Choke Design

Choke Fundamentals

Inductor/Choke Fundamentals

Inductors, commonly called "chokes" in VIC terminology, are the workhorses of the resonant circuit. They store energy in their magnetic field and, together with capacitors, determine the resonant frequency and voltage magnification capability of the VIC.

What is an Inductor?

An inductor is a passive electrical component that stores energy in a magnetic field when current flows through it. The fundamental properties are:

Inductance (L):

Measured in Henries (H), inductance quantifies the magnetic flux linkage per unit current:

$$L = N?/I = N^{2}?A/l$$

Where:

> - N = number of turns
> - Φ = magnetic flux
> - I = current
> - μ = permeability of core material
> - A = cross-sectional area of core
> - l = magnetic path length

Key Inductor Parameters

Parameter	Symbol	Units	Importance
Inductance	L	Henry (H)	Determines resonant frequency with C

Parameter	Symbol	Units	Importance
DC Resistance	DCR, R_{dc}	Ohms (Ω)	Limits Q factor and causes losses
Self-Resonant Frequency	SRF	Hz	Must be > operating frequency
Quality Factor	Q	Dimensionless	Ratio of reactance to resistance
Saturation Current	I_{sat}	Amps (A)	Max current before inductance drops

Inductor Construction

A practical inductor consists of:

1. **Wire:** Conductor wound into coils (turns)
2. **Core:** Material inside the coil (air, ferrite, iron, etc.)
3. **Form:** Structure that holds the winding

Types of Cores

Core Type	Permeability	Frequency Range	VIC Application
Air core	1 (reference)	Any (no losses)	High-Q, low inductance
Iron powder	10-100	Up to ~10 MHz	Good for VIC frequencies
Ferrite	100-10000	10 kHz - 100 MHz	Most common for VIC
Laminated iron	1000-10000	50/60 Hz to ~10 kHz	Lower VIC frequencies

Inductance Formulas

Single-Layer Solenoid (air core):

$L = (N^2??A)/l = (N^2 r^2)/(9r + 10l)\ \mu H$

Where r and l are in inches (Wheeler's formula)

With Magnetic Core:

$$L = A_L \times N^2 \text{ (nH)}$$

Where A_L is the inductance factor of the core (nH/turn²)

Toroidal Core:

$$L = (???_r N^2 A) / (2?r_{mean})$$

DC Resistance (DCR)

The DC resistance is determined by the wire properties:

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

Where:

- ρ = resistivity of wire material (Ω·m)
- l_{wire} = total wire length $\approx N \times \pi \times d_{coil}$
- A_{wire} = wire cross-sectional area

Q Factor of Inductors

Inductor Q Factor:

$$Q = ?L/R = 2?fL/R_{total}$$

R_{total} includes:

- DC resistance of wire
- Skin effect losses (increases with frequency)
- Proximity effect losses
- Core losses (hysteresis + eddy currents)

Self-Resonant Frequency (SRF)

Every inductor has parasitic capacitance between turns and layers:

$$\text{SRF} = 1 / (2??(LC_{\text{parasitic}}))$$

Design Rule:

SRF should be at least 10× the operating frequency.

At frequencies above SRF, the inductor acts like a capacitor!

VIC Choke Design Goals

1. **Target inductance:** Sets resonant frequency with capacitor
2. **Low DCR:** Maximizes Q factor
3. **High SRF:** Ensures proper operation at intended frequency
4. **Adequate current rating:** Won't saturate or overheat
5. **Appropriate core:** Low losses at operating frequency

Key Tradeoff: More turns = more inductance, but also more wire = more DCR. The design challenge is achieving the target inductance with minimum resistance, which means selecting appropriate wire gauge, core material, and winding technique.

Next: Core Materials & Properties →

Core Materials

Core Materials & Properties

The core material of an inductor dramatically affects its performance. Choosing the right core is essential for achieving the desired inductance, Q factor, and frequency response in VIC applications.

Why Use a Core?

A magnetic core increases inductance by providing a low-reluctance path for magnetic flux:

$$L = ????N^2A/l$$

The relative permeability (μ_r) of the core multiplies the inductance compared to an air core.

Core Material Comparison

Material	μ_r (typical)	Frequency Range	Saturation	Cost
Air	1	Any	N/A	Free
Iron Powder	10-100	1 kHz - 100 MHz	High (0.5-1.5T)	Low
Ferrite (MnZn)	1000-10000	1 kHz - 1 MHz	Low (0.3-0.5T)	Medium
Ferrite (NiZn)	50-1500	100 kHz - 500 MHz	Low (0.3-0.4T)	Medium
Laminated Silicon Steel	2000-6000	50 Hz - 10 kHz	High (1.5-2.0T)	Low
Amorphous Metal	10000-100000	50 Hz - 100 kHz	High (1.5T)	High
Nanocrystalline	15000-100000	1 kHz - 1 MHz	High (1.2T)	High

Core Losses

All magnetic cores dissipate energy through two mechanisms:

1. Hysteresis Loss

Energy lost each time the core is magnetized and demagnetized.

$P_h ? f \times B_{max}^n$ $(n ? 1.6\text{-}2.5)$

Proportional to frequency and flux density.

2. Eddy Current Loss

Circulating currents induced in the core material.

$P_e ? f^2 \times B_{max}^2$

Proportional to frequency squared - dominates at high frequencies.

Steinmetz Equation

$$P_{core} = k \times f^{?} \times B^{?} \times \text{Volume}$$

Where k, α, β are material-specific constants from datasheets.

Ferrite Materials for VIC

Ferrites are the most common choice for VIC frequencies (1-50 kHz):

Material	μ_i	Optimal Frequency	Application
3C90 (TDK)	2300	25-200 kHz	Power transformers
N87 (EPCOS)	2200	25-500 kHz	General purpose
N97 (EPCOS)	2300	25-150 kHz	Low loss
3F3 (Ferroxcube)	2000	100-500 kHz	Higher frequency
77 Material (Fair-Rite)	2000	Up to 1 MHz	EMI/RFI suppression

Iron Powder Cores

Micrometals and Amidon iron powder cores are popular for their:

- High saturation flux density
- Gradual saturation (soft saturation)
- Good temperature stability
- Self-gapping (distributed gap)

Common Iron Powder Mixes

Mix	μ	Color	Frequency Range
Mix 26	75	Yellow/White	DC - 1 MHz
Mix 52	75	Green/Blue	DC - 3 MHz
Mix 2	10	Red/Clear	1 - 30 MHz
Mix 6	8	Yellow	10 - 50 MHz

Core Shapes

Toroidal

Doughnut shape with closed magnetic path. Excellent flux containment, low EMI. Harder to wind but very efficient.

E-Core / EI-Core

E-shaped halves that mate together. Easy to wind on bobbin. Can add air gap easily.

Pot Core

Cylindrical with center post. Shields winding from external fields. Good for sensitive applications.

Rod Core

Simple cylindrical rod. Open magnetic path, lower inductance per turn but no saturation issues.

Core Saturation

When the magnetic flux density exceeds the saturation limit:

- Permeability drops dramatically

- Inductance decreases
- Current increases rapidly
- Core heating increases

Avoiding Saturation:

$B_{peak} = (L \times I_{peak}) / (N \times A_e) < B_{sat}$

Always check that peak flux density stays below saturation limit of your core material.

Recommendations for VIC

Frequency Range	Recommended Core	Notes
1-10 kHz	N97/3C90 ferrite or iron powder	Low loss at these frequencies
10-50 kHz	N87/3F3 ferrite	Good balance of µ and loss
50-200 kHz	3F3/3F4 ferrite or Mix 26 powder	Lower permeability, lower loss
>200 kHz	NiZn ferrite or Mix 2 powder	Designed for high frequency

VIC Matrix Calculator: The Choke Design module includes a core database with A_L values and frequency recommendations. Select your core and it will calculate the required turns for your target inductance.

Next: Wire Gauge & Material Selection →

Wire Selection

Wire Gauge & Material Selection

The wire used to wind an inductor directly affects its DC resistance, current capacity, and Q factor. Proper wire selection is essential for maximizing VIC circuit performance.

Wire Gauge Systems

Wire size is commonly specified using the American Wire Gauge (AWG) system:

AWG	Diameter (mm)	Area (mm²)	Ω/m (Copper)	Max Current (A)
18	1.024	0.823	0.0210	2.3
20	0.812	0.518	0.0333	1.5
22	0.644	0.326	0.0530	0.92
24	0.511	0.205	0.0842	0.58
26	0.405	0.129	0.1339	0.36
28	0.321	0.081	0.2128	0.23
30	0.255	0.051	0.3385	0.14
32	0.202	0.032	0.5383	0.09

Note: AWG follows logarithmic progression. Each 3 AWG steps doubles resistance, halves area.

Wire Materials

Material	Resistivity ($\times 10^{-8}$ Ω·m)	Relative to Copper	Use Case
Copper	1.68	1.0× (reference)	Best for high Q
Aluminum	2.65	1.6×	Lightweight applications

Material	Resistivity (×10⁻⁸ Ω·m)	Relative to Copper	Use Case
SS304	72	~43×	Corrosion resistance
SS316	74	~44×	Better corrosion resistance
SS430 (Ferritic)	~100	~60×	Magnetic, high resistance
Nichrome (80/20)	108	~64×	Heating elements, damping
Kanthal A1	145	~86×	High-temp resistance wire

Effect of Material on Q Factor

Q Factor Relationship:

```
Q = 2?fL / R
```

Since R is proportional to resistivity, using high-resistivity wire dramatically reduces Q:

Copper wire Q = 100	→ SS316 wire Q ≈ 2.3
Copper wire Q = 50	→ Nichrome wire Q ≈ 0.8

When to Use Resistance Wire

Despite lower Q, resistance wire has valid uses:

- **Current limiting:** Built-in current limit without separate resistor
- **Damping:** Prevents excessive ringing
- **Safety:** Limits power in fault conditions
- **Meyer's designs:** Some original VIC designs used stainless steel wire

Warning: Using resistance wire in a resonant circuit dramatically reduces voltage magnification. A Q of 2 means you only get 2× voltage gain instead of 50× or 100× with copper.

Skin Effect

At high frequencies, current flows primarily near the wire surface:

Skin Depth (?):

`? = ?(? / (? × f × ?? × ??))`

For Copper:

`?(mm) ? 66 / ?f(Hz)`

1 kHz	δ ≈ 2.1 mm
10 kHz	δ ≈ 0.66 mm
100 kHz	δ ≈ 0.21 mm

Skin Effect Mitigation

- **Litz wire:** Multiple thin insulated strands twisted together
- **Flat/ribbon wire:** More surface area for same cross-section
- **Use finer gauge:** If wire radius ≈ δ, skin effect is minimal

Magnet Wire Types

Insulation Type	Temp Rating	Voltage Rating	Notes
Polyurethane (solderable)	130°C	~100V/layer	Can solder through coating
Polyester-imide	180°C	~200V/layer	Good general purpose
Polyamide-imide	220°C	~300V/layer	High temp applications
Heavy build (HN)	Various	~500V/layer	Thicker insulation
Triple insulated	Various	~3000V	Safety-rated isolation

Wire Selection Guidelines for VIC

For Maximum Q (recommended):

- Use **copper magnet wire**
- Choose gauge based on skin depth at operating frequency
- Use largest gauge that fits the core/bobbin
- Consider Litz wire for frequencies >50 kHz

For Current-Limited Applications:

- Use stainless steel or nichrome
- Calculate required resistance: $R = V_{max}/I_{limit}$
- Accept reduced Q factor as tradeoff

Calculating Wire Length

Wire Length for N Turns:

$l_{wire} ? N \times ? \times d_{coil}$

Where d_{coil} is the average coil diameter.

Resulting DCR:

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

VIC Matrix Calculator: The Choke Design tool automatically calculates DCR based on your wire gauge, material, and number of turns. It shows the resulting Q factor and voltage magnification for your design.

Next: Bifilar Winding Technique →

Bifilar Windings

Bifilar Winding Technique

Bifilar winding is a special technique where two wires are wound together in parallel on a core. This configuration creates unique electromagnetic properties that are particularly relevant to VIC designs, including inherent capacitance between windings and special transformer-like coupling.

What is Bifilar Winding?

In a bifilar winding, two conductors are wound side-by-side along the entire length of the coil:

```
Standard Winding:         Bifilar Winding:

   _____________            ═══════════════
   │ │ │ │ │ │              ║A║B║A║B║A║B║
   └─┘ └─┘ └─┘              ╚═╝ ╚═╝ ╚═╝

Single wire wound           Two wires (A & B)
around core                 wound together

Cross-section view:

Standard:    Bifilar:
  ○ ○ ○       ○ ● ○ ●
  ○ ○ ○       ● ○ ● ○

○ = Wire A    ● = Wire B
```

Bifilar Winding Properties

Property	Effect	VIC Relevance
High inter-winding capacitance	Built-in C between A and B	May replace discrete capacitor
Near-unity coupling	k ≈ 1 between windings	Efficient energy transfer
Cancellation modes	Some flux cancellation possible	Affects net inductance

Property	Effect	VIC Relevance
Lower SRF	High $C_{parasitic}$ reduces SRF	Consider in frequency selection

Connection Configurations

1. Series Aiding (Same Direction):

End of A connects to start of B → Fluxes add

$L_{total} = L_A + L_B + 2M ? 4L$ (for k=1)

2. Series Opposing (Opposite Direction):

End of A connects to end of B → Fluxes subtract

$L_{total} = L_A + L_B - 2M ? 0$ (for k=1)

3. Parallel Connection:

Starts connected, ends connected → Current splits

$L_{total} = L/2$ (for identical windings)

4. Transformer Mode:

A is primary, B is secondary → Voltage transformation

$V_B/V_A = N_B/N_A = 1$ (for bifilar)

Calculating Bifilar Capacitance

Approximate Inter-Winding Capacitance:

$C_{winding} ? ???_r \times (l_{wire} \times d_{wire}) / s$

Where:

> > - l_{wire} = length of each wire

> > - d_{wire} = wire diameter
> > - s = spacing between wires (≈ insulation thickness × 2)
> > - ε_r = dielectric constant of insulation

Typical Values:

For magnet wire on ferrite: 10-100 pF per meter of winding

Bifilar in VIC Context

Meyer's designs reportedly used bifilar chokes in several ways:

As Primary/Secondary Pair

L1 and L2 wound as bifilar on same core:

- Tight coupling between primary and secondary
- Built-in capacitance may serve as C1
- Simpler construction (single winding operation)

As Choke Sets

Matched pairs for symmetrical circuits:

- Identical L values guaranteed
- Common-mode rejection possible
- Push-pull drive configurations

Winding Techniques

Tips for Bifilar Winding:

1. **Keep wires parallel:** Twist them together before winding or use a jig
2. **Maintain tension:** Even tension prevents gaps and loose spots

3. **Mark the wires:** Use different colors or tag ends carefully
4. **Wind in layers:** Complete one layer before starting next
5. **Insulate between layers:** Add tape for voltage isolation

Measuring Bifilar Parameters

Measurement	Configuration	What It Tells You
L_A alone	Measure A, B open	Inductance of winding A
$L_{series\text{-}aid}$	A end to B start, measure	$L_A + L_B + 2M$
$L_{series\text{-}opp}$	A end to B end, measure	$L_A + L_B - 2M$
$C_{winding}$	Measure C between A and B	Inter-winding capacitance

Calculating Coupling Coefficient:

$M = (L_{series\text{-}aid} - L_{series\text{-}opp}) / 4$

$k = M / ?(L_A \times L_B)$

For true bifilar winding: k ≈ 0.95-0.99

Advantages and Disadvantages

Advantages:

- Built-in capacitance may simplify circuit
- Excellent magnetic coupling
- Matched characteristics between windings
- Compact construction

Disadvantages:

- Lower SRF due to high parasitic capacitance
- Difficult to adjust windings independently
- Insulation must handle full voltage difference
- More complex to wind correctly

VIC Matrix Calculator: The Choke Design section includes options for bifilar windings. It can calculate the expected inter-winding capacitance and adjust the SRF estimate accordingly. When designing bifilar chokes, the calculator helps ensure compatibility with your target resonant frequency.

Next: Parasitic Capacitance & SRF →

Parasitic Effects

Parasitic Capacitance & SRF

Real inductors have parasitic capacitance between turns and layers that limits their useful frequency range. Understanding these effects is critical for VIC design, as they determine the maximum operating frequency and affect circuit tuning.

Sources of Parasitic Capacitance

Parasitic capacitance in inductors comes from several sources:

1. Turn-to-Turn Capacitance (C_{tt})

Capacitance between adjacent turns in the same layer. Depends on wire spacing and insulation.

2. Layer-to-Layer Capacitance (C_{ll})

Capacitance between winding layers. Often the largest contributor in multi-layer coils.

3. Winding-to-Core Capacitance (C_{wc})

Capacitance between the winding and the magnetic core (if conductive or grounded).

4. Winding-to-Shield Capacitance

In shielded inductors, capacitance to the external shield.

Self-Resonant Frequency (SRF)

The parasitic capacitance resonates with the inductance at the Self-Resonant Frequency:

$$SRF = 1 / (2??(L \times C_{parasitic}))$$

Behavior at SRF:

> > - Impedance is maximum (parallel resonance)
> > - Inductor is neither inductive nor capacitive
> > - Phase angle crosses through 0°

Above SRF:

The "inductor" behaves as a **capacitor**! Impedance decreases with frequency.

Impedance vs. Frequency

```
|Z|
 ↑
 |                    /\
 |                   /  \     ← Peak at SRF
 |                  /    \
 |                 /      \
 |               /         \
 |             /            \
 |           /               \
 |         /                  \
 |       /                     \
 |     /                        \
 |   /   Inductive region        \ Capacitive region
 | /      |Z| = 2πfL              \ |Z| = 1/(2πfC)
 └─────────────────────────────────────────────→ f
                      SRF

Phase:  +90° ───────────┬─────────── −90°
                       0° (at SRF)
```

Operating Frequency Guidelines

f_{op} / SRF	Behavior	Recommendation
< 0.1 (< 10%)	Nearly ideal inductor	**Preferred range**
0.1 - 0.3 (10-30%)	Slight inductance increase	Acceptable with correction

f_{op} / SRF	Behavior	Recommendation
0.3 - 0.7 (30-70%)	Significant deviation	Caution - Q drops
> 0.7 (> 70%)	Near or past SRF	**Do not use**

Effective Inductance Near SRF

As frequency approaches SRF, the apparent inductance increases:

$$L_{eff} = L_{dc} / [1 - (f/SRF)^2]$$

Example:

- L_{dc} = 10 mH, SRF = 100 kHz
- At 30 kHz: L_{eff} = 10 / [1 - 0.09] = 11.0 mH (+10%)
- At 50 kHz: L_{eff} = 10 / [1 - 0.25] = 13.3 mH (+33%)
- At 70 kHz: L_{eff} = 10 / [1 - 0.49] = 19.6 mH (+96%)

Minimizing Parasitic Capacitance

Winding Techniques:

1. **Single-layer winding:** Eliminates layer-to-layer capacitance
2. **Space-wound turns:** Increases turn-to-turn distance
3. **Honeycomb/basket winding:** Crosses turns to reduce adjacent voltage
4. **Bank winding:** Winds in sections to reduce voltage across layers
5. **Progressive winding:** Keeps voltage gradient low between adjacent turns

Design Choices:

- Use fewer turns (requires higher permeability core)
- Use thinner insulation (but watch voltage ratings)
- Use air-core (eliminates winding-to-core capacitance)
- Choose toroidal cores (natural progressive winding)

Calculating Parasitic Capacitance

Turn-to-Turn Capacitance (Simplified)

$C_{tt} ? ???_r \times l_{turn} \times d_{wire} / s$

Where s is the spacing between adjacent turn centers.

Layer-to-Layer Capacitance

$C_{ll} ? ???_r \times A_{layer} / t_{insulation}$

Where A_{layer} is the overlapping area between layers.

Total Parasitic Capacitance

The total equivalent capacitance is complex because the distributed capacitances see different voltages. For a rough estimate:

$C_{parasitic} ? C_{ll}/3 + C_{tt}/N$

The 1/3 factor accounts for voltage distribution across layers.

Measuring SRF

Method 1: Impedance Analyzer

1. Connect inductor to impedance analyzer
2. Sweep frequency and plot |Z|
3. SRF is where impedance peaks

Method 2: Signal Generator + Oscilloscope

1. Connect inductor in series with known resistor
2. Drive with sine wave, sweep frequency
3. Monitor voltage across inductor
4. SRF is where voltage peaks (current minimum)

Method 3: Resonance with Known Capacitor

1. Measure inductance at low frequency
2. Add known capacitor in parallel
3. Find new resonant frequency
4. Calculate parasitic C from the difference

SRF in VIC Design

Problem	Symptom	Solution
Operating too close to SRF	Resonance frequency higher than calculated	Reduce tuning cap or use different choke
Operating above SRF	No resonance, circuit acts capacitive	Must redesign with fewer turns
Low SRF in bifilar winding	Limited usable frequency range	Accept limitation or use separate chokes

VIC Matrix Calculator: The Choke Design module estimates SRF based on winding geometry and displays a warning if your operating frequency is too close to SRF. It also calculates the effective inductance at your operating frequency.

Next: DC Resistance and Q Factor →

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:

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

Where:

> - ρ = resistivity of wire material (Ω·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 μ core	L increases	Fewer turns needed	Variable*
Larger core	L increases	Longer mean turn	Often improves
Copper vs. SS wire	No change	R × 40-60	Q ÷ 40-60

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

Q Factor Calculation

Q Factor at Operating Frequency:

$$Q = 2?fL / R_{total}$$

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_{out} (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: ±1-5%

Method 2: 4-Wire (Kelvin) Measurement

- Eliminates lead resistance error
- Required for low DCR (<1 Ω)
- Uses separate sense and current leads
- Accuracy: ±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:

$R(T) = R_{20°C} \times [1 + ?(T - 20)]$

Where α ≈ 0.00393 /°C for copper

Example:

At 80°C: $R = R_{20°C} \times 1.24$ (+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 Ω	Optimize winding
L2 DCR	1-50 Ω	Optimize winding
Capacitor ESR	0.01-1 Ω	Use low-ESR caps
WFC solution resistance	10-10000 Ω	Electrode design, electrolyte
Connection resistance	0.01-1 Ω	Solid connections
Driver output resistance	0.1-10 Ω	Low $R_{ds(on)}$ MOSFETs

Practical Example

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

Required R_{max}:

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

Wire selection (100 turns on 25mm toroid):

Mean turn length ≈ 80mm, total wire = 8m

- 22 AWG copper: 8m × 0.053 Ω/m = 0.42 Ω ✓
- 26 AWG copper: 8m × 0.134 Ω/m = 1.07 Ω ✓
- 30 AWG copper: 8m × 0.339 Ω/m = 2.71 Ω ✓
- 22 AWG SS316: 8m × 2.3 Ω/m = 18.4 Ω ✗ (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 →