EXPERIMENT 4-17

THE Q METER AND ITS USE

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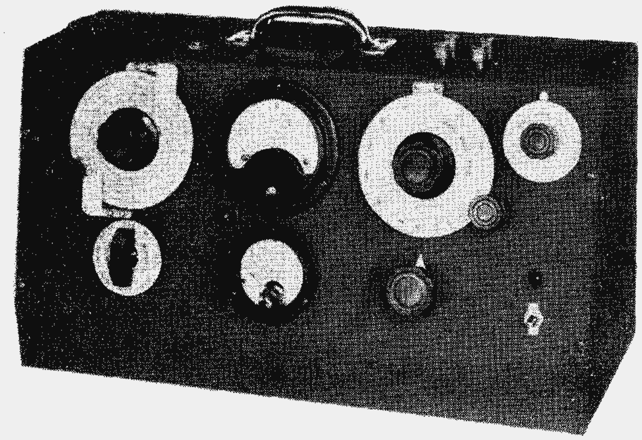

FIG. 4-35. Q METER.
(Courtesy Boonton Radio Corp.)

In most radio frequency work it is important to obtain a large ratio of reactance to resistance in the reactive elements of the circuit. This ratio is called the *Q* of the circuit.

$$Q = \frac{X_L}{R} = 2\pi f\,\frac{L}{R} = \frac{X_C}{R} = \frac{1}{2\pi fCR}$$

A high Q is required to obtain good efficiency, good wave form, good frequency stability, high gain, etc.

The *Q* meter is an instrument that measures the *Q* of a reactance element directly. It may also be used to measure:

- the reactance and resistance of a circuit,
- the distributed capacity of a circuit,
- the resonant frequency of a tuned circuit, etc.

Fig. 4—32 shows the fundamental circuit of the *Q* meter.

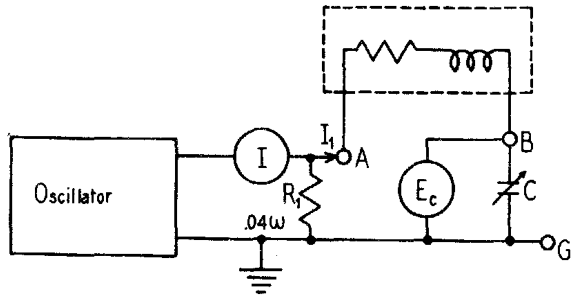

FIG. 4-32. FUNDAMENTAL CIRCUIT OF *Q* METER.

The instrument consists of the variable frequency oscillator, the thermocouple ammeter *I*, the standard resistor *R′*, the standard condenser *C*, and the vacuum–tube voltmeter E_C.

> In the Boonton Type l6OA the frequency range is 50–75 megacycles; *C* has a range of 30-450 microfarads; the *Q* range is 50 to 600. In the Type l70A the frequency range is 30-200 megacycles, *C* has a range of 10–60 microfarads, and the Q range is 80 to l200.

The oscillator supplies a current *I* to *R′* and the unknown and *C*. Since *R′* is very small compared with the impedance of the external circuit, the voltage *E* is equal to *IR′*. Hence the reading *I* gives an indication of the voltage impressed on the circuit.

If the unknown and C are tuned to resonance (i.e., *C* adjusted until E_C = Max.)

$$I' = \frac{E}{R} \qquad (1)$$

where *R* is the effective series resistance of the unknown and *C*. Also

$$E_C = I' X_C = \frac{E X_C}{R} = QE \qquad (2)$$

Hence if *E* is held constant by holding *I* constant, E_C reads directly proportional to *Q* and this meter may be calibrated directly in terms of *Q*. Since E_C is proportional to *E*, *I* may be calibrated in terms of a multiplying factor for extending the *Q* range of the instrument.

> If the distributed capacity *cd* is appreciable in comparison with *C*, the actual *Q* will be = *Q(1 + cd/C)*. This correction is usually negligible.

The above method is applicable for measuring inductance but not for measuring capacity or very low or high values of inductance. This difficulty may be overcome by connecting a coil *L* across terminals *AB*, resonating the circuit, and reading C_1,

Q_1, and the frequency f. The unknown impedance Z is then connected in series with L as shown in Fig. 4–33(a), or in parallel with C as shown in Fig. 4–33(b).

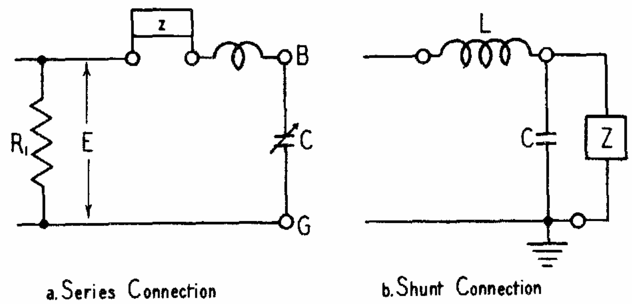

FIG. 4-33. MEASUREMENT OF IMPEDANCE.

C is again adjusted for resonance and the new values C_2 and Q_2 are read. The constants of the circuit may then be calculated by means of the equations given in Table 4–1.

TABLE 4-1. EQUATIONS FOR CALCULATING CONSTANTS OF AN IMPEDANCE

Quantity	Test Circuit of Fig. 4-33a Results in terms of Fig. 4-34a	Test Circuit of Fig. 4-33b Results in terms of Fig. 4-34b
Q	$\frac{Q_1 Q_2 (C_1 - C_2)}{C_1 Q_1 - C_2 Q_2}$	$\frac{Q_1 Q_2 (C_2 - C_1)}{C_1 (Q_1 - Q_2)}$
R	$\frac{1.59 \times 10^8 (C_1 Q_1 - C_2 Q_2)}{C_1 C_2 Q_1 Q_2 f}$	$\frac{1.59 \times 10^8 (Q_1 Q_2)}{C_1 f (Q_1 - Q_2)}$
X	$\frac{1.59 \times 10^8 (C_1 - C_2)}{C_1 C_2 f}$	$\frac{1.59 \times 10^8}{(C_2 - C_1) f}$
L	$\frac{2.53 \times 10^{10} (C_1 - C_2)}{C_1 C_2 f}$	$\frac{2.53 \times 10^{10}}{(C_2 - C_1) f^2}$
C	$\frac{C_1 C_2}{C_2 - C_1}$	$C_1 - C_2$
	If $C_1 > C_2$, X is inductive If $C_1 < C_2$, X is capacitive	If $C_1 > C_2$, X is capacitive If $C_1 < C_2$, X is inductive

C_1 and Q_1 values with unknown removed; C_2 and Q_2 values with unknown in circuit. C in micro-microfarads, L in henries, f in cycles.

For simplicity in calculating, the values are given in terms of the equivalent series circuit of the unknown for the series–

connected test and in terms of the equivalent parallel circuit for the parallel—connected test.

Table 4—2 gives the equations that may be used to change the values from the equivalent series circuit to the values for the equivalent parallel circuit, or vice versa.

TABLE 4-2. EQUATIONS FOR CONVERTING FROM EQUIVALENT SERIES TO EQUIVALENT PARALLEL CIRCUIT

Quantity	Series Circuit (Fig. 4-34a)	Parallel Circuit (Fig. 4-34b)
R	$\left(\frac{1}{1+Q^2}\right) \times R$ Par	$(1+Q^2) \times R$ Ser
X	$\left(\frac{Q^2}{1+Q^2}\right) \times X$ Par	$\left(\frac{1+Q^2}{Q^2}\right) \times R$ Ser
L	$\left(\frac{Q^2}{1+Q^2}\right) \times L$ Par	$\left(\frac{1+Q^2}{Q^2}\right) \times L$ Ser
C	$\left(\frac{1+Q^2}{Q^2}\right) \times C$ Par	$\left(\frac{Q^2}{1+Q^2}\right) \times C$ Ser

The method of arriving at the quantities in Table 4—2 may be illustrated by deriving the expression for the Q of a circuit as measured by the series connection method in Fig. 4—33(a). Let X_1 and R_1 represent the reactance and resistance of coil L, and let X and R represent the reactance and resistance of the unknown impedance.

For the measurements with the unknown removed from the circuit

$$Q_1 = \frac{X_1}{R_1} = \frac{1}{\omega C_1} \qquad (3)$$

and

$$X_1 = \frac{1}{\omega C_1} \qquad (4)$$

Similarly with the unknown inserted in the circuit

$$Q_2 = \frac{X_1 + X}{R_1 + R} = \frac{1}{\omega C_2 (R_1 + R)} \qquad (5)$$

and

$$X_1 + X = \frac{1}{\omega C_2} \qquad (6)$$

where X would be negative if it were capacitive. The Q of the unknown will be

$$Q = \frac{X}{R} \qquad (7)$$

Solving (5) for R and (6) for X, we have

$$R = \frac{X_1 + X}{Q_2} - R_1 = \frac{1}{\omega C_2 Q_2} - R_1 \qquad (8)$$

and

$$X = \frac{1}{\omega C_2} - X_1 \qquad (9)$$

Substituting in (5) gives

$$Q = \frac{\dfrac{1}{\omega C_2} - X_1}{\dfrac{1}{\omega C_2 Q_2} - R_1} = \frac{Q_2 - \omega C_2 Q_2 X_1}{1 - \omega C_2 Q_2 R_1} \qquad (10)$$

But from (4) $X_1 = \dfrac{1}{\omega C_1}$, and from (3) $R_1 = \dfrac{1}{\omega C_1 Q_1}$

Hence

$$Q = \frac{Q_2 - \dfrac{C_2}{C_1} Q_2}{1 - \dfrac{C_2}{C_1}\dfrac{Q_2}{Q_1}} = \frac{Q_1 Q_2 (C_1 - C_2)}{C_1 Q_1 - C_2 Q_2} \qquad (11)$$

One limitation of the Q meter is that the size of the various components must be such that the circuit can be tuned to resonance by means of C. This condition may usually be satisfied by the proper choice of L and of the correct connection. For low–impedance circuits the series connection is usually preferred, and for high impedance the parallel connection is usually better.

The distributed capacity of a coil may be measured by the method shown in Fig. 4–32. The coil is connected to AB, C is set to about 50 picofarads, and the frequency is adjusted to resonance. The frequency is then set at half the previous value and the circuit is adjusted to resonance by adjusting C for resonance. The distributed capacity C_d is then

$$C_d = \frac{C_2 - 4C_1}{3} \qquad (12)$$

where C_2 and C_1 represent the two settings of C.

The resonant frequency of a tuned circuit may be determined by loosely coupling this circuit to the inductance *L* in the *Q* meter circuit. The *Q* of the *Q* meter circuit will drop when the external circuit is tuned to the same frequency as that of the *Q* meter circuit.

Precautions

1. The circuit must always be tuned to resonance by adjusting *C* for maximum reading of the *Q* meter.
2. All leads must be short and heavy.
3. The terminals *A* and *B* are not grounded; hence the unknown circuit should not be grounded except when the parallel connection is used.
4. The accuracy of the device for a very low or a very high Q is definitely limited.
5. The coils *L* must be shielded and precautions must be taken to prevent picking up extraneous signals.

Procedure

1. Measure the *Q*, *R*, and *I* of a number of coils covering a wide range of inductances. Be sure to use both the series and parallel method.
2. Obtain data for and plot curves of *Q* and *R* against frequency over a wide range. Repeat this for several different types of coils.
3. Determine the effect of a coil shield on the *Q* of the coil.
4. Measure the capacity and *Q* of a number of condensers. Be sure to use both series and parallel methods.
5. Obtain data for and calculate the distributed capacity of a coil. Calculate the resonant frequency of the coil (i.e., frequency at which C_d and the coil inductance are in resonance).
6. Measure the self—inductance of both windings of a radio frequency transformer. Measure the inductance of the windings connected series aiding and series opposing. Calculate *M* from

$$L_{Sereies} = L_1 + L_2 - 2M$$

REFERENCES

Boonton Radio Corp., Instructions and Manual of Radio—Frequency Measurements for Q Meters, Type 100A 160A and 170A.

Brown, H. A., *Radio Frequency Electrical Measurements*, pp. 69—71.

Glasgow, B. S., *Principles of Radio Engineering*, p. 30.

Hund, A., *Radio Frequency Measurements*.

Rao, V. V. L., “The Q Meter and Its Theory,” Proceedings, IRE, November, 1942, p. 502.