COLLEGE OF ENGINEERING AND TECHNOLOGIES

ALMUSTAQBAL UNIVERSITY

Electronics Circuits

CTE 204

Lecture 6

- Op amp Equivalent Circuit -

(2024 - 2025)

Dr. Zaidoon AL-Shammari

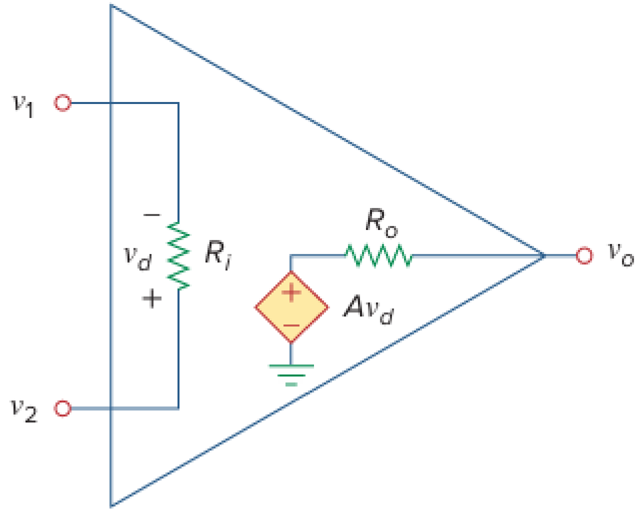
Lecturer / Researcher

zaidoon.waleed@mustaqbal-college.edu.iq

Equivalent Circuit

- The equivalent circuit model of an op amp is shown in Figure below.

- The output section consists of a voltage-controlled source in series with the output resistance Ro.



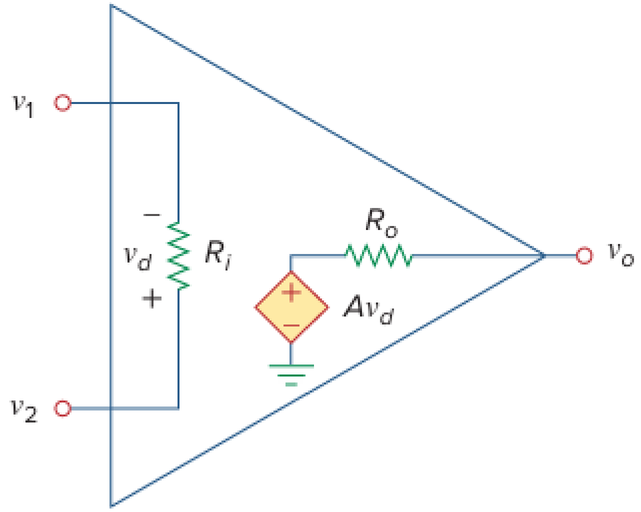
Equivalent Circuit

- It is evident from Figure below that the input resistance Ri is the Thevenin equivalent resistance seen at the input terminals.

- While the output resistance Ro is the Thevenin equivalent resistance seen at the output.

- The differential input voltage Vd is given by

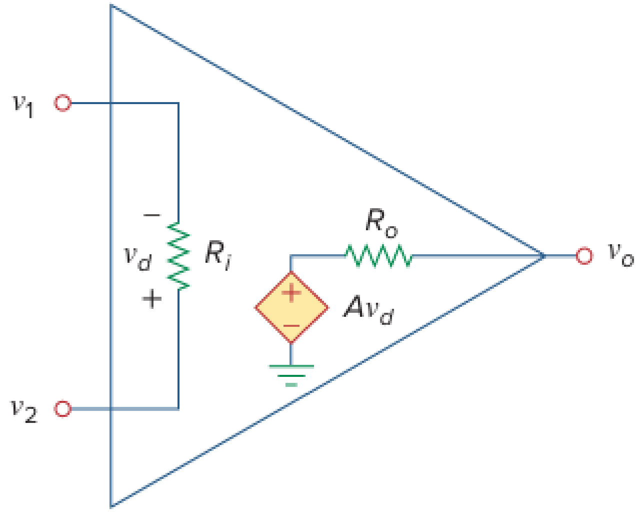
$$v_d = v_2 - v_1$$



Equivalent Circuit

- Where v1 is the voltage between the inverting terminal and ground and v2 is the voltage between the noninverting terminal and ground.

- The op amp senses the difference between the two inputs, multiplies it by the gain A, and causes the resulting voltage to appear at the output.



- Thus, the output Vo is given by

$$v_o = Av_d = A(v_2 - v_1)$$

Equivalent Circuit

- A is called the open-loop voltage gain because it is the gain of the op amp without any external feedback from output to input.

- Table below shows typical values of voltage gain A, input resistance Ri, output resistance Ro, and supply voltage VCC.

Typical ranges for op amp parameters.

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

Equivalent Circuit

- The concept of feedback is crucial to our understanding of op amp circuits.

- A negative feedback is achieved when the output is fed back to the inverting terminal of the op amp.

- When there is a feedback path from output to input, the ratio of the output voltage to the input voltage is called the closed-loop gain.

Equivalent Circuit

- As a result of the negative feedback, it can be shown that the closed-loop gain is almost insensitive to the open-loop gain A of the op amp.

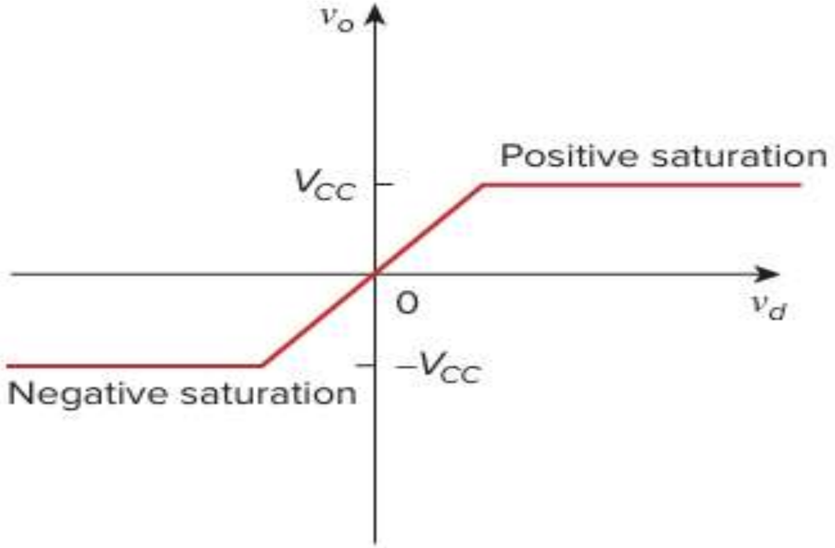
- For this reason, op amps are used in circuits with feedback paths.

- A practical limitation of the op amp is that the magnitude of its output voltage cannot exceed |VCC|.

Equivalent Circuit

- In other words, the output voltage is dependent on and is limited by the power supply voltage.

- Figure below illustrates that the op amp can operate in three modes, depending on the differential input voltage Vd:



Equivalent Circuit

Al-Mustaqbal University

1. Positive saturation, $v_o = V_{CC}$.
2. Linear region, $-V_{CC} \leq v_o = Av_d \leq V_{CC}$.
3. Negative saturation, $v_o = -V_{CC}$.

- If we attempt to increase Vd beyond the linear range, the op amp becomes saturated and yields Vo = VCC or Vo = −VCC.

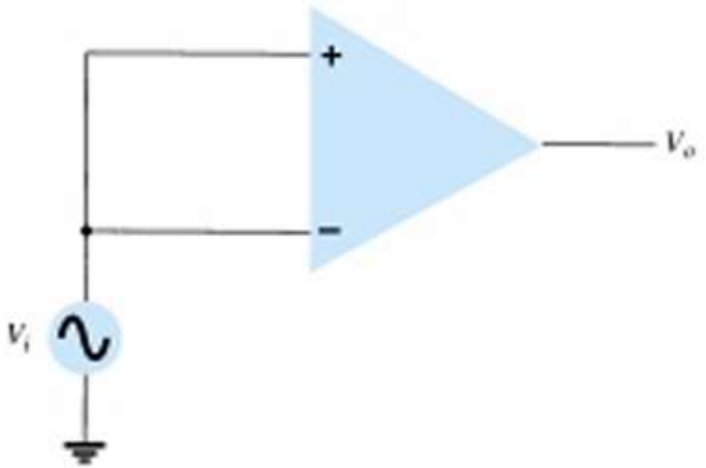
- Throughout this level of study, we will assume that our op amps operate in the linear mode.

- This means that the output voltage is restricted by $-V_{CC} \leq v_o \leq V_{CC}$

Common-Mode Operation

- When the same input signals are applied to both inputs, common-mode operation results, as shown in Figure below.

- Ideally, the two inputs are equally amplified, and since they result in opposite polarity signals at the output, these signals cancel, resulting in (0) V output. Practically, a small output signal will result.



Double-Ended Output

- The difference output is referred to as a floating signal since neither output terminal is the ground (reference) terminal.

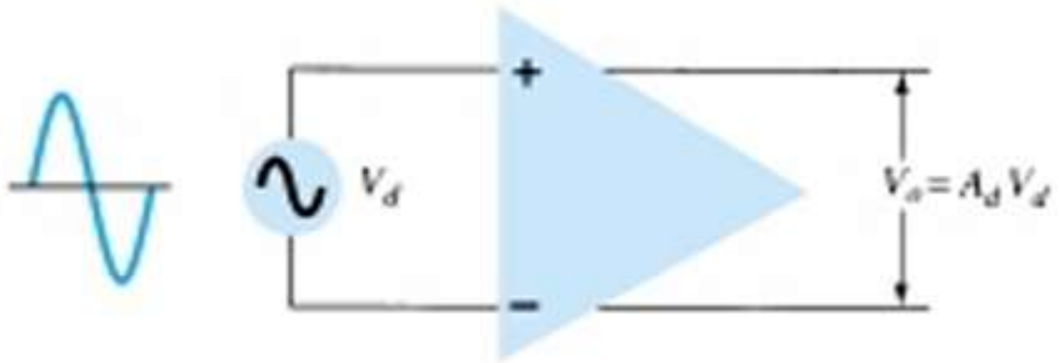
- Notice that the difference output is twice as large as either Vo1 or Vo2 since they are of opposite polarity and subtracting them results in twice their amplitude [i.e., 10 V - (- 10 V) = 20 V].

Double-Ended Output

- Figure below shows a differential input, differential output operation.

- The input is applied between the two input terminals and the output taken from between the two output terminals.

- This is fully differential operation.



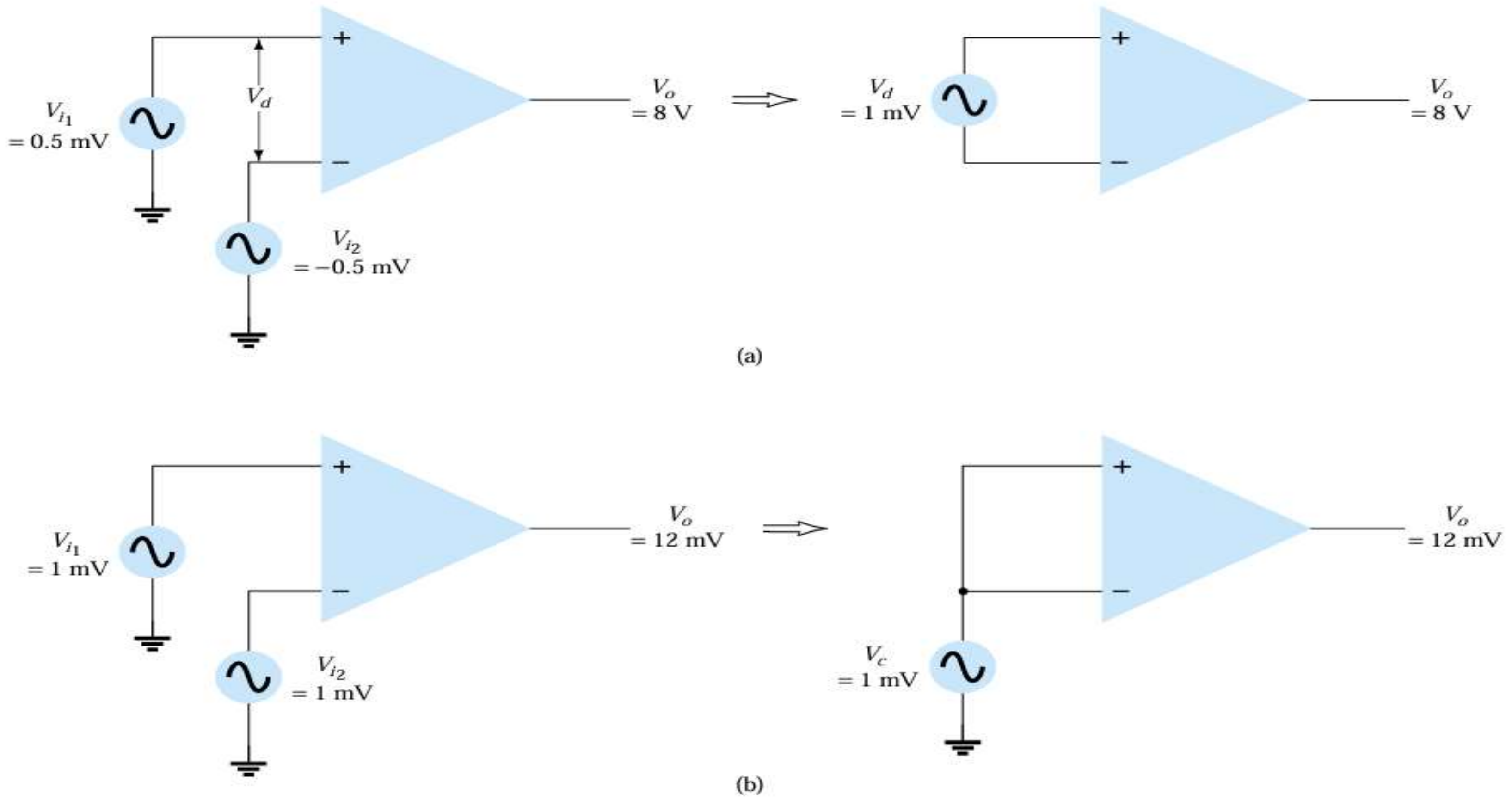
Common-Mode Rejection Ratio

- Having obtained Ad and Ac.
- We can now calculate a value for the common-mode rejection ratio (CMRR).
- Which is defined by the following equation:

$$\text{CMRR} = \frac{A_d}{A_c}$$

Example

Calculate the CMRR for the circuit measurements shown in Figure below



Sol

From the measurement shown in Figure a, using the procedure in step 1 above, we obtain

$$A_d = \frac{V_o}{V_d} = \frac{8\text{ V}}{1\text{ mV}} = 8000$$

From the measurement shown in Figure b, using the procedure in step 2 above, we obtain

$$A_c = \frac{V_o}{V_c} = \frac{12\text{ mV}}{1\text{ mV}} = 12$$

The value of CMRR is

$$\text{CMRR} = \frac{A_d}{A_c} = \frac{8000}{12} = \mathbf{666.7}$$