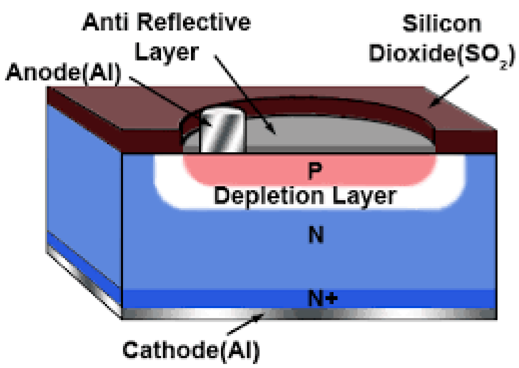
Module-1

Contents:

1.1 Photodiode:

A photodiode is a p-n junction device which converts light energy to electrical energy. It is used in reverse biased condition.

Construction:



The photodiode is made up of two layers of P-type and N-type semiconductor. In this the p-type material is formed from diffusion of lightly doped P-type substrate, and N-type layer is grown on N-type Substrate. The contacts are made up of metals to form two terminal cathode and anode. The top of the diode is protected by a layer of Silicon dioxide (Sio2) in which there is window for light to shine on semiconductor. This window is coated with a thin anti-reflective layer of Silicon Nitride (SiN) to allow maximum obsorption of light and an anode connection of aluminium (Al) is provided to the P-type layer.

Working Principle:

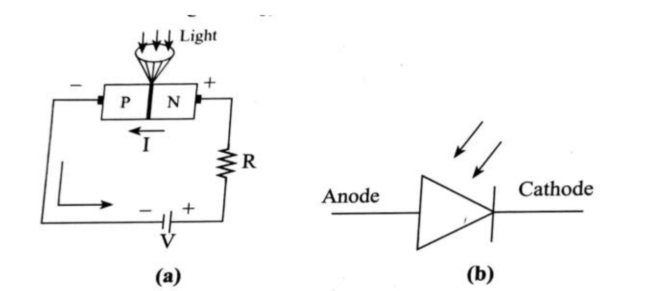


FIGURE 2-46: Photodiode in reverse bias (b) Symbol

When light falls on the photodiode, the photons hit the valence band electrons and make them free, the flow of these free electrons increases with increase in light intensity, hence the current flows in photodiode. The current which flows across photodiode is called as *photocurrent*. In this way photodiode converts light energy into electrical energy.

V-I characteristics of Photodiode:

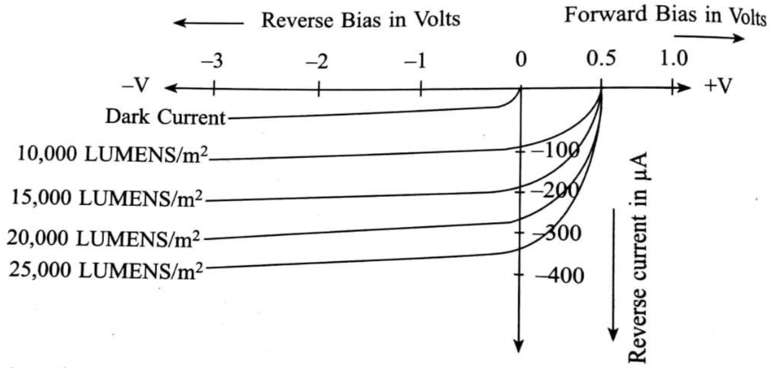


FIGURE 2-47: VI characteristics of photodiode

The reverse current that flows when there is no light is called as **Dark current**, the first curve represents dark current, the characteristics are shown in negative region because the photodiode can be operated in reverse biased only.

Applications:

- Photodiodes can be used as smoke detectors, in compact disc players and television and remote controls in VCRs.
- It can also be used in street lights, camera light meters, and to meaure light intensity in science and industry.

1.2 Light Emitting Diode:

LED converts light energy into electrical energy, LED is a PN junction diode which emits light when an electric current passes through it in forward direction.

Construction:

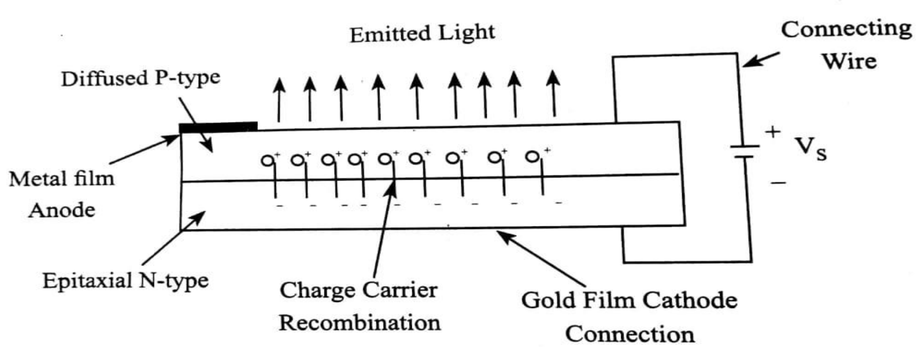


FIGURE 2-48: Cross-sectional view of diffused LED

the Semiconductor layer of **P-Type** is placed above **N-Type, P-type** is the surface on which light emitted can be easily seen, the metal is used on the P-Type layer to provide anode connection to the diode, similarly Gold layer is coated on N-type to provide cathode connection.

Working Principle:

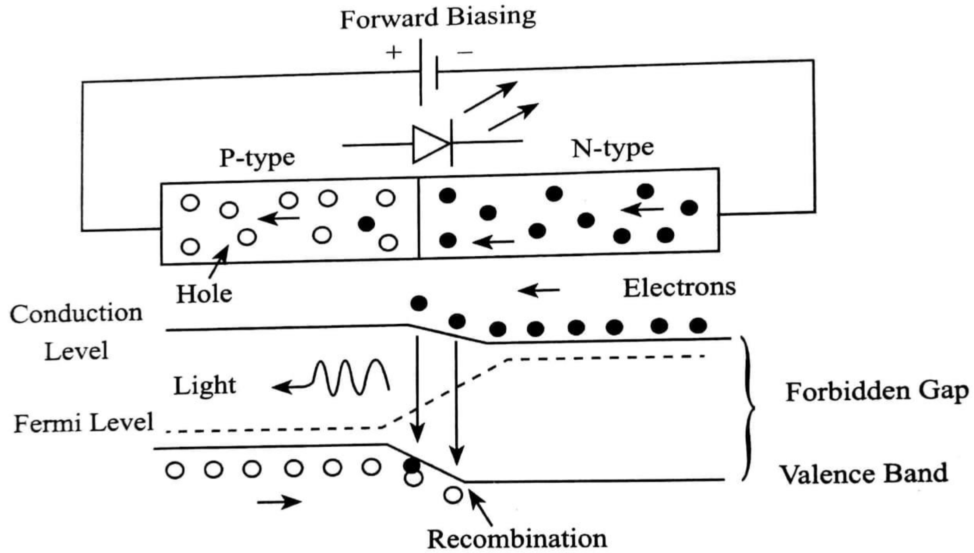


FIGURE 2-49: Working of LED

When a PN-junction is forward biased, the electrons in n region cross the junction and recombine with holes in P-region, electrons loose energy when they recombine with holes, this energy is converted into light by the special material used in the LED. The energy released depends on the forbidden gap energy which determines the color of the emitted light.

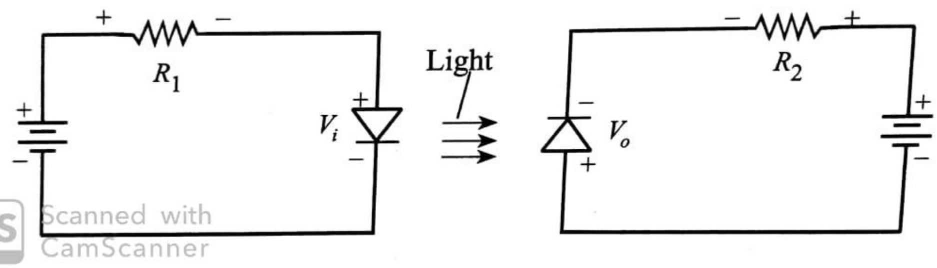
Applications:

- LED is used in remote control systems such as TV or LCD remote
- Used in Electronic calculators for showing the digital data
- Used in traffic signals
- Used in digital computers for displaying digital data
- Used in digital watches and automotive heat lamps.

1.3 Photocoupler

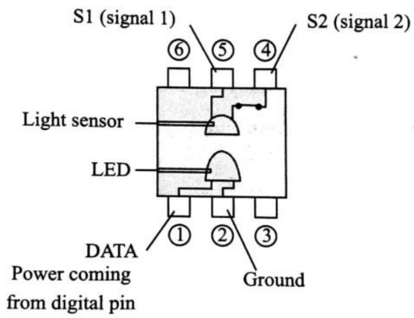
Photocoupler is the combination of LED and Photodiode

Construction:



As shown in circuit diagram, LED is forward biased and photodiode is reverse biased, the light emitted by LED will fall on photodiode which converts light into electrical energy, when LED is OFF no current will follow through photodiode. LED and photodiode are electrically isolated.

Working Principle:



(b)

FIGURE 2-50: Photocoupler operation

When voltage is not applied to pin1, the LED is OFF and the circuit connected to pins 4 and 5 is experiencing no current flow, when voltage is applied to pin1 LED switches ON, the photosensor detects light and current flows through the circuit connected to pins 4 and 5.

Applications:

- signal isolation
- Power control
- Modem communications
- Switch mode power supplies

BJT biasing:

Connecting DC voltage and resistors to BJT is called as BJT Biasing, there are three types of Biasing

1. Base Bias or Fixed Bias

2. Collector to Base Bias

3. Voltage Divider Bias

Base Bias:

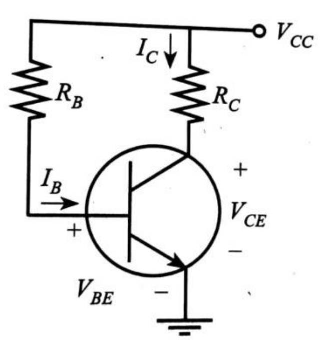


FIGURE 4-2: Base bias circuit

the above figure shows base bias circuit, A base resistance R_B is used between V_{CC} and base to establish the base current I_B, because V_{CC} and R_B are fixed quantities, I_B remains fixed and hence it is also called as Base Bias.

By applying KVL to BE loop, we get

$V_{CC} = I_B R_B + V_{BE}$

$I_B = V_{CC} - V_{BE} / R_B$ (V_{BE}=0.7)

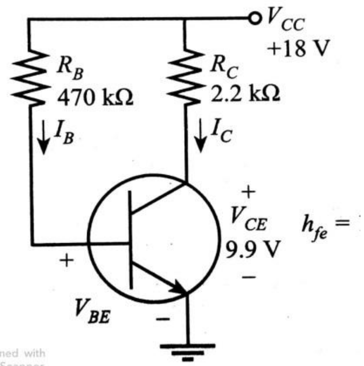
Collector current $I_C = \beta I_B$

By applying KVL to CE loop, we get

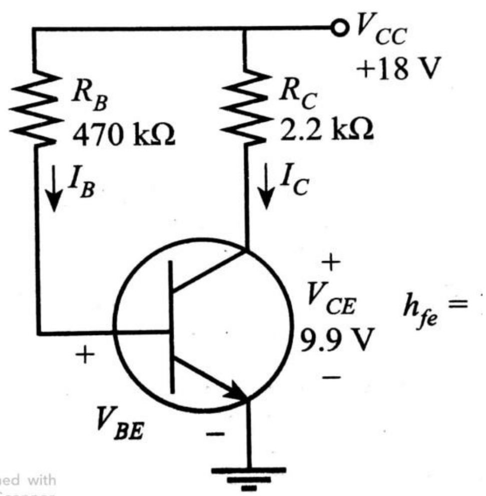
$V_{CC} = I_C R_C + V_{CE}$

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

Problem: The base bias circuit is shown in figure below for the values indicated. Calculate I_B, I_C and V_{CE}

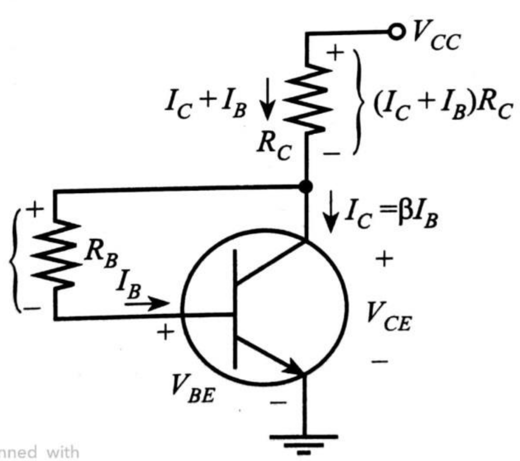


Problem: Calculate the maximum and minimum Levels of I_C and V_{CE} for the base bias circuit shown below when $h_{fe(min)}$ = 50 and $h_{fe(max)}$=200



Refer class notes for answers of above problems

Collector to base Bias:



the collector to base bias circuit shown in the above circuit has the base resistor R_B connected between the transistor and base terminals.

By applying KVL to BE loop, we get

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

$V_{CC} = I_CR_C + I_B(R_C+R_B)+V_{BE}$

$V_{CC} = \beta I_BR_C + I_B(R_C+R_B) + V_{BE}$

$V_{CC} = I_B(\beta R_C+R_C+R_B) + V_{BE}$

$\mathbf{I_B = V_{CC} - V_{BE} / (\beta+1)R_C + R_B}$

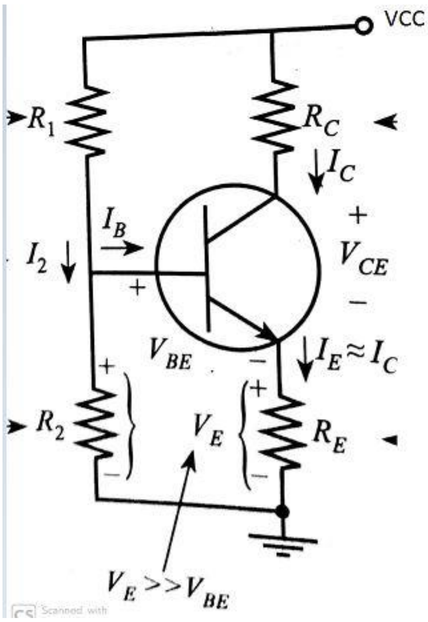
Collector current $\mathbf{I_C = \beta I_B}$

By applying KVL to CE loop, we get

VCC = (IC+IB)RC + VCE

$V_{CE} = V_{CC} - (I_C+I_B)R_C$

Voltage divider Bias:



In the above circuit, base voltage $\mathbf{V_B = V_{CC}\ R_2 / R_1 + R_2}$, voltage divider bias circuits are normally designed to have the current I_2 much larger than base current IB i.e., $I_2 >> I_B$ hence $I_1 \approx I_2$

Base voltage $\mathbf{V_B = V_{CC}\ R_2 / R_1 + R_2}$

Emitter voltage $V_E = I_E R_E$

$\mathbf{V_{BE} = V_B - V_E}$

$\mathbf{V_E = V_B - V_{BE}}$

$\mathbf{I_E R_E = V_B - V_{BE}}$

$\mathbf{I_E = V_B - V_{BE} / R_E}$

Collector current $I_C \approx I_E$

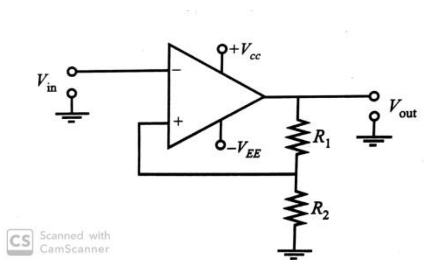
By applying KVL to CE loop, we get

$V_{CC} = I_C R_C + V_{CE} + I_E R_E$

$V_{CC} = I_C(R_C + R_E) + V_{CE} \quad (I_C \approx I_E)$

$V_{CE} = V_{CC} - I_C(R_C + R_E)$

Inverting Schmitt trigger:



In inverting Schmitt trigger, input voltage Vin is applied to the inverting input terminal and the feedback voltage is applied to non inverting terminal through resistor R_2.

UTP = Vsat R_2 / R_1 + R_2

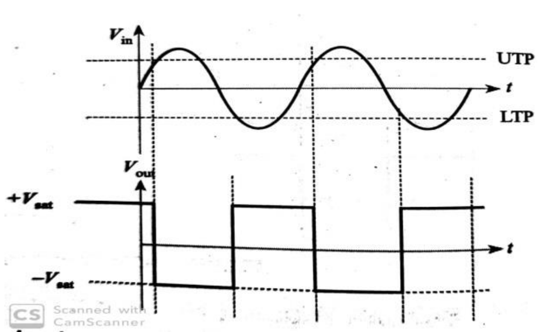
LTP = -Vsat R_2 / R_1 + R_2

Case(i) when Vin > UTP Vout = -Vsat

Case(ii) when Vin < LTP Vout = +vsat

As shown in the above equations when input voltage Vin becomes equal or greater than upper trigger point output voltage Vout changes to positive saturation voltage -Vsat, when Vin becomes equal or less than lower trigger point Vout changes to +Vsat.

Input and output Waveforms:



1. Design a Schmitt trigger whose threshold voltages are ±5V. Draw its waveforms choosing opamp with Vsat = ±13.5V with supply voltage ±15V.

2. for the circuit shown R2=120Ω and R1 =51Ω Determine the threshold volatges, if power supply applied to opamps are +15V and =15V.

3. Design Schmitt trigger circuit with UTP =4V and LTP=2V, Assume Vsat = 14V.

555 timer:

Note : Refer class notes for solutions of above problems.

Inverting Schmitt trigger with reference Volatge:

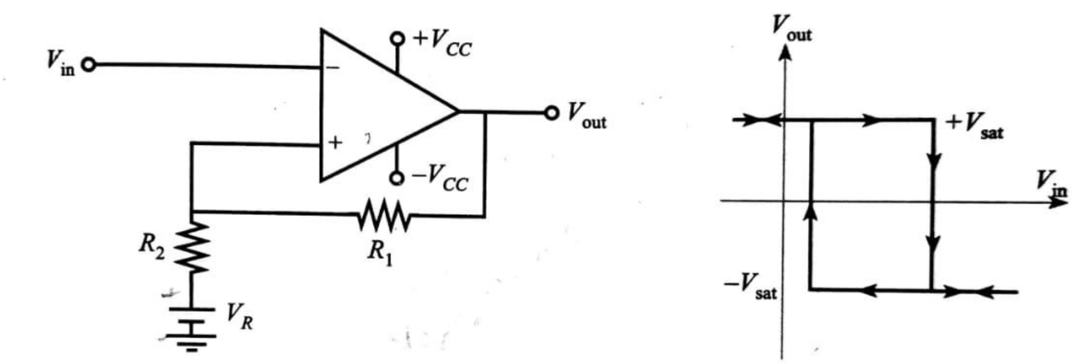


FIGURE 7-31(a): Inverting schmitt trigger circuit **(b) Transfer characteristics showing hysteresis**

Using reference voltage, the hysteresis loop can be shifted to either side of origin.

UTP = (VsatR2 / R1+R2) + (V_R R_1 / R_1 + R_2)

LTP = (-VsatR2 / R1+R2) + (V_R R_1 / R_1 + R_2)

Case(i) when Vin > UTP Vout = -Vsat

Case(ii) when Vin < LTP Vout = +vsat

As shown in the above equations when input voltage Vin becomes equal or greater than upper trigger point output voltage Vout changes to positive saturation voltage -Vsat, when Vin becomes equal or less than lower trigger point Vout changes to +Vsat.

Non- inverting Schmitt trigger:

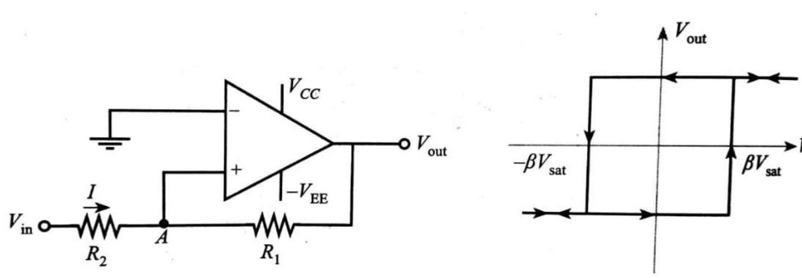


FIGURE 7-37(a): Non-inverting Schmitt trigger circuit **FIGURE 7-37(b) Transfer characteristics showing hysteresis**

In non-inverting Schmitt trigger, input voltage Vin is applied to non inverting terminal. When Vin becomes equal or greater than UTP Vout changes to positive saturation voltage Vsat, when Vin becomes less than LTP Vout changes to –Vsat.

UTP = VsatR_2 / R_1 **LTP = -Vsat R_2 / R_1**

Case(i) when Vin > UTP Vout = +Vsat

Case(ii) when Vin < LTP Vout = - vsat

Hysteresis voltage V_H = UTP – LTP = 2Vsat R_2/R_1

Input and output waveforms:

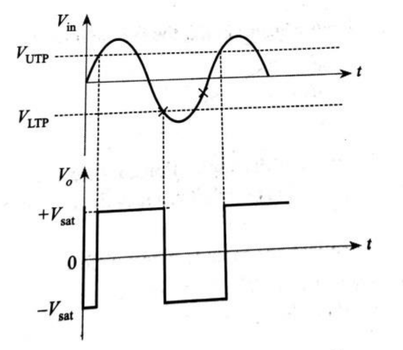


FIGURE 7-37(c): Input output waveform.

Problem: For Schmitt trigger R1 =3KΩ and R2 =1KΩ calculate UTP and LTP and V_H, Assume saturation volatges are ±12v.

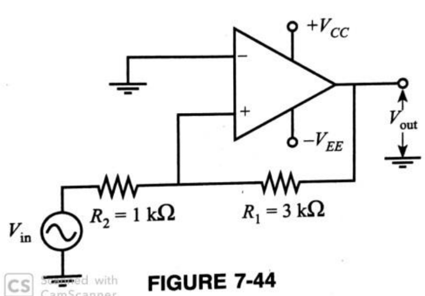


FIGURE 7-44

Sol) Given R1 =3KΩ and R2 =1KΩ Vsat = 12V

UTP = Vsat R_2 / R_1

= 12 × 1K / 3K

= 4V

LTP $= -V_{sat} R_2 / R_1$

$= -12 \times 1K / 3K$

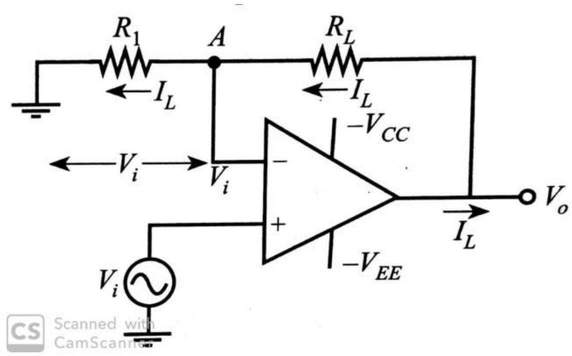
$= -4V$

Hysteresis Volatge $V_H = 2 V_{sat} R_2 / R_1$

$V_H = 2 \times 12 \times 1K / 3K$

$V_H = 8V$

Voltage to Current Converter:



In V-I converter output current is proportional to input Voltage.

The voltage at the inverting terminal is equal to voltage across resistor R_1

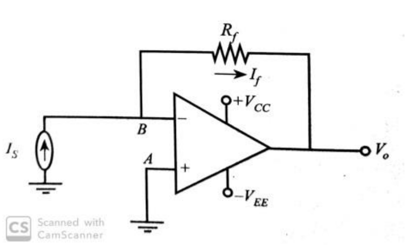
Hence $V_A = I_L R_1$

In ideal opamp, voltage at non inverting terminal is equal to inverting terminal

Hence $V_i = I_L R_1$

$V_i \propto I_L$

Current to Voltage Converter:



In current to voltage converter, input current is proportional to output voltage.

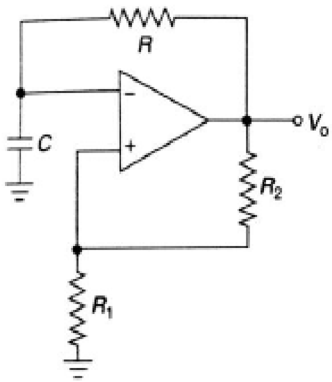
The current $I_s = V_B - V_{out} / R_f$

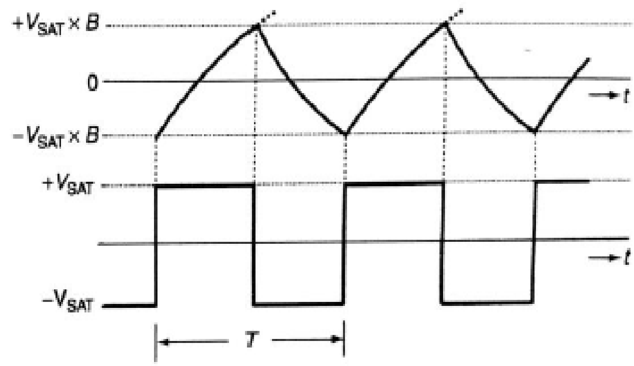
The voltage at node B = 0 due to the virtual ground in ideal opamp.

Hence $I_s = -V_{out} / R_f$

$I_s \propto V_{out}$

Relaxation Oscillator:





An Oscillator which produces Non-Sinusoidal output is called as Relaxation Oscillator.

Operation:

Assume initial output of OP-AMP is at $+V_{sat}$, hence voltage at non-inverting terminal is $V_+ = +V_{sat}R_1 / R_1+R_2$, when Vsat is applied to capacitor it starts charging, when capacitor voltage exceeds the voltage at non-inverting terminal output of OP-AMP changes from +Vsat to –Vsat.

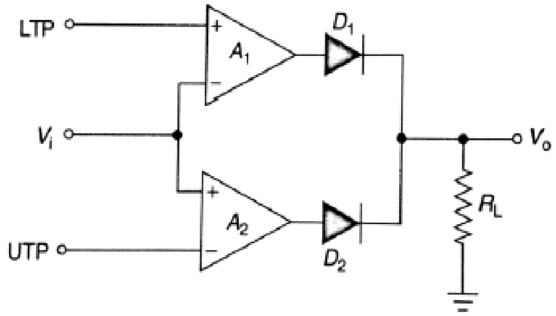
Now, Vout = **--**Vsat, the voltage appearing at non-inverting input is $-V_{sat}R_1 / R_1+R_2$, when –Vsat is applied capacitor starts discharging, when capacitor voltage becomes more negative than the voltage at non-inverting input, the output switches from –Vsat to +Vsat.

The charging and discharging of capacitor continues and cycle repeats to produce rectangular output waveform as shown in the figure.

Time period of output waveform T = 2RCln(1+B/1-B)

B→ Feed-back Fraction B= R_1/R_1+R_2

Window Comparator:*******



In Window Comparator, there are two reference voltages called Lower and upper trip points, **UTP (Upper Trip Point)** **LTP (Lower Trip Point)**

A1 → Inverting Comparator **A2 →Non-Inverting Comparator**

Operation:

Case 1: When Vin < LTP

When Vin<LTP output of A1 is +Vsat, hence D1 is forward Biased, output of A2 is –Vsat hence D2 is reverse Biased, the output of A1 is connected to output hence output voltage is equal to +Vsat.

When $V_{in} < LTP$ $V_{out} = +V_{sat}$

Case 2 : When Vin >UTP

When Vin>UTP, output of A1 is –Vsat, output of A2 is +Vsat, hence D1 and D2 are reverse and forward biased respectively, the output of A2 is connected to Vout

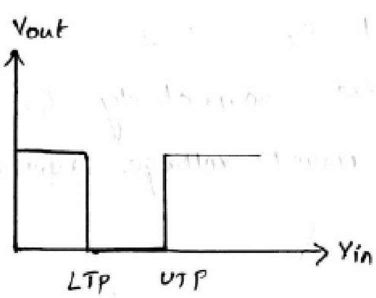
When $V_{in} > UTP$ $V_{out} = -V_{sat}$

Case 3: When LTP < V_{in} <UTP

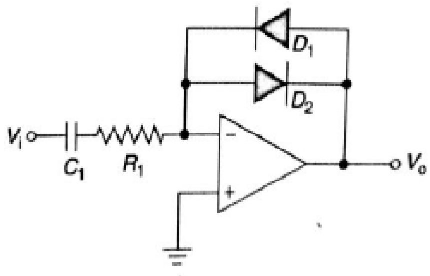
When Vin is greater than LTP and Less than UTP, outputs of both OP-AMPs are –Vsat, hence both diodes are reverse biased, hence output of neither op-amp is connected to Vout, hence Vout is zero

When $LTP < V_{in} < UTP$ $V_{out} = 0$

Transfer characteristics of Window-Comparator:



Non-Linear Amplifier:

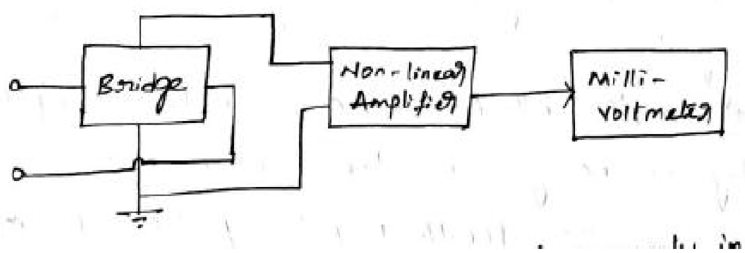


An amplifier in which gain is very large for weak input signals, and very small for large input signals is referred to as Non-Linear Amplifier.

Operation:

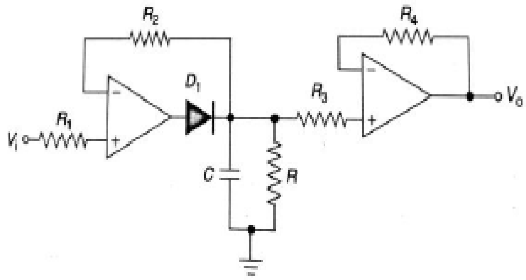
- For small values of input signal, diodes acts as open circuit and gain is high due to minimum feedback.
- For Large values of input signal, diodes conduct and offer very small resistance and thus gain is Low.

Application of Non-Linear Amplifier:



As shown in figure, output of Bridge is connected to Non-linear amplifier, for large variations of bridge output nonlinear amplifier produces small variations which can be measured using Milli-Voltmeter. If bridge output is connected directly to Milli-voltmeter, the large variations of bridge output cannot be measured in it, hence Non-Linear amplifier can be used between bridge and Milli-Voltmeter.

Peak-Detector Circuit:



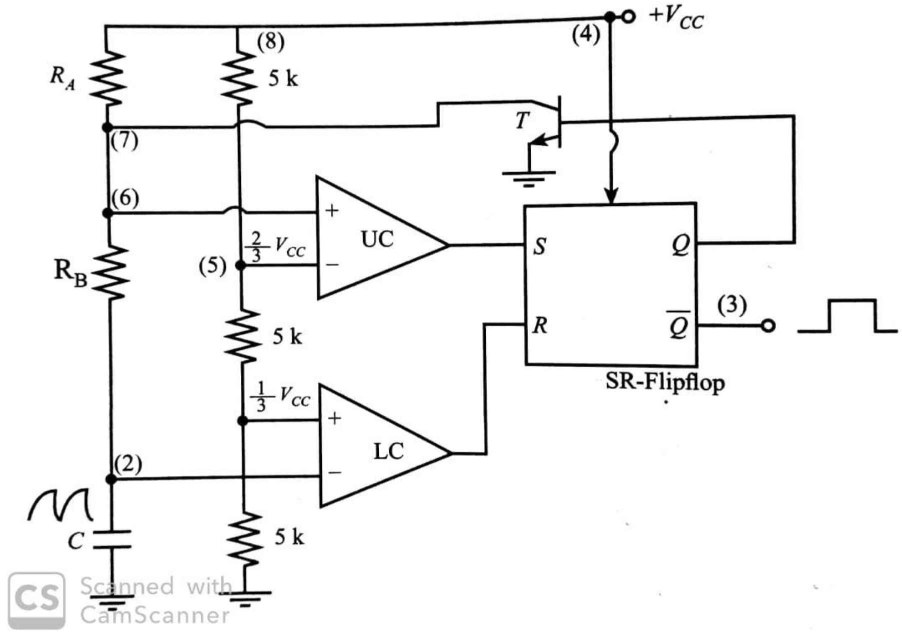
Peak- detector circuit produces a voltage at the output equal to peak voltage of input signal, the above figure shows positive peak amplitude of the input signal.

Operation:

When a sine signal is applied at the input of op-amp 1, During positive cycle, the output of op-amp1 is also positive, which makes diode forward biased, hence capacitor starts charging, it charges to V_p. the voltage across capacitor V_p is applied as input to OP-AMP 2 which is voltage follower, hence the voltage V_P appears at the output of second OP-AMP.

Note: this circuit can be made to detect the negative peak by reversing the direction of diode.

Astable multivibrator Using IC-555:



ON time Operation:

At time t=0, capacitor voltage Vc = 0, the same capacitor voltage is applied to Lower comparator (LC), as Vc=0 which is less than Vcc /3. The output of lower comparator goes high, since R=1 the output will become high, this causes transistor to go off and capacitor starts charging through resistors R_A and R_B.

OFF time Operation:

As soon as Vc exceeds 2Vcc/3 the upper comparator output goes high and it will set the SR flip-flop i.e S=1 and R=0 and Q=1, which will turn on Transistor and output at pin(3) goes LOW.

The capacitor discharges through R_B and transistor to the ground, the discharge time is called as **OFF time (T_D).** when capacitor voltage becomes Vcc/3, lower comparator outptut goes high. This process of charging and discharging is continuous and hence circuit oscillates. The schematic diagram and waveforms are shown in figure below.

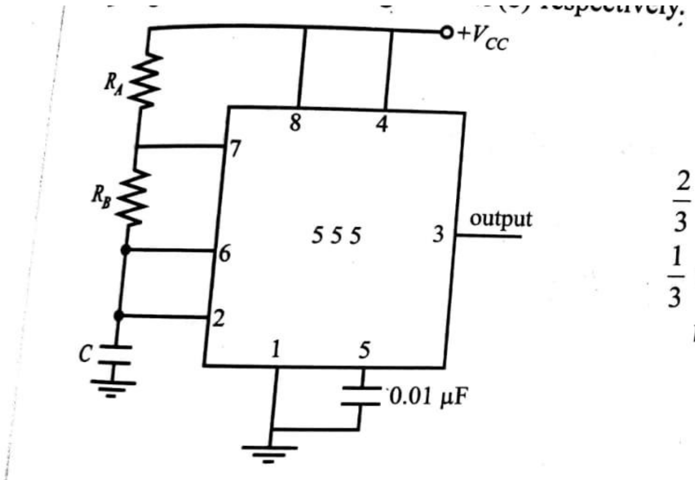


FIGURE 7-13(a): Schematic of IC–555 in Astable mode

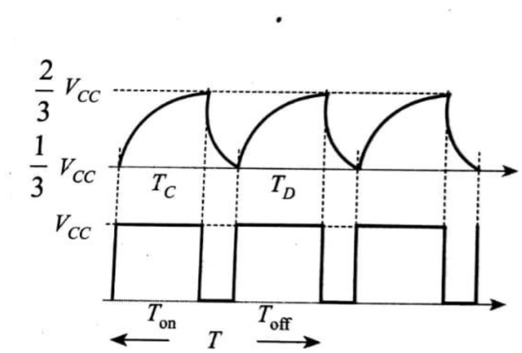


FIGURE 7-13(b): Wave form for Astable operation

Expression for charging time Tc or T_{ON} :

The voltage across capacitor is given as $V_C = V_F + (V_I – V_F)\ e^{-t/RC}$

During charging time T_C, the initial voltage on the capacitor is V_I = Vcc/3 and final voltage is V_F = Vcc, since charging takes place through both R_A and R_B the capacitor equation is given as

$$2Vcc / 3 = Vcc + (Vcc/3 – Vcc)\ e^{-TON/(RA + RB)C}$$

Hence $\mathbf{T_{ON} = 0.693(R_A + R_B)\ C}$

Expression for discharging time T_D or T_{OFF}:

During discharging time, capacitor initial voltage is 2Vcc/3 and final voltage is 0.

Hence capacitor equation is given as

$$Vcc/3 = 0 + (2Vcc/3 – 0)\ e^{-TD/RBC}$$

Hence $T_{OFF} = 0.693R_BC$

Total Time Period:

$T = T_{ON} + T_{OFF} = 0.693\ (R_A + 2R_B)C$

Frequency $f = 1 / T = 1.44 / (R_A + 2R_B)C$

Duty Cycle:

$\mathbf{D = T_{ON} / T = 0.693(R_A + R_B)\ C / 0.693(R_A + 2R_B)C}$

Hence D = $(R_A + R_B) / (RA + 2R_B)$

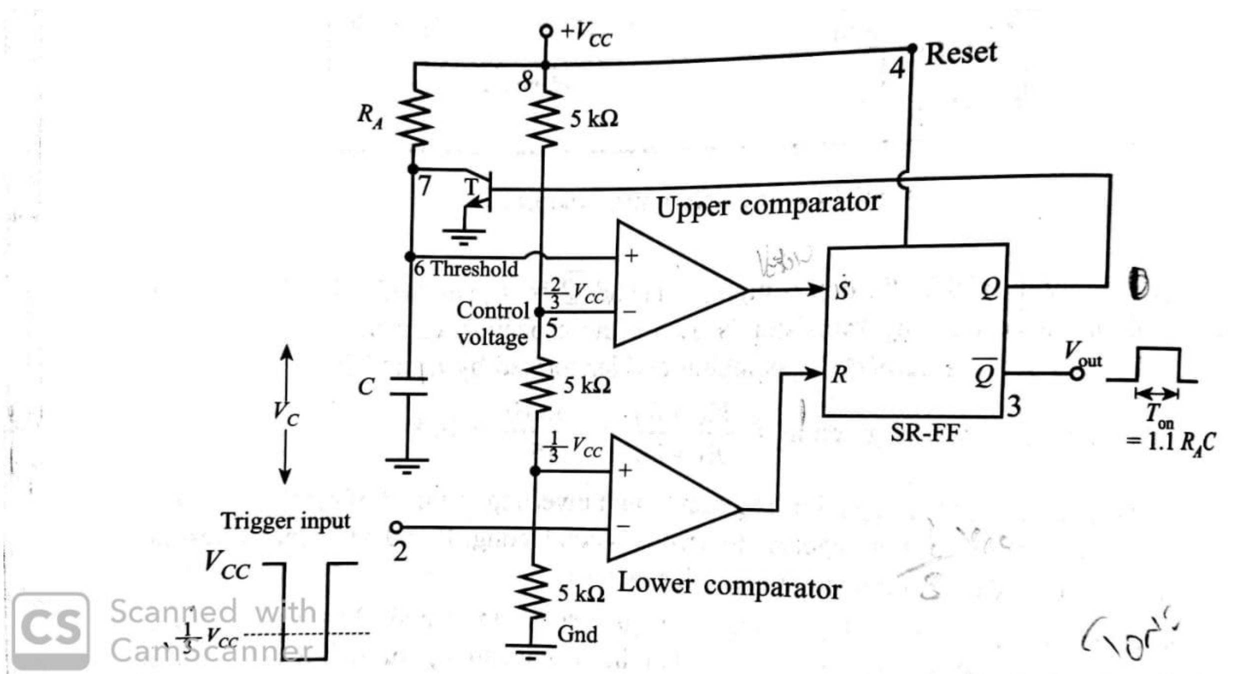
1. A 555 timer is configured to operate in astable mode with R_A = 5KΩ R_B = 5KΩ and C = 0.01µF, Determine the frequency of the output and duty cycle.

2. Design Astable multivibrator using 555 timer for a frequency of 2KHz and a duty cycle of 75%. Assume C=0.1µF

3. For an Astable multivibrator circuit R1=22KΩ, R2 = 30KΩ and C=0.5µF. find ON and OFF period of output waveform.

Note: Refer class notes for solutions of above problems

Monostable Multivibrator:

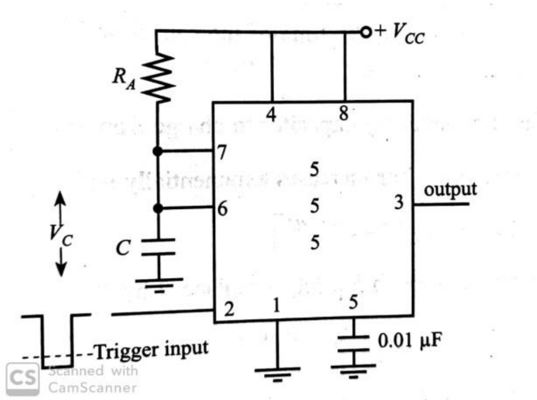


The above figure shows monostable using 555 timer IC, this circuit is called as monostable multivibrator because it has only one stable state, resistor R_A and capacitor C are components connected externally to 555.

Operation:

Initially the capacitor voltage is 0, hence the output of upper comparator is HIGH, which sets the Flip-flop, hence Q=1 and the output at pin3 is LOW. When negative trigger pulse is applied at trigger input of lower comparator, then circuit state remains unchanged until trigger pulse goes below Vcc/3. Once trigger pulse goes below Vcc/3 lower comparator output goes high and flip-flop resets, hence the output at pin3 goes HIGH, and transistor T turns OFF, as T is OFF capacitor starts charging through R_A in an exponential manner, when capacitor voltage becomes more than 2Vcc/3 the upper comparator output become HIGH which sets the flip flop and the output at pin3 becomes LOW.

Schematic Diagram: **Waveforms**



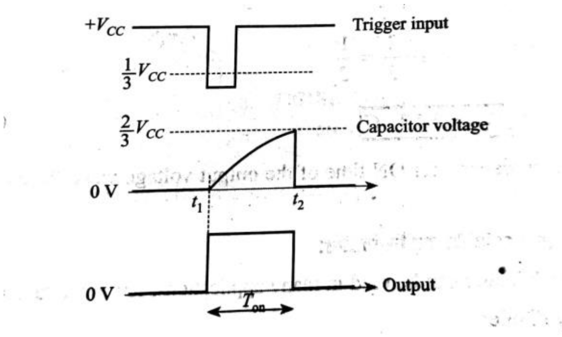


FIGURE 7-6: Waveforms of monostable multivibrator

Expression For T_{ON}:

Voltage across capacitor is given as $V_C = V_F + (V_I – V_F)\ e^{-t/RC}$

According to above equation the voltage across capacitor during charging time is

$$2V_{CC}/3 = V_{CC} + (0-V_{CC})e^{-TON/RAC}$$

$$e^{-TON/RAC} = 0.33$$

$$-T_{ON}/ R_AC = \log 0.33$$

$$T_{ON} = 1.1R_AC$$

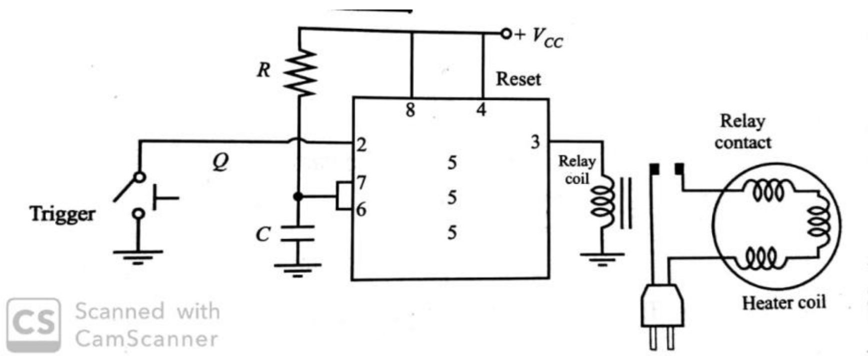
Problem: Find the resistive element value to generate T=10ms time delay, using 555 timer as a monostable multivibrator Assume C=0.47µF

Sol) $T_{ON} = 1.1\ RC$

$$10\times10^{-3} = 1.1\times R\times0.47\times10^{-6}$$

$$R = 19.34K\Omega$$

Problem: Design a timer that can turn on a heater immediately after pressing the button and it should hold the heater in ON state for 10 seconds.



The relay coil should be energized for 10 seconds to hold heater ON so T_{ON} is 10 seconds and choosing C=47µF

Since $T_{ON} = 1.1RC$

$$10 = 1.1 \times R \times 47 \times 10^{-6}$$

$$R = 193.42\ K\Omega$$

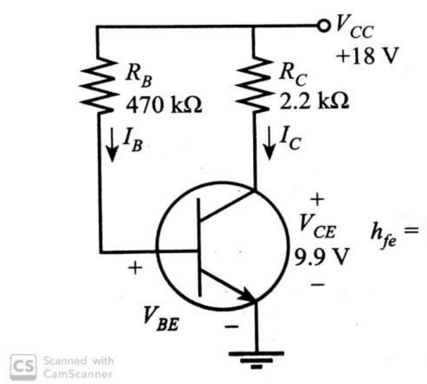
Important Questions

1. Explain working principle of Photodiode and LED

2. With neat diagram explain the working principle of Photocoupler

3. Find I_C, I_B, and V_{CE} for voltage divider bias circuit.

4. Problem: The base bias circuit is shown in figure below for the values indicated. Calculate I_B, I_C and V_{CE}



5. Explain inverting Schmitt trigger operation with waveforms.

6. Problem: For Schmitt trigger R1 =3KΩ and R2 =1KΩ calculate UTP and LTP and V_H, Assume saturation volatges are ±12v.

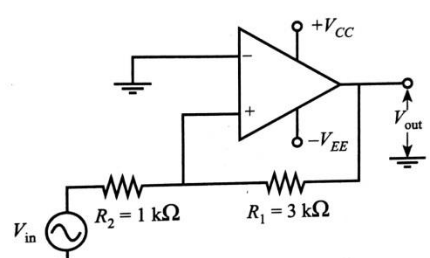


FIGURE 7-44

7. With the help of neat diagram explain the operation of Window Comaprator.

8. Explain the working of op-amp relaxation oscillator with neat diagram.

9. Explain the working of IC 555 timer as an Astable multivibrator.

10. A 555 timer is configured to operate in astable mode with R_A = 5KΩ R_B = 5KΩ and C = 0.01μF, Determine the frequency of the output and duty cycle.

11. Draw and explain peak detector circuit using OP-AMP.