Electronic Circuits

Operational Amplifier

Lecture 7

Dr. Roaa Mubarak

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

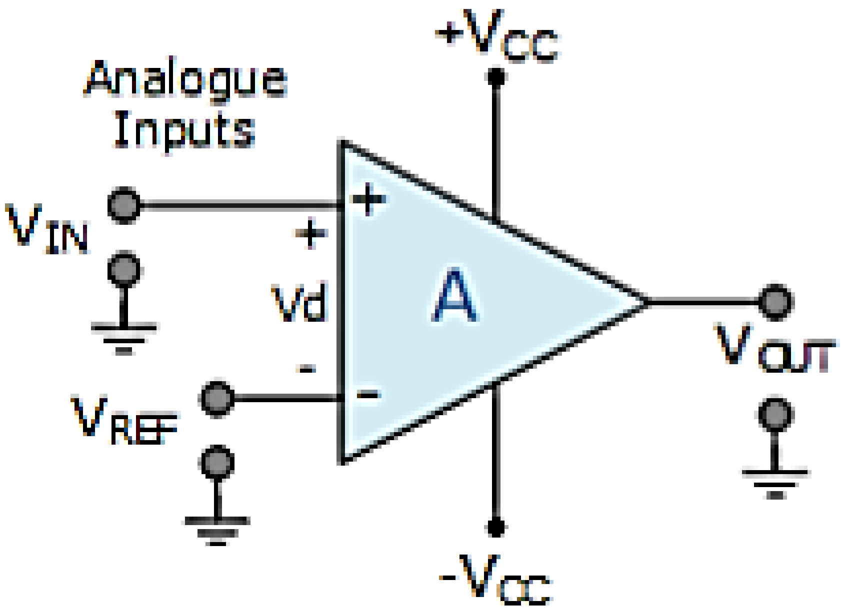
14- The Comparator

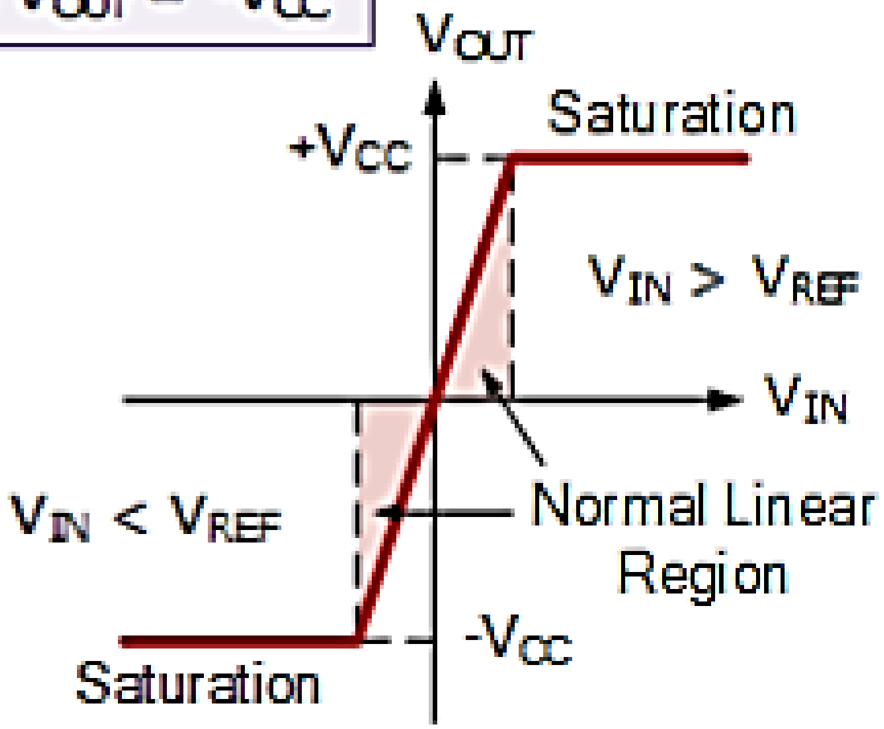
- The comparator is an electronic decision making circuit that makes use of an operational amplifiers very high gain in its open-loop state, that is, there is no feedback resistor.
- The Op-amp comparator compares one analogue voltage level with another analogue voltage level, or some preset reference voltage, Vref and produces an output signal based on this voltage comparison. In other words, the op-amp voltage comparator compares the magnitudes of two voltage inputs and determines which is the largest of the two.

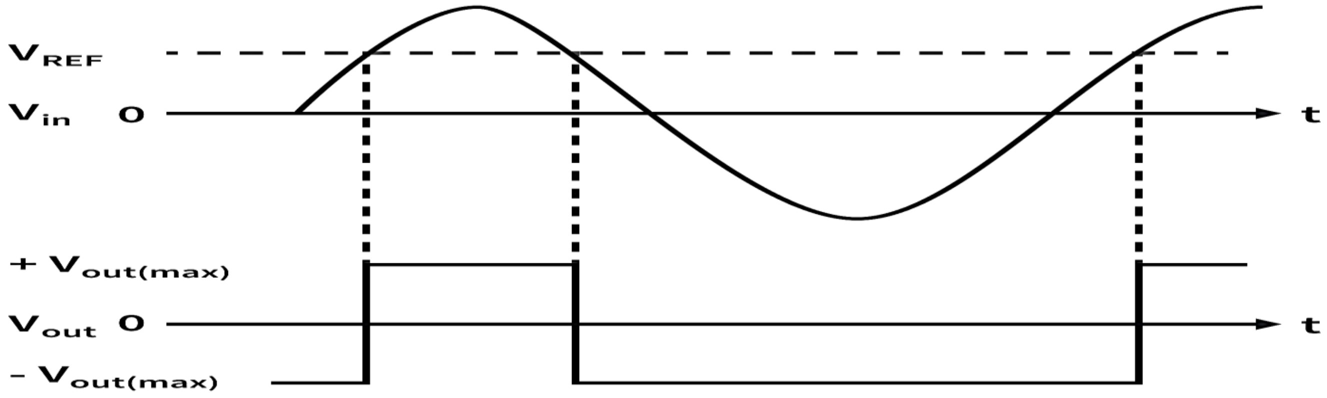
14- The Comparator

If $V_{IN} > V_{REF}$ then $V_{OUT} = +V_{CC}$

If $V_{IN} < V_{REF}$ then $V_{OUT} = -V_{CC}$

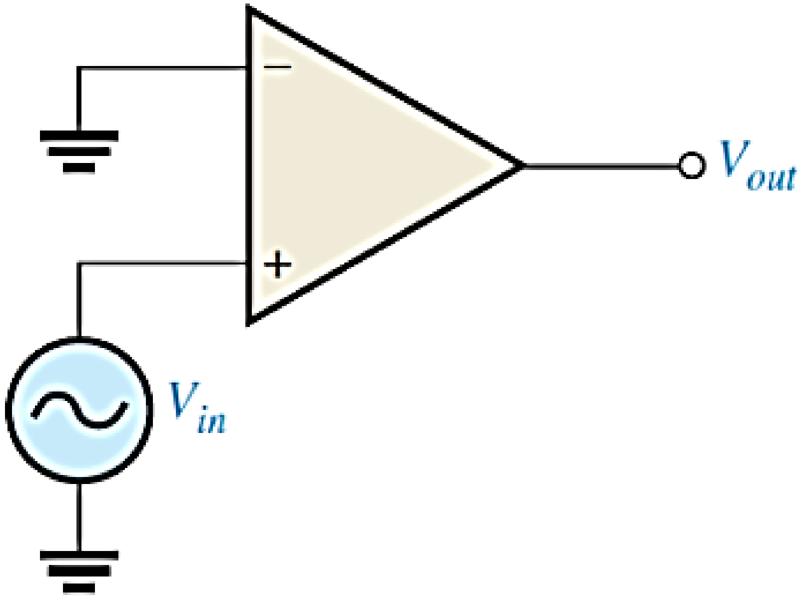




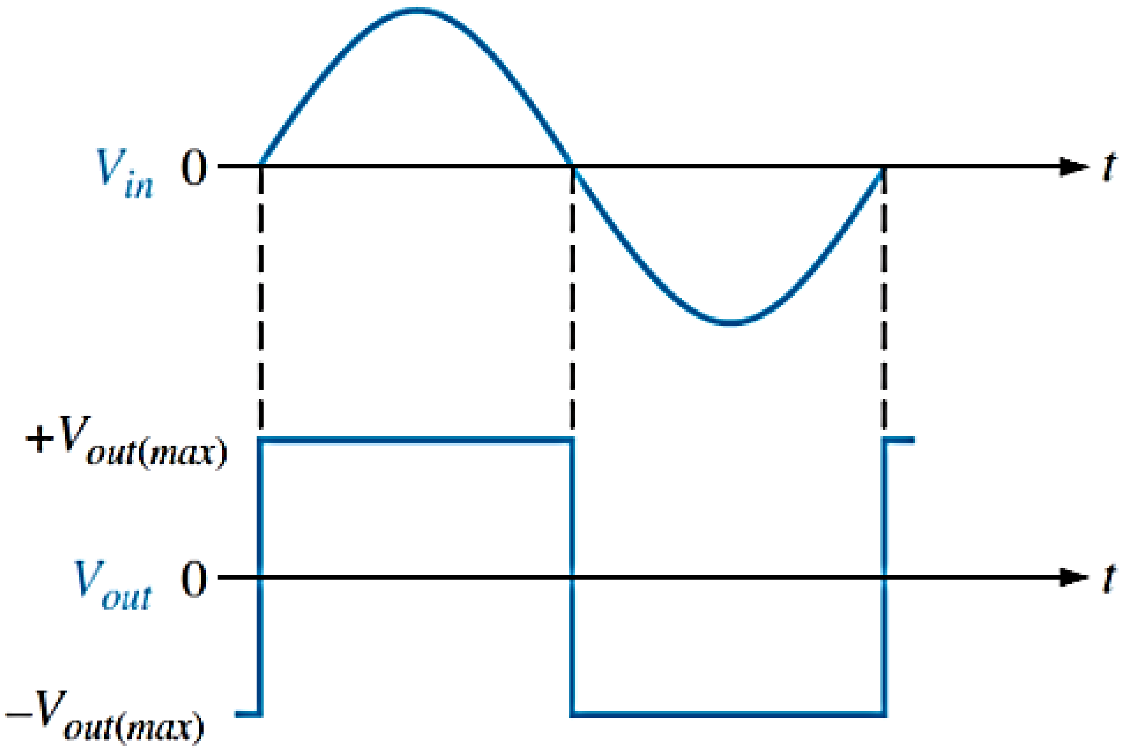


14- The Comparator

- **Zero-level Detection**



(a)

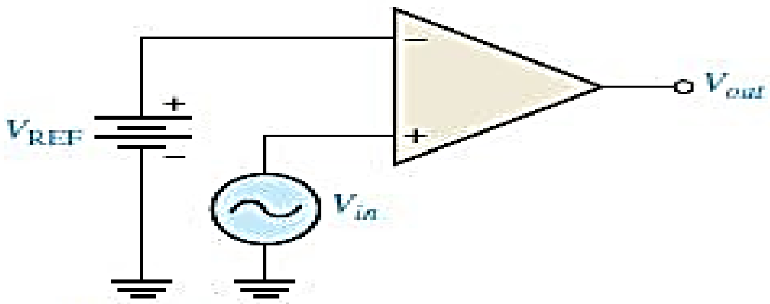


(b)

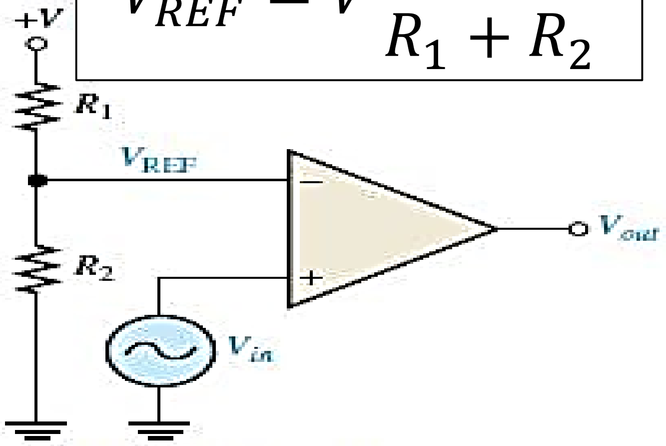
14- The Comparator

- **NonZero-level Detection**

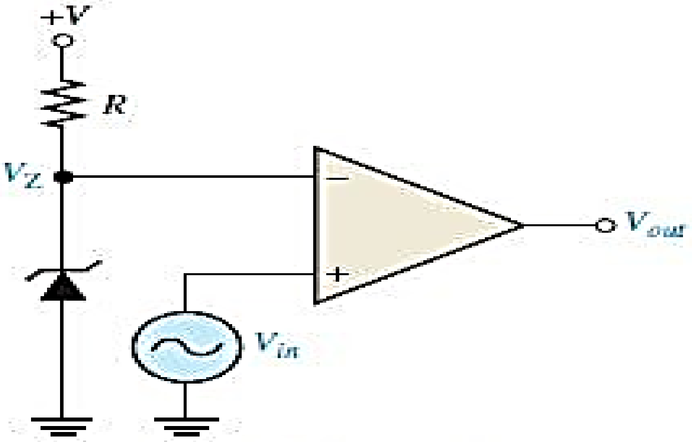
$$V_{REF} = V\frac{R_2}{R_1 + R_2}$$



(a) Battery reference



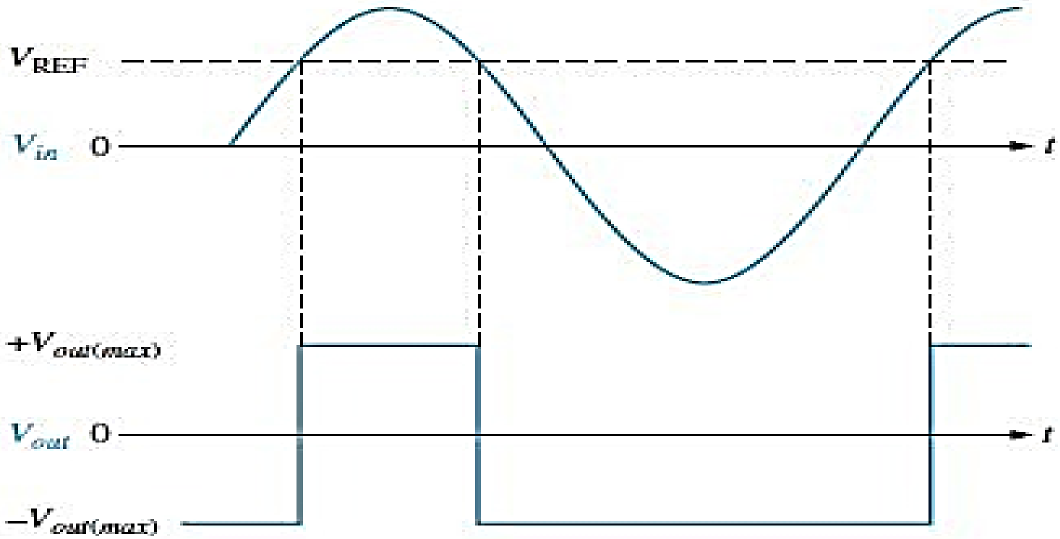
(b) Voltage-divider reference



(c) Zener diode sets reference voltage

$$V_{REF} = V_R$$

$$V_{REF} = V_Z$$

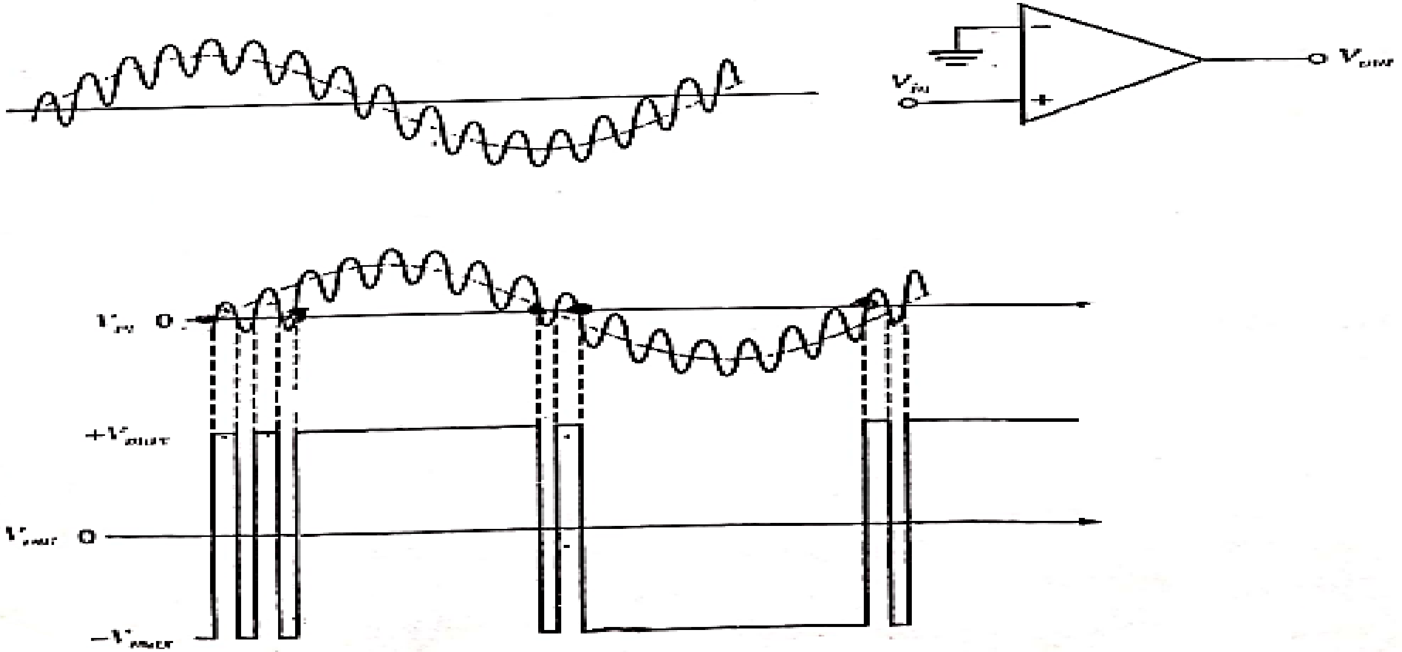


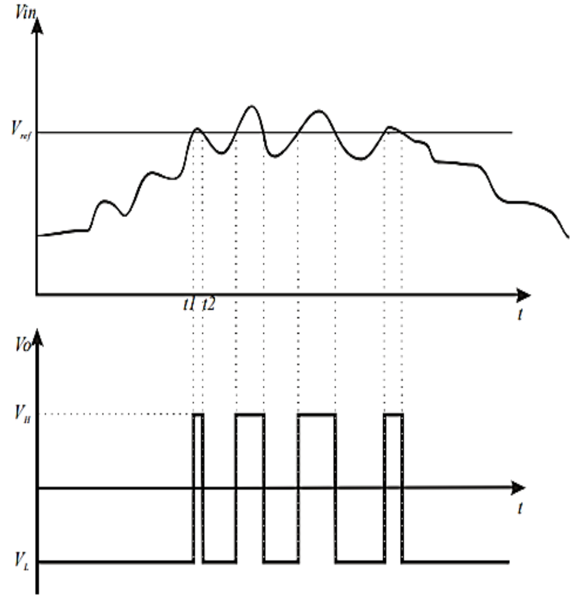
(d) Waveforms

14- The Comparator

- **Op-amp Comparator with Positive Feedback**

The operational amplifiers can be configured to operate as comparators in their open-loop mode, and this is fine if the input signal varies rapidly or is not too noisy. However if the input signal, Vin is slow to change or electrical noise is present, then the op-amp comparator may oscillate switching its output back and forth between the two saturation states, +Vcc and -Vcc as the input signal hovers around the reference voltage, Vref level. One way to overcome this problem and to avoid the op-amp from oscillating is to provide positive feedback around the comparator.





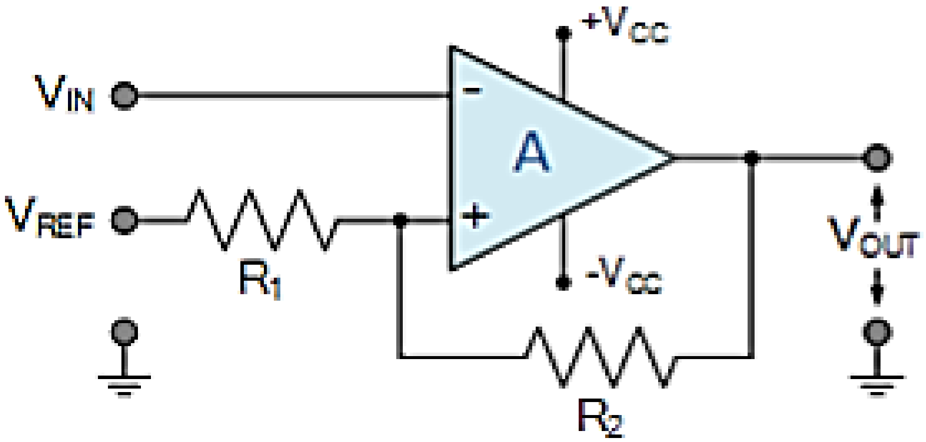
15- The Schmitt trigger

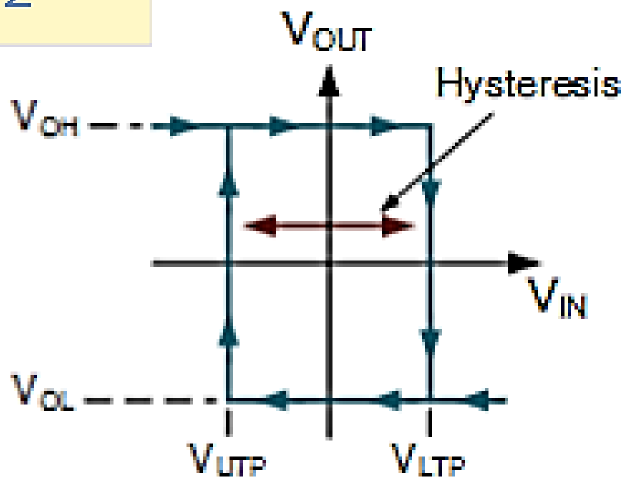
- The use of positive feedback around an op-amp comparator means that once the output is triggered into saturation at either level, there must be a significant change to the input signal Vin before the output switches back to the original saturation point. This difference between the two switching points is called hysteresis producing what is commonly called a Schmitt trigger circuit.

a. Inverting Op-amp Comparator with Hysteresis

- For the inverting comparator circuit below, Vin is applied to the inverting input of the op-amp. Resistors R1 and R2 form a voltage divider network across the comparator providing the positive feedback with part of the output voltage appearing at the non-inverting input. The amount of feedback is determined by the resistive ratio of the two resistors used and which is given as voltage divider equation: Where β (beta) can be used to indicate the feedback fraction.

$$\beta = \frac{R_1}{R_1 + R_2}$$





a. Inverting Op-amp Comparator with Hysteresis

- When the input signal is less than the reference voltage, Vin < Vref , the output voltage will be HIGH, VoH and equal to the positive saturation voltage. As the output is HIGH and positive, the value of the reference voltage on the non-inverting input will be approximately equal to: +β*Vcc called the Upper Trip Point or UTP.
- As the input signal, Vin increases it becomes equal to this upper trip point voltage, VUTP level at the non-inverting input. This causes the comparators output to change state becoming LOW, VoL and equal to the negative saturation voltage as before.
- But the difference this time is that a second trip point voltage value is created because a negative voltage now appears at the non-inverting input which is equal to:-β*Vcc as a result of the negative saturation voltage at the output. Then the input signal must now fall below this second voltage level, called the Lower Trip Point or LTP for the voltage comparators output to change or switch back to its original positive state.

a. Inverting Op-amp Comparator with Hysteresis

- So we can see that when the output changes state, the reference voltage at the non-inverting input also changes creating two different reference voltage values and two different switching points. One called the Upper Trip Point (UTP) and the other being called the Lower Trip Point (LTP). The difference between these two trip points is called Hysteresis.

- The amount of hysteresis is determined by the feedback fraction, β of the output voltage fed back to the non-inverting input. The advantage of positive feedback is that the resulting comparator Schmitt trigger circuit is immune to erratic triggering caused by noise or slowly changing input signals within the hysteresis band producing a cleaner output signal as the op-amp comparators output is only triggered once.

a. Inverting Op-amp Comparator with Hysteresis

- So for positive output voltages, Vref = +β*Vcc, but for negative output voltages, Vref = -β*Vcc. Then we can say that the amount of voltage hysteresis will be given as:

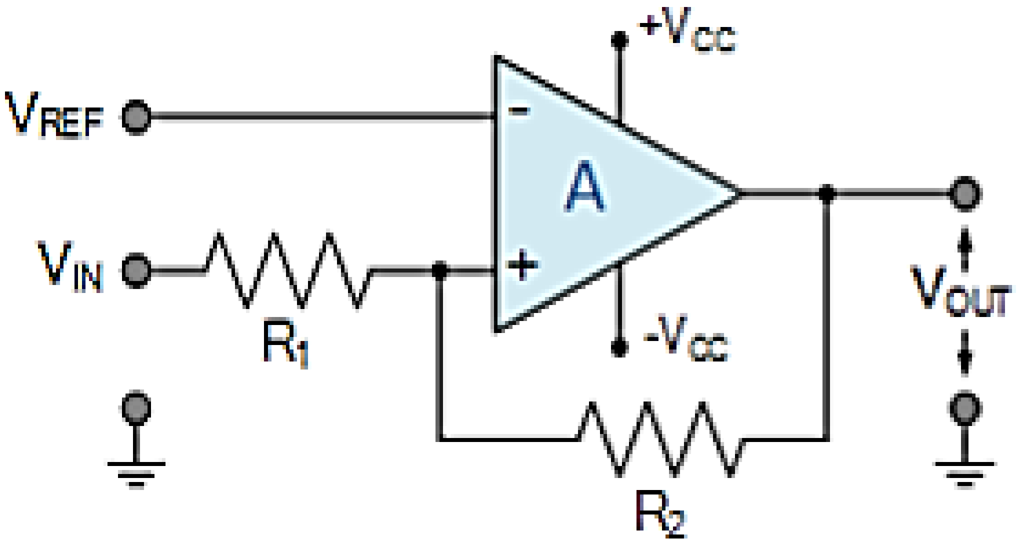
$$V_{HYSTERESIS} = V_{UTP} - V_{LTP}$$

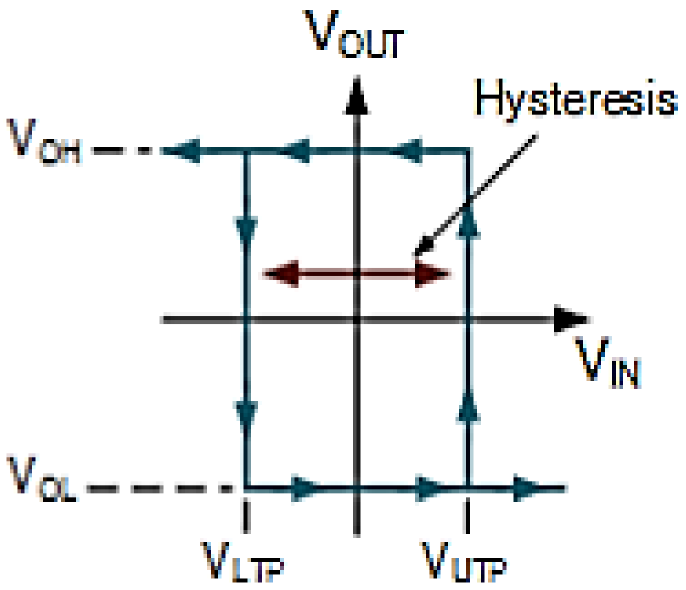
$$V_{HYSTERESIS} = +\beta Vcc - (-\beta Vcc)$$

$$\therefore V_{HYSTERESIS} = 2\beta Vcc$$

b. Non-inverting Op-amp Comparator with Hysteresis

- Note that the arrows on the hysteresis graph indicate the direction of switching at the upper and lower trip points.





Comparator example

- An operational amplifier is to be used with positive feedback to produce a Schmitt trigger circuit. If resistor, R1 = 10kΩ and resistor, R2 = 90kΩ, what will be the values of the upper and lower switching points of the reference voltage and the width of the hysteresis if the op-amp is connected to a dual ±10v power supply. Given: R1 = 10kΩ, R2 = 90kΩ. Power supply +Vcc = 10v and -Vcc = 10v.
- Solution:

Feedback Fraction:

$$\beta = \frac{R_1}{R_1 + R_2} = \frac{10k\Omega}{10k\Omega + 90k\Omega} = 0.1$$

Upper Voltage Trip Point, V_{UTP}

$$UTP = \left(\frac{R_1}{R_1 + R_2}\right) \times (+Vcc) = +\beta Vcc$$

$$\therefore\ UTP = 0.1 \times (+10) = +1.0V$$

Comparator example

Lower Voltage Trip Point, V_{LTP}

$$LTP = \left(\frac{R_1}{R_1 + R_2}\right) \times (-Vcc) = -\beta Vcc$$

$$\therefore\ LTP = 0.1 \times (-10) = -1.0V$$

Hysteresis width:

$$V_{(HYS)} = UTP - LTP$$

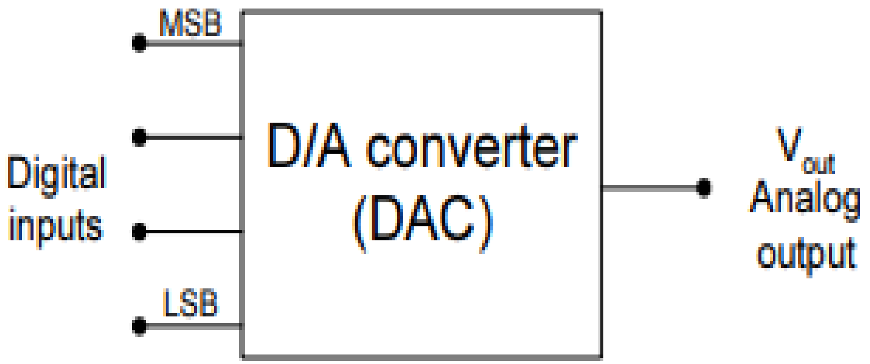
$$V_{(HYS)} = +\beta Vcc - (-\beta Vcc) = 1.0V - (-1.0V) = 2.0V$$

$$\text{also:}\ V_{(HYS)} = 2\beta Vcc = 2 \times 0.1 \times 10 = 2.0V$$

- Then the reference voltage Vref , switches between +1V and -1V as the output saturates from one level to the other. Hopefully we can see from this simple example that the width of this hysteresis, 2 volts in total, can be made larger or smaller simply by adjusting the voltage divider ratio of the feedback resistors R1 and R2 .

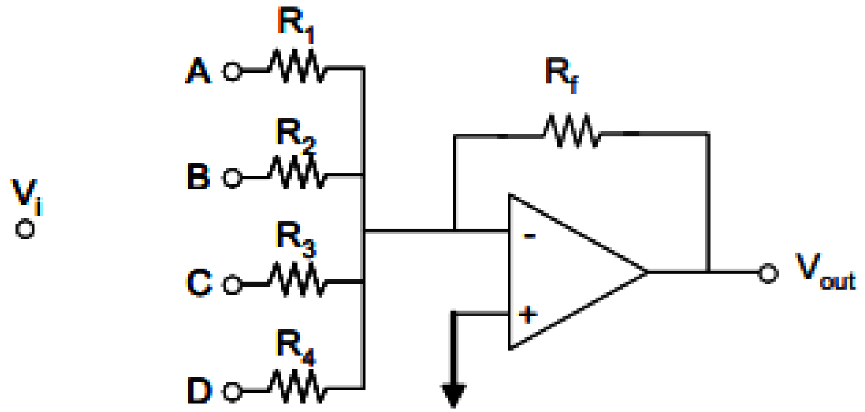
16- Digital to Analog Converter

- There are two basic type of converters, digital-to-analog (DACs or D/As) and analog-to-digital (ADCs or A/Ds). Their purpose is fairly straightforward. In the case of DACs, they output an analog voltage that is a proportion of a reference voltage, the proportion based on the digital word applied.
- Basically, D/A conversion is the process of taking a value represented in digital code (such as straight binary or BCD) and converting it to a voltage or current which is proportional to the digital value. Figure shows the symbol for a typical 4-bit D/A converter.



16- Digital to Analog Converter

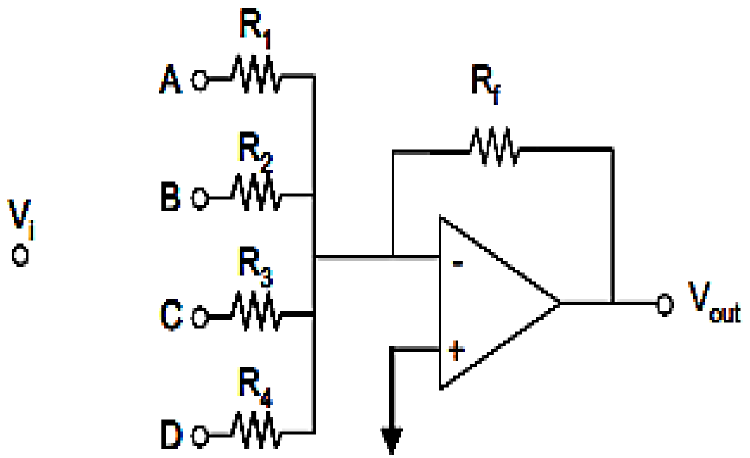
- The following is an examination of a 4-bit binary digital-to-analog converter, shown below. This circuit can convert a 4-bit binary signal into an analog equivalent.
- Based on your experience with op-amp circuits, you probably recognize this as an adder circuit, where the voltages input at A, B, C, and D are scaled based on the ratio of Rf to the input resistor, then summed. The key to the operation of this circuit as a D/A converter lies in the ability to turn the inputs "on" (logic state 1) or "off" (logic state 0) to correspond to a particular 4-bit binary "word" (a combination of four distinct 1's and 0's that serve to make up some binary number). If this were an 8-bit converter, there would need to be 8 distinct inputs.



16- Digital to Analog Converter

- We can derive the output of this converter as follows:

$$I_A+I_B+I_C+I_D=I_F$$



- Using Ohm's law to substitute V/R for I:

$$\frac{V_A-0}{R_1}+\frac{V_B-0}{R_2}+\frac{V_C-0}{R_3}+\frac{V_D-0}{R_4}=\frac{0-V_{out}}{R_f}$$

- After a little algebra:

$$R_f\left(\frac{V_A}{R_1}+\frac{V_B}{R_2}+\frac{V_C}{R_3}+\frac{V_D}{R_4}\right)=-V_{out}$$

- Where VA, VB, VC, and VD are the voltage inputs at A, B, C, D. In this converter, the magnitude of these voltages depends on the logic state for each bit and the size of the reference voltage (Vi).

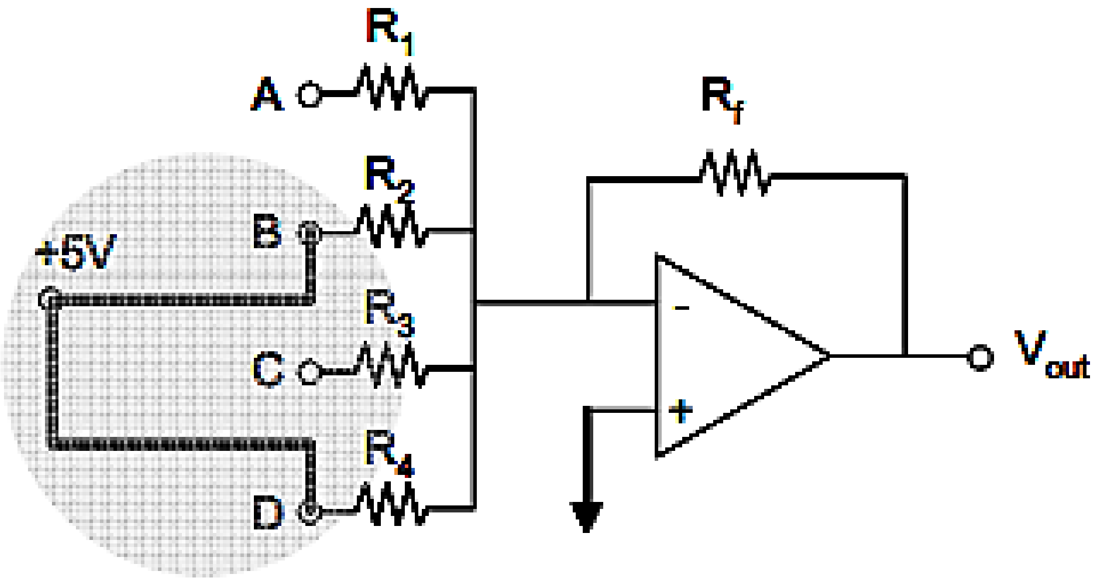
16- Digital to Analog Converter

- An example may help with this. Let's assume we want to convert the 4-bit number 1010 to its analog component. We begin by assigning each of the bits to a particular input on the converter. The four bits correspond to 2^0 , 2^1 , 2^2 , and 2^3 , with the bit 2^0 called the Least Significant Bit (LSB) and the bit 2^3 termed the Most Significant Bit (MSB). Let's make the following assignments:

Binary Value	Input	Analog Equivalent
0001 (LSB)	A	$2^0 = 1$
0010	B	$2^1 = 2$
0100	C	$2^2 = 4$
1000 (MSB)	D	$2^3 = 8$

16- Digital to Analog Converter

- So, for our digital 1010, the converter would apply Vi, which is typically +5 volts, to inputs B and D, while leaving A and C at 0 V, and the output of the converter would be:



$$R_f\left(\frac{0V}{R_1}+\frac{+5V}{R_2}+\frac{0V}{R_3}+\frac{+5V}{R_4}\right)=-V_{out}$$

16- Digital to Analog Converter

- In order to make a prediction of the actual voltage output, we need to assign vales to the resistors in the circuit. In principle, most any resistance would work, but a little consideration of utility makes some choices better than others. Another look at the table above suggests that the word 0010 should output a voltage twice the size of 0001, while 0100 should be four times the size of 0001 and 1000 eight times the size. Therefore, it is useful to design the circuit to give this 1:2:4:8 scaling of the reference voltage. In order to accomplish this, the resistors for larger bits must have a smaller resistance (or larger weighting). More importantly, the resistance must decrease by the 1:2:4:8 ratio. The following pattern emerges: R2 = R1/2, R3 = R1/4, and R4 = R1/8. Under these conditions, the output function of the system becomes:

$$R_f\left(\frac{V_A}{R_1}+\frac{V_B}{R_1/2}+\frac{V_C}{R_1/4}+\frac{V_D}{R_1/8}\right)=-V_{out}$$

After some more algebra, we get a final relationship:

$$\frac{R_f}{R_1}(V_A+2V_B+4V_C+8V_D)=-V_{out}$$