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The Nature Of Q

W. CULLEN MOORE *Engineering Manager*

A discussion of the physical concepts underlying a familiar and useful, but not always fully appreciated, quantity -- "Quality Factor."

The familiar symbol, Q, has something in common with a certain famous 19th century elephant of Indostan. You may recall that in the poem six blind men each investigated the same elephant with the agreement that they would report their findings to each other and thereby determine the true nature of an elephant. One chanced to touch the side of the elephant and reported "God bless me! But the elephant is very like a wall." Another, touching the tail, proclaimed an elephant was like a rope. The third, chancing upon a leg, avowed the elephant to be kind of a tree, and so on. The confusion of reports prompted the poet to observe in conclusion that, "Each was partly in the right, and all were in the wrong."

And so it is with Q. The concept of Q which each engineer favors is the one based on the way in which he uses Q most frequently. It might be to describe selectivity curves, or the resonant rise in voltage, or the impedance of a parallel resonant circuit, or the envelope of a damped wave train. If one were to ask for a definition of Q, the most common response probably would be "Q equals $\omega L/R_s$". But like the description of the elephant, this too is partly right and partly wrong. The reason is, that while one can obtain a numerical value for Q by dividing the quantity (ωL) by R, it tells little or nothing about the real nature of Q.

The expression $\omega L/R_s$ is a dimensionless ratio and therefore a pure number. As such it enjoys no distinction from other pure numbers. If we are to look for the *meaning* of Q as a basis for its description, we must look for a physical concept. We may then explore the implications and applications of this concept in a variety of specific situations.

Figure 1. The importance of the quantity Q in the analysis of electronic circuits and components has made the Q Meter a familiar laboratory tool. Here, H. J. Lang, BRC Sales Engineer, is checking the accuracy of a Q Meter Type 260-A with the new Q-Standard.

Let us go one step further in our analysis of the expression $\omega L/R_s$. It is not immediately apparent why this *particular* numerical ratio should be chosen to describe certain characteristics of components and circuits over all the other similar ratios which might be set up. The reason for this choice once again refers back to the concept involved in the establishment of a definition for Q. We shall see presently that the basic idea leads directly to a simple expression by which we can determine a numerical magnitude.

In the first place, the Q of a circuit or component has practical significance only when an alternating current, usually sinusoidal in waveform, is flowing through it. The circuit parameters associated with alternating currents, namely capacitance and inductance, have the common characteristic of being capable of storing energy. An inductor stores energy in the form of an electromagnetic field surrounding its winding. A capacitor stores energy in the form of polarization of the dielectric. Each of these systems will deliver most of the stored energy back into the circuit from which it came. These common characteristics indicate that perhaps we should look to energy relationships for an appropriate description of the behavior of circuits.

As mentioned above, most, but not all of the energy stored in an inductor or a capacitor is delivered back into the total system. If we start with this energy concept, we are in a position to derive a *figure* of *merit* for the system in terms of its ability to store energy as compared with the energy it wastes.

Continued on Page 2

YOU WILL FIND. . .

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The Nature of Q (continued)

DERIVATION OF $Q=\omega L/R$

In describing the behavior of a circuit in which an alternating current is flowing (as shown in Fig. 2), it is most convenient to use as our interval one complete current cycle. During this interval the system will have experienced all of its configurations of energy distribution and will have returned as nearly as possible to the starting condition. We are interested in the ratio of the total energy stored in the system to the amount of energy dissipated per cycle by the system.

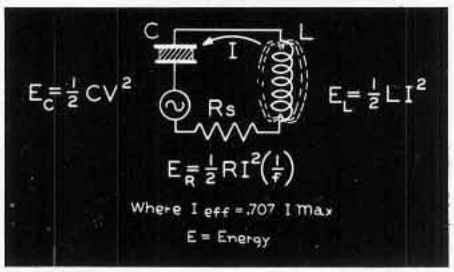


Figure 2. Energy relationships in an elementary a-c series circuit.

To calculate the total stored energy, let us select that portion of the cycle at which all the energy is stored in the field of the inductor. (This is quite arbitrary, as we could just as well assume all the energy to be stored in the capacitor.) We recall from electrical engineering that the energy stored in the field surrounding an inductor is equal to $1/2\ LI^2$. In this case I will be the peak current in amperes.

The *average power* lost in the resistor is $1/2R_sI^2$, where R_s is the total series resistance of all elements in the circuit, and I is the peak current in amperes. The factor 1/2 appears because the (*effective* current) $= .707$ (*peak* current, I), and $(.707I)^2 = 1/2I^2$.

The energy lost per cycle is equal to the average power times the time of one cycle, $T = (1/f)$, or $1/2R_sI^2T$.

The ratio of stored energy to energy dissipated per cycle becomes:

$$\frac{\frac{1}{2}LI^2}{\frac{1}{2}I^2R_sT} = \frac{1}{T}\frac{L}{R_s} = \frac{fL}{R_s} = \frac{1}{2\pi}\frac{2\pi fL}{R_s}$$

$$= \frac{1}{2\pi}\frac{\omega L}{R_s} = \frac{1}{2\pi}Q$$

Hence: $Q = 2\pi \dfrac{\text{total energy stored}}{\text{energy dissipated per cycle}}$

Thus we see that the familiar expression giving the magnitude of the quantity Q follows directly from the basic concept of the ability of a component or circuit to store energy and the energy dissipated per cycle.

Q IN A PARALLEL CIRCUIT

The above analysis has been made on the assumption of a so-called series circuit which assumes all losses in the circuit to be represented by a single resistor in series with a lossless inductor and a lossless capacitor. We are now interested in obtaining an expression for the case in which we are looking at the circuit from the outside, or parallel connection, in which the resistor, the inductor, and the capacitor are all in parallel as shown in Fig. 3.

An equivalent expression for Q for the two circuits of Fig. 3 can be obtained most readily if we consider the current distributions when the applied alternating current has the same frequency as the resonant frequency of the R-L-C combinations. In Fig. 3-a, the current, I, flowing through the circuit from point A to point B is controlled by the parallel resonant impedance of the circuit:

$$Z_{AB} = \frac{(-j\frac{1}{\omega C})(j\omega L + R_s)}{(-j\frac{1}{\omega C}) + (j\omega L + R_s)}$$

At resonance: $|\frac{1}{\omega C}| = |\omega L| = X,$

where $|\ |$ indicates magnitude, so that

$$Z_{AB} = \frac{(-jX)\ (+jX + R_s)}{-jX\ + jX + R_s} = \frac{X^2 - jXR_s}{R_s}$$

$$= \frac{X^2}{R_s} + (-jX).$$

The absolute magnitude of this impedance is

$$Z_{AB} = \sqrt{\left(\frac{X^2}{R_s}\right)^2 + X^2} = X\sqrt{\frac{X^2}{R_s^2} + 1}.$$

Or, $\quad Z = \omega L\ \sqrt{Q^2+1}$

For most practical purposes this reduces to:

$$Z = Q\omega L,$$

which is the impedance of a parallel reasonant circuit. For the external current flowing through Figure 3-a we may then write, $I = E/Q\omega L$.

Referring to Figure 3-b, we may consider that the combination of C and L, with all losses now accumulated into the equivalent parallel resistor R_p, forms at resonance an infinite impedance circuit in shunt with a finite resistor R_p. The current flowing through such a circuit will be $I = E/R_p$.

Equating: $\dfrac{E}{Q\omega L} = \dfrac{E}{R_p}$; or, $Q\omega L = R_p$

Rewriting: $Q = R_p/\omega L$.

where R_p = total effective parallel circuit resistance in ohms.

It is convenient to remember that for the series case, R_s is in the denominator and Q becomes very large as the dissipative component R_s becomes small. In the case of the parallel resonance circuit, the larger the shunt resistance the larger the value of Q.

Summarizing:

$$Q = \frac{\omega L}{R_s} = \frac{1}{\omega C R_s} = \frac{R_p}{\omega L} = \omega C R_p$$

SELECTIVITY

We have seen how the expression $Q = \omega L/R_s$ can be derived directly from power consideration in an R-L-C circuit. By extending the analysis of power relationship in such circuits we can also derive an expression

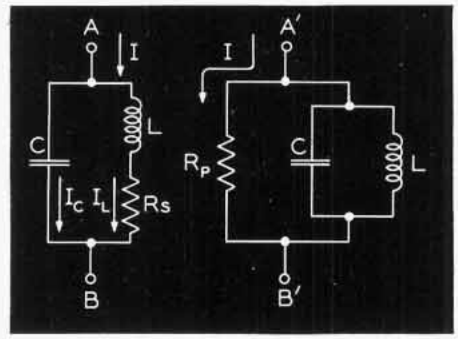


Figure 3. Current distributions in parallel resonant circuits.

which describes the selectivity, or response-versus-frequency, curve for circuits in the vicinity of their natural resonant frequency.

To begin with, we will need to establish two points on the resonance curve for reference. A convenient choice of points is one in which the net circuit inductive or capacitive reactance equals the resistance in the circuit. These two points can be shown to lie at frequencies at which the power in the circuit is one half the power at the maximum response frequency. (See Fig. 4.)

Assume that the reactance equals the resistance. Then the total circuit impedance is equal to the following:

$$Z = \sqrt{R_s^2 + X^2} = \sqrt{R_s^2 + R_s^2}$$

$$= \sqrt{2R_s^2} = 1.414R_s$$

We must remember that this new impedance consists of the original resistance plus some reactance. Only the resistance component of the impedance consumes power. If we apply the same voltage to this circuit at the selected frequency as at the resonant frequency, the current at the new selected frequency will be $I_f = 0.707\ I_o$ where I_o is the current at resonance. The power dissipated in the circuit is then

$$W_f = I_f^2R_s = (.707I_0)^2R_s = .5\ I_0^2R_s$$

$$= .5W_0$$

Let us now see what frequency relationships are involved. Near resonance, if we change the frequency by a small amount Δf toward a higher frequency, the net reactance of the circuit will change due to two equal contributions in the same direction: (1) there will be a small increase in the inductive reactance due to the increased frequency, and (2) there will be an equal amount of decrease in the capacitive reactance. The net change in reactance is the sum of these two equal changes. The change in reactance due to the increased inductive reactance alone is $\Delta X_1 = 2\pi\Delta fL$, and the change in the total reactance is

$$\Delta X = 2(2\pi\Delta fL) = 4\pi\Delta fL.$$

Choose Δf equal to the difference between the frequency at either of the half-power points, f_1 or f_2, and the resonance frequency, f_0. Since we have seen that at the half-power points $X = R$, we can write the two following equations:

$$R_s = 4\pi(f_0 - f_1)\ L$$
$$= 4\pi f_0 L - 4\pi f_1 L$$

$$R_s = 4\pi(f_2 - f_0)\ L$$
$$= -4\pi f_0\ L + 4\pi f_2 L.$$

Adding these two equations:

$$2R = 4\pi(f_2 - f_1)L.$$

Re-arranging and multiplying both sides by f_0

$$\frac{f_0}{(f_2 - f_1)} = \frac{2\pi f_0 L}{R_s} = \frac{\omega L}{R_s} = Q$$

This is the application of Q which is most familiar to radio engineers; namely, an expression of the selectivity of a resonant circuit in terms of Q. As we see above, it is based on the *power* dissipated in the circuit at two selected frequencies.

RESONANT RISE IN VOLTAGE

Let us now look at another common manifestation of the Q of a resonant circuit; namely the voltage multiplication phenomena.

Consider once again the series circuit of Fig. 2 having a total equivalent series resistance, Rs, and a circulating current caused by a small sinusoidal voltage, e, injected in series with the circuit. At series resonance

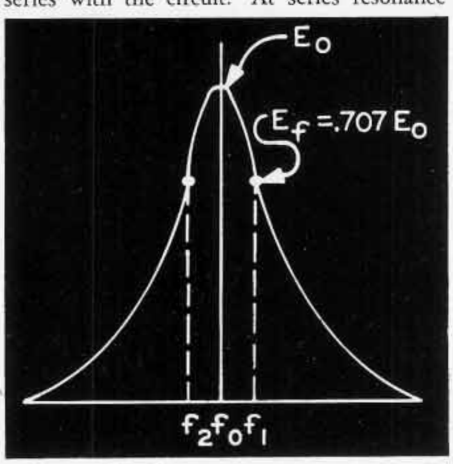


Figure 4. Resonance curve, showing half-power points.

the current circulating within the resonant circuit is limited only by the resistance and will be $I_0 = e/R_s$. This circulating current will produce a voltage across the inductor equal to $E = I_0\ \omega L = (e/R_s)\ \omega L$.

The resonant rise in voltage then is

$$\frac{E}{e} = \frac{\omega L}{R_s} = Q$$

This is often written

$$E = Qe.$$

For relatively high values of R_s (corresponding to low Q) we must also account for the drop across the resistor:

$$E = I_0\ \sqrt{R_s^2 + \omega^2 L^2}$$

$$= \frac{e}{R_s}\ \sqrt{R_s^2 + \omega^2 L^2} = e\ \sqrt{1 + \frac{\omega^2 L^2}{R_s^2}}$$

So for this case

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

Of course we could just as well have analyzed this circuit from the standpoint of the voltage across the capacitor, but we would have arrived at exactly the same results.

POWER DISSIPATION

Proceeding directly out of the method by which we derive Q, namely from the standpoint of energy, we can see that the net Q of the complete oscillator circuit describes the manner in which the circuit causes the current to flow in alternate directions, and describes the energy lost per cycle in the process. This lost energy per cycle must be made up by the power supply of the system or oscillation will die out.

We know that a circuit consisting of an inductor, a capacitor and a resistor in series, which is charged and allowed to oscillate, will experience an exponential decay in the magnitude of the peak current. This decay follows the form $\left(\epsilon^{-\frac{R}{2L}T}\right)$. The portion of this expression R/2L is defined as the *damping coefficient*, and describes the amount by which each successive cycle is lower than its predecessor, as shown in Fig. 5. If we multiply the damping coefficient by the time for one cycle, we obtain the expression known as the *logarithmic decrement* of a circuit, which includes the effect of frequency. In each successive cycle of period T we obtain the following current ratios:

$$\frac{I_2}{I_1} = \epsilon^{-\frac{R}{2L}T} = \epsilon^{-\delta}$$

But $T = \frac{1}{f}$, so $\delta = \frac{R_s}{2fL}$, or $\delta = \frac{\pi}{Q}$

Rewriting: $Q = \frac{\pi}{\delta}$

We see that in this application Q is intimately linked with the rate of decay of oscillation in a dissipative circuit. Before we leave the subject of Q and power, let us mention briefly two other factors which find common usage in electrical engineering. The first of these is the *phase angle* between the

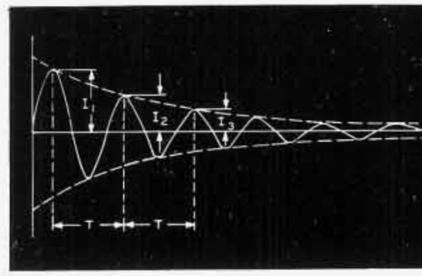


Figure 5. Q as a damping factor.

current and the driving voltage in a circuit containing reactance and resistance. If we once again arbitrarily limit ourselves to consideration of inductors, the expression for phase angle is the familiar formula:

$$\tan\phi = \omega L/R_s = Q$$

Or: Q = (tangent of the phase angle.)

Closely associated with the phase angle is the *power factor*. The power factor of an inductor is the ratio of the total *resistance* absorbing power to the total *impedance* of the device, and is designated by Cos ϕ:

$$\cos\phi = \frac{R_s}{\sqrt{R_s^2 + \omega^2 L^2}} = \frac{R_s}{R_s\sqrt{1 + \frac{\omega^2 L^2}{R_s^2}}}$$

$$= \frac{1}{\sqrt{1 + Q^2}}$$

This is approximately $\cos\phi = \frac{1}{Q}$.

THE Q METER

Practically all of the relationships mentioned above have been used in radio and electrical engineering for a great many years. However, the expression Q and its numerical value of $Q = \omega L/R_s$ did not come into popular usage until the early 1930's. The need for the rapid measurement of Q arose with the growth of the broadcast receiver industry, and Boonton Radio Corporation demonstrated the first *"Q-METER"* at the Rochester IRE Meeting in November, 1934.

A numerical quantity for Q might be obtained by measuring each of the parameters involved in any of the various forms which have been given above. However, certain of these expressions lend themselves to direct measurement much more readily than others. Originally, the favored method was to actually measure ωL and R_s. Later, measurements of Q were based on the frequency relationship, using a heterodyne detector system. This method is feasible but demands great accuracy of the variable frequency generator in order to obtain resasonable accuracy of the final result.

An expression equivalent to the frequency relationship can be written in terms of capacitance. For the series resonant case we obtain the following:

$$Q = \frac{2C_0}{C_2 - C_1}$$

The multiplier 2 is introduced because the change in frequency is proportional to the square root of the change in capacitance. For incremental quantities this reduces to 2.

The relationship which has found almost universal acceptance in the design of instruments for the direct measurement of Q makes use of the resonant rise of voltage principle outlined above. In such instruments, a small radio frequency voltage of known magnitude is injected into the resonating circuit across a very small series resistor. At resonance this voltage causes a current to flow which is limited only by the magnitude of the total equivalent series resistance of the circuit. The current flowing through the inductor results in the resonant rise of voltage given by $E = eQ$. This magnified voltage is read by a vacuum tube voltmeter connected across the resonating capacitor. Since the series voltage injected into the circuit is known, it is possible to calibrate the scale of the voltmeter directly in values of Q.

CONCLUSION

We have seen that the conventional expression for the magnitude of Q can be derived from the basic concept of energy stored compared to energy dissipated per cycle in a resonant system. Its use as a measure of the damping effect in decaying wave trains, its relationship to phase angle and power factor, and the selectivity of a resonant circuit are seen to come out of energy and power considerations. In addition to these factors, such critical basic measurements as radio frequency resistance of a wide variety of components, the loss angle of capacitors, dielectric constants, characteristics of antennas, and transmission line parameters are all part of the continually expanding list made practical by a simple, direct-reading instrument for the measurement of Q, the *Q-Meter*.

BIBLIOGRAPHY

While the equations given above for the various quantities involving Q may be found in many places, the references below offer an excellent presentation of the energy concept:

Principles of Radio Communication; 2nd Edition, 1927, J. H. Morecroft; John Wiley and Son; Page 255 and following.

Radiotron Designers Handbook; 4th Edition, 1952, Radio Corporation of America; Harrison, New Jersey, Page 409 and following.

Vacuum Tube Oscillators, 1st Edition, 1953, William A. Edson; John Wiley and Son; Pages 20-21.

Vacuum Tube Circuits; 1st Edition, 1948, Lawrence B. Arguimbau, John Wiley and son; Pages 184-185.

THE AUTHOR

W. Cullen Moore was graduated from Reed College in 1936 with a B.A. degree in physics. He studied advanced Electrical Engineering, specializing in microwaves and UHF, at Northwestern University between 1939 and 1942, and received an M.A. in physics from Boston University in 1949. From 1940 to 1947 he was Senior Project Engineer for Motorola, Inc., where he directed work on FM receiver design and signal generating equipment. During the war, he had charge of the development of the SCR-511 "Cavalry Set", the redesign of the SCR-536 "Handie-Talkie", and airborne communications equipment.

Between 1947 and 1951, Mr. Moore was a Project Supervisor at the Upper Air Research Laboratory at Boston University, where he supervised the design of rocket-borne electronic equipment. During the same period he taught electronics as an instructor in the B. U. Physics Department. In 1951 he joined Tracerlab, Inc., where he remained as Chief Engineer until 1953, when he accepted the position of Engineering Manager of Boonton Radio Corporation.

Basic Formulas Involving Q

A. TWO-TERMINAL IMPEDANCE

FORMULAS RELATING EQUIVALENT SERIES AND PARALLEL COMPONENTS

$$Q = \frac{X_s}{R_s} = \frac{\omega L_s}{R_s} = \frac{1}{\omega C_s R_s} = \frac{R_p}{X_p} = \frac{R_p}{\omega L_p} = R_p \omega C_p$$

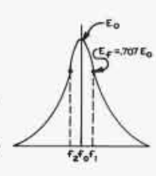
General Formula	Q greater than 10	Q less than 0.1	General Formula	Q greater than 10	Q less than 0.1
$R_s = \frac{R_p}{1+Q^2}$	$R_s = \frac{R_p}{Q^2}$	$R_s = R_p$	$R_p = R_s(1+Q^2)$	$R_p = R_s Q^2$	$R_p = R_s$
$X_s = X_p \frac{Q^2}{1+Q^2}$	$X_s = X_p$	$X_s = X_p Q^2$	$X_p = X_s \frac{1+Q^2}{Q^2}$	$X_p = X_s$	$X_p = \frac{X_s}{Q^2}$
$L_s = L_p \frac{Q^2}{1+Q^2}$	$L_s = L_p$	$L_s = L_p Q^2$	$L_p = L_s \frac{1+Q^2}{Q^2}$	$L_p = L_s$	$L_p = \frac{L_s}{Q^2}$
$C_s = C_p \frac{1+Q^2}{Q^2}$	$C_s = C_p$	$C_s = \frac{C_p}{Q^2}$	$C_p = C_s \frac{Q^2}{1+Q^2}$	$C_p = C_s$	$C_p = C_s Q^2$

B. TUNED CIRCUIT

1. Selectivity

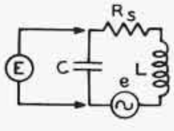
$$Q = \frac{f_0}{f_1 - f_2} = \frac{2C_0}{C_2 - C_1}$$

Where f_1 and f_2 are half-power points and C_0, C_1, and C_2 are capacitance values at f_0, f_2 and f_1 respectively.



2. Resonant Rise in Voltage $Q = \frac{E}{e}$

For relatively large R_s (low Q), $E = e\sqrt{1+Q^2}$



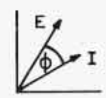
3. Power Dissipation

a. Power Factor = $\cos \phi$

$$= \frac{R}{\sqrt{R^2+L^2\omega^2}} = \frac{1}{\sqrt{1+Q^2}}$$

and for inductors, Q =

$$\tan = \frac{\omega L}{\phi}$$



b. Damped Oscillations $Q = \frac{\pi}{\delta}$, where δ is the logarithmic decrement.

Figure 1. The Q-Standard Type 513-A

The Q-Standard

A NEW REFERENCE INDUCTOR FOR CHECKING Q METER PERFORMANCE

Dr. Chi Lung Kang
James E. Wachter

Widespread acceptance of the Q Meter as a basic tool for electronic research and development has lead, in recent years, to an increasing demand for some convenient means of checking the performance and accuracy of the instrument periodically in the field.

As a result of this demand, BRC engineers have developed the recently-announced Q-Standard Type 513-A, a highly stable reference inductor, intended specifically for use in checking the performance of Q Meters Type 160-A and 260-A. By comparing the accurately-known parameters of this inductor directly with the corresponding values read on the Q Meter, the user may now obtain a dependable indication of the accuracy with which his Q Meter is operating.

The Q-Standard is designed and constructed to maintain, as nearly as possible, constant electrical characteristics. In external appearance the unit is very similar to the inductors (Type 103-A) which are available for use as accessory coils in a variety of Q Meter measurements. This resemblance is only superficial, however, since highly specialized design and manufacturing techniques have been required to provide the high degree of electrical stability demanded of such a unit.

The inductance element consists of a high-Q coil of Litz wire wound on a low-loss steatite form. After winding, the coil is heated to remove any moisture present, coated with silicone varnish, and baked. A stable, carbon-film resistor is shunted across the coil to obtain the proper Q-versus-frequency characteristics. The coil form is mounted on a copper base which in turn is fitted to a cylindrical, copper shield can. The coil leads are brought through the base to replaceable banana plug connectors which allow the unit to be plugged directly into the Q Meter COIL posts. The low potential connector is mounted directly on the base, while the high potential connector is insulated from the base by a steatite bushing. To provide maximum protection against moisture, the unit is hermetically sealed, evacuated, and filled with dry helium under pressure.

ELECTRICAL CHARACTERISTICS

The principal electrical characteristics of each individual Q-Standard are measured at the factory and stamped on the nameplate of the unit. These include the inductance (L), the distributed capacity (C_d), and 3 values of effective Q (Q_e) and indicated Q (Q_i), determined at frequencies of 0.5, 1.0 and 1.5 mc, respectively.

The effective Q may be defined as the Q of the Q-Standard assembly mounted on the Q-Meter, exclusive of any losses occurring in the measuring circuit of the Q Meter itself. It differs from the true Q by an amount which depends largely on the distributed capacitance of the inductor. At the frequencies for which Q_e is given, the following relation is approximately correct:

$$\text{TRUE } Q = Q_e \left(1 + C'_d / C'\right)$$

Where C' and C'_d are corrected values of resonating capacitance and distributed capacitance, respectively, as described below.

The Q of the unit as read on an average Q Meter (indicated Q) will differ from the effective Q by a small percentage which is the result of certain losses inherent in the measuring circuit of the instrument. These losses are minimized, and may usually be disregarded in all but exacting measurements. However, to provide a more accurate check on the Q Meter reading, The Q-Standard is also marked with values of indicated Q. Small variations in the calibration of both the Q Meter and the Q Standard may cause individual instruments to deviate slightly from the expected reading, but a Q Meter Type 160-A or 260-A which indicates within $\pm 7\%$ of the Q_i value marked on the Q-Standard may be considered to be operating within its specified tolerances. Although quantitative indications are not possible, it is worthwhile to note, when wider deviations are encountered, that an error which is greatest at 0.5 mc may indicate calibration inaccuracy, while one which becomes severe at 1.5 mc may be caused by excessive shunt loading effects.

In addition to checking indicated Q, the Q-Standard may be used to determine the calibration accuracy of the Q Meter resonating capacitor. This may be done readily by tuning the measuring circuit to resonance at any desired frequency within the resonant limits of the Q-Standard, and comparing the reading on the capacitor dials with the value predicted by the expression,

$$C = \frac{1}{\omega^2 L} - C_d$$

The measuring circuit of a Q Meter Type 160-A or 260-A, with a Q-Standard mounted on the COIL posts, is represented in Fig. 2-a. Here R_q is the Q Meter shunt loss, Q is the

Q-indicating meter, R_i is the Q Meter injection resistor, and C' is the resonating capacitance. L, R and C_d' represent the inductance, series resistance and corrected distributed capacitance, respectively, of the Q-Standard. The equivalent circuit shown in Fig. 2-b indicates the corresponding *effective* parameters of the Q-Standard, which are related to the values in Fig. 2-a as follows:

$$L_e = \frac{L}{1-\omega\ LC_d'}$$

$$R_e = \frac{R}{(1-\omega^2 LC_d')^2}$$

$$Q_e = \frac{\omega\ Le}{R_e}$$

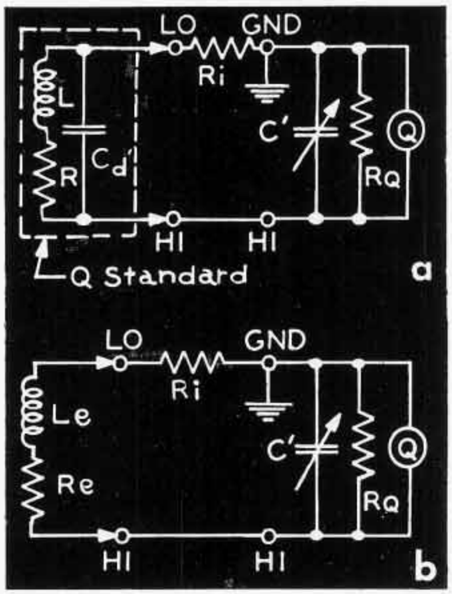


Figure 2. Schematic representation of Q Meter measuring circuit with Q-Standard attached.

It is worthwhile to consider, briefly, the corrected value of distributed capacitance (C_d') mentioned above. This value is the distributed capacitance of the Q-Standard when it is actually mounted on the Q Meter. It differs by a small, constant value from the distributed capacitance (C_d) marked on the nameplate, because of a capacitance shift caused by the proximity of the Q-Standard shield can to the Q Meter HI post. This proximity causes the transfer of a small value of capacitance from between the Q Meter HI post and ground to between the HI post and the Q-Standard shield can. This results in a change in the calibration of the resonating capacitor, and a corresponding change in the Q-Standard distributed capacity.

Thus, if the tuning dial of the resonating capacitor is adjusted to a value, C, with nothing attached to the coil posts, the actual value of tuning capacitance will be reduced by a small constant to a new value, C', when the Q-Standard is connected. At the same time, the distributed capacitance of the Q-Standard is increased to become Cd'. The magnitude of this effect is 0.4 $\mu\mu f$, and we may write,

$$C' = C - 0.4\ \mu\mu f$$

$$C_d' = C_d + 0.4\ \mu\mu f$$

When the Q-Standard is used to check the calibration of the resonating capacitor, in the manner described above the value, Cd, indicated on the nameplate is used. In other applications, however, where accurate results are desired, the corrected values, C' and Cd', must be used. In determining Q_e for example,

$$Q_e = \frac{\omega\ Le}{R_e} = \frac{1}{R_e\ \omega C'},$$

it can be seen that the correction may assume some importance, particularly at 1.5 mc, where C' is relatively small.

It should be noted that, in order to hold this proximity effect constant, particular care has been taken to provide for accurately-reproducible positioning of the Q-Standard with respect to the Q Meter HI post. For this purpose, the base of the high-potential connector serves as a mounting stop. When this connector is fully inserted in the HI post, the low potential connector (which is the shorter of the two) will not be fully seated in the LO post, and the insulated support attached to the Q-Standard base will not touch the top of the Q Meter cabinet.

If desired, a secondary standard inductor may be derived from the Q-Standard by means of a comparison method which is both simple and accurate. The accuracy of the Q Meter, which is the only equipment needed, has only higher order effects on the results.

The inductor selected should have electrical parameters and outside shield dimensions which are fairly close to those of the Q-Standard. The standardization (i.e. accurate determination of the effective Q of the secondary standard) is done as follows: First, plug the Q-Standard into the Q Meter and resonate the measuring circuit at one of the three frequencies (0.5, 1.0 or 1.5 mc) for which Q_e is given on the Q-Standard nameplate. Then replace the Q Standard with the secondary standard and obtain readings of $\triangle Q$ (from the $\triangle Q$ scale) and $\triangle C$ ($C_1 - C_2$). With the data given on the Q-Standard nameplate, determine C' from,

$$C' = \frac{1}{2L} - (C_d + 0.4\ \mu\mu f)$$

The effective Q of the secondary standard may then be determined from the relation,

$$Q_e(\text{unkown}) = \frac{\omega(C'+\Delta C)}{\frac{\omega C'}{Q_e} + \frac{\omega C'}{(Q+\Delta Q)}\left[(1+\frac{\Delta C}{C'})(1-\frac{\Delta Q}{Q+\Delta Q})-1\right]}$$

where C_d, L and Q_e are given on the Q-Standard nameplate.

Service Note

REPLACING THE THERMOCOUPLE ASSEMBLY TYPE 565-A IN THE Q METER TYPE 260-A

It is the function of the Q Meter thermocouple to monitor accurately the voltage injected by the oscillator into the measuring circuit. Although the unit in the Q Meter Type 260-A has been made considerably more rugged than that of the older Q Meter Type 160-A, it is necessarily a sensitive device which may be subject to damage or burnout under prolonged overload. For this reason, care is necessary in operating the instrument to avoid increasing the oscillator output (indicated on the XQ Meter) into the "red-lined" region beyond the indicated X1 value.

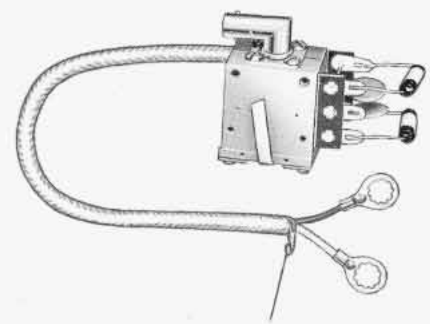


Figure 1. Thermocouple Assembly Type 565-A

If thermocouple failure should occur, the assembly may be replaced, by the user, with a new assembly obtained from the factory, if the proper care is taken. In ordering, it is necessary to include the serial number of the Q Meter in which the thermocouple is to be used since they must be individually matched. The procedure outlined below is presented as reference material for the convenience of Q Meter Type 260-A owners.

CHECKING FOR THERMOCOUPLE FAILURE

If no reading can be obtained on the XQ meter, thermocouple burnout may be sus-

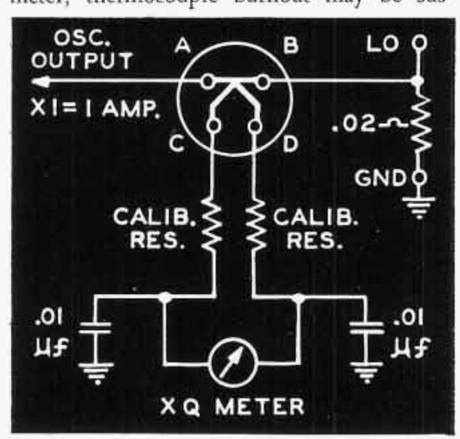


Figure 2. Thermocouple circuit of the Q Meter Type 260-A.

pected. Since this symptom may also be produced by failure of the local oscillator, however, the output of the latter should be checked first. This may be done by measuring from point A (See Fig. 2) to ground with a vacuum tube voltmeter. If the oscillator produces a voltage across these points, disconnect one lead from the XQ meter and check for continuity between points A-C, A-B, B-D and C-D. An open circuit between any of these indicates thermocouple failure. The maximum resistance of the XQ meter is 65 ohms; the total resistance of the junction circuit loop, including the XQ meter, calibration resistors and thermocouple element, can vary from 85 to 115 ohms. CAUTION: Do not disassemble the thermocouple unit.

REPLACEMENT PROCEDURE

The 565-A thermocouple replacement assembly for the Q Meter Type 260-A includes the thermocouple unit itself, a 0.02 ohm insertion resistor, two calibration resistors and two filter capacitors. Replacement of the assembly should be made as follows:

1. Remove the front panel and chassis assembly from the Q Meter cabinet and place it, face down, on a flat work surface.
2. Remove the UG-88/U plug from the receptacle at the rear of the thermocouple assembly.
3. Unscrew and remove the LO binding post terminal nut. Then, using a right-angle soldering iron (see Fig. 3), carefully unsolder the thin metal strap which connects the thermocouple unit to the bottom of the LO post.
4. Remove the terminal lugs from the XQ meter and unclamp the cable from the front panel and resonating capacitor frame.
5. Remove the four mounting screws from the thermocouple assembly, and carefully remove the assembly from the Q Meter.
6. Install the new unit and connect the attached cable to the XQ meter terminals, observing the indicated polarity. Clamp the cable to the front panel and resonating capacitor frame.

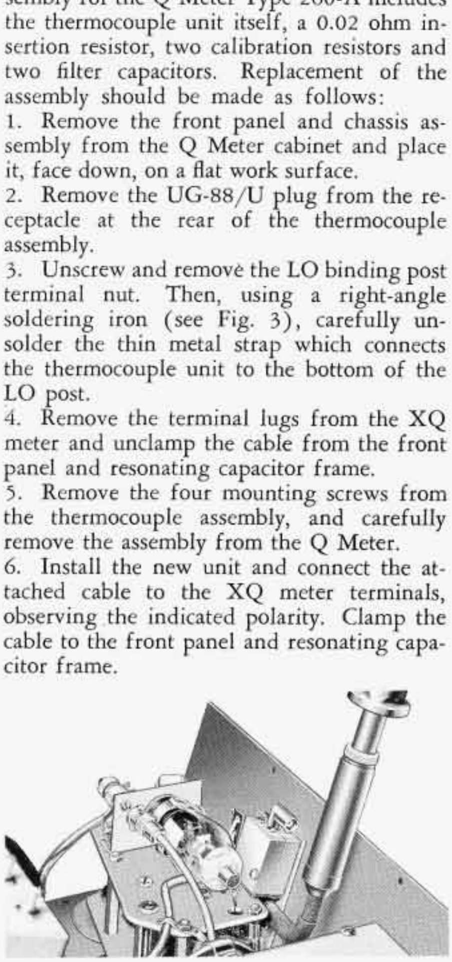


Figure 3. Using a right-angle soldering iron to solder the thermocouple connecting strap in place

7. Trim the connecting strap to a length which will permit it to reach the bottom of the LO post with a small amount of slack to allow for binding post movement. Solder this strap to the LO post, being careful not to leave the iron in contact with the strap any longer than necessary.
8. Replace the binding post nut and return the instrument to its cabinet.— **E. GRIMM**

an introduction to BOONTON RADIO CORPORATION

Frank G. Marble, ***Sales Manager***

The Boonton Radio Corporation was formed in 1934. Since that time it has been developing, designing, and manufacturing precision electronic instruments. To understand some of the details of the Company's growth, we must take a look at the field of electronics for a few years preceding 1934.

Many of the concepts that made wireless communication possible were discovered before the First World War. During this war many new ideas evolved and considerable practical experience was gained in the use of the new ideas. A keen public appreciation of the usefulness of the transmission of intelligence over a distance without wire connection appeared at this period. In the years following the war, manufacturers began devoting time and money to the use of radio devices for many purposes. They found it necessary to obtain component parts which were new to most of them, and they needed methods for testing both the component parts and their final products.

Under these conditions the Radio Frequency Laboratories was organized in Boonton, New Jersey. The staff consisted, at first, of one radio engineer, and their work concerned the manufacture of coil forms and other radio parts using insulating material. As time passed, additional technical personnel was added and the work of general engineering consultation was undertaken. This type of work naturally led to a good understanding of test equipment requirements.

In 1934, Mr. William D. Loughlin, who had been President of Radio Frequency Laboratories, together with several of his associates, formed the Boonton Radio Corporation. The first product of the new company was a Q Meter which read Q directly on a meter scale. Up until that time the measurement of Q had been made indirectly by use of bridges for measuring the effective reactance and resistance concerned. These measurements had been subject to error because of the techniques required, and useful measurements took a great deal of time. With the new Q Meter, measurements were simple and rapid, and the instrument proved capable of many additional valuable laboratory measurements on basic components and circuits. The flexible, accurate, easily used instrument was accepted almost immediately by the growing radio industry.

By 1941 a new model, replacing the earlier Q Meter, was introduced and the Company undertook development work on a frequency-modulated signal generator to meet the requirements for test equipment which the new frequency-modulated communication equipment demanded. Commercial instruments were made available and Boonton Radio Corporation continues to this date to make several forms of frequency-modulated test signal generators.

The early years of the Second World War brought the use of higher and higher frequencies, and a Q Meter similar to the earlier models, but applicable to higher frequencies, was designed. At the same time the activities of the Company were directed more and more to military applications. Its Q Meter and Frequency Modulated Signal Generators were widely used in military work and the Company produced a pulse modulated RF signal generator for use in testing radar systems. This instrument was produced in large quantities and is still used by all military services.

At the end of the War the FM Signal Generator was redesigned to permit coverage of a wider frequency range, to include AM as well as FM, and to obtain deviations in frequency which did not vary with carrier frequency. This instrument had very low leakage and a wide selection of accurately calibrated output voltages. It soon became the standard in its field and still maintains that position.

The aircraft transportation field in the 1940's was developing more accurate methods of navigation and better methods of landing in bad weather. A system for solving these problems was approved by the Civil

Aeronautic Administration and put in use both commercially and by the military services. Unusually accurate and specialized test equipment was required by this system and Boonton Radio Corporation was asked to undertake a design. A Signal Generator for Navigation equipment was produced in 1947 and an additional piece of equipment for testing receivers used in landing airplanes came very shortly after this. In 1952 the Company produced a more advanced model of the "Glide Path" testing equipment for the landing of aircraft.

In the last few years, the Company has turned its efforts to the development of self-contained, broad-band, flexible instruments containing RF bridges for measurement of components and cables. A new instrument, the RX Meter, was introduced which measures parallel resistance and parallel reactance of two-terminal networks over the LF and VHF ranges. The low frequency and high frequency Q Meters have been redesigned to include new features which increase the usefulness and accuracy of the equipment.

Companies, like people, have characteristics which identify them. From its formation to the present time, the Boonton Radio Corporation has built products of high quality. No attempt has been made to produce cheap instruments, and the quality and usefulness per invested dollar has been kept high. Close tolerances, high stability, mechanical soundness, and broad applicability have all been built into the Company's equipment. The Company regards its products as fine general-purpose tools for electronics craftsmen.

A Note From The Editor...

Since this is the first issue of THE NOTEBOOK, it seems appropriate to take a few lines to define the policies and purpose of our new publication. Briefly, THE NOTEBOOK has been planned and produced in order to distribute, to you and to as many interested persons as possible, information which we feel to be of value on the theory and practice of radio frequency testing and measurement.

In the past we have limited ourselves substantially to advertising, catalogs and instruction manuals for the broad distribution of such information. Inevitably, much important data was found to be too detailed for ads and catalogs; many new applications and techniques were learned or developed after publication of the instruction manuals. To provide a means, therefore, of informing you periodically of new methods and developments, and to furnish you with reference and background material of value in the application of our test equipment, THE NOTEBOOK has been established.

We feel that the name which we have selected is particularly appropriate, since much of the information which it will contain will be taken from our field and laboratory engineering notebooks, and since this and subsequent issues will, we believe, find a place in your own reference notebook. For the latter purpose, we have adopted standard notebook dimensions and punching in selecting our format.

Because the Q Meter is so well known and widely used, we have devoted most of the first issue to this instrument and the quantity which it measures. Our lead article discusses the nature of Q itself, using an approach somewhat different from the usual textbook handling of the subject. Then we have included some information on the recently-developed Q-Standard, a reference inductor designed to provide a check on Q Meter performance. A service note provides detailed information on the replacement of the thermocouple in the Q Meter Type 260-A. Finally, to introduce ourselves to you, we have included a brief outline of the history of our company.

THE NOTEBOOK will be published four times a year; in March June, September and December. A written request, giving your company, title and mailing address is enough to start you as a subscriber. If you have any suggestions, comments or questions concerning the contents or policies of THE NOTEBOOK, we would be happy to have you direct them to Editor, THE NOTEBOOK, Boonton Radio Corp., Boonton, N. J.

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