Resonant Charging

Resonant Charging Principle

Resonant charging is a technique where energy is transferred to a capacitive load (the WFC) in a controlled, oscillatory manner. Unlike direct DC charging, resonant charging can achieve higher efficiency and allows voltage magnification beyond the source voltage.

Conventional vs. Resonant Charging

Aspect	DC Charging (R-C)	Resonant Charging (L-C)
Final voltage	= V_{source}	Can exceed V_{source} (up to 2× for half-wave)
Energy efficiency	50% max (half lost in R)	Can approach 100% (minimal loss in L)
Charging curve	Exponential (slow)	Sinusoidal (faster)
Peak current	V/R at start	V/Z_0 (controlled by L)

Basic Resonant Charging Circuit

```
 Switch (S)
────○/○────────────────────────────
           │                │
           │                │
V_source   │                │
    +      │                │
           │     ┌─────┐  ──┴──
           │     │  L  │  ──┬──  C (WFC)
           │     └──┬──┘    │
           │        │       │
           │        │       │
───────────┴────────┴───────┴──────

                           GND

When S closes:
1. Current builds in L (energy stored in magnetic field)
2. Current flows into C, charging it
```

```
    3. Voltage on C rises
    4. At peak voltage, current reverses (or S opens)
```

Half-Cycle Resonant Charging

In half-cycle mode, the switch opens when capacitor voltage reaches maximum:

Ideal Half-Cycle Charging (lossless):

$V_{C,max} = 2 \times V_{source}$

Charging Time:

t_{charge} = ??(LC) = ?/?? = 1/(2f?)

This is exactly half the resonant period.

Why 2× Voltage?

Energy Conservation:

1. Initially: All energy in source (voltage V_s)
2. Quarter cycle: Energy split between L (current max) and C ($V = V_s$)
3. Half cycle: All energy in C, current = 0
4. For energy to be conserved: $\frac{1}{2}CV_c^2 = C \times V_s^2$ (accounting for work done by source)
5. This gives $V_c = 2V_s$

Resonant Charging with Losses

Real circuits have losses that reduce the voltage gain:

With Resistance (damped case):

$V_{C,max} = V_{source} \times (1 + e^{-?R/(2?(L/C))})$

$V_{C,max} = V_{source} \times (1 + e^{-?/(2Q)})$

Approximation for high Q:

$V_{C,max}$? $2V_{source} \times (1 - ?/(4Q))$

Voltage Gain vs. Q Factor

Q Factor	$V_{C,max}/V_{source}$	Efficiency
∞ (ideal)	2.00	100%
100	1.98	98.4%
50	1.97	96.9%
20	1.92	92.5%
10	1.85	85.5%
5	1.73	73%

Continuous Resonant Excitation

In the VIC, instead of single pulses, we drive the circuit continuously at the resonant frequency:

Steady-State Resonance:

Energy from the source compensates for losses each cycle, maintaining a steady oscillation amplitude.

Voltage Magnification:

$V_C = Q \times V_{source}$

This is much greater than the 2× from single-pulse resonant charging when $Q > 2$.

Resonant Charging in VIC Context

The VIC uses resonant charging principles in several ways:

1. **Primary tank:** C1 is resonantly charged through L1
2. **Secondary transfer:** Energy transfers resonantly to WFC through L2
3. **Cumulative effect:** Multiple stages multiply the magnification

Timing and Switching

For optimal resonant charging:

Critical Timing Points:

- **Turn-on:** When capacitor voltage is minimum (or at desired starting point)
- **Turn-off:** When current through inductor reaches zero (zero-current switching)
- **Period:** Should match or be a harmonic of the resonant frequency

Zero-Current Switching (ZCS):

Turning off when current is zero minimizes switching losses and eliminates inductive kick.

Energy Flow Analysis

```
Time →

V_C:    ───/\    /\    /\    /\───
          /  \  /  \  /  \  /  \
         /    \/    \/    \/    \

I_L:    ─/\    /\    /\    /\───
         /  \  /  \  /  \  /  \
        /    \/    \/    \/    \

Energy in C: High → Low  → High → Low
Energy in L: Low  → High → Low  → High

Total energy (minus losses) remains constant in steady state.
```

Advantages of Resonant Charging for WFC

- **High voltage:** Achieves voltages beyond source capability
- **Low current draw:** Source only provides loss compensation
- **Controlled energy delivery:** Sinusoidal rather than impulsive
- **Efficient:** Minimal resistive losses when Q is high
- **Self-limiting:** Voltage limited by Q factor, not infinite

Key Principle: Resonant charging exploits the energy storage capability of inductors and capacitors. By timing the energy injection to match the natural oscillation, we can build up substantial energy in the circuit with modest input power—the same principle used in pushing a swing at just the right moment.

Next: Step-Charging Ladder Effect →

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