EE 254

Electronic Instrumentation

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Lecture Note #03

Content (Brief)

2. Op-Amp Applications

- Linear Applications
  - Inverting amplifiers
  - Noninverting amplifiers
  - Differential amplifiers
  - Summing amplifiers
  - Integrators
  - Differentiators
  - Low/ High pass filters
  - Instrumentational amplifiers

- Nonlinear Applications
  - Precision rectifiers
  - Peak detectors
  - Schmitt-trigger comparator
  - Logarithmic amplifiers

Inverting Amplifier

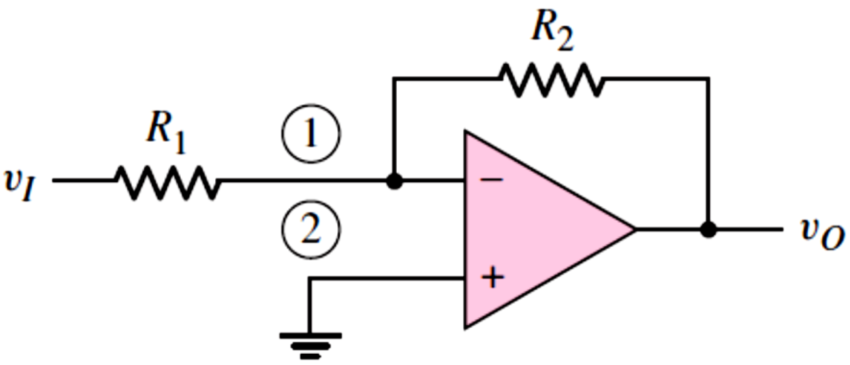
Inverting Amplifier

- What is Inverting Amplifier?
- What is the circuit diagram?
- What can you say about the gain of the amplifier?

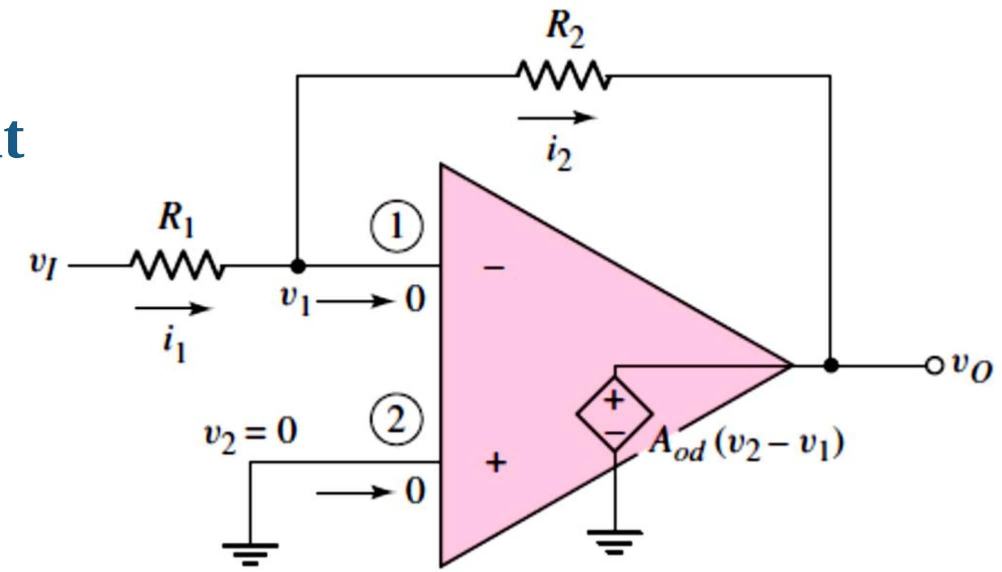
Inverting Amplifier

- What would be the output if the feedback resistor is removed?

Inverting Amplifier



Inverting op-amp circuit



The voltage gain

$$A_v = \frac{v_O}{v_I}$$

The input current

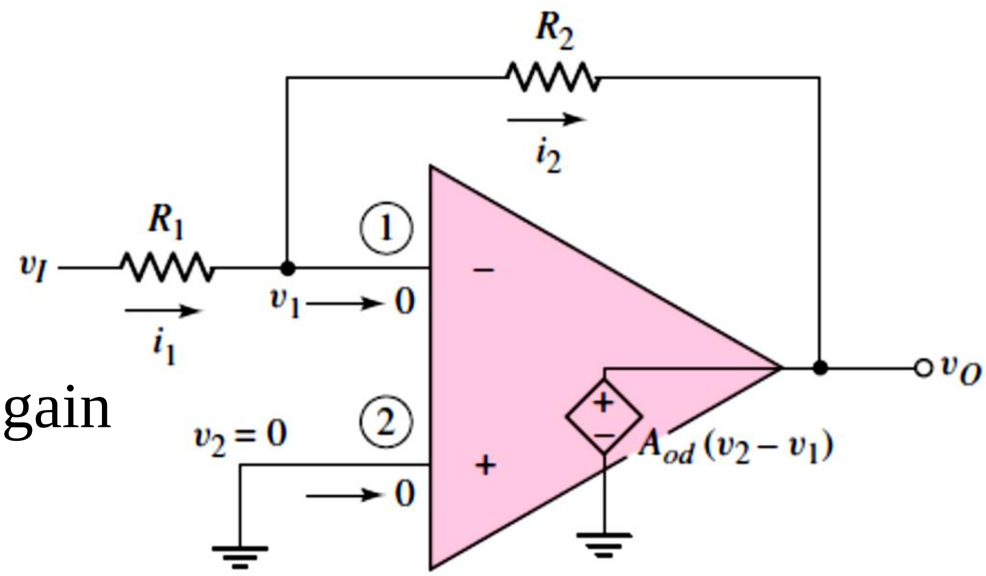
$$i_1 = \frac{v_I - v_1}{R_1} = \frac{v_I}{R_1}$$

Inverting op-amp equivalent circuit

Inverting Amplifier

The output voltage

$$v_O = v_1 - i_2 R_2 = 0 - \left(\frac{v_I}{R_1}\right) R_2$$



Inverting op-amp equivalent circuit

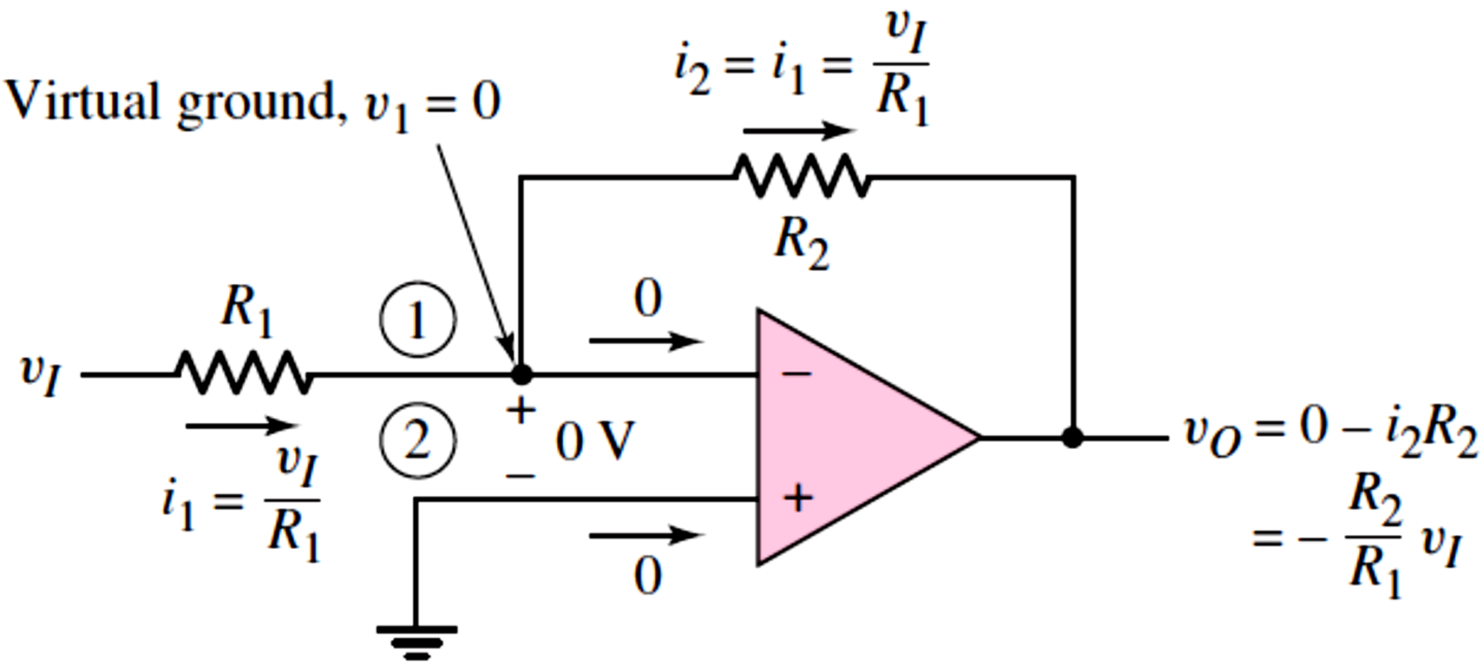
Therefore, the closed-loop voltage gain

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

The input resistance

$$R_i = \frac{v_I}{i_1} = R_1$$

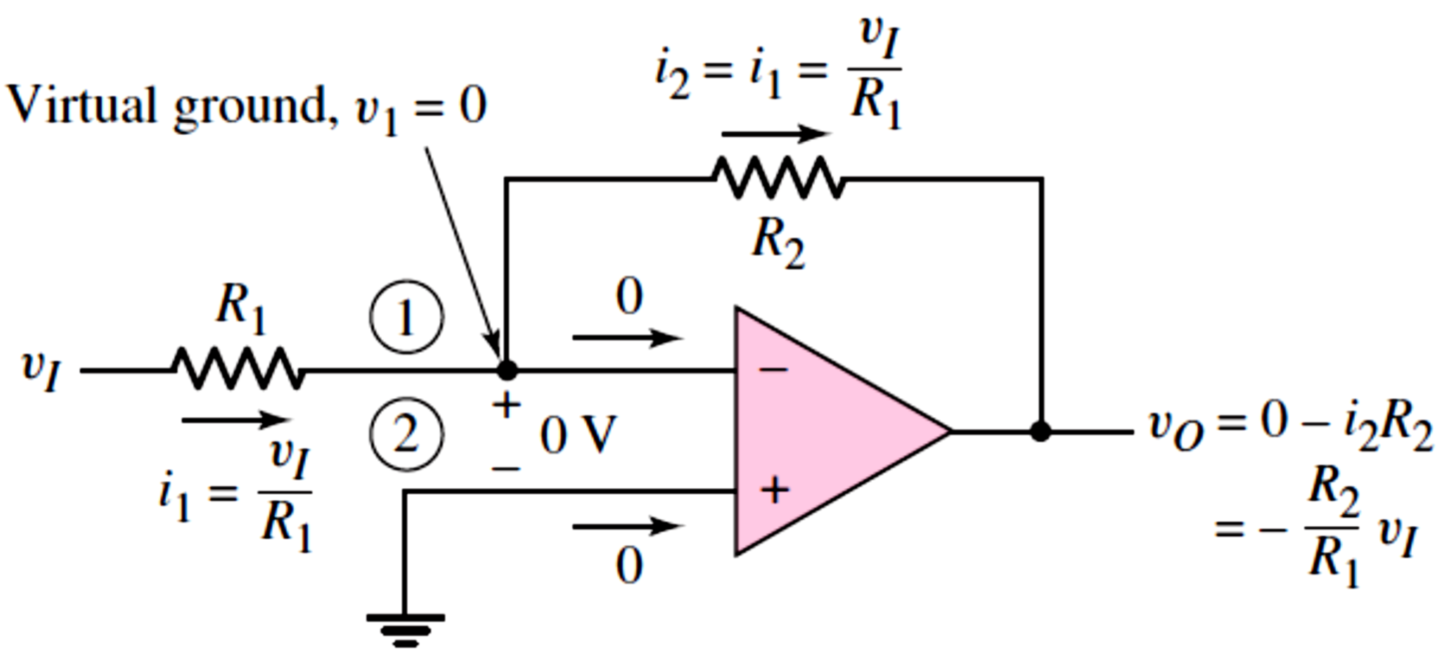
Inverting Amplifier



Currents and voltages in the inverting op-amp

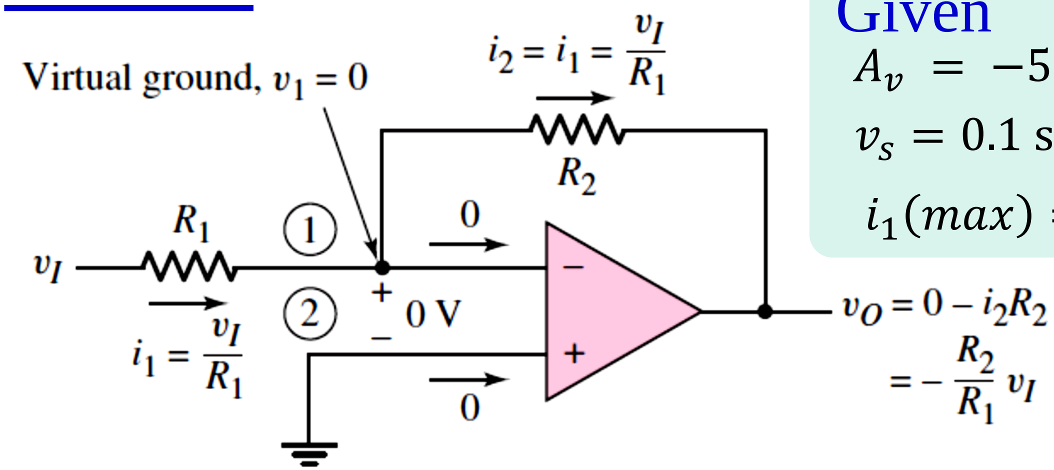
Ex. 01: Design an Inverting Amplifier

The circuit configuration to be designed is shown in the figure. Design the circuit such that the voltage gain is $A_v = -5$. Assume the op-amp is driven by an ideal sinusoidal source, $v_s = 0.1\sin\omega t\ (V)$, that can supply a maximum current of 5 μA. **Assume that frequency $\boldsymbol{\omega}$ is low so that any frequency effects can be neglected.**



Ex. 01: Design an Inverting Amplifier

Solution:



Given

$A_v = -5$

$v_s = 0.1\ \sin\omega t\ (V)$

$i_1(max) = 5\ \mu A$

The input current i_1

$$i_1 = \frac{v_I}{R_1} = \frac{v_s}{R_1}$$

If $i_1(max) = 5\ \mu A$

$$R_1 = \frac{v_s(max)}{i_1(max)} = \frac{0.1}{5 \times 10^{-6}} \Rightarrow 20k\Omega$$

The **closed-loop gain** A_v is given by $A_v = -\frac{R_2}{R_1} = -5$

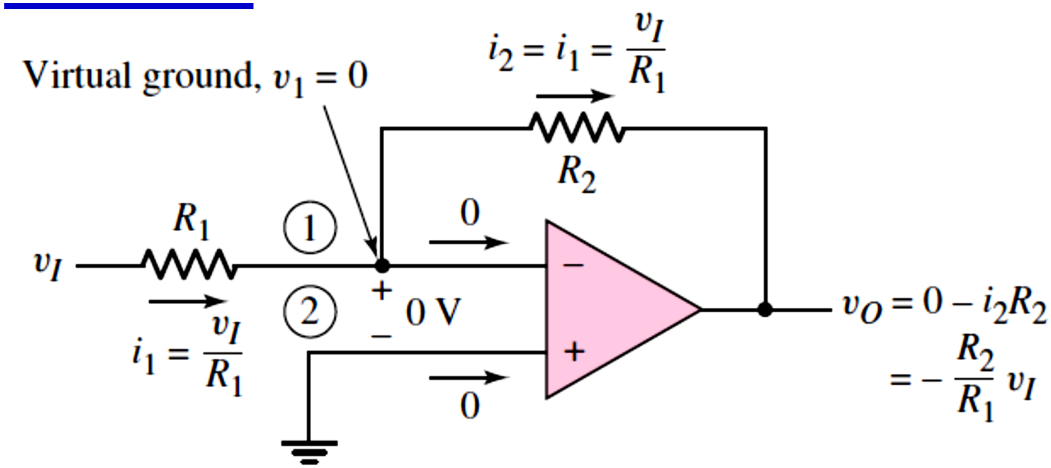
We then have $R_2 = 5R_1 = 5(20) = 100k\Omega$

Trade-offs: If the signal source has a **finite output resistance** and the desired output voltage is $v_o = -0.5\ \sin\omega t$, the circuit must be redesigned.

Assume the output resistance of the source is $R_S = 1\ k\Omega$.

Ex. 01: Design an Inverting Amplifier

Solution:



Redesign Solution:

The output resistance of the signal source is now part of the input resistance to the op-amp.

Then, $R_1 + R_S = \dfrac{v_s(max)}{i_1(max)} = \dfrac{0.1}{5 \times 10^{-6}} \Rightarrow 20k\Omega$

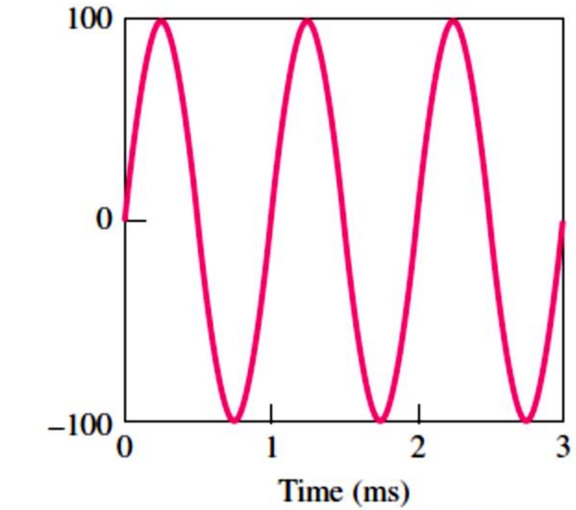
Since $R_S = 1\ k\Omega$, We then have; $R_1 = 19\ k\Omega$

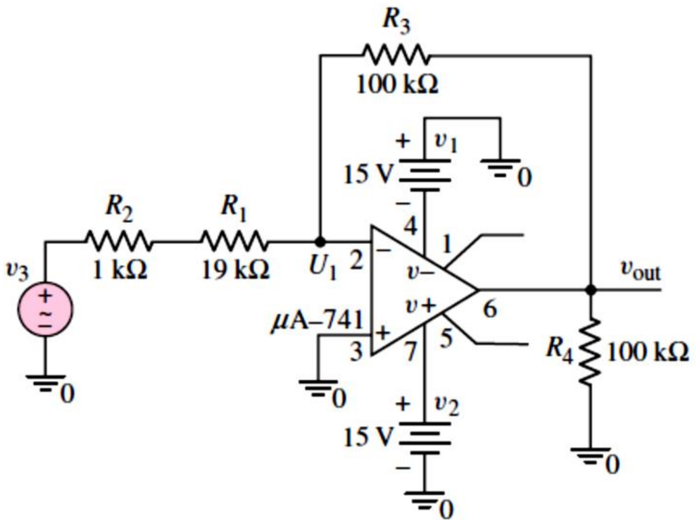
The feedback resistor is then;

$$R_2 = 5(R_1 + R_s) = 5(19 + 1) = 100\ k\Omega$$

Ex. 01: Design an Inverting Amplifier

Input Voltage





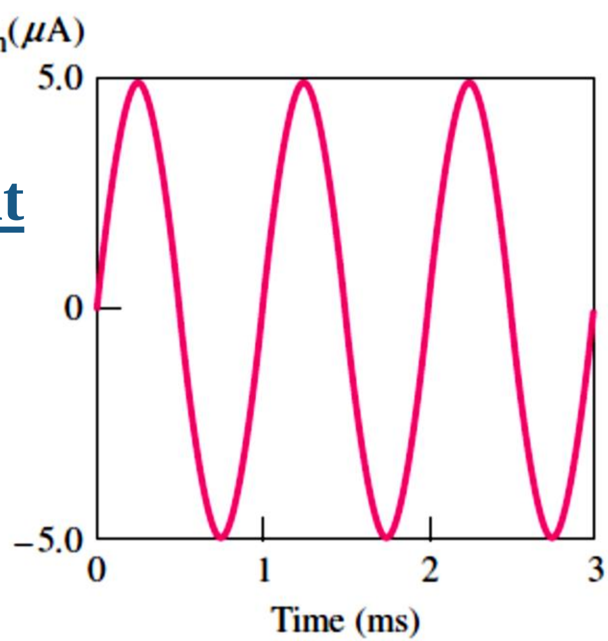
Given

$A_v = -5$

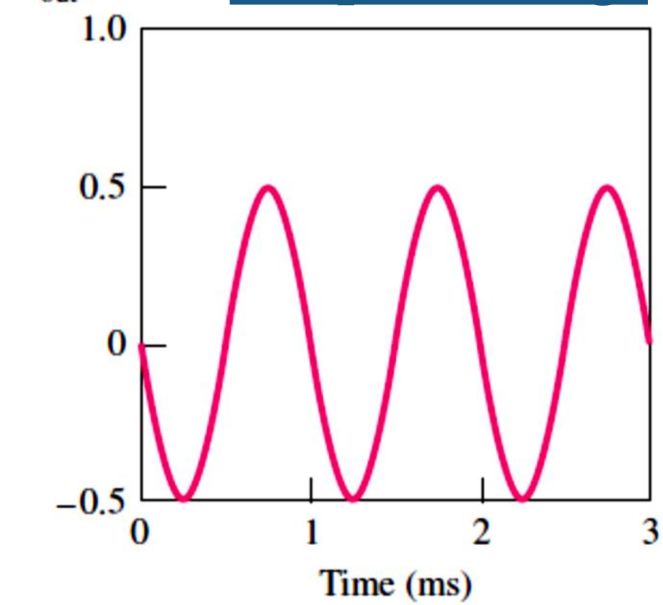
$v_s = 0.1\ \sin\omega t\ (V)$

$i_1(max) = 5\ \mu A$

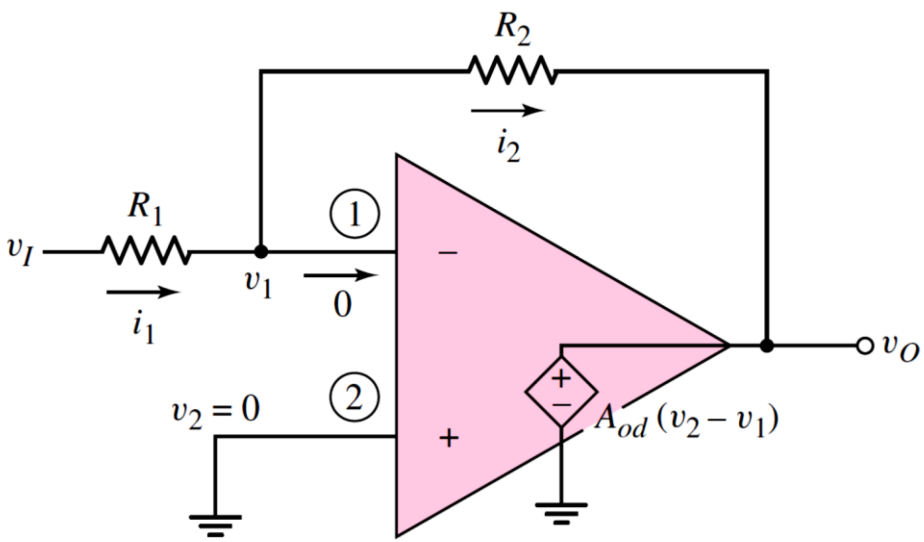
Input Current



Output Voltage



Effect of Finite Gain



The current through R_1

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

The current through R_2

$$i_2 = \frac{v_1 - v_O}{R_2}$$

The output voltage

$$v_O = -A_{od} v_1$$

The terminal (1) voltage

$$v_1 = -\frac{v_O}{A_{od}}$$

Then,

$$i_1 = \frac{v_I + \frac{v_O}{A_{od}}}{R_1} = i_2 = \frac{-\frac{v_O}{A_{od}} - v_O}{R_2}$$

Effect of Finite Gain

$$\frac{v_I + \frac{v_O}{A_{od}}}{R_1} = \frac{-\frac{v_O}{A_{od}} - v_O}{R_2}$$

Solving for the closed-loop gain

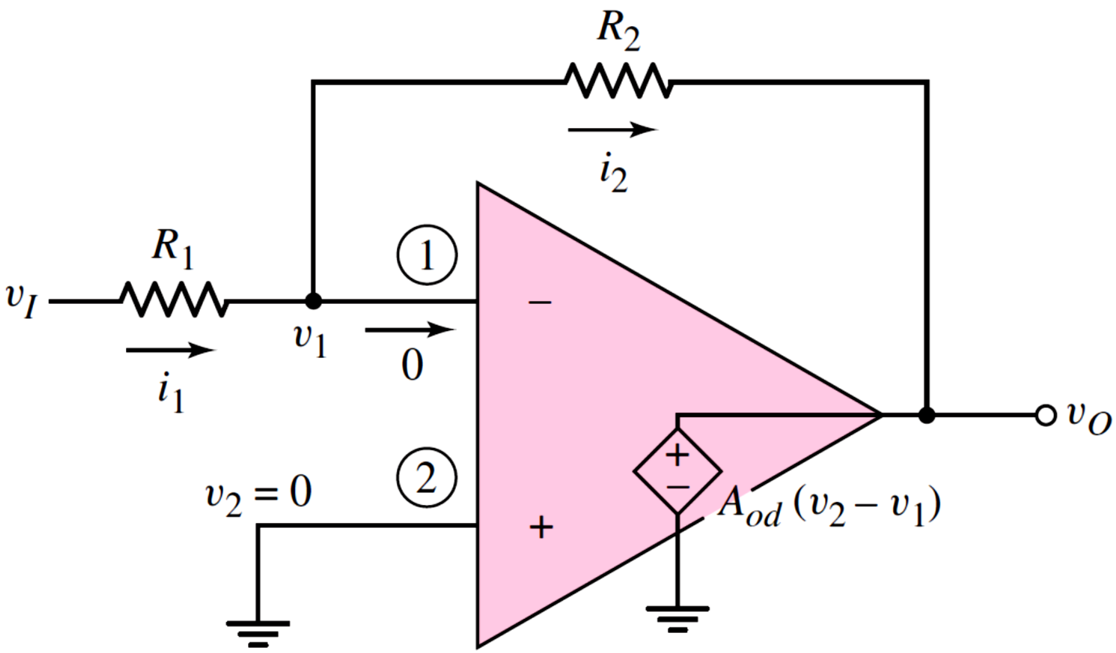
$$A_v = \frac{v_O}{v_I} = -\frac{R_2}{R_1}\frac{1}{\left[1 + \frac{1}{A_{od}}\left(1 + \frac{R_2}{R_1}\right)\right]}$$

If $A_{od} \rightarrow \infty$, the gain becomes same as the ideal closed-loop gain

$$A_v = \frac{v_O}{v_I} = \lim_{A_{od}\rightarrow\infty}\left(-\frac{R_2}{R_1}\frac{1}{\left[1 + \frac{1}{A_{od}}\left(1 + \frac{R_2}{R_1}\right)\right]}\right) = -\frac{R_2}{R_1}$$

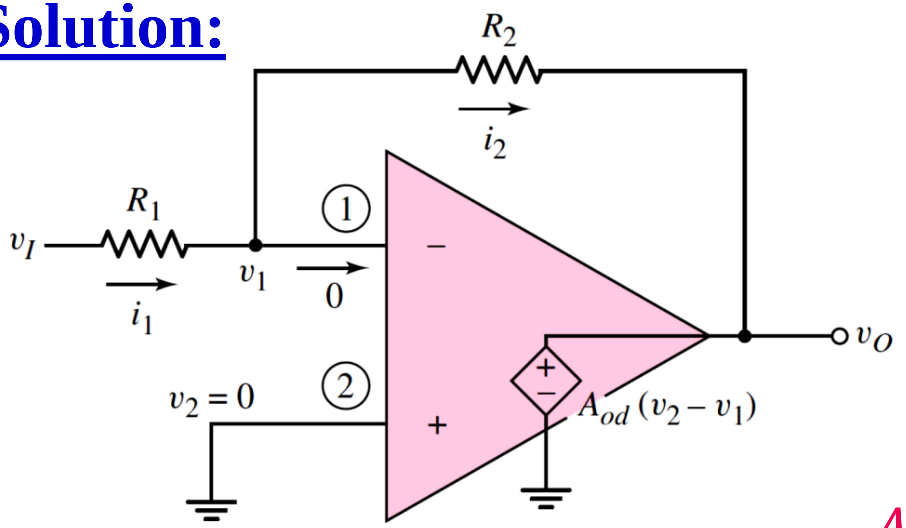
Ex. 02: Study the Effect of A_{od}

Determine the deviation from the ideal due to a finite differential gain. Consider an inverting op-amp with $R_1 = 10k\Omega$ and $R_2 = 100k\Omega$. Determine the closed-loop gain for: $A_{od} = 10^2, 10^3, 10^4, 10^5$, and 10^6. Calculate the percent deviation from the ideal gain.



Ex. 02: Study the Effect of A_{od}

Solution:



The ideal closed-loop gain;

$$A_v = -\frac{R_2}{R_1} = -\frac{100}{10} = -10$$

If $A_{od} = 10^2$,

$$A_v = \frac{v_O}{v_I} = -\frac{R_2}{R_1}\frac{1}{\left[1 + \frac{1}{A_{od}}\left(1 + \frac{R_2}{R_1}\right)\right]}$$

Then;

$$A_v = -\frac{100}{10} \cdot \frac{1}{\left[1 + \frac{1}{10^2}\left(1 + \frac{100}{10}\right)\right]} = -\frac{10}{(1 - 0.11)} = -9.01$$

Which is a 9.9% deviation from the ideal.

Ex. 02: Study the Effect of A_{od}

Solution:

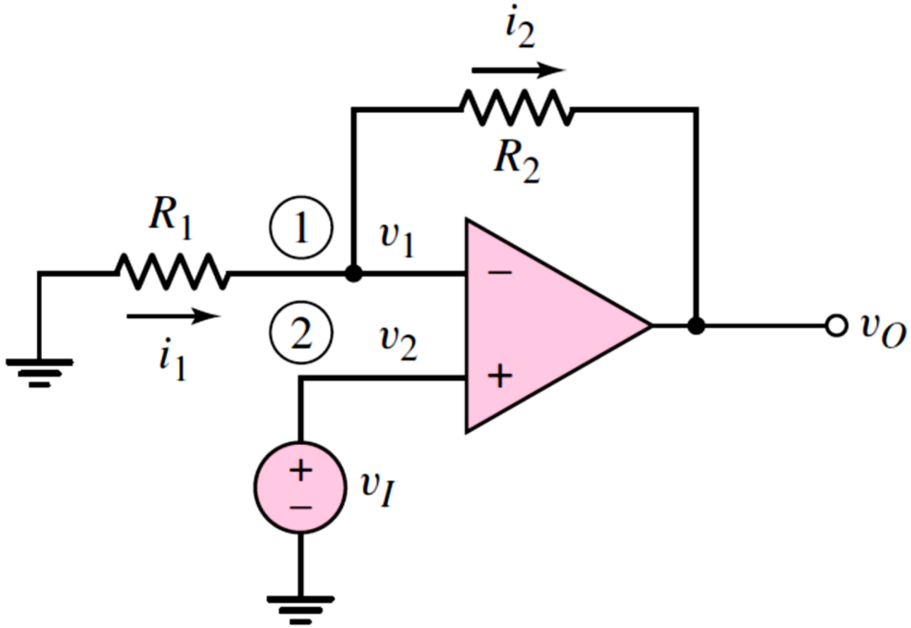
For the other differential gain values, we have the following results:

A_{od}	A_v	Deviation (%)
10^2	−9.01	9.9
10^3	−9.89	1.1
10^4	−9.989	0.11
10^5	−9.999	0.01
10^6	−9.9999	0.001

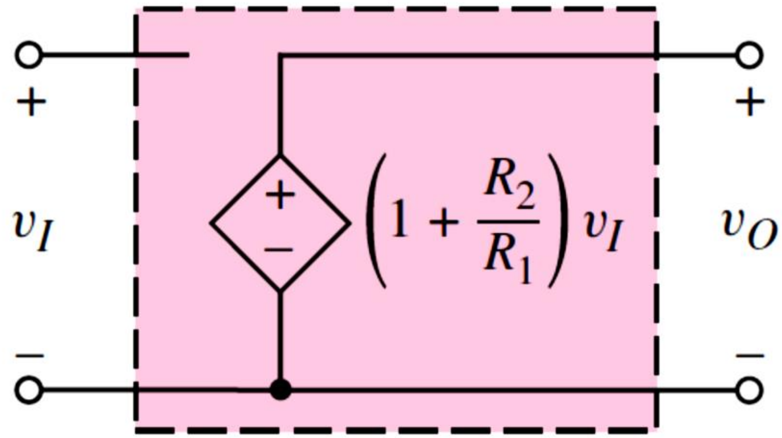
- In this case, the open loop gain must be at least 10^3 in order to be within 1% of the ideal gain.
- At low frequencies, most op-amp circuits have gains on the order of 10^5, so achieving the required accuracy is not difficult.

Non-Inverting Amplifier

Non-inverting Amplifier



Non-inverting op-amp circuit



Equivalent circuit of ideal noninverting op-amp

We assume that no current enters the input terminals. Since $v_1 = v_2$, then $v_1 = v_I$, and current i_1 is given by

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

Non-inverting Amplifier

Current i_2 is given by

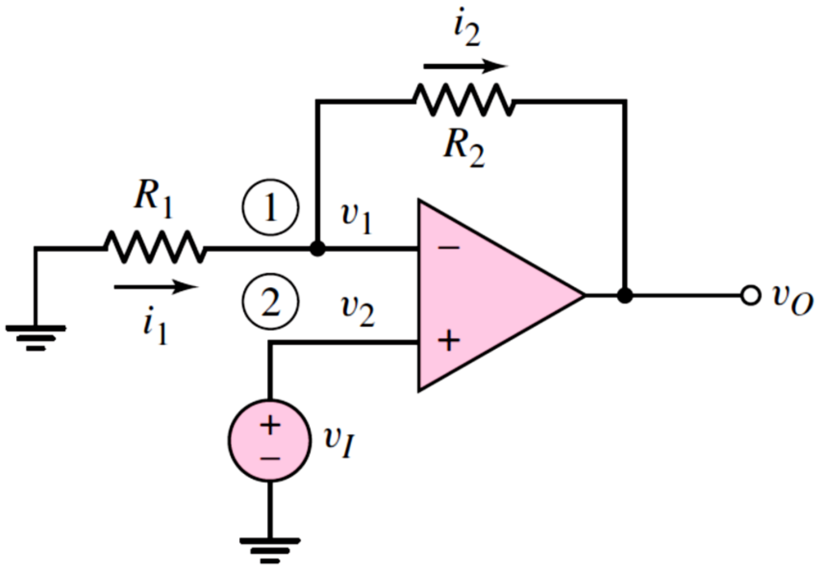
$$i_2 = \frac{v_1 - v_O}{R_2} = \frac{v_I - v_O}{R_2}$$

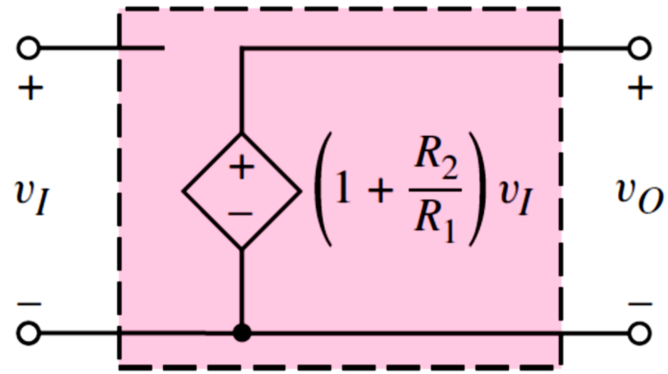
As before, $i_1 = i_2$, so that

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

The closed-loop voltage gain A_v

$$A_v = \frac{v_O}{v_I} = 1 + \frac{R_2}{R_1}$$





Equivalent circuit of ideal noninverting op-amp