

# DCR Effects

## DC Resistance and Q Factor

The DC resistance (DCR) of an inductor is the primary factor limiting its Q factor and thus the voltage magnification achievable in a VIC circuit. Understanding and minimizing DCR is essential for high-performance designs.

### What is DCR?

DCR is simply the resistance of the wire used to wind the inductor, measured with direct current:

$$R_{dc} = \rho \times l_{wire} / A_{wire}$$

Where:

- $\rho$  = resistivity of wire material ( $\Omega \cdot m$ )
- $l_{wire}$  = total wire length (m)
- $A_{wire}$  = wire cross-sectional area ( $m^2$ )

## DCR and Inductor Design

For a given inductance, DCR depends on the design choices:

Design Change	Effect on L	Effect on DCR	Net Q Effect
More turns	$L \propto N^2$	$R \propto N$	$Q \propto N$ (improves)
Larger wire gauge	No change	R decreases	Q improves
Higher $\mu$ core	L increases	Fewer turns needed	Variable*
Larger core	L increases	Longer mean turn	Often improves

Design Change	Effect on L	Effect on DCR	Net Q Effect
Copper vs. SS wire	No change	$R \times 40-60$	$Q \div 40-60$

\*Core losses may offset wire resistance reduction at high frequencies

## Q Factor Calculation

Q Factor at Operating Frequency:

$$Q = 2\pi fL / R_{total}$$

Total Resistance includes:

$$R_{total} = R_{dc} + R_{skin} + R_{proximity} + R_{core}$$

At low frequencies,  $R_{dc}$  dominates. At high frequencies, skin effect and core losses become significant.

## Voltage Magnification Impact

Since voltage magnification equals Q at resonance:

Example Comparison:

Scenario	L	DCR	Q @ 10kHz	V <sub>out</sub> (12V in)
22 AWG Copper	10 mH	5 Ω	126	1,508 V
26 AWG Copper	10 mH	13 Ω	48	580 V
22 AWG SS316	10 mH	220 Ω	2.9	34 V
22 AWG Nichrome	10 mH	320 Ω	2.0	24 V

## Measuring DCR

### Method 1: Multimeter

- Simple and quick
- Set meter to lowest resistance range
- Subtract lead resistance
- Accuracy:  $\pm 1-5\%$

## Method 2: 4-Wire (Kelvin) Measurement

- Eliminates lead resistance error
- Required for low DCR ( $< 1 \Omega$ )
- Uses separate sense and current leads
- Accuracy:  $\pm 0.1\%$

## Method 3: LCR Meter

- Measures L and DCR together
- Can measure at different frequencies
- Shows equivalent series resistance (ESR)
- Best for complete characterization

# Optimizing DCR

## Design Strategies:

1. **Use the largest wire that fits:** Fill the available winding area
2. **Choose copper:** Unless current limiting is specifically needed
3. **Use higher permeability core:** Fewer turns needed for same L
4. **Optimize core size:** Larger cores have more room for thicker wire
5. **Consider parallel windings:** Two parallel wires = half the DCR

## Practical Limits:

- Wire must fit on the core with proper insulation

- Multiple layers increase parasitic capacitance
- Very thick wire is hard to wind neatly
- Cost and availability of materials

# Temperature Effects

Wire resistance increases with temperature:

$$R(T) = R_{20^{\circ}\text{C}} \times [1 + \alpha(T - 20)]$$

Where  $\alpha \approx 0.00393 /^{\circ}\text{C}$  for copper

## Example:

At  $80^{\circ}\text{C}$ :  $R = R_{20^{\circ}\text{C}} \times 1.24$  (+24% increase)

This means Q drops by ~20% when the choke heats up!

# DCR in the VIC System

The total resistance in a VIC circuit includes:

Source	Typical Range	Mitigation
L1 DCR	1-50 $\Omega$	Optimize winding
L2 DCR	1-50 $\Omega$	Optimize winding
Capacitor ESR	0.01-1 $\Omega$	Use low-ESR caps
WFC solution resistance	10-10000 $\Omega$	Electrode design, electrolyte
Connection resistance	0.01-1 $\Omega$	Solid connections
Driver output resistance	0.1-10 $\Omega$	Low $R_{\text{ds(on)}}$ MOSFETs

# Practical Example

Target: 10 mH inductor at 10 kHz with  $Q > 50$

Required  $R_{\text{max}}$ :

$$Q = 2\pi fL/R \quad R = 2\pi fL/Q = 2\pi \times 10000 \times 0.01 / 50 = 12.6$$

### Wire selection (100 turns on 25mm toroid):

Mean turn length  $\approx$  80mm, total wire = 8m

- 22 AWG copper:  $8\text{m} \times 0.053 \Omega/\text{m} = 0.42 \Omega$  ✓
- 26 AWG copper:  $8\text{m} \times 0.134 \Omega/\text{m} = 1.07 \Omega$  ✓
- 30 AWG copper:  $8\text{m} \times 0.339 \Omega/\text{m} = 2.71 \Omega$  ✓
- 22 AWG SS316:  $8\text{m} \times 2.3 \Omega/\text{m} = 18.4 \Omega$  ✗ (Q = 34)

**Result:** 22-30 AWG copper all meet the requirement. 22 AWG gives highest Q but may be harder to wind.

**VIC Matrix Calculator:** Enter your wire gauge and material in the Choke Design tool. It calculates DCR automatically and shows how it affects Q factor and voltage magnification. The calculator warns if your DCR is too high for effective resonance.

*Chapter 5 Complete. Next: Water Fuel Cell Design →*

---

Revision #1

Created 2026-01-01 20:42:20 UTC by Chris Bake

Updated 2026-01-01 20:42:29 UTC by Chris Bake