

Cell Capacitance

Calculating WFC Capacitance

Accurate calculation of WFC capacitance is essential for VIC circuit design. This page provides formulas and methods for determining the effective capacitance of various electrode configurations.

Total WFC Capacitance Model

The WFC has multiple capacitance contributions:

Series Model (simplified):

$$1/C_{\text{total}} = 1/C_{\text{edl,anode}} + 1/C_{\text{geo}} + 1/C_{\text{edl,cathode}}$$

For Practical VIC Frequencies:

At kHz frequencies, $C_{\text{edl}} \gg C_{\text{geo}}$, so:

$$C_{\text{total}} \approx C_{\text{geo}}$$

The geometric capacitance dominates for typical electrode gaps (>0.5 mm).

Geometric Capacitance Formulas

Parallel Plates

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

Quick Formula for Water:

$$C \text{ (nF)} = 0.0708 \times A(\text{cm}^2) / d(\text{mm})$$

Example:

- $A = 50 \text{ cm}^2$, $d = 1 \text{ mm}$
- $C = 0.0708 \times 50 / 1 = 3.54 \text{ nF}$

Concentric Cylinders

$$C = 2\pi\epsilon_r L / \ln(r_o/r_i)$$

Quick Formula for Water:

$$C \text{ (nF)} = 4.45 \times L(\text{cm}) / \ln(r_o/r_i)$$

Thin Gap Approximation (when gap \ll radius):

$$C \text{ (nF)} \approx 0.0708 \times 2\pi r_{\text{avg}}(\text{cm}) \times L(\text{cm}) / d(\text{mm})$$

Multiple Tubes (Array)

$$C_{\text{total}} = n \times C_{\text{single tube pair}}$$

Where n is the number of tube pairs in parallel.

Meyer's 9-Tube Array Example:

- 9 concentric tube pairs
- Each pair: $C \approx 5 \text{ nF}$
- Total: $C = 9 \times 5 = 45 \text{ nF}$

Capacitance Calculator Table

Area (cm ²)	Gap 0.5mm	Gap 1.0mm	Gap 1.5mm	Gap 2.0mm
25	3.54 nF	1.77 nF	1.18 nF	0.89 nF
50	7.08 nF	3.54 nF	2.36 nF	1.77 nF
100	14.2 nF	7.08 nF	4.72 nF	3.54 nF
200	28.3 nF	14.2 nF	9.44 nF	7.08 nF

Area (cm ²)	Gap 0.5mm	Gap 1.0mm	Gap 1.5mm	Gap 2.0mm
500	70.8 nF	35.4 nF	23.6 nF	17.7 nF

Including EDL Effects

For more accurate modeling at lower frequencies or smaller gaps:

EDL Capacitance per Electrode:

$$C_{edl} = c_{dl} \times A$$

Where $c_{dl} \approx 20\text{-}40 \mu\text{F}/\text{cm}^2$ for stainless steel in water.

Total with EDL:

$$1/C_{total} = 1/C_{geo} + 2/C_{edl}$$

(Factor of 2 because both electrodes have EDL)

Example:

- $A = 100 \text{ cm}^2$, $d = 1 \text{ mm}$, $c_{dl} = 25 \mu\text{F}/\text{cm}^2$
- $C_{geo} = 7.08 \text{ nF}$
- $C_{edl} = 25 \mu\text{F}/\text{cm}^2 \times 100 \text{ cm}^2 = 2500 \mu\text{F} = 2.5 \text{ mF}$
- $1/C = 1/7.08\text{nF} + 2/2.5\text{mF} \approx 1/7.08\text{nF}$
- $C_{total} \approx 7.08 \text{ nF}$ (EDL negligible)

Measuring WFC Capacitance

Method 1: LCR Meter

- Most accurate method
- Measure at 1 kHz and 10 kHz (should be similar)
- Provides both C and R (ESR)
- Temperature affects reading

Method 2: RC Time Constant

1. Connect WFC in series with known resistor R
2. Apply step voltage
3. Measure time to reach 63% of final voltage
4. $C = \tau / R$

Method 3: Resonant Frequency

1. Connect WFC with known inductor L
2. Drive with variable frequency
3. Find resonant peak
4. $C = 1 / (4\pi^2 f_0^2 L)$

Capacitance Variations

WFC capacitance can change during operation:

Factor	Effect on C	Typical Change
Temperature increase	C decreases (ϵ_r drops)	-0.4%/°C
Gas bubble formation	C decreases (less water)	-5% to -30%
Water level drop	C decreases	Proportional
Electrode coating	C may decrease	Variable
Applied voltage	Minor change	±5%

Design Workflow

1. Determine Required C

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

2. Choose Electrode Gap

1-2 mm is typical. Smaller = higher C, larger = lower C.

3. Calculate Required Area

$$A = C \times d / (\epsilon_r \epsilon_0) = C(\text{nF}) \times d(\text{mm}) / 0.0708 \text{ (cm}^2\text{)}$$

4. Design Electrodes

Choose plate dimensions or tube sizes to achieve area.

5. Verify by Measurement

Build prototype and measure actual capacitance.

VIC Matrix Calculator: The Water Profile section calculates WFC capacitance automatically. Enter electrode type, dimensions, and gap. The calculator also shows how the capacitance affects resonant frequency and provides warnings if values are outside recommended ranges.

Next: Matching WFC to Circuit →

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