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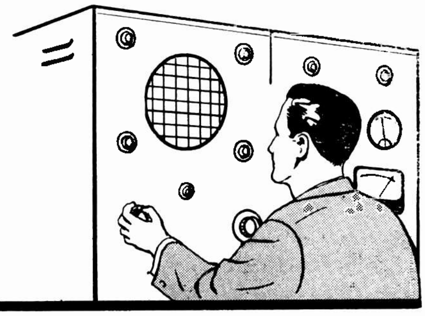

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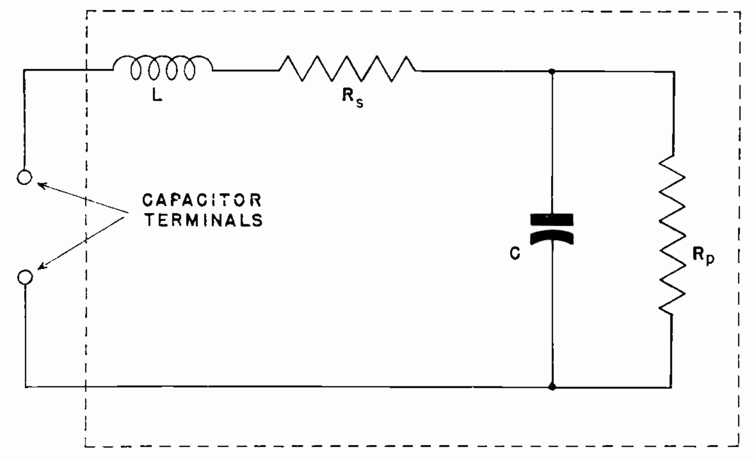
Basic Measurement of Capacitance

Part 1

By the Engineering Department, Aerovox Corporation



BLACK-BOX EQUIVALENT OF CAPACITOR

FIG. 1

A practical capacitor may be represented as a black box containing resistances and inductance in addition to capacitance. Figure 1 shows the equivalent circuit of the capacitor with lumped L, C, and R constants. In this network, the inductance L is determined principally by dimensions of leads, terminals, plates, clamps, and attachments, C is the capacitance at any frequency, R_s is the equivalent series resistance determined by ohmic resistance of leads, terminals, and plates, skin effect, and other inphase factors, and R_p is the equivalent shunt resistance determined principally by dielectric leakage. At dc, R_s is the leakage resistance of the dielectric between the plates (a very high resistance in good capacitors) and leakage over terminals. Generally shunt resistance due to paths across the external surface of the

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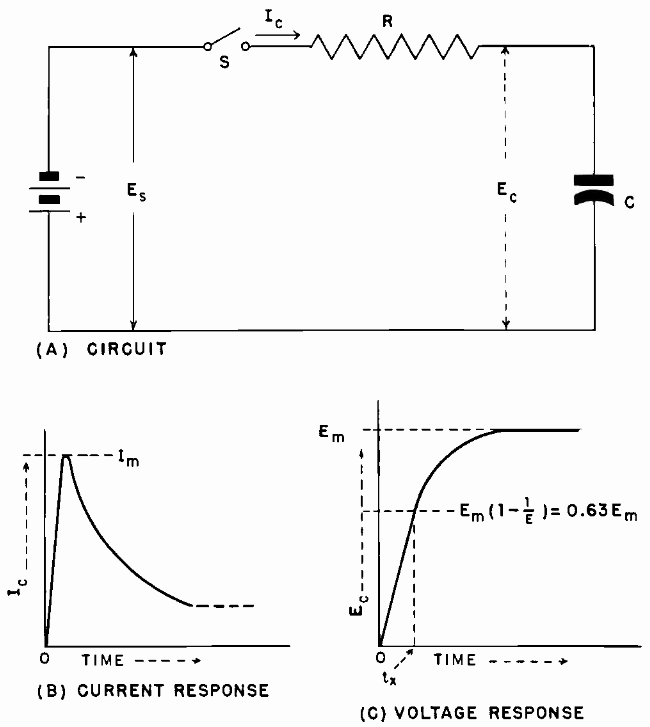
capacitor or through the encapsulating material is so high as to have no consequential effect at dc. At frequencies below the ringing frequency of the capacitor the effect of L is not important and the effect of R_s is limited to the phase angle between the currents and voltage.

Practical capacitance measurement entails the measurement of a quantity, C, which is only one component in a black-box network. Accounting for the other components is often a problem. (A case in point is that of the simple capacitance meter which cannot discriminate between the reactance and resistance of the capacitor and therefore gives an *apparent capacitance* indication which may be considerably in error.) Conventional bridge techniques provide separate reactive and resistance balances, so that R at the test frequency is either indicated directly as equivalent series resistance, power factor, or Q. The capacitance obtained in these measurements closely approaches the geometric capacitance, dependent however on the type of dielectric. R-F resonant-circuit measurements, in which capacitance is determined from the resonant frequency of a circuit, are subject to error due to stray circuit capacitance and the error in identifying the inductance. These errors are minimized by the substitution process if the test frequency is sufficiently removed from the natural resonant frequency of the capacitor.

When an a-c test method is suspect or when a bridge or similar instrument is not immediately available, recourse must be had to fundamental d-c test methods. With the subsidiary effects of L and R_s eliminated at dc, the C value obtained through such methods, when properly handled, may be accepted as the geometric capacitance. This method does not hold for electrolytic capacitors. These methods often are preferable to others when the end application of a capacitor is a slow-speed unipolar service such as timing, energy storage, and some forms of memory storage.



(A) CIRCUIT

(B) CURRENT RESPONSE

(C) VOLTAGE RESPONSE

CAPACITOR CHARGING CHARACTERISTICS

FIG. 2

FUNDAMENTAL RELATIONSHIPS

The basic relationship between capacitance, voltage, and charge is expressed:

(1) $C = Q/E = It/E$

Where C is the capacitance (farads), Q the quantity of electricity (coulombs), E the voltage (volts), I the current (amperes), and t the time (seconds).

If C is expressed in microfarads and I in milliamperes, Equation (1) may be rewritten:

(2) $C = 10^6\ (Q/E) = 10^3\ (It/E)$

When a constant dc voltage is applied to a capacitor in series with a noninductive resistor, the capacitor is not charged instantaneously if the circuit as a whole is more than critically damped. Instead, charging current flows into the capacitor, first rapidly to a maximum and then gradually decreases. Thus, when Switch S is closed in Figure 2(A), the resulting rise and decay of the charging current, I_c, follows the general pattern shown in Figure 2(B). At the same time, the voltage (E_c) across the capacitor increases with time, as shown in Figure 2(C), until at full charge the capacitor voltage equals the supply voltage ($E_c = E_s$). The charging current at any instant after the peak current is reached may be determined from the following relationship:

(3) $I = (E_s/R)\ \epsilon^{-t/RC\ *}$

Where I is the instantaneous charging current (amperes), E_s the supply voltage (volts), R the series resistance (ohms), t the time interval between closure of the switch and the instant of interest, C the capacitance (farads), and ϵ the base of natural logarithms = 2.7183.

* Note $R\ 7\ 10\sqrt{L/C}$

Equation (3) may be solved for capacitance in terms of the current at a selected instant after current has reached its maximum value. Capacitance also may be determined similarly in terms of the capacitor voltage at a selected instant along the rise curve such as that shown in Figure 2(C). However, this method will not be reliable unless certain precautions are taken. For example, the final current (dotted portion of Figure 2B) is a steady value determined by the shunt leakage resistance of the capacitor. Also, the voltage across the capacitor and the current may be influenced by dielectric absorption. Errors due to these sources may be minimized by observation of current or voltage over a restricted time interval:

(4) $t = RC$ Where t is the time constant (seconds), C the capacitance (farads), and R the circuit resistance (ohms).

When the voltage is under observation, t is the time interval between zero and the instant (t_x in Figure 2C) at which the capacitor voltage, E_c, has risen to $(1\text{-}1/\epsilon)$ of its final value, E_m. This is approximately 63% of the final value, as shown in Figure 2(C). Equation (4) then may be solved for capacitance:

(5) $C = t/R$

If C is expressed in microfarads instead of farads, this equation becomes:

(6) $C = 10^6\ (t/R)$

And if C is expressed in microfarads and t in milliseconds:

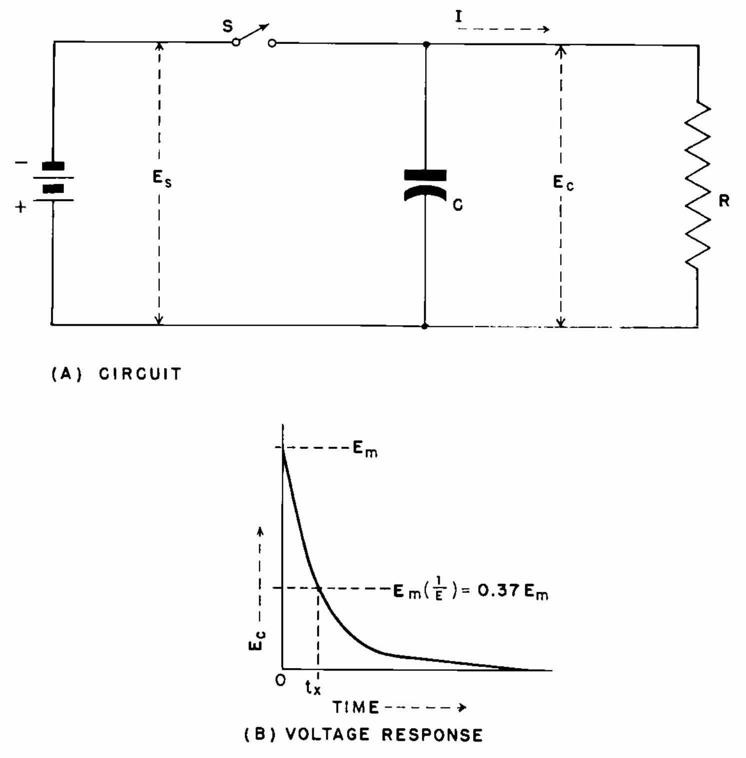
(7) $C = 10^3\ (t/R)$

The discharge characteristic of a capacitor also may be employed, but in a slightly different manner. When Switch S is closed in Figure 3(A), Capacitor C is charged by the steady d-c voltage source. The capacitor voltage quickly equals the supply voltage ($E_c = E_s$). This is the maximum voltage point shown as E_m in Figure 3(B). When the switch subsequently is opened, a discharge current (I) flows through Resistor R. This current initially is large but it decreases exponentially, as the discharge progresses, eventually reaching zero, as shown in Figure 3(B).

The time constant is taken over the interval between zero time, when the capacitor voltage is maximum (E_m in Figure 3B), and time t_x, when the voltage has decreased to $1/\epsilon$ of its initial maximum value. This is approximately 37% of the initial maximum. As before (Equation 7), $C = 10^3\ (t/R)$, where C is in microfarads, t in milliseconds, and R in ohms.

When capacitance is determined by this basic method, the choice of scheme (i. e., charge, discharge, current, or voltage) depends upon available instruments. For example, when current is employed, the indicating instrument must be a recorder or oscillograph if a permanent record is desired, and should have low resistance unless its internal resistance is made the exclusive circuit resistance or figured into the total value of R. Furthermore, its inductance must be negligible. When voltage is employed, the instrument must be a recorder, oscillograph, or time-calibrated oscilloscope. In either of the latter, the input resistance of the instrument must be very high to obviate loading effects A high-resistance preamplifier must be employed if the instrument resistance is low. In some instances, a camera will be required for recording the oscilloscope or oscillograph tracing. As will be shown later, a high-resistance d-c vacuum-tube voltmeter may be used in some tests.

There is some objection to using the scheme in which charging current or voltage is studied, since it necessitates one or more trial runs to determine beforehand the value of E_m or I_m before the test can be made.



(A) CIRCUIT

(B) VOLTAGE RESPONSE

CAPACITOR DISCHARGE CHARACTERISTIC

FIG. 3

Part II in the next issue will describe practical measurement setups and procedures.

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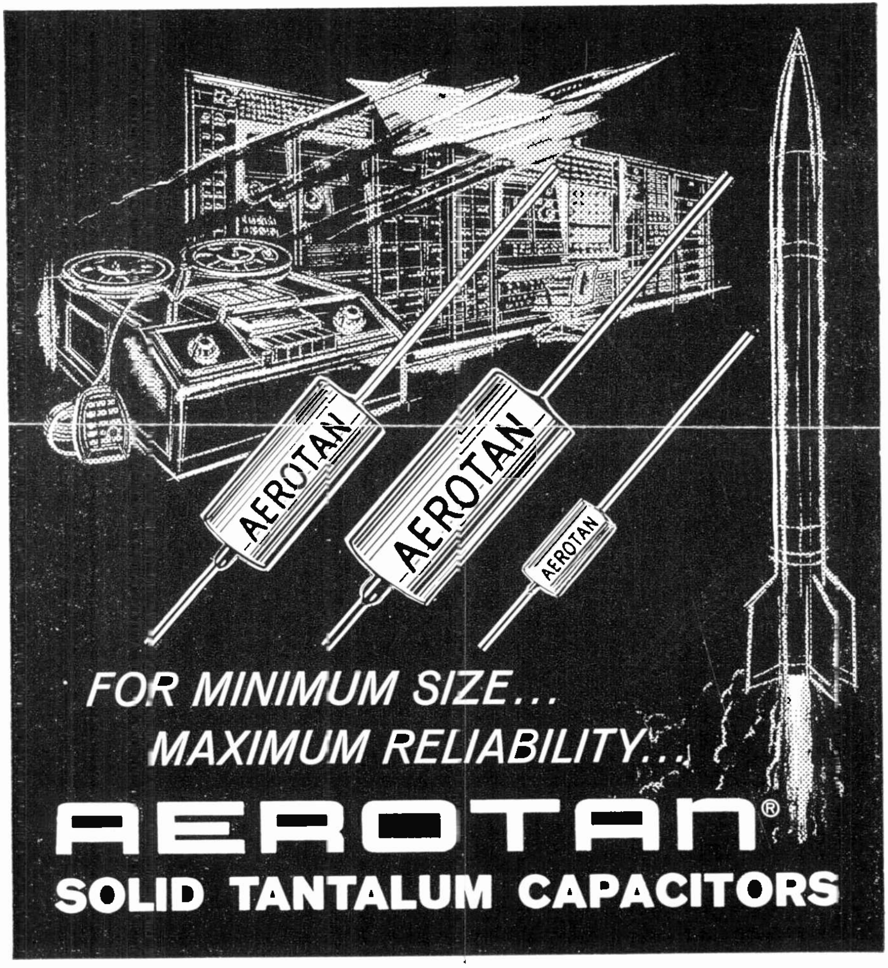
CAPACIBILITY*



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15 VDC	15 VDC	13 VDC	10 VDC
20 VDC	20 VDC	17 VDC	13 VDC
35 VDC	35 VDC	28 VDC	20 VDC

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