

Electrode Geometry

Electrode Geometry & Spacing

The physical design of WFC electrodes directly determines its electrical characteristics—capacitance, resistance, and field distribution. Proper geometry is essential for achieving target resonant frequencies and efficient operation.

Parallel Plate Electrodes

The simplest configuration with straightforward calculations:

Capacitance:

$$C = \epsilon_r \epsilon_0 A / d$$

For Water ($\epsilon_r \approx 80$):

$$C \text{ (pF)} \approx 708 \times A(\text{cm}^2) / d(\text{mm})$$

Example:

- 10 cm × 10 cm plates = 100 cm²
- 2 mm gap
- $C = 708 \times 100 / 2 = 35,400 \text{ pF} = 35.4 \text{ nF}$

Concentric Tube Electrodes

Cylindrical geometry provides more surface area:

Capacitance:

$$C = 2\pi\epsilon_r\epsilon_0 L / \ln(r_{\text{outer}}/r_{\text{inner}})$$

Simplified (for small gap relative to radius):

$$C = \frac{2\pi\epsilon_r \times 2r_{avg}L}{d}$$

Where $d = r_{outer} - r_{inner}$

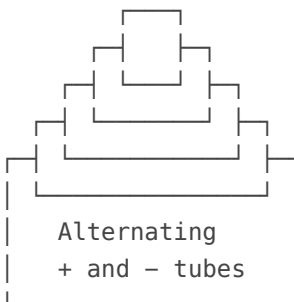
Example:

- Inner tube: 20 mm OD
- Outer tube: 22 mm ID
- Length: 100 mm
- Gap: 1 mm
- $C \approx 708 \times \pi \times 2.1 \times 10 / 1 = 46.7 \text{ nF}$

Tube Array Configurations

Multiple tubes in parallel increase total capacitance:

Top View of 9-Tube Array:



Each concentric pair adds to total capacitance.
 $C_{total} = C_1 + C_2 + C_3 + \dots$ (tubes in parallel)

Electrode Spacing Trade-offs

Gap Size	Capacitance	Resistance	Field Strength	Practical Issues
Very small (<0.5 mm)	Very high	Low	Very high	Bubble blocking, arcing risk
Small (0.5-1.5 mm)	High	Medium-low	High	Sweet spot
Medium (1.5-3 mm)	Medium	Medium	Medium	Easy to build

Gap Size	Capacitance	Resistance	Field Strength	Practical Issues
Large (>3 mm)	Low	High	Low	Needs more voltage

Electric Field Calculation

Field Strength (uniform field approximation):

$$E = V / d$$

Example:

- $V = 1000 \text{ V}$ (from VIC magnification)
- $d = 1 \text{ mm} = 0.001 \text{ m}$
- $E = 1000 / 0.001 = 1,000,000 \text{ V/m} = \mathbf{1 \text{ MV/m}}$

Note: Water breakdown occurs at ~30-70 MV/m, so typical VIC fields are well below breakdown.

Surface Area Considerations

Larger electrode area provides:

- Higher capacitance (more energy storage)
- Lower current density (longer electrode life)
- More sites for gas evolution
- Better heat dissipation

But requires:

- Larger choke inductance (to maintain resonant frequency)
- More water volume
- Larger enclosure

Dimensional Design Process

Step 1: Determine Target Capacitance

From resonant frequency and available inductance:

$$C_{\text{target}} = 1 / (4\pi^2 f^2 L)$$

Step 2: Choose Geometry Type

Plates, tubes, or array based on available materials and space.

Step 3: Select Gap Distance

Balance capacitance needs with practical concerns (1-2 mm typical).

Step 4: Calculate Required Area

$$A = C \times d / (\epsilon_0 \epsilon_r)$$

Step 5: Dimension the Electrodes

For plates: Choose L x W. For tubes: Choose radius and length.

Practical Design Example

Target: $f = 10$ kHz, $L = 50$ mH available

Required capacitance:

$$C = 1 / (4\pi^2 \times 10000^2 \times 0.05) = 5.07 \text{ nF}$$

Using parallel plates with 1.5 mm gap:

$$A = 5.07 \times 10^{-9} \times 0.0015 / (8.854 \times 10^{-12} \times 80) = 10.7 \text{ cm}^2$$

Electrode size: ~3.3 cm x 3.3 cm plates (quite small!)

For more practical size, use 1 mm gap:

$$A = 7.1 \text{ cm}^2 \approx 2.7 \times 2.7 \text{ cm plates}$$

Note: Very small WFC! May need to increase L_2 for practical electrode sizes.

Edge Effects

Real electrodes have fringing fields at edges that increase effective capacitance:

- For parallel plates, add $\sim 0.9d$ to each edge dimension
- For tubes, end effects can add 5-10% to capacitance
- Guard rings can reduce edge effects in precision applications

Electrode Alignment

Critical Requirements:

- **Parallelism:** Plates must be parallel for uniform field
- **Concentricity:** Tubes must be truly concentric
- **Uniform gap:** Variations cause hot spots and non-uniform current
- **Insulating spacers:** Use non-conductive materials (PTFE, ceramic)

Gas Evolution Considerations

When gas is produced, it affects the electrical characteristics:

- Bubbles displace water, reducing effective capacitance
- Bubble layer increases resistance
- Vertical orientation helps bubbles rise and escape
- Perforated electrodes allow better bubble release

VIC Matrix Calculator: The Water Profile section calculates WFC capacitance from your electrode dimensions. Enter geometry type, dimensions, and spacing to get accurate capacitance values for circuit design.

Next: Water Conductivity & Dielectric Properties →

Revision #1

Created 2026-01-01 20:43:53 UTC by Chris Bake

Updated 2026-01-01 20:44:05 UTC by Chris Bake