

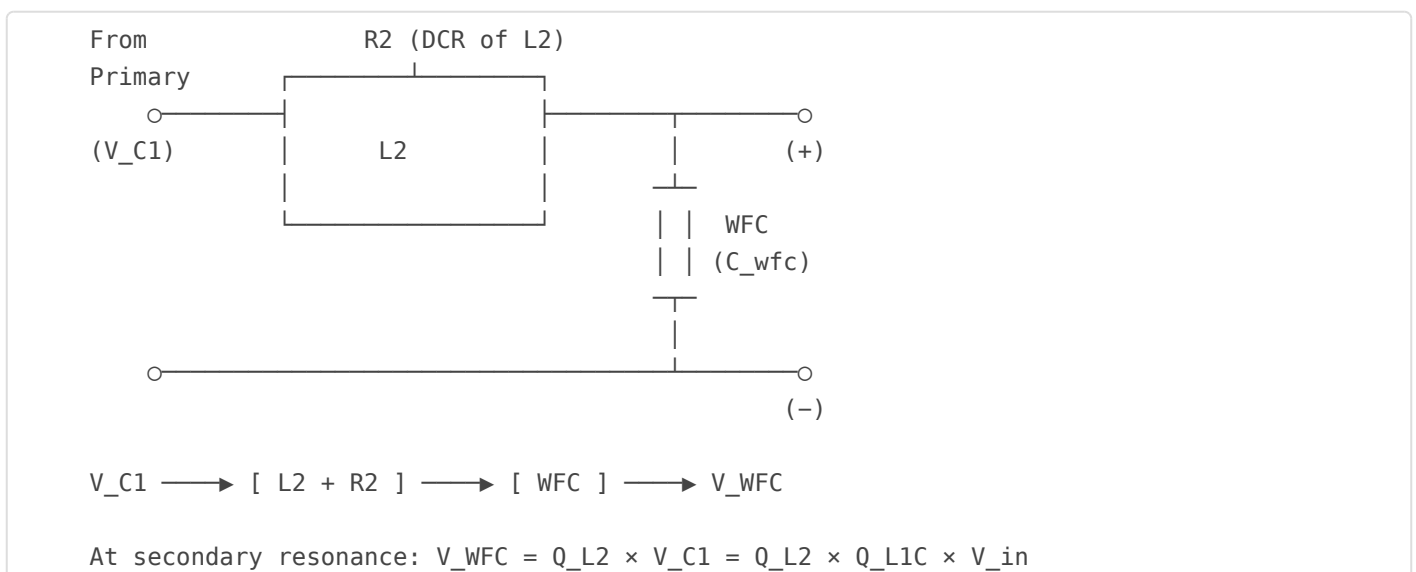
Secondary Side

Secondary Side (L2-WFC) Analysis

The secondary side of the VIC consists of the second inductor (L2) and the water fuel cell (WFC) acting as a capacitor. This stage receives the amplified signal from the primary and delivers the final voltage to the water. Proper design of this stage is critical for efficient energy transfer to the WFC.

Secondary Tank Circuit

L2 and the WFC capacitance form the secondary resonant tank:



The WFC as a Capacitor

The water fuel cell presents a complex impedance, but at VIC frequencies, it behaves predominantly as a capacitor:

WFC Capacitance Components:

- **Geometric capacitance:** $C_{\text{geo}} = \epsilon_0 \epsilon_r A/d$
- **EDL capacitance:** C_{edl} (in series, at each electrode)
- **Effective capacitance:** $C_{\text{wfc}} = f(C_{\text{geo}}, C_{\text{edl}}, \text{frequency})$

At typical VIC frequencies (1-50 kHz), C_{wfc} is dominated by C_{geo} .

Secondary Resonant Frequency

Secondary Resonance:

$$f_{\text{secondary}} = 1 / (2\pi \sqrt{L_2 \times C_{\text{wfc}}})$$

For Maximum Voltage Transfer:

$$\text{Ideally, } f_{0\text{secondary}} = f_{0\text{primary}}$$

$$\text{This means: } L_1 \times C_1 = L_2 \times C_{\text{wfc}}$$

Q Factor of Secondary Side

The secondary Q factor determines the second stage of voltage magnification:

Secondary Q Factor:

$$Q_{L_2} = (2\pi \times f \times L_2) / (R_2 + R_{\text{wfc}})$$

Where R_{wfc} is the effective resistance of the WFC (solution resistance + losses).

Total Voltage Magnification:

$$V_{\text{WFC}} = Q_{L_1 C} \times Q_{L_2} \times V_{\text{in}}$$

Example:

- $Q_{L1C} = 30, Q_{L2} = 20, V_{in} = 12V$
- $V_{WFC} = 30 \times 20 \times 12 = 7,200V$ theoretical

Cascaded Resonance Effects

When both stages resonate at the same frequency, the effects multiply:

Configuration	Total Magnification	Notes
Only primary resonance	Q_{L1C}	L2-WFC not tuned
Only secondary resonance	Q_{L2}	L1-C1 not tuned
Dual resonance	$Q_{L1C} \times Q_{L2}$	Maximum magnification
Harmonic secondary	Variable	Secondary at $2f_0, 3f_0$, etc.

Impedance Matching Considerations

For efficient energy transfer between primary and secondary:

Characteristic Impedance Match:

$$Z_{\text{primary}} = \sqrt{L1/C1}$$

$$Z_{\text{secondary}} = \sqrt{L2/C_{wfc}}$$

Matching these impedances can improve energy transfer, though it's not always achievable or necessary.

Effect of WFC Properties on Secondary

WFC Parameter	Effect on Secondary	Design Response
Higher C_{wfc}	Lower f_0 , lower Z_0	Increase L2 or reduce C1
Higher R_{wfc}	Lower Q_{L2}	Use purer water or optimize gap

WFC Parameter	Effect on Secondary	Design Response
Larger electrode area	Higher C_{wfc}	Requires larger L2
Narrower gap	Higher C_{wfc} , lower R_{wfc}	Trade-off between C and R

Bifilar Choke Considerations

When L2 is bifilar wound (or when L1 and L2 are wound together as a bifilar pair):

- **Inherent capacitance:** The bifilar winding has capacitance between turns
- **Magnetic coupling:** Energy transfers inductively between windings
- **Lower SRF:** The inter-winding capacitance lowers self-resonant frequency
- **Complex tuning:** The system becomes a coupled resonator

Calculating L2 for Given WFC

Given: Target frequency and WFC capacitance

$$L2 = 1 / (4\pi^2 f^2 C_{wfc})$$

Example:

- $f_0 = 10 \text{ kHz}$
- $C_{wfc} = 5 \text{ nF}$ (typical small WFC)
- $L2 = 1 / (4\pi^2 \times 10^4 \times 5 \times 10^{-9}) = 50.7 \text{ mH}$

Sanity check: This is a reasonable inductance, achievable with ~500-1000 turns on a ferrite core.

Power Delivery to WFC

The actual power delivered to the WFC depends on its resistive component:

Power in WFC Resistance:

$$P_{wfc} = I_{wfc}^2 \times R_{wfc}$$

Where:

$$I_{wfc} = V_{WFC} / Z_{wfc} \quad ? \quad V_{WFC} \times ? \times C_{wfc}$$

This power heats the water and drives electrochemical reactions.

Voltage Distribution Across WFC

The high voltage across the WFC creates an electric field:

Electric Field in WFC:

$$E = V_{WFC} / d$$

Where d is the electrode gap.

Example:

- $V_{WFC} = 1000V$, $d = 1mm$
- $E = 1000V / 0.001m = 1 \text{ MV/m} = 10 \text{ kV/cm}$

This is a substantial electric field that can influence molecular behavior in water.

Design Guidelines for L2

1. **Match resonant frequency:** L2 should resonate with C_{wfc} at the same frequency as L1-C1
2. **Minimize DCR:** R2 directly reduces Q_{L2} and thus voltage magnification
3. **Consider coupling:** If using transformer-coupled design, mutual inductance matters
4. **Account for WFC changes:** C_{wfc} varies with temperature, voltage, and bubble formation
5. **Leave tuning margin:** Design L2 slightly higher, fine-tune with small series capacitor if needed

Key Insight: The secondary side is where VIC theory meets reality. The WFC is not an ideal capacitor—it has losses, frequency-dependent behavior, and changes during operation. Successful

VIC design must account for these real-world effects.

Next: Resonant Charging Principle →

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