Electronic Circuits

Operational Amplifier

Lecture 2

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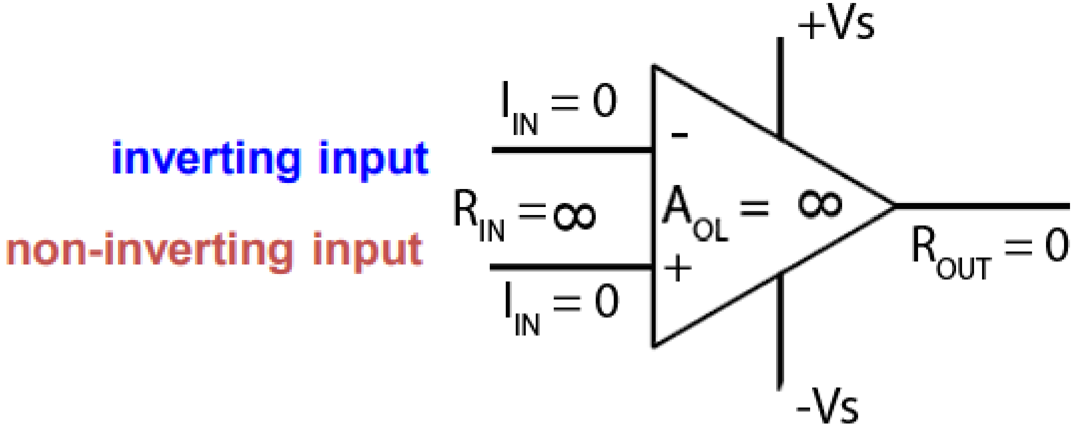
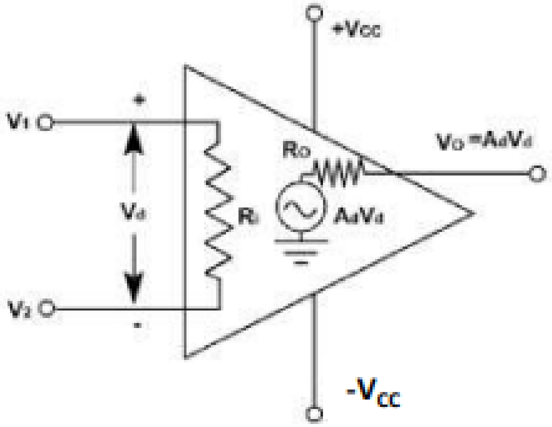
Operational Amplifier (Ideal vs. Actual)

Properties	Ideal	Actual (Real or Typical)
1. Open loop gain	∞	High ≥ 10^4
2. Open loop bandwidth	∞	Very high
3. Input resistance	∞	High ≥ 10 MΩ
4. Output resistance	0	Low ≤ 500 Ω
5. Input current	0	< 0.5 μA
6. Offset voltage & current	0	Low < 10mv , < 0.2 nA

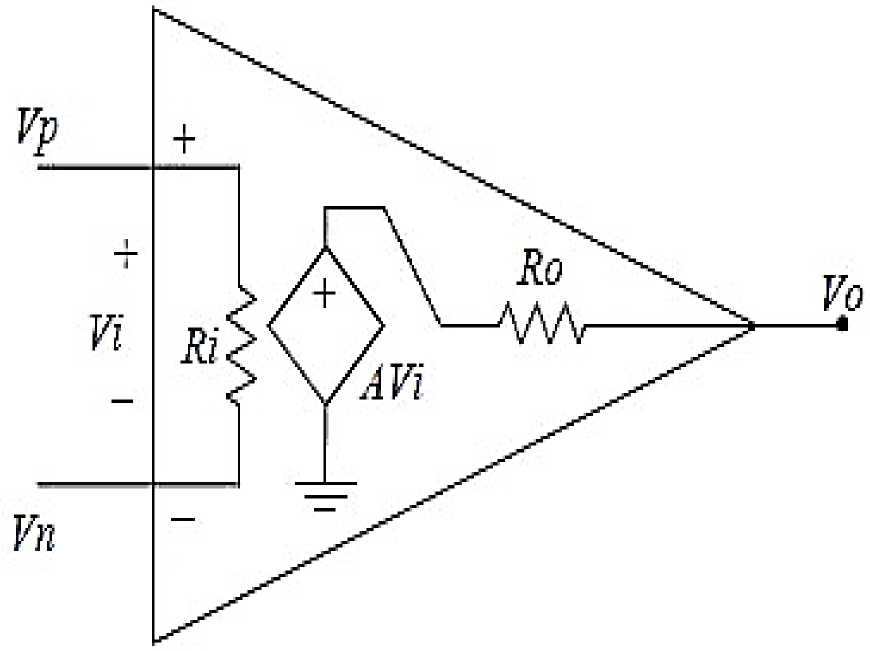


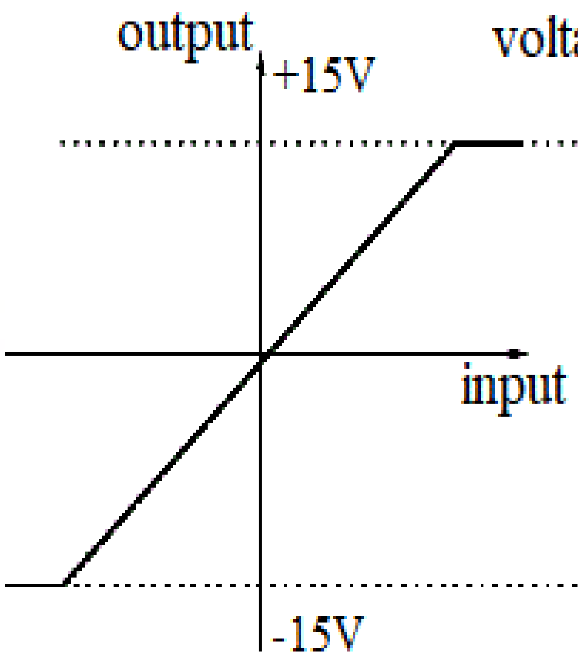
Ideal Op Amp



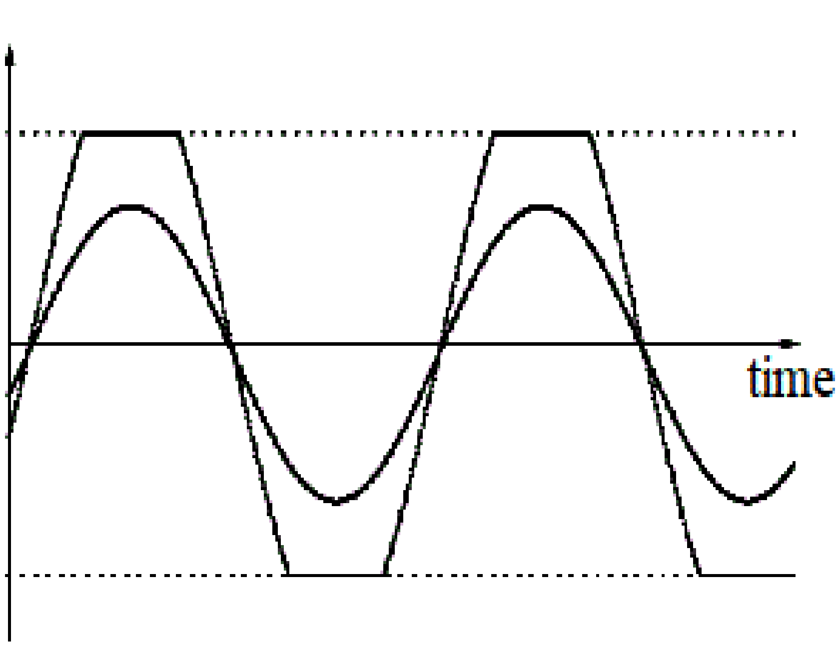
Actual Op Amp

Actual Operational Amplifier



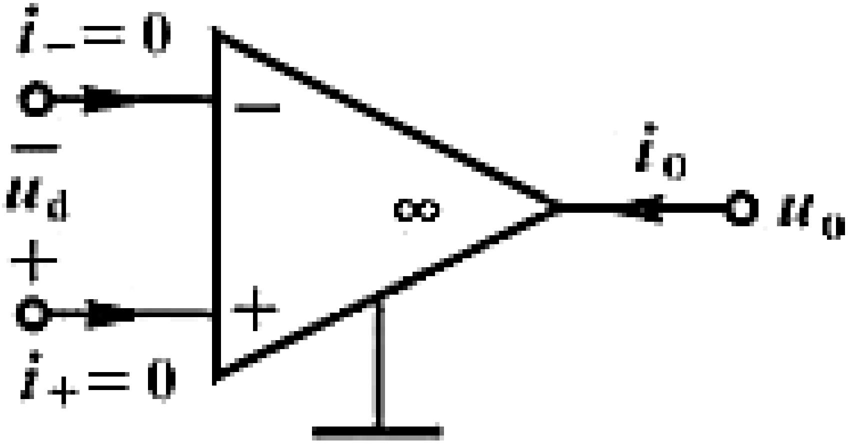


saturation characteristic

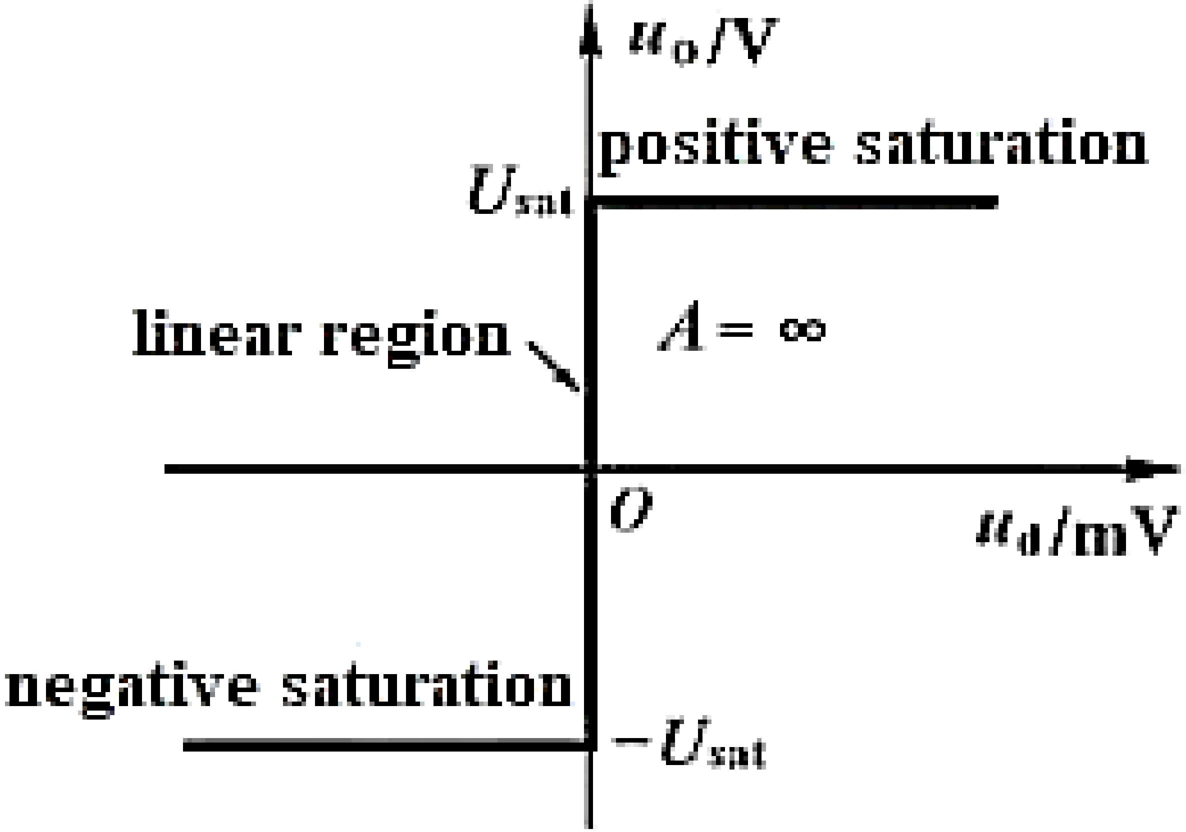


waveform clipping

Ideal Operational Amplifier



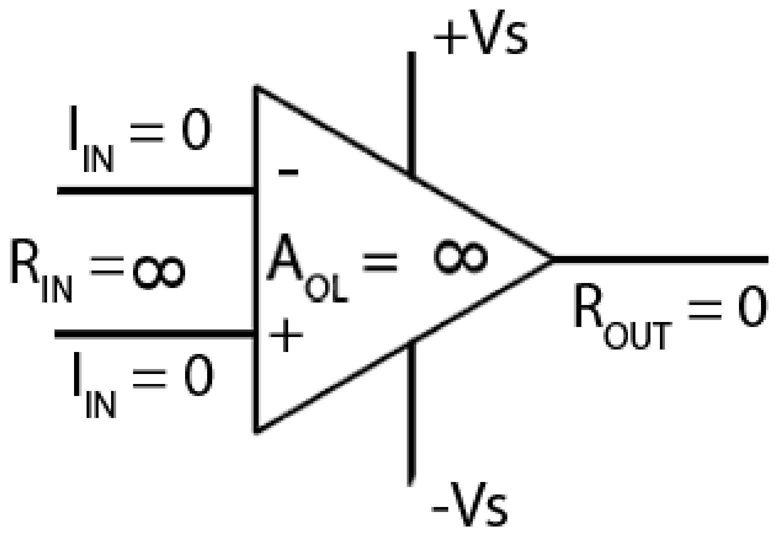
(a)



(b)

Ideal Op-Amp

- **The input Currents of Op-Amp $\boldsymbol{I_{\mathrm{in}} = 0}$ $(\mathbf{R_{in}} = \infty)$**
- **Infinite Voltage gain $\boldsymbol{A = \infty}$**
- **Zero Output Impedance $(\boldsymbol{R_{out} = 0})$**



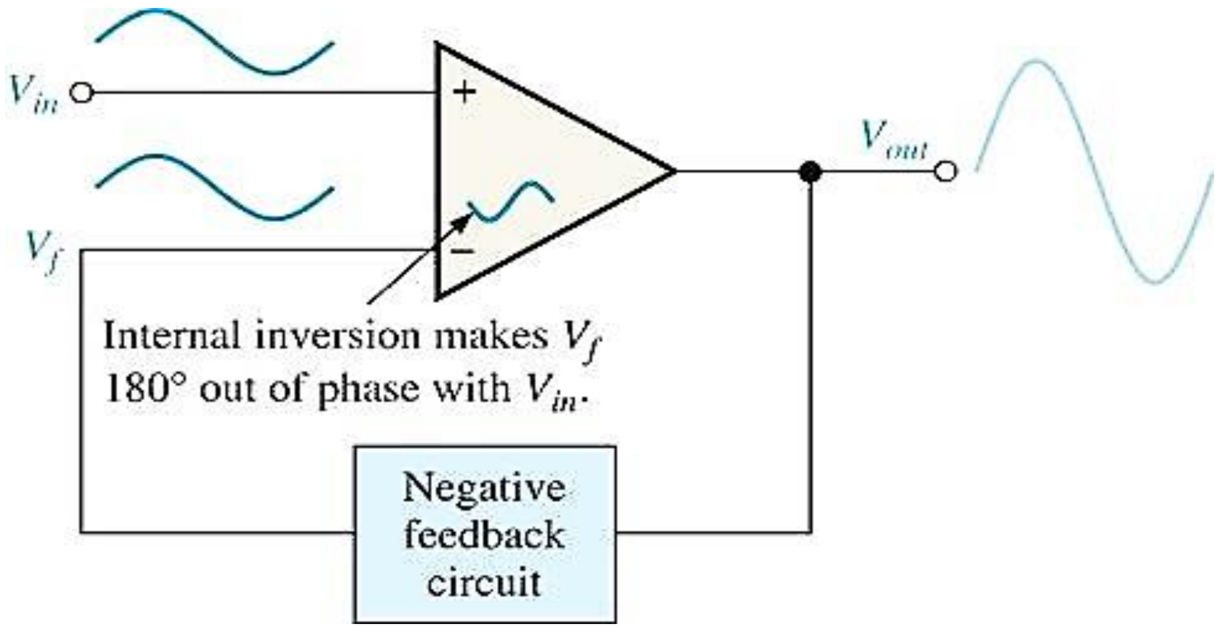
Gulden Rules of Op-Amp

- The inputs to the op-amp draw or source no current (true whether negative feedback or not)

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

- The op-amp with negative feedback forces the two inputs v+ and v- to have the same voltage, even though no current flows into either input. This is sometimes called a “Virtual short”

Negative Feedback



- Negative feedback is the process whereby a portion of the output voltage of an amplifier is returned to the input with a phase angle that is opposite to the input signal.
- The open-loop gain of an op-amp is usually very high (more than 100,000).
- With negative feedback the gain of op-amp (called close-loop gain *Acl*) can be reduced and controlled so that an op-amp can function as a linear amplifier.

Op-Amp with Negative Feedback

- **Close-Loop Voltage Gain, *Acl***

- The close-loop voltage gain is the voltage of an op-amp with external feedback.

- The amplifier circuit consists of an op-amp and an external negative feedback circuit.

- The feedback from the output is connected to the inverting input of the op-amp.

- The negative feedback is determined and controlled by external components.

Op-Amp Applications

Linear Applications

1- The Inverting Amplifier

2-The Noninverting Amplifier

3- Summing Amplifier

4- Subtractor

5- Voltage Follower

6- Controlled Sources

7- Integrator

8- Differentiator

Op-Amp Applications

- **Non linear Applications**

9- Logarithmic Amplifier

10- Anti-Logarithmic Amplifier

11- Analog Multiplier

12- Analog Divider

13- Voltage Regulator

14- Comparator

15- Schmitt Trigger

16- Digital to Analog Converter

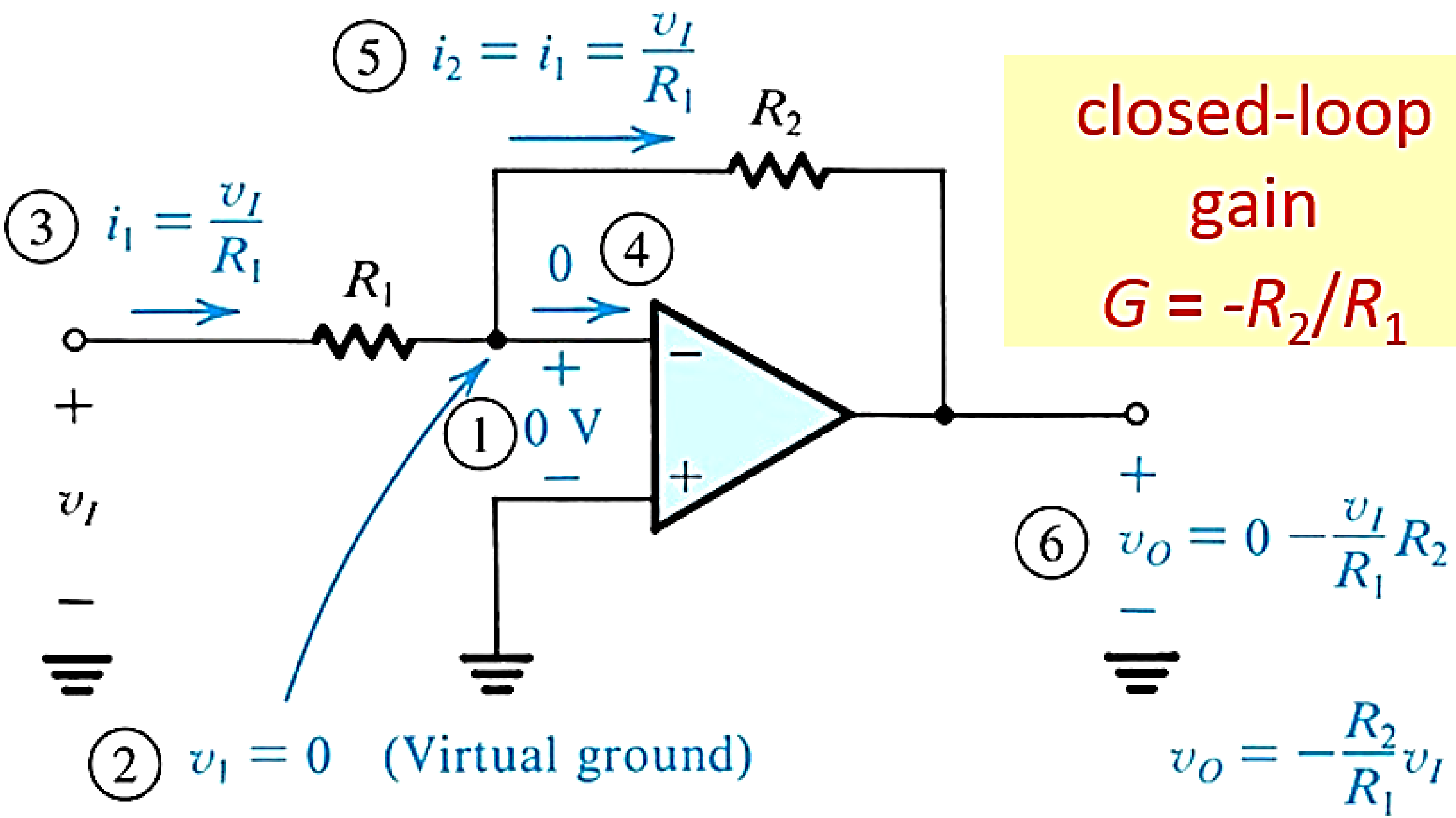
17- Rectifying using Op-Amp

18- Clipping using Op-Amp

19- Instrumentation Amplifier

Op-Amp Applications

1-Inverting Amplifier



closed-loop gain

$G = -R_2/R_1$

1-Inverting Amplifier

We Have

$$I_{in} = \frac{V_{in}}{R_i} \quad I_f = \frac{-V_{out}}{R_f}$$

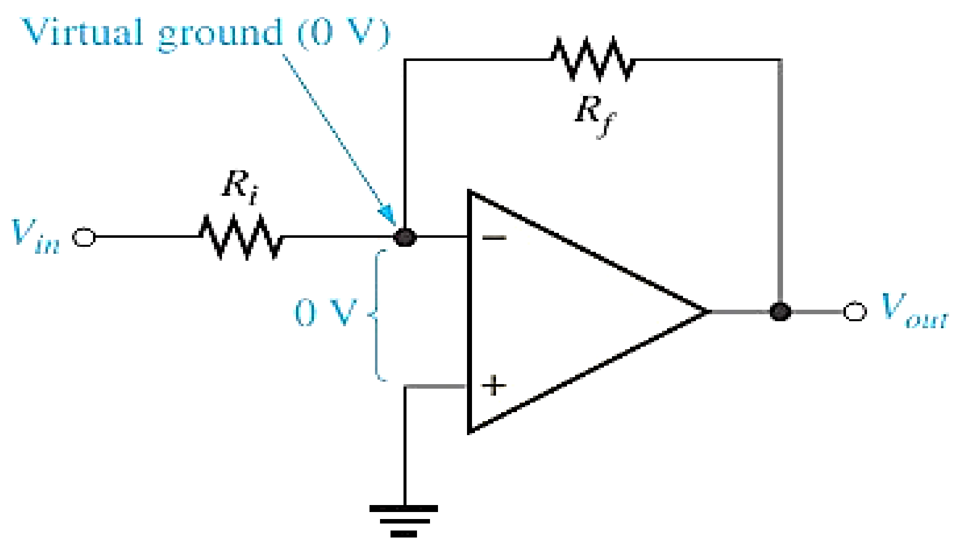
Since $I_{in} = I_f$

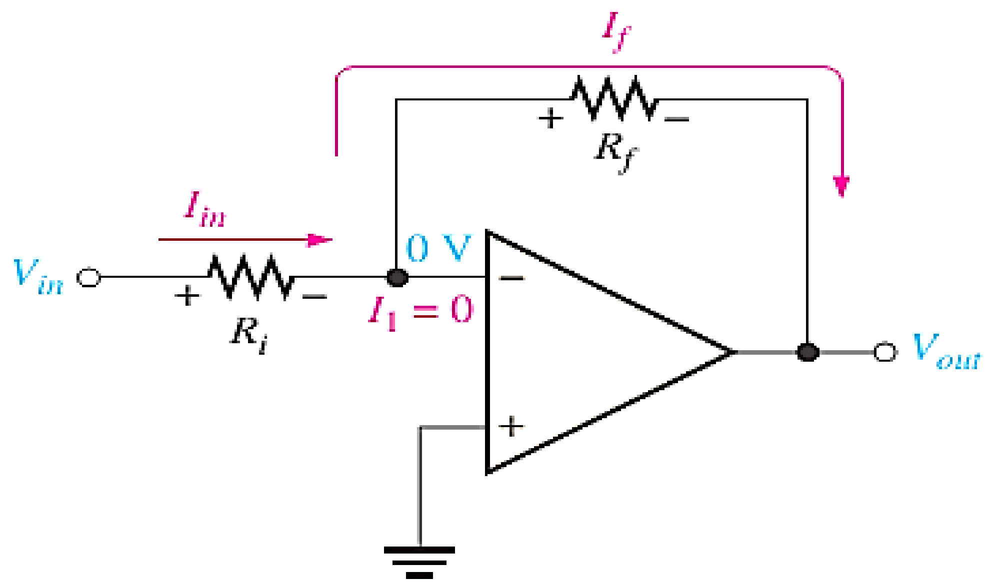
$$\frac{V_{in}}{R_i} = \frac{-V_{out}}{R_f}$$

$$\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_i}$$

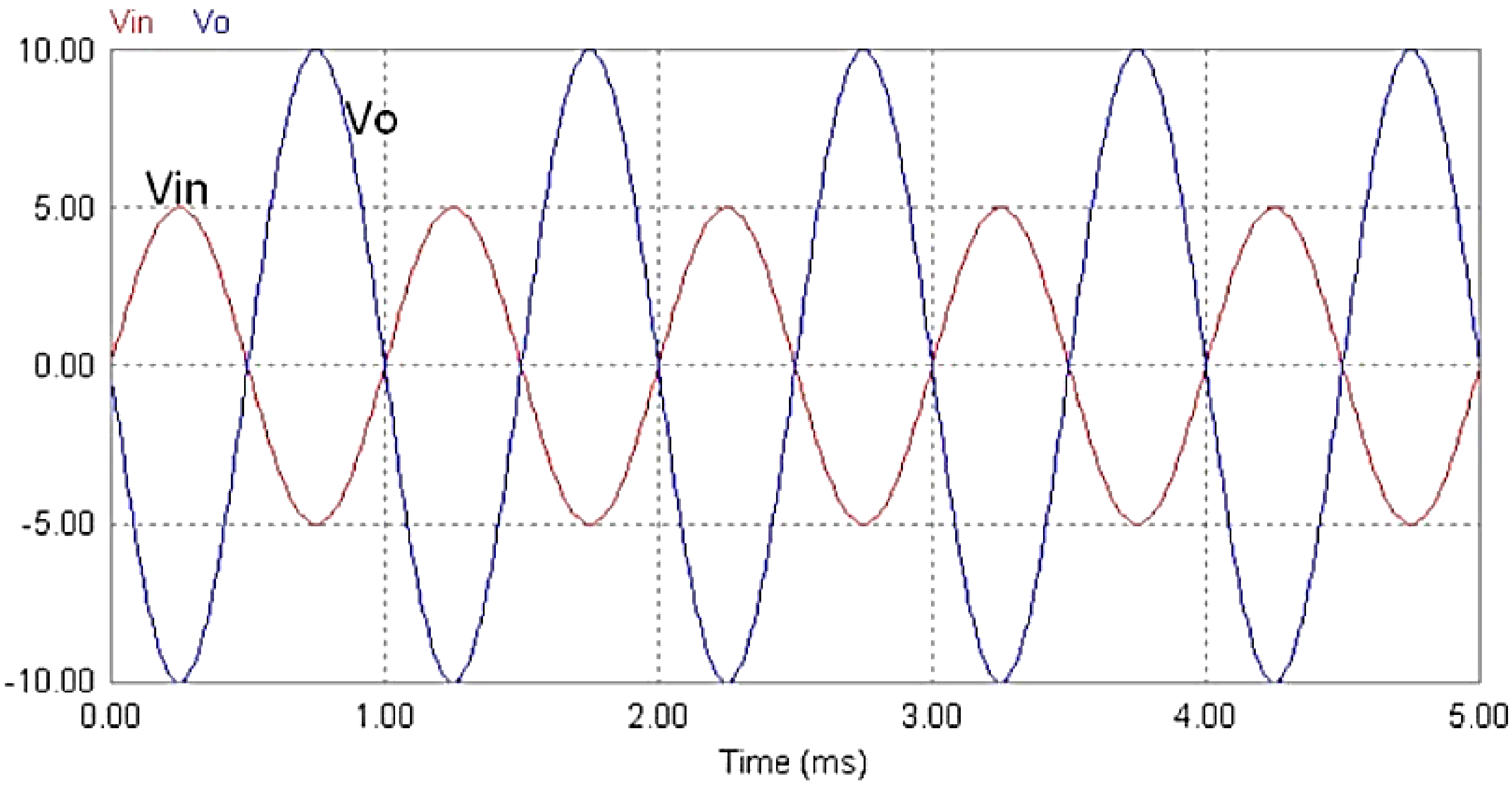
The closed loop gain

$$A_{cl(I)} = -\frac{R_f}{R_i}$$





1-Inverting Amplifier



1-Inverting Amplifier example

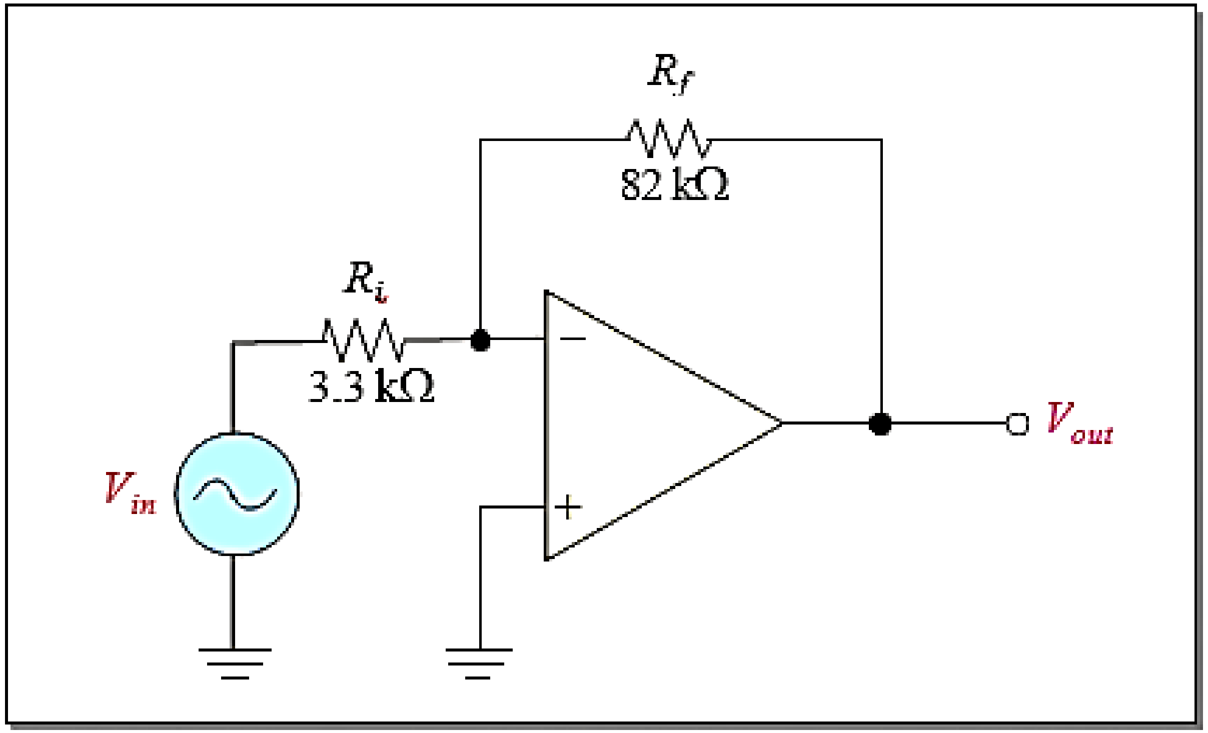
Determine the gain of the inverting amplifier shown.

Solution:

$$A_{cl(I)} = -\frac{R_f}{R_i}$$

$$= -\frac{82\ \text{k}\Omega}{3.3\ \text{k}\Omega}$$

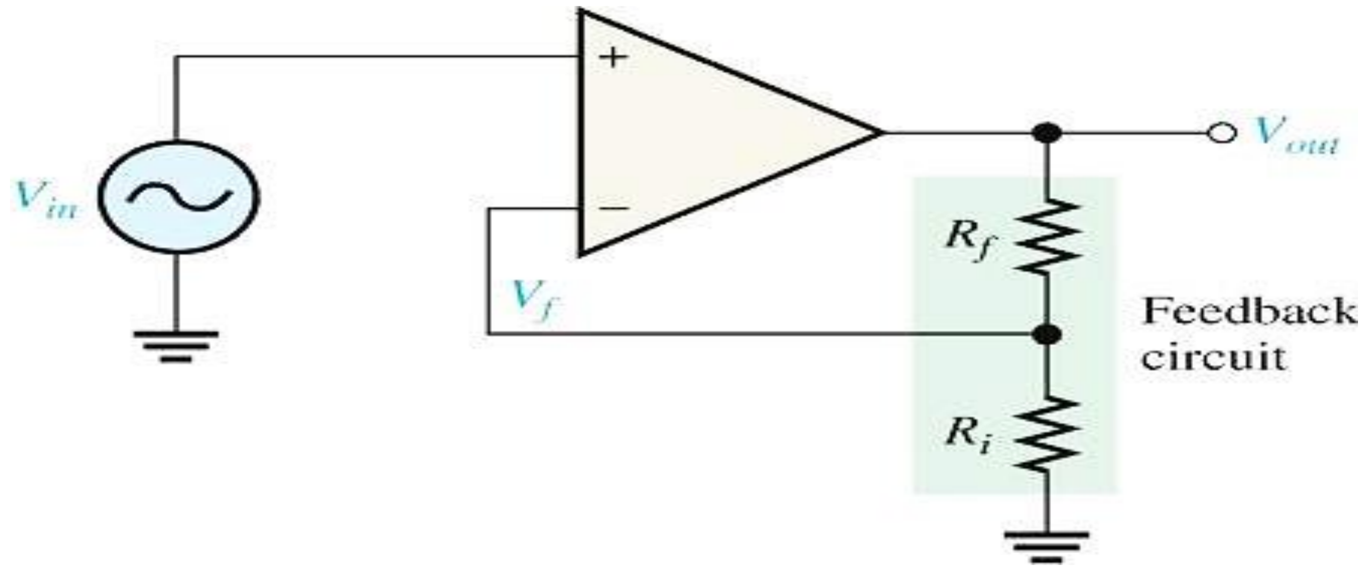
$$= -24.8$$



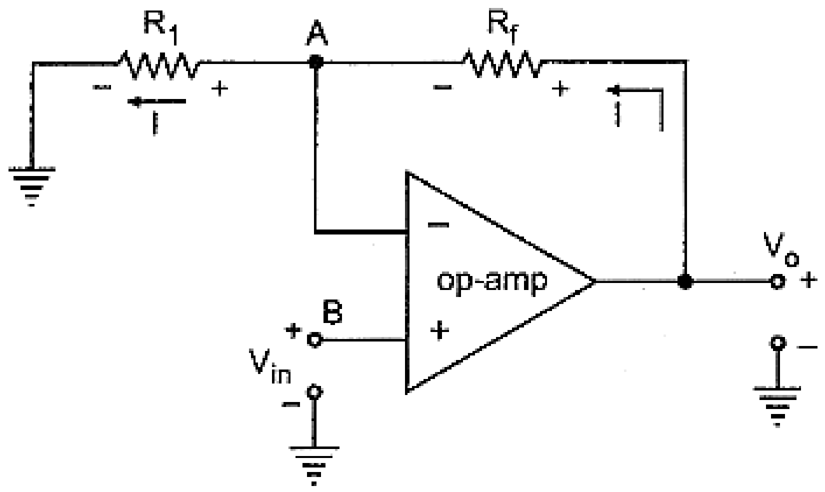
The minus sign indicates inversion.

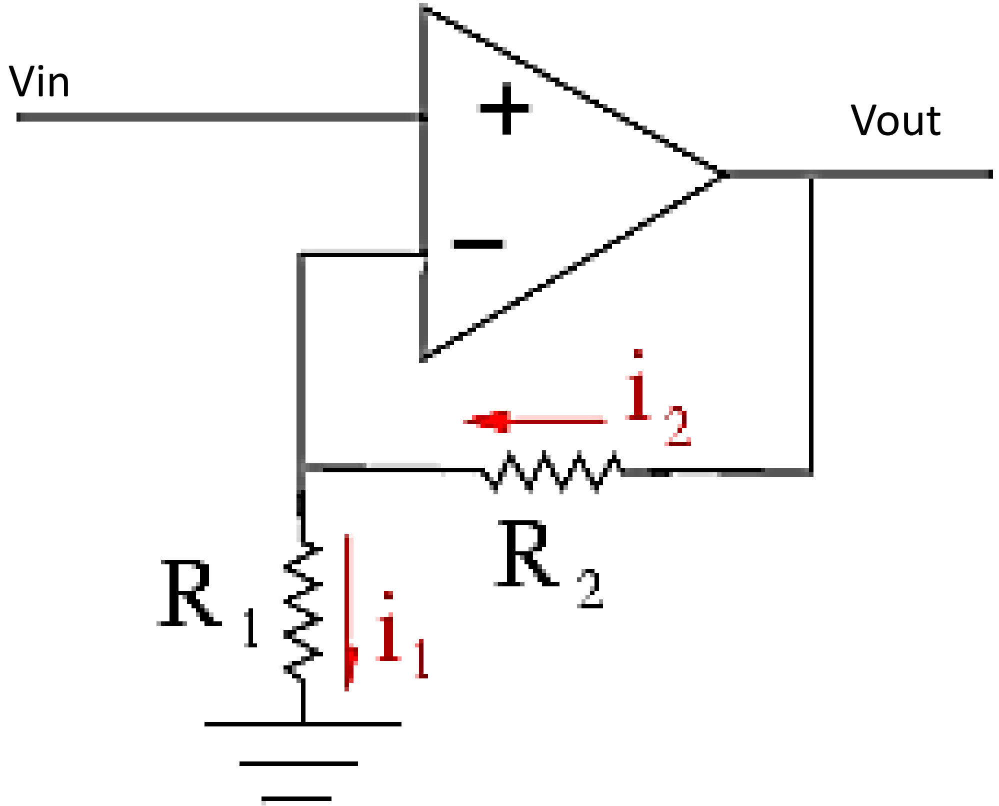
2- Noninverting Amplifier

- A **noninverting amplifier** is a configuration in which the signal is on the noninverting input and a portion of the output is returned to the inverting input.
- The feedback circuit is formed by input resistance Ri and feedback resistance Rf.
- This feedback creates a voltage divider circuit which reduces Vout and connects the reduced voltage Vf to the inverting input



2- Noninverting Amplifier



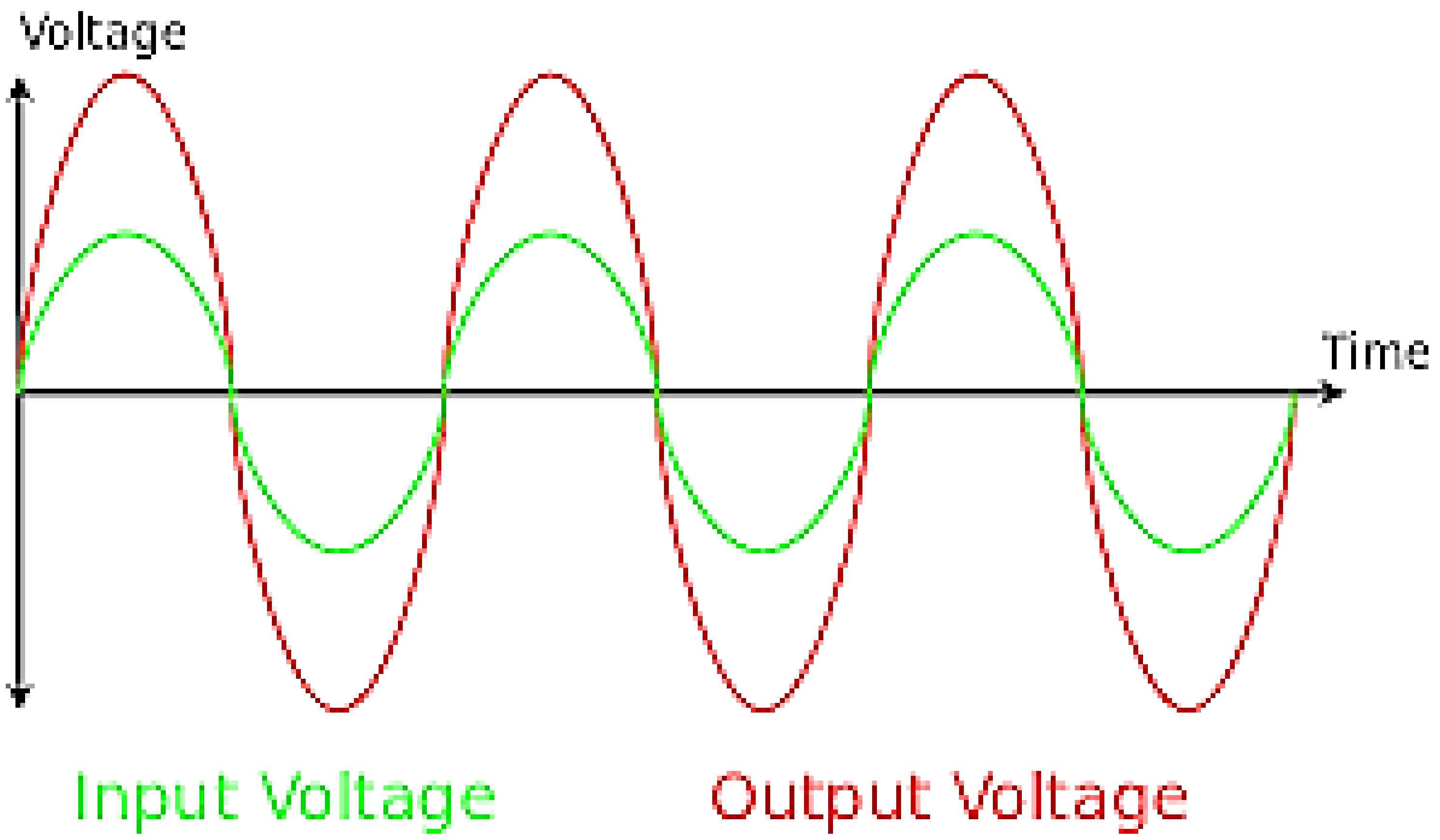


$$i_2 - i_1 = 0$$

$$\frac{V_{out} - V_{in}}{R_2} - \frac{V_{in}}{R_1} = 0$$

$$\frac{V_{out}}{V_{in}} = \frac{(R_1 + R_2)}{R_1}$$

2- Noninverting Amplifier



2-Noninverting Amplifier example

Determine the gain of the noninverting amplifier shown.

Solution:

$$A_{cl(NI)} = 1 + \frac{R_f}{R_i}$$

$$= 1 + \frac{82\ \text{k}\Omega}{3.3\ \text{k}\Omega}$$

$$= 25.8$$