Voltage Magnification

Voltage Magnification at Resonance

Voltage magnification is the cornerstone of VIC circuit operation. At resonance, the voltage across reactive components (inductors and capacitors) can be many times greater than the input voltage. This is how the VIC develops high voltages across the water fuel cell while drawing modest current from the source.

The Principle of Voltage Magnification

In a series resonant circuit, even though the total impedance is at minimum (just resistance), the individual voltages across L and C can be much larger than the source voltage. This isn't "free energy"—it's the result of energy continuously cycling between the inductor and capacitor.

Key Insight:

At resonance, V_L and V_C are equal in magnitude but opposite in phase. They cancel each other in the circuit loop, but individually each represents a real voltage that can do work.

Voltage Magnification Formula

Q-Based Magnification:

$V_{output} = Q \times V_{input}$

Impedance-Based Magnification:

```
Magnification = Z? / R = (1/R) × ?(L/C)
```

Both formulas give the same result since $Q = Z_0/R$ for a series circuit.

Practical Examples

Input Voltage	Q Factor	Output Voltage	Application
12V	10	120V	Low-Q experimental setup
12V	50	600V	Typical VIC circuit
12V	100	1200V	High-Q optimized circuit
24V	50	1200V	Higher input voltage approach

Where the Magnified Voltage Appears

In a Series LC Circuit

- **Across the inductor:** $V_L = Q \times V_{source}$ (leads current by 90°)
- **Across the capacitor:** $V_C = Q \times V_{source}$ (lags current by 90°)
- **Across resistance:** $V_R = V_{source}$ (in phase with current)

In the VIC Circuit

The water fuel cell acts as the capacitor, so the magnified voltage appears directly across the water:

VIC Voltage Path:

Source → L1 → C1 (series resonance for initial magnification)

Transformed via coupling to → L2 → WFC (secondary resonance)

Result: High voltage across water fuel cell electrodes

Two Approaches to Magnification

Method 1: Maximize Q

Increase Q by reducing resistance:

- Use copper wire instead of resistance wire
- Use larger gauge wire
- Minimize connection resistances
- Use low-ESR capacitors

Method 2: Optimize Z?/R Ratio

Increase characteristic impedance relative to resistance:

- Increase inductance (more turns, larger core)
- Decrease capacitance (for same resonant frequency, requires more inductance)
- The ratio $\sqrt{L/C}$ determines Z_0

Design Trade-off:

For a given resonant frequency $f_0 = 1/(2\pi\sqrt{LC})$:

> > - Higher L with lower C → Higher Z_0 → Higher magnification (but more wire, more DCR)
> > - Lower L with higher C → Lower Z_0 → Lower magnification (but less wire, less DCR)

The optimal design balances these factors.

Energy Considerations

Voltage magnification doesn't violate energy conservation:

Power In = Power Dissipated

At steady-state resonance:

- Current through circuit: $I = V_{source}/R$
- Power from source: $P = V_{source} \times I = V_{source}^2/R$
- Power dissipated in R: $P = I^2R = V_{source}^2/R$ (same!)

The high voltage across L and C represents *reactive power*—energy that sloshes back and forth but isn't consumed.

Real Power vs. Reactive Power

Type	Symbol	Unit	Description
Real Power	P	Watts (W)	Actually consumed, heats resistors
Reactive Power	Q (or VAR)	Volt-Amperes Reactive	Oscillates, stored in L and C
Apparent Power	S	Volt-Amperes (VA)	Total power flow

Magnification in the VIC Matrix Calculator

The VIC Matrix Calculator displays voltage magnification in several ways:

In Choke Designs

- **Q Factor:** Calculated from inductance and DCR
- **Voltage Magnification:** Equals Q for series resonance
- **Z_0/R Magnification:** Alternative calculation method
- **Example Output:** Shows actual voltage with 12V input

In Circuit Profiles

- **Q_L1C:** Q factor of primary side (L1 with C1)
- **Q_L2:** Q factor of secondary side (L2 with WFC)
- **Voltage Magnification:** Expected magnification at resonance

Practical Note: Real circuits achieve somewhat less than theoretical magnification due to losses not accounted for in simple models (core losses, radiation, dielectric losses in capacitors, etc.). Expect 70-90% of calculated values in practice.

Safety Warning

?? High Voltage Hazard

Resonant circuits can develop dangerous voltages even from low-voltage sources:

- A 12V source with Q=50 produces 600V peaks
- These voltages can cause electric shock or burns
- Energy stored in capacitors remains after power is removed
- Always discharge capacitors before handling circuits
- Use appropriate insulation and safety equipment

Chapter 1 Complete. Next: The Electric Double Layer (EDL) →

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