BASIC ELECTRONIC CIRCUITS

Amplifiers, and Op-Amps

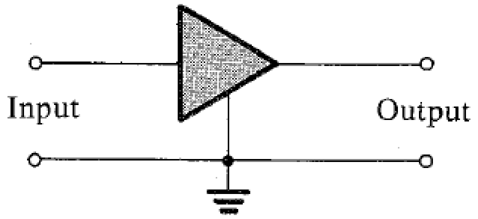
Content

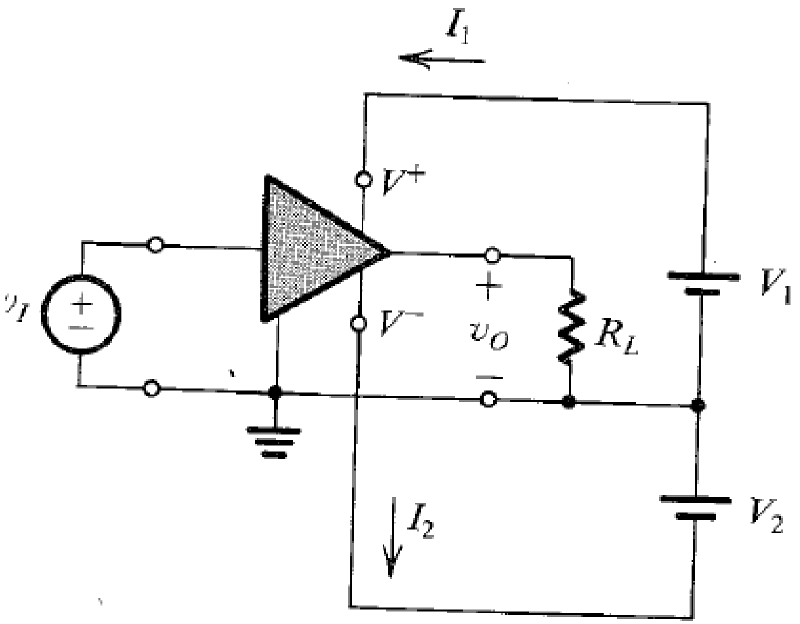
- Amplifiers
- Amplifier Parameters
- Amplifier types
- Operational Amplifiers
- Basic characteristics
- Configurations: Inverting, noninverting etc.

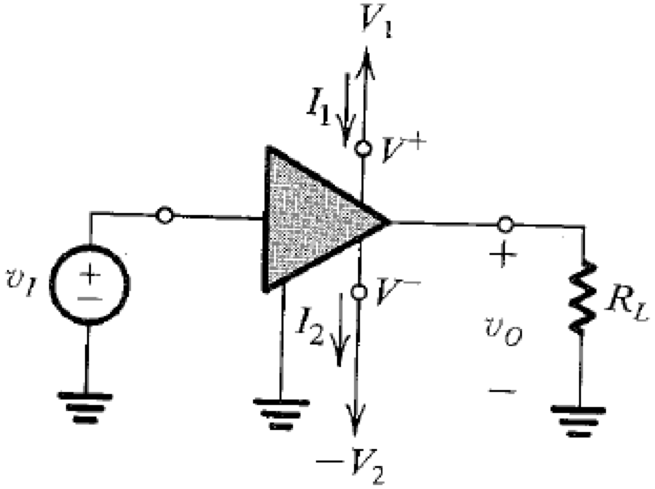
Amplifiers

- **Signal Amplification**:
  - Increase the amplitude of the signal without changing the other parameters.
- Why the signal amplification is needed?
  - The weak signal are too small for reliable processing
- **Linearity**: it is essential to make sure that the information contained in the signal is not changed and no new information is introduced. Then the output signal will be exact replica of that at the input.
- Any changes in waveform is considered to be distortion and is obviously undesirable.
- Ex: Voltage amplifier, Power Amplifier.

Amplifier Power supplies







- DC power delivered to the amplifier is

$$P_{dc} = V_1 I_1 + V_2 I_2$$

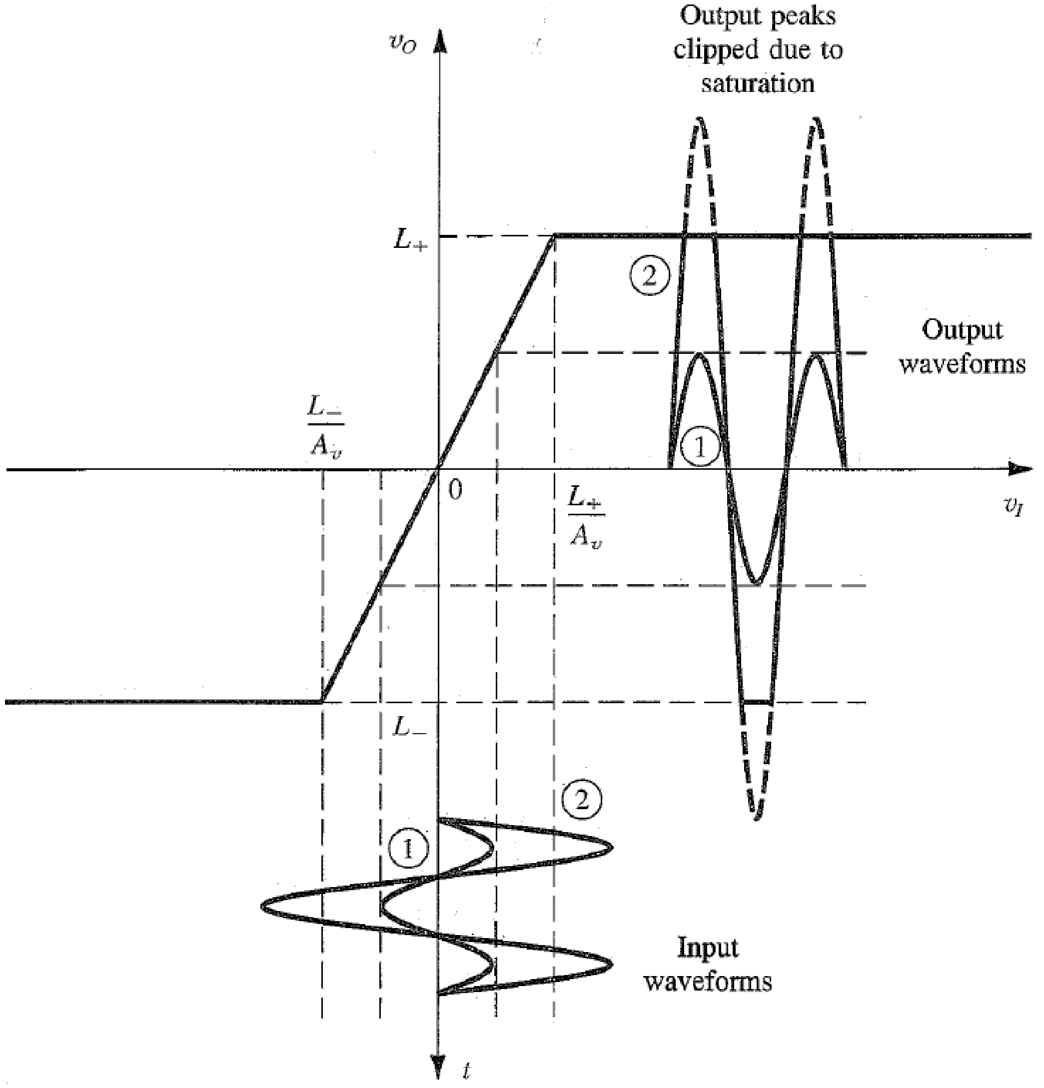
- Power balance equation for the amplifier is

$$P_{dc} + PI = PL + Pdissipted$$

- Amplifier efficiency

$$\eta = \frac{P_L}{P_{dc}} \times 100$$

Amplifier Saturation



Amplifier parameters

- Gain
- Frequency response
- Bandwidth
- Input impedance
- Output impedance

Gain

- Measure of the amplification of an amplifier
- Ratio of the output signal amplitude to input signal amplitude
- Symbol – *A*
- Voltage gain (A_V), Current gain (A_i), power gain (A_P)

$$A_V = \frac{V_{out}}{V_{in}} \qquad A_I = \frac{I_{out}}{I_{in}} \qquad A_P = \frac{P_{out}}{P_{in}}$$

Voltage Gain in dB= 20 log |Av|

Current Gain in dB= 20 log |Ai|

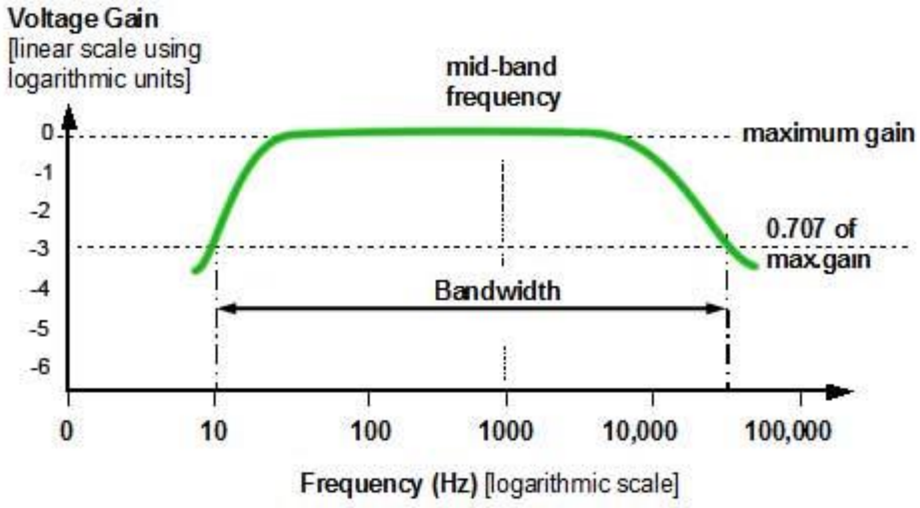
Power Gain in dB= 10 log Ap

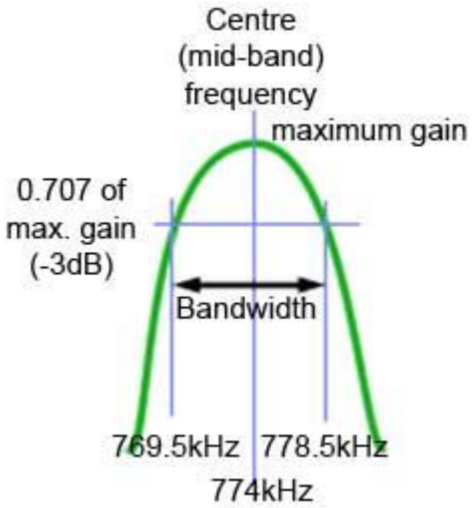
Input and output Impedance

- Input impedance: impedance experienced as the amount of current able flow into the input terminals
- Depends upon, frequency of the signal, gain of the amplifier, and load connected at the output terminals.
- Output impedance: responsible for the fall in signal voltage at the output terminals, when current is drawn from the output terminals.

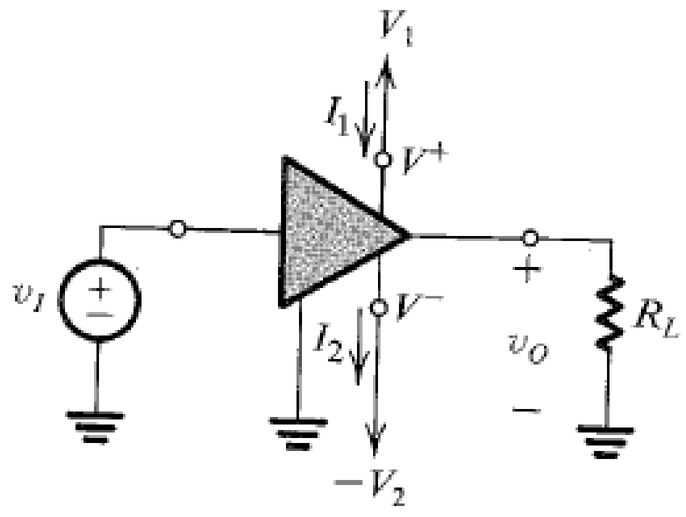
Frequency Response and Bandwidth

- Do not have same gain at all frequencies
- Ex: Audio amplifier can amplify only audio frequencies (<20 KHz).
- Band of frequencies over which the amplifier has a useful gain.





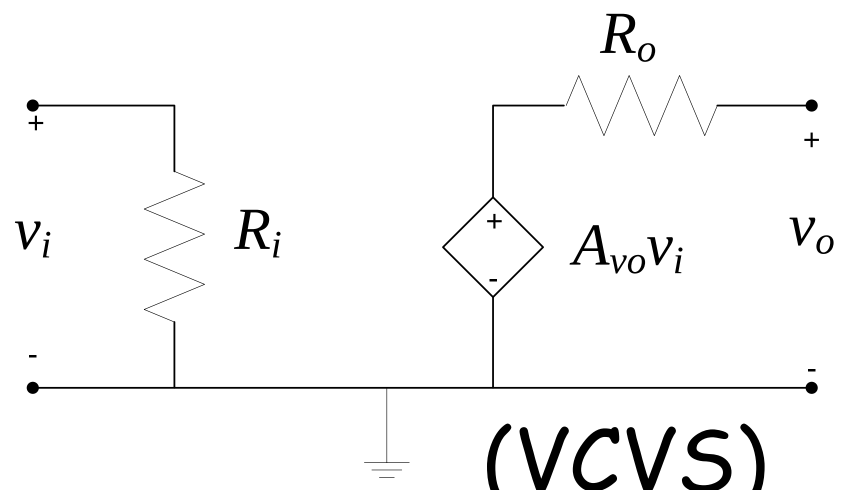
- Consider an amplifier operating from ±10 V power supplies. It is fed with a sinusoidal voltage having 1 V peak and delivers a sinusoidal voltage output of 9 V peak to a 1 KΩ load. The amplifier draws a current of 9.5 mA from each of its two power supplies. The input current of the amplifier is found to be sinusoidal with 0.1 mA peak. Find the voltage gain, the current gain, the power gain, the power drawn from the dc supplies, the power dissipated in the amplifier and the amplifier efficiency.



Circuit Model: Voltage amplifier

- Open-Circuit Voltage gain

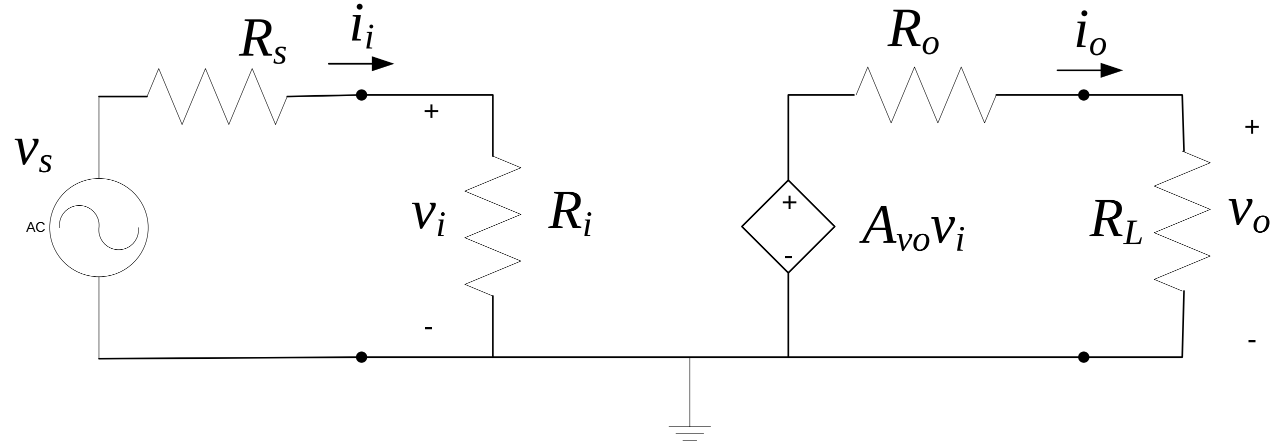
$$A_{Vo} = \frac{V_{out}}{V_{in}}\Big|_{\text{io=0}}$$

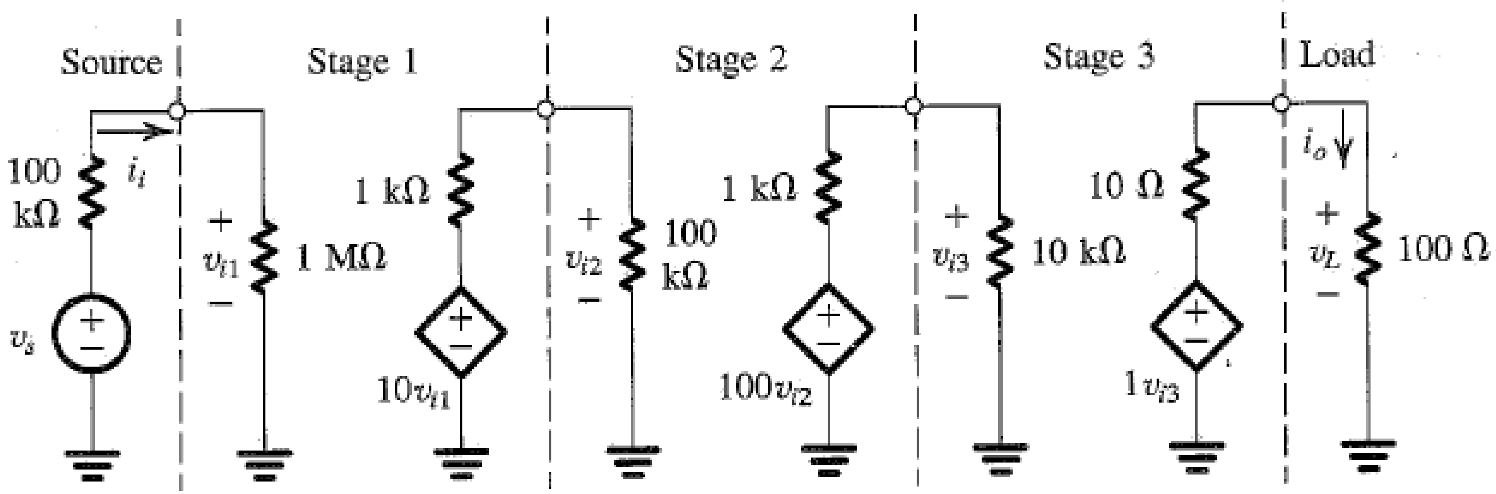


(VCVS)

- Ideal characteristics

$$R_i = \infty \quad R_o = 0$$





- Determine overall voltage gain, current gain, and power gain.

Current Amplifier

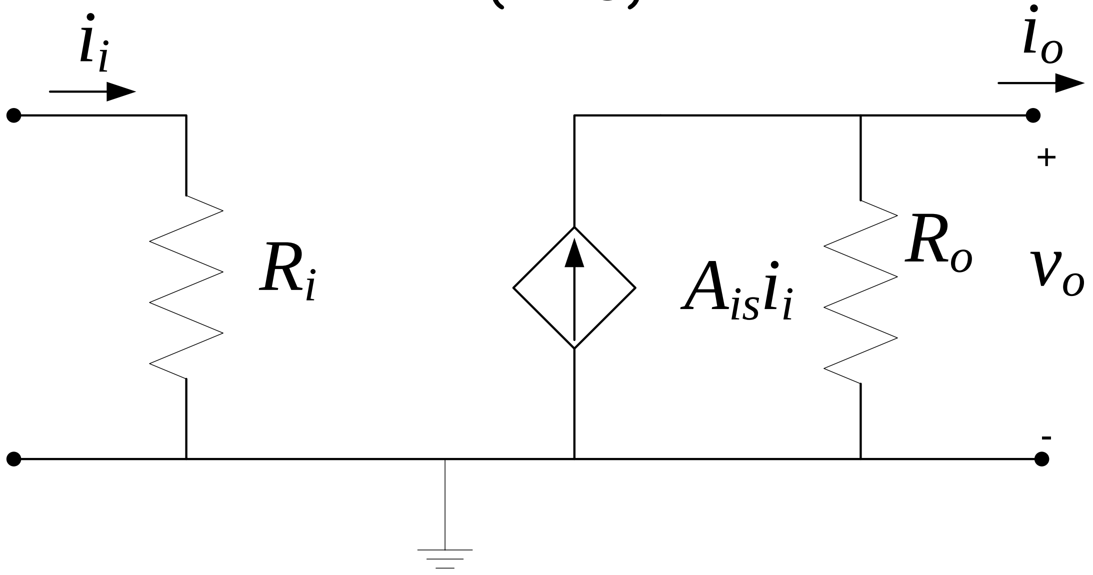
- Short-Circuit current Gain

$$A_{is} = \frac{i_o}{i_i}\Big|_{vo\ =\ 0}$$

- Ideal characteristics

$$R_i = 0 \quad R_o = \infty$$

(CCCS)



$$A_{vo} = A_{is}\ \frac{R_o}{R_i}$$

Transconductance Amplifier

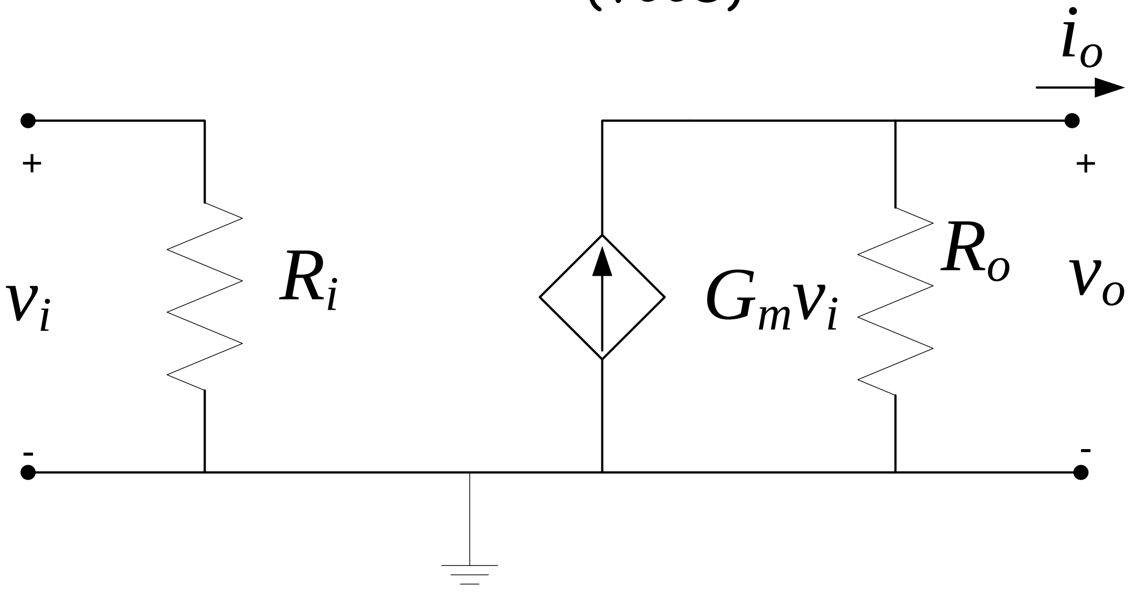
- Short-Circuit Transconductance

$$G_m = \frac{i_o}{v_i}\Big|_{vo\ =\ 0}$$

- Ideal characteristics

$$R_i = \infty \quad R_o = \infty$$

(VCCS)



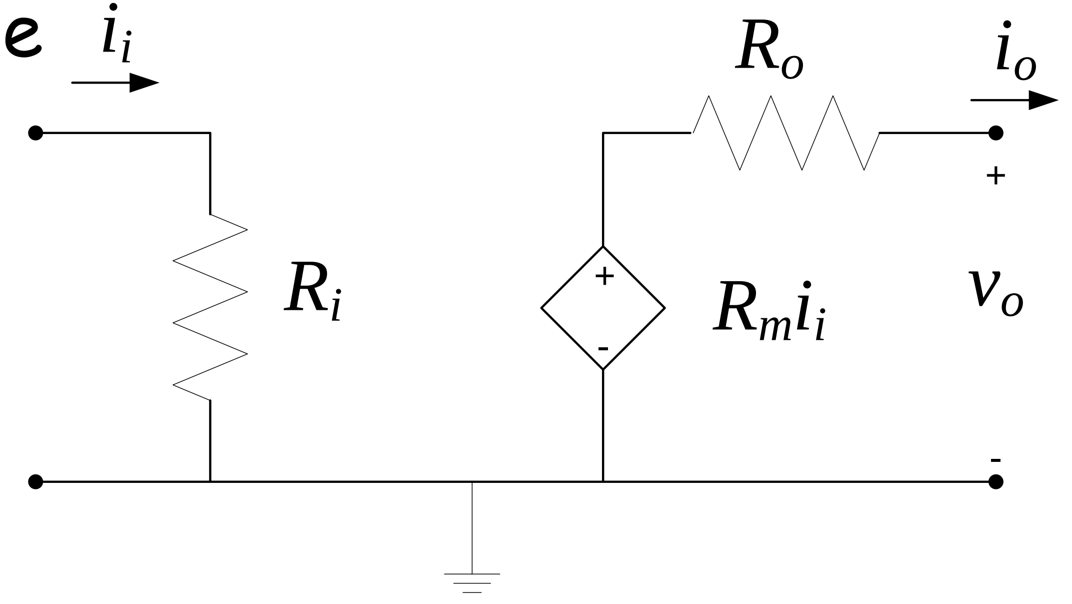
$$A_{vo} = G_m R_o$$

Transresistance Amplifier

(CCVS)

- Open circuit transresistance

$$R_m = \frac{v_o}{i_i}\Big|_{io\ =\ 0}$$



- Ideal characteristics

$$R_i = 0 \quad R_o = 0$$

$$A_{vo} = \frac{R_m}{R_i}$$

Operational Amplifiers

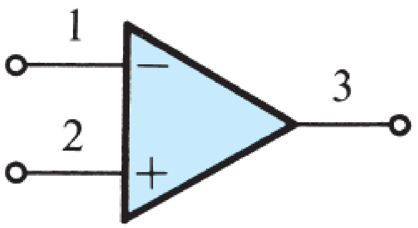
- Widely used in almost all modern communication, instrumentation, and computation systems because they are “Versatile”.

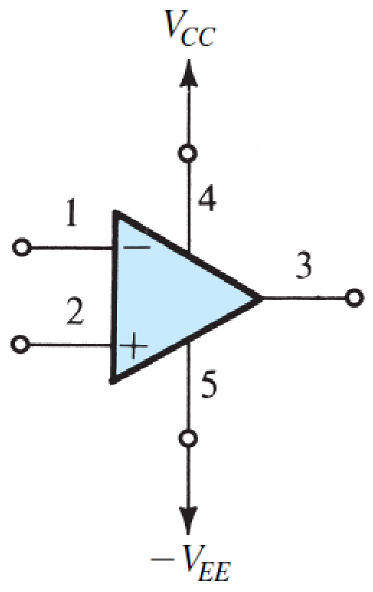
- OP-amps are used to overcome the shortcomings of basic amplifier like low i/p impedance, moderate gain, and limited bandwidth.

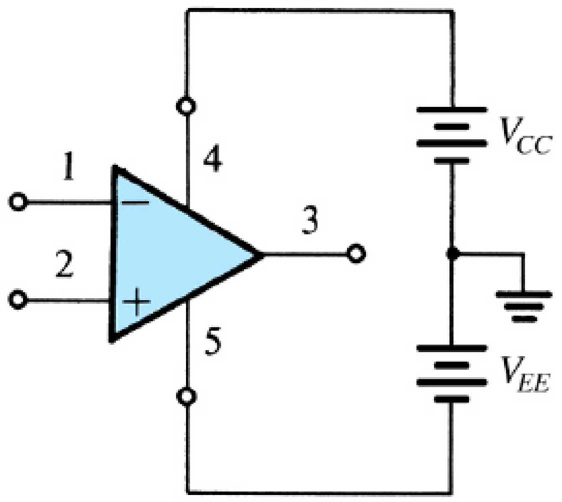
- The op-amp is made up of a large number of transistors and resistors etc., here we consider it as a circuit building block, study its terminal characteristics and its applications.

The Ideal Op-Amp: terminals

- 3 terminals: Two input and one output.
- No terminal of the op-amp package is physically connected to ground.

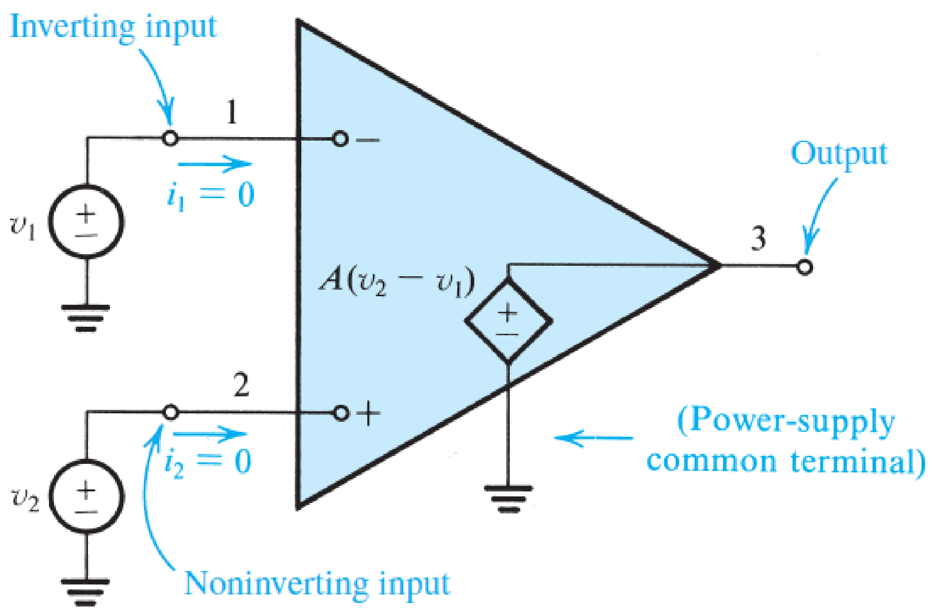






Function and characteristics

- Basic function is to sense the difference between the voltage signals applied at its input terminals.
  - Infinite input impedance
  - Zero output impedance
  - Zero common mode gain
  - Infinite open-loop gain A
  - Infinite bandwidth



Equivalent Circuit (VCVS) model of the ideal OP-AMP

Differential input, single-ended output amplifier

Differential and common-mode signals

- Differential input single

$$v_{Id} = v_2 - v_1$$

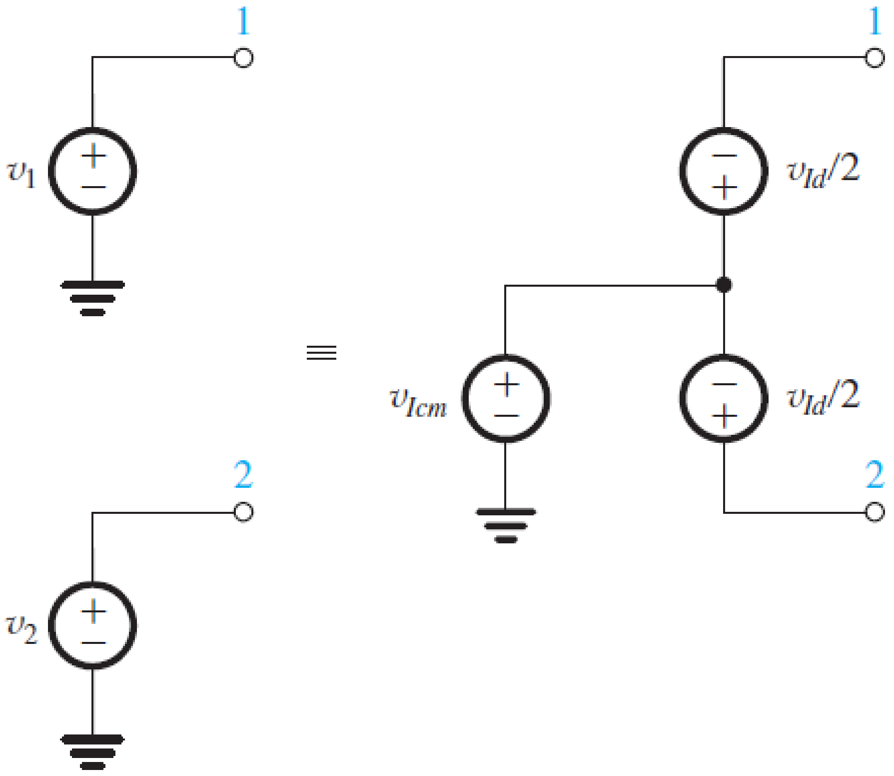
- Common mode input signal

$$v_{Icm} = \frac{1}{2}(v_1 + v_2)$$

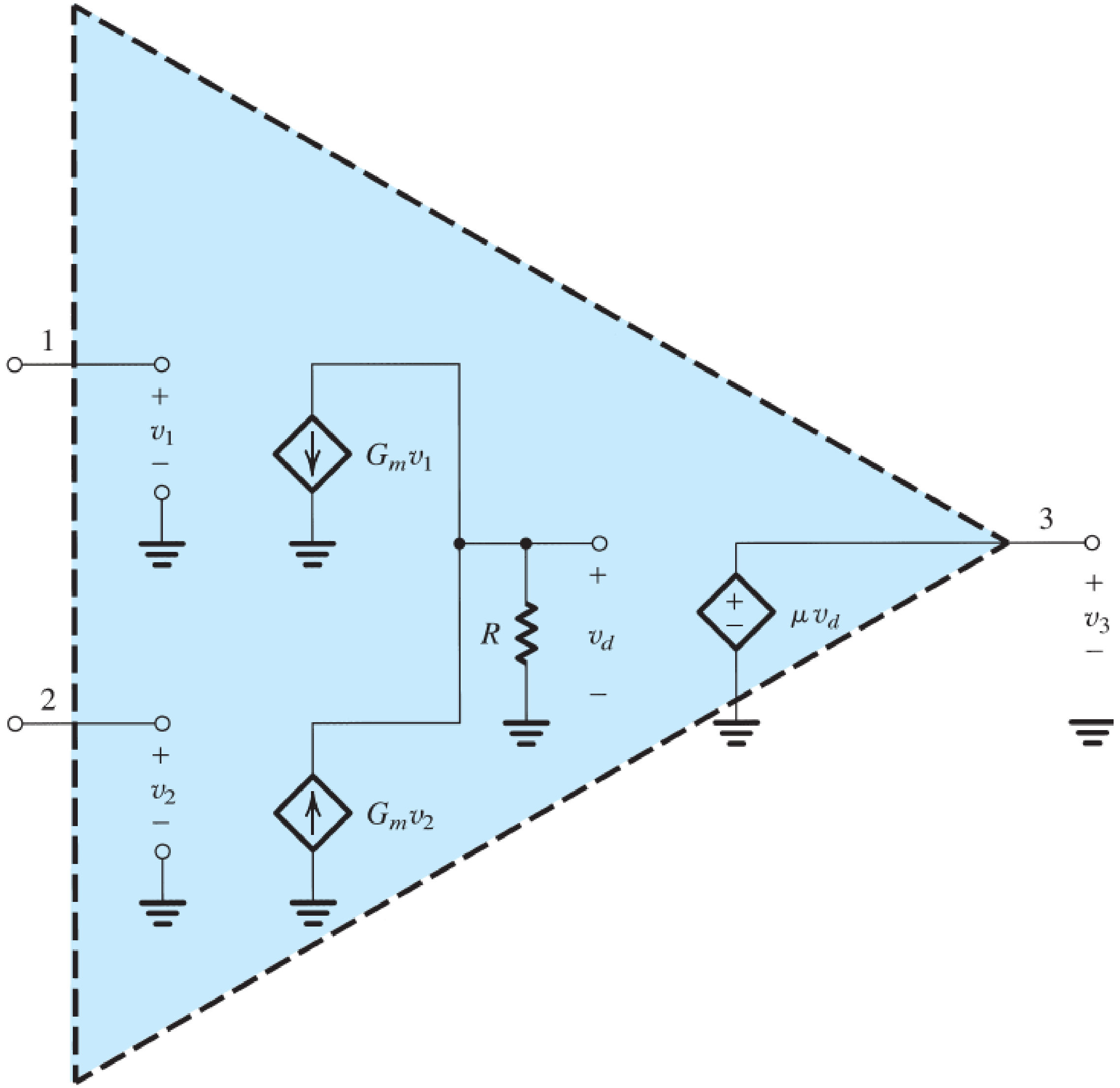
- Hence, V_1 and V_2 are,

$$v_1 = v_{Icm} - v_{Id}/2$$

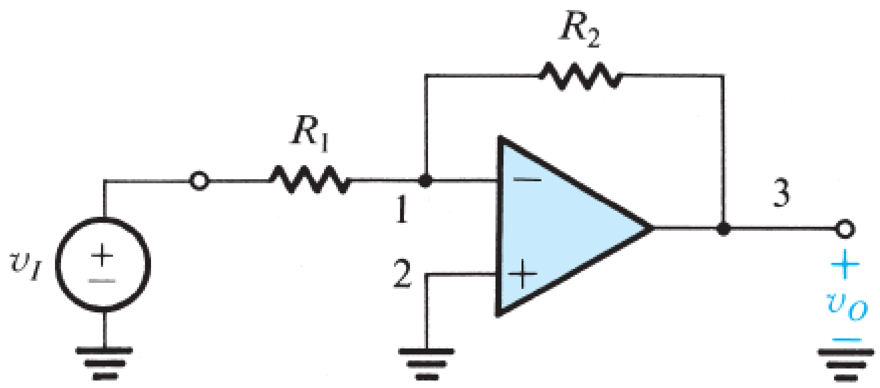
$$v_2 = v_{Icm} + v_{Id}/2$$



- The internal circuit of a particular amplifier is shown here. Express v3, as a function v1 and v2. For the case Gm = 10 mA/V, R = 10 K V/A, and μ = 100, find the value of open-loop gain A.

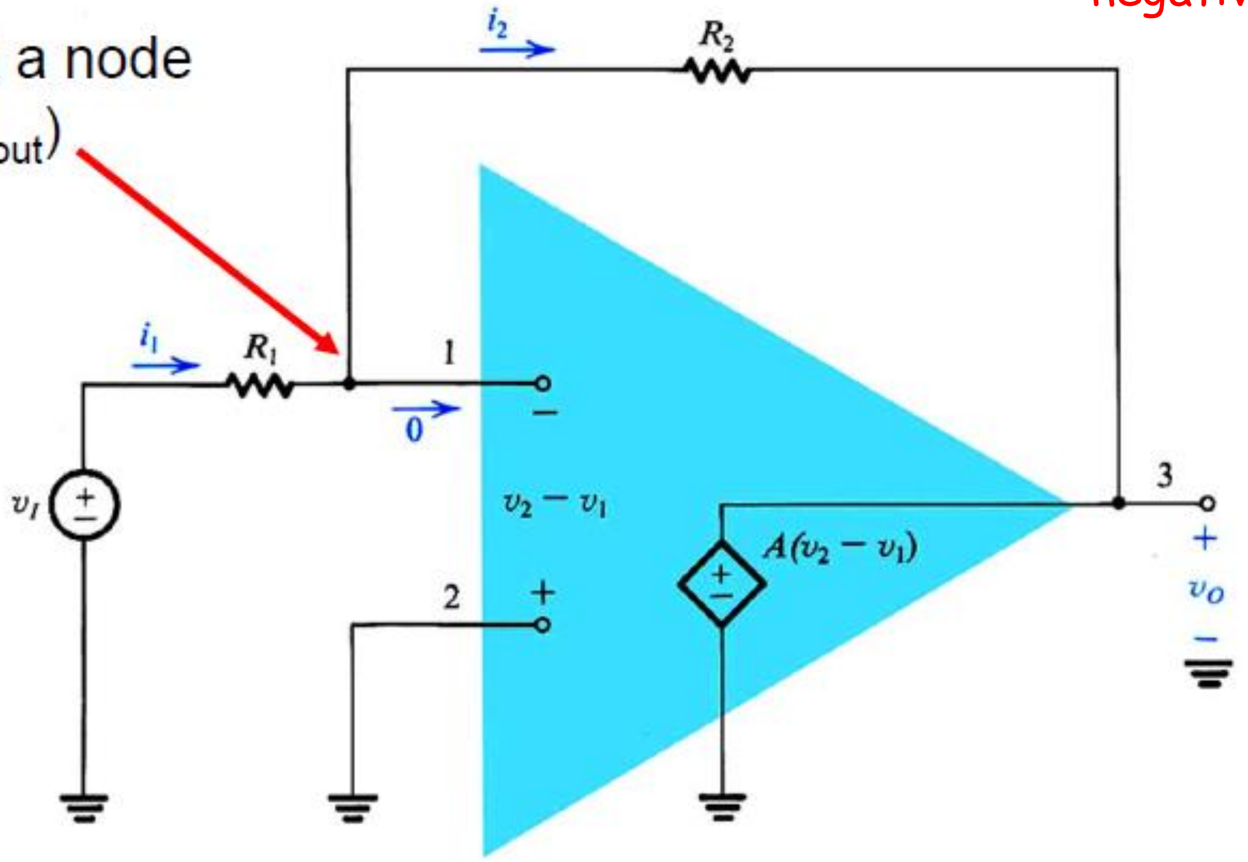


Inverting Configuration

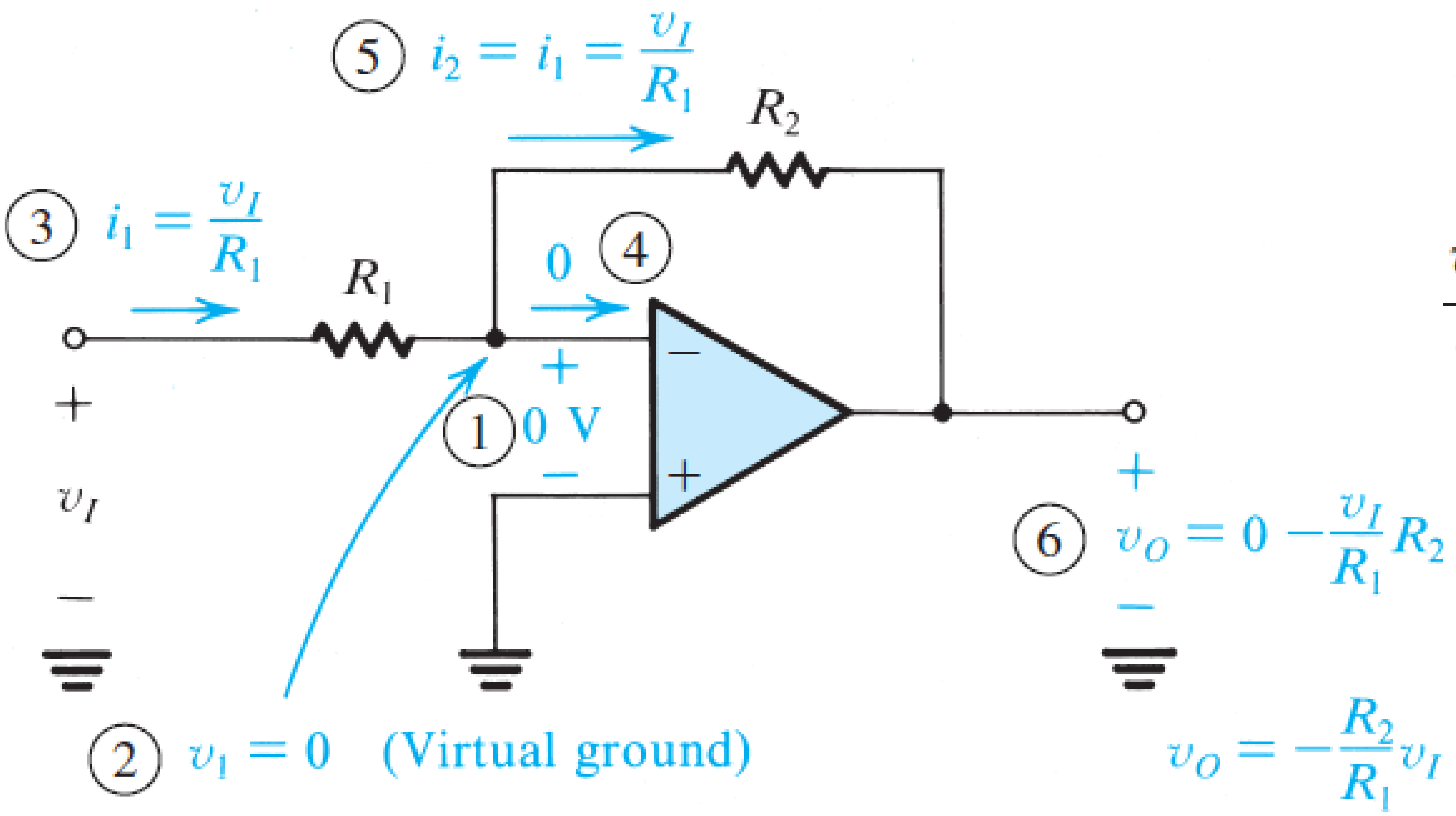


"negative feedback"

Current at a node ($I_{in}=I_{out}$)



"Virtual short Circuit"



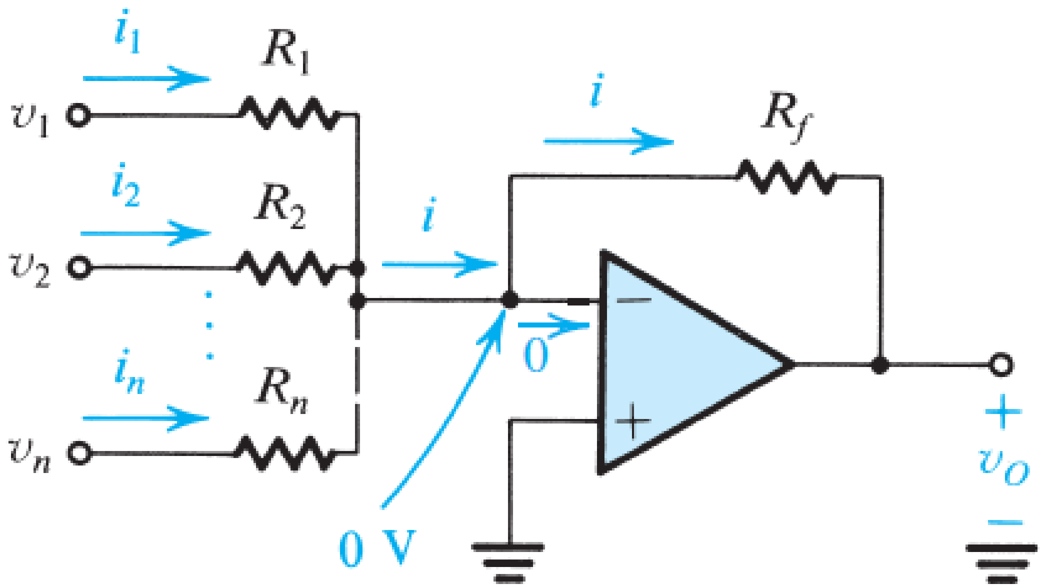
$$\frac{v_O}{v_I} = -\frac{R_2}{R_1}$$

Closed loop gain is independent of open-loop gain, entirely depends on the passive elements.

Application: The weighted Summer

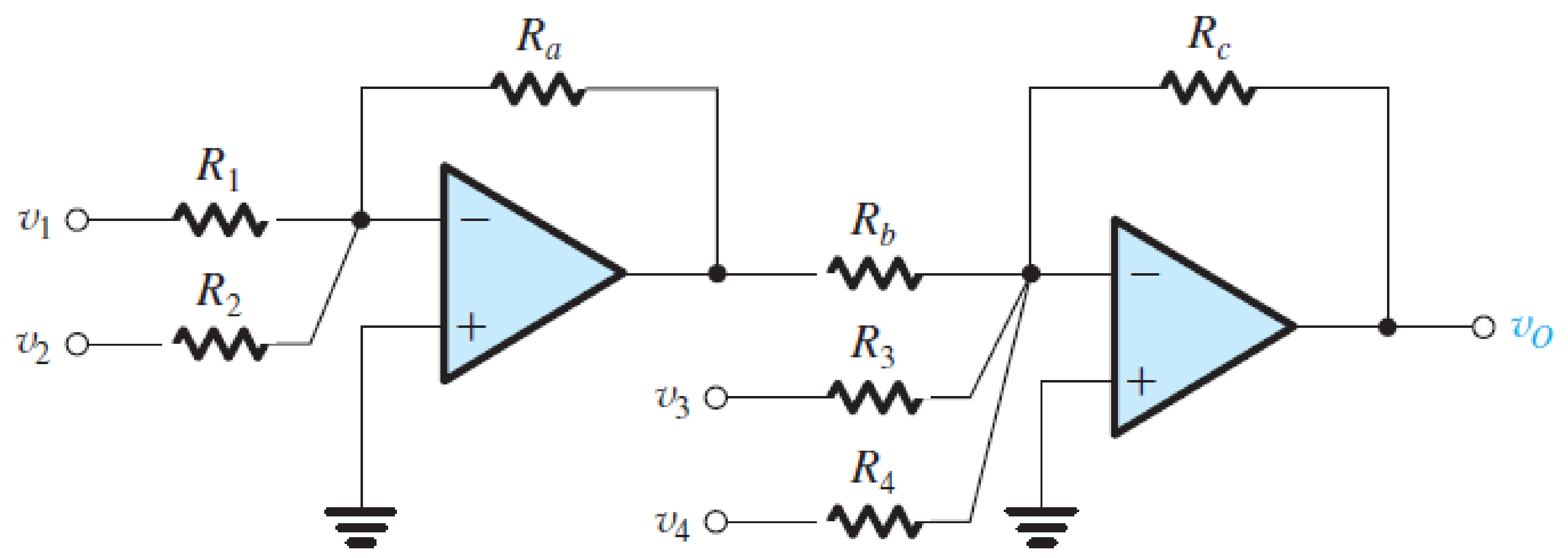
$$i = i_1 + i_2 + \cdots + i_n$$

$$v_O = 0 - iR_f = -iR_f$$



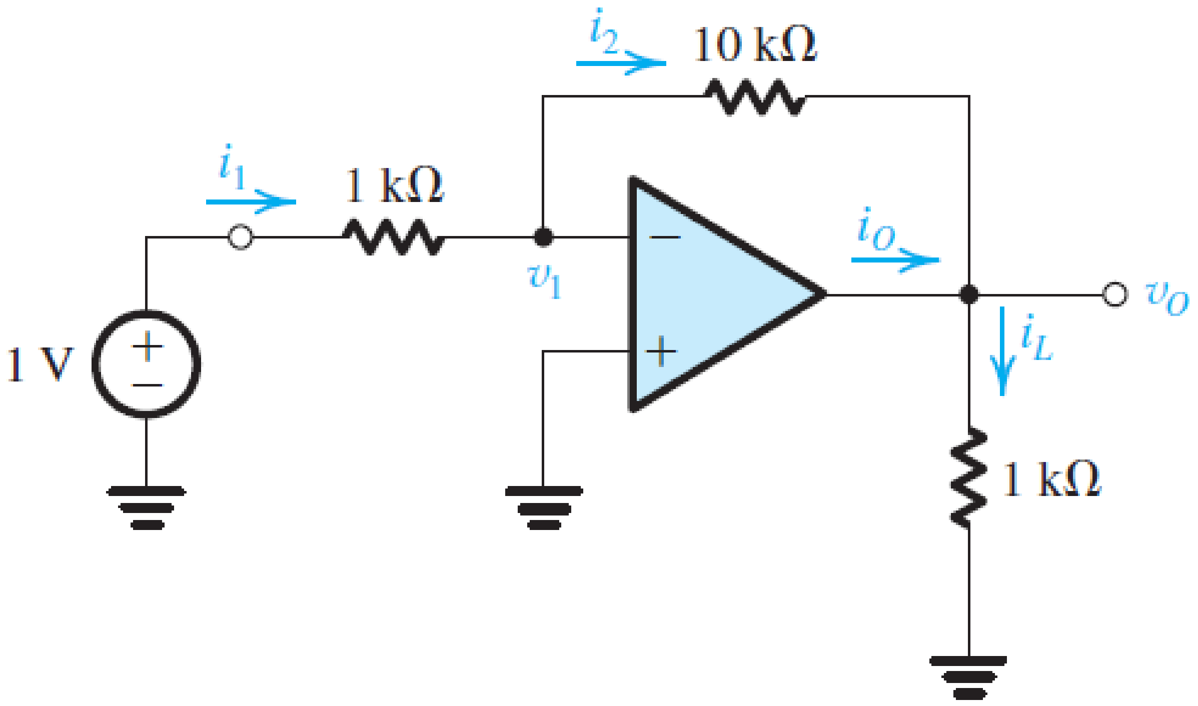
$$v_O = -\left(\frac{R_f}{R_1}v_1 + \frac{R_f}{R_2}v_2 + \cdots + \frac{R_f}{R_n}v_n\right)$$

Summing signals with opposite sign

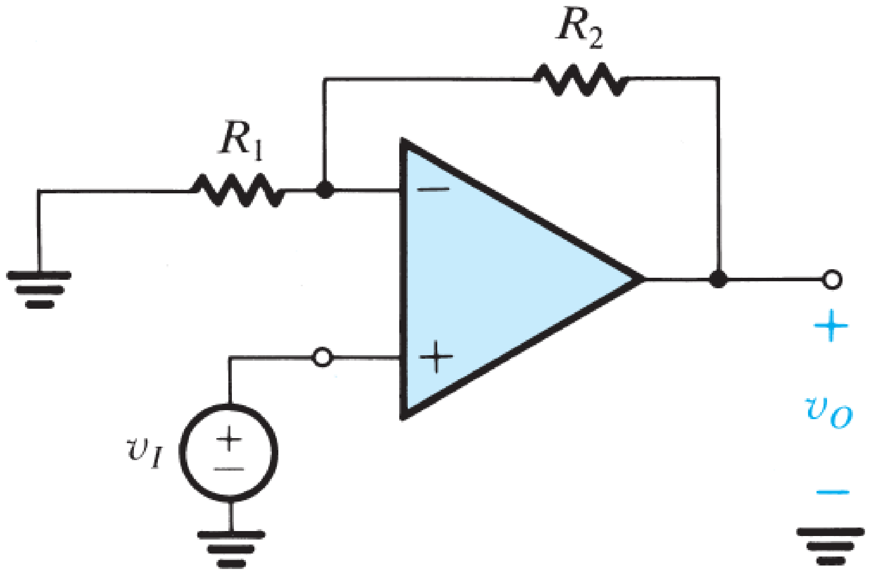


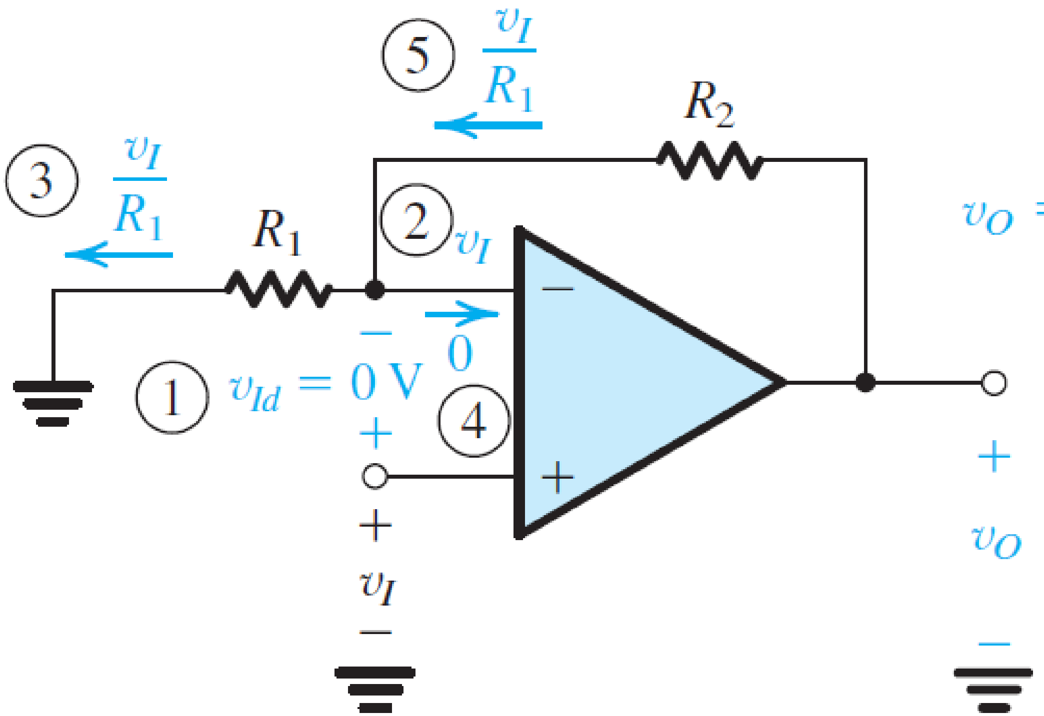
$$v_O = v_1\left(\frac{R_a}{R_1}\right)\left(\frac{R_c}{R_b}\right) + v_2\left(\frac{R_a}{R_2}\right)\left(\frac{R_c}{R_b}\right) - v_3\left(\frac{R_c}{R_3}\right) - v_4\left(\frac{R_c}{R_4}\right)$$

Determine the values of v_1, i_1, i_2, v_o, i_L, and i_o. Also determine the values of V_o/V_I, I_L/i_1 and power gain Po/Pi



Noninverting Configuration

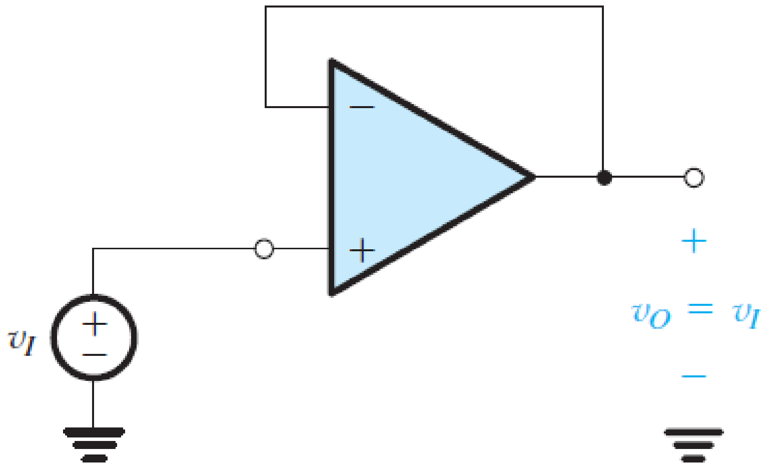


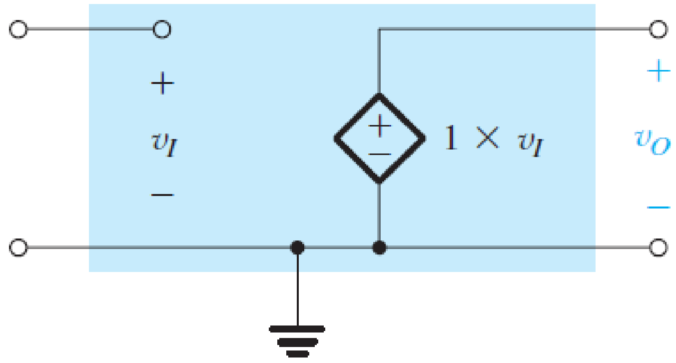


$$v_O = v_I + \frac{v_I}{R_1}R_2 = v_I\left(1 + \frac{R_2}{R_1}\right) \quad (6)$$

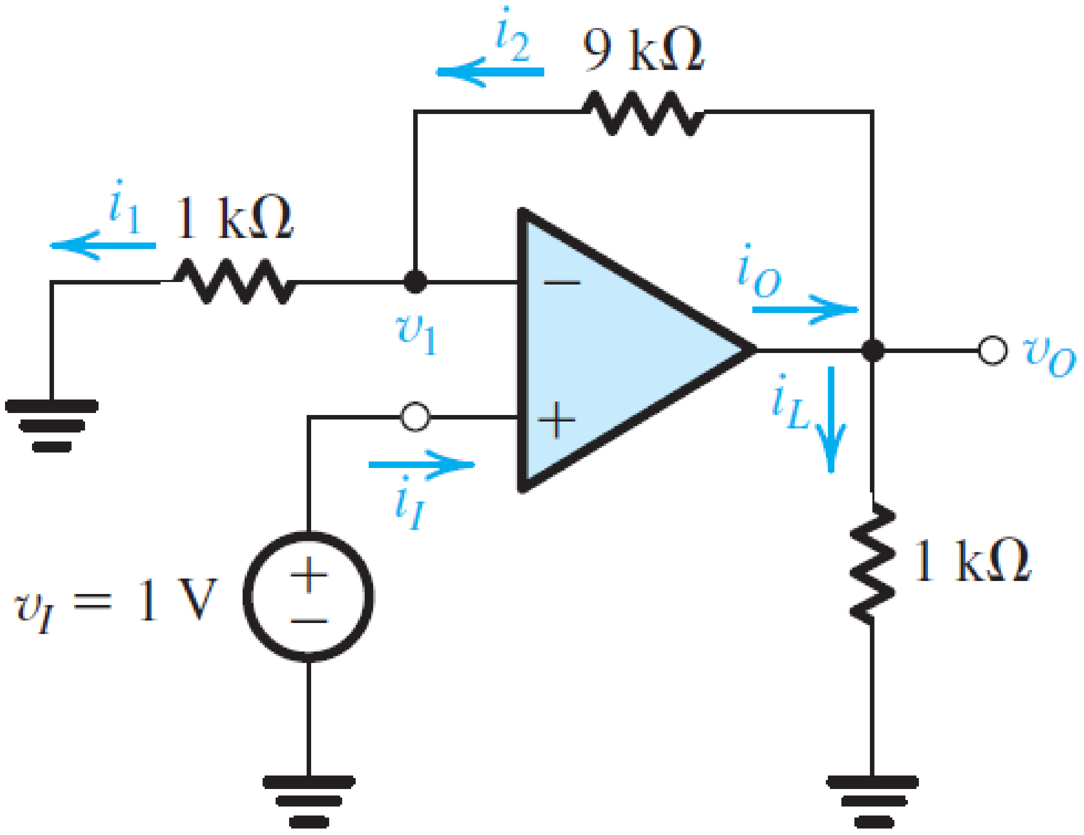
Application: Voltage follower

- High input impedance is a desirable feature of non inverting configuration.
- Unity-gain amplifier or Voltage follower.
- Used as an impedance transformer.





Determine the values of i_I, v_1, i_1, i_2, v_o, i_L, and i_o. Also determine the values of V_o/V_I, I_L/i_I and power gain P_L/P_I

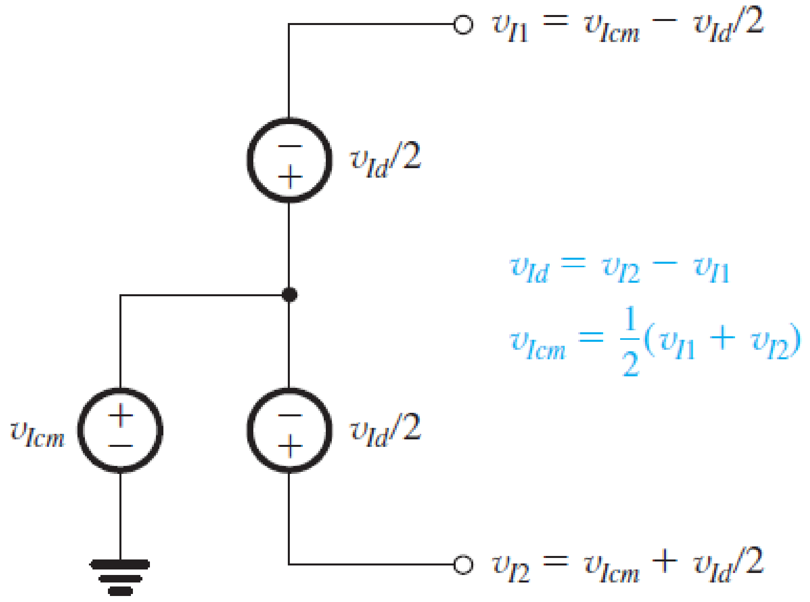


Difference Amplifier

- A difference amplifier is one that responds to the difference between the two signals applied at its input and ideally rejects signals that are common to the two inputs.

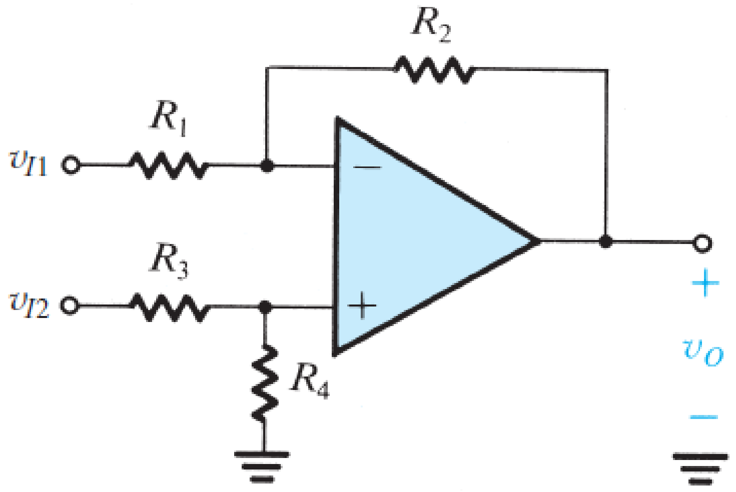
$$v_O = A_d v_{Id} + A_{cm} v_{Icm}$$

$$\text{CMRR} = 20 \log \frac{|A_d|}{|A_{cm}|}$$



Single Op-amp difference amplifier

- Combination of inverting and noninverting configurations.



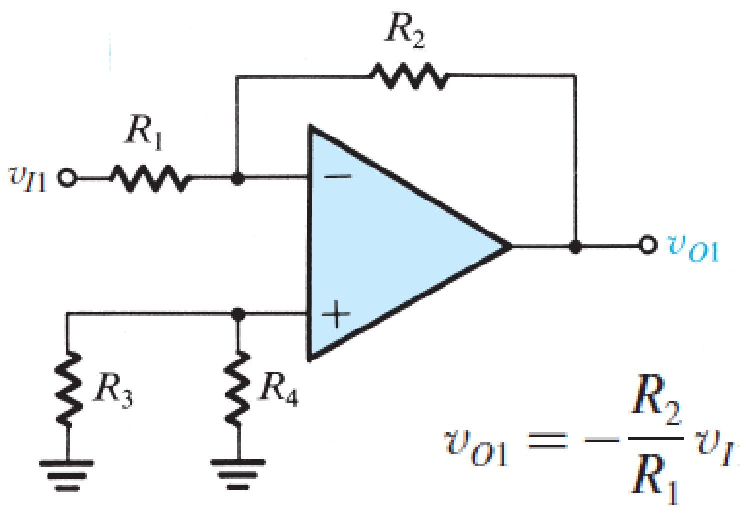
- Common mode signals need to be rejected, hence the magnitude of the inverting and noninverting must be same.

- Hence attenuate the gain of the +ve path from $(1+R_2/R_1)$ to R_2/R_1.

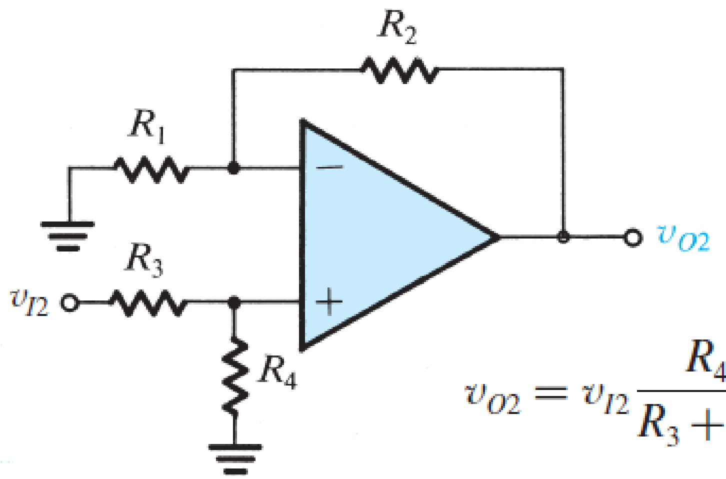
$$\frac{R_4}{R_4+R_3}\left(1+\frac{R_2}{R_1}\right)=\frac{R_2}{R_1}$$

$$\frac{R_4}{R_3}=\frac{R_2}{R_1}$$

- By Superposition:



$$v_{O1} = -\frac{R_2}{R_1} v_{I1}$$



$$\frac{R_4}{R_3} = \frac{R_2}{R_1}$$

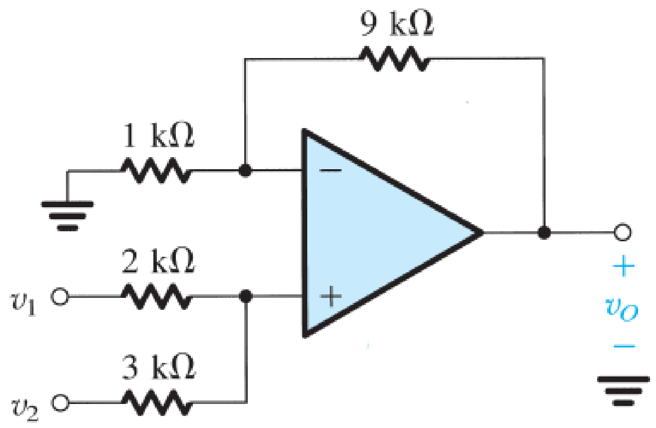
$$v_{O2} = v_{I2} \frac{R_4}{R_3 + R_4}\left(1 + \frac{R_2}{R_1}\right) = \frac{R_2}{R_1} v_{I2}$$

$$v_O = \frac{R_2}{R_1}(v_{I2} - v_{I1}) = \frac{R_2}{R_1} v_{Id}$$

$$A_d = \frac{R_2}{R_1}$$

$R_3 = R_1$ and $R_4 = R_2$

- Use superposition to determine Vo



$$v_O = 6v_1 + 4v_2$$

- If the 1K resistor is disconnected from the ground and connected to V3 , determine Vo.

$$v_O = 6v_1 + 4v_2 - 9v_3$$

- Design a non inverting amplifier with a gain of 2. At the maximum output voltage of 10 V the current in the voltage divider is to be 10 μ A.

$$v_0 = 10\,V$$

$$G = 2 = 1 + R_2/R_1$$

$$R_1 = R_2$$

$$\frac{v_0 - v_1}{R_2} = 10\ \mu\mathrm{A}$$

$$\frac{v_1}{R_1} = 10\ \mu\mathrm{A}$$

$$v_o = 2v_1$$

$$v_1 = 5\,V$$

$$R_1 = 0.5\,M\Omega$$