Q Factor

Quality Factor (Q) Explained

The Quality Factor, or Q, is one of the most important parameters in resonant circuit design. It quantifies how "sharp" a resonance is and directly determines the voltage magnification achievable in a VIC circuit.

What is Q Factor?

The Q factor is a dimensionless parameter that describes the ratio of energy stored to energy dissipated per cycle in a resonant system. A higher Q means:

- Lower losses relative to stored energy
- Sharper resonance peak
- Higher voltage magnification at resonance
- Narrower bandwidth
- Longer ring-down time when excitation stops

Q Factor Formula

For a series RLC circuit, Q can be calculated several ways:

Primary Definition:

$$Q = (2? \times f? \times L) / R$$

Alternative Forms:

$$Q = X_L / R = (?L) / R$$

$$Q = 1 / (?CR) = X_C / R$$

$$Q = (1/R) \times ?(L/C) = Z? / R$$

Where:

> - f_0 = resonant frequency (Hz)
> - L = inductance (Henries)
> - R = total series resistance (Ohms)
> - C = capacitance (Farads)
> - $\omega = 2\pi f_0$ (angular frequency)
> - $Z_0 = \sqrt{(L/C)}$ (characteristic impedance)

Physical Meaning of Q

Q can be understood as:

Q = 2π × (Energy Stored / Energy Dissipated per Cycle)

A Q of 100 means the circuit stores 100/(2π) ≈ 16 times more energy than it loses per cycle.

Q Factor and Voltage Magnification

At resonance, the voltage across the inductor (or capacitor) is magnified by the Q factor:

$$V_L = V_C = Q \times V_{input}$$

Example: With Q = 50 and V_{input} = 12V:

V_L = 50 × 12V = **600V** across the inductor!

This is why Q factor is so critical in VIC design—it directly determines how much voltage amplification the circuit provides.

Factors Affecting Q

Resistance Sources

Resistance Source	Description	How to Minimize
Wire DCR	DC resistance of the wire	Use larger gauge, shorter length, or copper

Resistance Source	Description	How to Minimize
Skin Effect	AC resistance increase at high frequency	Use Litz wire or multiple strands
Core Losses	Hysteresis and eddy currents in core	Use appropriate core material for frequency
Capacitor ESR	Equivalent series resistance of capacitor	Use low-ESR capacitors (film, ceramic)
Connection Resistance	Resistance at joints and connections	Use solid connections, avoid corrosion

Wire Material Impact on Q

Different wire materials have vastly different resistivities:

Material	Relative Resistivity	Effect on Q
Copper	1.0× (reference)	Highest Q (best for resonant circuits)
Aluminum	1.6×	Good Q, lighter weight
SS316	~45×	Lower Q, but corrosion resistant
SS430 (Ferritic)	~60×	Much lower Q, magnetic properties
Nichrome	~65×	Very low Q, used for heating elements

Typical Q Values

- **Air-core inductors:** Q = 50-300 (very low losses)
- **Ferrite-core inductors:** Q = 20-100 (depends on frequency)
- **Iron-powder cores:** Q = 50-150
- **Practical VIC chokes:** Q = 10-50 (with resistance wire, lower)

Q and Bandwidth Relationship

Q is inversely related to bandwidth:

```
BW = f? / Q
```

Where BW is the -3dB bandwidth (the frequency range where response is within 70.7% of peak).

Example: At f_0 = 10 kHz with Q = 50:

BW = 10,000 / 50 = **200 Hz**

Practical Q Measurement

Q can be measured experimentally by:

1. **Frequency sweep method:** Find f_0 and the -3dB points, then $Q = f_0/BW$
2. **Ring-down method:** Count cycles for amplitude to decay to 1/e (37%)
3. **LCR meter:** Direct measurement at specific frequencies

VIC Design Insight: While higher Q gives more voltage magnification, it also means the circuit is more sensitive to frequency drift and component tolerances. A practical VIC design balances high Q for voltage gain against stability and ease of tuning.

Next: Bandwidth & Ring-Down Decay →

Revision #1
Created 2026-01-01 20:35:35 UTC by Chris Bake
Updated 2026-01-01 20:35:47 UTC by Chris Bake