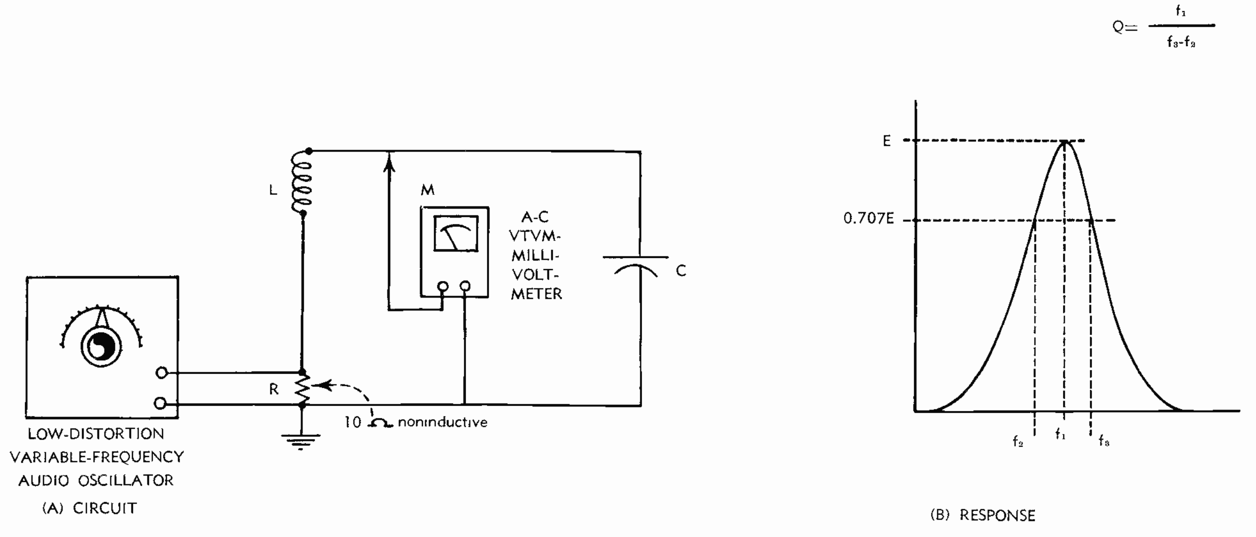


(A) CIRCUIT

(B) RESPONSE

FIGURE 4. SUSCEPTANCE VARIATION METHOD

Follow this procedure: (1) Set oscillator to test frequency (f_1). This is the resonant frequency of the LC test circuit and is indicated by peak deflection of the vtvm. (2) At this point, adjust oscillator output and meter range for a convenient readable deflection, E. (3) Detune oscillator to a below-resonance frequency (f_2) at which the deflection falls to 0.707E. (4) Next, detune oscillator to an above-resonance frequency (f_3) at which the deflection again falls to 0.707E (Figure 4B shows the resultant tuning curve). In Steps 3 and 4, the oscillator output must not be changed from that selected in Step 1. (5) From the frequency readings, calculate Q:

(7) $Q = f_1/(f_3 - f_2)$

OTHER METHODS

Several other techniques of a-f Q determination deserve notice here. Each will be found useful in situations governed by available equipment, time requirements, and suitability.

Conventional Q Meter. The standard rf-type Q meter sometimes has provision for disconnecting its internal r-f oscillator and connecting in its place an external audio oscillator. This permits the regular Q meter to be used at low frequencies and is an advantage, since the indicating meter reads Q directly. In most instances, however, the internal variable tuning capacitor will not provide enough capacitance (450 pf is a common maximum), so that a suitable high-Q external capacitor must be connected to the Q-meter C_X terminals to resonate a coil under test, or a suitable high-Q external inductor must be connected to the Q-meter L_X terminals to resonate a capacitor under test.

Calculation from Measured Inductance and Resistance. If the inductance (L) of a coil is previously measured at the desired test frequency (f) by any available reliable method, and the d-c resistance (R) is then measured on the assumption that at audio frequencies the d-c and a-c resistance are essentially the same. the approximate Q then may be calculated from those values:

(8) $Q = (2\pi fL)/R$

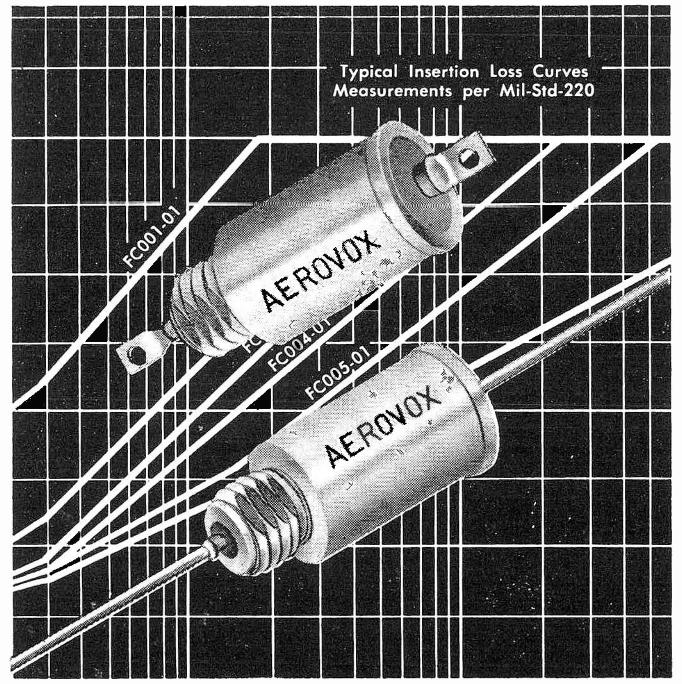
There is no comparable method of determining capacitor Q, since (unlike the coil) the capacitor affords no direct access to its series resistance component.

Calculation from Measured Impedance and Resistance. If the impedance (Z) of a coil is previously measured at the desired test frequency by any available reliable method, and the d-c resistance (R) is then measured on the assumption that the d-c and a-c resistance are essentially the same at audio frequencies, the approximate Q (for Q values of 10 or higher) may be calculated from those values:

(9) $$Q = \frac{\sqrt{Z^2 - R^2}}{R}$$

Calculation from Measured Voltage, Current, and Resistance. If a voltage (E) at the desired test frequency is applied to a coil and the resultant current (I) measured, and if then the d-c resistance (R) of the coil is measured on the assumption that the d-c and a-c resistance are essentially the same at audio frequencies, the E, I, and R values may be used to calculate the approximate Q of the coil for Q values of 10 or higher:

(10) $$Q = \frac{\sqrt{(E/I)^2 - R^2}}{R}$$



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Determining Q At Audio Frequencies

By the Engineering Department, Aerovox Corporation

The radio-frequency Q meter is a familiar instrument in the well-equipped electronics laboratory. Its routine use in the evaluation of high-frequency coils and capacitors also is familiar. Not so commonplace, however, is the low-frequency Q meter for testing the high-L coils and high-C capacitors used at audio frequencies. Such instruments are available (average price $1563) both with meter-plus-dial readout and with digital readout but generally are found only in those laboratories devoted to lower-frequency measurements. Nevertheless, the need occasionally arises to determine the Q of an iron-cored coil or large capacitor in laboratories equipped principally, or exclusively, for high-frequency work. This article explains some of the low-frequency Q-measurement techniques, other than use of a special low-frequency Q meter, which are available to the technician. In general, they involve only equipment which is readily available in the average laboratory.

PRELIMINARY CONSIDERATIONS

Numerically, the figure of merit (Q) of a coil or capacitor is the ratio of its reactance to its resistance:

(1) $Q = X/R = (wL)/R = 1/(wCR)$

The resistive component is assumed to be a-c resistance, and this quantity may or may not be equal to the d-c resistance. Usually it is higher in value. That this is true resistance, rather than reactance, is evident from the fact that a current through it is in phase with the applied voltage. The a-c resistance results from the combined effect of several factors.

In a coil, these include d-c (ohmic) resistance of the wire, terminals, and insulation; effect of shielding; shape of coil; and nature of the core material. In a capacitor, they include d-c (leakage) resistance of the dielectric and case material, plates, leads, and terminals; and nature of the dielectric material. Skin effect is an important ingredient of a-c resistance but is not so noticeable at audio frequencies as at radio frequencies.

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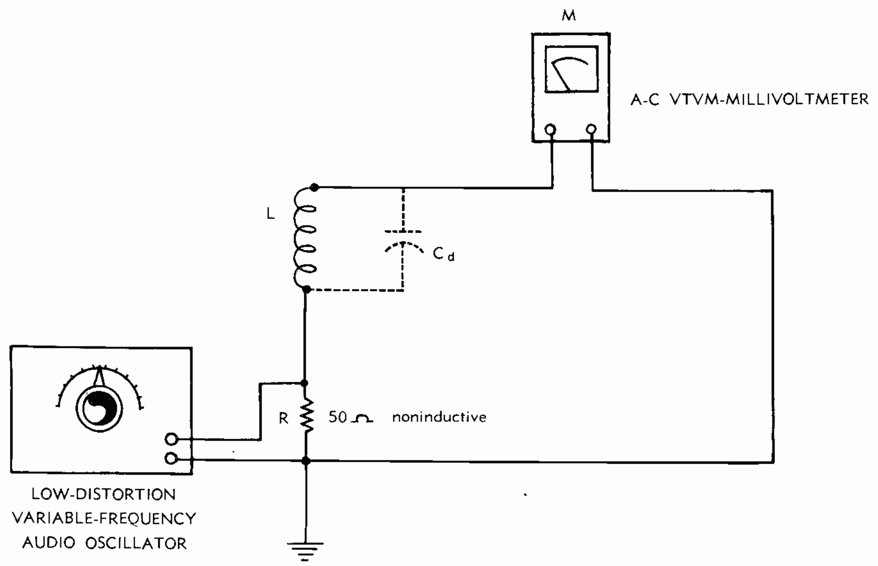

FIGURE 1. TEST SETUP FOR SELF-RESONANT FREQUENCY OF COIL

Audio-frequency coils usually have a large number of turns of wire per unit volume, so that the distributed capacitance of such a coil is significant in value. This capacitance (C_d) tunes the inductance (L) of the coil to a self-resonant frequency ($f_r = 1/2\pi\,(LC)^{1/2}$) which must be predetermined, and avoided in conventional Q measurements. High-C capacitors for use at audio frequencies usually exhibit no self-resonance in the a-f test-frequency spectrum. To determine the self-resonant frequency of a coil, use the test setup shown in Figure 1: (1) Keep all leads short. (2) Keep coil L out of magnetic fields. (3) Set oscillator to its lowest frequency. (4) Set oscillator to zero output. (5) Set vtvm to its lowest range. (6) Adjust oscillator output for a slight deflection of vtvm. (7) Tune oscillator slowly upward in frequency, noting that meter reading increases. (8) Continue tuning, noting that at some frequency the meter reading rises to a maximum (peak deflection) and that it decreases at higher frequencies. Adjust oscillator output and meter range, if necessary, to prevent off-scale deflection. (9) At peak deflection, read self-resonant frequency (f_r) of coil directly from oscillator dial. In subsequent Q measurements, it will be advisable to avoid test frequencies within the range $\frac{1}{2}f_r$ to $2f_r$.

The instruments used in a Q-measuring setup must be of good quality. An audio oscillator, for example, must have minimum distortion, low-impedance output, high stability, freedom from hum and spurious signals, and excellent frequency accuracy. A v-t voltmeter must have high input impedance (10 megohms minimum recommended), freedom from hum, and excellent accuracy and stability. Any coil or capacitor used in the test must have high Q and excellent stability, and its value must be accurately known. (Laboratory-type inductors and standard mica capacitors—singly or in decade boxes—are recommended.) When bridges or similar instruments are used to measure Q, or to determine power factor, dissipation factor, or affective-resistance values from which Q subsequently is calculated, those instruments must provide high accuracy in their Q, pf, D, or R functions.

Low-frequency measurement circuits are especially susceptible to the effects of hum fields. Q-test setups accordingly should be shielded, grounded, wired with short heavy leads, and otherwise protected as required in the particular setup. Any signal injection component, such as a coupling resistor, should be low-impedance. Resistors must be noninductive. The setup should be protected from large temperature changes during the test, and from moisture. When a bridge or similar instrument is used, the component under test must be connected to it by the shortest and heaviest leads practicable.

To prevent overloading a component under test and thus reducing the accuracy of measurement, the lowest test-signal voltage must be employed which will afford accurately readable indications.

BRIDGE METHODS

Many a-f bridges give a direct reading of Q for inductors, or of dissipation factor, power factor, or effective resistance for capacitors (from which capacitor Q may be calculated). It must be remembered, however, that direct-reading dials for this purpose are calibrated on the basis of a single frequency, such as 1000 cps, and must be corrected at other test frequencies. The measurement technique varies somewhat with different instruments, but the usual method is

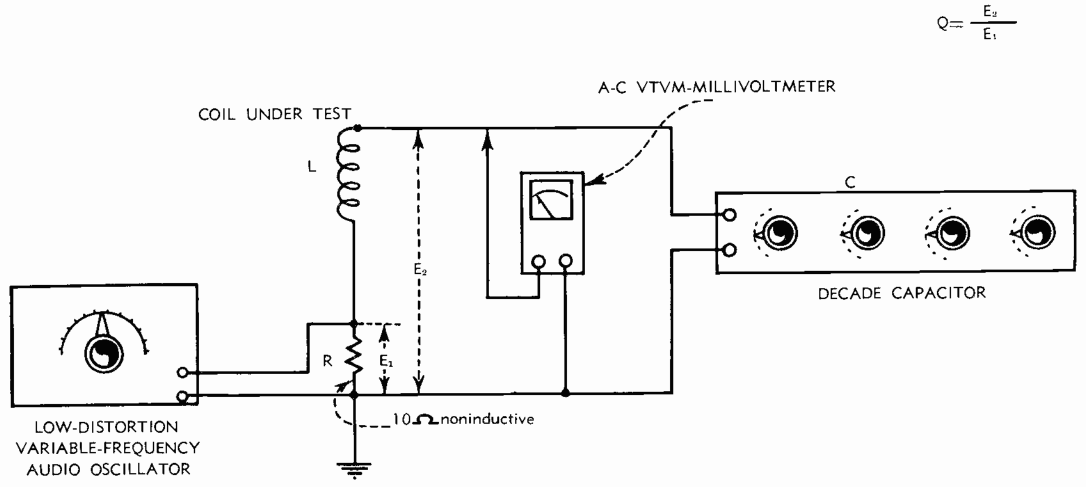

FIGURE 2. Q-VOLTMETER METHOD: COILS

to balance the bridge first for the reactive component (inductance or capacitance) and next for the resistive component (Q, D, pf, R, G).

Depending upon make and model of bridge, various ranges and accuracies are provided. Typical of the portable impedance bridge (measurement ranges of C, 1 pf to 100 mfd; L, 1 µh to 1000 hy) are the following: Q, 0.02–1000 and D, 0.001–50, both at ±5% accuracy at 1000 cps. A laboratory-type capacitance bridge covering the capacitance range 0.1–1000 pf typically affords a D range of 0.000001 to 1 at ±0.1% accuracy. A typical laboratory-type inductance bridge covering the inductance range 0.01 µh to 10 hy commonly affords an R_e range of 0.002–100,000 ohms at ±3% accuracy.

When the secondary bridge balance gives dissipation factor (D), calculate Q from that value:

(2) $Q = 1/D$

When this balance gives power factor (pf, in percent), calculate Q from that value when pf is 10% or less:

(3) $Q = 100/pf$

When it gives effective resistance (R_e in ohms), calculate Q:

(4) $Q = (wL)/R_e$ L is in henrys

When the secondary balance gives conductance (G, in ohms), calculate Q:

(5) $Q = 1/(wLG)$ L is in henrys

Q-VOLTMETER METHOD

The Q-voltmeter method is the technique employed in the well-known rf-type Q meter. Here, a standard voltage is injected into a series-resonant circuit (comprised by the component under test and a standard component of the opposite reactance), and Q determined as a function of the resonant-circuit voltage. Laboratory parts may quickly be assembled into a bench setup for this test.

Coil Q. Figure 2 shows the setup for checking the Q of a coil. In this arrangement, the coil (L) under test is resonated to the test frequency (f_r) by means of a high-quality decade capacitor (C). The latter should be a mica unit chosen to provide the required tuning capacitance ($C = 1/\pi^2 f^2 L$) in steps small enough for fine tuning. The test signal, obtained from a low-distortion audio oscillator, is injected into the test circuit across a 10-ohm noninductive coupling resistor, R. If the oscillator will not tolerate this low-resistance load, a suitable stepdown transformer must then be connected between the oscillator and resistor R.

Follow this procedure: (1) Set oscillator to desired test frequency. (2) Temporarily connect high lead of vtvm to top of resistor R, and adjust oscillator output for a convenient voltage (E_1), say 0.1 v across the coupling resistor. (3) Return high lead of vtvm to top of coil, as shown in Figure 2. (4) Adjust capacitance of decade capacitor C for resonance, as indicated by peak deflection of vtvm. (5) Recheck voltage E_1 at top of resistor R (as in Step 2), readjusting

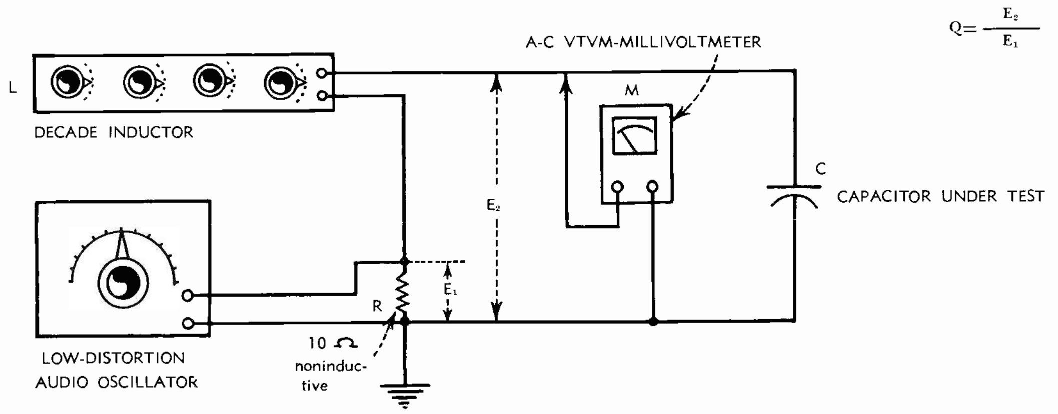

FIGURE 3. Q-VOLTMETER METHOD: CAPACITORS

oscillator output, if necessary, to restore original level. (6) Return vtvm to top of coil L and read resonant voltage; record as E_2. (7) From the two voltages, calculate Q:

(6) $Q = E_2/E_1$

Capacitor Q. Figure 3 shows the setup for checking the Q of capacitor. In this arrangement, the capacitor (C) under test is resonated to the test frequency (f_r) by means of a high-quality decade inductor. The latter must be chosen to provide the required tuning inductance ($L = 1/4\pi^2 f^2 C$) in steps small enough for fine tuning. Furthermore, the Q of the inductor itself must be much higher than that expected in the capacitor under test.

As in the previous setup, the test signal from a low-distortion audio oscillator is injected into the circuit across a 10-ohm noninductive coupling resistor, R.

(If the oscillator cannot tolerate this low-impedance load, a suitable stepdown transformer must be connected between the oscillator and resistor R.)

Follow this procedure: (1) Set oscillator to desired test frequency. (2) Temporarily connect high lead of vtvm to top of resistor R, and adjust oscillator output for a convenient voltage (E_1), say 0.1 v across the resistor. (3) Return high lead of vtvm to top of inductor, as shown in Figure 3. (4) Adjust inductance of decade inductor L for resonance, as indicated by peak deflection of vtvm. (5) Recheck voltage E_1 at top of resistor R (as in Step 2), readjusting oscillator output, if necessary, to restore to original level. (6) Return vtvm to top of inductor L and read resonant voltage; record as E_2. (7) From the two voltages, calculate Q according to Equation (6).

It should be noted that this method is less successful with capacitors than with coils when the capacitors are inherently high-Q components, such as the mica type. The reason for this is that the Q of such a capacitor is very much higher than that of the best high-inductance test inductor.

SUSCEPTANCE VARIATION METHOD

Fundamentally, this method involves a simple examination of the selectivity of a resonant circuit containing the coil or capacitor under test and a component of the opposite reactance. This resonant circuit is comprised by L and C in Figure 4 (A). If the capacitor is being tested for Q, inductance L must be chosen for resonance with capacitance C at the desired test frequency; if the coil is being tested, capacitance C must be chosen for resonance with inductance L. If the absolute test frequency is immaterial, then any value of C or L, as the case may be, can be used. In any event, however, the added component, whether L or C, must have the highest Q obtainable.

The test signal is injected into the circuit across the 10-ohm noninductive coupling resistor, R. (If the oscillator cannot tolerate this low-resistance load, a suitable stepdown transformer must be connected between the oscillator and resistor R.)