

VIC Matrix Calculator

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Calculator Overview

VIC Matrix Calculator Overview

The VIC Matrix Calculator is a comprehensive design tool that integrates all the concepts covered in this educational series. It allows you to design, simulate, and optimize complete VIC circuits by calculating component values, resonant frequencies, Q factors, and system behavior.

Calculator URL: <https://matrix.stanslegacy.com>

What the Calculator Does

The calculator brings together multiple design domains:

1. Choke Design Module

Calculate inductance, DCR, parasitic capacitance, and SRF for custom wound chokes.

- Core selection (ferrite, iron powder, air core)
- Wire gauge and material selection
- Bifilar winding support
- Multi-layer winding calculations

2. Water Profile Module

Model the WFC as an electrical component with all relevant parameters.

- Electrode geometry (plates, tubes, arrays)
- Water conductivity effects
- Temperature compensation
- EDL and solution resistance

3. Circuit Profile Module

Combine chokes and WFC into complete VIC circuits for analysis.

- Primary and secondary resonance
- Q factor and bandwidth
- Voltage magnification
- Ring-down characteristics

4. Simulation Module

Visualize circuit behavior and optimize performance.

- Frequency response plots
- Time-domain waveforms
- Impedance analysis
- Sensitivity analysis

Design Workflow

The recommended workflow for using the calculator:

1. **Define Requirements:** Target frequency, available components, constraints
2. **Design/Select Chokes:** Use Choke Design module or enter measured values
3. **Configure Water Profile:** Enter WFC geometry and water properties
4. **Create Circuit Profile:** Combine components and select topology
5. **Run Simulation:** Analyze resonance, Q, and system behavior
6. **Optimize:** Adjust parameters to improve performance
7. **Build & Verify:** Construct circuit and compare to predictions

Key Features

Feature	Description	Benefit
Real-time Calculations	Results update instantly as you change parameters	Rapid design iteration
Warning System	Alerts for out-of-range values or design issues	Avoid common mistakes
Saved Profiles	Store and recall choke, water, and circuit configurations	Compare designs easily
Interconnected Models	Changes propagate through entire system	See full system impact
Educational Notes	Tooltips and explanations throughout	Learn while designing

Input vs. Output Parameters

You Provide (Inputs):

- Core dimensions and material properties
- Wire gauge, material, and turn count
- Electrode geometry and spacing

- Water conductivity and temperature
- Operating frequency or frequency range

Calculator Provides (Outputs):

- Inductance (L), DCR, parasitic capacitance
- Self-resonant frequency (SRF)
- WFC capacitance and ESR
- Resonant frequency (f_0)
- Q factor, bandwidth, ring-down time
- Voltage magnification ratio
- Impedance characteristics
- Frequency response curves

Accuracy and Limitations

Parameter	Typical Accuracy	Notes
Inductance	±10-20%	Core properties vary; always verify
DCR	±5%	Depends on wire tables accuracy
WFC Capacitance	±15%	Fringe effects, water purity affect results
Q Factor	±20-30%	Multiple loss mechanisms; use as estimate
Resonant Frequency	±10-15%	Depends on L and C accuracy

Important: The calculator provides design estimates. Always verify critical parameters with measurements on actual components. Real-world results may vary due to manufacturing tolerances, stray inductance/capacitance, and environmental factors.

Getting Started

To begin using the VIC Matrix Calculator:

1. Navigate to the application dashboard
2. Start with the module that matches your first design decision:
 - If you have specific chokes → Start with Choke Design
 - If you have a specific WFC → Start with Water Profile
 - If you have target frequency → Work backwards from Circuit Profile
3. Follow the guided workflow to complete your design

Tip: The following pages in this chapter provide detailed guidance on each module. Work through them in order for the best understanding of the calculator's capabilities.

Next: Component Input Parameters →

Component Inputs

Component Input Parameters

This page details all input parameters used across the VIC Matrix Calculator modules. Understanding what each parameter means and how to determine its value is essential for accurate calculations.

Choke Design Inputs

Core Parameters

Parameter	Symbol	Units	Description
Core Type	—	—	Toroid, E-core, rod, bobbin, or air-core
Core Material	—	—	Ferrite mix, iron powder, or air
Relative Permeability	μ_r	—	Material permeability (1 for air, 2000+ for ferrite)
AL Value	A_l	nH/turn ²	Inductance factor (from core datasheet)
Outer Diameter	OD	mm	Core outer diameter (toroids)
Inner Diameter	ID	mm	Core inner diameter (toroids)
Height	H	mm	Core height/thickness

Finding Core Parameters:

- Check manufacturer datasheet for A_l and μ_r

- Measure physical dimensions with calipers
- For unknown cores, estimate μ_r from material type

Wire Parameters

Parameter	Symbol	Units	Description
Wire Gauge	AWG	AWG	American Wire Gauge number
Wire Material	—	—	Copper, aluminum, silver
Number of Turns	N	turns	Total turns wound on core
Number of Layers	n_{layers}	—	Winding layers (affects parasitic C)
Winding Style	—	—	Single, bifilar, or multi-filar

Bifilar-Specific Parameters

Parameter	Description
Choke Role	Primary (L1), Secondary (L2), or Bifilar Set
Coupling Coefficient	k value between bifilar windings (typically 0.95-0.99)
Inter-winding Insulation	Thickness and material of insulation between wires

Water Profile Inputs

Electrode Geometry

Parameter	Symbol	Units	Description
Electrode Type	—	—	Parallel plates, concentric tubes, tube array
Electrode Area	A	cm ²	Active electrode surface area

Parameter	Symbol	Units	Description
Electrode Gap	d	mm	Distance between electrodes
Inner Radius	r_i	mm	Inner tube radius (cylindrical)
Outer Radius	r_o	mm	Outer tube radius (cylindrical)
Tube Length	L	cm	Submerged tube length
Number of Tubes	n	—	Tube pairs in array

Water Properties

Parameter	Symbol	Units	Description
Water Conductivity	σ	$\mu\text{S/cm}$	Electrical conductivity of water
Water Temperature	T	$^{\circ}\text{C}$	Operating temperature
Dielectric Constant	ϵ_r	—	Relative permittivity (~80 for water at 20°C)

Measuring Conductivity:

- Use a TDS or conductivity meter
- Distilled water: 1-10 $\mu\text{S/cm}$
- Tap water: 200-800 $\mu\text{S/cm}$
- If unknown, 500 $\mu\text{S/cm}$ is a reasonable tap water estimate

Circuit Profile Inputs

Component Selection

Parameter	Description
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Primary Choke (L1)	Select from saved choke designs or enter values
Secondary Choke (L2)	Select from saved choke designs or enter values
Water Profile (WFC)	Select from saved water profiles or enter values
Primary Capacitor (C1)	Capacitance value for primary resonance
Tuning Capacitor	Optional capacitor in parallel with WFC

Operating Parameters

Parameter	Symbol	Units	Description
Operating Frequency	f_{op}	kHz	Pulse generator frequency
Input Voltage	V_{in}	V	Peak pulse voltage
Duty Cycle	D	%	Pulse on-time percentage
Source Resistance	R_s	Ω	Driver output impedance

Direct Value Entry

If you have measured values for components (rather than designing from scratch), you can enter them directly:

For Chokes:

- Inductance (measured at low frequency)
- DC Resistance (measured with ohmmeter)
- Self-Resonant Frequency (if known)

For WFC:

- Capacitance (measured with LCR meter)
- ESR or solution resistance

Best Practice: When possible, measure actual component values and compare to calculated values. This helps identify measurement errors and improves your understanding of the calculator's accuracy for your specific components.

Next: Simulation Tab Explained →

Simulation Tab

Simulation Tab Explained

The Simulation tab provides visual analysis of your VIC circuit design. It generates frequency response curves, time-domain waveforms, and key performance metrics that help you understand and optimize circuit behavior.

Simulation Overview

The simulation performs several types of analysis:

1. Frequency Domain Analysis

Sweeps through a frequency range to show how the circuit responds at different frequencies.

2. Impedance Analysis

Shows how circuit impedance varies with frequency, identifying resonant points.

3. Time Domain Analysis

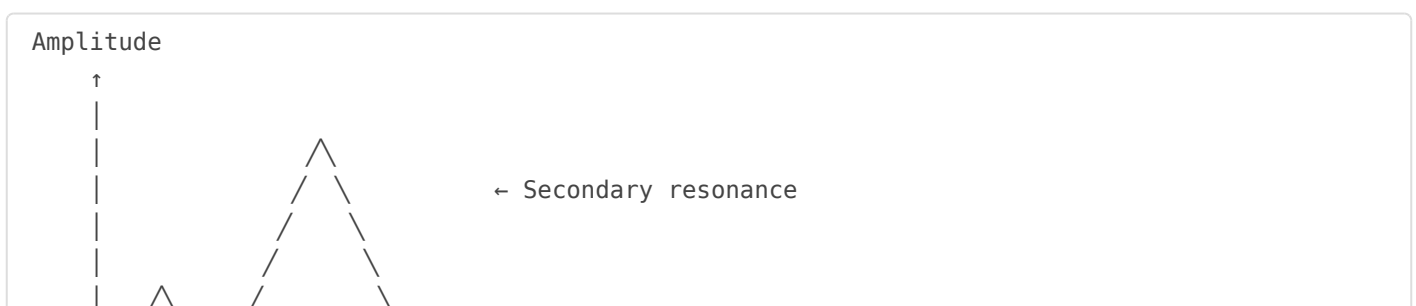
Simulates actual voltage and current waveforms during pulse operation.

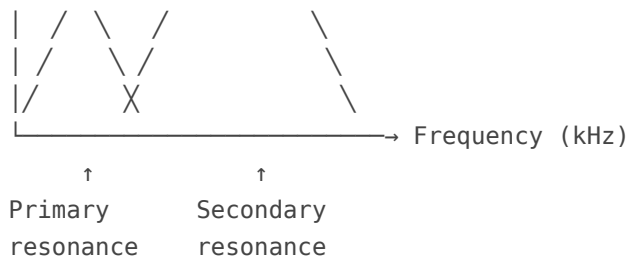
4. Ring-down Analysis

Shows how oscillations decay after excitation stops.

Frequency Response Display

The frequency response plot shows amplitude vs. frequency:





Key Features in Plot

Feature	What It Means	Ideal Characteristic
Peak Height	Voltage magnification at resonance	Higher = more voltage gain
Peak Sharpness	Q factor (sharp = high Q)	Depends on application
Peak Location	Resonant frequency f_0	Should match design target
-3dB Bandwidth	Frequency range at 70.7% of peak	Narrower = higher Q
Multiple Peaks	Primary and secondary resonances	Aligned for max transfer

Calculated Metrics

The simulation calculates and displays these key values:

Resonance Parameters

Primary f_0:	Resonant frequency of L1-C1 tank
Secondary f_0:	Resonant frequency of L2-C _{wfc} tank
Match Status:	How well primary and secondary are tuned

Q Factor Metrics

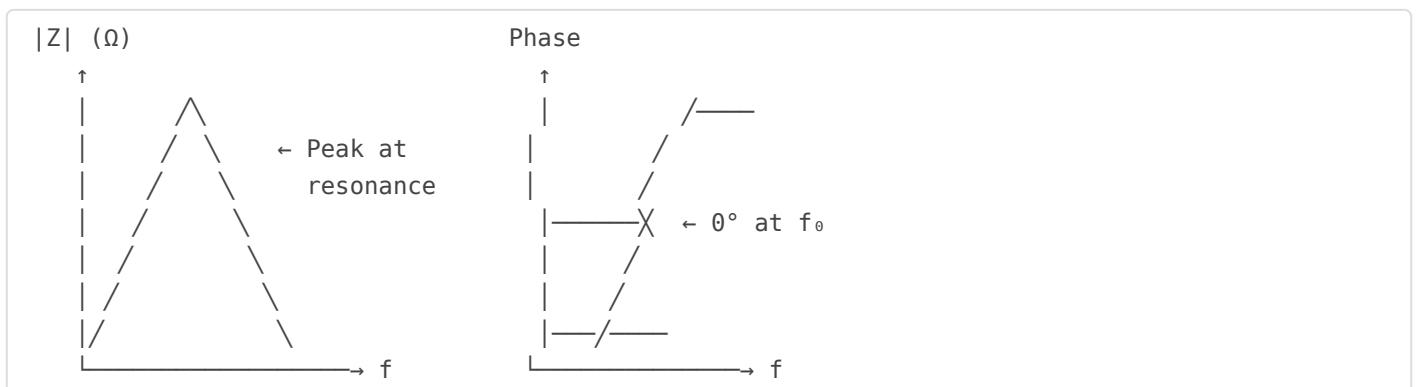
Primary Q:	Q factor of primary circuit
Secondary Q:	Q factor of secondary circuit
System Q:	Effective Q of coupled system

Performance Metrics

Voltage Magnification:	V_{out}/V_{in} at resonance
Bandwidth:	-3dB frequency range
Ring-down Time:	Time constant $\tau = 2L/R$
Ring-down Cycles:	Oscillation cycles during decay

Impedance Plot

Shows circuit impedance magnitude and phase vs. frequency:



Interpreting Impedance

- **Peak impedance:** Maximum at parallel resonance
- **Minimum impedance:** At series resonance points

- **Phase = 0°:** Indicates resonant frequency
- **Positive phase:** Inductive behavior (current lags)
- **Negative phase:** Capacitive behavior (current leads)

Time Domain Waveforms

The time-domain view shows actual voltage and current over time:

Waveforms Displayed:

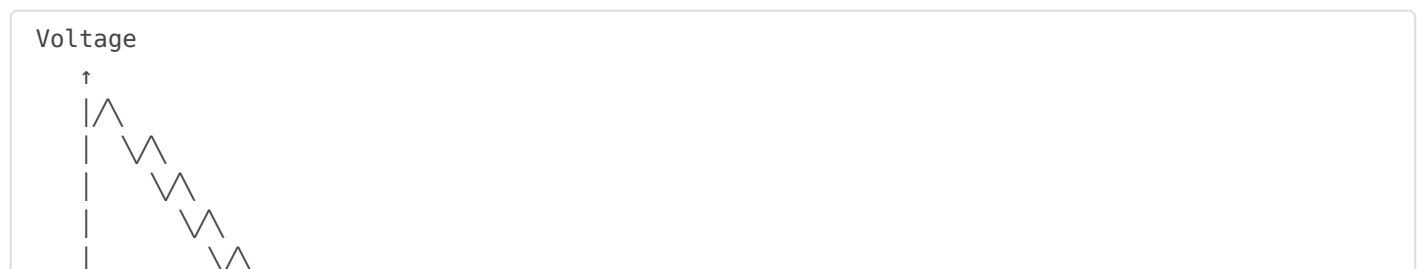
- **Input Voltage:** The driving pulse waveform
- **Primary Current:** Current through L1
- **WFC Voltage:** Voltage across the water cell
- **WFC Current:** Current through the cell

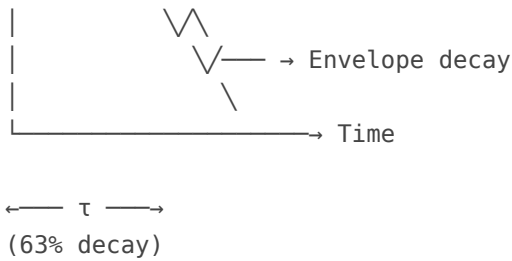
What to Look For:

- Voltage build-up during resonance
- Ring-down oscillations after pulse ends
- Phase relationship between V and I
- Settling time and stability

Ring-Down Display

Shows oscillation decay after excitation stops:





Ring-Down Metrics

Metric	Formula	Significance
Time Constant (τ)	$\tau = 2L/R$	Time to decay to 37%
Ring-down Cycles	$n \approx 0.733 \times Q$	Oscillations before decay
Settling Time	$\sim 5\tau$ for 99% decay	Time to reach steady state

Warning Indicators

The simulation flags potential issues:

Warning	Meaning	Action
⚠ Near SRF	Operating frequency close to choke SRF	Reduce frequency or redesign choke
⚠ Low Q	Q factor below recommended threshold	Reduce losses (DCR, water R)
⚠ Frequency Mismatch	Primary and secondary not aligned	Adjust C1 or component values
⚠ High Voltage	Magnified voltage exceeds safe limits	Verify insulation ratings

Using Simulation Results

Design Iteration Process:

1. Run initial simulation with your component values

2. Check if resonant frequency matches your target
3. Evaluate Q factor—is it sufficient for your goals?
4. Look for warnings and address them
5. Adjust parameters and re-simulate
6. Compare before/after to verify improvements

Pro Tip: Save your circuit profile before making changes. This allows you to compare different configurations side-by-side and roll back if needed.

Next: Circuit Optimization Strategies →

Optimization

Circuit Optimization Strategies

This page covers practical strategies for optimizing your VIC circuit design using the calculator. Learn how to achieve specific goals like maximizing Q, hitting a target frequency, or optimizing voltage magnification.

Optimization Goals

Different applications may prioritize different characteristics:

Goal	Optimize For	Trade-offs
Maximum Voltage	High Q, matched resonance	Narrower bandwidth, critical tuning
Stable Operation	Moderate Q, wide bandwidth	Lower peak voltage
Frequency Flexibility	Lower Q, broader response	Reduced magnification
Energy Efficiency	Minimize losses (DCR, R_{sol})	May require larger components

Strategy 1: Maximizing Q Factor

Q determines voltage magnification and selectivity. To maximize Q:

Reduce Choke DCR:

- Use larger wire gauge (lower AWG number)
- Use copper instead of aluminum
- Minimize wire length (fewer turns with higher- μ core)

- Consider Litz wire for high frequencies

Reduce Solution Resistance:

- Increase water conductivity slightly (add small amount of electrolyte)
- Increase electrode area
- Decrease electrode gap (but watch capacitance change)
- Ensure good electrode contact

Increase L or Decrease C:

- Higher L/C ratio raises $Z_0 = \sqrt{L/C}$
- $Q = Z_0/R$, so higher Z_0 means higher Q
- Must maintain same $f_0 = 1/(2\pi\sqrt{LC})$

Q Factor Relationships:

$$Q = 2\pi f L/R = Z/R = \sqrt{L/C}/R$$

To double Q: halve R, or quadruple L (while quartering C to maintain f_0)

Strategy 2: Hitting Target Frequency

When you need a specific resonant frequency:

Approach A: Fixed L, Adjust C

1. Design or select choke for desired L
2. Calculate required C: $C = 1/(4\pi^2 f_0^2 L)$
3. If $C_{wfc} \neq$ required C:
 - Add parallel capacitor if C_{wfc} is too low
 - Modify electrode geometry if adjustment is large

Approach B: Fixed C, Adjust L

1. Measure or calculate WFC capacitance
2. Calculate required L: $L = 1/(4\pi^2 f_0^2 C)$
3. Design choke for that inductance

Approach C: Adjust Both

1. Start with practical component ranges
2. Use calculator to explore L/C combinations
3. Choose combination that also optimizes Q

Fine-Tuning Frequency

Adjustment	Effect on f_0	Typical Range
Add parallel capacitor	Decreases f_0	1-50 nF typical
Adjust core gap (if gapped)	Changes L → changes f_0	±20% L adjustment
Add/remove turns	Changes L significantly	$L \propto N^2$

Adjustment	Effect on f_0	Typical Range
Change water level	Changes C → changes f_0	Proportional to area

Strategy 3: Matching Primary to Secondary

For maximum energy transfer, align primary and secondary resonances:

Exact Match ($f_{\text{pri}} = f_{\text{sec}}$):

- Maximum voltage transfer at resonance
- Narrow combined response
- Requires precise tuning

Slight Offset (5-10% difference):

- Broader frequency response
- More tolerant of drift
- Slightly reduced peak transfer

Calculator Approach:

1. Design secondary (L2 + WFC) first—this is usually more constrained
2. Calculate secondary f_0

3. Select C1 to tune primary to match: $C1 = 1/(4\pi^2f_0^2L1)$
4. Verify with simulation

Strategy 4: Optimizing for Available Components

When working with existing components:

Step 1: Characterize What You Have

- Measure L of available chokes
- Measure C of your WFC
- Note DCR values

Step 2: Calculate Natural Resonance

$$f_0 = 1/(2\pi\sqrt{LC})$$

This is where your circuit wants to resonate.

Step 3: Evaluate Performance

- Is f_0 in your driver's range?
- Is Q acceptable at this frequency?
- Are there SRF issues?

Step 4: Adjust as Needed

- Add tuning capacitor if f_0 is too high
- Consider different choke if f_0 is way off
- Accept the natural f_0 if performance is good

Sensitivity Analysis

Understanding how sensitive your design is to variations:

Parameter Change	Effect on f_0	Effect on Q
L +10%	f_0 -5%	Q +5%
C +10%	f_0 -5%	Q -5%
R +10%	No change	Q -10%
Temperature +10°C	f_0 +2% (due to ϵ_r drop)	Q +5% (R_{sol} drops)

Common Optimization Mistakes

? Chasing Extreme Q

Very high Q makes the circuit sensitive to drift and hard to tune. Q of 50-100 is often more practical than $Q > 200$.

? Ignoring SRF

A design that works on paper fails if operating frequency is too close to SRF. Always check this!

? Forgetting Water Resistance

Solution resistance often dominates losses. Pure distilled water has higher resistance than you might expect.

? Not Accounting for Parasitics

Real circuits have stray inductance and capacitance. Leave margin for these effects.

? Over-constraining the Design

If you fix too many parameters, you may have no degrees of freedom for optimization.

Optimization Checklist

1. Define your primary optimization goal
2. Identify fixed constraints (available components, frequency range)
3. Calculate baseline performance
4. Identify largest loss contributor (DCR vs R_{sol})
5. Make targeted improvements to dominant loss
6. Verify SRF is $>3\times$ operating frequency
7. Check that primary/secondary are reasonably matched
8. Run simulation to verify improvements
9. Consider sensitivity to variations
10. Document final design parameters

Remember: Optimization is iterative. The calculator makes it easy to try variations quickly. Don't expect to find the optimal design on the first try—explore the design space!

Next: Interpreting Calculation Results →

Interpreting Results

Interpreting Calculation Results

Understanding what the calculator's output values mean and how to use them for practical circuit construction. This page helps you translate numbers into actionable design decisions.

Understanding Output Values

Inductance Results

Output	Typical Range	What It Means
L (inductance)	1-100 mH	Primary choke property, affects f_0 and Q
DCR	0.1-50 Ω	Wire resistance, major Q limiter
SRF	50 kHz - 1 MHz	Maximum usable frequency
$C_{\text{parasitic}}$	10-500 pF	Stray capacitance, determines SRF
Wire Length	1-50 m	Total wire needed for winding

Capacitance Results

Output	Typical Range	What It Means
C_{wfc}	1-100 nF	WFC capacitance, sets resonance with L
R_{solution}	0.1-100 Ω	Water resistance, affects Q
Z_0 (characteristic)	100-10,000 Ω	$\sqrt{L/C}$, impedance at resonance

Circuit Results

Output	Typical Range	Interpretation
f_0 (resonant freq)	1-100 kHz	Where circuit resonates naturally
Q factor	5-200	Resonance sharpness, voltage gain
Bandwidth	50 Hz - 5 kHz	Usable frequency range around f_0
$V_{\text{magnification}}$	5x - 200x	Voltage gain at resonance
Ring-down τ	0.1-10 ms	Decay time constant
Ring-down cycles	3-150	Oscillations during decay

What "Good" Values Look Like

? Well-Designed VIC Circuit:

- Q factor: 30-100 (good balance of gain vs. stability)
- f_0 : Within your driver's frequency range
- Operating frequency: < 30% of SRF (preferably < 10%)
- Primary/Secondary f_0 match: Within 5-10%
- Bandwidth: Wide enough to accommodate drift
- Voltage magnification: As needed for your application

? Warning Signs:

- $Q < 10$: Very low—circuit barely resonates
- $Q > 300$: Extremely sharp—hard to tune, sensitive to drift
- $f_{\text{op}} > 0.5 \times \text{SRF}$: Operating too close to SRF
- $\text{DCR} > Z_0/10$: Resistance dominates, poor Q
- Primary/Secondary mismatch > 20%: Poor energy transfer

Translating Results to Construction

Wire Length and Turns

The calculator provides wire length and turn count. When winding:

- **Add 10-20% to wire length** for lead connections and margins
- **Count turns carefully**— L varies as N^2 , so turn count is critical
- **Verify L after winding**—actual may differ from calculated

Component Selection

Calculated Value	Selection Guidance
$C1 = 47.3 \text{ nF}$	Use 47 nF standard value (within 1%)
$C1 = 31.2 \text{ nF}$	Use 33 nF or parallel 22+10 nF
$L = 15.7 \text{ mH}$	Wind for 16 mH, fine-tune with parallel C

Understanding Accuracy Limits

Know what to expect from calculated vs. measured values:

Parameter	Expected Accuracy	Why Variation Occurs
Inductance	$\pm 10\text{-}20\%$	Core μ_r varies, winding geometry imperfect
DCR	$\pm 5\%$	Wire tables accurate, but length varies
SRF	$\pm 30\%$	Parasitic C is hard to model precisely
C_{wfc}	$\pm 15\%$	Fringe effects, water purity variation
R_{solution}	$\pm 20\%$	Conductivity varies with temperature
f_0 (calculated)	$\pm 15\%$	Depends on L and C accuracy
Q factor	$\pm 25\%$	Multiple loss mechanisms combine

Comparing Calculated vs. Measured

When Measured f_r is Lower Than Calculated:

- Actual L is higher than calculated
- Stray capacitance adding to C_{total}
- WFC capacitance underestimated

When Measured f_r is Higher Than Calculated:

- Actual L is lower than calculated
- Core saturation reducing effective L
- WFC capacitance overestimated

When Measured Q is Lower Than Calculated:

- Additional losses not accounted for (core loss, skin effect)
- Poor connections adding resistance
- Water conductivity different than assumed

Using Results for Troubleshooting

Observation	Calculator Check	Likely Issue
No resonance found	Check SRF vs. operating frequency	Operating above SRF
Very weak resonance	Check calculated Q	High losses, low Q

Observation	Calculator Check	Likely Issue
Resonance at wrong frequency	Verify L and C inputs	Input error or mismeasurement
Less voltage gain than expected	Compare Q values	Actual losses higher
Resonance drifts during use	Check temperature effects	Water heating, capacitance changing

Results Summary Checklist

Before building, verify these from your results:

1. f_0 is within driver frequency range
2. f_0 is < 30% of SRF (ideally < 10%)
3. Q is in acceptable range (typically 20-150)
4. Voltage magnification won't exceed component ratings
5. Wire gauge handles expected current
6. Primary and secondary frequencies are matched
7. No warning indicators are present
8. Results are saved for reference

Final Advice: The calculator gives you an excellent starting point. Always plan to measure your actual circuit and iterate. The goal is to get close enough that minor tuning (adjusting C1, trimming frequency) achieves optimal performance.

Chapter 7 Complete. Next: Advanced Topics →

VIC Matrix Calculator Application

The VIC Matrix Calculator (v6) can be found at the following url:

<https://matrix.stanslegacy.com>