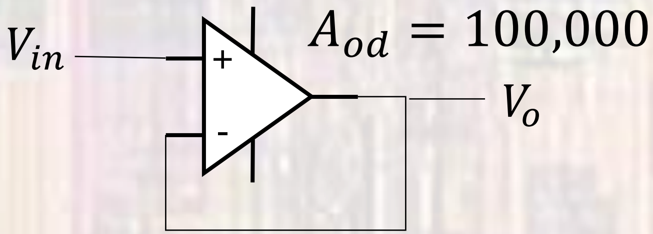
OpAmp Circuits

Last updated 4/14/22

OpAmp Circuits

- Most opamps are operated in negative feedback configurations
  - Output feeds back to the - input

- Voltage Follower



$$V_o = A_{od}(V_+ - V_-)$$

$$V_o = A_{od}(V_{in} - V_o)$$

$$V_o = \frac{A_{od}}{1 + A_{od}} V_{in} = V_{in}|_{A_{od} \gg 1}$$

$$\boxed{A_v = \frac{V_o}{V_{in}} = \frac{A_{od}}{1 + A_{od}} = 1}$$

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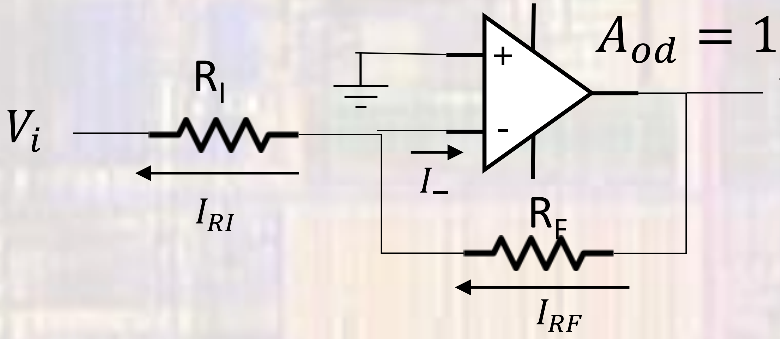
OpAmp Circuits

- Fixed Gain Inverting Amplifier
  - Gnd ref



$A_{od} = 100{,}000$

$I_{RF} = I_{RI} + I_- = I_{RI}$

$$I_{RF} = \frac{V_o - V_-}{R_F} = \frac{V_o - \left(V_+ - \frac{V_0}{A_{od}}\right)}{R_F} \qquad I_{RI} = -\frac{V_i - V_-}{R_I} = -\frac{V_i - \left(V_+ - \frac{V_0}{A_{od}}\right)}{R_I}$$

$$\frac{V_o - \left(\cancelto{0}{V_+} - \cancelto{0}{\frac{V_0}{A_{od}}}\right)}{R_F} = -\frac{V_i - \left(\cancelto{0}{V_+} - \cancelto{0}{\frac{V_0}{A_{od}}}\right)}{R_I}$$

$$\boxed{V_o = -\frac{R_F}{R_I} V_i} \qquad \boxed{A_v = -\frac{R_F}{R_I}}$$

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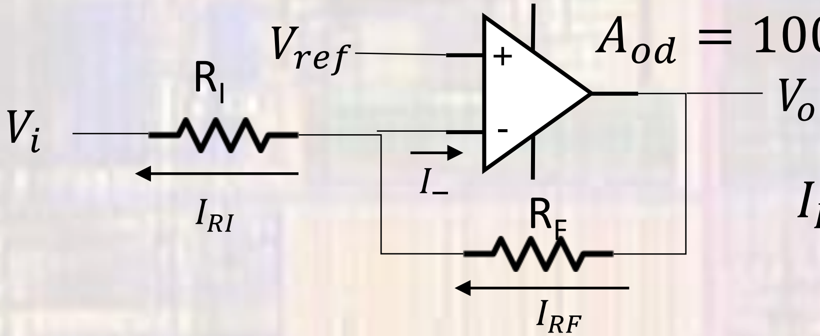
OpAmp Circuits

- Fixed Gain Inverting Amplifier
  - Arbitrary ref



$$A_{od} = 100{,}000$$

$$I_{RF} = I_{RI} + I_- = I_{RI}$$

$$I_{RF} = \frac{V_o - V_-}{R_F} = \frac{V_o - \left(V_{ref} - \frac{V_0}{A_{od}}\right)}{R_F} \qquad I_{RI} = -\frac{V_i - V_-}{R_I} = -\frac{V_i - \left(V_{ref} - \frac{V_0}{A_{od}}\right)}{R_I}$$

$$\frac{V_o - \left(V_{ref} - \cancelto{0}{\frac{V_0}{A_{od}}}\right)}{R_F} = -\frac{V_i - \left(V_{ref} - \cancelto{0}{\frac{V_0}{A_{od}}}\right)}{R_I}$$

$$\boxed{V_o = -\frac{R_F}{R_I}V_i + \left(1 + \frac{R_F}{R_I}\right)V_{ref}}$$

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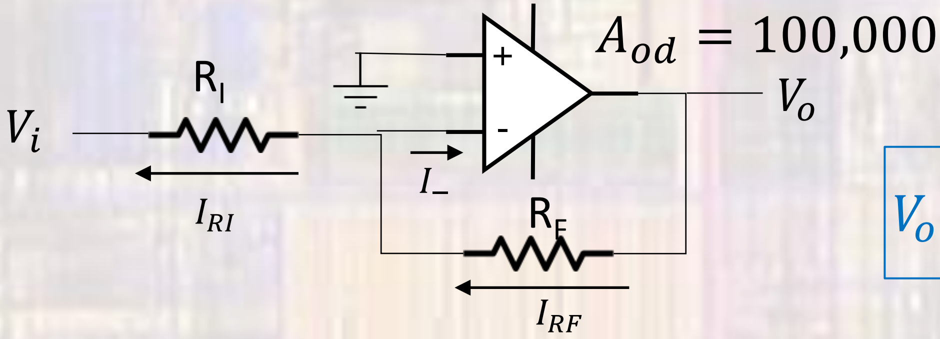
OpAmp Circuits

- Inverting Amplifier
  - Second look



$$V_o = -\frac{R_F}{R_I} V_i$$

$$V_- = V_i + V_{R_I} = V_i + (V_o - V_i)\frac{R_I}{R_I + R_F}$$

$$V_- = \frac{V_i R_I + V_i R_F + V_o R_I - V_i R_I}{R_I + R_F} = \frac{V_i R_F + V_o R_I}{R_I + R_F} = \frac{V_i R_F - \frac{R_F}{R_I} V_i R_I}{R_I + R_F}$$

$$V_- = \frac{V_i R_F - R_F V_i}{R_I + R_F} = 0$$

V_- is called a virtual ground

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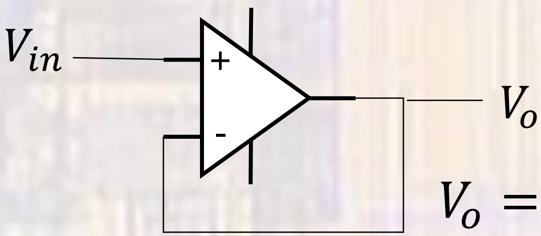
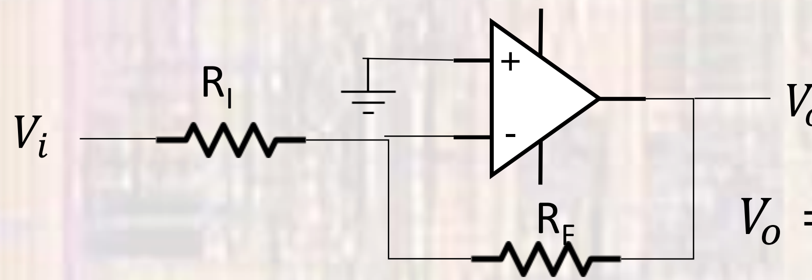
OpAmp Circuits

- Inverting Amplifier

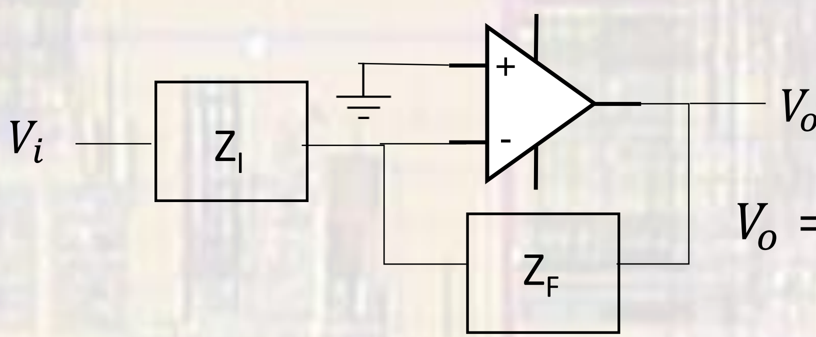
An opamp in a negative feedback configuration will drive its output to force the V+ and V- inputs to be equal



$$V_o = V_{in}$$



$$V_o = -\frac{R_F}{R_I} V_i$$



$$V_o = -\frac{Z_F}{Z_I} V_i$$

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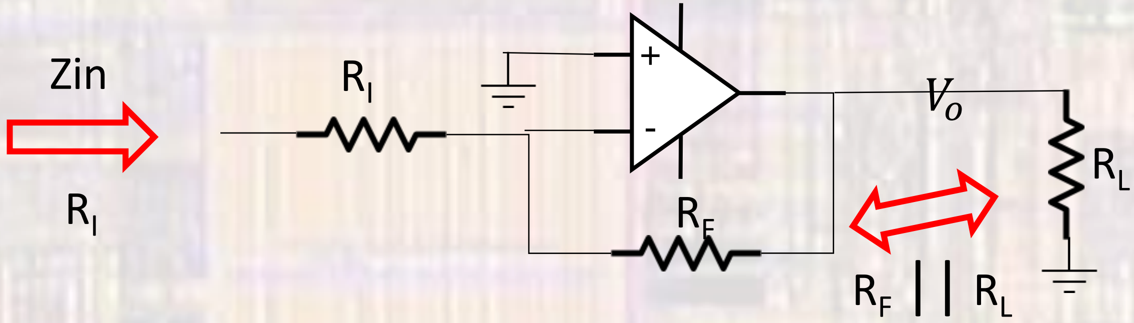
OpAmp Circuits

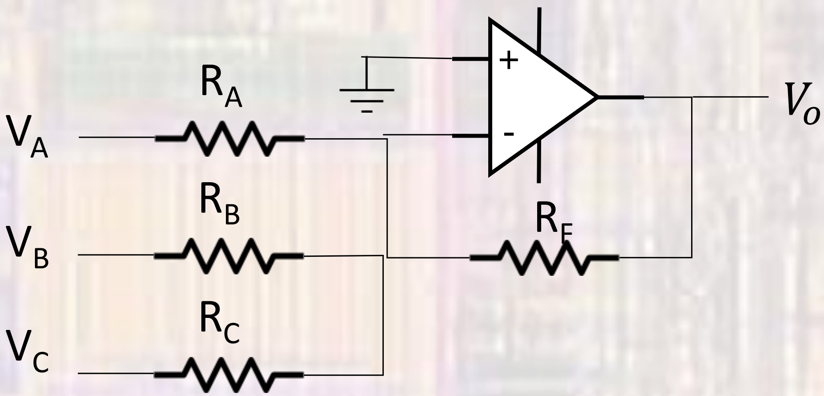
- Fixed Gain Inverting Amplifier



Input impedance concerns
Input current and input offset current concerns
Output impedance concerns

OpAmp Circuits

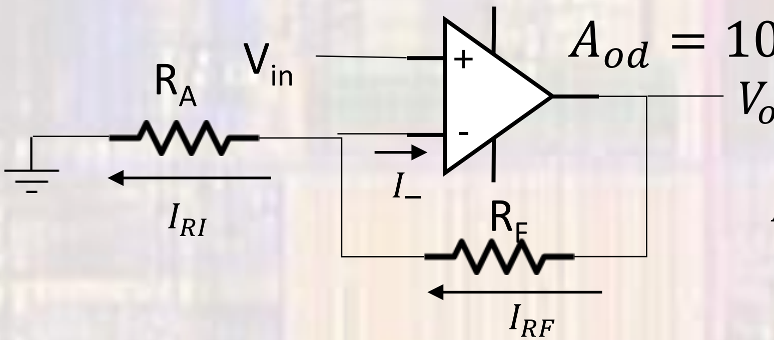
- Fixed Gain Inverting Summing Amplifier
  - By superposition



$$V_o = -\frac{R_F}{R_A}V_A - \frac{R_F}{R_B}V_B - \frac{R_F}{R_C}V_C$$

OpAmp Circuits

- Fixed Gain Non-Inverting Summing Amplifier
  - Full Analysis



$$A_{od} = 100{,}000$$

$$I_{RF} = I_{RA} + I_{-} = I_{RA}$$

$$I_{RF} = \frac{V_o - V_-}{R_F} = \frac{V_o - \left(V_{in} - \frac{V_0}{A_{od}}\right)}{R_F}$$

$$I_{RA} = \frac{V_- - 0}{R_A} = \frac{V_{in} - \frac{V_0}{A_{od}}}{R_A}$$

$$\frac{V_o - V_{in} + \cancelto{0}{\frac{V_0}{A_{od}}}}{R_F} = \frac{V_{in} - \cancelto{0}{\frac{V_0}{A_{od}}}}{R_A}$$

$$\boxed{V_o = \left(1 + \frac{R_F}{R_A}\right) V_{in}}$$

$$\boxed{A_v = 1 + \frac{R_F}{R_A}}$$

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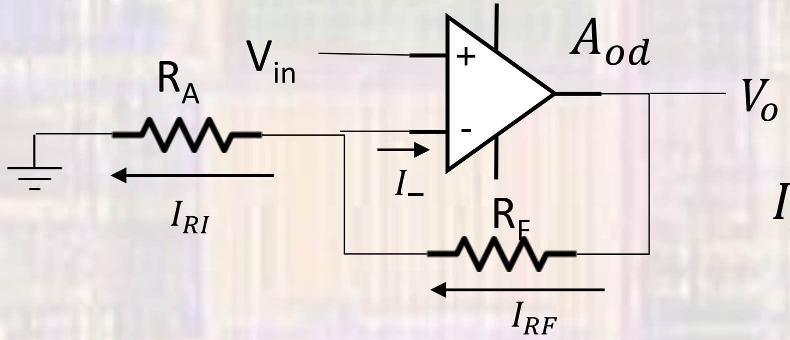
OpAmp Circuits

- Fixed Gain Non-Inverting Summing Amplifier
  - Simplified analysis
    - Output moves to make the + and – inputs equal



$$I_{RF} = I_{RA} + I_- = I_{RA}$$

$$I_{RF} = \frac{V_o - V_-}{R_F} = \frac{V_o - V_{in}}{R_F}$$

$$I_{RA} = \frac{V_- - 0}{R_A} = \frac{V_{in}}{R_A}$$

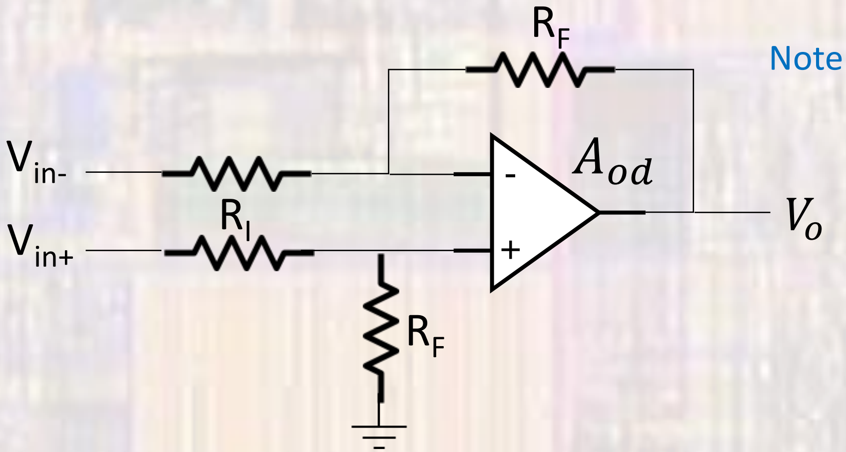
$$\frac{V_o - V_{in}}{R_F} = \frac{V_{in}}{R_A}$$

$$\boxed{V_o = \left(1 + \frac{R_F}{R_A}\right) V_{in}}$$

$$\boxed{A_v = 1 + \frac{R_F}{R_A}}$$

OpAmp Circuits

- Difference Amplifier



Note: no power pins
Amplifier flipped upside down

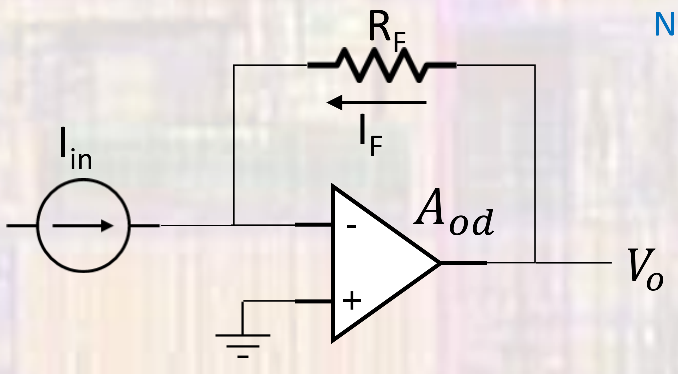
$$V_+ = V_{in+}\frac{R_F}{R_I + R_F} = V_-$$

$$\frac{V_{in-} - V_-}{R_I} = -\frac{V_o - V_-}{R_F}$$

$$\boxed{V_o = \frac{R_F}{R_I}(V_{in+} - V_{in-})}$$

OpAmp Circuits

- Current to Voltage Converter



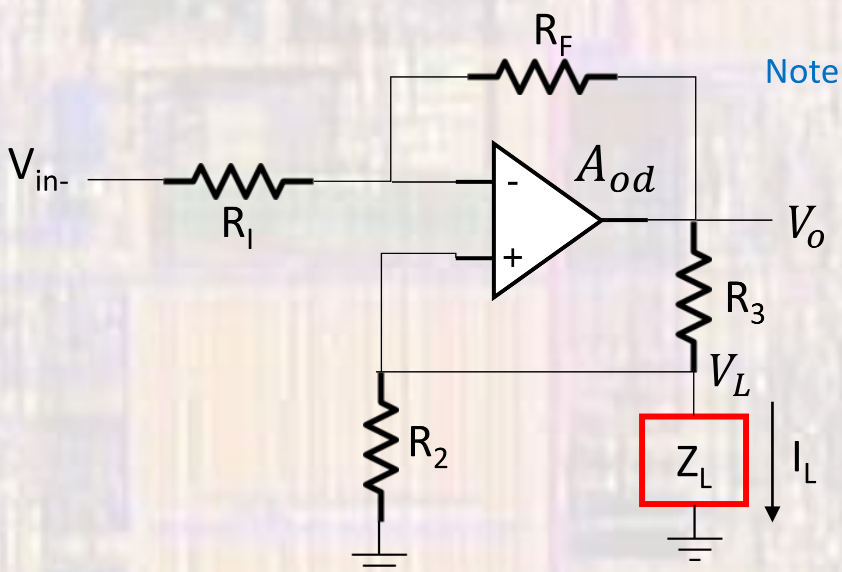
Note: no power pins
Amplifier flipped upside down

$$I_F = \frac{V_o - \cancel{V_-}^{\,0}}{R_F} = -I_{in}$$

$$\boxed{V_o = -I_{in} R_F}$$

OpAmp Circuits

- Voltage to Current Converter



Note: no power pins
Amplifier flipped upside down

$$I_L = \left.\frac{-V_{in}}{R_2}\right|_{\frac{R_F}{R_2R_3}=\frac{1}{R_2}}$$

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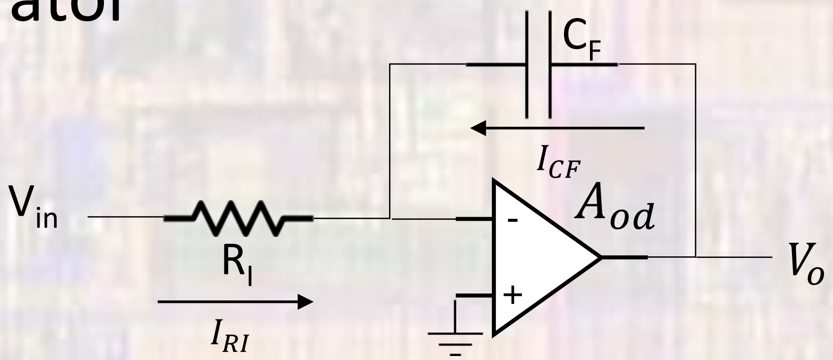
OpAmp Circuits

- Integrator



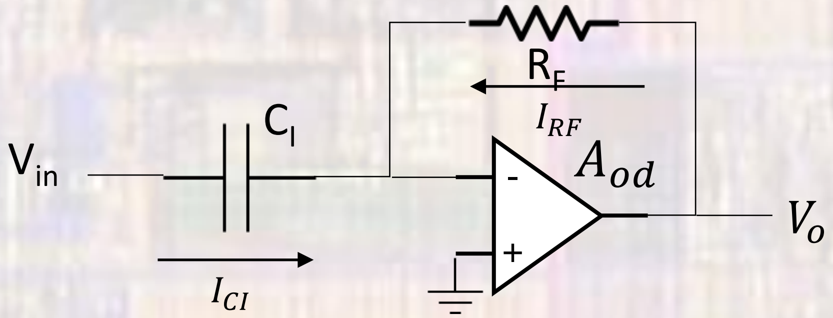
$$I_{CF} = C_F \frac{d_{vo}}{d_t} = -\frac{V_{in}}{R_I}$$

$$d_{vo} = -\frac{V_{in}}{C_F R_I} d_t$$

$$\boxed{V_o = V_{CF_0} - \frac{1}{C_F R_I} \int_0^t V_{in}(t')\, d_{t'}}$$

OpAmp Circuits

- Differentiator



$$I_{CI} = C_I \frac{d_{vin}}{d_t} = -\frac{V_o}{R_F}$$

$$\boxed{V_o = -R_F C_I \frac{d_{vin}}{d_t}}$$

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