Alexander-Sadiku
Fundamentals of Electric Circuits

Chapter 5
Operational Amplifier

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.

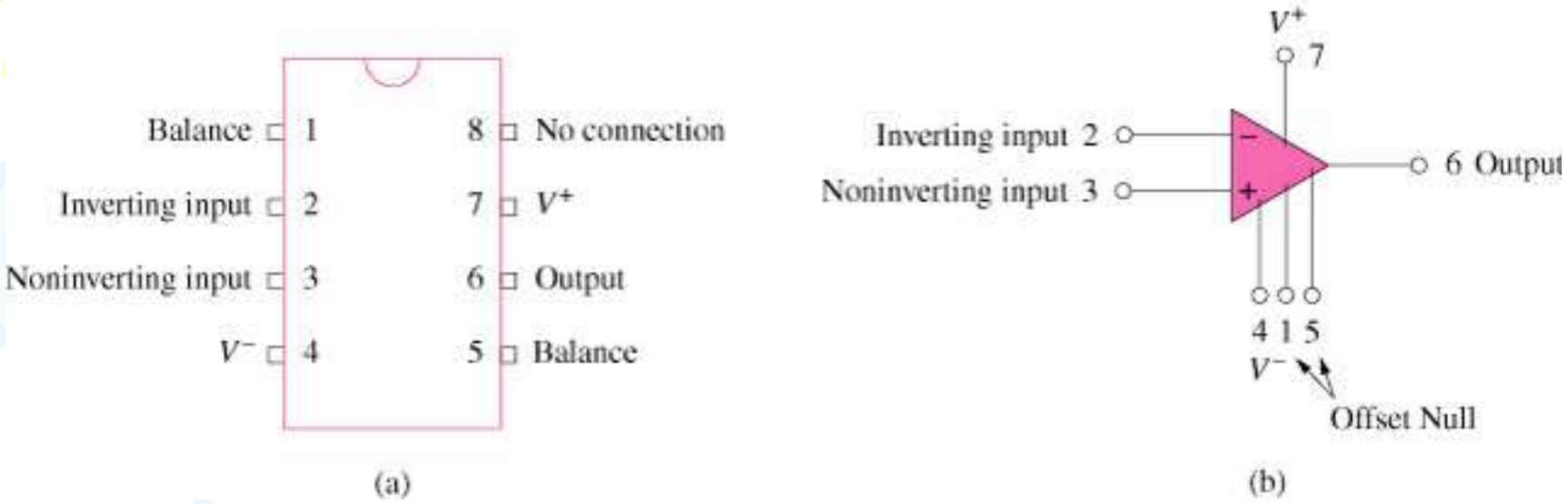
Operational Amplifier - Chapter 5

- 5.1 What is an Op Amp?
- 5.2 Ideal Op Amp
- 5.3 Configuration of Op Amp
- 5.4 Cascaded Op Amp
- 5.5 Application
  - Digital-to Analog Converter

5.1 What is an Op Amp (1)

- It is an electronic unit that behaves like a voltage-controlled voltage source.
- It is an active circuit element designed to perform mathematical operations of ***addition***, ***subtraction***, ***multiplication***, ***division***, ***differentiation*** and ***integration***.

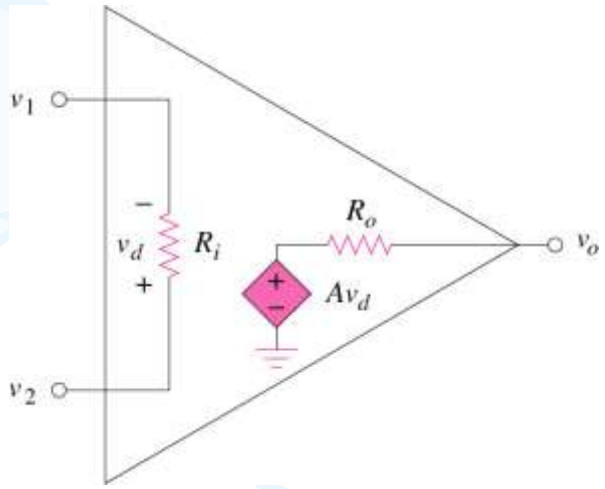
5.1 What is an Op Amp (2)



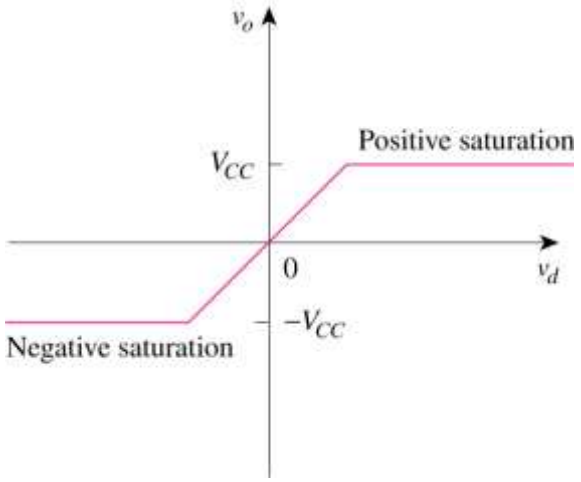
A typical op amp: (a) pin configuration, (b) circuit symbol

5.1 What is an Op Amp (3)

The equivalent circuit Of the non-ideal op amp



Op Amp output: v_o as a function of V_d



$$v_d = v_2 - v_1; \;\; v_o = Av_d = A(v_2 - v_1)$$

5.1 What is an Op Amp (4)

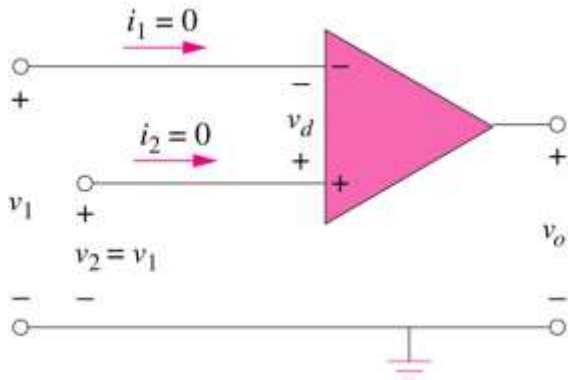
Typical ranges for op amp parameters

Parameter	Typical range	Ideal values
Open-loop gain, A	10^5 to 10^8 Ω	∞
Input resistance, R_i	10^5 to 10^{13} Ω	∞ Ω
Output resistance, R_o	10 to 100 Ω	0 Ω
Supply voltage, V_{CC}	5 to 24 V	

5.2 Ideal Op Amp (1)

An ideal op amp has the following characteristics:

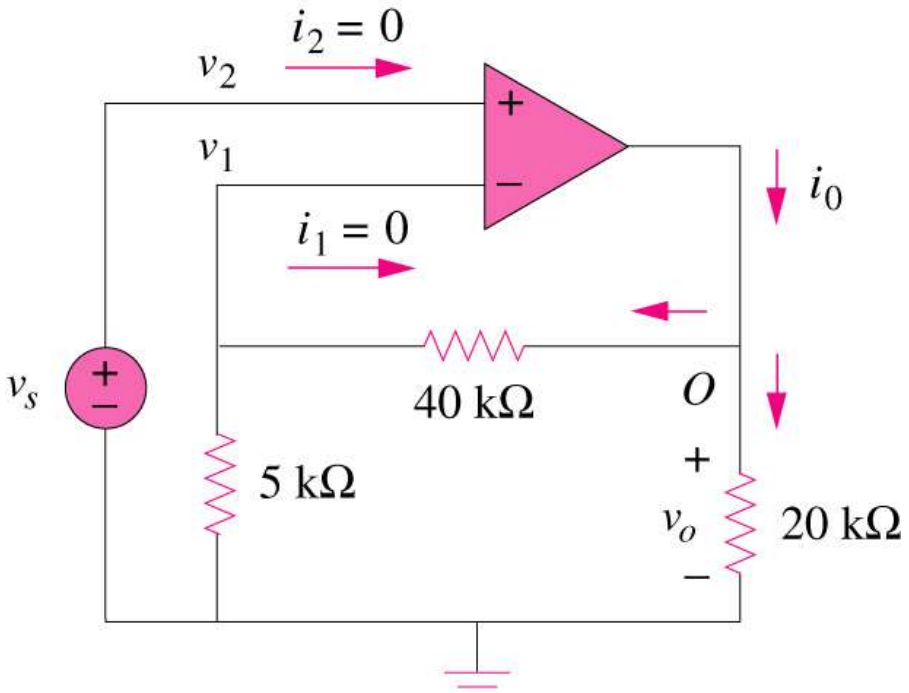
1. Infinite open-loop gain, $A \approx \infty$
2. Infinite input resistance, $R_i \approx \infty$
3. Zero output resistance, $R_o \approx 0$



5.2 Ideal Op Amp (2)

Example 1:

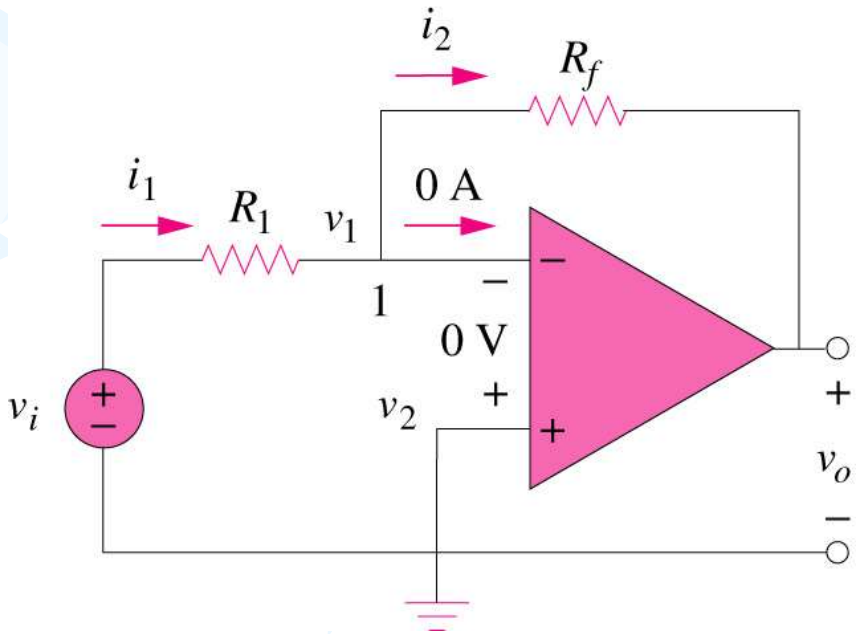
Determine the value of i_o.



*Refer to in-class illustration, textbook Ans: 0.65mA

5.3 Configuration of Op amp (1)

- Inverting amplifier reverses the polarity of the input signal while amplifying it

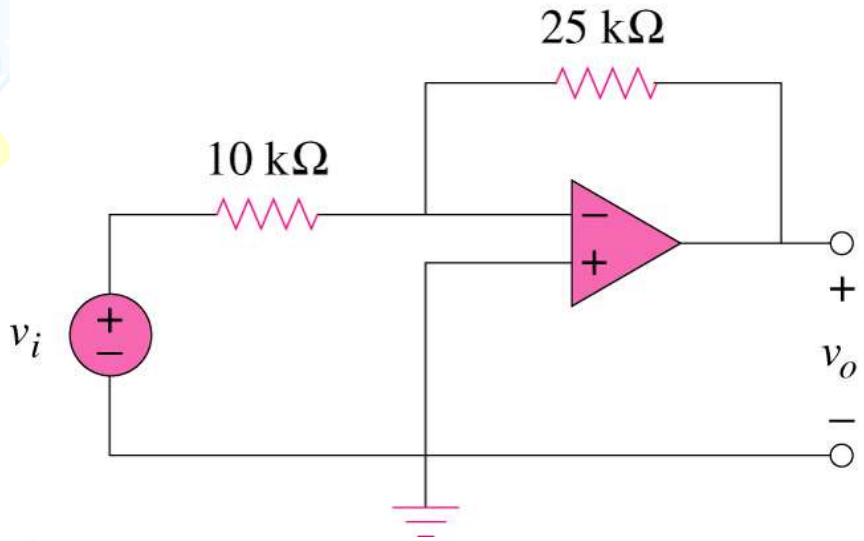


$$v_o = -\frac{R_f}{R_1} v_i$$

5.3 Configuration of Op amp (2)

Example 2

Refer to the op amp below. If v_i = 0.5V, calculate: (a) the output voltage, v_o and (b) the current in the 10kΩ resistor.



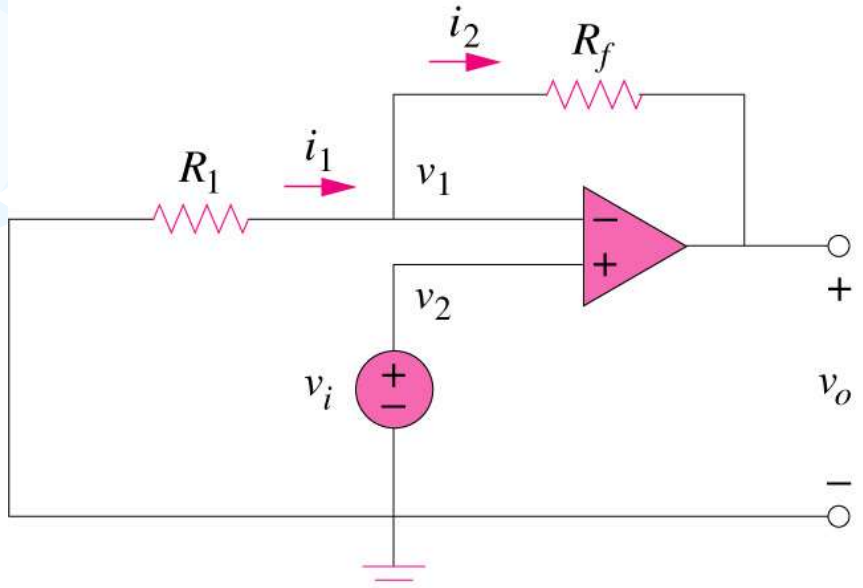
Ans:

(a) -1.25V; (b) 50μA

*Refer to in-class illustration, textbook

5.3 Configuration of Op amp (3)

- Non-inverting amplifier is designed to produce positive voltage gain

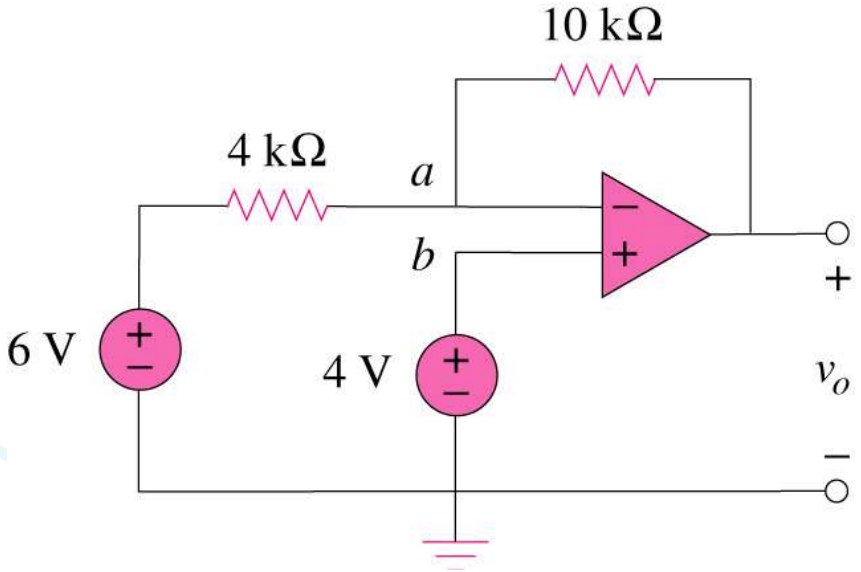


$$v_o = \left(1 + \frac{R_f}{R_1} v_i\right)$$

5.3 Configuration of Op amp (4)

Example 3

For the op amp shown below, calculate the output voltage v_o.

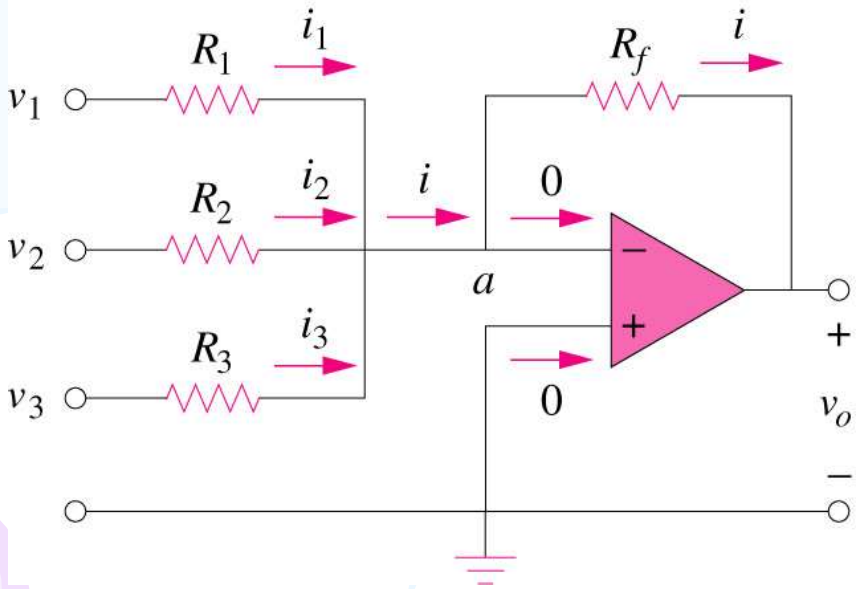


*Refer to in-class illustration, textbook

Ans: -1V

5.3 Configuration of Op amp (5)

- Summing Amplifier is an op amp circuit that combines several inputs and produces an output that is the weighted sum of the inputs.

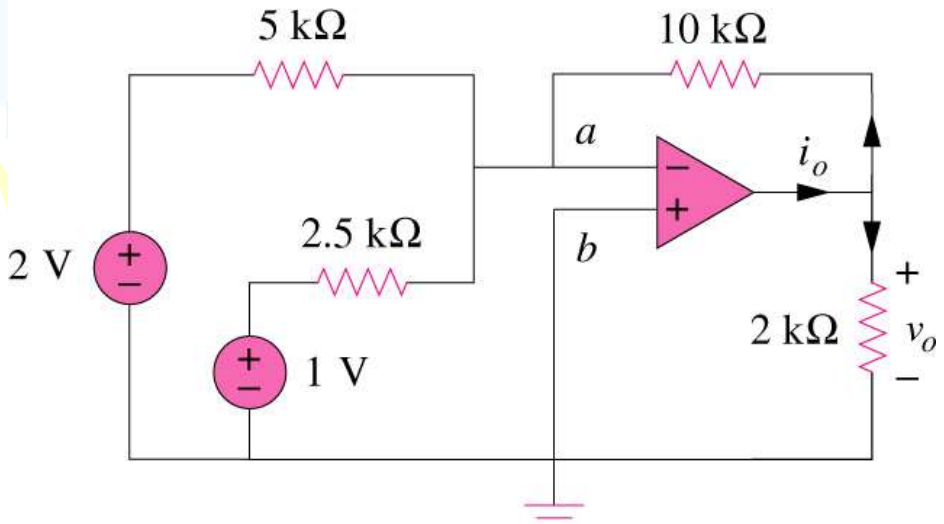


$$v_o = -\left(\frac{R_f}{R_1}v_1 + \frac{R_f}{R_2}v_2 + \frac{R_f}{R_3}v_3\right)$$

5.3 Configuration of Op amp (6)

Example 4

Calculate v_o and i_o in the op amp circuit shown below.

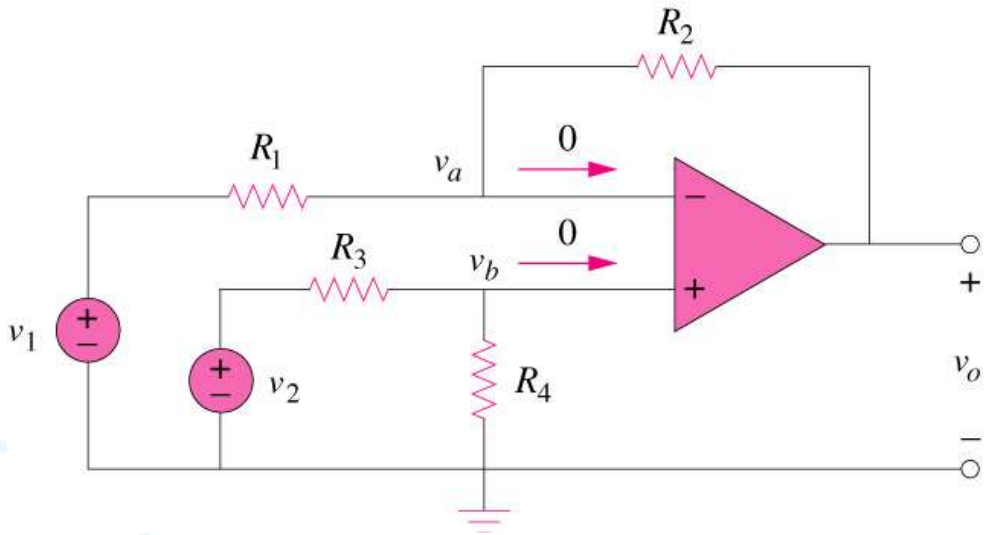


*Refer to in-class illustration, textbook

Ans: -3.8V, -1.425mA

5.3 Configuration of Op amp (7)

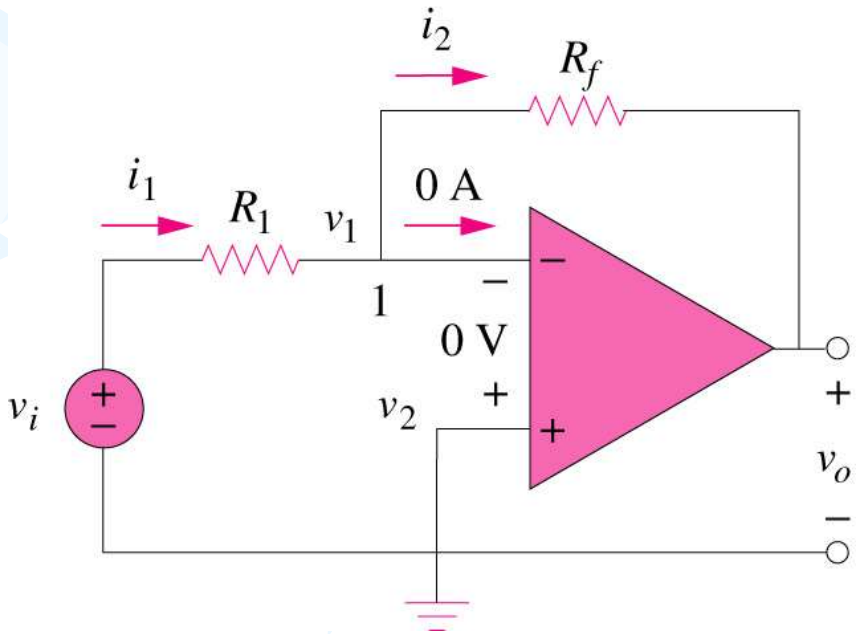
- Difference amplifier is a device that amplifies the difference between two inputs but rejects any signals common to the two inputs.



$$v_o = \frac{R_2(1+R_1/R_2)}{R_1(1+R_3/R_4)}v_2 - \frac{R_2}{R_1}v_1 \Rightarrow v_o = v_2 - v_1 \text{, if } \frac{R_2}{R_1} = \frac{R_3}{R_4} = 1$$

5.3 Configuration of Op amp (1)

- Inverting amplifier reverses the polarity of the input signal while amplifying it

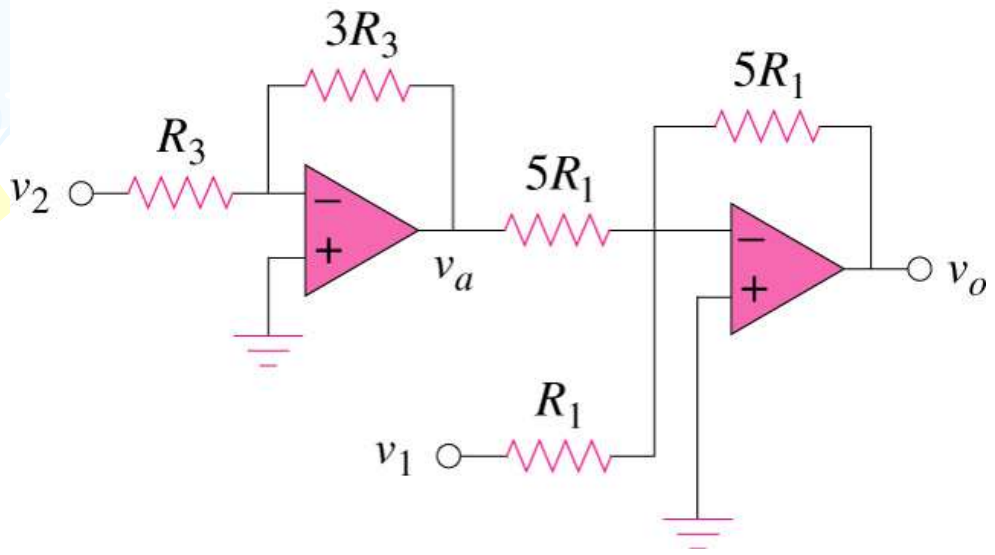


$$v_o = -\frac{R_f}{R_1} v_i$$

5.3 Configuration of Op amp (6)

Example 5

Determine R_1, R_2, R_3 and R_4 so that $v_o = -5v_1+3v_2$ for the circuit shown below.



Ans:

R_1 = 10kΩ

R_2 = 50kΩ

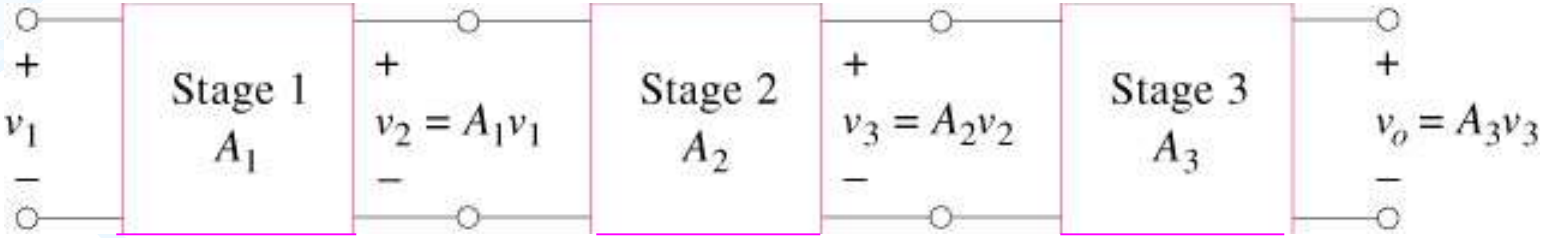
R_3 = 20kΩ

R_4 = 20kΩ

*Refer to in-class illustration, textbook

5.4 Cascaded Op Amp (1)

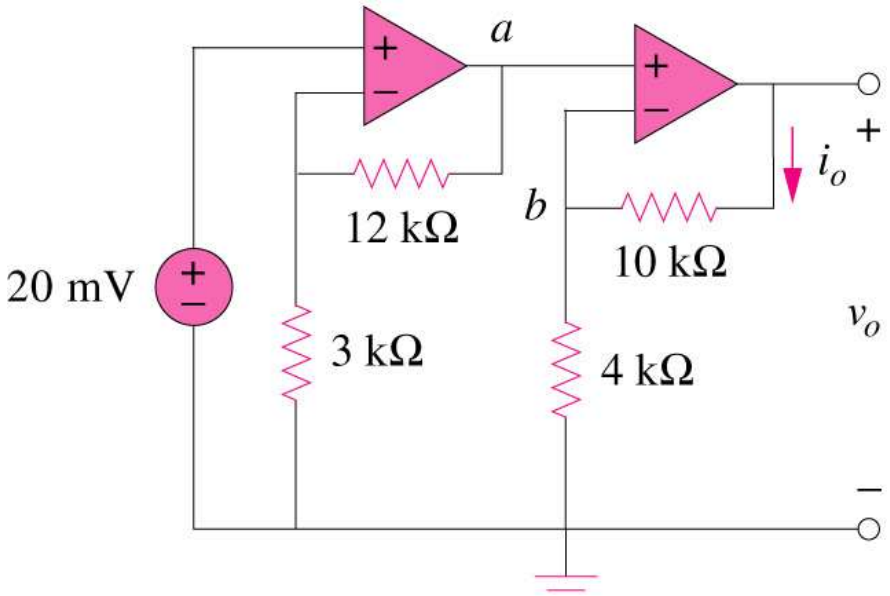
- It is a head-to-tail arrangement of two or more op amp circuits such that the output to one is the input of the next.



5.4 Cascaded Op Amp (2)

Example 6

Find v_o and i_o in the circuit shown below.



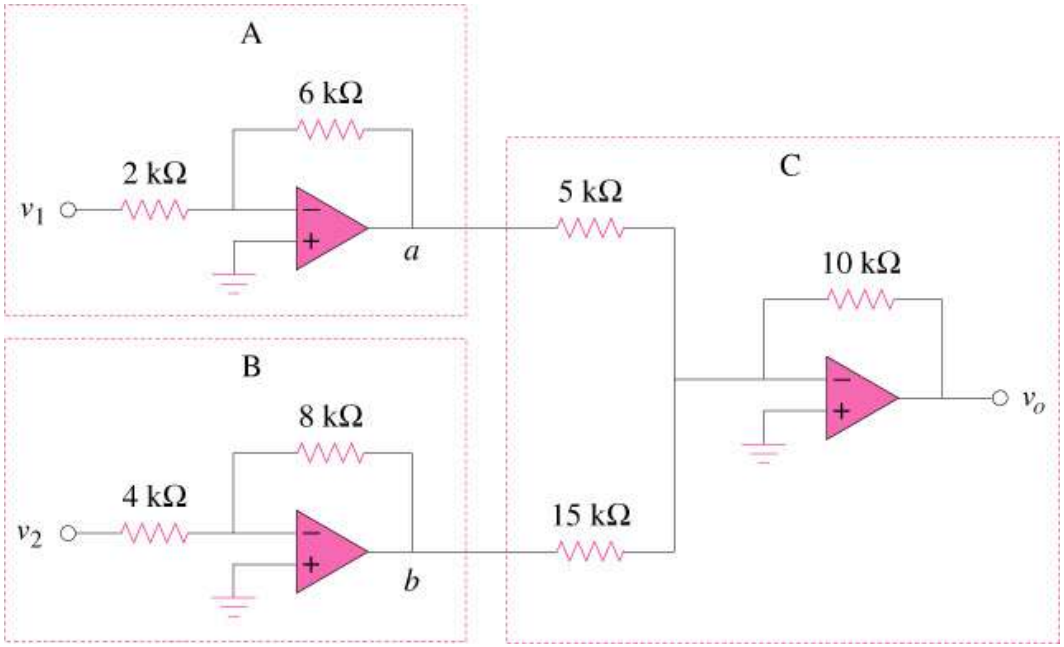
*Refer to in-class illustration, textbook

Ans: 350mV, 25μA

5.4 Cascaded Op Amp (3)

Example 7

If v_1 = 1V and v_2 = 2V, find v_o in the op amp circuit shown below.



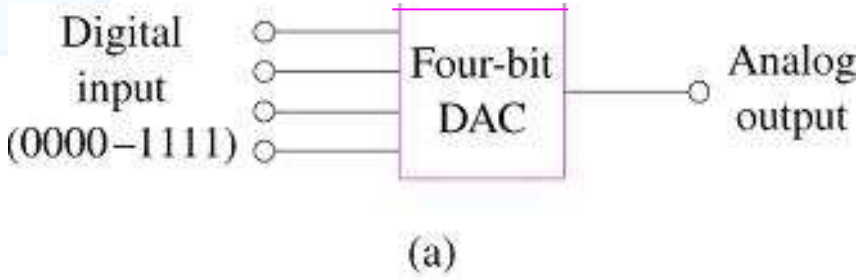
*Refer to in-class illustration, textbook

Ans: 8.667 V

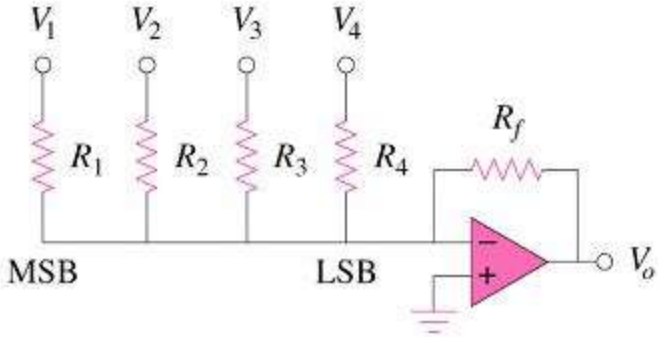
5.5 Application (1)

- Digital-to Analog Converter (DAC) : it is a device which transforms digital signals into analog form.

Four-bit DCA: (a) block diagram (b) binary weighted ladder type



(a)



(b)

$$-V_0 = \frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3 + \frac{R_f}{R_4}V_4$$

where

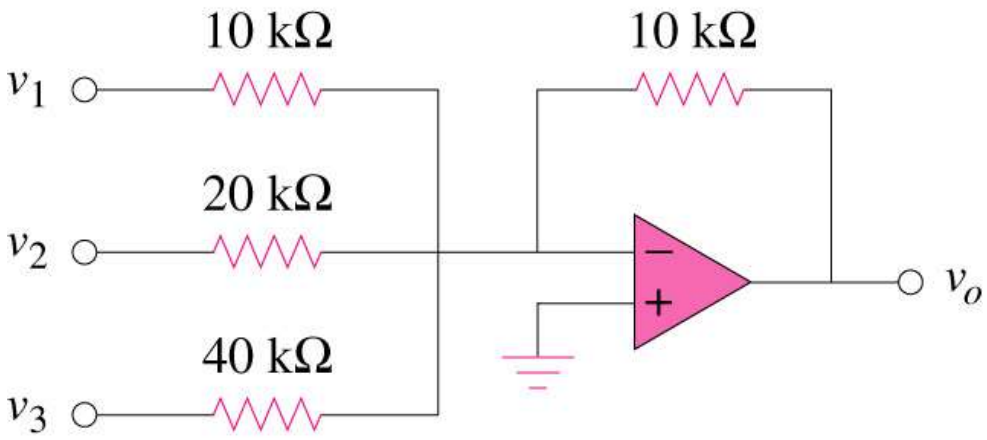
V_1 – MSB, V_4 – LSB

V_1 to V_4 are either 0 or 1 V

5.5 Application(2)

Example 8

For the circuit shown below, calculate v_o if v_1= 0V,v_2=1V and v_3 = 1V.



*Refer to in-class illustration, textbook

Ans:-0.75V