Note: The following information applies to frequency tuned circuit applications.

The Q formula calculates the ratio of reactance to effective resistance for an inductor and thus indicates its quality. For electrical wave filters, an increase in Q provides sharper cut-off, higher attenuation ratios, and better defined resonance. Q is affected by the distributed capacitance of an inductor's winding.

Neglecting the effects of self-resonance caused by the distributed capacitance (see paragraph 4c, below) Q can be calculated, when designing inductors, by this formula:**

$$Q = \frac{\omega L}{R_{dc} + R_{ac} + R_{cd}}$$

Q = quality factor
L = inductance (henries)
ω = 2π X frequency (frequency in hertz)
R_{dc} = dc winding resistance (ohms)
R_{ac} = resistance due to core losses (ohms)
R_{cd} = resistance due to dielectric losses in winding (ohms)

The Q curves published in this manual are not to be construed as guaranteed minimum values. Instead they represent what might be attainable under ideal conditions. They were developed theoretically and have been checked with various core sizes and inductances to assure reasonable correspondence to the real world of wire, insulation and winding. The user's ability to get equivalent results depends in part upon his ability to duplicate the assumed conditions.
These are:

1. A "full-wound core" is defined to be one in which the minimum winding ID or residual hole left after winding is one-half of the inside diameter of the core.
2. This leaves a useful winding area which is three-quarters of the available window area. It was assumed that 70% of this space would be filled with copper wire including heavy synthetic film insulation.
3. The dc resistance of a full-wound core varies as the square of the number of turns in the same manner that the resultant inductance varies as the square of the turns. Therefore, each core size has a table of calculated ohms per millihenry based on the "full-wound core" definition above. This resistance determines the positive slope of the low frequency portion of the Q curve and is assumed to be independent of inductance.
4. Three factors affect the high frequency performance of an inductor.
   a. The most fundamental is the loss of the core material which is mostly responsible for the negative slope of the low inductance curves at frequencies above the frequency of maximum Q. This is calculated from Legg's equation (see next section).

This analysis follows Herman Blinchikoff, "Toroidal Inductor Design," ***Electro-Technology,* November, 1964.

   b. The second factor is caused by dielectric loss. Dielectric loss resistance is significant at higher frequencies and can be calculated from the equation found in Terman's Handbook.***

$$R_{cd} = d\omega^3 L^2 C_d$$

d =power factor of distributed capacitance

Values of d

125μ & over	.0118
60μ	.0417
26μ	.0750
14μ	.0900

ω = 2π X frequency in hertz
L = Inductance in henries
C_d = distributed capacitance in farads

   c. The most dramatic factor is the effect of self resonance of the distributed capacitance and the inductance. For small inductances, such as the 0.001 henry or the 0.01 henry curve for each core, the self-resonant frequency f_o is well above the normal useful frequency range of the component. Therefore, these curves tend to indicate the component performance with a negligible effect of self resonance. The distributed capacitance and the self inductance determine a self-resonant frequency according to:

$$f_o = \frac{1}{2\pi\sqrt{LC_d}} \text{ hertz.}$$

At some lower frequency, f, the value Q_f can be calculated from:

$$Q_f = Q\left[1 - \left(\frac{f}{f_o}\right)^2\right]$$

where Q is calculated from determined values of loss resistances as indicated above, and Q_f is the apparent Q, taking into account the effect of the distributed capacitance. It should be noted that when f is 20% of f_o, Q_f is 96% of its original value. However, when f is 70% of f_o, Q_f drops to 51% of its original value. The apparent value of the inductance, L_a, is also affected as follows:

$$L_a = \frac{L}{1 - \left(\frac{f}{f_o}\right)^2}$$

5. Because the distributed capacitance is determined by the winding method, the user can obtain different results from those plotted, depending on this value of the capacitance. Each Q curve is marked with the capacitance value used.

***_**Radio Engineer's Handbook,**_ F.E. Terman, McGraw-Hill, Inc., New York (1943), p. 84.

Molybdenum Permalloy Core Loss at Low Magnetic Flux Densities

LEGG'S EQUATION[1]...total core loss at low flux densities is the sum of three component losses - hysteresis, residual and eddy current. Values of typical loss coefficients are found in the following table for each permeability. The core loss in terms of ohms per henry per unit of permeability is calcuated from Legg's Equation:

$$\frac{R_{ac}}{\mu L} = aB_{max} f + cf + ef^2$$

Watts of loss from Legg's Equation may be determined by:

$$\text{Watts of Loss} = 3.98\, B^2_{max}\, Al \left[\frac{R_{ac}}{\mu L}\right] 10^{-9}$$

or

$$\text{Watts of Loss} = \frac{3.98\, B^2_{max}\, Al}{\mu 10^6} \left[\text{ohms/mhy**}\right]$$

** from core loss curves

R_{ac} = effective resistance due to core losses (ohms)
μ = permeability of core
L = inductance (henries)
a = hysteresis loss coefficient
B_{max} = maximum flux density (gausses)
c = residual loss coefficient
f = frequency (hertz)
e = eddy loss coefficient
A = core area (cm^2)
l = mean magnetic path (cm)

Molybdenum Permalloy Electrical Specifications and Typical Loss Coefficients

SPECIFICATIONS					TYPICAL VALUES		
Perm. μ ±8%	Maximum Core Loss $\frac{R_{ac}}{\mu L}$ $\frac{\text{ohms}}{\text{Henry} \times \mu}$	Test: Flux Density (Gausses)	Test: Frequency Hertz	Maximum Permeability Change after Magnetization†	Hysteresis Loss Coefficient a	Residual Loss Coefficient c	Eddy Current Loss Coefficient e
300	0.25	20	1800	± 0.5%	1.1×10^{-6}	30.0×10^{-6}	43.0×10^{-9}
250	0.25	20	1800	± 0.5%	1.2×10^{-6}	26.0×10^{-6}	37.0×10^{-9}
205	0.25	20	1800	± 0.5%	1.3×10^{-6}	25.0×10^{-6}	30.0×10^{-9}
173	0.20	20	1800	± 0.5%	1.4×10^{-6}	25.0×10^{-6}	25.0×10^{-9}
160	0.20	20	1800	± 0.5%	1.5×10^{-6}	25.0×10^{-6}	22.0×10^{-9}
147	0.20	20	1800	± 0.5%	1.6×10^{-6}	25.0×10^{-6}	20.0×10^{-9}
125	0.20	20	1800	± 0.5%	1.6×10^{-6}	25.0×10^{-6}	13.0×10^{-9}
60	1.50	10	8000	± 0.3%	3.2×10^{-6}	50.0×10^{-6}	10.0×10^{-9}
26	70	4	75000	± 0.2%	6.9×10^{-6}	96.0×10^{-6}	7.7×10^{-9}
14	65	4	75000	± 0.1%	11.4×10^{-6}	143.0×10^{-6}	7.1×10^{-9}

† *Measured three minutes after the application of a dc magnetizing force of 30 oersteds for 60 and higher permeabilities or 60 oersteds for 26 and 14 permeabilities.*

1-*Legg, V.E., "Magnetic Measurements at Low Flux Densities Using the A-C Bridge," The Bell System Technical Journal, Vol. 15, January, 1936, pp. 39-63.*

Charts showing the typical core loss resistance in ohms per millihenry for each permeability material are found on pages 11 and 12.