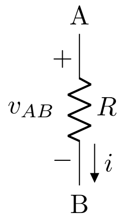
Ohm's Law



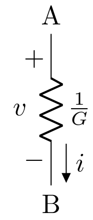
$v_{AB} = iR$

$v_A = v_B + iR$

$i = \frac{v_{AB}}{R}$

$i = \frac{v_A - v_B}{R}$

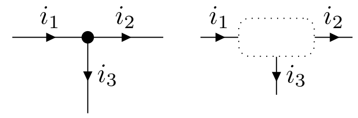
Conductance



$v = \frac{i}{G}$

$i = vG$

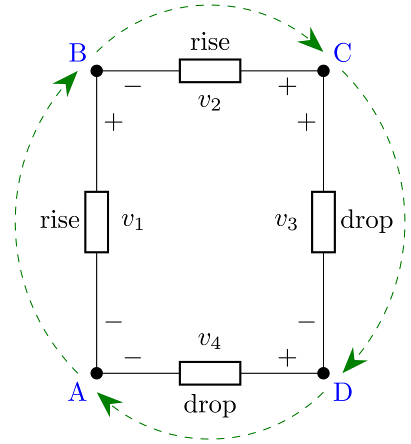
KCL



$\sum$ currents in $= \sum$ currents out

$i_1 = i_2 + i_3$

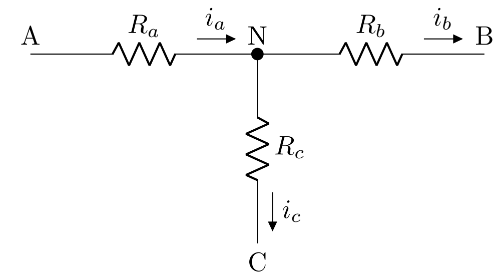
KVL



$\sum$ rises $= \sum$ drops

$v_1 + v_2 = v_3 + v_4$

Node-Voltage

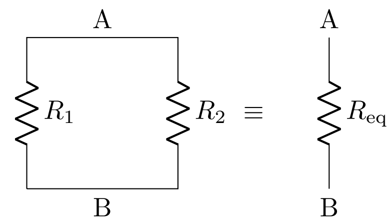


Equation at node N:

$i_a = i_b + i_c$

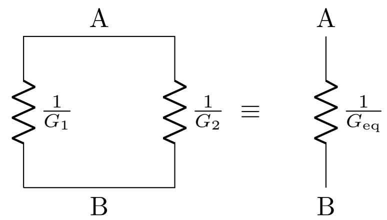
$\frac{v_A - v_N}{R_a} = \frac{v_N - v_B}{R_b} + \frac{v_N - v_C}{R_c}$

Parallel Resistors



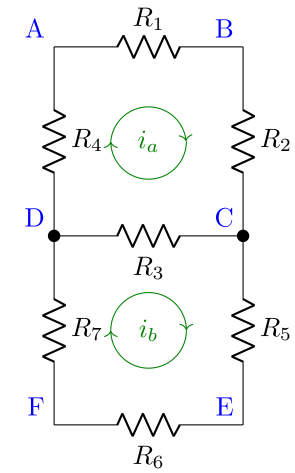
$R_{\text{eq}} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)^{-1} = \frac{R_1 R_2}{R_1 + R_2}$

Parallel Conductance



$G_{\text{eq}} = G_1 + G_2$

Mesh Currents



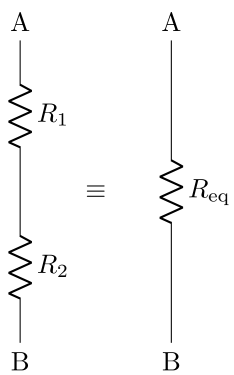
KVL equation for mesh a:

$R_1\,(i_a) \;+\; R_2\,(i_a) \;+\; \underbrace{R_3\,(i_a - i_b)}_{i_a \text{ overlaps } i_b} \;+\; R_4\,(i_a) \;= 0$

KVL equation for mesh b:

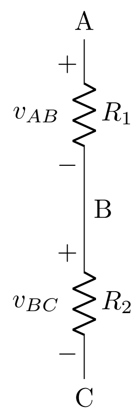
$R_5\,(i_b) \;+\; R_6\,(i_b) \;+\; \underbrace{R_3\,(i_b - i_a)}_{i_a \text{ overlaps } i_b} \;+\; R_7\,(i_b) \;= 0$

Series Resistors



$R_{\text{eq}} = R_1 + R_2$

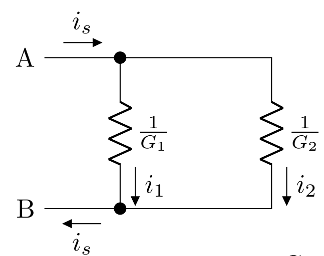
Voltage Divider



$v_{AB} = v_{AC}\frac{R_1}{R_1 + R_2}$

$v_{BC} = v_{AC}\frac{R_2}{R_1 + R_2}$

Current Divider

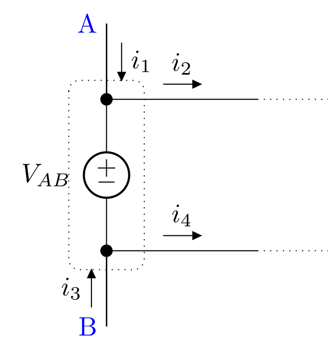


$i_1 = i_s\frac{G_1}{G_1 + G_2}$

$i_2 = i_s\frac{G_2}{G_1 + G_2}$

Super-Node

Use with node-voltage method.



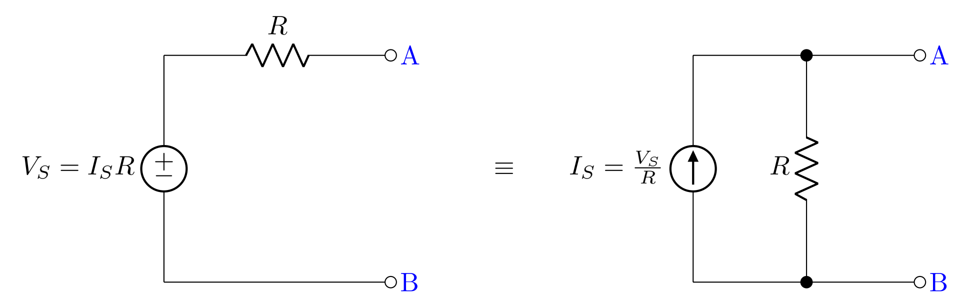
KCL wraps around two nodes to avoid voltage source.

$\sum$ currents in $= \sum$ currents out

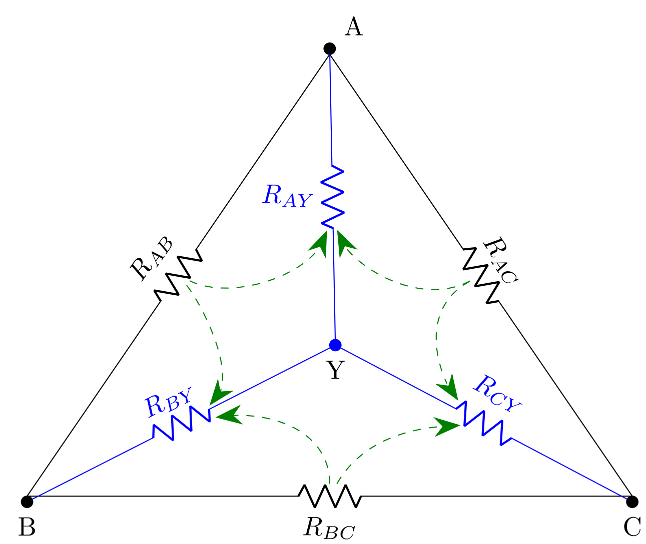
KCL: $i_1 + i_3 = i_2 + i_4$

Constraint: $v_A - v_B = v_{AB}$

Source Transformation



$\Delta - Y$ Transform



Denominator:
$D = R_{AB} + R_{AC} + R_{BC}$

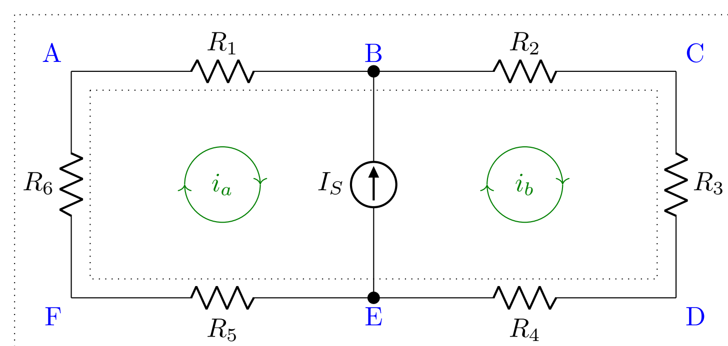
$R_{AY} = \frac{R_{AB} R_{AC}}{D}$

$R_{BY} = \frac{R_{AB} R_{BC}}{D}$

$R_{CY} = \frac{R_{AC} R_{BC}}{D}$

Super-Mesh

Use with mesh-current method



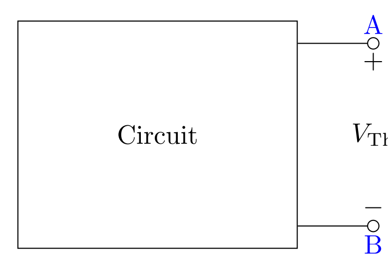
KVL wraps around two meshes to avoid current source.

KVL equation: $R_1 i_a + R_2 i_b + R_3 i_b + R_4 i_b + R_5 i_a + R_6 i_a = 0$

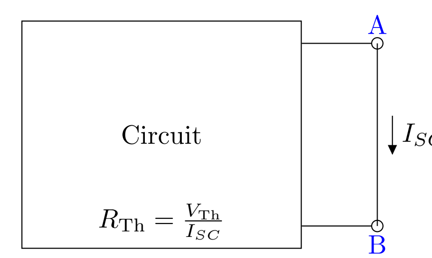
Mesh Constraint: $i_b - i_a = I_S$

Thevenin Equivalent Circuit

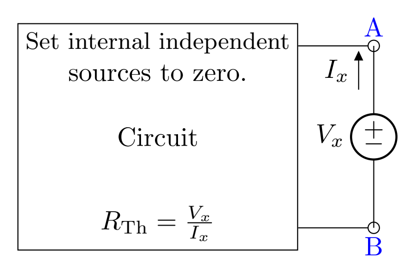
Thevenin Voltage



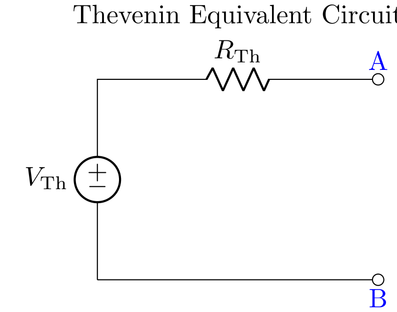
Short-Circuit Current Method



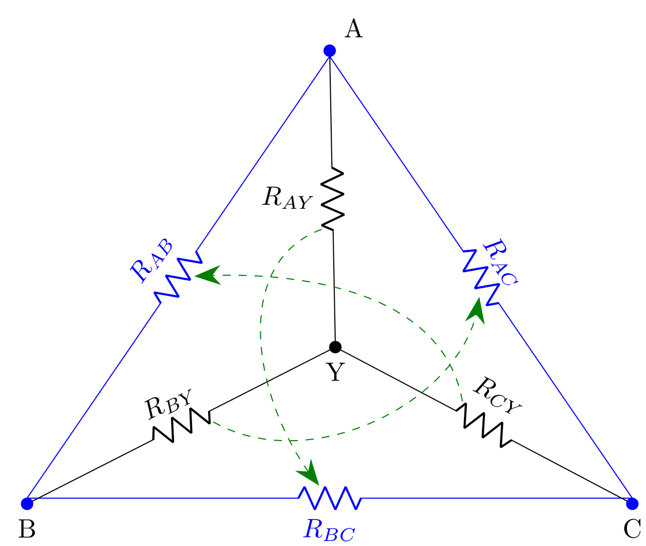
Test Voltage Source Method



Thevenin Equivalent Circuit



$Y - \Delta$ Transform



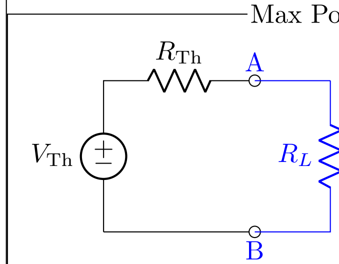
Numerator:
$N = R_{AY} R_{BY} + R_{AY} R_{CY} + R_{BY} R_{CY}$

$R_{AB} = \frac{N}{R_{CY}}$

$R_{BC} = \frac{N}{R_{AY}}$

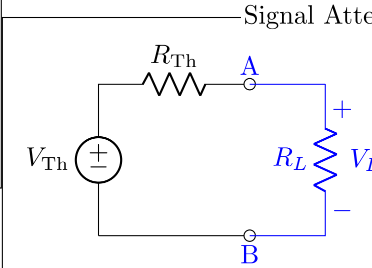
$R_{AC} = \frac{N}{R_{BY}}$

Max Power Transfer



Load power is maximum when $R_L = R_{\text{Th}}$

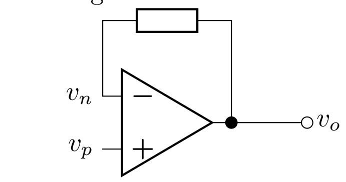
Signal Attenuation



Voltage across load is $V_L = V_{\text{Th}}\left(\frac{R_L}{R_L + R_{\text{Th}}}\right)$

Ideal Op Amp

Negative Feedback

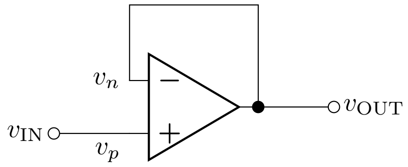


Virtual Short: $v_n \approx v_p$

Open-loop: $v_o = A\,(v_p - v_n)$

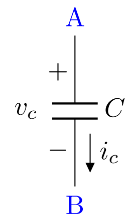
Ideal: $A \to \infty$

Follower Configuration



$v_{\mathrm{OUT}} = v_n \approx v_p = v_{\mathrm{IN}}$

Capacitor



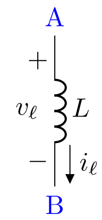
$$i_c = C\frac{d\,v_c}{dt}$$

$$v_c = V_0 + \frac{1}{C}\int_0^t i_c\,d\tau$$

$$q_c = Cv_c$$

Voltage cannot change instantaneously.
Steady-state: **open circuit**.
Stored energy: $E = \frac{1}{2}Cv_c^2$

Inductor



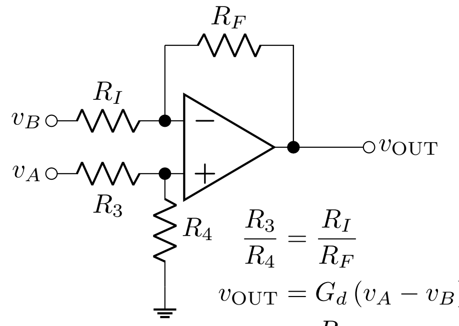
$$v_\ell = L\frac{d\,i_\ell}{dt}$$

$$i_\ell = I_0 + \frac{1}{L}\int_0^t v_\ell\,d\tau$$

$$\phi_\ell = Li_\ell$$

Current cannot change instantaneously.
Steady-state: **short circuit**.
Stored energy: $E = \frac{1}{2}Li_\ell^2$

Difference Amplifier

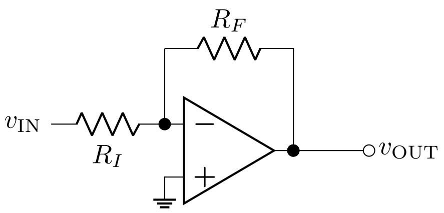


$$\frac{R_3}{R_4} = \frac{R_I}{R_F}$$

$$v_{\mathrm{OUT}} = G_d\,(v_A - v_B)$$

$$G_d = \frac{R_F}{R_I}$$

Inverting Configuration

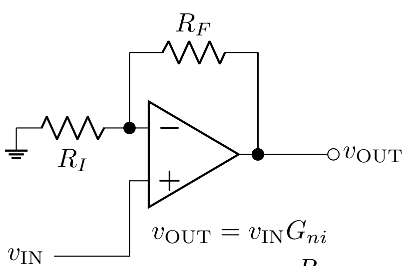


$$v_{\mathrm{OUT}} = v_{\mathrm{IN}}G_i$$

$$G_i = -\frac{R_F}{R_I}$$

$$v_n \approx v_p = 0$$

Non-Inverting Configuration

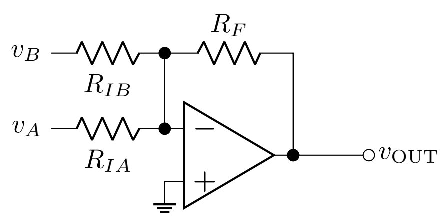


$$v_{\mathrm{OUT}} = v_{\mathrm{IN}}G_{ni}$$

$$G_{ni} = 1 + \frac{R_F}{R_I}$$

$$v_n \approx v_p = v_{\mathrm{IN}}$$

Summing Configuration

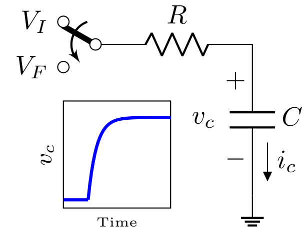


$$v_{\mathrm{OUT}} = v_AG_A + v_BG_B$$

$$G_A = -\frac{R_F}{R_{IA}}$$

$$G_B = -\frac{R_F}{R_{IB}}$$

Capacitor RC Step Response

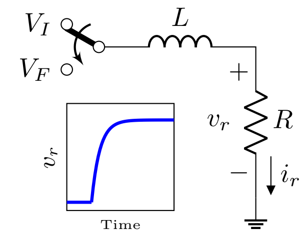


Initial: $v_c(0) = V_I$
Final: $v_c(\infty) = V_F$

Transient: $t > 0$
$v_c(t) = V_F + (V_I - V_F)\,e^{-t/\tau}$

Time Constant: $\tau = RC$

Inductor LR Step Response

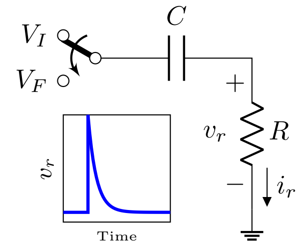


Initial: $v_r(0) = V_I$
Final: $v_r(\infty) = V_F$

Transient: $t > 0$
$v_r(t) = V_F + (V_I - V_F)\,e^{-t/\tau}$

Time Constant: $\tau = L/R$

Capacitor CR Step Response

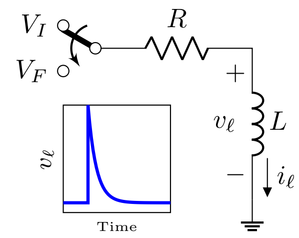


Initial: $v_r(0) = 0$
Final: $v_r(\infty) = 0$

Transient: $t > 0$
$v_r(t) = (V_F - V_I)\,e^{-t/\tau}$

Time Constant: $\tau = RC$

Inductor RL Step Response

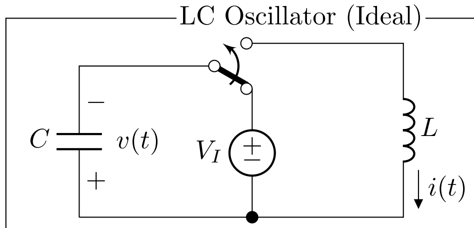


Initial: $v_\ell(0) = 0$
Final: $v_\ell(\infty) = 0$

Transient: $t > 0$
$v_\ell(t) = (V_F - V_I)\,e^{-t/\tau}$

Time Constant: $\tau = L/R$

LC Oscillator (Ideal)



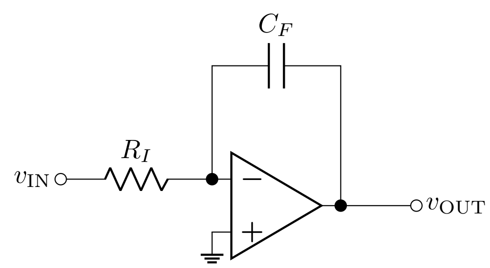
Energy oscillates between
inductor and capacitor, $v(t) = V_I\cos(\omega t)$

Frequency: $\omega = \sqrt{\frac{1}{LC}}$ rad/sec

$f = \frac{\omega}{2\pi}$ Hz

Current: $i(t) = V_I\sqrt{\frac{C}{L}}\sin(\omega t)$

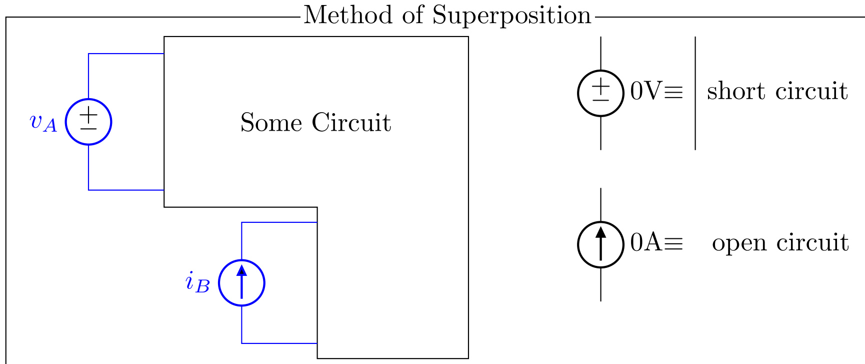
Integrator Configuration



$v_{\mathrm{OUT}} = V_I - \frac{1}{R_IC_F}\int_0^t v_{\mathrm{IN}}(\tau)d\tau$

Initial voltage is V_I at time zero. Switch or resistor can be inserted across C_F to define initial conditions.

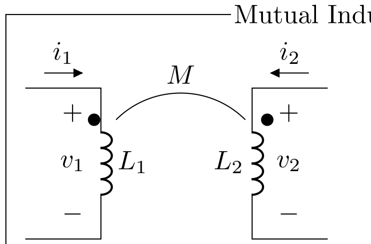
Method of Superposition



Circuit With Multiple **Independent** Sources:
Solve **partial solutions** for one source at a time,
set all other independent sources to zero.
Combined Solution is the sum of partial solutions
for every node and branch.

Example:
First: Set $i_B = 0$, solve voltages v'_k and currents i'_j in the circuit.
Next: Set $v_A = 0$, solve voltages v''_k and currents i''_j in the circuit.
Combine: sum $v_k = v'_k + v''_k$ and $i_j = i'_j + i''_j$.

Mutual Inductance



$$v_1 = L_1\frac{di_1}{dt} + M\frac{di_2}{dt}$$

$$v_2 = L_2\frac{di_2}{dt} + M\frac{di_1}{dt}$$

SI Prefixes

SI Prefix	Scale
a "atto"	10^{-18}
f "femto"	10^{-15}
p "pico"	10^{-12}
n "nano"	10^{-9}
u or μ "micro"	10^{-6}
m "milli"	10^{-3}
c "centi"	10^{-2}
d "deci"	10^{-1}
da "deka"	10^{1}
h "hecto"	10^{2}
k "kilo"	10^{3}
M "mega"	10^{6}
G "giga"	10^{9}
T "terra"	10^{12}

Basic Units

Thing	Unit	Equivalent Units
Charge	Q or C "Coulomb"	
Energy	J "Joule"	
Power	W "Watt"	J/s
Voltage	V "Volt"	J/Q
Current	A "Amp(ere)"	Q/s
Flux Linkage	Wb "Weber"	V·s
Frequency	Hz (cycles per second)	radians/sec = 2π×Hz
Resistance	Ω "Ohm"	V/A
Conductance	℧ "Mho" or S "Siemens"	A/V
Capacitance	F "Farad"	Q/V
Inductance	H "Henry"	Wb/A