Electronics and Instrumentations

Operational Amplifiers (Op-Amps)

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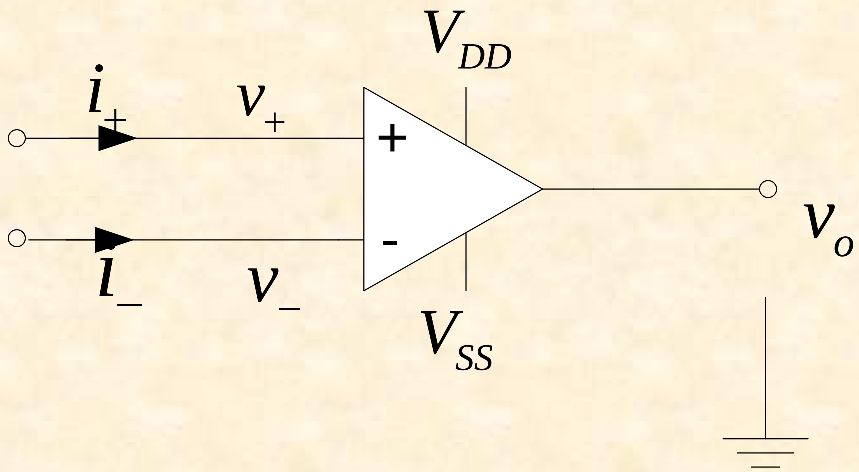
Operational Amplifiers (Op Amps)

- **Ideal Op Amp**
- Non-inverting Amplifier
- Unity-Gain Buffer
- Inverting Amplifier
- Differential Amplifier
- Current-to-Voltage Converter
- Non-ideal Op Amp

Ideal Op Amp



$$V_{SS} < v_0 < +V_{DD}$$

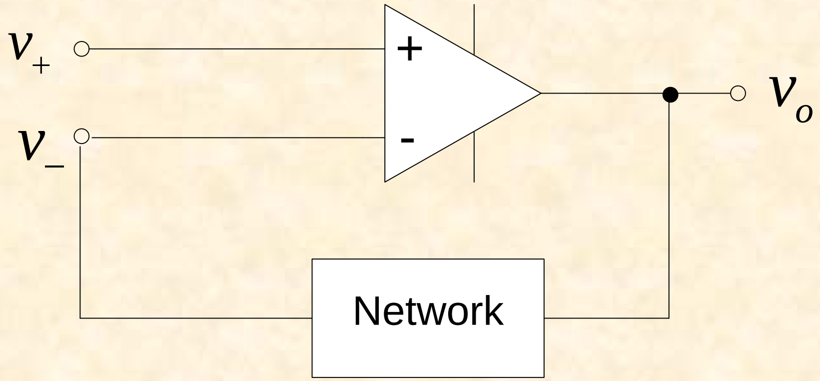
1) $$v_0 = A_v\left(v_+ - v_-\right)$$

The open-loop gain, A_v, is very large, approaching infinity.

2) $$i_+ = i_- = 0$$

The current into the inputs are zero.

Ideal Op Amp with Negative Feedback



Golden Rules of Op Amps:

1. The output attempts to do whatever is necessary to make the voltage difference between the inputs zero.

2. The inputs draw no current.

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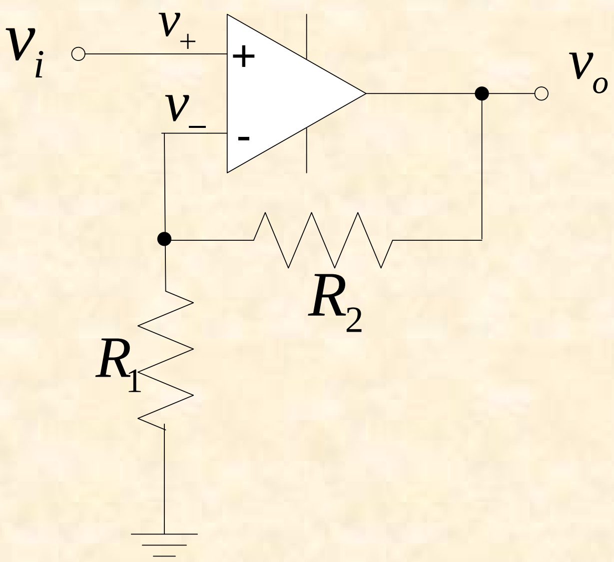
Non-inverting Amplifier



Closed-loop voltage gain

$$A_F = \frac{v_o}{v_i}$$

$$v_i = v_+ = v_- = \frac{R_1}{R_1 + R_2} v_o$$

$$A_F = \frac{v_o}{v_i} = 1 + \frac{R_2}{R_1}$$

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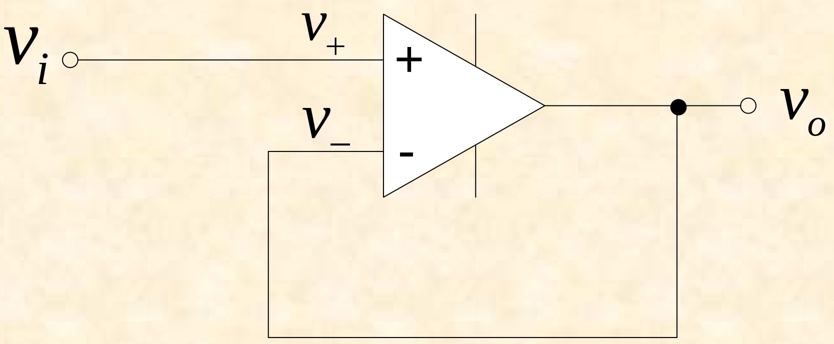
Unity-Gain Buffer



Closed-loop voltage gain

$$A_F = \frac{v_o}{v_i}$$

$$v_i = v_+ = v_- = v_o$$

$$A_F = \frac{v_o}{v_i} = 1$$

Used as a "line driver" that transforms a high input impedance (resistance) to a low output impedance. Can provide substantial current gain.

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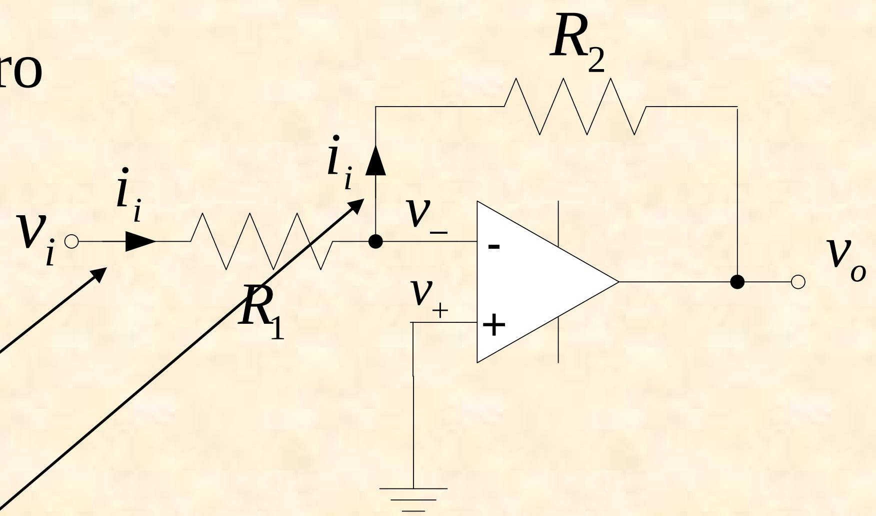
Inverting Amplifier

Current into op amp is zero



$$v_- = v_+ = 0$$

$$i_i = \frac{v_i - 0}{R_1} = \frac{v_i}{R_1}$$

$$i_i = \frac{0 - v_0}{R_2} = \frac{-v_0}{R_2}$$

$$\frac{v_i}{R_1} = \frac{-v_0}{R_2}$$

$$A_F = \frac{v_o}{v_i} = -\frac{R_2}{R_1}$$

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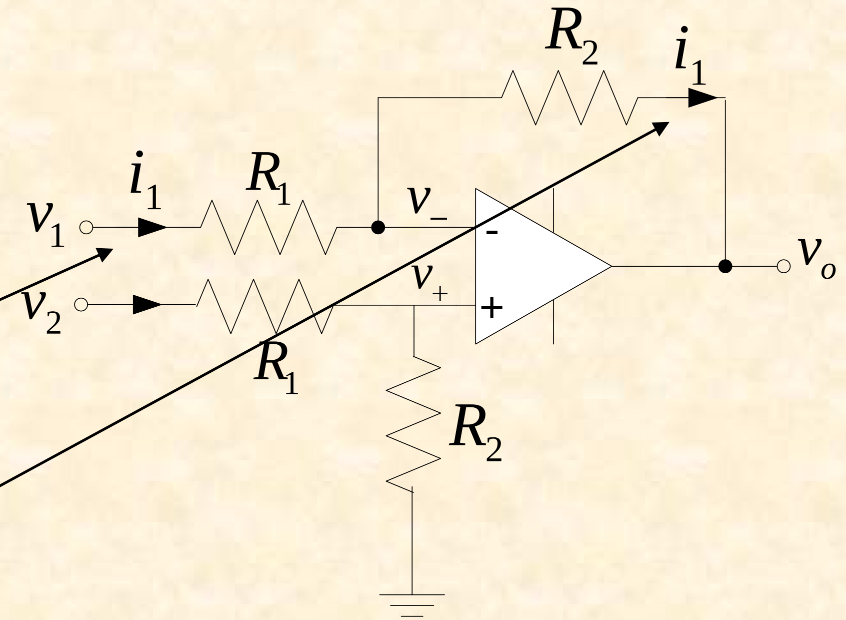
Differential Amplifier

Current into op amp is zero



$$v_- = v_+$$

$$i_1 = \frac{v_1 - v_-}{R_1}$$

$$i_1 = \frac{v_- - v_0}{R_2}$$

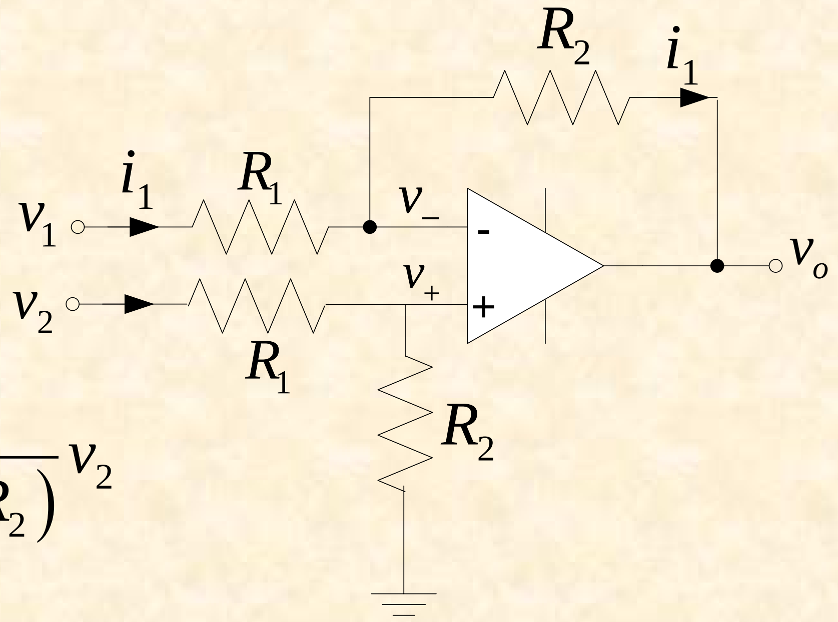
$$\frac{v_1 - v_+}{R_1} = \frac{v_+ - v_0}{R_2}$$

$$v_+ = \frac{R_2}{R_1 + R_2} v_2$$

$$\frac{v_1 - \frac{R_2}{R_1 + R_2} v_2}{R_1} = \frac{\frac{R_2}{R_1 + R_2} v_2 - v_0}{R_2}$$

Differential Amplifier

$$\frac{v_1 - \frac{R_2}{R_1+R_2}v_2}{R_1} = \frac{\frac{R_2}{R_1+R_2}v_2 - v_0}{R_2}$$



$$v_0 = -\frac{R_2}{R_1}v_1 + \frac{R_2}{R_1+R_2}v_2 + \frac{R_2^2}{R_1\left(R_1+R_2\right)}v_2$$

$$v_0 = -\frac{R_2}{R_1}v_1 + \frac{R_2}{R_1+R_2}\left(1+\frac{R_2}{R_1}\right)v_2$$

$$v_0 = \frac{R_2}{R_1}\left(v_2 - v_1\right)$$

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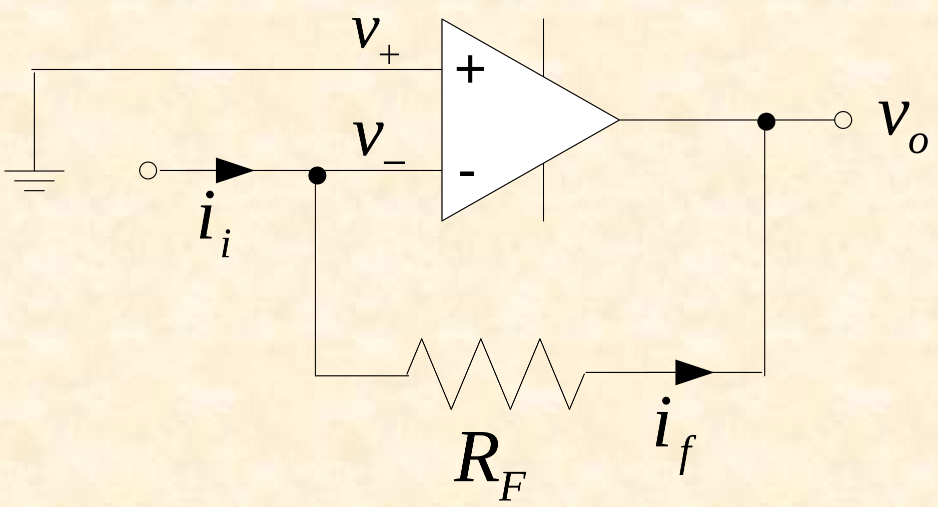
Current-to-Voltage Converter



$$i_i = i_f$$

$$v_- = v_+ = 0$$

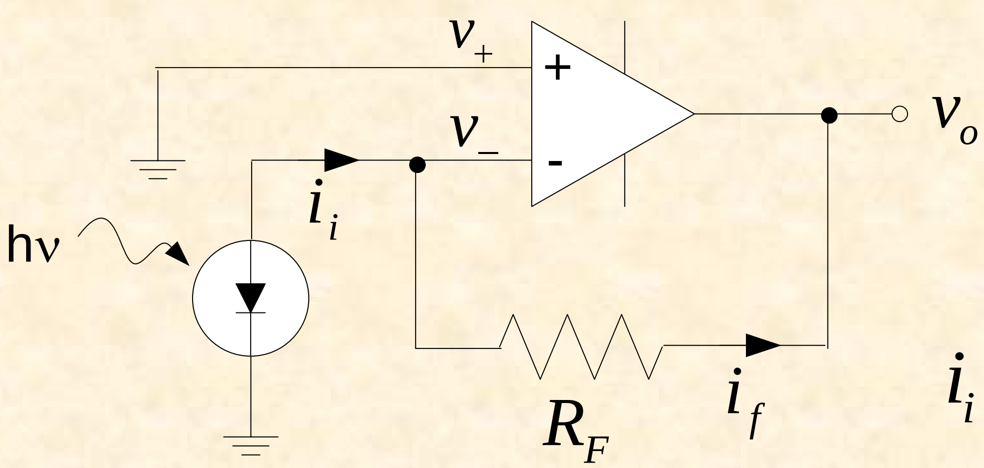
$$0 - v_0 = i_f R_F$$

$$v_0 = -i_i R_F$$

$$\text{Transresistance } = \Delta v_0 / \Delta i_i = -R_F$$

Photodiode Circuit

$$i_i = 25\mu\text{A per milliwatt of incident radiation}$$



At 50 mW

$$i_i = 50 \times 25 \times 10^{-6} = 1.25\text{mA}$$

Assume $R_F = 3.2\text{k}\Omega$

$$v_0 = -i_i R_F = -1.25 \times 10^{-3} \times 3.2 \times 10^{3} = -4\text{V}$$

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Non-ideal Op Amp

- Output voltage is limited by supply voltage(s)
- Finite gain ($\sim 10^5$)
- Limited frequency response
- Finite input resistance (not infinite)
- Finite output resistance (not zero)
- Finite slew rate $\quad \text{slew rate} = dv_0(t)/dt_{MAX}$
- Input bias currents
- Input bias current offset
- Input offset voltage
- Finite common mode rejection ratio (CMRR)