Module 1

Anupama V
Assistant Professor

Optoelectronic Devices

- Study of devices that emit, detect and control light in the wavelength spectrum ranging from ultraviolet to far infrared
- Includes
  - Electrical-to-optical transducers
  - Optical-to-electrical transducers

Photodiode

- Light detector semiconductor device that converts light energy into electric current or voltage which depends upon the mode of operation
- Upper cut-off wavelength λc=1240/Eg
- (Eg - bandgap energy)

p-n junction diode

- Under reverse bias, a small amount of electric current generated due to minority charge carriers
- Application of external reverse voltage to the p-n junction diode will not increase the population of minority charge carriers
- Reason: Minority carriers generated at n-side or p-side will recombine in the same material, before they cross the junction
- No electric current flows.

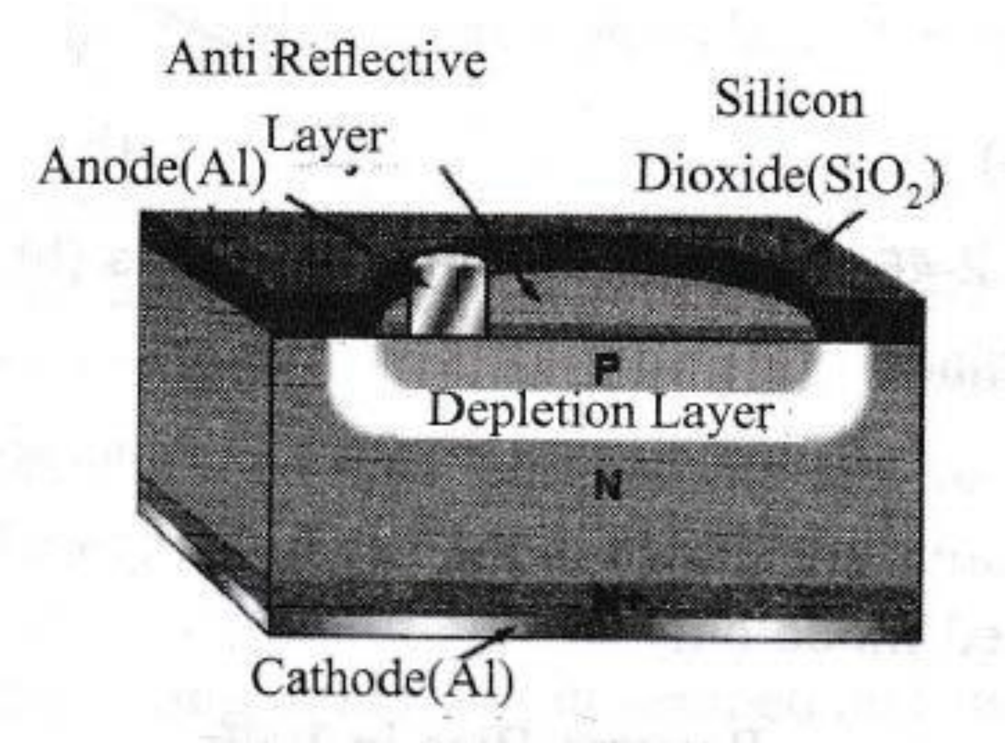
Photodiode

- Apply external energy directly to the depletion region to generate more charge carriers
- Photodiode is designed to generate more number of charge carriers in depletion region
- Light or photons as the external energy to generate charge carriers in depletion region

Photodiode : Construction

- *ion implantation* : surface of a layer of N-type is bombarded with P- type silicon ions to produce a P-type layer
- *Diffusion* : excess electrons move from N-type towards P-type and excess holes move from P-type towards N-type
- Results in the removal of free charge carriers close to the PN-junction, so creating a depletion layer

Photodiode : Construction



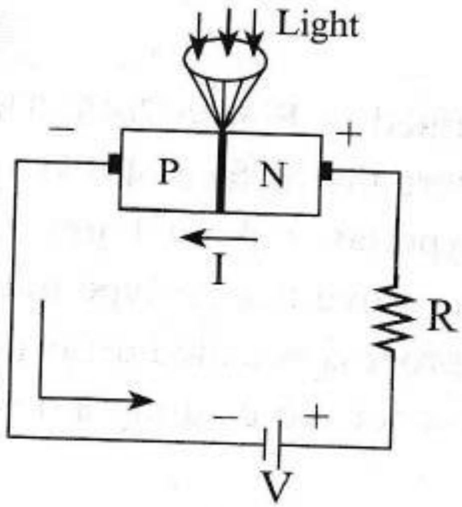
Photodiode : Construction

- Silicon Dioxide (SiO_2) in which there is a window for light to shine on the semiconductor.
- Silicon Nitride (SiN) to allow maximum absorption of light
- An anode connection of aluminium (Al) is provided to the P-type layer
- A more heavily doped N+ layer to provide a low resistance connection to the cathode

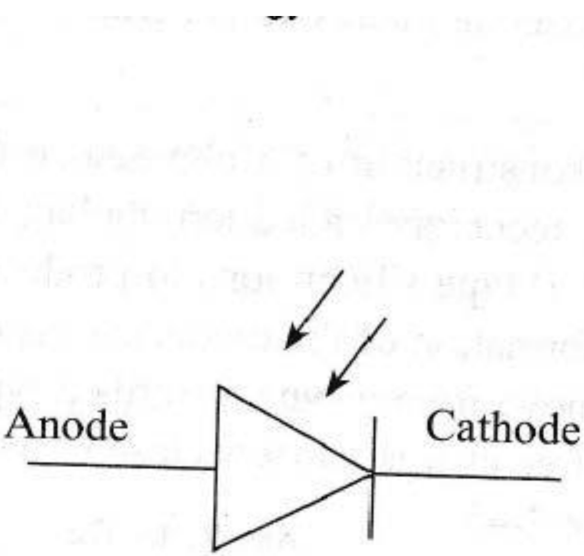
Photodiode : Working Principle

- The junction of Photodiode is illuminated by the light source; the photons strike the junction surface.
- The photons impart their energy in the form of light to the junction.
- Due to which electrons from valence band get the energy to jump into the conduction band.
- This leaves positively charged holes in the valence band, so producing 'electron-hole pairs' in the depletion layer.

Photodiode : Working Principle

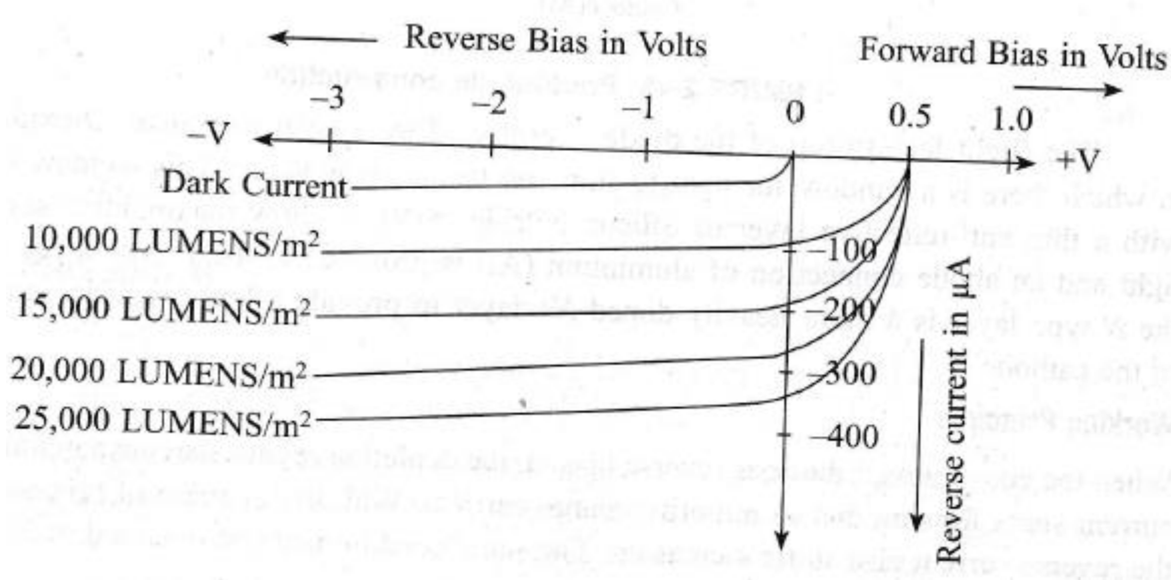


(a)



(b)

Photodiode:V-I Characteristics



Reverse bias current is the summation of reverse saturation current and short circuit current.

Photodiode : Applications

- Consumer electronics devices like smoke detectors, compact disc players, and televisions and remote controls in VCRs.
- Photodiodes are frequently used for exact measurement of the intensity of light in science and industry.

Light Emitting Diode (LED)

- The LED is a PN-junction diode which emits light when an electric current passes through it in the forward direction
- Electroluminescence is the properly of the material to convert electrical energy into light energy

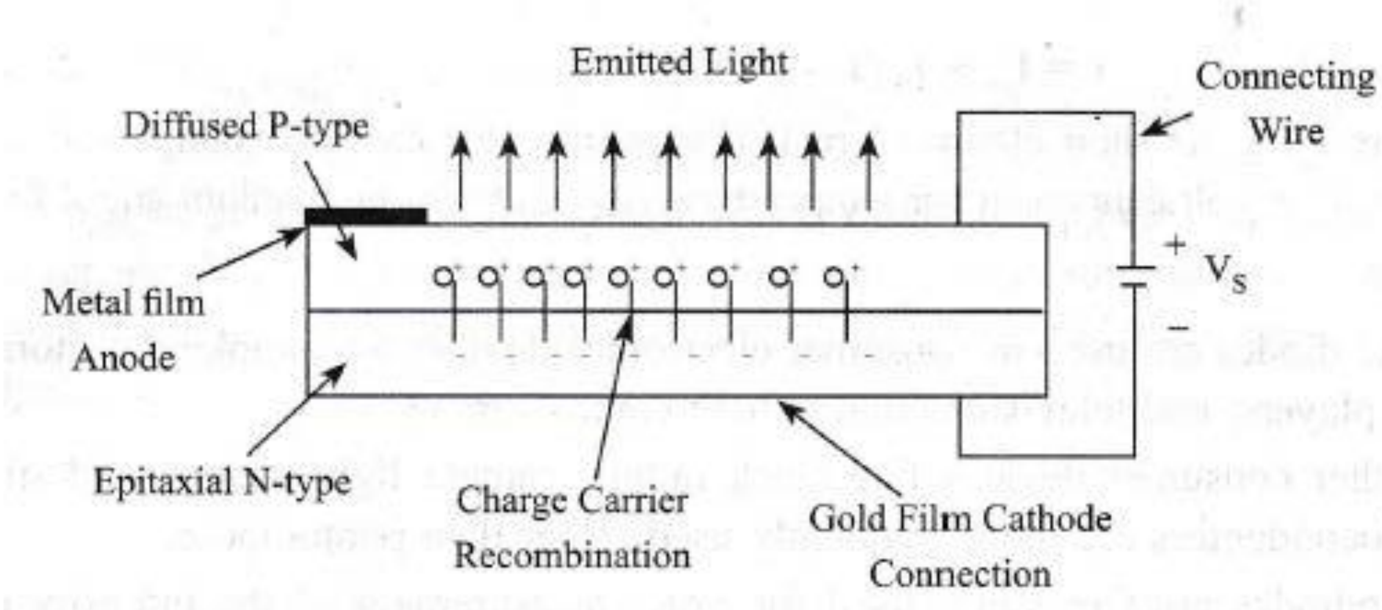
LED : Construction

- The semiconductor material used in LED is Galliurn Arsenide (GaAs), Gallium phosphide (GaP) or Gallium Arsenide Phosphide (GaAsP).
- The semiconductor layer of P-type is placed above N-type because the charge carrier recombination occurs in P-type.
- If *P-type is placed below the N-type, the emitted light cannot be seen.*

LED : Construction

- The semiconductor material used in LED is Galliurn Arsenide (GaAs), Gallium phosphide (GaP) or Gallium Arsenide Phosphide (GaAsP).
- The semiconductor layer of P-type is placed above N-type because the charge carrier recombination occurs in P-type.

LED : Construction



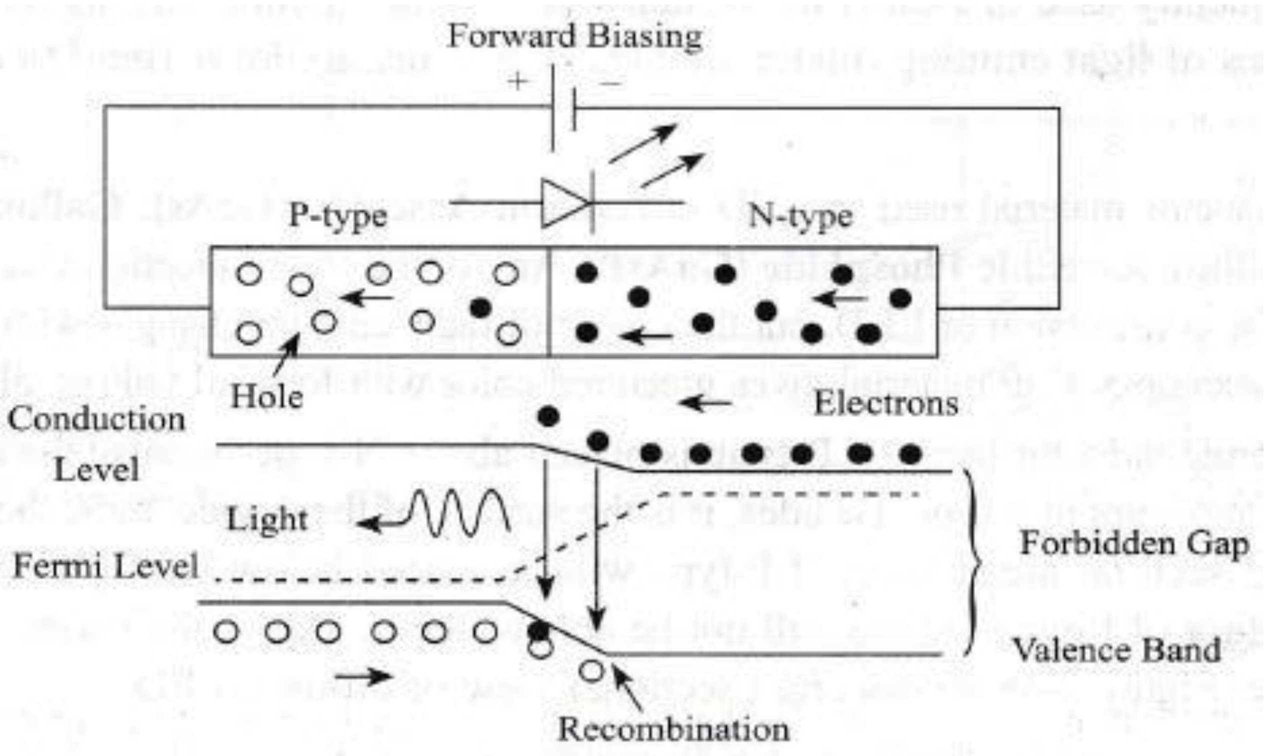
LED : Construction

- The P-type layer is formed from diffusion of semiconductor material.
- The metal film is used on the P-type layer to provide anode connection to the diode.
- Gold-film layer is coated on N-type to provide cathode connection. The Gold-film layer on N-type also provides reflection from the bottom surface of the diode.
- If any significant part of radiated light tends to hit bottom surface then that will be reflected from the bottom surface to the device top surface. This increases LED's efficiency.

LED : Working Principle

- The charge carriers recombine in a forward-biased P-N junction as the electrons cross from the N-region and recombine with the holes existing in the P-region.
- Free electrons are in the conduction band of energy levels
- Holes are in the valence energy band.
- Energy level of the holes is less than the energy levels of the electrons.
- Some portion of the energy must be dissipated to recombine the electrons and the holes. This energy is emitted in the form of heat and light.

LED :Working Principle



LED :Working Principle

- Electron emit electromagnetic energy in the form of photons.
- The energy of photons is equal to the gap between the valence and the conduction band.
- Color of light can be determined by the band gap of semiconductor material.

LED : Applications

- LEDs are used in remote control systems such TV or LCD remote.
- Used in traffic signals for controlling the traffic crowds in cites.
- Used in digital computers for displaying the computer data.
- Used in electronic calculators for showing the digital data.
- Used in digital watches and automotive heat lamps.

Photocoupler

- Photocoupler or Optocoupler is a device that transfers electrical signals between two isolated circuits by using light.

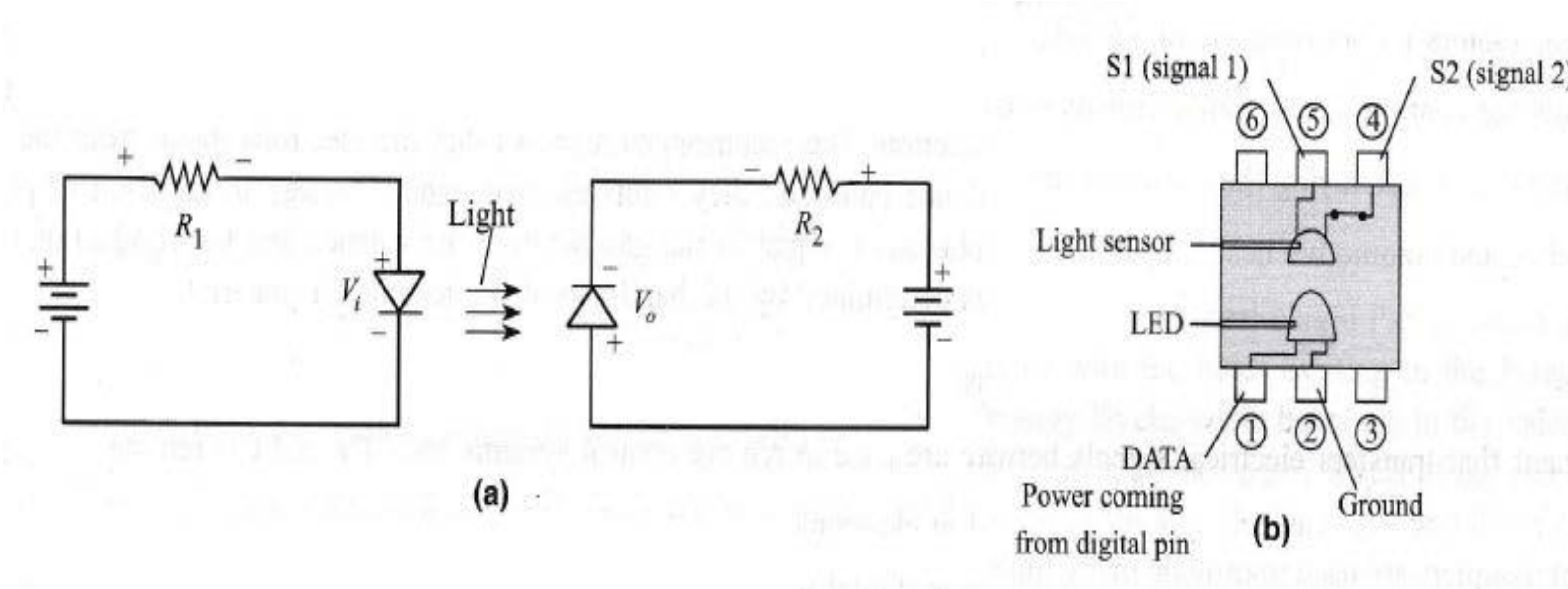
Photocoupler : Construction

- All optocouplers consist of two elements: a light source (a LED) and a photosensor (a photoresistor, photodiode, phototransistor, silicon-controlled rectifier (SCR), or triac); which are separated by a dielectric (non-conducting) barrier

Photocoupler : Working

- When input current is applied to the LED, it switches ON and emits infrared light
- The photosensor then detects this light and allows current to flow through the output side of the circuit
- When the LED is off, no current will flow through the photosensor.
- By this method, the two flowing currents are electrically isolated. It consists of LED and photodiode; where the circuits are isolated electrically.
- In the following Figure, LED is forward biased, photodiode is reverse biased and output exists across R2.

Photocoupler : Working



Photocoupler : Applications

- Input and output switching in electronically noisy environments.
- Controlling transistors and triacs.
- Switch-mode power supplies.
- PC/ Modem communication.
- Signal isolation.
- Power control.

BJT BIASING

- A transistor (Bipolar Junction Transistor-BJT) is a sandwich of one type of semiconductor (P-type or N-type) between two layers of other type.

- Three types of biasing a transistor:

1. *Base bias or Fixed bias,*
2. *Collector-to-Base bias,*
3. *Voltage-divider bias.*

BASE BIAS or FIXED BIAS:

Applying Kirchoff's Voltage Law (KVL) to the base circuit;

$V_{CC} - I_B R_B - V_{BE} = 0$

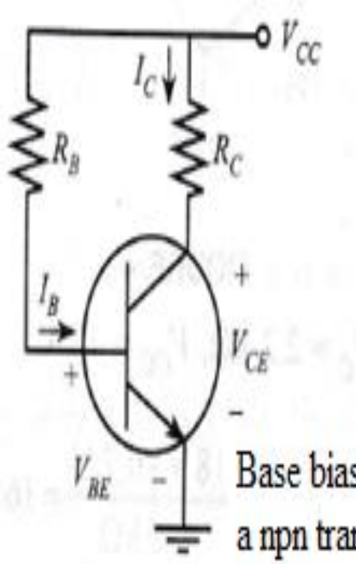
Or, $I_B = (V_{CC} - V_{BE})/R_B$ --------------------- (1)

V_{BE} is 0.7 V for Silicon and 0.3 V for Germanium transistor.

Applying the KVL to the collector circuit;

$V_{CC} - I_C R_C - V_{CE} = 0$

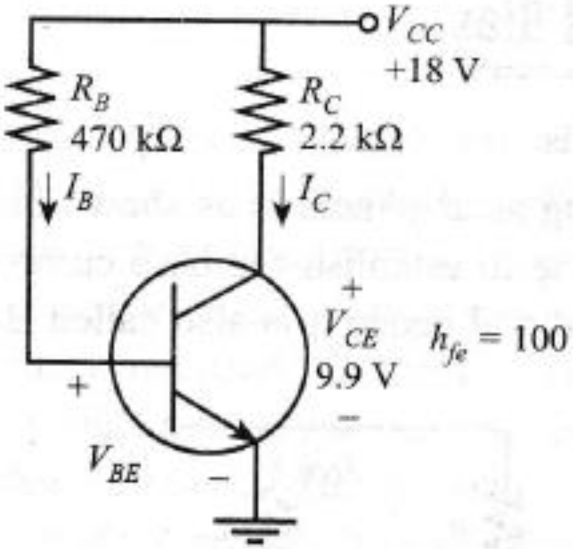
Or, $V_{CE} = V_{CC} - I_C R_C$ -------------------- (2)



Base bias circuit using a npn transistor

Example 1:

The base bias circuit is shown in Figure for the values indicated calculate I_{B}, I_C and V_{CE}.



Given: $R_B = 470\ \text{k}\Omega$, $R_C = 2.2\ \text{k}\Omega$, $V_{CC} = 18\ \text{V}$

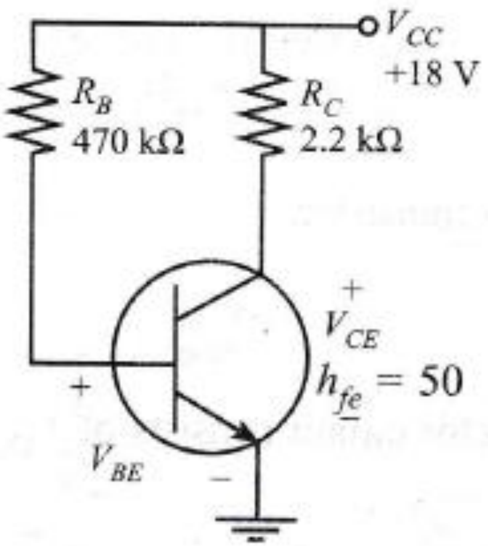
$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{18\ \text{V} - 0.7\ \text{V}}{470\ \text{k}\Omega} = 36.8\ \mu\text{A}$$

$$I_C = h_{fe} I_B = 100 \times 36.8\ \mu\text{A} = 3.68\ \text{mA}$$

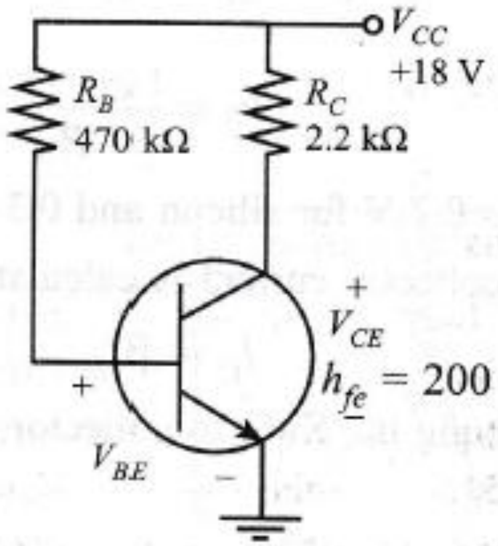
$$V_{CE} = V_{CE} - I_C R_C = 18\ \text{V} - (3.68\ \text{mA} \times 2.2\ \text{k}\Omega) = 9.9\ \text{V}$$

Example 2:

Calculate the maximum and minimum levels of I_C and V_{CE} for the base bias circuit in Figure (a), when $h_{fe(min)} = 50$ and $h_{fe(max)} = 200$.

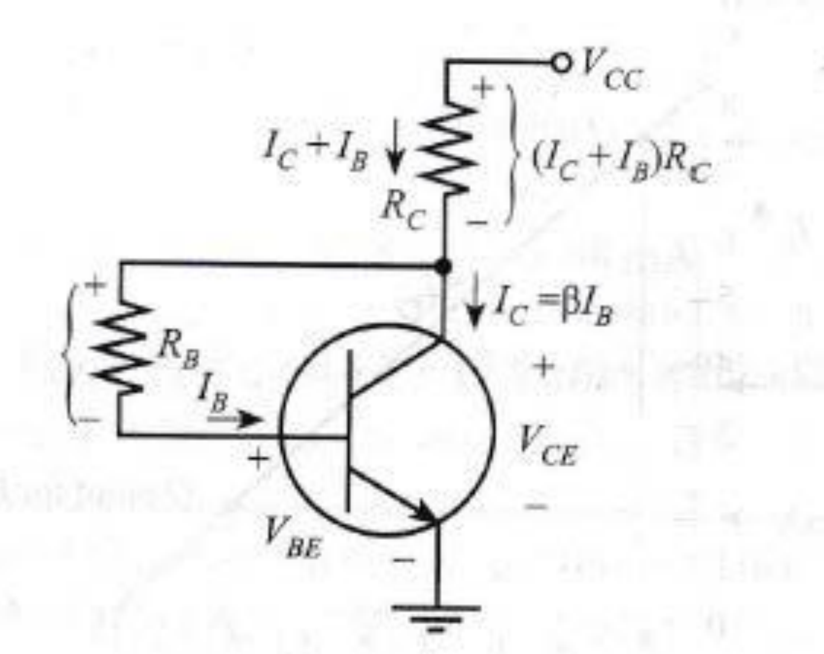


(a): Conditions for $h_{fe(min)}$



(b): Conditions for $h_{fe(max)}$

COLLECTOR-TO-BASE BIAS CIRCUIT:



COLLECTOR-TO-BASE BIAS CIRCUIT:

Applying KVL to the outer loop;

$V_{CC} – (I_C + I_B) R_C – V_{CE} = 0$ Or, $V_{CE} = V_{CC} – (I_C + I_B) R_C$ ------------------- (3a)

Applying KVL to the loop V_{CE}, I_BR_B, and V_{BE};

$V_{CE} – V_{BE} – I_BR_B = 0$ Or, $V_{CE} = V_{BE} + I_BR_B$ ------------------- (3b)

Equating equations 3a and 3b;

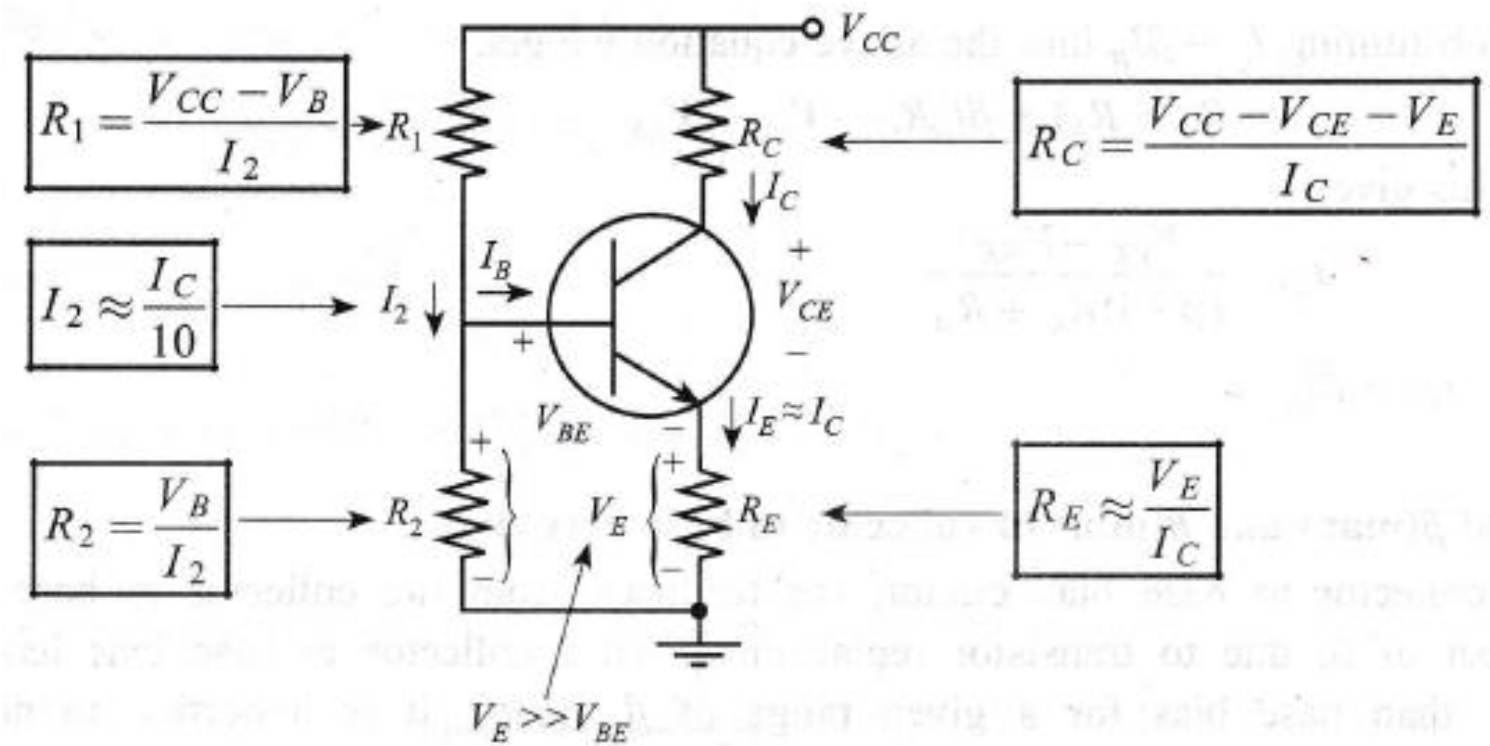
$V_{CC} – (I_C + I_B) R_C = V_{BE} + I_BR_B$

Or, $(I_C + I_B) R_C + I_BR_B = V_{CC} – V_{BE}$ i.e., $I_B (R_C + R_B) + I_CR_C = V_{CC} – V_{BE}$

Substituting $I_C = \beta I_B$ in above equation, we get;

$I_B (R_C + R_B) + \beta I_BR_C = V_{CC} – V_{BE}$ Gives, $I_B = (V_{CC} – V_{BE})/(\beta+1)R_C + R_B$ ------------------- (4)

VOLTAGE DIVIDER (EMITTER CURRENT) BIAS CIRCUIT:



VOLTAGE DIVIDER /EMITTER CURRENT BIAS CIRCUIT:

Applying KVL to the loop V_{CC}, R_1, and R_2, we get;

$V_{CC} - I_1R_1 - I_2R_2 = 0$ Or, $I_1R_1 + I_2R_2 = V_{CC}$ -------------------- (5)

We have; $I_1 = I_2 + I_B$

Voltage divider bias circuits are normally designed to have a voltage divider current I_2 very much greater than transistor base current I_B. i.e., $I_2 >> I_B$. Hence, $I_1 \approx I_2$ -------------------- (6)

Using 6 in 5; $I_2R_1 + I_2R_2 = V_{CC}$ i.e., $I_2 (R_1 + R_2) = V_{CC}$ Or, $\boldsymbol{I_2 = (V_{CC}) / (R_1 + R_2)}$

V_B is the voltage across R_2. i.e., $V_B = I_2R_2$ Or, $\boldsymbol{V_B = (V_{CC} * R_2) / (R_1 + R_2)}$

V_E is the voltage across R_E. i.e., $\boldsymbol{V_E = I_ER_E}$

Applying KVL to the base-emitter loop; $V_B - V_{BE} - V_E = 0$ i.e., $\mathbf{V_{BE} = V_B - V_E}$

Or, $V_E = V_B - V_{BE}$ i.e., $I_ER_E = V_B - V_{BE}$ Hence, $\boldsymbol{I_E = (V_B - V_{BE}) / R_E}$

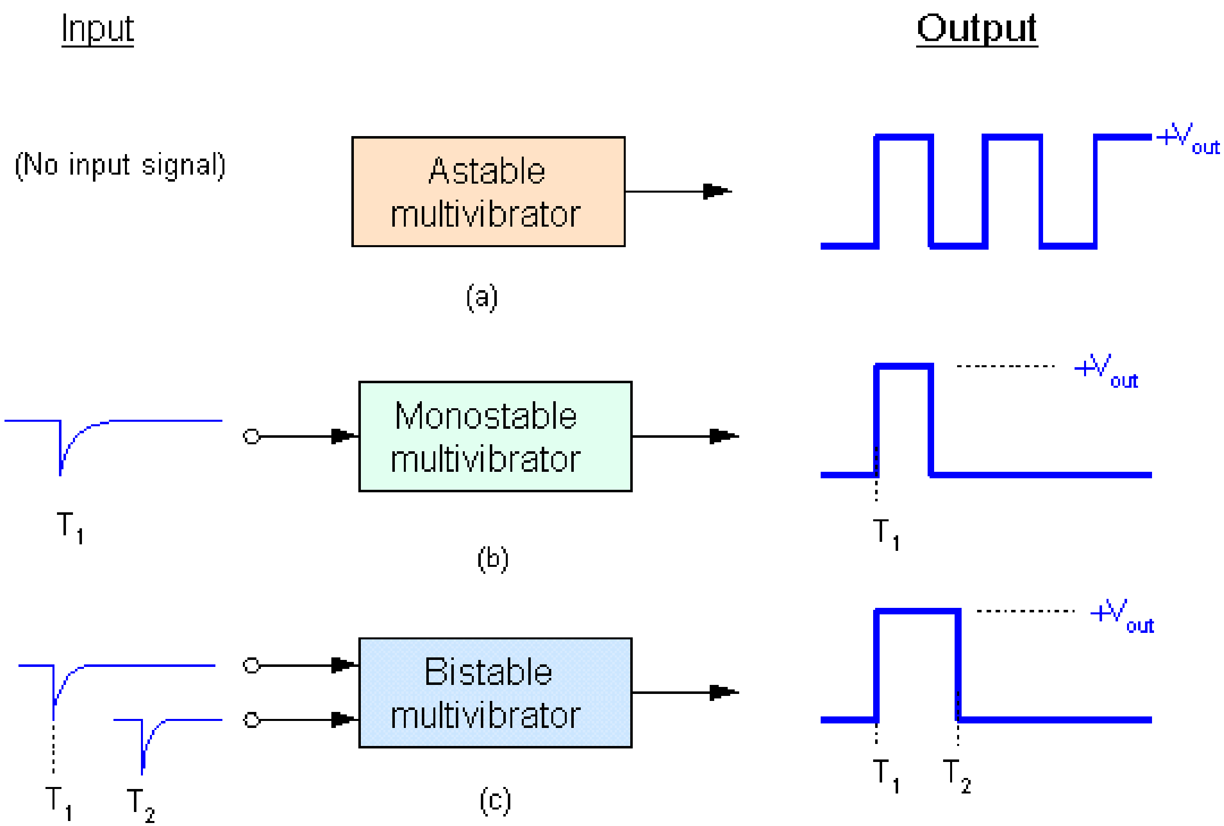
Applying KVL to the collector-emitter loop; $V_{CC} - I_CR_C - V_{CE} - I_CR_E = 0$ $[I_E \approx I_C]$

i.e., $\boldsymbol{V_{CE} = V_{CC} - I_C (R_C + R_E)}$

MULTIVIBRATORS USING IC-555

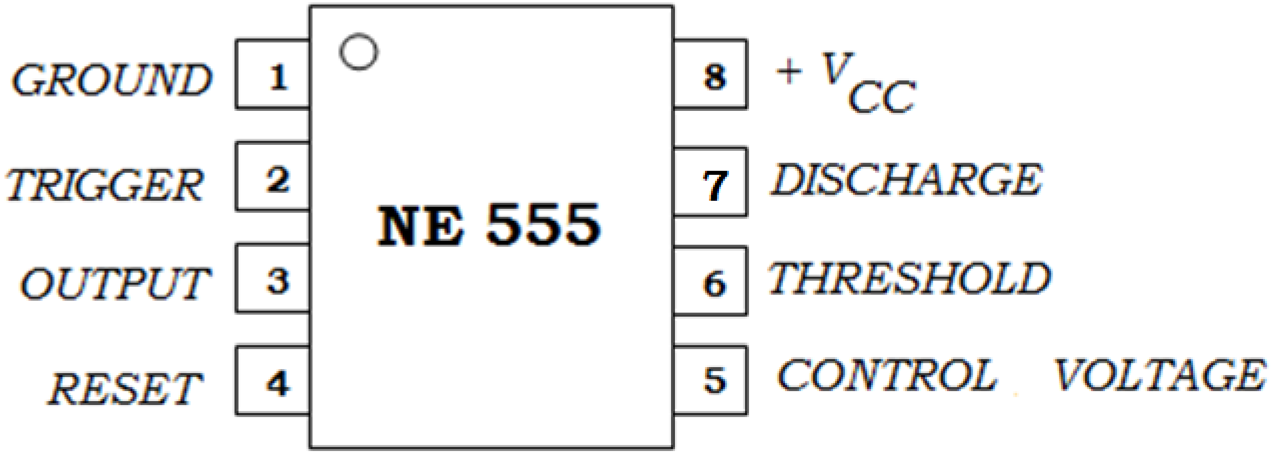
- A *multivibrator* circuit oscillates between a "HIGH" state and a "LOW" state producing a continuous output.
- It generates square, rectangular, pulse waveforms, also called nonlinear oscillators or function generators.
- There are basically three types of clock pulse generation circuits:
  - **Astable** – A *free-running multivibrator* that has **NO** stable states but switches continuously between two states this action produces a train of square/rectangular wave pulses at a fixed frequency.
  - **Monostable** – A *one-shot multivibrator* that has only **ONE** stable state and is triggered externally with it returning back to its first stable state.
  - **Bistable** – A *flip-flop* that has TWO stable states that produces a single pulse either positive or negative in value.

MULTIVIBRATORS USING IC-555

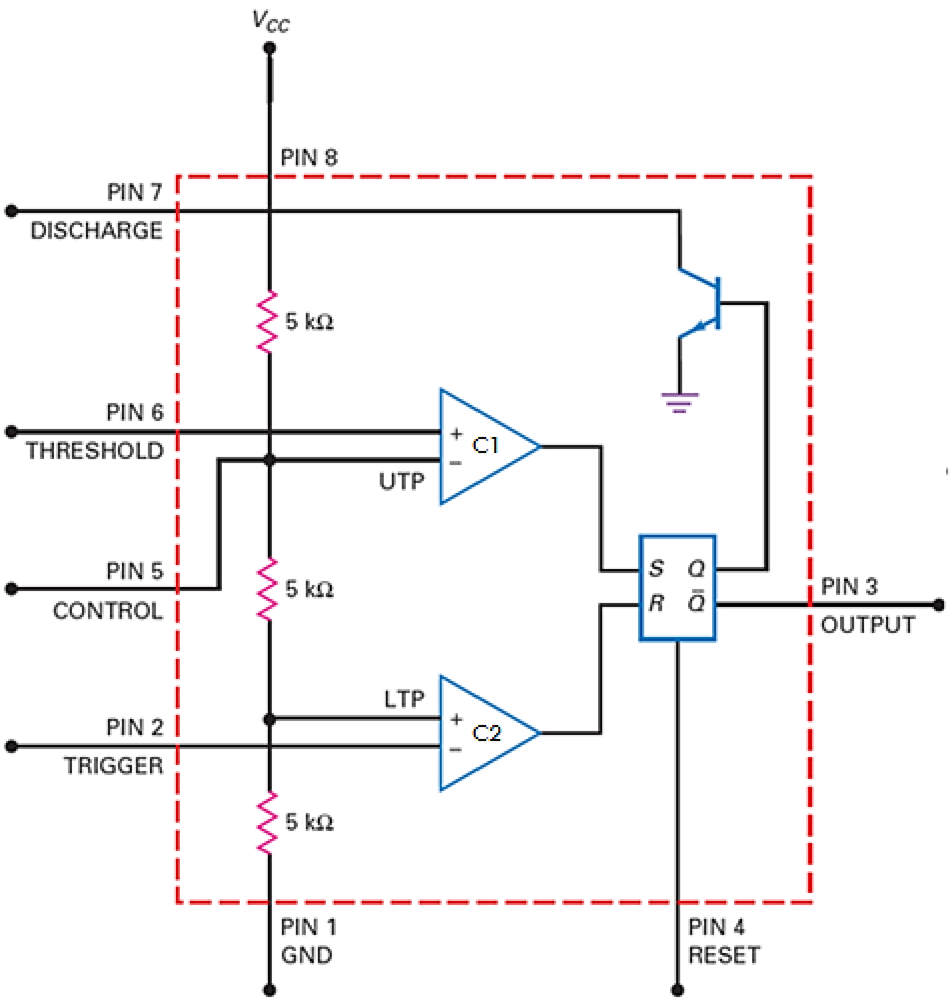


Integrated Circuit(IC) Multivibrators

- The NE555 (also LM555, CA555) is a widely used *IC timer*, a circuit that can run in either of two modes: **monostable** (one stable state) or **astable** (no stable states).

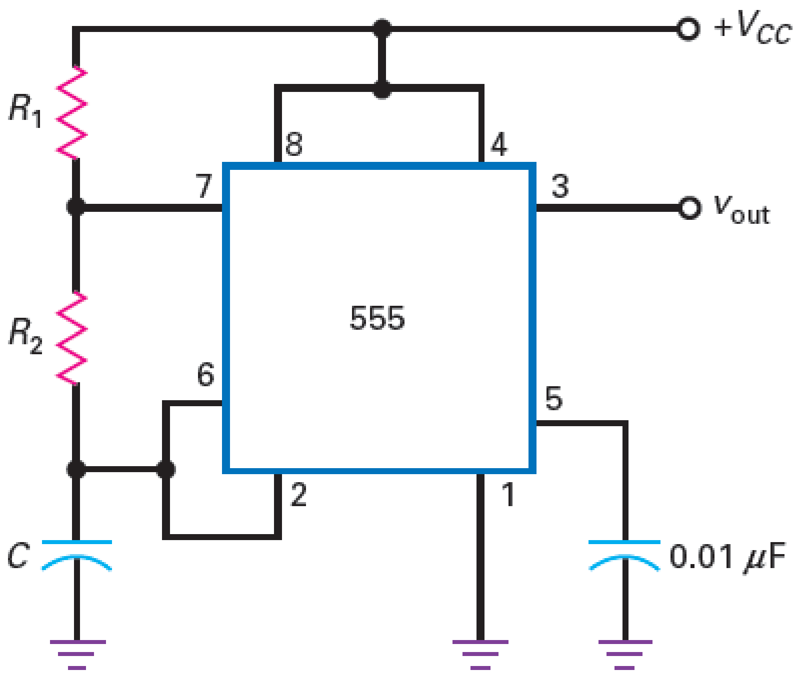


Integrated Circuit(IC) Multivibrators



Integrated Circuit(IC) Multivibrators
Astable Operation of the 555 Timer

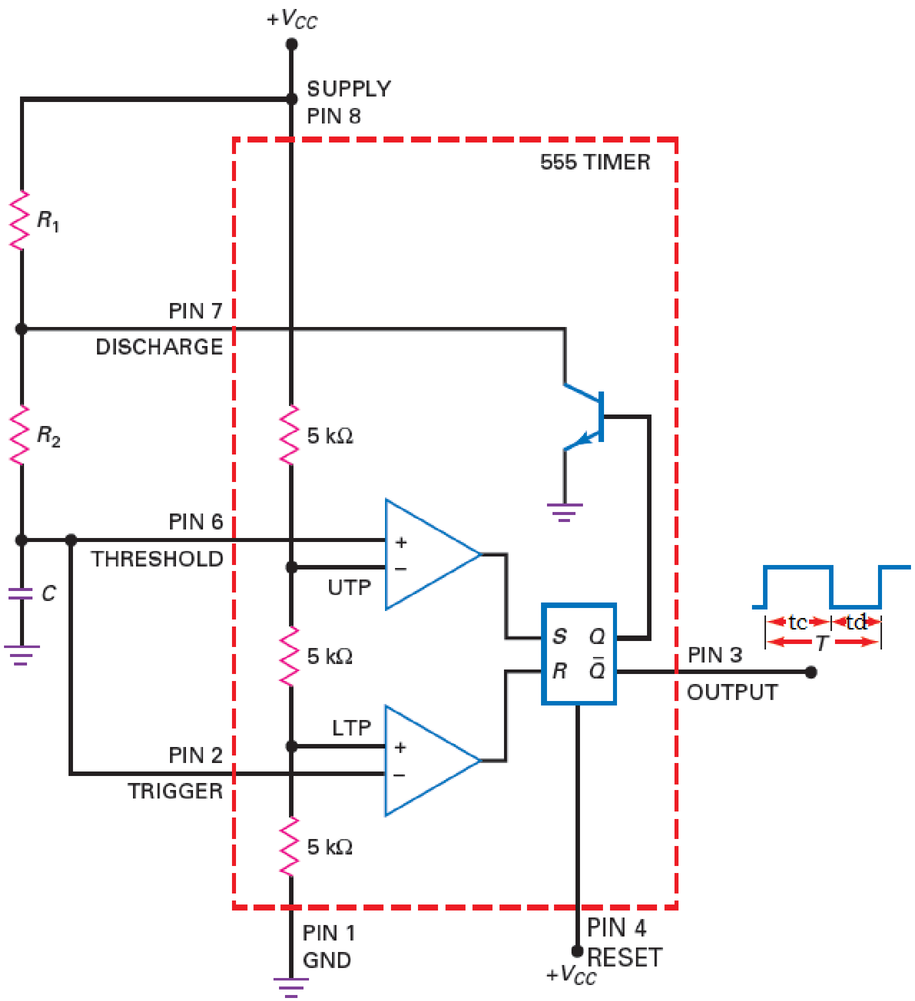
- Circuit Diagram

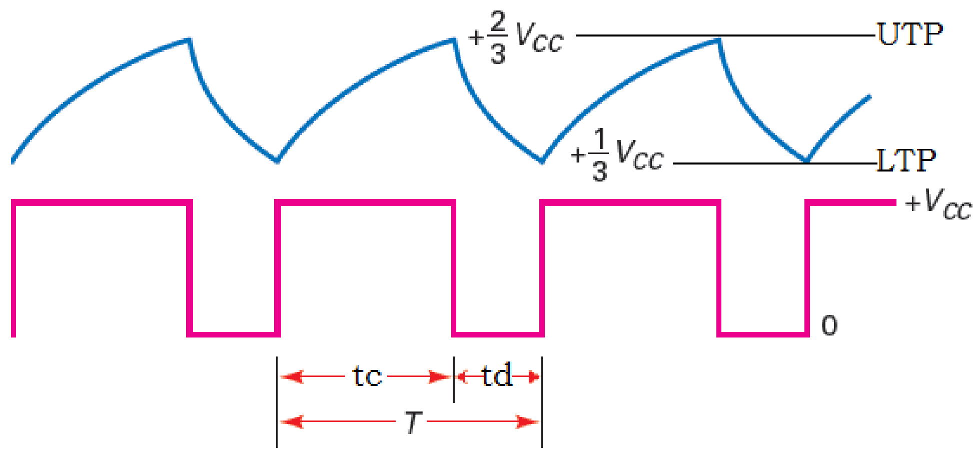


- Charge time (High Time)
  - $t_c = 0.693(R_1 + R_2)C$
- Discharge time (Low Time)
  - $t_d = 0.693R_2C$
- Total Time period T is
  - $T = t_c + td$
- The frequency is given by
  - $f_O = \frac{1}{T}$
- The duty cycle is
  - $\%D = \frac{t_c}{T}$

Integrated Circuit(IC) Multivibrators

Astable Operation of the 555 Timer





Capacitor and output waveforms

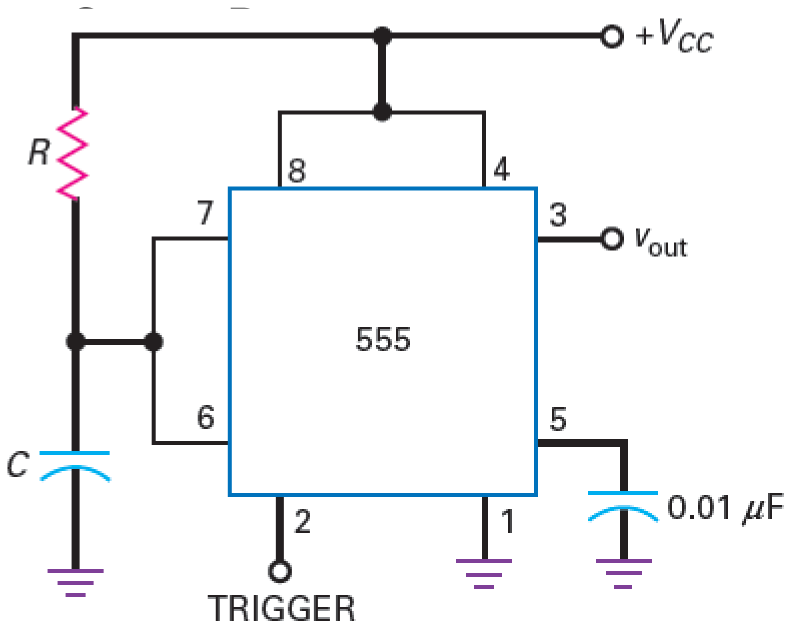
Integrated Circuit(IC) Multivibrators

Astable Operation of the 555 Timer

- When *Q* is low, the transistor is cut off and the capacitor is charging through R1 and R2 resistance. Because of this, the charging time constant is (*R*1+*R*2)*C*. As the capacitor charges, the threshold voltage (pin 6) increases. Eventually, the threshold voltage exceeds $\frac{2}{3}V_{CC}$. Then, the upper comparator sets the flip-flop.
- With *Q* high, the transistor saturates and grounds pin 7. The capacitor now discharges through *R*2. Therefore, the discharging time constant is *R*2*C*. When the capacitor voltage drops to slightly less than $\frac{1}{3}V_{CC}$, the lower comparator resets the flip-flop.
- The output is a rectangular wave that swings between 0 and V_{CC}. Since the charging time constant is longer than the discharging time constant, the output is nonsymmetrical. Depending on resistances *R*1 and *R*2, the duty cycle is between 50 and 100 percent.
- When *R*1 is much smaller than *R*2, the duty cycle approaches 50 percent. Conversely, when *R*1 is much greater than *R*2, the duty cycle approaches 100 percent.
- To make the duty cycle to become less than 50 percent. By placing a diode in parallel with *R*2 (anode connected to pin 7), the capacitor will effectively charge through *R*1 and the diode. The capacitor will discharge through *R*2.

Integrated Circuit(IC) Multivibrators

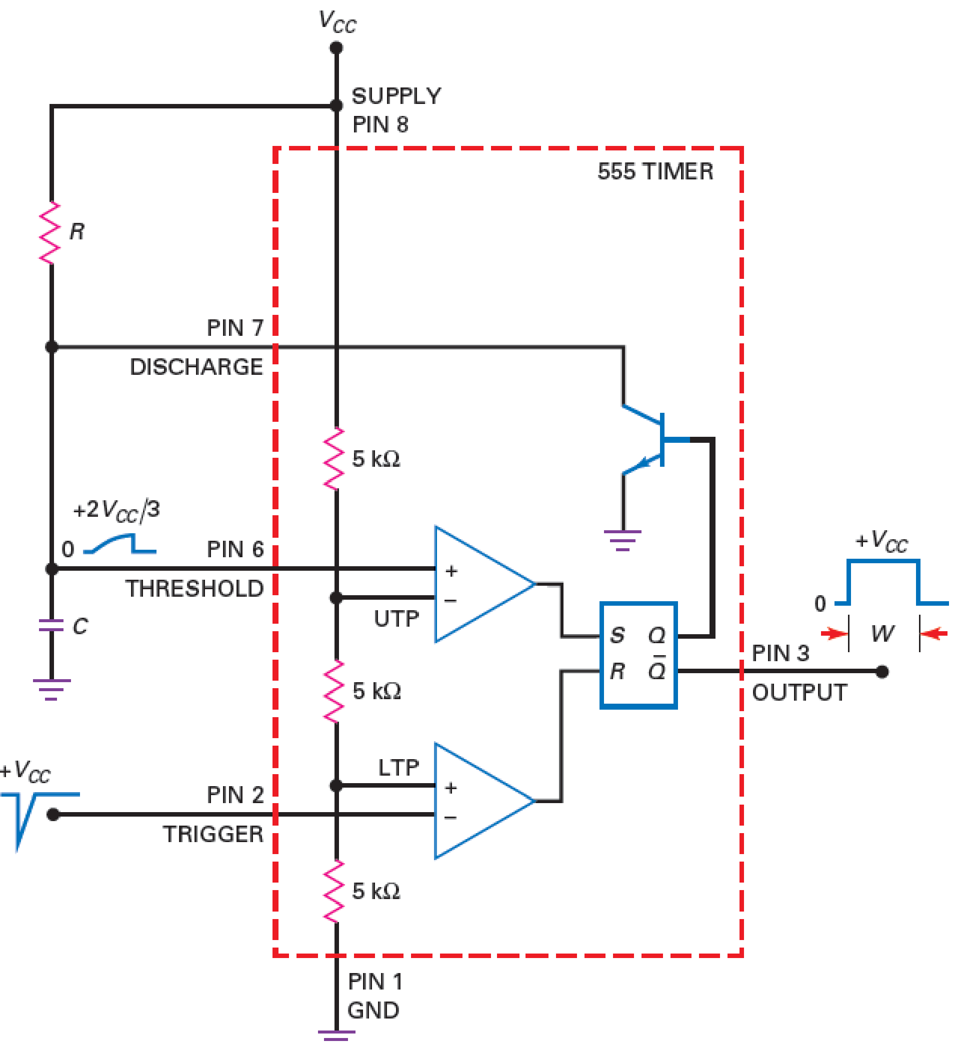
Monostable Operation of the 555 Timer

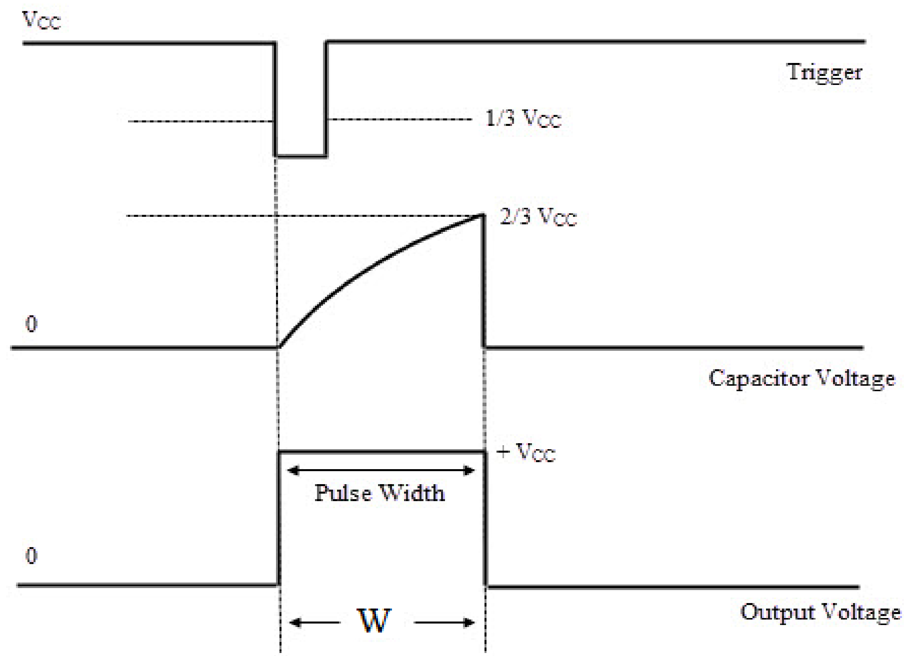


- Pulse Width is
  - W=1.1RC
- The circuit has an external resistor *R* and a capacitor *C*.
- The voltage across the capacitor is used for the threshold voltage to pin 6.
- When the trigger arrives at pin 2, the circuit produces a rectangular output pulse from pin 3.

Integrated Circuit(IC) Multivibrators

Monostable Operation of the 555 Timer

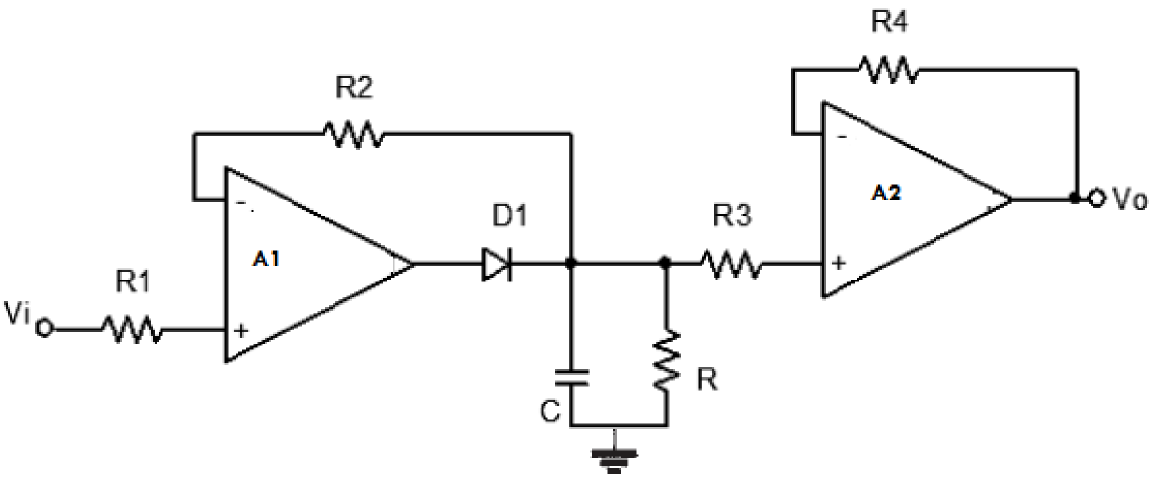


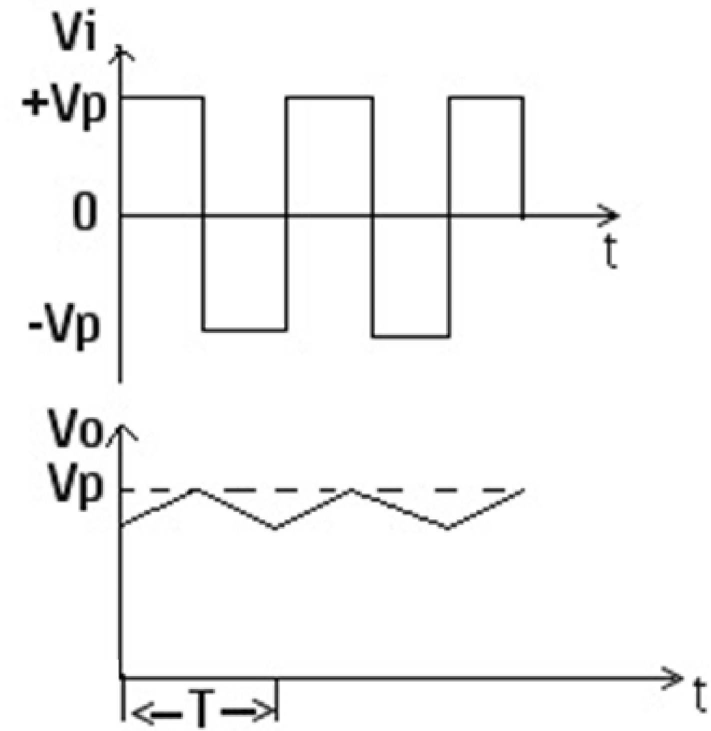


Integrated Circuit(IC) Multivibrators
Monostable Operation of the 555 Timer

- Initially, the Q output of the RS flip-flop is high. This turn ON the transistor and the capacitor discharge to ground through pin 7. The circuit will remain in this state until a trigger arrives at pin 2.
- When the trigger input falls to slightly less than $\frac{1}{3}V_{CC}$ the lower comparator resets the flip-flop. Since Q has changed to low, the transistor goes OFF, allowing the capacitor to charge. At this time, $\bar{Q}$ has changed to high.
- The capacitor now charges exponentially through R as shown in waveform. When the capacitor voltage is slightly greater than $\frac{2}{3}V_{CC}$, the upper comparator sets the flip-flop. The high Q turns ON the transistor, which discharges the capacitor almost instantly. At the same instant, $\bar{Q}$ returns to the low state and the output pulse ends.
- $\bar{Q}$ remains low until another input trigger arrives.

Peak Detector Circuit





- RC ≥ 10T

Applications:

- Used for AM in communication
- Used in test and measurement instrumentation applications.

Peak Detector Circuit

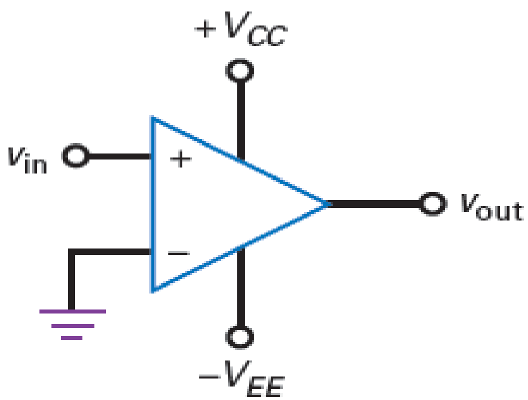
- During +ve half cycle when the input voltage is positive, the diode is conducting/ON and capacitor charges to the peak of the input voltage.
- Second, when the input voltage is negative during –ve half cycle, the diode is non-conducting/OFF and the capacitor discharges through the load resistor.
- As long as the discharging time constant is much greater than the period of the input signal (T), the output voltage will be approximately equal to the peak value of the input voltage.
- This can achieved by making discharging time constant *RC* can be made much longer than the period of the input signal ($RC \geq 10\ T$), will get almost perfect peak detection of low-level signals.
- If the peak-detected signal has to drive a small load, to avoid loading effects by connecting the voltage follower (op-amp buffer) isolates the small load resistor from the peak detector. This prevents the small load resistor from discharging the capacitor too quickly.

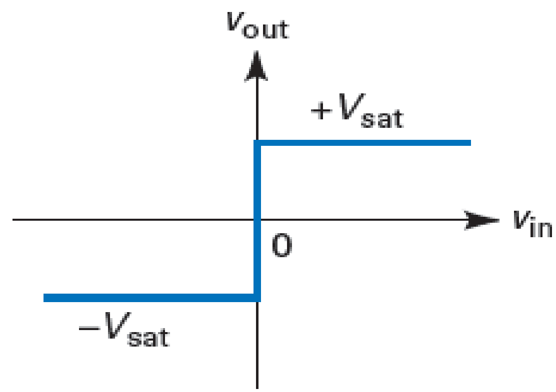
Comparator

- Comparator circuit compares a single voltage on one input of op-amp with a known voltage called reference voltage (Trip point or trigger point) on the other input and produces high or low output depending upon relative magnitude of two input.
  - Comparators with Zero Reference
  - Comparators with Nonzero References
  - Comparators with Hysteresis or Schmitt Trigger
  - Window Comparator

Comparators with Zero Reference

- Non-Inverting Comparator

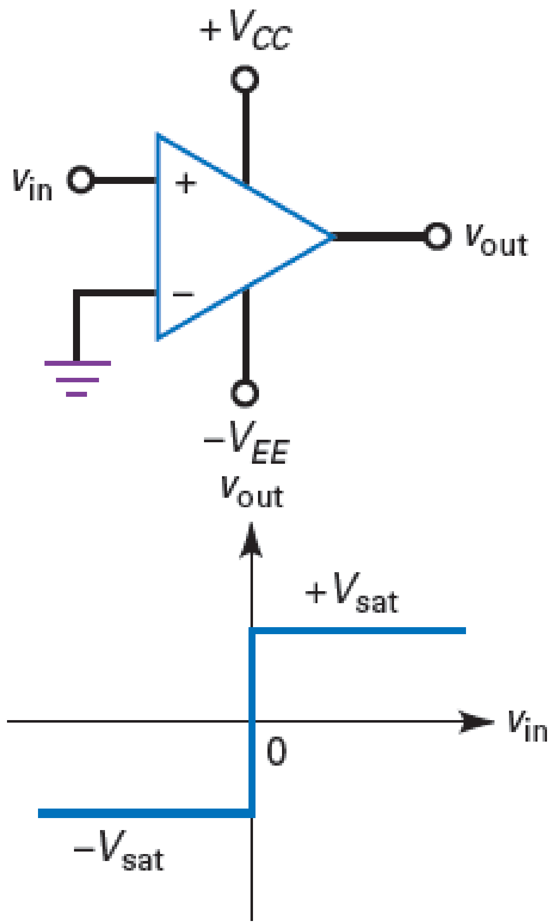


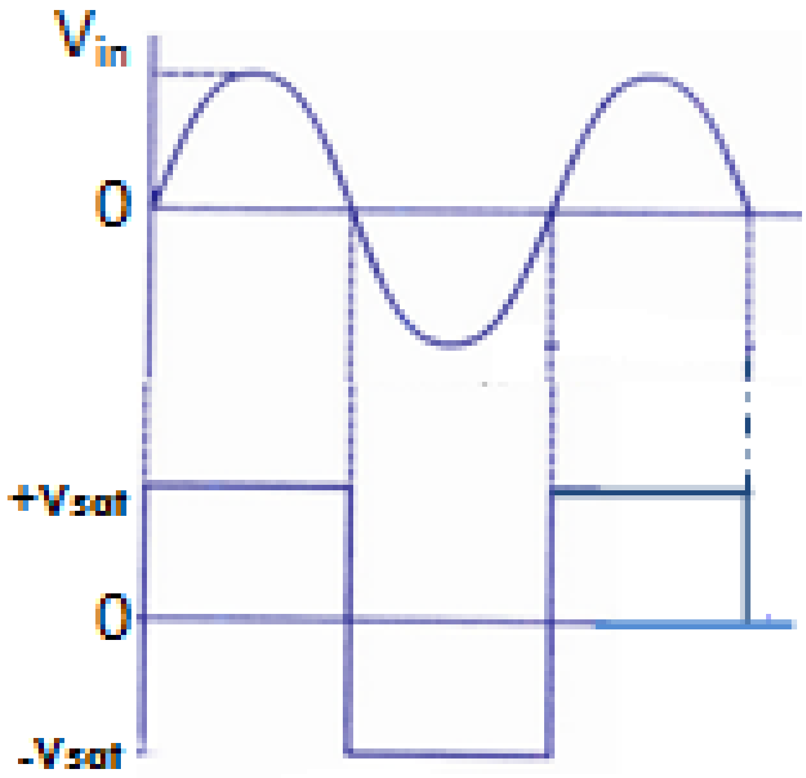


- Because of the high open-loop voltage gain, a positive input voltage produces positive saturation, and a negative input voltage produces negative saturation.
- Above circuit is called a **zero-crossing detector** because the output voltage ideally switches from low to high or vice versa whenever the input voltage crosses zero (input compares with zero reference voltage).

Comparators with Zero Reference

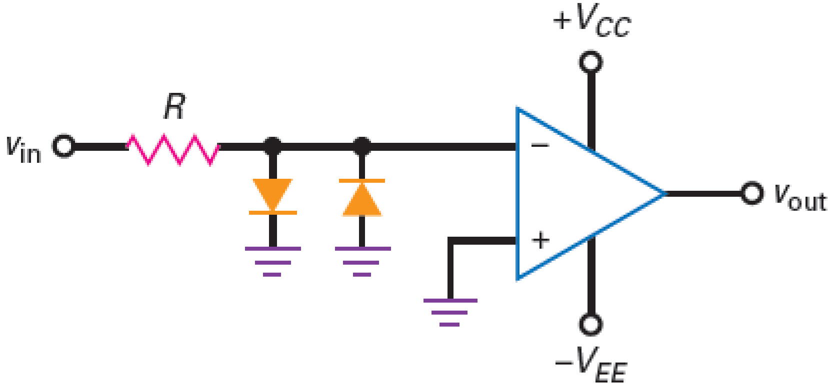
- Non-Inverting Comparator

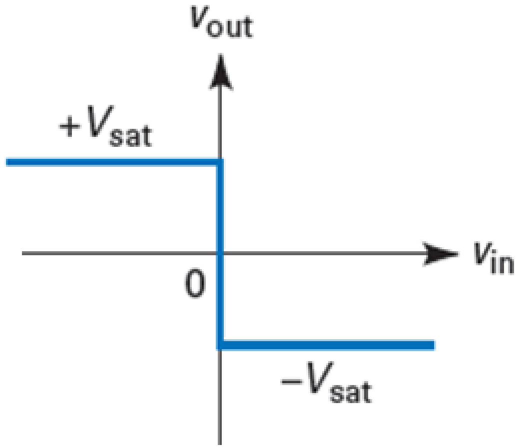




Comparator

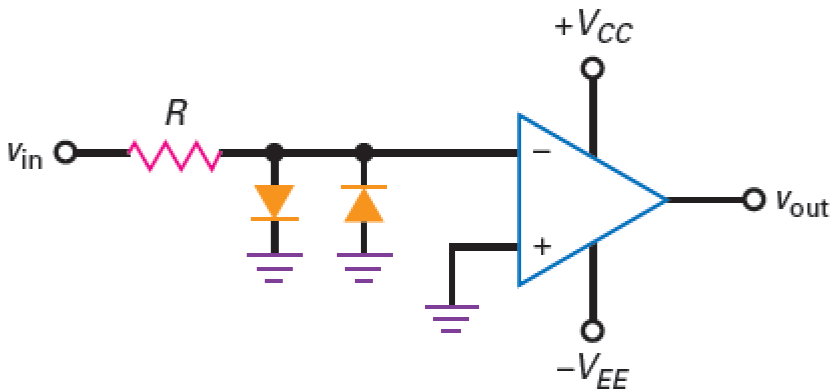
Comparators with Zero Reference

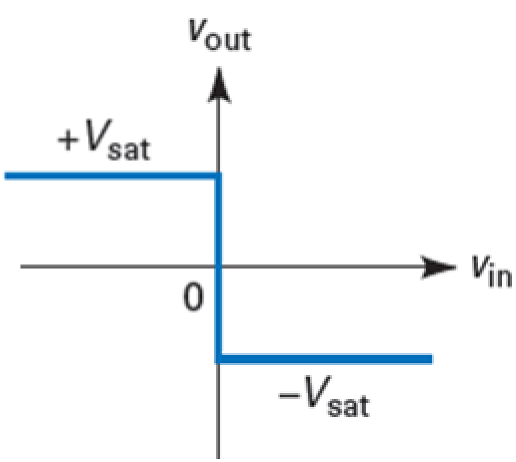


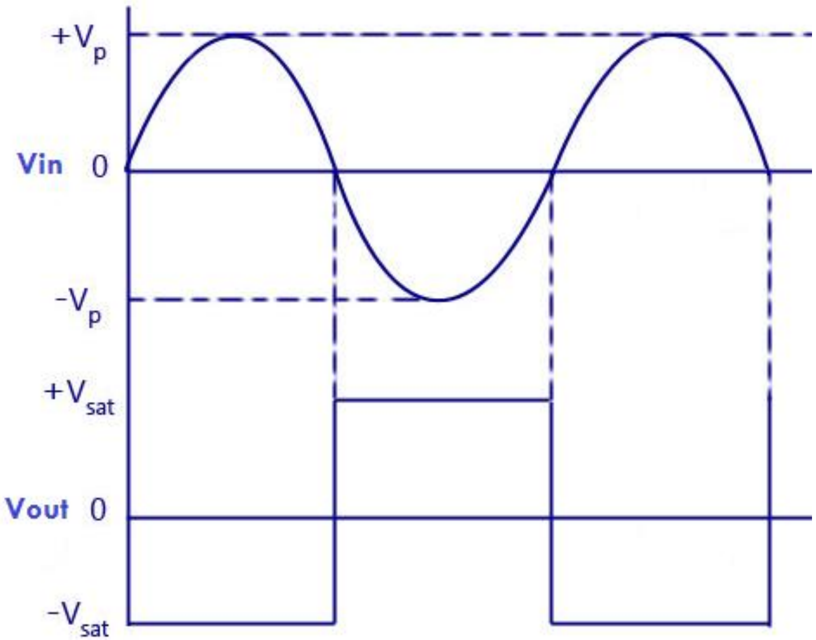


- The input signal drives the inverting input of the comparator. In this case, a positive input voltage produces a maximum negative saturation, as shown in above diagram. On the other hand, a negative input voltage produces a maximum positive saturation.

Comparators with Zero Reference

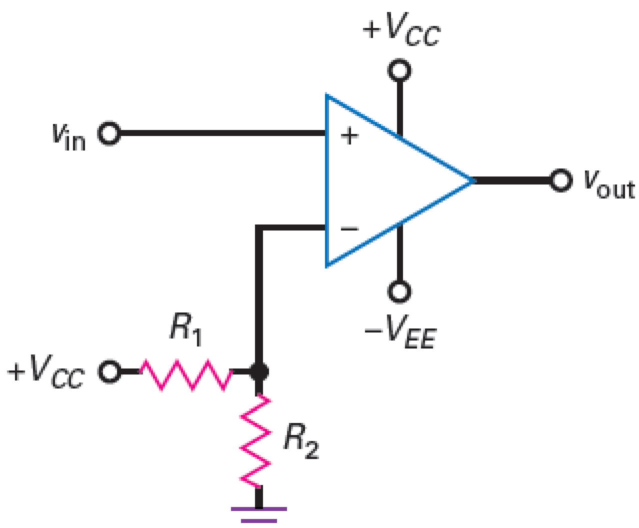




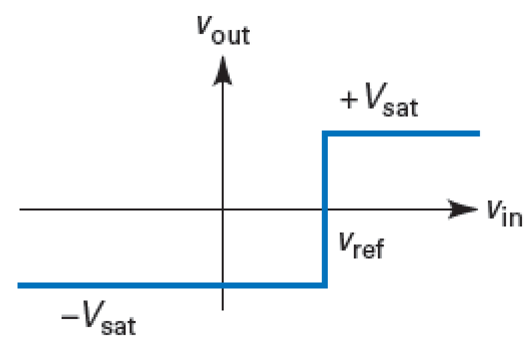


Comparators with Nonzero References

- Non-Inverting Comparator: Positive reference



$$v_{ref} = \frac{R_2}{R_1 + R_2} V_{CC}$$

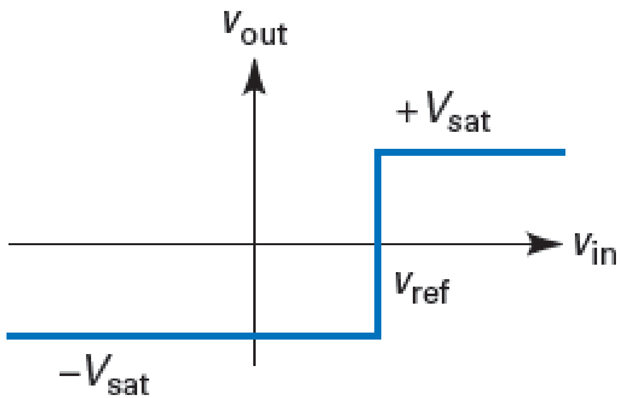


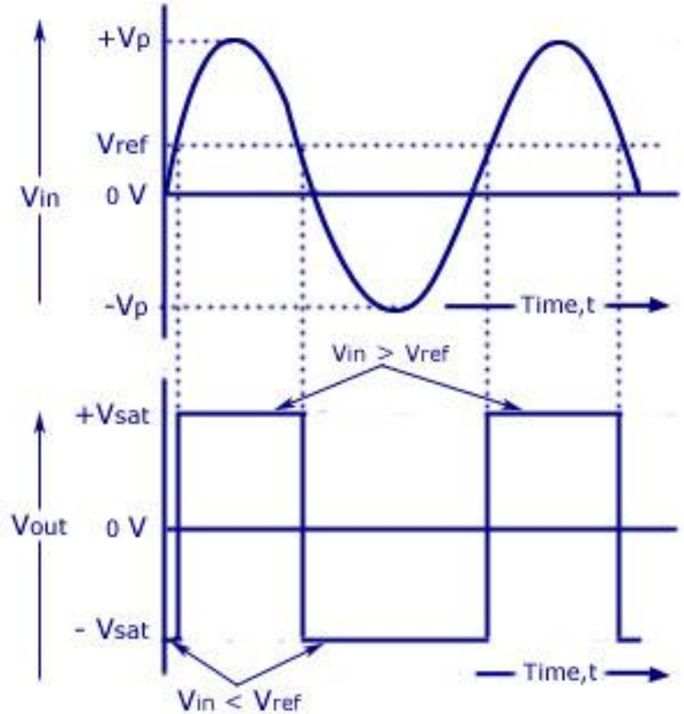
nd the output voltage is high (+Vsat). When *V*in is less than *V*ref, the differential input voltage is negative and the output voltage is low (-Vsat).

- Vin > Vref then Vout = +Vsat
- Vin < Vref then Vout = - Vsat

Comparators with Nonzero References

- Non-Inverting Comparator: Positive reference

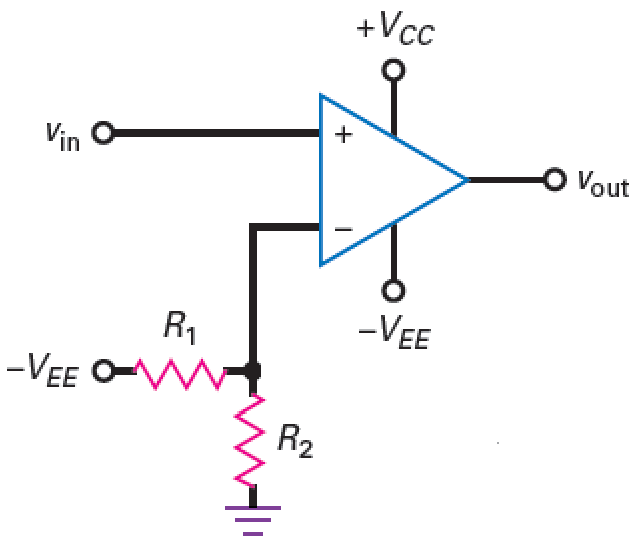




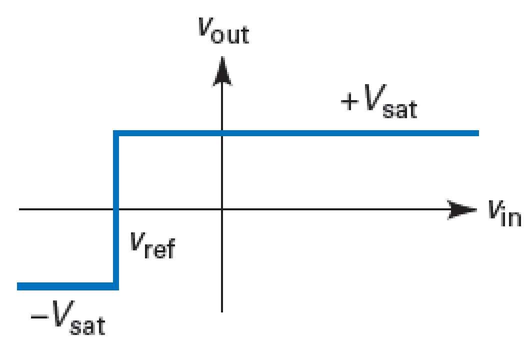
Input and Output Waveforms
For Positive Vref

Comparators with Nonzero References

- Non-Inverting Comparator: Negative reference



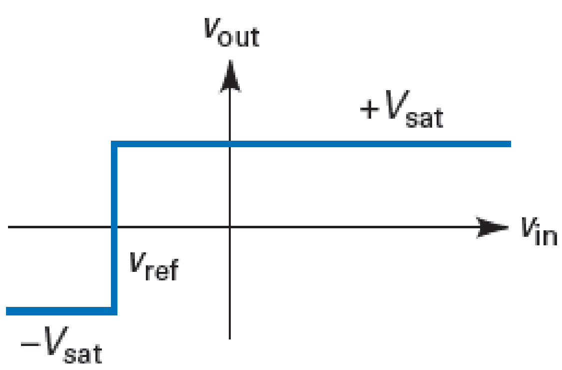
$$v_{ref} = \frac{R_2}{R_1 + R_2} - V_{EE}$$

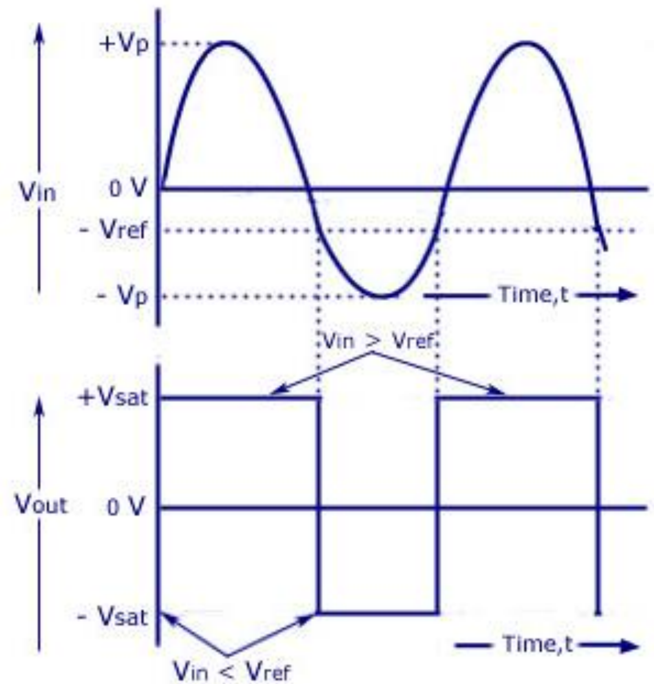


- Vin > Vref then Vout = + Vsat
- Vin < Vref then Vout = - Vsat

Comparators with Nonzero References

- Non-Inverting Comparator: Negative reference



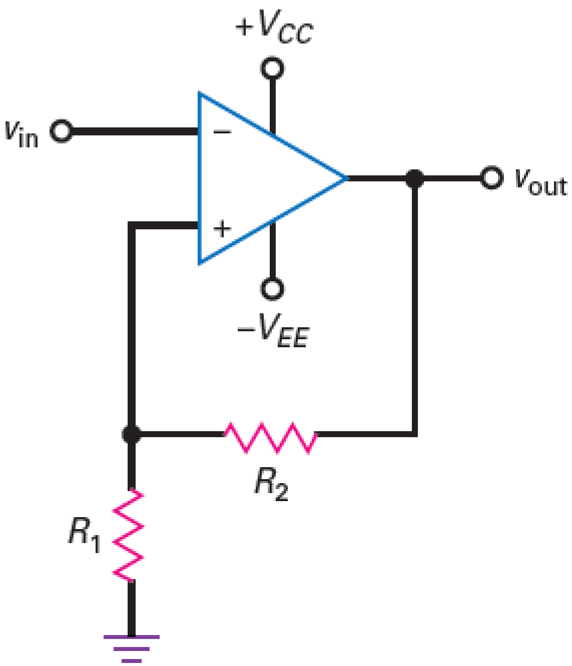


Input and Output Waveforms
For Negative Vref

Comparators with Hysteresis /Schmitt Trigger

- **Inverting Schmitt trigger**
- When the comparator is positively saturated, a positive voltage is fed back to the noninverting input. This positive feedback voltage holds the output in the high state.
- Similarly, when the output voltage is negatively saturated, a negative voltage is fed back to the noninverting input, holding the output in the low state.

Schmitt Trigger

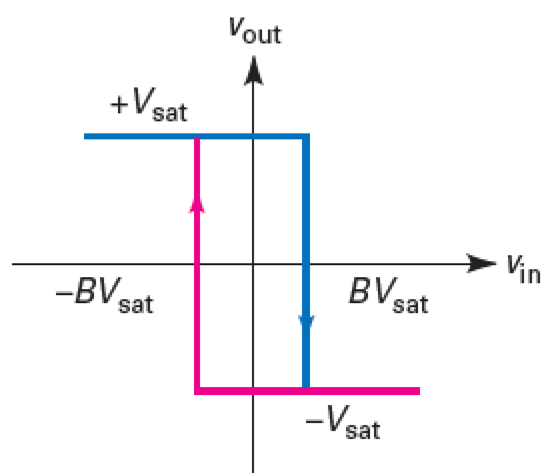
- 

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

$$\text{UTP} = BV_{sat}$$

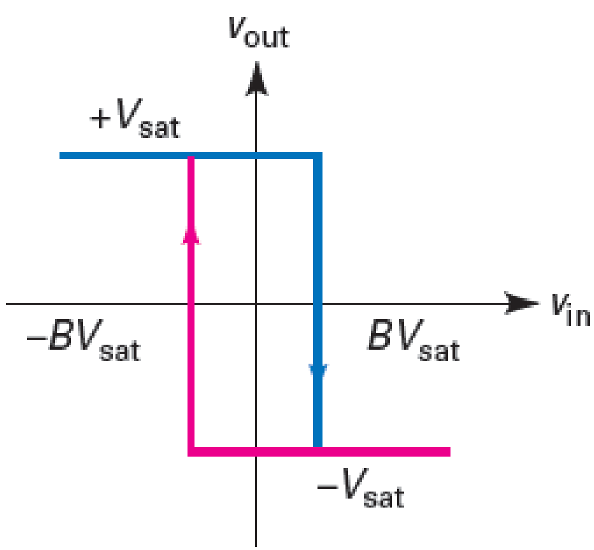
$$\text{LTP} = -BV_{sat}$$

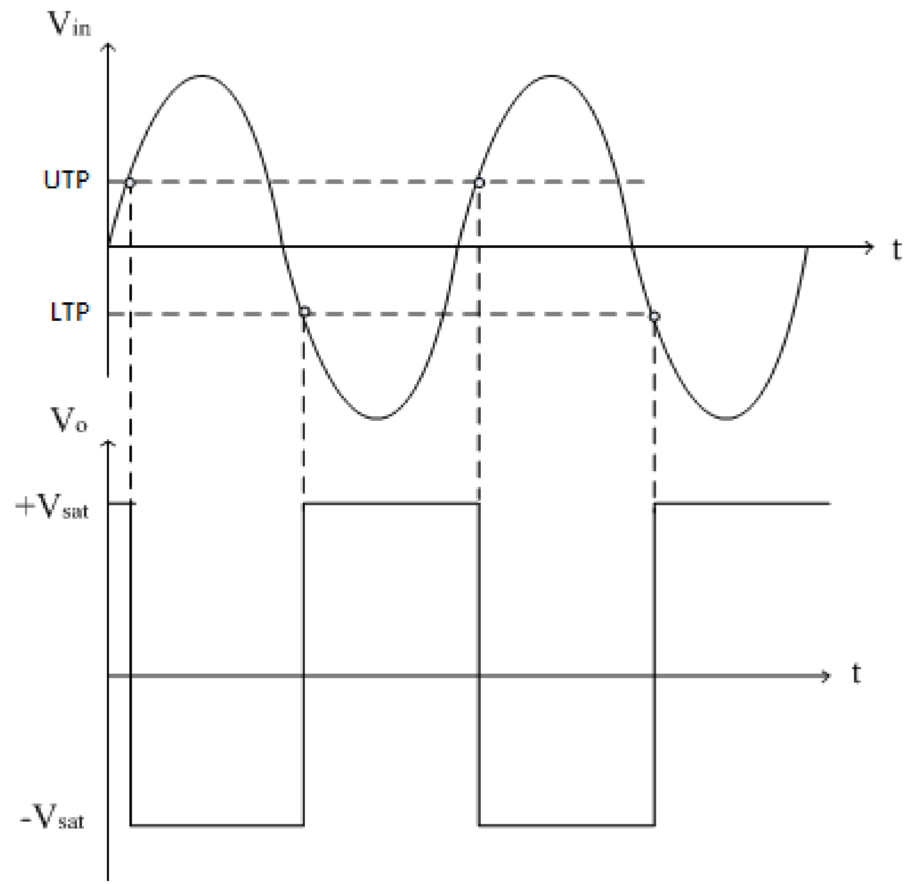
$$V_H = 2BV_{sat}$$



Schmitt Trigger

- **Inverting Schmitt trigger**





Schmitt Trigger

- **Inverting Schmitt trigger**
- The output voltage will remain in a given state until the input voltage exceeds the reference voltage for that state.
- For instance, if the output is positively saturated, the reference voltage is +*BV*sat. The input voltage must be increased to slightly more than +*BV*sat to switch the output voltage from positive to negative, as shown in input/output response has hysteresis.
- Once the output is in the negative state, it will remain there indefinitely until the input voltage becomes more negative than -*BV*sat. Then, the output switches from negative to positive shown in input/output response has hysteresis.

Schmitt Trigger

Applications of Schmitt Trigger:

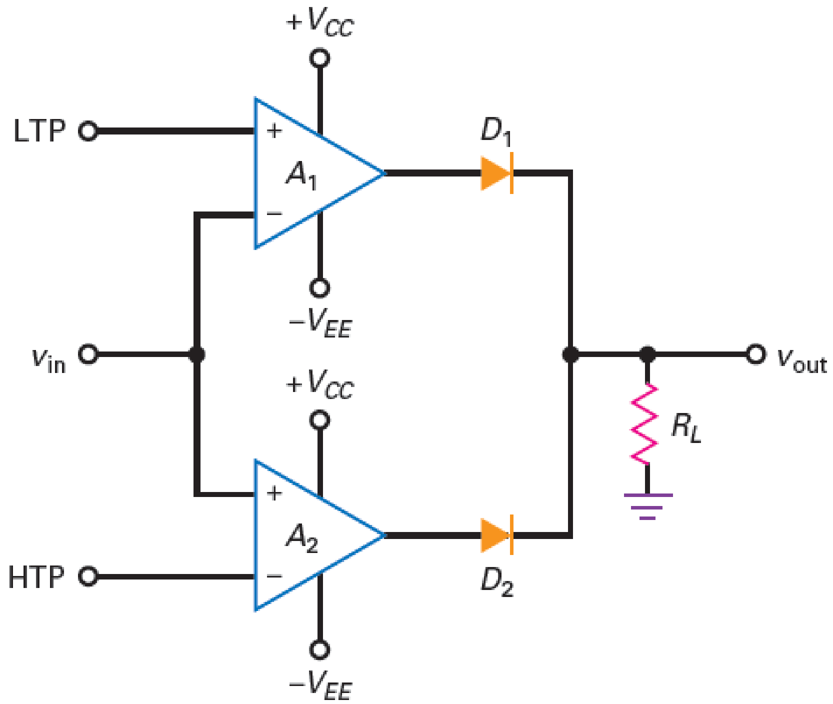
Schmitt trigger is used in many applications, where level needs to be sensed. Hysteresis is used to reduce the multiple transitions that can occur around.

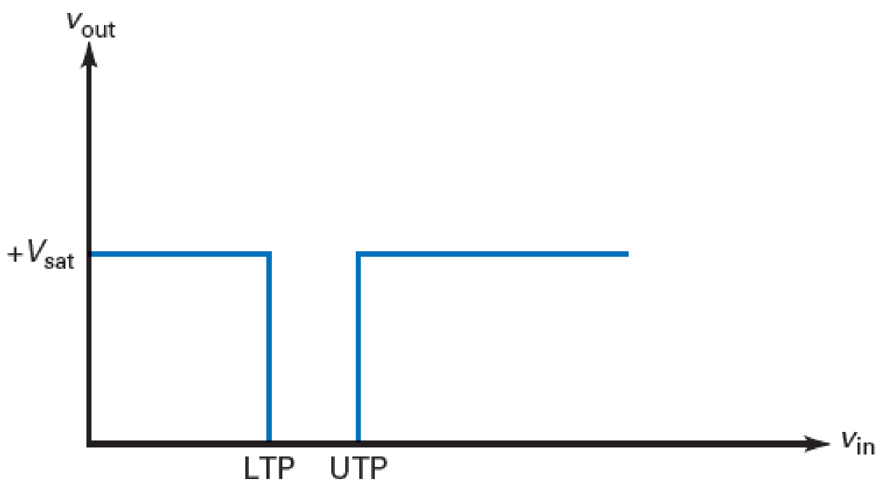
- Digital to analog conversion
- Level detection
- Line reception.

Window Comparator

- An ordinary comparator indicates when the input voltage exceeds a certain limit or threshold.
- A **window comparator** (also called a *double-ended limit detector*) detects when the input voltage is between two limits called the *window*. To create a window comparator, will use two comparators with different thresholds.

Window Comparator





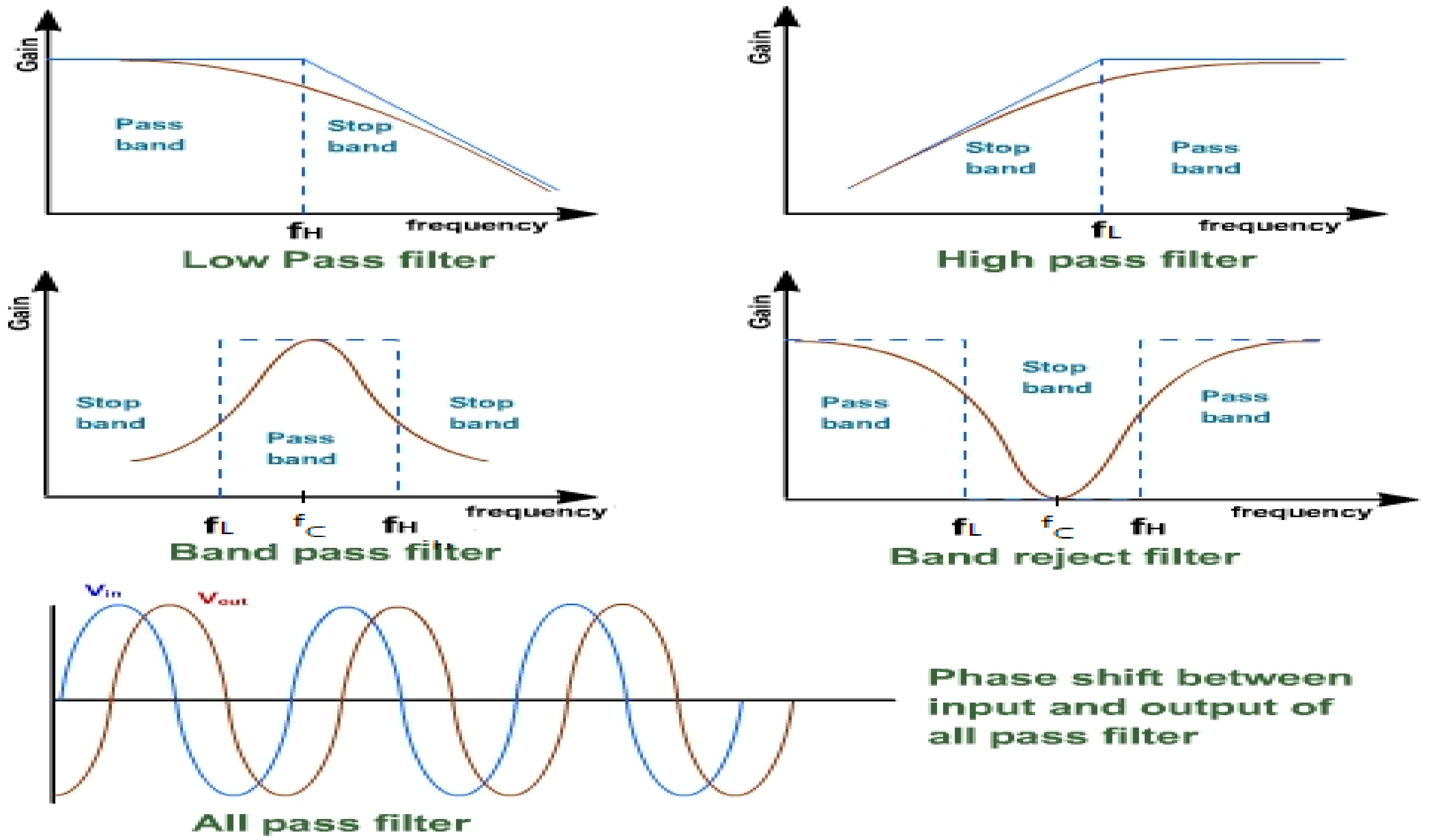
Window Comparator

- **Low Output between Limits**
- Circuit shows a window comparator that can produce a low output voltage when the input voltage is between a lower and an upper limit.
- When *V*in is less than LTP or greater than UTP, the output is high. When *V*in is between LTP and UTP, the output is low.
- Operation:
  - When *V*in < LTP, comparator *A*1 has a positive output and *A*2 has a negative output. Diode *D*1 is on and *D*2 is off. Therefore, the output voltage is high.
  - Similarly, when *V*in > UTP, comparator *A*1 has a negative output and *A*2 has a positive output. Diode *D*1 is off, *D*2 is on, and the output voltage is high.
  - When LTP < *V*in < UTP, *A*1 has a negative output, *A*2 has a negative output, *D*1 is off, *D*2 is off, and the output voltage is low.

Active Filters

- An electric filter is often a frequency selective circuit that passes a specified band of frequency and blocks or attenuates signals of frequencies outside this band.
- Active filters employs transistor or op-amp in addition to resistor and capacitor.
- RC network are used for filter.
- The most commonly used filters are follows:
  - Low pass filters
  - High pass filter
  - Band pass filter
  - Band reject filter.
  - All pass filter
- Next slide shows the frequency response characteristics of the five types of filter. The ideal response is shown by dashed line. While the solid lines indicates the practical filter response.

Active Filters

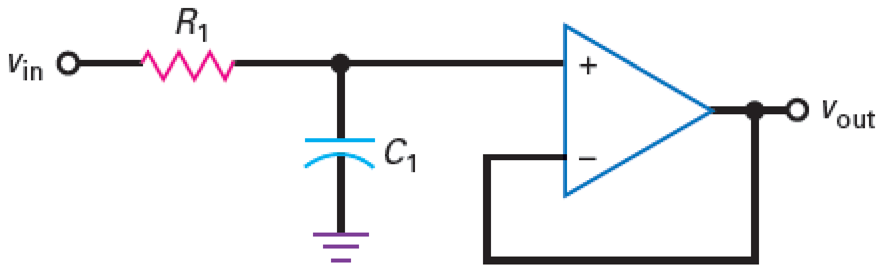


Active Filters

- A filter that provides a constant output from dc up to a cut-off frequency f_H and then passes no signal above that frequency is called an ideal low-pass filter.
- A filter that provides or passes signals above a cutoff frequency f_L is a high-pass filter, as shown in previous slide.
- When the filter circuit passes signals that are above one ideal cutoff frequency (f_L) and below a second cutoff frequency, (f_H) it is called a bandpass filter.
- Two types of filters
  - First Order Filter – One capacitor used
  - Second Order Filter – Two or more capacitor used

Active Filters- **Low-pass filter**

- **Non-Inverting unity gain**



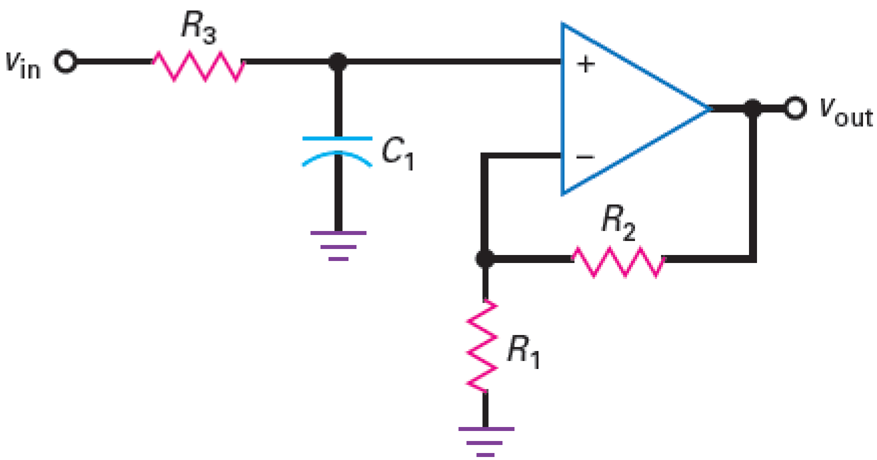
$$A_v = 1$$

$$f_c = \frac{1}{2\pi R_1 C_1}$$

  - It is nothing more than an *RC* lag circuit and a voltage follower. The voltage gain is: *Av* = 1.
  - When the frequency increases above the cutoff frequency, the capacitive reactance decreases and reduces the noninverting input voltage.
  - Since the *R1C1* lag circuit is outside the feedback loop, the output voltage rolls off. As the frequency approaches infinity, the capacitor becomes a short and there is zero input voltage.

Active Filters- **Low-pass filter**

- **Non-Inverting with voltage gain**



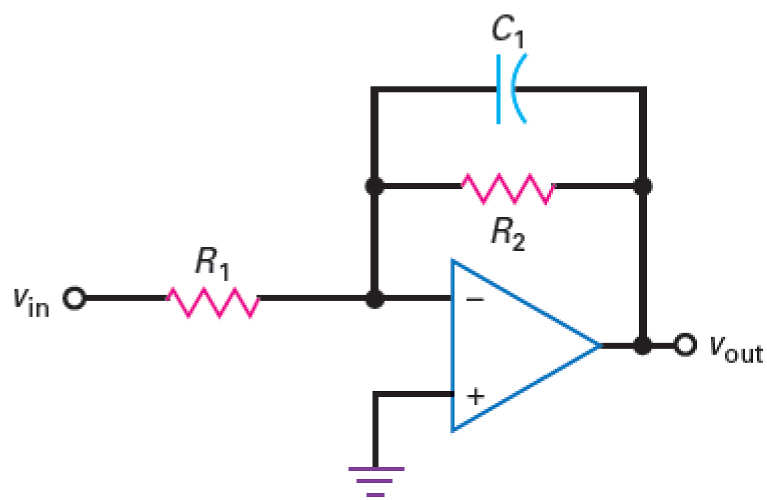
$$A_v = \frac{R_2}{R_1} + 1$$

$$f_c = \frac{1}{2\pi R_3 C_1}$$

  - Although it has two additional resistors, it has the advantage of voltage gain.

Active Filters- **Low-pass filter**

- **Inverting with voltage gain**



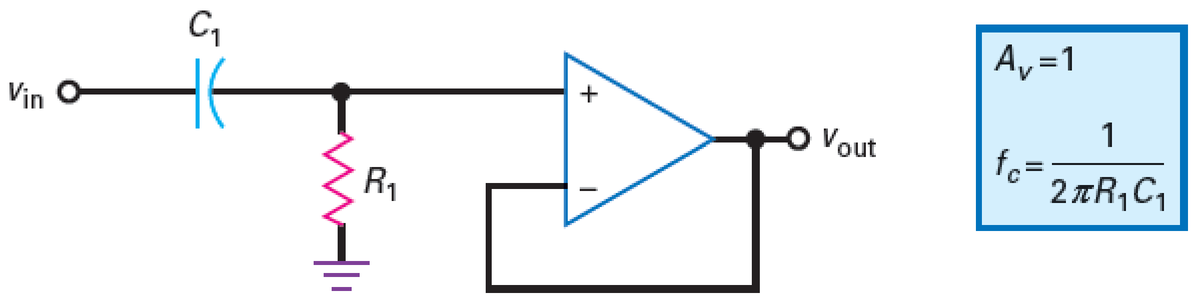
$$A_v = \frac{-R_2}{R_1}$$

$$f_c = \frac{1}{2\pi R_2 C_1}$$

  - As the frequency increases, the capacitive reactance decreases and reduces the impedance of the feedback branch. This implies less voltage gain.
  - As the frequency approaches infinity, the capacitor becomes a short and there is no voltage gain.

Active Filters- **High-pass filter**

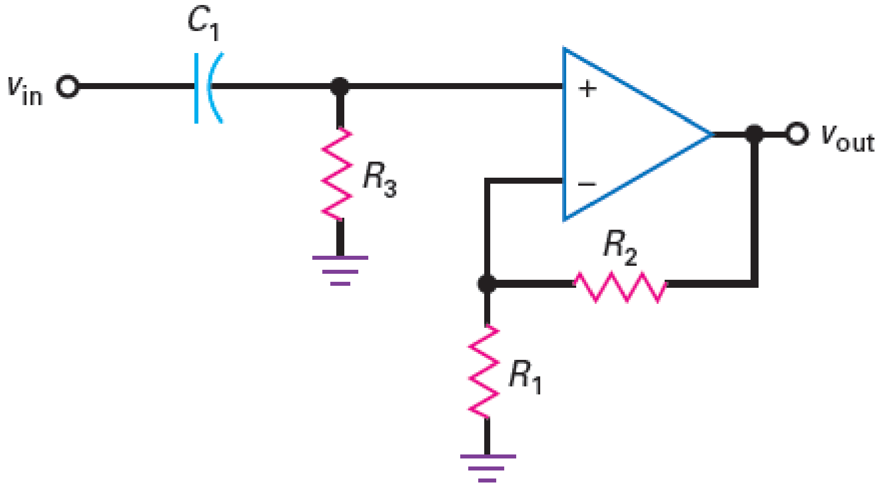
- **Non inverting unity gain**



- When the frequency decreases below the cutoff frequency, the capacitive reactance increases and reduces the noninverting input voltage.
- Since the *R1C1* circuit is outside the feedback loop, the output voltage rolls off. As the frequency approaches zero, the capacitor becomes an open and there is zero input voltage.

Active Filters- **High-pass filter**

- **Non-Inverting with voltage gain**

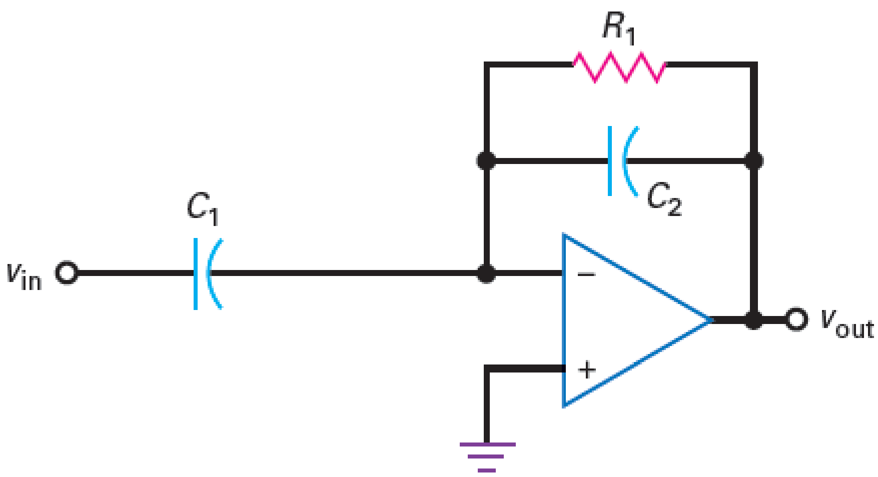


$$A_v = \frac{R_2}{R_1} + 1$$

$$f_c = \frac{1}{2\pi R_3 C_1}$$

Active Filters- **High-pass filter**

- **Inverting with voltage gain**

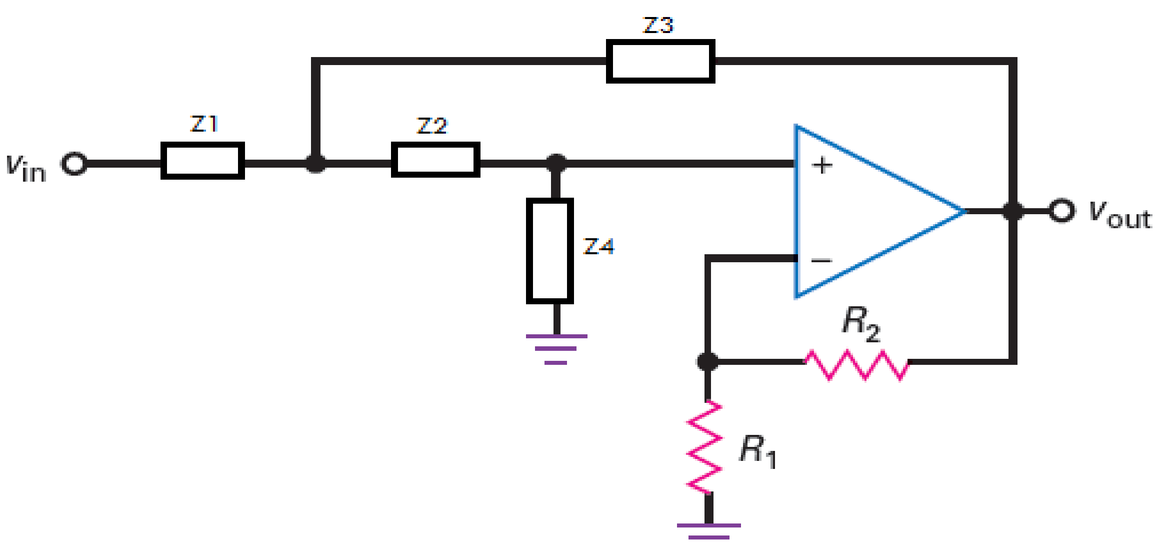


$$A_v = \frac{-C_1}{C_2}$$

$$f_c = \frac{1}{2\pi R_1 C_2}$$

Active Filters- Second Order Filter
Low Pass/High Pass Filter

- **Generalized form of second order filter**



$$A_v = \frac{R_2}{R_1} + 1$$

$$Q = \frac{1}{3 - A_v}$$

$$f_p = \frac{1}{2\pi RC}$$

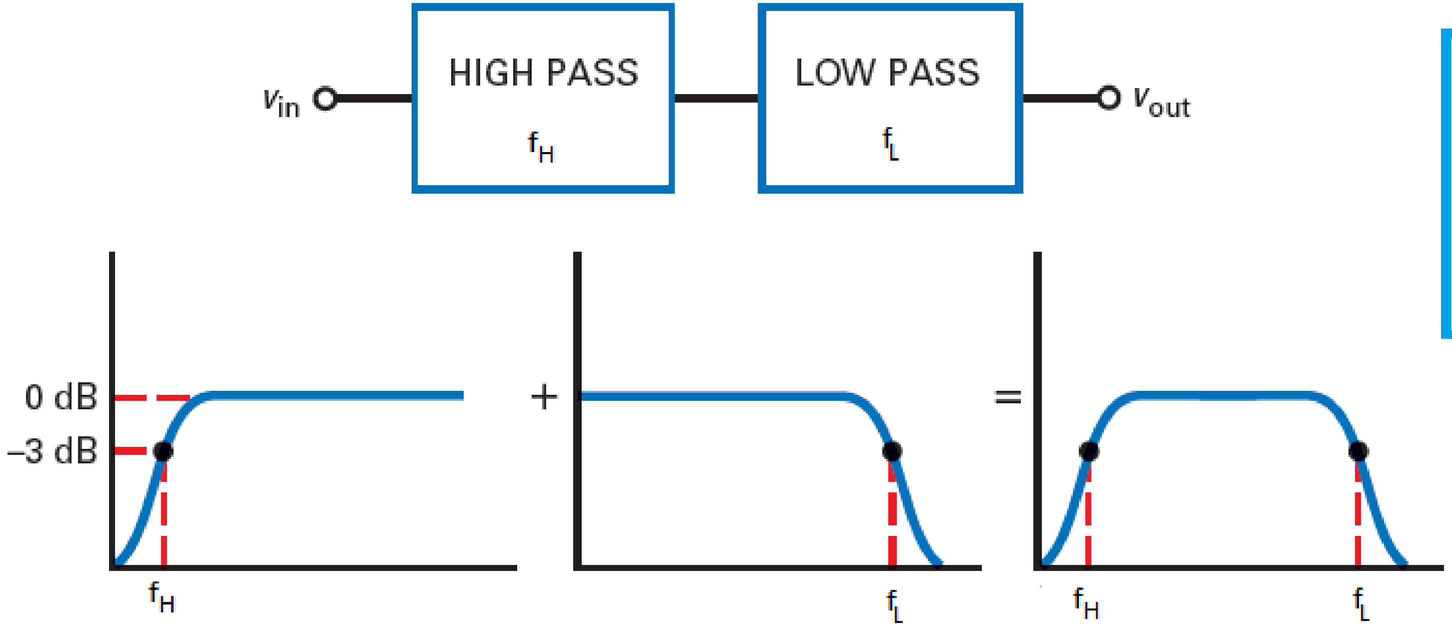
- If Z1=Z2=R and Z3=Z4=C get second order low pass filter
- If Z1=Z2=C and Z3=Z4=R get second order high pass filter

Active Filters- **Band-pass Filter**

- Two types of band pass filter
  - Wide band pass filter
  - Narrow band pass filter

Active Filters- **Band-pass Filter**

- **Wide Band Pass Filters**
  - Cascade of low-pass and high-pass filter



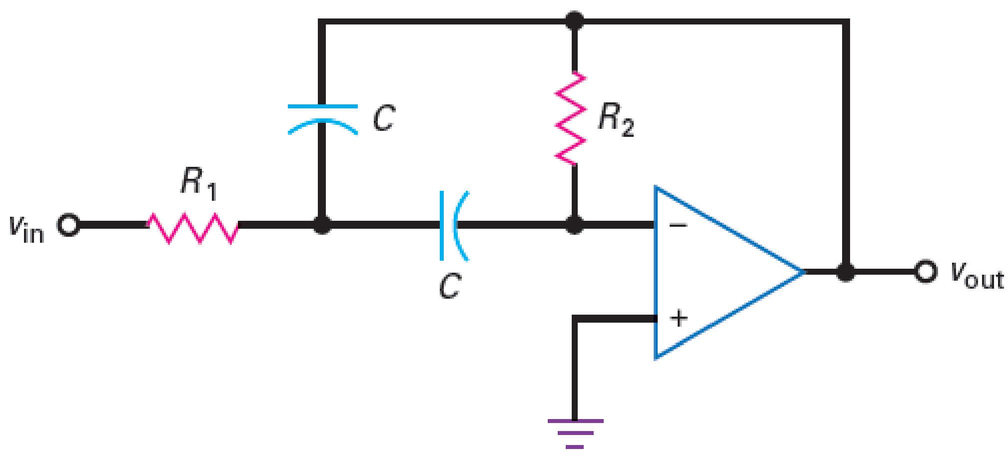
$$f_0 = \sqrt{f_1 f_2}$$

$$\mathrm{BW} = f_2 - f_1$$

$$Q = \frac{f_0}{\mathrm{BW}}$$

Active Filters- **Band-pass Filter**

- **Narrow Band Pass Filters**



$$A_v = \frac{-R_2}{2R_1}$$

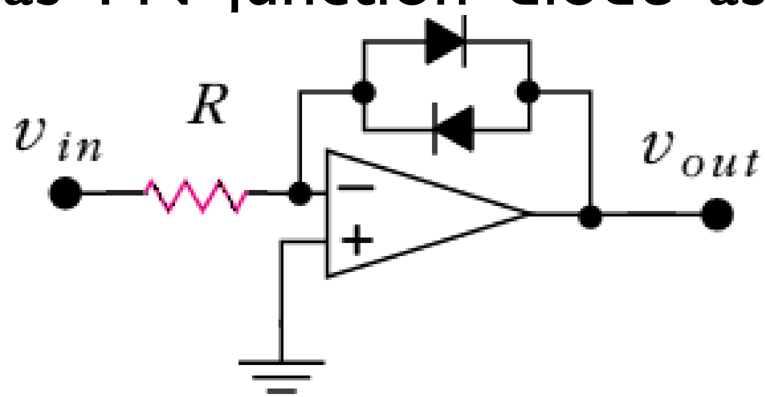
$$Q = 0.5\sqrt{\frac{R_2}{R_1}}$$

$$f_0 = \frac{1}{2\pi C\sqrt{R_1 R_2}}$$

- In the circuit the input signal goes to the inverting input rather than the noninverting input. Also the circuit has two feedback paths, one through a capacitor and another through a resistor.

Non-Linear Amplifier

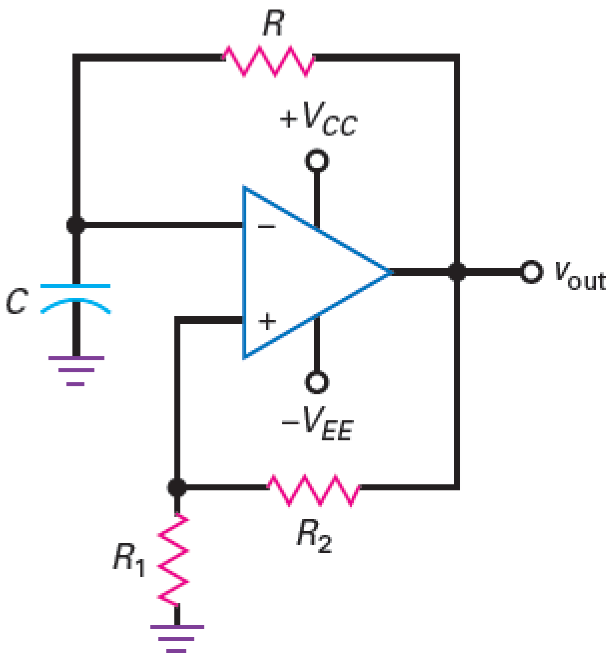
- In this amplifier the gain value is non-linear function of the amplitude of the input signal.
- The gain may be large for weak signal and very small for large signal this can achieved using non-linear device such as PN junction diode as shown below. Also called l

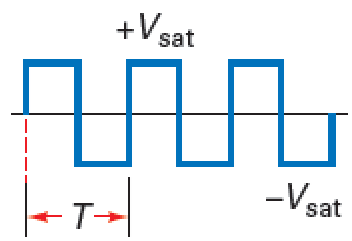


Non-Linear Amplifier

- **Working:**
  - For small value of input signal, diodes act as open circuit and the gain is high due to minimum feedback.
  - When the amplitude of input signal is large, diodes offer very small resistance and thus gain is low.

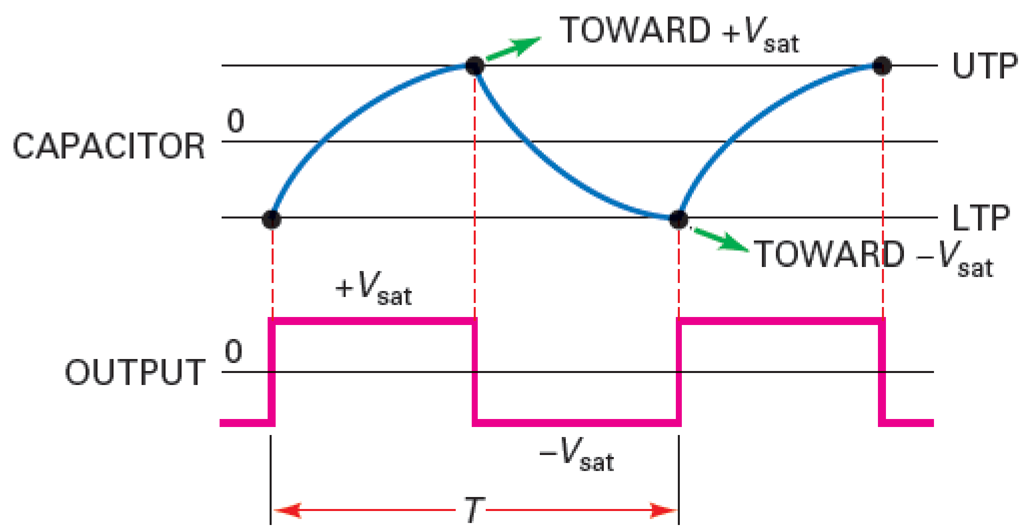
Relaxation Oscillator





$$T = 2RC \ln \frac{1 + B}{1 - B}$$

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

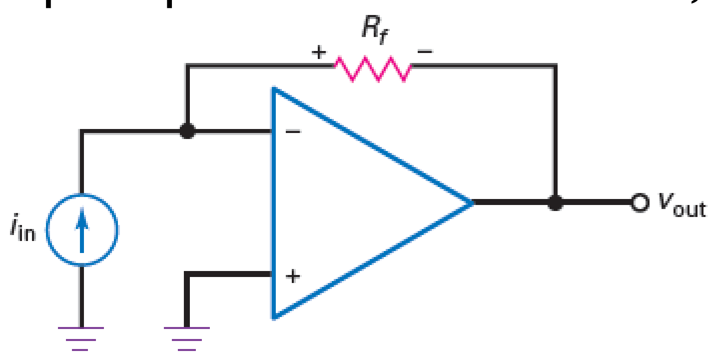


Relaxation Oscillator

- In circuit, there is no input signal.
- Nevertheless, the circuit produces a rectangular output signal. This output is a square wave that swings between –*V*sat and +*V*sat. How is this possible?
- Assume that the output is in positive saturation. Because of feedback resistor *R*, the capacitor will charge exponentially toward +*V*sat, as shown in waveform. But the capacitor voltage never reaches +*V*sat because the voltage crosses the UTP. When this happens, the output square wave switches to –*V*sat.
- With the output now in negative saturation, the capacitor discharges, as shown in waveform. When the capacitor voltage crosses through zero, the capacitor starts charging negatively toward –*V*sat. When the capacitor voltage crosses the LTP, the output square wave switches back to +*V*sat. The cycle then repeats.

Current-To-Voltage Converter

- Also called transimpedance amplifier
- Consider the simple Op-Amp circuit to convert *I to V, as shown in the following Figure.*



Since, current through the Op-Amp is negligible; $I_S = I_f$

$$I_s = I_f = \frac{V_B - V_0}{R_f}$$

By virtual ground concept; as node *A* is grounded, node *B* will be virtually grounded. Therefore, $V_B = 0$.

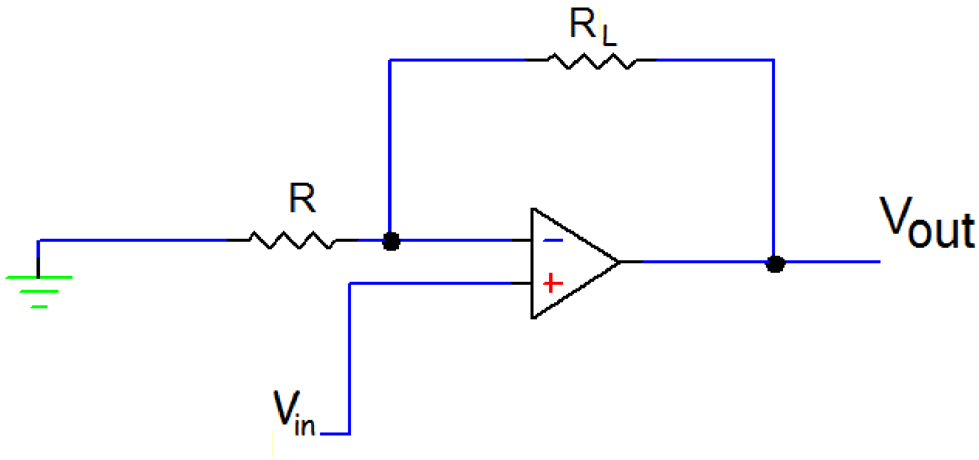
Therefore,

$$I_s = \frac{-V_0}{R_f} \quad Or, \quad V_0 = I_S R$$

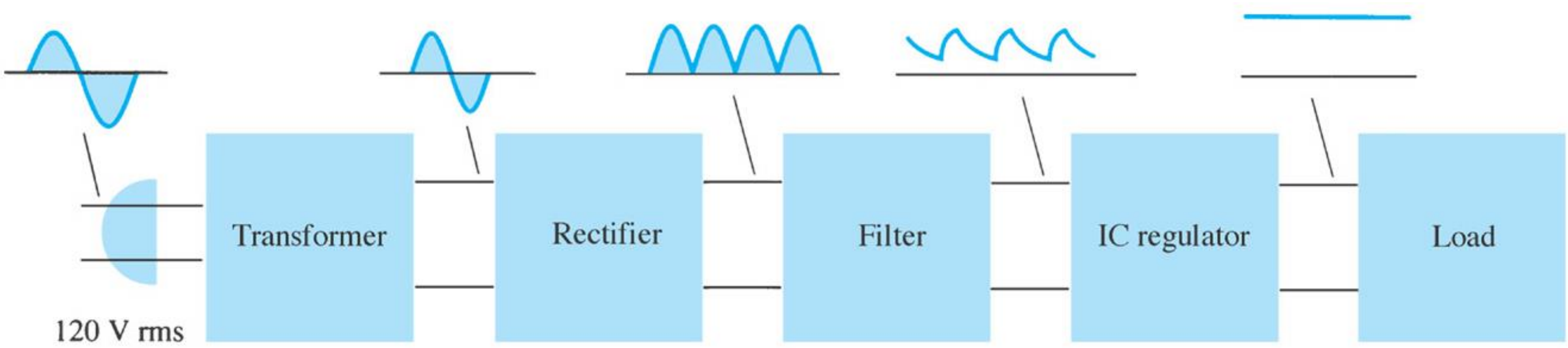
Thus, output is proportional to the input current I_S, and the circuit works as *I* to *V* converter.

Voltage-To-Current Converter

- Also called transconductance amplifier
- For a single input, the current in the load resistor is given by $I_L = I = Vin/R$. from this equation it is obvious that the output current I_L is independent of load resistance and is proportional to the input voltage. This is because of the virtual ground at the inverting input terminal of the op-amp.



VOLTAGE REGULATORS :Introduction



- ***Power supply***: a group of circuits that convert the ***standard ac voltage*** (120V, 60 Hz) provided by the wall outlet to ***constant dc voltage***
- ***Transformer*** : a device that step up or step down the ***ac voltage*** provided by the wall outlet to a desired amplitude through the *action* of a *magnetic field*
- .

VOLTAGE REGULATORS :Introduction

- ***Rectifier***: a diode circuits that converts the ***ac input voltage*** to a ***pulsating dc voltage***
- The pulsating dc voltage is **only suitable** to be used as a battery charger, but **not good enough** to be used as a dc power supply in a radio, stereo system, computer and so on.
- ***Filter***: a circuit used to reduce the fluctuation in the rectified output voltage or ripple. This provides a ***steadier*** dc voltage.
- ***Regulator***: a circuit used to produces a ***constant*** dc output voltage by reducing the ripple to negligible amount. One part of power supply.

VOLTAGE REGULATORS :Introduction

- Voltage regulation is the process of keeping a voltage steady under conditions of changing applied voltage, changing load and temperature.
- There are two types of voltage regulators: shunt and series.

NEED FOR REGULATORS

A voltage regulator is used for two reasons:-

- To regulate or vary the output voltage of the circuit.
- To keep the output voltage constant at the desired value in-spite of variations in the supply voltage or in the load current.

VOLTAGE REGULATORS:

Factors Affecting the Load Voltage:

1. ***Load current (I_L):*** Ideally the output voltage should remain constant in-spite of changes in the load current, but practically the power supply without regulator, the load voltage decreases as load current, I_L, increases. For practical power supply regulator, the load voltage must be constant through load to full load condition.
2. ***Line voltage:*** The input to the rectifier is AC (230 V) is the line voltage. This input decides the output voltage level. If input changes, output also changes. So this affects the performance of power supply. So ideally voltage must remain constant irrespective of any changes in the line voltage.
3. ***Temperature:*** In the power supply, the rectifier unit is used which uses PN-junction diode. As the diode characteristics are temperature dependent, the overall performance of the power supply is temperature dependent.

VOLTAGE REGULATORS:
Performance Parameters of a Power Supply:

1. ***Line Regulation:*** If the input to the rectifier unit i.e. 230 V changes, the output DC of rectifier will also change and since the output of rectifier is applied to the regulator, the output of regulator will also vary. Thus the source causes the change in output. This is as *source regulation* or *line regulation*. It is defined as the change in regulated DC output for a given change in input (line) voltage. Ideally the source regulation should be zero and practically it should be as low as possible.
2. ***Load Regulation:*** *Load regulation* is defined as the change in the regulated output voltage when load current is changed from zero (no load) to maximum value (full load). The load regulation ideally should be zero, but practically it should be as small as possible. The following Figure shows the load regulation characteristics. Percentage load regulation $= \left[\frac{V_{NL} - V_{FL}}{V_{FL}}\right] * 100$

VOLTAGE REGULATORS:

Performance Parameters of a Power Supply:

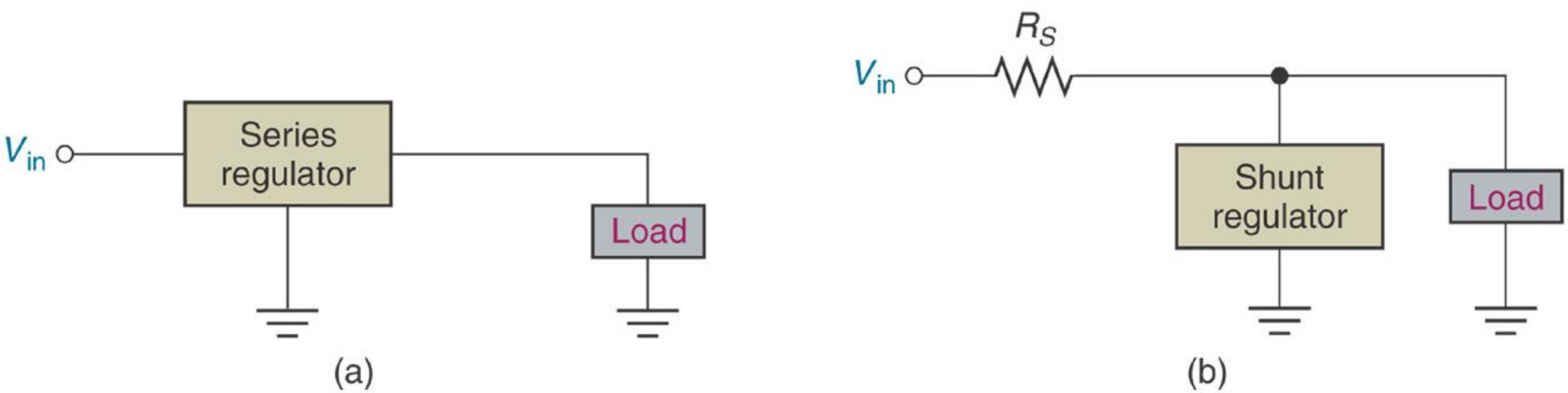
3. ***Voltage Stability factor (S_V):*** *Voltage stability factor* shows the dependency of output voltage on the input line voltage. *Voltage stability factor* is defined as the percentage change in the output voltage which occurs per volt change in input voltage, where load current and temperature are assumed to be constant. Smaller the value of this factor, better is the performance of power supply.
4. ***Temperature Stability Factor (S_r):*** As in the chain of power supply we are using semiconductor devices (diodes in rectifier block) the output voltage is temperature dependent. Thus the *temperature stability* of the power supply will be determined by temperature coefficients of various temperature sensitive semiconductor devices. So, it is better to choose the low temperature coefficient devices to keep output voltage constant and independent of temperature. S_r must be as small as possible, and ideally it should it should be zero for a power supply.
5. ***Ripple Rejection Factor (RR):*** The output of rectifier and filter consists of ripples. *Ripple rejection* is defined as a factor which shows how effectively the regulator rejects the ripples and attenuates it from input to output. As ripples in the output are small compared to input, the *RR* is very small and in dB, it is in negative value. Ripple rejection factor $= \frac{V_{RIPPLE}\ (OUTPUT)}{V_{RIPPLE}\ (INPUT)}$

When expressed in decibels, ripple rejection equals 20 log $\left[\frac{V_{RIPPLE}\ (OUTPUT)}{V_{RIPPLE}\ (INPUT)}\right] dB$

$$\text{Also, } V_{RIPPLE}\,(output) = \frac{V_{RIPPLE}\ (INPUT)}{1+Loop\ Gain}$$

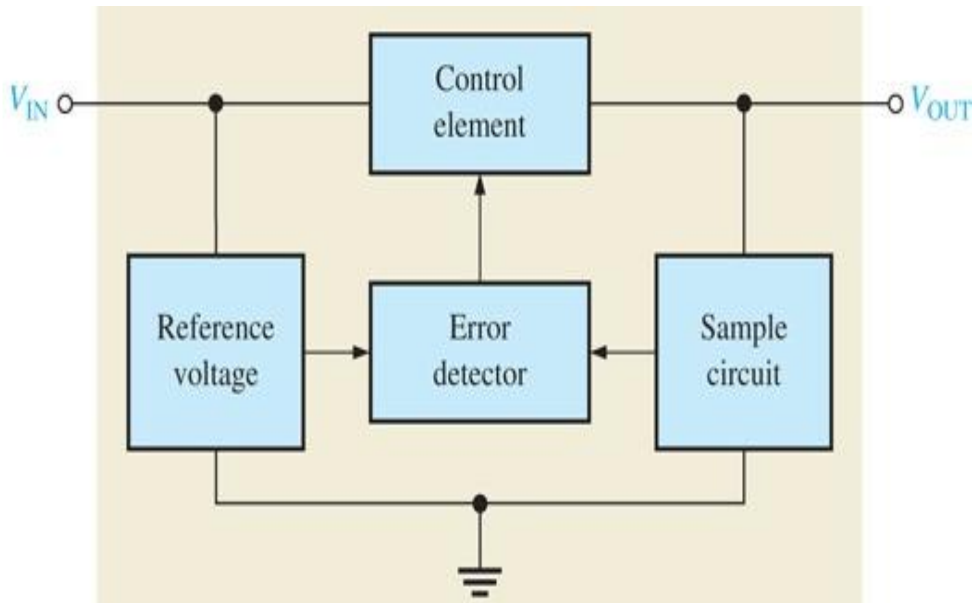
VOLTAGE REGULATORS: Types of Regulator

- The series regulator is connected in **series** with the load
- The shunt regulator is connected in **parallel** with the load.



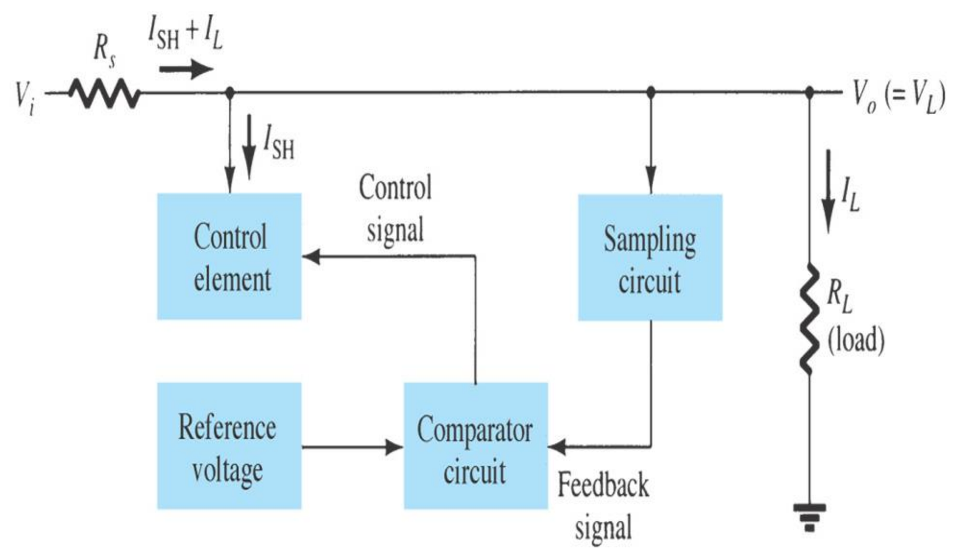
VOLTAGE REGULATORS: Series Regulator Circuit

- **Control element** in series with load between input and output.
- Output **sample circuit** senses a change in output voltage.
- **Error detector** compares sample voltage with reference voltage → causes control element to compensate in order to maintain a constant output voltage



VOLTAGE REGULATORS: Series Regulator Circuit

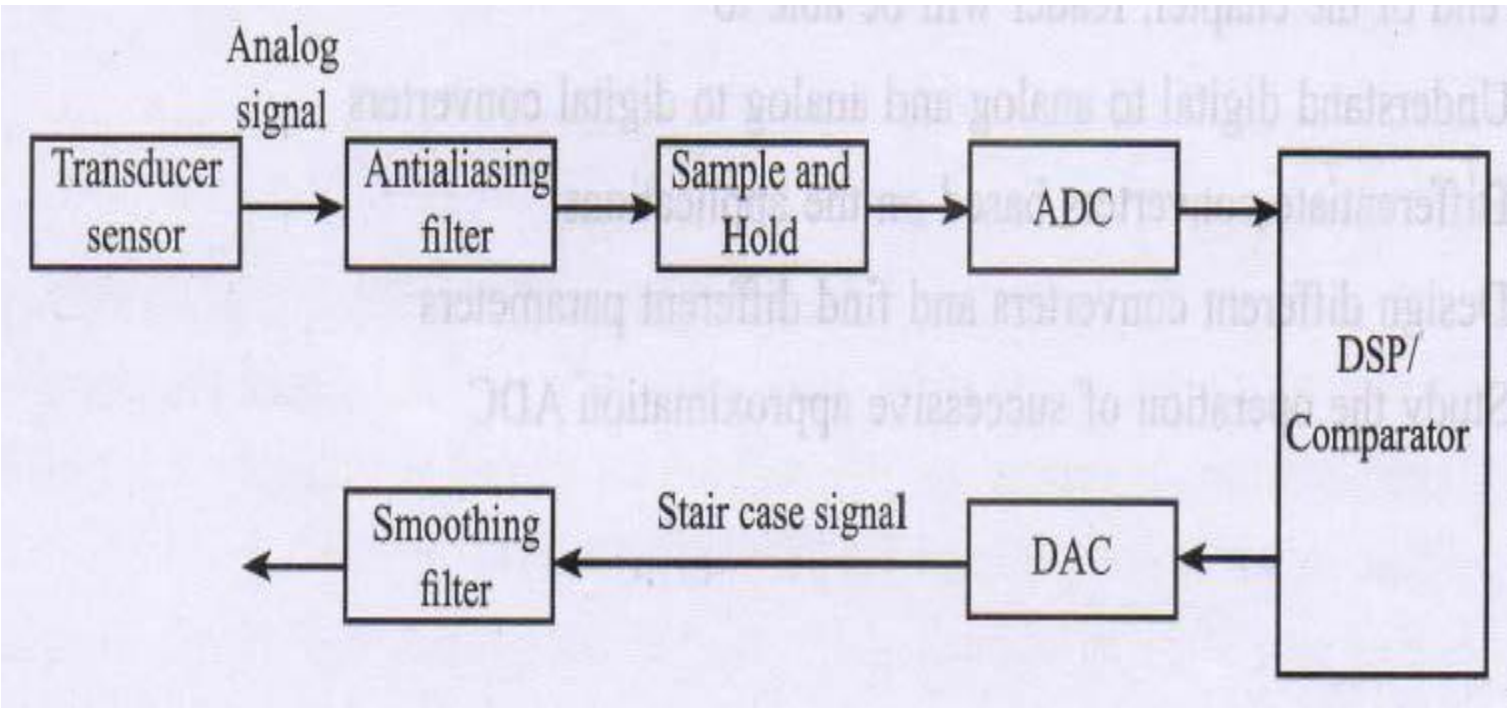
- The unregulated input voltage provides current to the load.
- Some of the current is pulled away by the **control element**.
- If the load voltage tries to change due to a change in the load resistance, the **sampling circuit** provides a feedback signal to a **comparator**.
- The resulting difference voltage then provides a control signal to vary the amount of the current shunted away from the load to maintain the regulated output voltage across the load.



D to A and A to D converter

- WHY A to D?
  - Real world signal appear in analog form
  - Difficult to process, transmit, store in physical form
  - Computer perform operation quickly , efficiently
  - Development in digital technology
- WHY D to A?
  - Computer need to communicate with physical processes , people

Typical A/D and D/A Converter



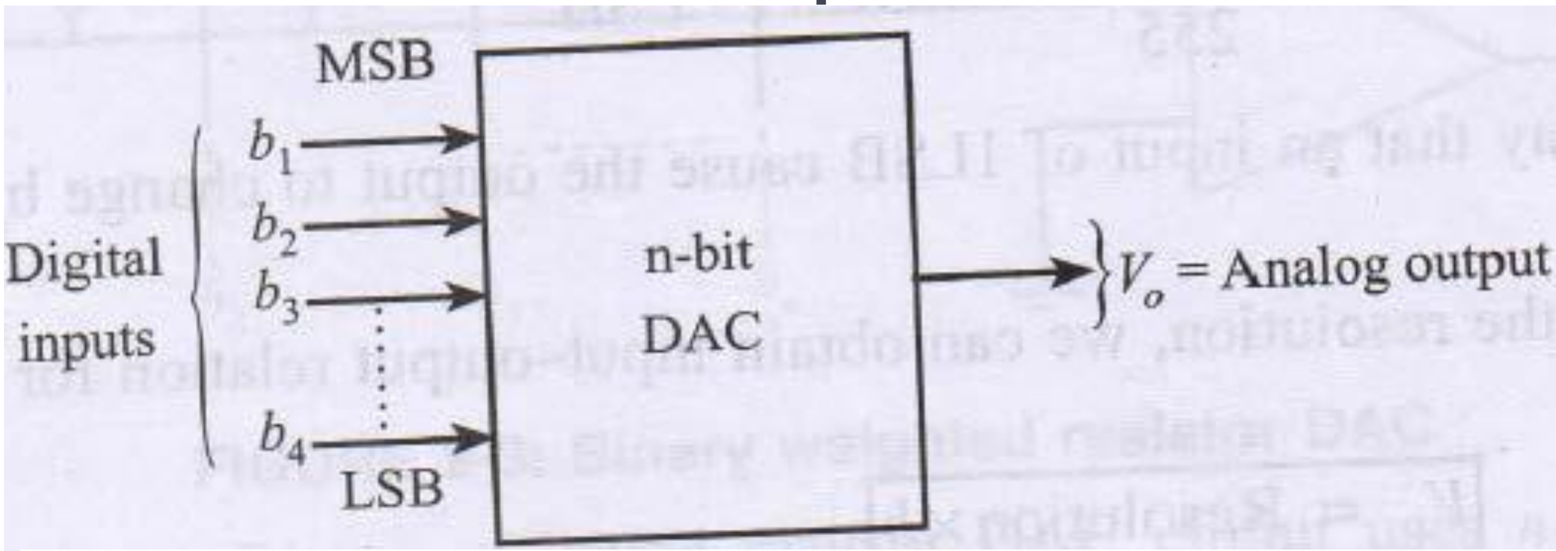
Typical A/D and D/A Converter

1. Obtain analog signal from sensor or transducer
2. Using anti aliasing filter restrict bandwidth of the signal
3. Sample the signal at a frequency rate more than twice maximum frequency of band limited frequency
4. Hold sampled signal using hold circuit during conversion

Typical A/D and D/A Converter

1. Feed the discrete signal to A to D Converter
2. A to D Converter converts the signal to digital signal
3. Digital signal is converted to analog signal using D to A Converter
4. Output of D to A Converter is stair case waveform
5. Stair case waveform is passed through smoothing filter to remove quantized noise

Basic DAC Techniques



$$V_0 = kV_{FS}(b_1 2^{-1} + b_2 2^{-2} + b_3 2^{-3} + \ \dots\ b_n 2^{-n})$$

Where, V_0 – Output voltage

V_{FS} – Full scale output voltage

k – Scaling factor (usually 1)

$b_1 . . ., b_n$ – n-bit binary fractional word with decimal point located at the left

b_1 – MSB with a weight = $V_{FS}/2$

b_n – LSB with a weight = $V_{FS}/2^n$

Performance Parameters of DAC

1. **Resolution:**

   Ratio of change in output voltage resulting from a change of LSB at the digital input.

   $Resolution = V_{OFS}/2^n - 1$

   $V_0 = Resolution \ x \ b$

2. **Accuracy**

   Measure of how close the actual output voltage is to the theoretical output value

$$Accuracy = \frac{V_{oFS}}{(2^n - 1)2}$$

Performance Parameters of DAC

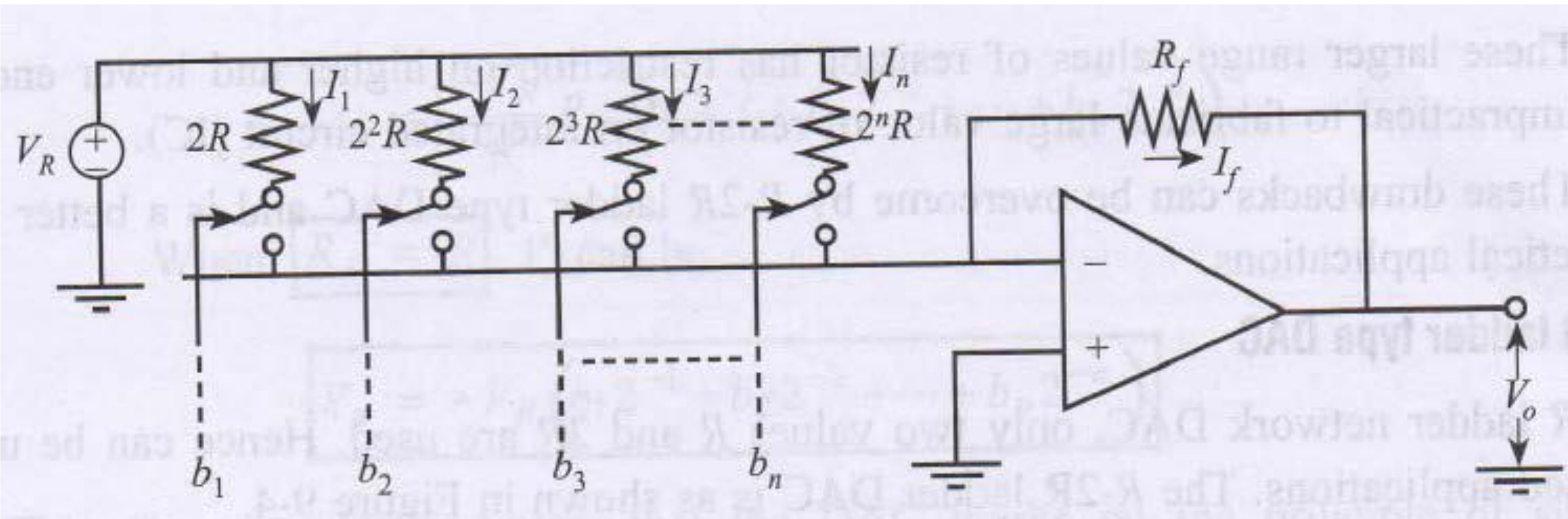
3. Setting Time:

   Setting time is the time required for a DAC output to settle within ± 1/2 LSB of final value for a given digital input.

3. Stability:

   The performance of a DAC is not stable due to the parameters such as temperature, power supply variations, and ageing.

Binary Weighted Resistor DAC



- When the switch is ON : $I = V_R/R$
- When the switch is OFF : I = 0.

Binary Weighted Resistor DAC

- total current through R_f

$$I = I_1 + I_2 + I_3 + \ldots + I_n$$

$$= \frac{V_R}{2^1 R} b_1 + \frac{V_R}{2^2 R} b_2 + \frac{V_R}{2^3 R} b_3 + \ldots + \frac{V_R}{2^n R} b_n$$

$$= \frac{V_R}{R} [b_1 2^{-1} + b_2 2^{-2} + b_3 2^{-3} + \ldots + b_n 2^{-n}]$$

The output voltage is; $V_0 = -I_f R_f$

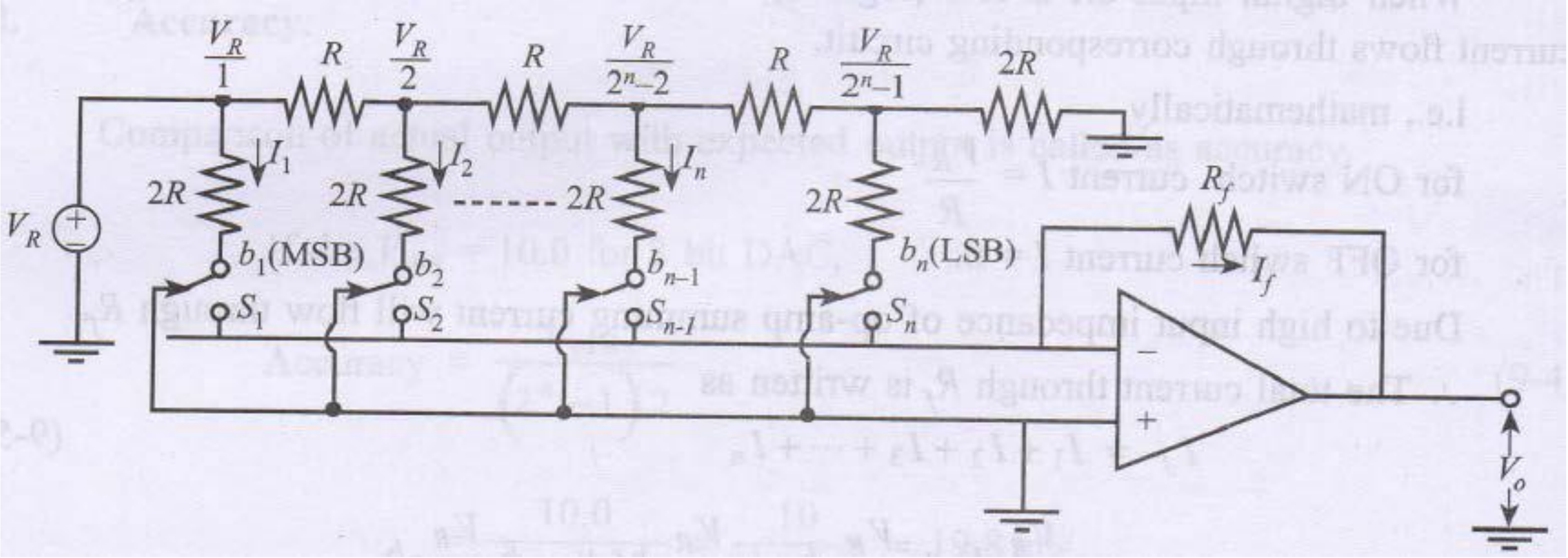
$$i.e., V_0 = \frac{-V_R}{R} R_f [b_1 2^{-1} + b_2 2^{-2} + b_3 2^{-3} + \ldots + b_n 2^{-n}]$$

If $R_f = R$; Or, $\boldsymbol{V_0 = -V_R [b_1 2^{-1} + b_2 2^{-2} + b_3 2^{-3} + \ldots + b_n 2^{-n}]}$

Drawbacks of DAC

- Large range of resistor values are required, as resistance values increases like $2^1R, 2^2R, 2^3R, \ldots, 2^nR$.
- Practically it's difficult to fabricate large values of resistors on IC.

R-2R Ladder type DAC



- Due to virtual ground, both the positions of the switches are at ground potential, and currents through the resistances are constant.

R-2R Ladder type DAC

The current flowing through each of 2R resistances;

$$I_1 = \frac{V_R}{2R} \qquad I_2 = \frac{V_R/2}{2R} = \frac{V_R}{4R} \qquad I_3 = \frac{V_R/4}{2R} = \frac{V_R}{8R} \qquad I_n = \frac{V_R/(2^n - 1)}{2R}$$

$$\text{But, } V_0 = -I_f R_f = -R_f(I_1 + I_2 + \ldots + I_N)$$

$$i.e., V_0 = -R_f\left[\frac{V_R}{2R}b_1 + \frac{V_R}{4R}b_2 + \ldots + \frac{V_R}{2^n R}b_n\right]$$

$$\text{Or, } V_0 = -\frac{V_R}{R}R_f[b_1 2^{-1} + b_2 2^{-2} + \ldots + b_n 2^{-n}]$$

If $R_f = R$; $\quad \boldsymbol{V_0 = -V_R[b_1 2^{-1} + b_2 2^{-2} + \ldots + b_n 2^{-n}]}$

R-2R Ladder type DAC : Advantages

- As it requires only two types of resistors, fabrication and accurate value of R-@R can be designed.
- Node voltage remains constant, and hence, slow down effect can be avoided.

Example 1:

The digital input for a 4 bit DAC is $D = 0111$. Calculate its output voltage take $V_{oFS} = 15$ V.

$$\text{Resolution} = \frac{V_{oFS}}{2^n - 1} = \frac{15}{2^4 - 1} = 1\text{ V / LSB}$$

$$\therefore V_o = \text{Resolution} \times D$$

$$D = \text{Decimal values } (0111) = 7$$

$$V_o = \frac{1\text{ V}}{\text{LSB}} \times 7 = 7\text{ V}$$

$$\therefore \boxed{V_o = 7\text{ V}}$$

Example 2:

A 8 bit DAC having resolution of 22mv/LSB. Calculate V_{oFS} and output if the input is $(10000000)_2$.

Given: resolution = 22 mV, Input = $(1000000)_2$

$$\text{Resolution} = \frac{V_{oFS}}{2^n - 1}$$

$$22mv = \frac{V_{oFS}}{2^8 - 1}$$

$$V_{oFS} = 5.6 \text{ V}$$

D = equivalent of $(10000000)_2 = 128$

$V_o = 22 \times 10^{-3} \times 128 = 2.8$ V.

Example 3:

Calculate output voltage produced by DAC, when output range is between 0 and 10 V for input binary number.

a) 10 (2 bit DAC) b) 0011

a) From equation (9-7) we can write,

$$V_o = 10\text{ V}\left(1\times\frac{1}{2}+0\times\frac{1}{4}\right) = 5\text{ V}$$

b) From equation (9-7) we can write,

$$V_o = 10\text{ V}\left(0\times\frac{1}{2}+0\times\frac{1}{4}+1\times\frac{1}{8}+1\times\frac{1}{16}\right)$$

$$= 1.875\text{ volts.}$$

Example 4:

Calculate the values of the LSB and full scale output for 4 bit DAC for 0 to 10 V range.

We have,

$$\text{LSB} = \frac{1}{2^4} = \frac{1}{16}$$

For 10 V range,

$$\text{LSB} = \frac{10\text{ V}}{16} = 625\text{ mV}$$

and

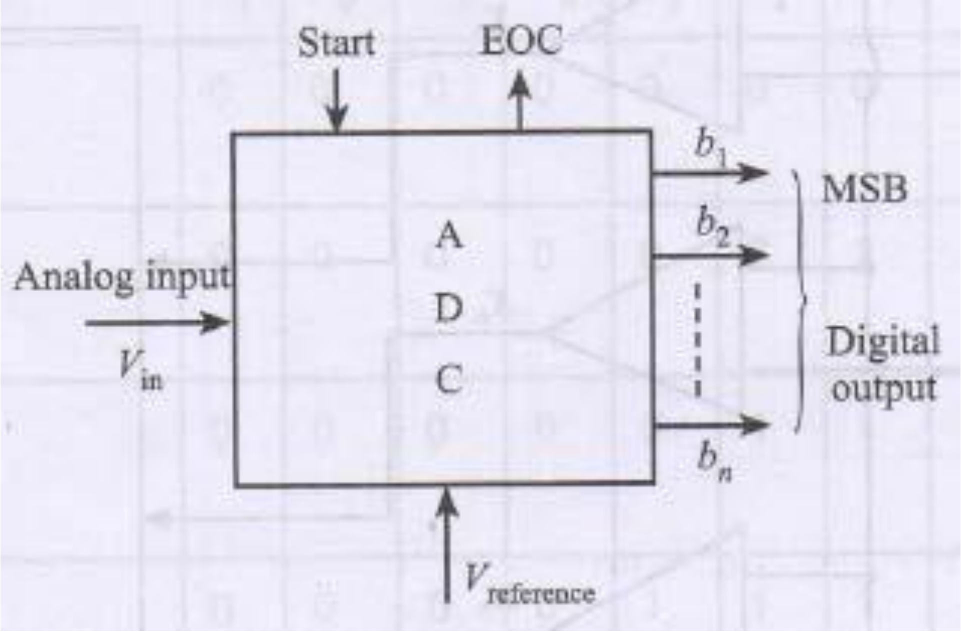
$$\text{MSB} = \left(\frac{1}{2}\right)\text{Fullscale}$$

$$= \frac{1}{2}\times 10 = 5\text{ V}$$

Full scale output = Full scale voltage – 1 LSB

= 10 – 625 mV = 9.375 V

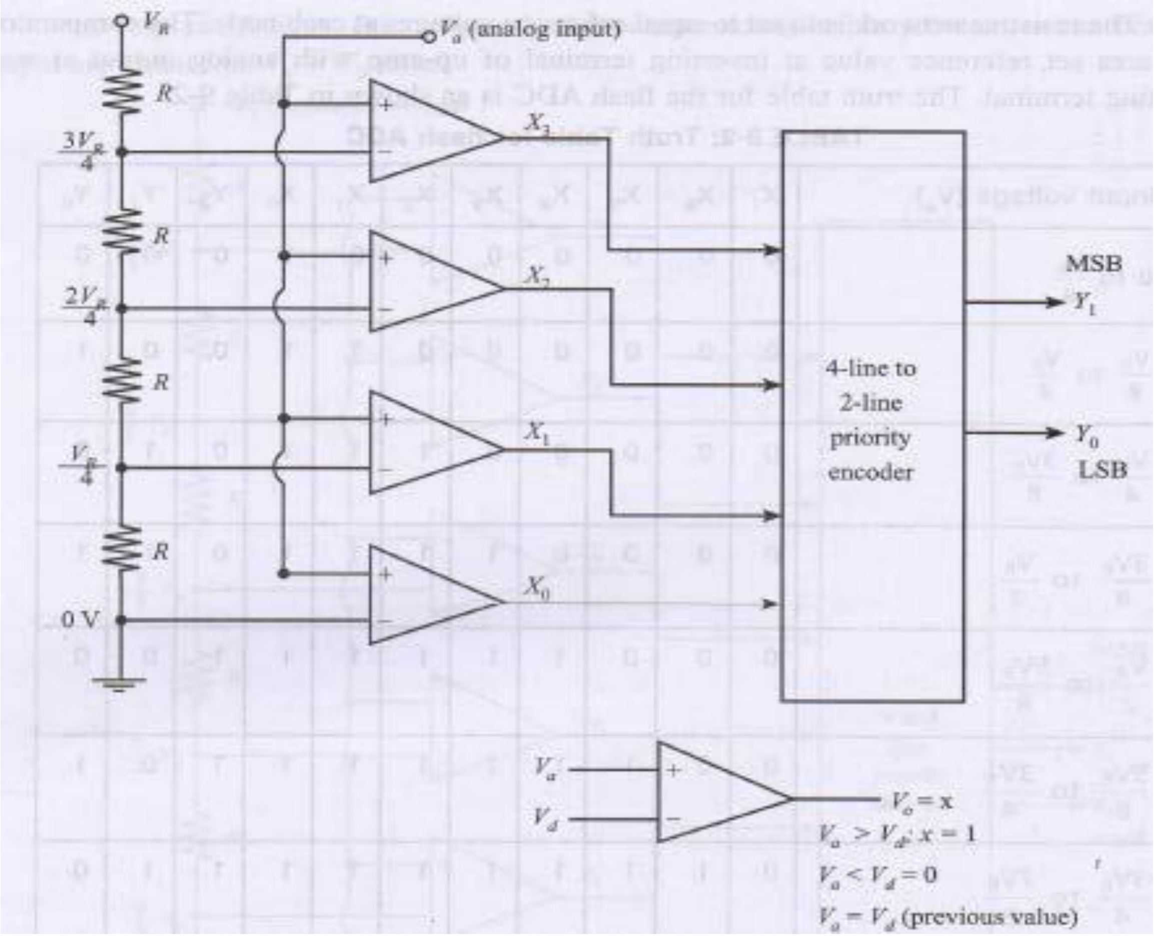
A-D Converters



- Types: Direct type ADCs and Integrated type ADCs

Flash (Comparator/ Parallel) type ADC:

- 2-bit Flash ADC

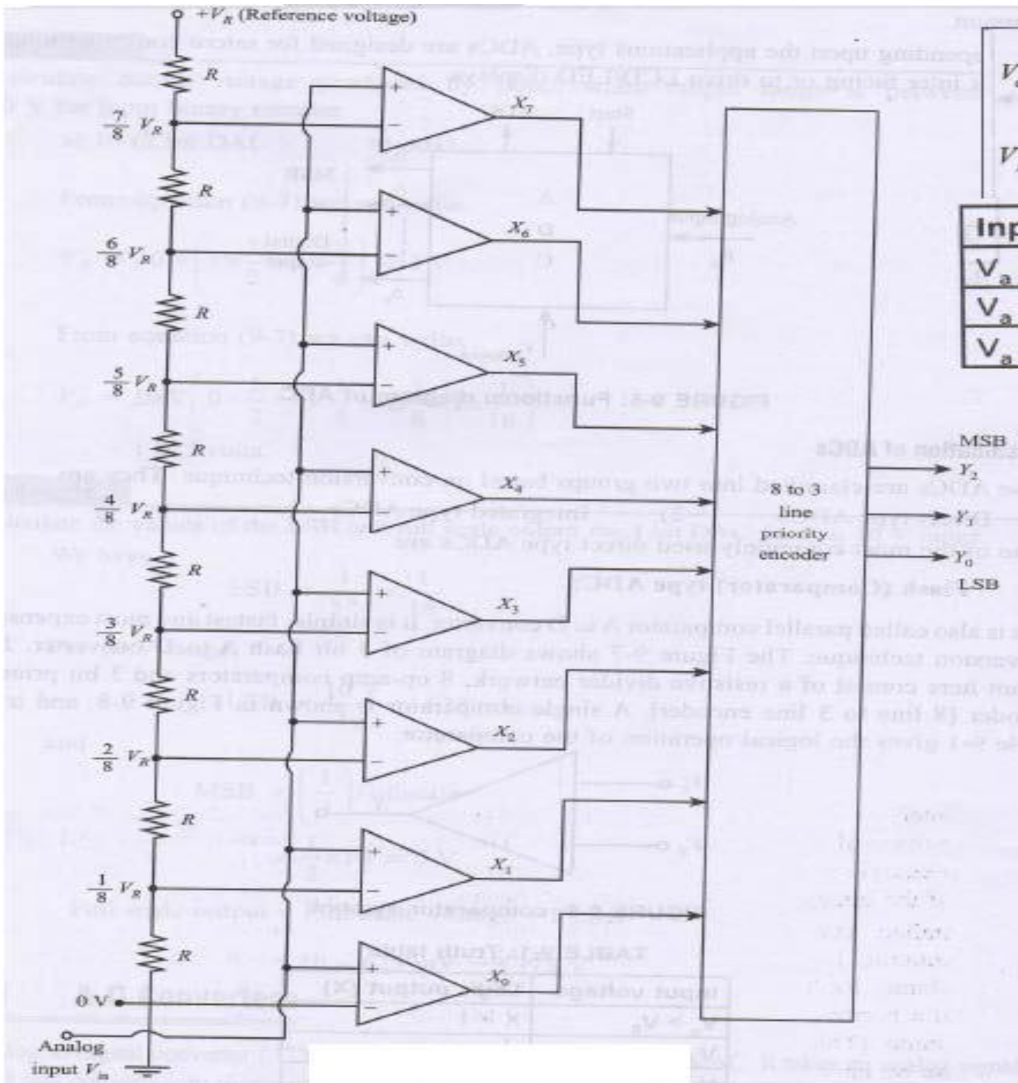


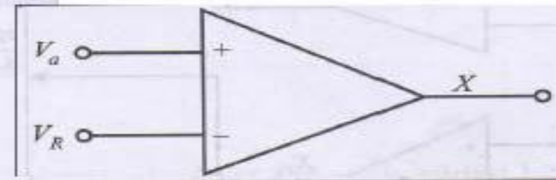
Flash (Comparator/ Parallel) type ADC:

- 2-bit Flash ADC

Analog input voltage (V_a)	X_3	X_2	X_1	X_0	Y_1	Y_0
0 to $\frac{V_R}{4}$	0	0	0	1	0	0
$\frac{V_R}{4}$ to $\frac{2V_R}{4}$	0	0	1	1	0	1
$\frac{2V_R}{4}$ to $\frac{3V_R}{4}$	0	1	1	1	1	0
$\frac{3V_R}{4}$ to V_R	1	1	1	1	1	1

3-bit Flash ADC





Input voltage	Logic output (X)
$V_a > V_R$	X = 1
$V_a < V_R$	X = 0
$V_a = V_R$	Previous value

3-bit Flash ADC

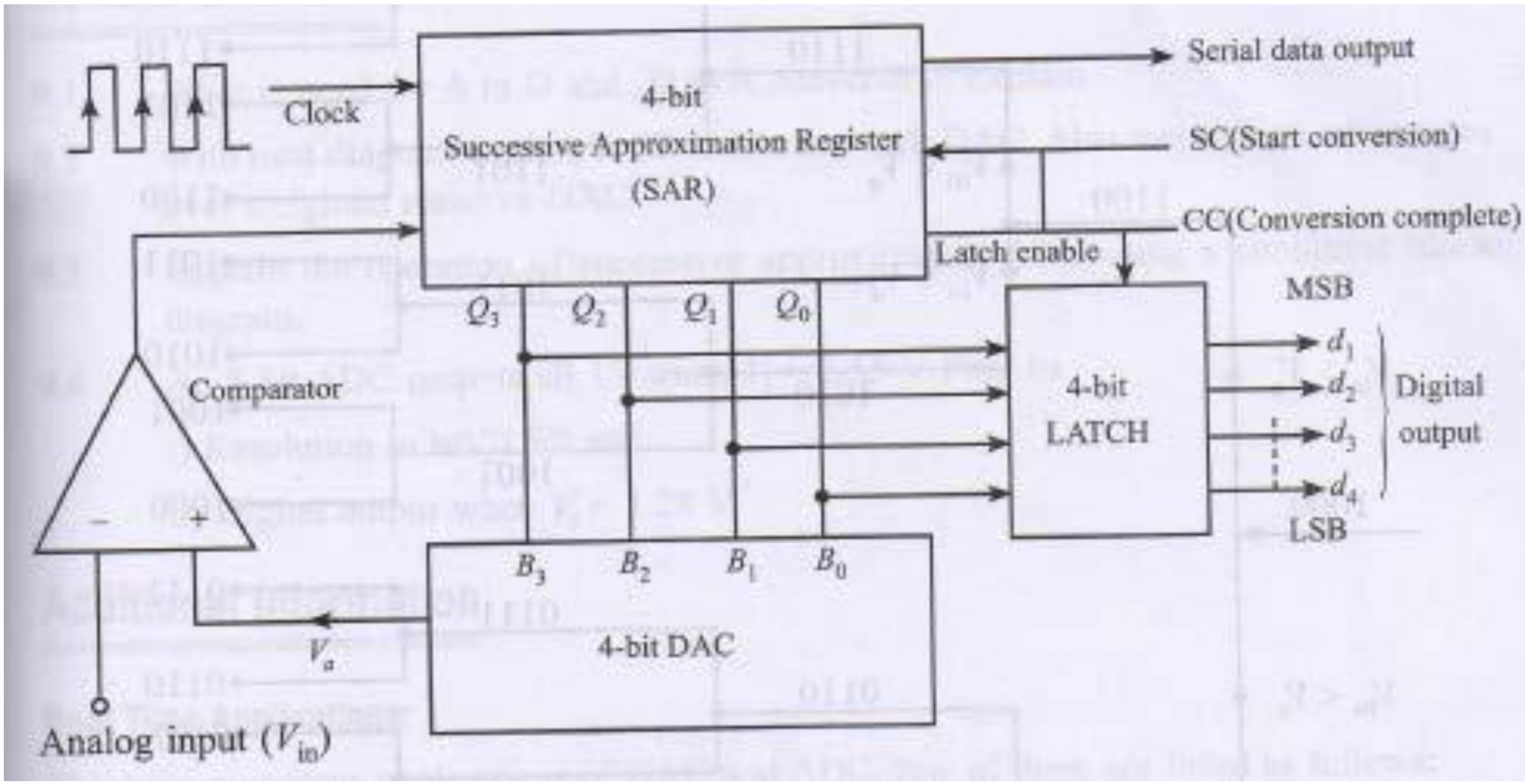
Input voltage (V_a)	X_7	X_6	X_5	X_4	X_3	X_2	X_1	X_0	Y_2	Y_1	Y_0
0 to $\frac{V_R}{8}$	0	0	0	0	0	0	0	1	0	0	0
$\frac{V_R}{8}$ to $\frac{V_R}{4}$	0	0	0	0	0	0	1	1	0	0	1
$\frac{V_R}{4}$ to $\frac{3V_R}{8}$	0	0	0	0	0	1	1	1	0	1	0
$\frac{3V_R}{8}$ to $\frac{V_R}{2}$	0	0	0	0	1	1	1	1	0	1	1
$\frac{V_R}{2}$ to $\frac{5V_R}{8}$	0	0	0	1	1	1	1	1	1	0	0
$\frac{5V_R}{8}$ to $\frac{3V_R}{4}$	0	0	1	1	1	1	1	1	1	0	1
$\frac{3V_R}{4}$ to $\frac{7V_R}{8}$	0	1	1	1	1	1	1	1	1	1	0
$\frac{7V_R}{8}$ to V_R	1	1	1	1	1	1	1	1	1	1	1

Flash (Comparator/ Parallel) type ADC:

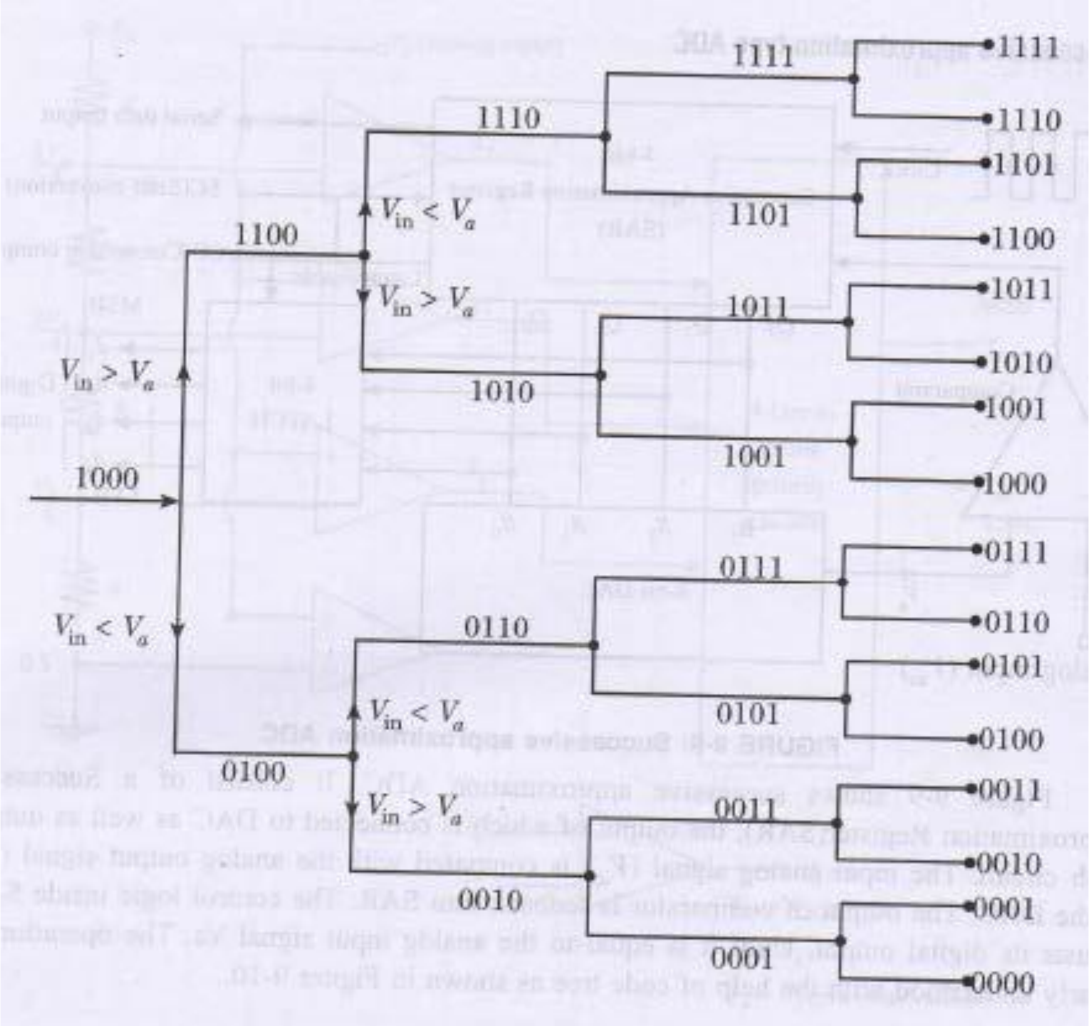
- ***Advantages:***
  - High speed

- ***Disadvantages:***
  - Number of comparators required is almost double for each added bit
  - Eg.: For 2-bit ADC; No. of Comparators = 4 (22) For 3-bit ADC; No. of Comparators = 8 (23)

Successive Approximation type ADC



Successive Approximation type ADC



Successive Approximation type ADC

- The conversion time for *n-bit successive approximation ADC is (n + 2) clock periods.*
- ***Advantages:***
  - Considerably good speed
  - Good resolution.