Water Properties

Water Conductivity & Dielectric Properties

Water's electrical properties—conductivity and dielectric constant—directly affect WFC performance in VIC circuits. Understanding these properties helps predict circuit behavior and optimize design.

Dielectric Constant of Water

Water has an exceptionally high dielectric constant due to its polar molecular structure:

Relative Permittivity (?$_r$):

Pure water at 20°C:	$\varepsilon_r \approx 80$
Pure water at 25°C:	$\varepsilon_r \approx 78.5$
Pure water at 100°C:	$\varepsilon_r \approx 55$

Temperature Dependence:

?$_r$(T) ? 87.74 - 0.40 × T(°C)

Why Water's ?$_r$ is High

Water molecules are polar (have positive and negative ends). In an electric field, they align with the field, effectively multiplying the field's ability to store charge. This is why water-based capacitors have such high capacitance per unit volume.

Comparison with Other Materials

Material	ε_r	Relative Capacitance
Vacuum/Air	1	1× (reference)
PTFE (Teflon)	2.1	2.1×
Glass	4-10	4-10×
Ceramic	10-1000	10-1000×
Water	**80**	**80×**

Water Conductivity

Conductivity measures how easily current flows through water:

Conductivity (?) Units:

> > - Siemens per meter (S/m)
> > - Microsiemens per centimeter (μS/cm) - most common
> > - Millisiemens per centimeter (mS/cm)

1 S/m = 10,000 μS/cm = 10 mS/cm

Resistivity (? = 1/?):

ρ (Ω·cm) = 1,000,000 / σ (μS/cm)

Conductivity of Different Waters

Water Type	σ (µS/cm)	ρ (Ω·cm)	Source
Ultra-pure (Type I)	0.055	18,000,000	Lab grade
Deionized	0.1-5	200,000-10,000,000	DI systems
Distilled	1-10	100,000-1,000,000	Distillation
Rain water	5-30	33,000-200,000	Natural
Tap water (typical)	200-800	1,250-5,000	Municipal
Well water	300-1500	670-3,300	Ground water
Sea water	50,000	20	Ocean
0.1M NaOH	~20,000	~50	Electrolyte

Calculating Solution Resistance

For Parallel Plates:

$R_{sol} = ? \times d / A = d / (? \times A)$

Example:

- Tap water: $\sigma = 500\ \mu S/cm = 0.05\ S/m$
- Electrode area: $100\ cm^2 = 0.01\ m^2$
- Gap: 2 mm = 0.002 m
- $R_{sol} = 0.002 / (0.05 \times 0.01) = 4\ \Omega$

Effect on Q Factor

Solution resistance directly impacts circuit Q:

$Q_{total} = 2?fL / (R_{choke} + R_{sol} + R_{other})$

Example Impact:

Water Type	R_{sol}	Q (if R_{choke}=5Ω)
Distilled (σ=5 μS/cm)	~400 Ω	Q ≈ 1.5
Tap (σ=500 μS/cm)	~4 Ω	Q ≈ 70
Electrolyte (σ=20000 μS/cm)	~0.1 Ω	Q ≈ 125

Insight: Very pure water has high Q losses! For VIC resonance, moderate conductivity may be optimal.

Frequency Dependence

Both ε_r and σ vary with frequency:

Frequency	ε_r Effect	σ Effect
DC - 1 MHz	Constant (~80)	Constant (DC value)
1 MHz - 1 GHz	Begins to decrease	May increase
>1 GHz	Decreases significantly	High dielectric loss

For VIC frequencies (1-100 kHz), these effects are negligible.

Temperature Effects Summary

- **ε_r:** Decreases ~0.4% per °C (capacitance drops as water heats)
- **σ:** Increases ~2% per °C (resistance drops as water heats)
- **Net effect:** Resonant frequency increases slightly with temperature

Measuring Water Properties

Conductivity Meters:

- TDS meters (approximate, assume NaCl)
- True conductivity meters (more accurate)
- Laboratory grade (calibrated, temperature compensated)

DIY Measurement:

1. Use known electrode geometry cell
2. Measure AC resistance at 1 kHz (to avoid polarization)
3. Calculate σ from geometry and resistance

VIC Matrix Calculator: Enter water conductivity in the Water Profile section. The calculator computes solution resistance and shows its impact on circuit Q. Temperature compensation is also available.

Next: Calculating WFC Capacitance →

Revision #1
Created 2026-01-01 20:44:08 UTC by Chris Bake
Updated 2026-01-01 20:44:18 UTC by Chris Bake