ET 438b Sequential Control and Data Acquisition
Department of Technology

LESSON 3: OP AMP FUNDAMENTALS AND OPEN LOOP APPLICATIONS

LEARNING OBJECTIVES

After completing this lesson you will be

- List the characteristics of an ideal OP AMP
- Determine the frequency limit of an OP AMP due to slew rate limits
- Explain the effects of gain-bandwidth limits
- Explain the operation of voltage comparators using ideal and non-ideal OP AMPS

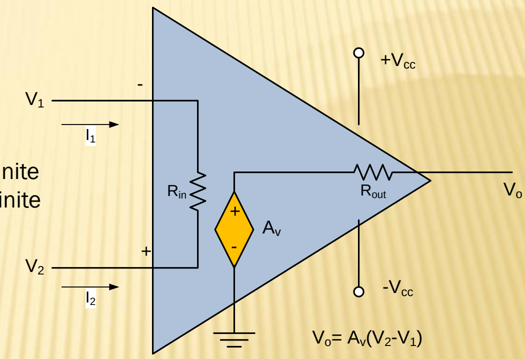
IDEAL OP AMPS

Ideal OP AMP Model

Parameters

<u>Idea</u>

Voltage Gain:	A_v = infinite
Input Resistance:	R_{in}= infinite
Output Resistance:	R_o = 0
Input I:	I_1=I_2=0
Cutoff Frequency, f_c:	infinite



<u>Typical (LM741)</u>

A_v = 200,000
R_i = 1-2 MΩ
R_0 = 75 Ω
I_1 = I_2 = 80 nA
f_c=1.5 MHz

NON-IDEAL OP AMP MODEL

Non-idea OP AMP parameters and characteristics

<u>Output offset voltage</u> - voltage on the output when both of the inputs are grounded. Typical value - 2 mV (LM741)

<u>Slew rate</u> - maximum rate of change of output voltage for large changes in the input voltage. Typical value - 0.5 V/µS = 500,000 V/s

<u>Gain-Bandwidth Product</u>-rate of frequency roll-off for OP AMP without feedback. Frequency at which the open loop gain of the OP AMP is 1 (0 dB). Typical 1 MHz (LM741) Applies to small signal level changes.

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NON-IDEA OP AMP PARAMETERS

Determine the frequency limit due to slew rate limiting.

Assume sine input and determine the rate of voltage change, dV/dt

$$v(t) = V_p \sin(2\pi ft)$$

$$\frac{dv}{dt} = (V_p 2\pi f)\cos(2\pi ft)$$

$$\frac{dv}{dt} = V_p 2\pi f_{max}$$

$$\frac{\frac{dv}{dt}}{2\pi V_p} = f_{max}$$

Maximum rate of change in sine occurs at t=0, so set t=0 in derivative to find f_{max}

Example dv/dt = 500,000 V/s , V_p = 10 V

Found in OP AMP Data Sheets

$$\frac{\frac{dv}{dt}}{2\pi V_p} = f_{max} \qquad \frac{500{,}000}{2\pi(10)} = 7958 \text{ Hz}$$

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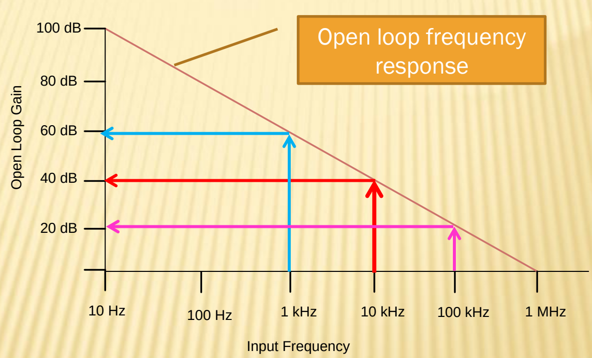
NON-IDEA OP AMP PARAMETERS

Gain-Bandwidth Product=GBP



GBP = (Gain)(Input Frequency) = 1 MHz

Find max frequency for 20 dB gain: $1\text{ MHz}/10^{(20/20)}$ = 1,000,000/10 = 100 kHz
Find max frequency for 40 dB gain: $1\text{ MHz}/10^{(40/20)}$ = 1,000,000/100 = 10 kHz
Find max frequency for 60 dB gain: $1\text{ MHz}/10^{(60/20)}$ = 1,000,000/1000 = 1 kHz

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PRACTICAL OP AMP OUTPUT LIMITS

OP AMP outputs typically saturate at 80% of supply voltages $\pm V_{cc}$

Output Voltage $V_o = A_v(V_2 - V_1)$

Output Range $0.8(-V_{cc}) \le V_o \le 0.8(+V_{cc})$

For a practical OP AMP with A_v = 100,000 find the difference voltage that will cause output saturation. ($\pm V_{cc}$ = 15 Vdc)

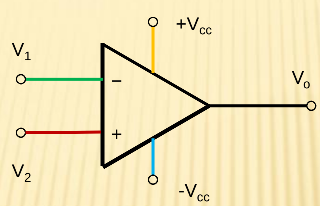
$$V_d = (V_2 - V_1) \quad \text{so } V_o/V_d = A_v$$

$$\frac{0.8(+V_{cc})}{A_V} = V_d = (V_2 - V_1)$$

$$\frac{0.8(15)}{100{,}000} = 0.12\text{ mV} = V_d$$

IDEAL VOLTAGE COMPARATORS

Open loop OP AMP operation



Ideal Voltage Comparator Operation

Transition take place exactly when voltages are equal

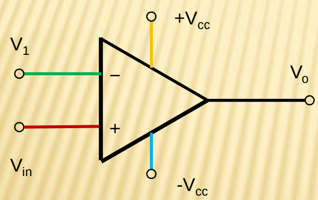
Operation Logic

When $V_1 \ge V_2$, $V_o = -V_{sat}$
When $V_2 \ge V_1$, $V_o = +V_{sat}$

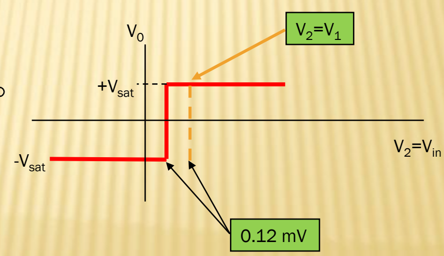
NON-IDEAL VOLTAGE COMPARATORS

Determine the voltage where output transition takes place with V_2 as input

$$V_2 - 0.12\text{ mV} = V_1$$
$$V_2 - 0.12\text{ mV} \geq V_1 \text{ then } V_0 = +V_{sat}$$



Input/Output Diagram



A_v < infinity produces small voltage error in comparator circuits

NON-IDEAL OP AMP COMPARATORS

Assume ±15 Vdc = $\pm V_{cc}$ A_v = 100,000. so

$V_{sat} = 0.8(\pm V_{cc}) = 0.8(\pm 15) = \pm 12$ Vdc

From previous calculation V_d = 0.12 mV

so $V_d = V_2 - V_1$ which gives $0.12\text{ mV} = V_2 - V_1$

Take V_1 as the input voltage

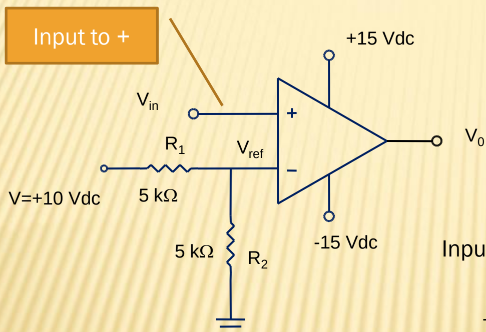
$$.12\text{ mV} = (V_2 - V_1)$$
$$0.12\text{ mV} + V_1 \geq V_2 \text{ then } V_0 = -V_{sat}$$

Take V_2 as the input voltage

$$0.12\text{ mV} = (V_2 - V_1)$$
$$0.12\text{ mV} - V_2 = -V_1$$

NON-INVERTING COMPARATORS

Circuit realization with OP AMPs



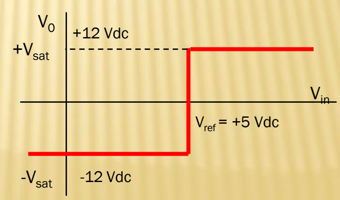
Find V_{ref} using voltage divider

$$V_{ref} = V\left(\frac{R_2}{R_1+R_2}\right)$$

$$V_{ref} = 10\left(\frac{5000}{5000+5000}\right) = 10(0.5) = 5.0\ \text{Vdc}$$

If $V_{in} > 5$ then V_O = +12 Vdc

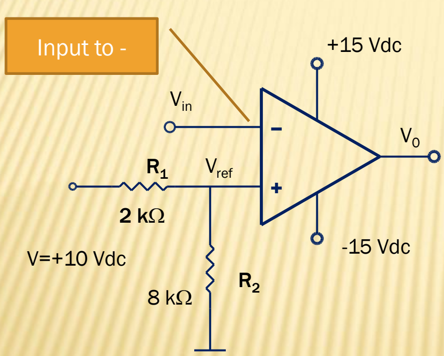
Input/output plot



Logic: When $V_{in} > V_{ref}$ $V_O = +V_{sat}$

INVERTING COMPARATORS

Use standard OP AMPs when slow transitions are expected in the input signal. (e.g. thermostat application). When higher speeds are needed use dedicated comparator IC. (LM311)



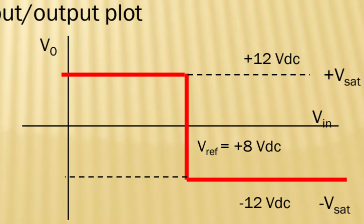
Find V_{ref} using voltage divider

$$V_{ref} = V\left(\frac{R_2}{R_1+R_2}\right)$$

$$V_{ref} = 10\left(\frac{8000}{8000+2000}\right) = 10(0.8) = 8.0\ \text{Vdc}$$

If $V_{in} > 8$ then V_O = -12 Vdc

Input/output plot



Logic: When $V_{in} > V_{ref}$ $V_O = -V_{sat}$

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END LESSON 3: OP AMP FUNDAMENTALS AND OPEN LOOP APPLICATIONS