design must take into consideration either or both the residual inductance of a capacitor and the resonant frequency.

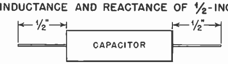
SECTION AND LEAD INDUCTANCE

The exact nature of capacitor inductance is not simple. However, the effective inductance is the combined inductance of leads, plates, clamps, tabs, and clips. In the case of the simplest rolled capacitor (See Figure 1), the total inductance would include lead inductance and the inductance of the rolled foil plates.

The rolled-plate inductance might be minimized considerably by a non-inductive type of construction, an example of which is shown in Figure 2. Here, instead of connecting a lead to the end of each plate, each turn of one plate is connected to one lead and each turn of the other plate to a second lead. This might be accomplished, as shown in Figure 2, by securing metal caps, as by soldering, to the tops of the foil-plate windings. There are numerous other schemes. By employing a non-inductive capacitor, internal inductance of the unit is reduced to a low order of magnitude and lead inductance becomes a determining factor.

Section inductance in the stacked-type capacitor (See Figure 3) is by nature lower than that encountered in the rolled type, because of the flat, rectangular shape of the plates. Section inductance is reduced still further by a type of construction suggested by Minnium[1]. Each element of the stack is built, as shown in Figure 4, by silvering circular electrodes on the dielectric. Figure 4-A shows a top view of such an element; Figure 4-B a cross section with exaggerated thickness. Current flow into the capacitor element from edge to edge

TOTAL INDUCTANCE AND REACTANCE OF ½-INCH LEADS



WIRE SIZE	DIAMETER (Mils)	INDUCTANCE (L) (μh)	REACTANCE (X_L) (Ohms at 100 kc.)
16	50.82	0.0184	0.0115
17	45.26	0.0189	0.0119
18	40.30	0.0195	0.0122
19	35.89	0.0201	0.0126
20	31.96	0.0207	0.0130
21	28.46	0.0213	0.0134
22	25.35	0.0219	0.0137
23	22.57	0.0225	0.0141
24	20.10	0.0231	0.0145
25	17.90	0.0237	0.0148
26	15.94	0.0243	0.0152

To find reactance at any frequency (f) higher than 100 kc., multiply value in X_L column by 0.01 f. *f is in kilocycles.*

To find reactance at any frequency (f) lower than 100 kc., divide value in X_L column by 100/f. *f is in kilocycles.*

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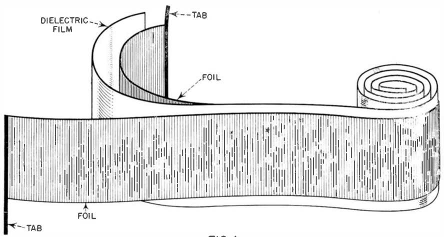


FIG. 1

of each plate is over a shorter path than can be achieved in a conventional rectangular stack, and effective series inductance is lowered.

As capacitors are normally wired into high-frequency circuits, the leads are straight and as short as practicable. Lead inductance accordingly may be calculated by the common method for straight, round wires. The inductance of short capacitor leads, while low, is effective in establishing resonance at normal operating frequencies. An 0.01-mfd. capacitor mounted with ½-inch leads of No. 20 wire will resonate as will be shown later, at 11 Mc. Clipping each lead to ⅛-inch, which is the practical length minimum for most installations, will raise the resonant frequency to 40 Mc.

Not all of the inductance in a stacked capacitor is due to leads, although a large percentage of the total inductance is traceable to that source. The actual capacitance at the resonant frequency is difficult to determine. For these reasons, some engineers prefer to measure capacitor resonant frequency and to disregard inductance.

Sinclair has shown that L is constant with frequency; but since it introduces a positive reactive component in series with the negative capacity reactance, causes a deviation in effective terminal capacitance at high frequencies.[2] A slight rise is noted likewise at low frequencies, but a constant-capacitance range is encountered at the medium frequencies.

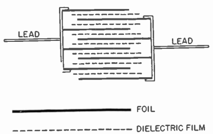


FIG. 3

CALCULATION OF LEAD INDUCTANCE

The inductance of capacitor leads may be calculated closely by means of the Bureau of Standards formula for straight, round wire.[3]

(1) $$L_0 = 0.002\, l \left(\log_e \frac{4l}{d} - 0.75\right) \mu h$$

When the common logarithm is employed, the equation becomes:

(2) $$L_0 = 0.002\, l \left(2.303 \log_{10} \frac{4l}{d} - 0.75\right) \mu h$$

In Equations (1) and (2), l and d are in centimeters. If l and d are expressed in inches, the equation becomes:

(3) $$L_0 = 0.00508\, l \left(2.303 \log_{10} \frac{4l}{d} - 0.75\right) \mu h$$

In these equations, l is the total length of the capacitor leads. If this total length is less than 2000 times the lead diameter, the term $2\ l/d$ must be added inside the parentheses in Equations (1) and (2), or $2.54\ l/d$ inside the parentheses in Equation (3).

These Equations will permit the calculation of lead inductance with

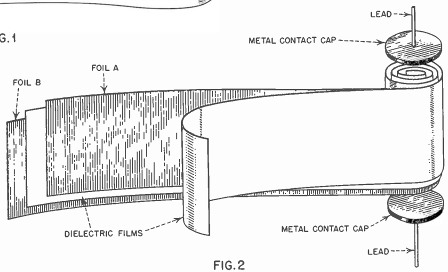
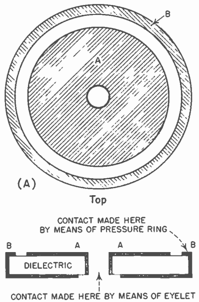


FIG. 2



(B) Cross Section
FIG. 4

sufficient accuracy for most practical purposes. The L_0 value obtained may then be used in the resonant frequensy formula to determine f_r, in all cases in which it is permissible to assume that capacitance at the resonant frequency is identical with the value measured at some lower frequency (such as 1000 c.p.s.) and that lead inductance is the predominant part of total capacitor inductance.

METHODS OF MEASURING CAPACITOR RESONANT FREQUENCY

Multiple Coil Method. In determining capacitor resonant frequency by means of a variable-frequency oscillator, energy from the oscillator is coupled into a tuned circuit containing the capacitor (See Figure 5). An a.c. vacuum-tube voltmeter is connected across the capacitor as a resonance indicator, or a grid-circuit milliammeter may be included in the oscillator for the same purpose.

When this method is employed, the resonant frequency will be in terms of the capacitance, in the circuit, the capacitor inductance, and the inductance of coil L. When maximum accuracy is not demanded, the coil inductance may be assumed to be the only L component in the circuit and the capacitance of the capacitor, as measured at a frequency lower than f_r the only effective capacitance. The resonant frequency then will be:

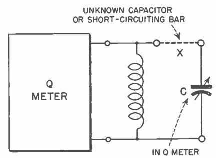


FIG. 7

(4) $$f_r = \frac{1}{6.28\sqrt{LC}}$$

For greater accuracy the method is somewhat different. The test circuit is set up successively with a number of coils of various sizes. The resonant frequency of each combination is determined by oscillator, and the inductance of each coil (with distributed capacitance considered) is measured (by means of a Q-Meter or inductance test oscillator) at the same frequency at which it resonated in the capacitor test circuit. A curve is then plotted with f_r values in the test circuit as the ordinates and coil inductance values as the abscissae. Inasmuch as the measurements cannot be carried beyond the point at which L is about half a turn, the curve must be extrapolated to show frequency at zero inductance (condition of resonance). Such a curve is shown in Figure 6, indicating the resonant frequency of a certain 0.02-mfd. capacitor as 6 Megacycles.

[1] Byron B. Minnium. U. S. Patent 2,348,693.
[2] D. B. Sinclair. *Gen. Radio Experimenter.* Apr. 1938, p. 5.
[3] Circular of the Natl. Bureau of Standards. C74 p. 243.

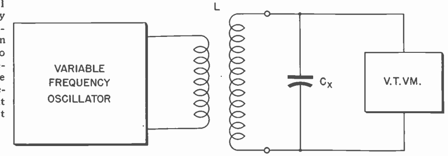


FIG. 5

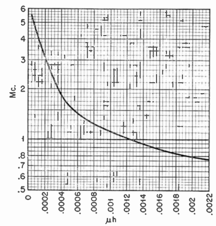


FIG. 6

The method of Sinclair[2] consists of plotting the reciprocal of the terminal capacitance (ordinates) as a function of $C_0{}^2$ (abscissae) in the frequency range in which C remains constant.

The slope of the curve is equal to L, and the intercept of the straight-line plot with the ordinate axis is equal to the reciprocal of the true capacitance.

Q-Meter Method. This method consists of resonating the standard *series measurement* circuit of a Q-Meter (See Figure 7) successively with a low-inductance short-circuiting bar (A) and the test capacitor (B) in place of the circuit.

It will be found that the settings of tuning capacitor C will differ with A and B successively in place. The oscillator frequency is then varied and the test circuit re-tuned, first with the bar and then with the test capacitor in place. The operation is repeated at a number of frequencies until interchanging the bar and capacitor no longer necessitates retuning the circuit. At this point, the oscillator frequency is the resonant frequency of the capacitor.

In the absence of a Q-Meter, this same method of inductance measurement may be employed with a variable-frequency oscillator, tuning capacitor, and v.t. voltmeter connected as shown in Figure 8.

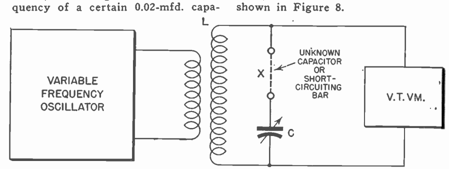


FIG. 8