

$$F = G \frac{m_1 m_2}{d^2}$$

Electrical Engineering 1

12026105

Chapter 5

Operational Amplifier

$$E + V = 2$$

$$E = mc^2$$

$$\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2}$$

$$\frac{df}{dt} = \lim_{h \rightarrow 0} \frac{f(t+h) - f(t)}{h}$$

Learning Objectives

By using the information and exercises in this chapter you will be able to:

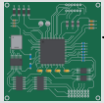
1. Comprehend how real operational amplifiers (op amps) function.
2. Understand that ideal op amps function nearly identically to real ones and that they can be used to model them effectively in a variety of circuit applications.
3. Realize how the basic inverting op amp is the workhorse of the op amp family.
4. Use the inverting op amp to create summers.
5. Use the op amp to create a difference amplifier.
6. Explain how to cascade a variety of op amp circuits.

วัตถุประสงค์การเรียนรู้

โดยใช้ข้อมูลและแบบฝึกหัดในบทนี้ นักเรียนจะสามารถ:

1. เข้าใจว่า OP AMP ทำงานอย่างไร
2. เข้าใจการทำงานของ OP AMP ในอุดมคตินั้นจะเหมือนกับ OP AMP ที่ใช้จริงและสามารถใช้ในการสร้างแบบจำลองได้อย่างมีประสิทธิภาพ
3. รู้ว่า OP AMP แบบอินเวอร์ชันพื้นฐานเป็นวิธีการทำงานของไฟล์ OP AMP Family
4. ใช้ OP AMP แบบกลับด้านเพื่อวงจรวก
5. ใช้ OP AMP เพื่อสร้างวงจรมพลิฟายเออร์
6. อธิบายวิธีการ OP AMP แบบหลั่น (Cascade)

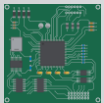
Operational Amplifier - Chapter 5



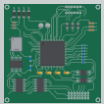
What is an Op Amp?



Ideal Op Amp



Configuration of Op Amp



Cascaded Op Amp

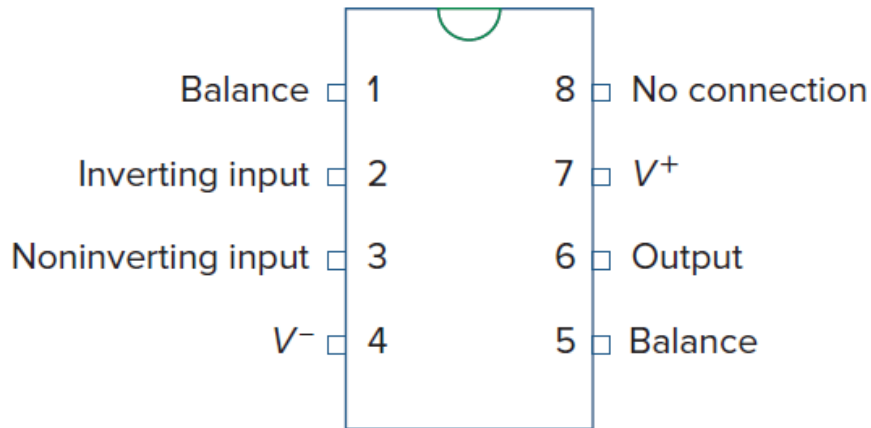


Application : Digital-to Analog
Converter

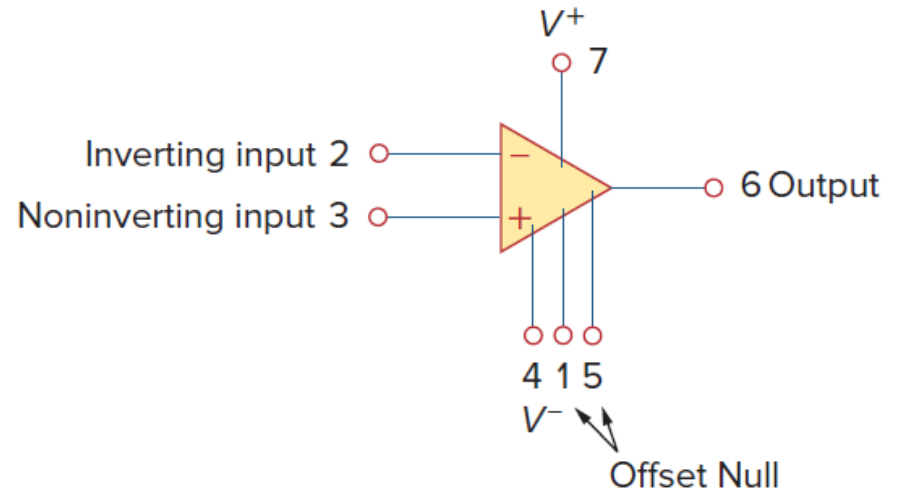
5.1 What is an Op Amp (1)

- It is an electronic unit that behaves like a voltage-controlled voltage source (VCVS).
- It is an active circuit element designed to perform mathematical operations of *addition*(+), *subtraction*(-), *multiplication*(×), *division*(/), *differentiation*($\frac{d}{dt}$), and *integration*($\int dt$).

5.1 What is an Op Amp (2)

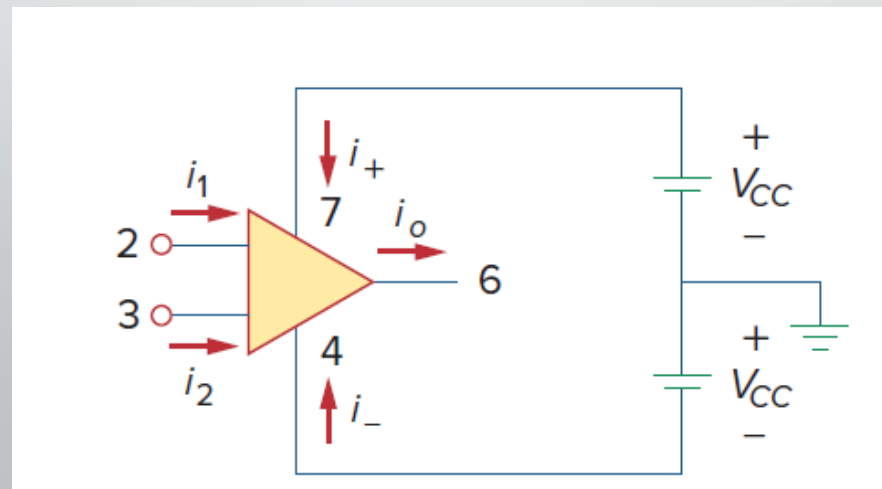


(a)



(b)

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



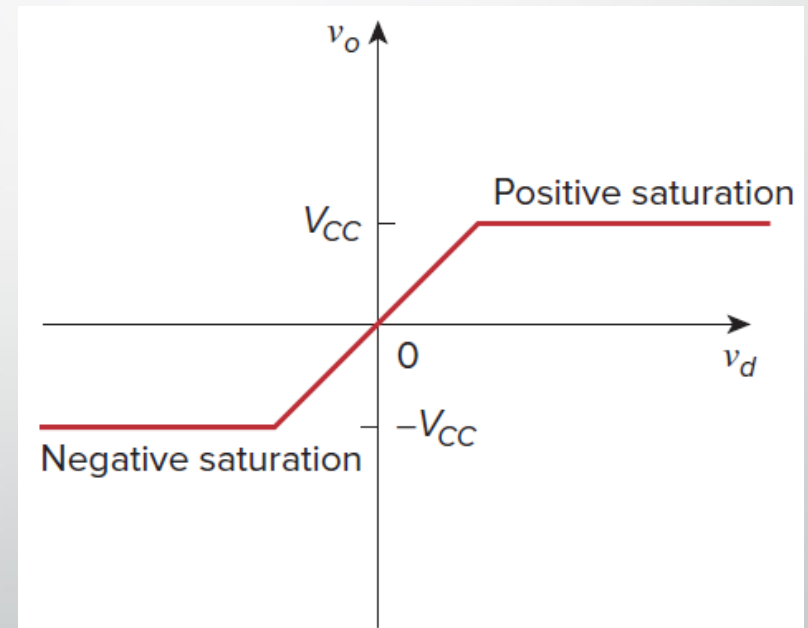
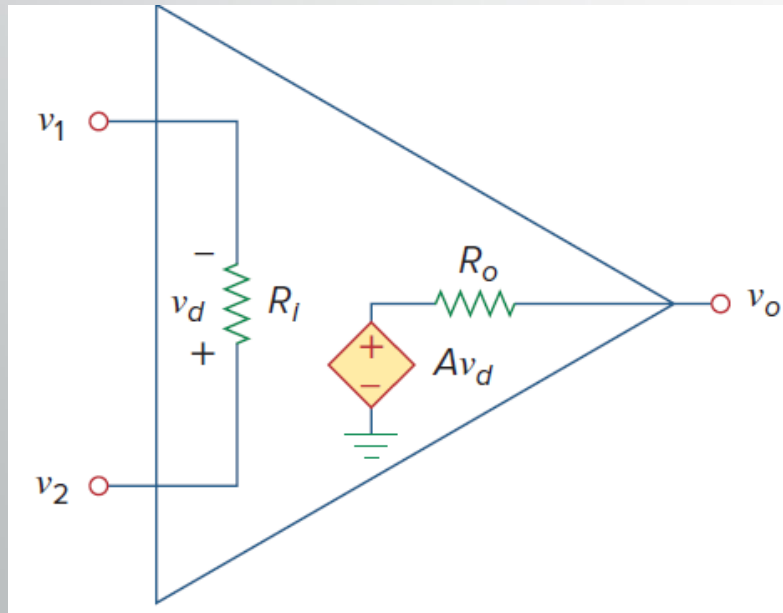
5.1 What is an Op Amp (3)

The equivalent circuit
Of the non-ideal op amp

Op Amp output:

v_o as a function of v_d or

$$v_o = Av_d$$



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

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 $10^8 \Omega$	$\infty \Omega$
Input resistance, R_i	10^5 to $10^{13} \Omega$	$\infty \Omega$
Output resistance, R_o	10 to 100 Ω	0 Ω
Supply voltage, VCC	5 to 24 V	

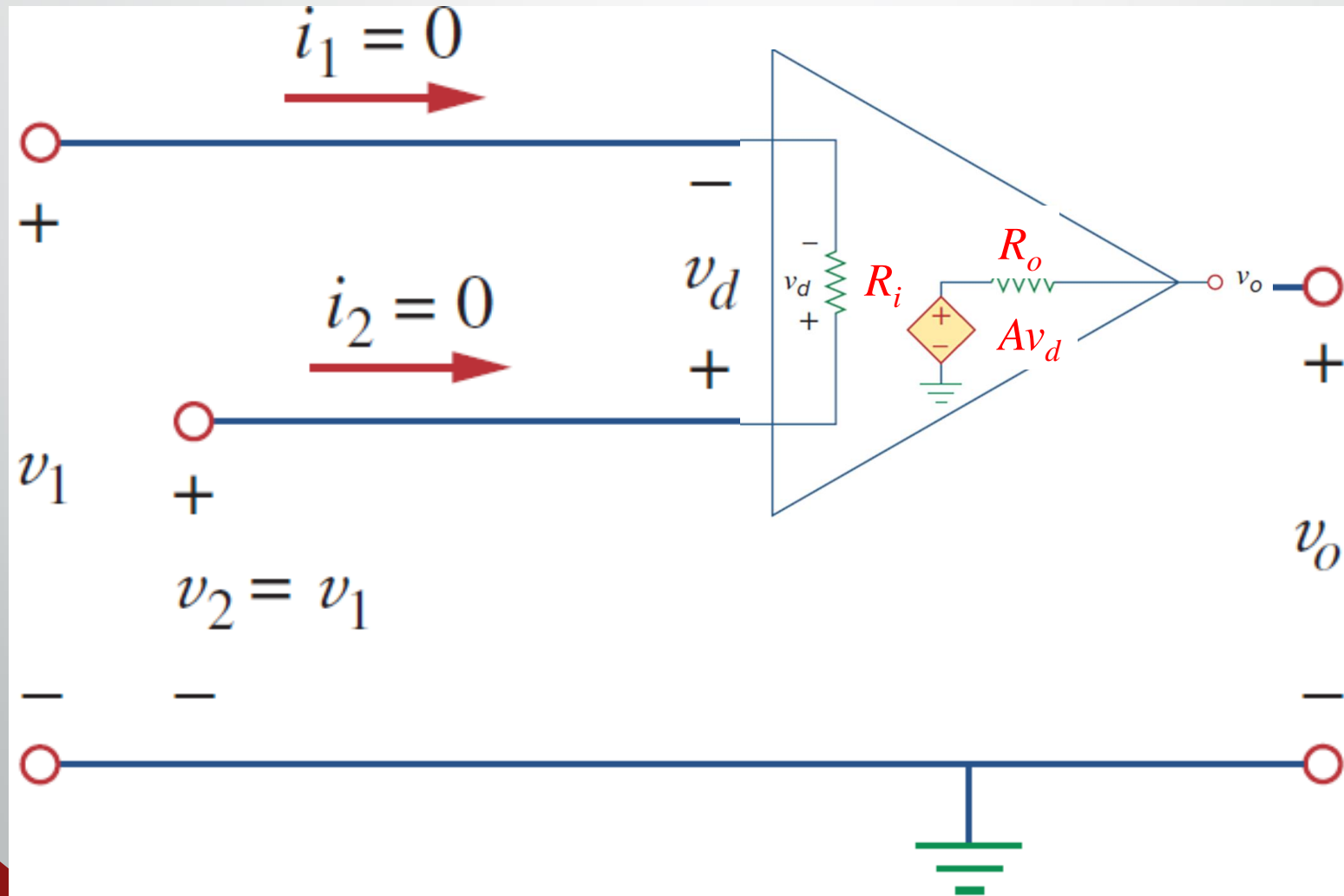
5.2 Ideal Op Amp (1)

An ideal op amp has the following characteristics:

$$A \approx \infty$$

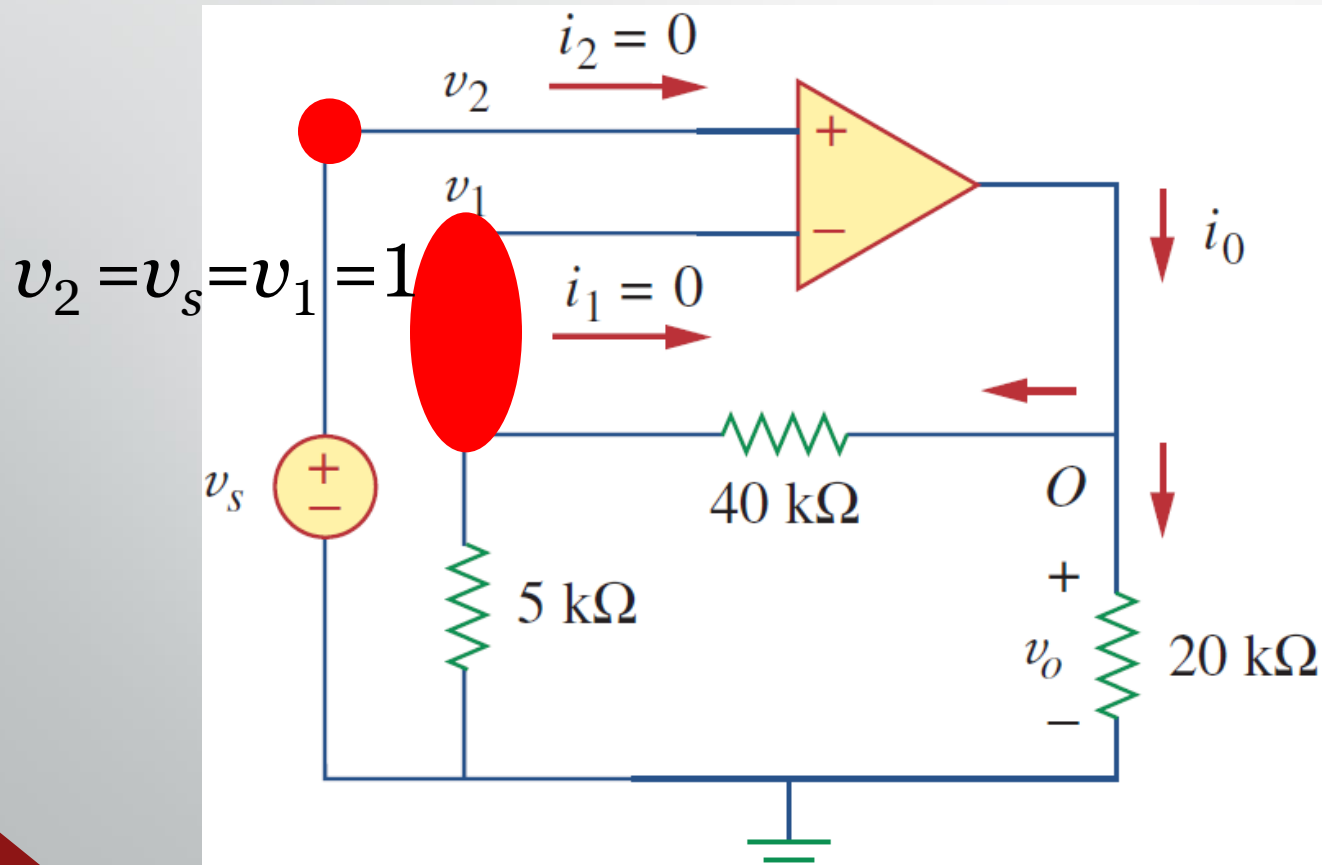
$$R_i \approx \infty$$

$$R_o \approx 0$$



5.2 Ideal Op Amp (2)

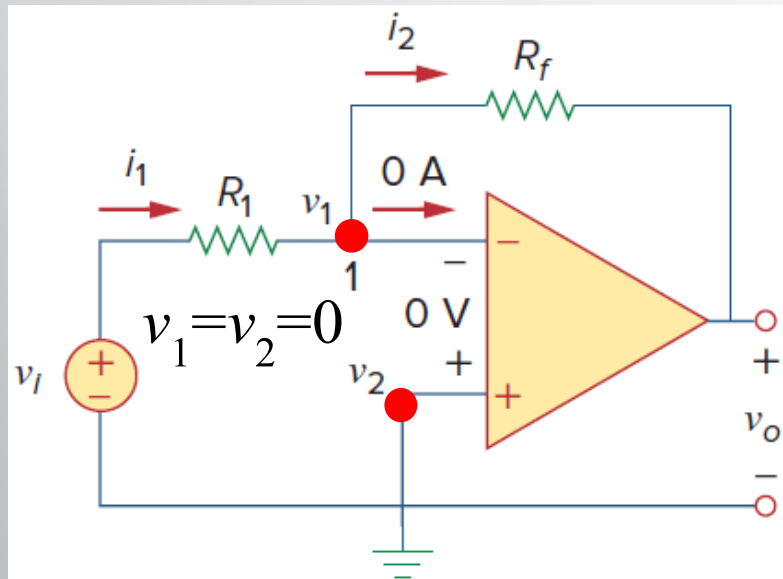
Ex.1: Determine the value of i_o if $v_s = 1$ V (Hint: Use KCL)



Ans: $650 \mu\text{A}$

5.3 Configuration of Op amp (1)

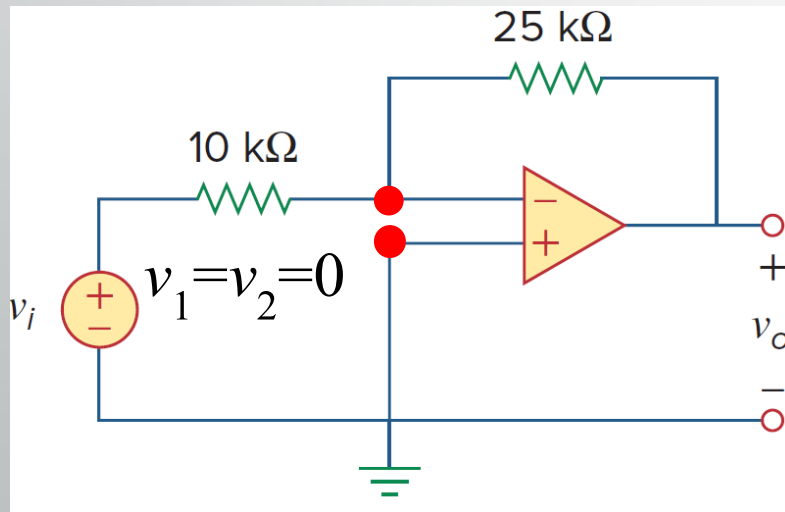
- Inverting amplifier reverses the polarity of the input signal while amplifying it



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

5.3 Configuration of Op amp (2)

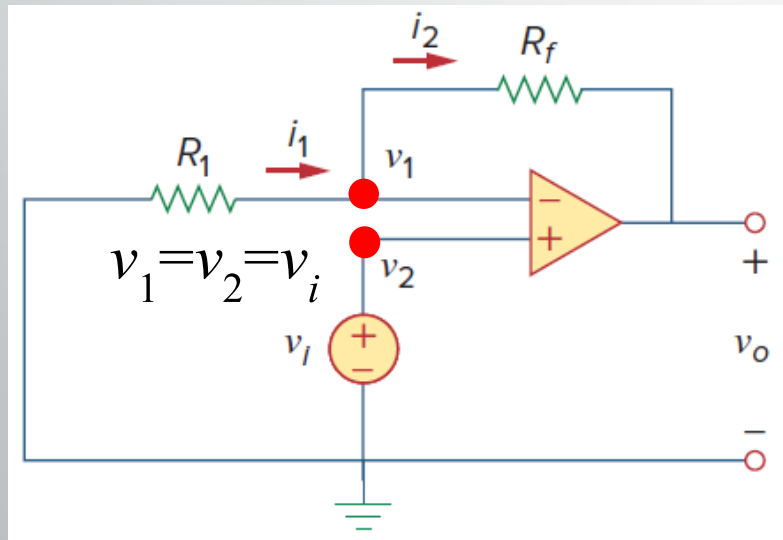
Ex.2 If $v_i = 0.5\text{V}$, calculate: (a) the output voltage, v_o and (b) the current in the $10\text{k}\Omega$ resistor.



Ans: (a) -1.25V ; (b) $50\mu\text{A}$

5.3 Configuration of Op amp (3)

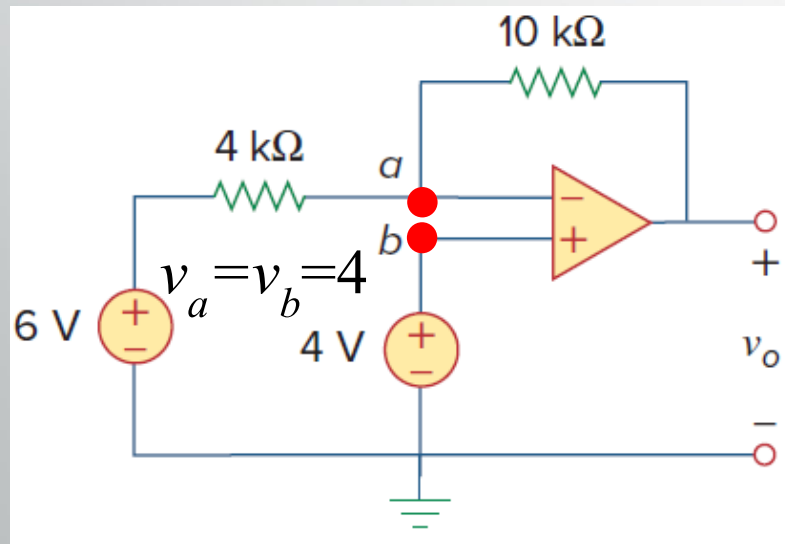
- Non-inverting amplifier is designed to produce positive voltage gain



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

5.3 Configuration of Op amp (4)

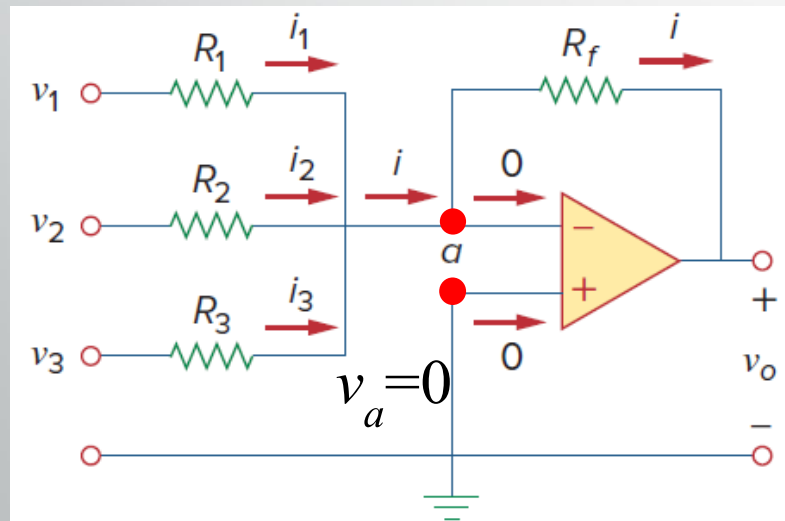
Ex.3 For the op amp shown below, calculate the output voltage v_o



Ans: -1V

5.3 Configuration of Op amp (5)

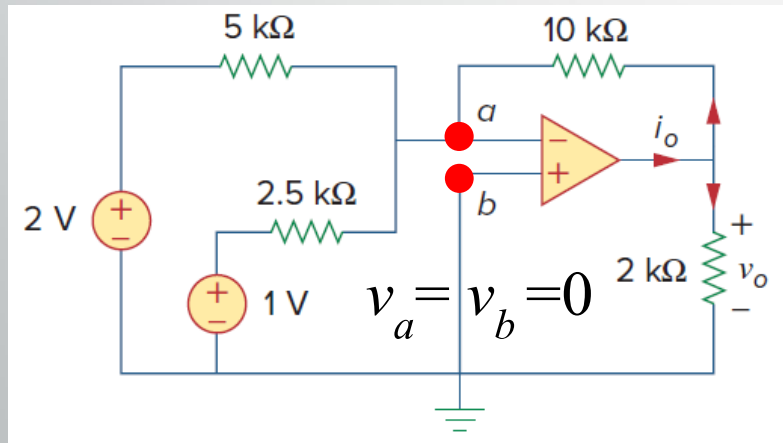
Summing Amplifier is an op amp circuit that combines several inputs and produces an output that is the weighted sum of the inputs.



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

5.3 Configuration of Op amp (6)

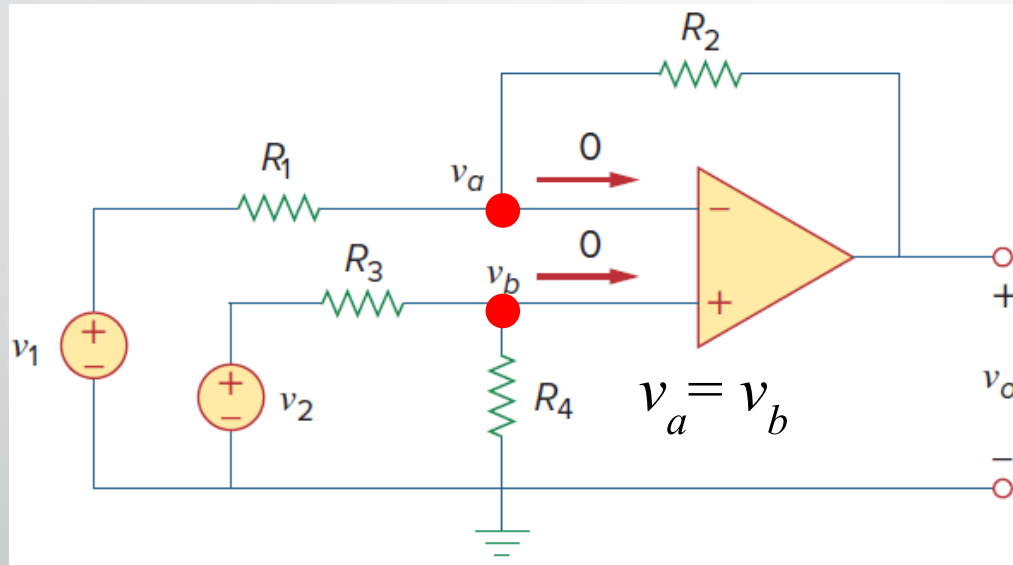
Ex.4 Calculate v_o and i_o in the op amp circuit shown below.



Ans: -8V, -4.8mA

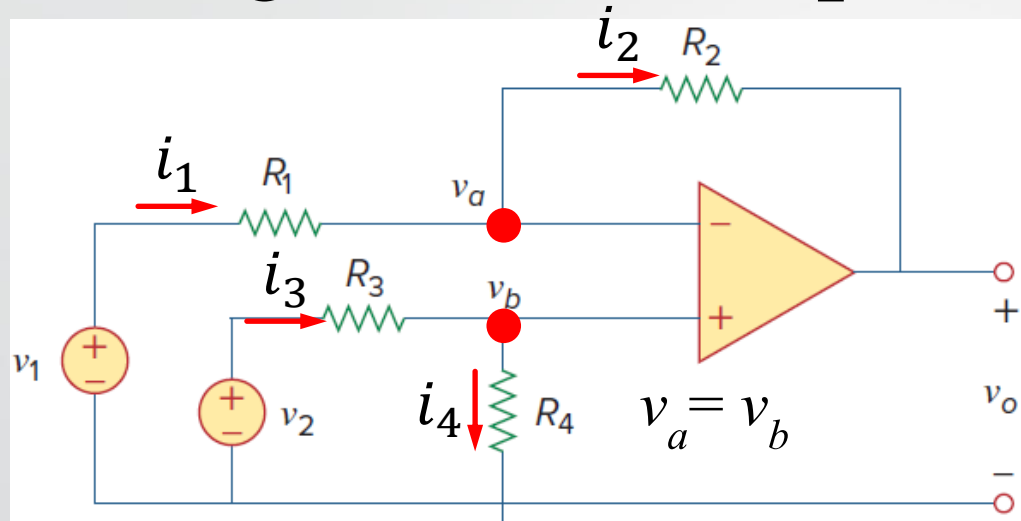
5.3 Configuration of Op amp (7)

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 (7-2)



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

ที่โหนด v_b : $i_3 = i_4$

$$\frac{v_2 - v_a}{R_3} = \frac{v_a}{R_4}$$

$$v_a = \frac{1}{R_3 \left(\frac{1}{R_4} + \frac{1}{R_3} \right)} v_2$$

$$v_a = \frac{1}{(1+R_3/R_4)} v_2$$

ที่โหนด v_a : $i_1 = i_2$

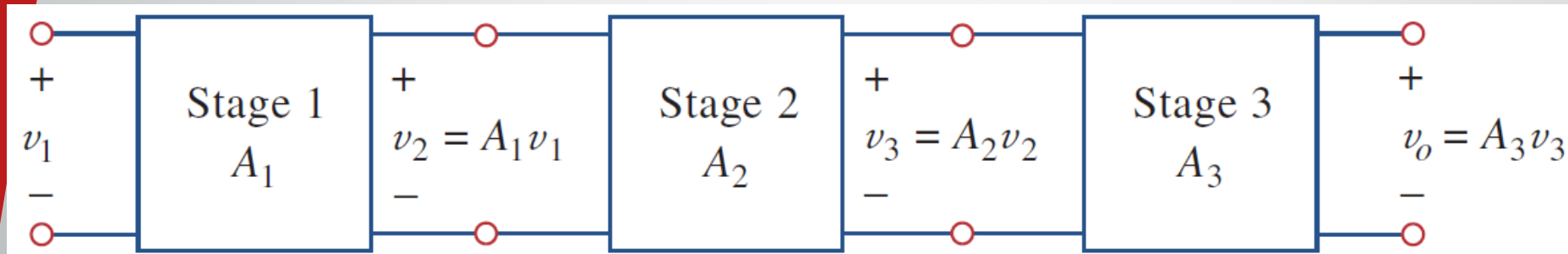
$$\frac{v_1 - v_a}{R_1} = \frac{v_a - v_o}{R_2}$$

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

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

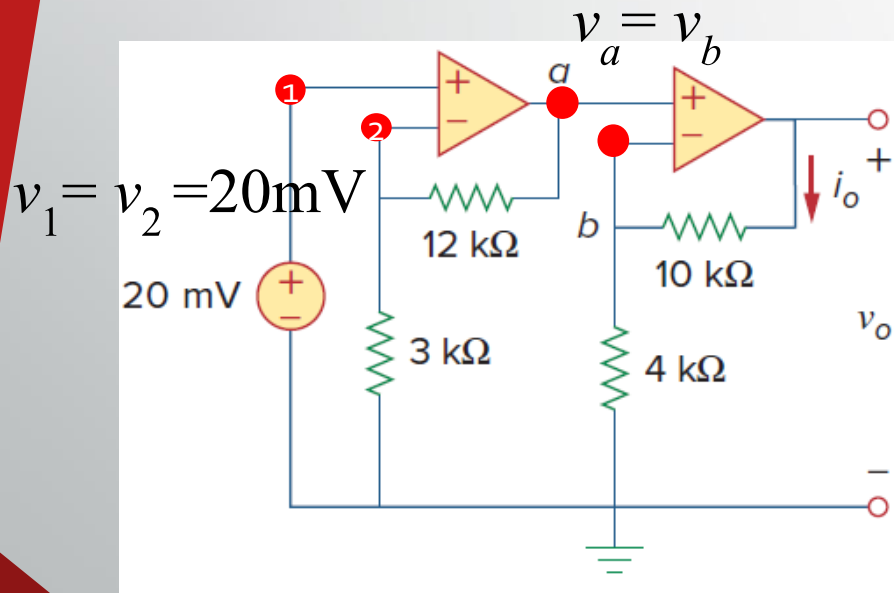
5.4 Cascaded Op Amp (1)

- 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)

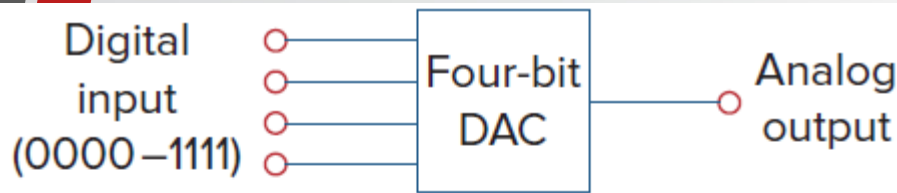
Ex.5 Find v_o and i_o in the circuit shown below.



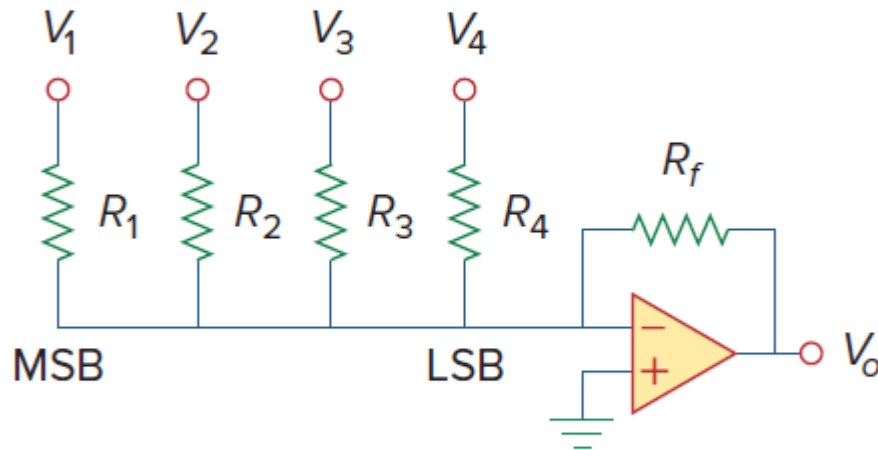
Ans: 350mV, 25μA

5.5 Application (1)

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



(a)



(b)

Figure 5.36

Four-bit DAC: (a) block diagram, (b) binary weighted ladder type.

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

where

V_1 most significant bit (MSB),

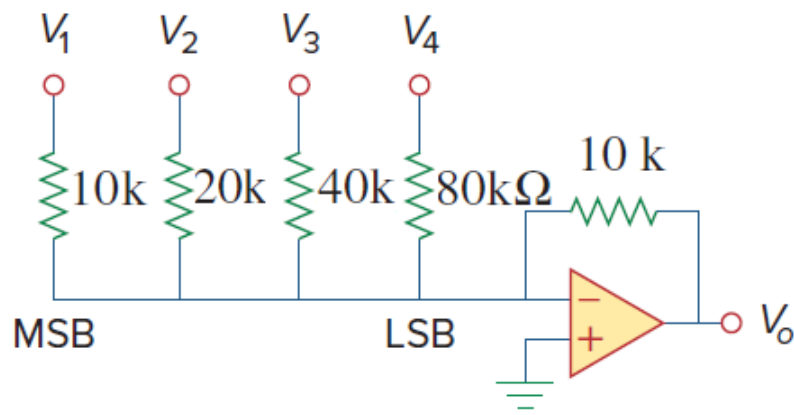
V_4 least significant bit (LSB).

V_1 to V_4 are either 0 or 1 V

- By using the proper input and feedback resistor values, the DAC provides a single output that is proportional to the inputs.

5.5 Application(2)

Ex.6 Circuit shown below, Obtain the analog output for binary inputs [0000], [0001], [0010],..., [1111].



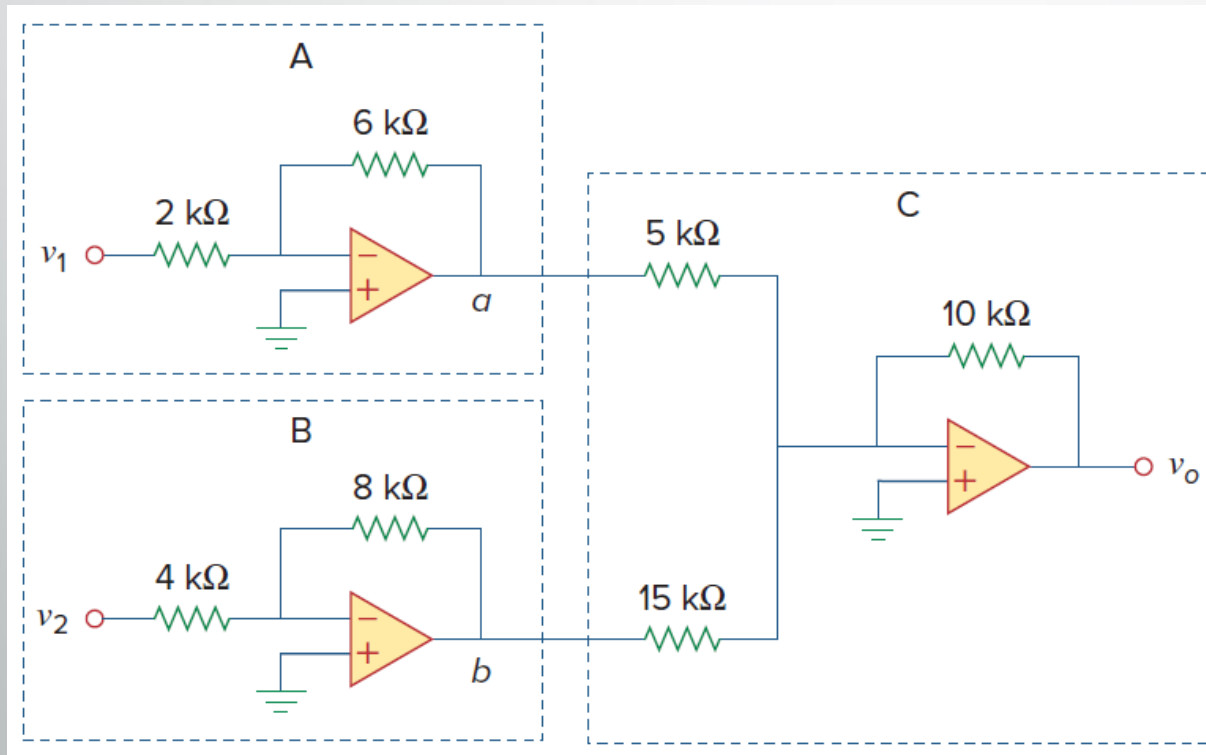
$$-V_o = \frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \frac{R_f}{R_3} V_3 + \frac{R_f}{R_4} V_4$$

$$-V_o = V_1 + 0.5V_2 + 0.25V_3 + 0.125V_4$$

- a digital input $[V_1 V_2 V_3 V_4] = [0000]$ produces an analog output of $-V_o = 0 \text{ V}$
- a digital input $[V_1 V_2 V_3 V_4] = [0001]$ produces an analog output of $-V_o = 0.125 \text{ V}$
- a digital input $[V_1 V_2 V_3 V_4] = [0010]$ produces an analog output of $-V_o = 0.25 \text{ V}$
- a digital input $[V_1 V_2 V_3 V_4] = [0011]$ produces an analog output of $-V_o = 0.375 \text{ V}$
- a digital input $[V_1 V_2 V_3 V_4] = [0100]$ produces an analog output of $-V_o = 0.5 \text{ V}$
- a digital input $[V_1 V_2 V_3 V_4] = [0101]$ produces an analog output of $-V_o = 0.625 \text{ V}$
- a digital input $[V_1 V_2 V_3 V_4] = [0110]$ produces an analog output of $-V_o = 0.75 \text{ V}$
- a digital input $[V_1 V_2 V_3 V_4] = [0111]$ produces an analog output of $-V_o = 0.875 \text{ V}$
- a digital input $[V_1 V_2 V_3 V_4] = [1000]$ produces an analog output of $-V_o = 1 \text{ V}$
- a digital input $[V_1 V_2 V_3 V_4] = [1001]$ produces an analog output of $-V_o = 1.125 \text{ V}$
- a digital input $[V_1 V_2 V_3 V_4] = [1010]$ produces an analog output of $-V_o = 1.25 \text{ V}$
- a digital input $[V_1 V_2 V_3 V_4] = [1011]$ produces an analog output of $-V_o = 1.375 \text{ V}$
- a digital input $[V_1 V_2 V_3 V_4] = [1100]$ produces an analog output of $-V_o = 1.5 \text{ V}$
- a digital input $[V_1 V_2 V_3 V_4] = [1101]$ produces an analog output of $-V_o = 1.625 \text{ V}$
- a digital input $[V_1 V_2 V_3 V_4] = [1110]$ produces an analog output of $-V_o = 1.75 \text{ V}$
- a digital input $[V_1 V_2 V_3 V_4] = [1111]$ produces an analog output of $-V_o = 1.875 \text{ V}$

5.4 Cascaded Op Amp (3)

Ex.7 If $v_1 = 1\text{V}$ and $v_2 = 2\text{V}$, find v_o in the op amp circuit shown below.



Ans: 8.667 V

5.5 Application(3)

TABLE 5.2

Input and output values of the four-bit DAC.

Binary input [$V_1V_2V_3V_4$]	Decimal value	Output $-V_o$
0000	0	0
0001	1	0.125
0010	2	0.25
0011	3	0.375
0100	4	0.5
0101	5	0.625
0110	6	0.75
0111	7	0.875
1000	8	1.0
1001	9	1.125
1010	10	1.25
1011	11	1.375
1100	12	1.5
1101	13	1.625
1110	14	1.75
1111	15	1.875

5.5 Application(4)

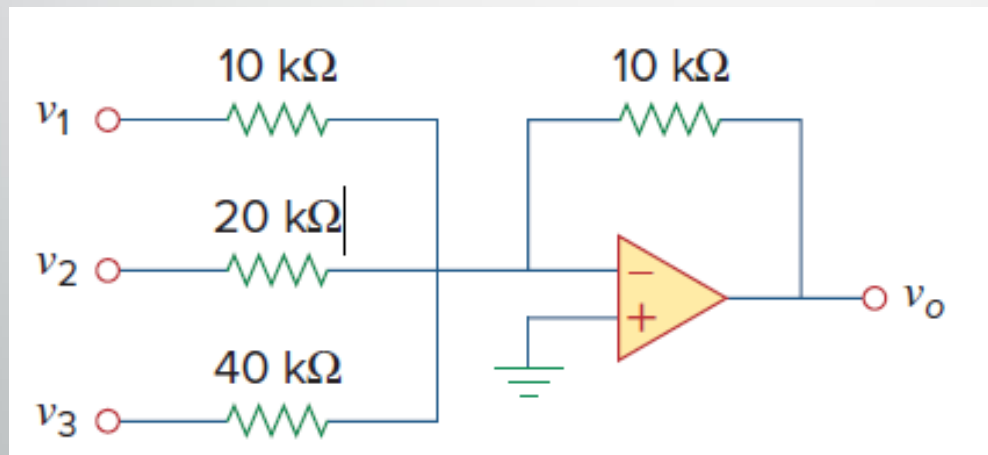
Ex.8 3-bit DAC is shown in Figure.

(a) Determine $|v_o|$ for $[v_1 v_2 v_3] = [010]$.

(b) Find $|V_o|$ if $[v_1 v_2 v_3] = [110]$.

(c) If $|v_o| = 1.25$ V is desired, what should be $[v_1 v_2 v_3]$?

(d) To get $|v_o| = 1.75$ V, what should be $[v_1 v_2 v_3]$?



Ans: 0.5 V, 1.5 V, [101], [111].