

Complete Formula Reference

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This appendix provides a comprehensive reference of all formulas used in VIC circuit design and analysis. Formulas are organized by category for easy lookup.

1. Resonance Formulas

Formula	Equation	Units
Resonant Frequency	$f_r = 1 / (2\pi\sqrt{LC})$	Hz
Angular Frequency	$\omega = 2\pi f = 1/\sqrt{LC}$	rad/s
Period	$T = 1/f = 2\pi\sqrt{LC}$	seconds
Inductance (given f_0 , C)	$L = 1 / (4\pi^2 f^2 C)$	Henries
Capacitance (given f_0 , L)	$C = 1 / (4\pi^2 f^2 L)$	Farads

2. Q Factor and Magnification

Formula	Equation	Notes
Q Factor (inductive)	$Q = 2\pi fL / R = \omega L/R$	At frequency f
Q Factor (capacitive)	$Q = 1 / (2\pi fCR) = 1/(\omega CR)$	At frequency f
Q from Z_0	$Q = Z/R = (1/R)\sqrt{L/C}$	Series RLC
Voltage Magnification	$V_{out} = Q \times V_{in}$	At resonance
Characteristic Impedance	$Z_0 = \sqrt{L/C}$	Ohms

3. Bandwidth and Damping

Formula	Equation	Notes
Bandwidth (-3dB)	$BW = f/Q = R/(2L)$	Hz
Decay Time Constant	$\tau = 2L/R$	seconds
Damping Factor	$\zeta = R/(2L)$	rad/s
Damped Frequency	$f_d = \sqrt{f^2 - \zeta^2/(4Q^2)}$	Hz
Ringdown Cycles (to 1%)	$N \approx 0.733 \times Q$	cycles

4. Capacitance Formulas

Formula	Equation	Notes
Parallel Plate	$C = \epsilon_r \epsilon_0 A/d$	$\epsilon_0 = 8.854 \times 10^{-12} \text{ F/m}$
Concentric Cylinders	$C = 2\pi\epsilon_r \epsilon_0 L / \ln(r_o/r_i)$	L = length
Capacitors in Series	$1/C_{total} = 1/C_1 + 1/C_2 + \dots$	
Capacitors in Parallel	$C_{total} = C_1 + C_2 + \dots$	
Energy in Capacitor	$E = \frac{1}{2}CV^2$	Joules

5. Inductance Formulas

Formula	Equation	Notes
Solenoid (air core)	$L = \mu_0 N^2 A/l$	$\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$
Wheeler's Formula	$L(\mu H) = N^2 r^2 / (9r + 10l)$	r, l in inches
A_L Method	$L = A_L \times N^2$	A_L in nH/turn ²
Inductors in Series	$L_{total} = L_1 + L_2$ (no coupling)	
Mutual Inductance	$M = k(L_1 L_2)$	k = coupling coefficient

Formula	Equation	Notes
Energy in Inductor	$E = \frac{1}{2}LI^2$	Joules

6. Resistance and Wire

Formula	Equation	Notes
Wire Resistance	$R = \rho L/A$	ρ = resistivity
Wire Area (AWG)	$A = \pi(d/2)^2$	d from wire tables
Skin Depth	$\delta = \sqrt{\rho / (\pi f \mu)}$	meters
Copper Skin Depth	$\delta(\text{mm}) \approx 66 / \sqrt{f(\text{Hz})}$	Quick approximation
Power Dissipation	$P = I^2R = V^2/R$	Watts

7. Impedance Formulas

Element	Impedance	Phase
Resistor	$Z = R$	0°
Capacitor	$Z = 1/(j\omega C) = -j/(\omega C)$	-90°
Inductor	$Z = j\omega L = j2\pi fL$	$+90^\circ$
CPE	$Z = 1/(Q(j\omega)^n)$	$-n \times 90^\circ$
Warburg	$Z = \sqrt{\rho s} \times (1-j)$	-45°

8. Electric Double Layer

Formula	Equation	Notes
Helmholtz Capacitance	$C_H = \epsilon \epsilon_0 A/d$	$d \approx 0.3 \text{ nm}$
Debye Length	$\lambda_D \approx 0.304 / \sqrt{c} \text{ (nm)}$	c in mol/L

Formula	Equation	Notes
Total EDL (series)	$1/C = 1/C_{\text{Stern}} + 1/C_{\text{diff}}$	

9. Cole-Cole Model

Complex Permittivity:

$$\epsilon^* = \epsilon_\infty + (\epsilon_s - \epsilon_\infty) / [1 + (j\omega\tau)^{1-\alpha}]$$

Effective Capacitance:

$$C_{\text{eff}}(\omega) = C \times [1 + (\omega\tau)^{2(1-\alpha)}]^{-1/2}$$

10. Step Charging

Formula	Equation	Notes
Ideal N pulses	$V_{C,N} = 2N \times V_s$	Lossless
Maximum voltage	$V_{\text{max}} = (4Q/\tau) \times V_s$	With losses
Half-cycle time	$t = \tau(LC)$	For single pulse

Physical Constants

Constant	Symbol	Value
Permittivity of free space	ϵ_0	8.854×10^{-12} F/m
Permeability of free space	μ_0	$4\pi \times 10^{-7}$ H/m
Relative permittivity (water)	ϵ_r	~80 at 20°C
Copper resistivity	ρ_{Cu}	1.68×10^{-8} $\Omega \cdot \text{m}$
Elementary charge	e	1.602×10^{-19} C
Boltzmann constant	k_B	1.381×10^{-23} J/K

Reference complete. Use with the VIC Matrix Calculator for automated calculations.

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