UNIT-4
Multivibrators

Multi means Many, vibrator means oscillator.

A circuit which can oscillate at a number of frequencies is called multivibrator.

(or) A circuit which generates many number of oscillations is called multivibrator.

Multivibrators are basically regenerative circuits and they have two cross-coupled inverters. Cross coupled means, the output of the first stage is coupled to the input of the second stage and the output of the second stage is coupled to the input of the first stage. Generally we are using resistors and capacitors for cross coupling.

Multivibrators are have two states. such as ① stable state ② quasi-stable state.

① stable state :- It is a state in which the device is remains on same state until external excitation is applied (Trigger pulse). Hence it is called permanent state.

② Quasi-stable state :- It is a state in which the device is remains on definate time. After that the device will automatically come out of Quasi stable state. Hence it is called Temporary state.

Multivibrators are classified 3 types - based on stable and quasi stable states.

They are (1) Bistable Multivibrator
(2) Monostable "
(3) Astable "

(1) Bistable Multivibrator:-

→ It has two stable states and no quasi stable states.
→ Both the coupling elements are resistors.
→ It is a basic memory element i.e flip-flop.
→ It is used to perform many digital operations such as counting and storing of binary data.
→ It is also called as 'Eccles - Jordan circuit' or flip-flop or binary.

(2) Monostable Multivibrator:-

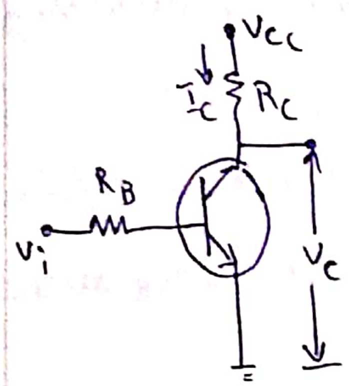
→ It has one stable state and one quasi stable state.
→ In this multivibrator one coupling element is capacitor and other coupling element is resistor.
→ It is used in pulse circuits. Mostly it is used as a 'gating circuit' and as a 'delay circuit' and Timer circuits
→ It is also called as 'one - shot' multivibrator.

(3) Astable Multivibrator:-

→ It has no stable states and two quasi stable states
→ In this multivibrator both coupling elements are capacitors.
→ It is used as a Master oscillator to generate square waves.
→ It is also called as free running Multivibrator.

Transistor operation:-

Transistor acts as a switch. In cut-off Region it acts as a open switch and saturation region it acts as short or closed switch.



T is ON state: if $V_i > V_\gamma$ then T is ON

if T is on, I_B is generated as well as I_C is increased.

∴ The O/P voltage $\downarrow V_C = V_{CC} - I_C R_C \uparrow$

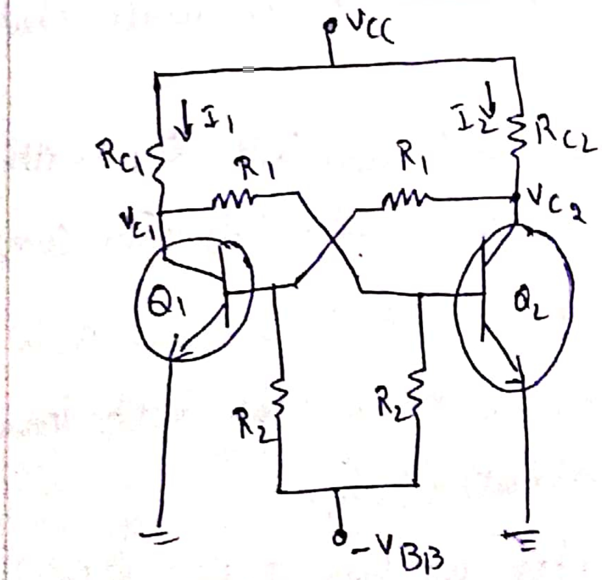
$V_C = V_{C(sat)} = 0.2V$

T is OFF state:-

if $V_i < V_\gamma$ then T is OFF. Therefore no output current I_C.

∴ $V_C = V_{CC} - I_C R_C = V_{CC}$ (cut off Region)

(1) Bistable Multivibrator:-



Q_1, Q_2 are Identical NPN Trans

R_1, R_2, R_C, and R_{C2} are resistors

($R_{C1} = R_{C2}$)

V_{CC} = supply voltage

V_{BB} = fixed bias voltage.

→ Q_1 and Q_2 are active devices which may be transistors (or) Vacume tubes.

→ The O/P of one amplifier is fed back to input of the other amplifier. This feed back is regenerative (+ve) feed back.

→ When I_1 increases slightly, the voltage drop accross the R_{C_1} increases.

$\downarrow$ i.e $V_{C_1} = V_{CC} - I_{C_1}R_{C_1} \uparrow$

→ The o/p at Q_1 decreases, so this effect of decreasing the base current of Q_2.

→ I_{B_2} decreases then I_{C_2} decreases because $I_C = \beta I_B$.

→ If I_{C_2} decreases, voltage drop across $I_2 R_{C_2}$ decreases. Hence voltage at Q_2 increases.

$$\therefore \uparrow V_{C_2} = V_{CC} - I_{C_2}R_{C_2} \downarrow$$

→ ~~This Age~~ Due to increase of V_{C_2}, the base current of Q_1 increases. This increases I_{C_1} of Q_1 i.e I_1. Thus I_1 furdhar increases. Hence V_C furdhar decreases, the base current of Q_2 further decreases, with the result that I_2 furthar decreses.

→ This regenarative process continuous till Q_2 is drive into cut off (OFF) and Q_1 is driven into Saturation (ON).

→ Thus when Q_1 is ON, Q_2 is OFF and when Q_1 is OFF and Q_2 is ON. It may be noted that both transistors are not ON or OFF simutaneously.

→ Thun it is seen that there are two stable states in which the transistors can remain indefinately. Hence the name binary or bistable Multivibrator.

Standard specifications:-

The following values may be assumed for the junction voltages.

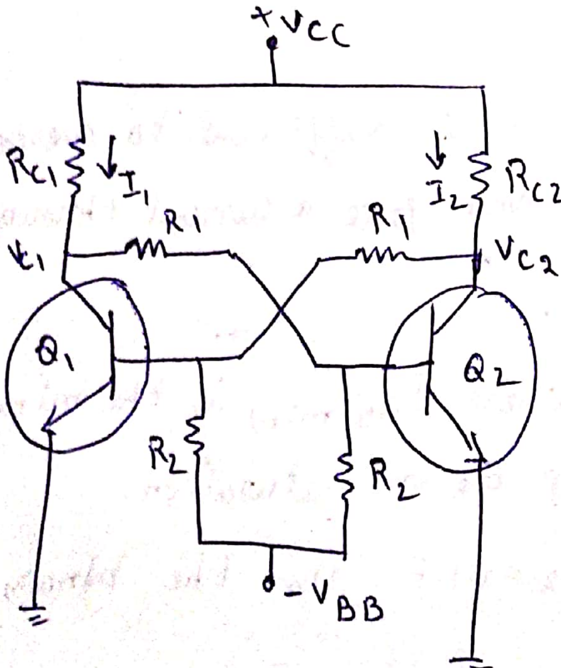
	V_{BE} (cut-off)	V_{BE} (active)	V_{BE} (sat)	V_{CE} (sat)	V_{BE} (cut in)
Si	$\leq 0V$	0.6V	0.7V	0.3V	0.5V
Ge	$\leq -0.1V$	0.2V	0.3V	0.1V	0.1V

→ If the transistor is in saturation, the following condition must be satisfied. i.e $I_B > I_{B(min)}$

$$\text{i.e } i_B > \frac{i_C}{h_{fe(min)}} \qquad [\because i_C = \beta I_b]$$

where $h_{fe(min)}$ is the minimum current gain needed to keep the transistor in saturation.

Bistable Multivibrator with Fixed Biasing:-

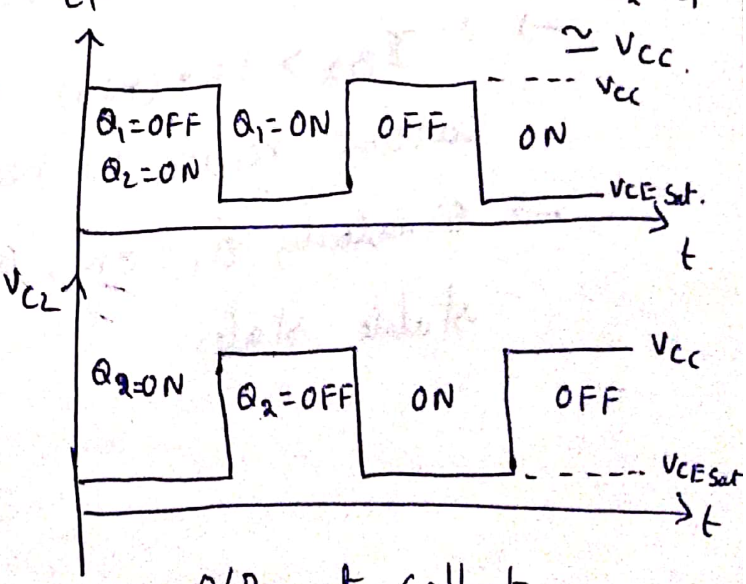


if Q_1 = OFF, Q_2 ON

$V_{C_1} = V_{CC}$ $\quad V_{C_2} = V_{CEsat}$

V_W = voltage swing $= V_{C_2} - V_{C_1}$

$\simeq V_{CC}$.



O/Ps at collectors

Analysis

→ Let it be assumed $Q_1 = OFF$ and $Q_2 = ON$

$Q_1 = OFF$ ↓ open circuit

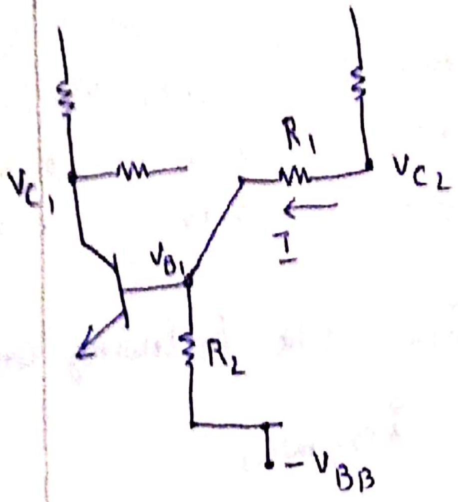
I_B, I_C is 0

$\therefore V_{C_1} = V_{CC}$

$Q_2 = ON$ ↓ closed or saturation

I_C is increasing

$\therefore V_{C_2} = V_{CE\,sat} = 0V$



$$I = \frac{V}{R} = \frac{V_{C_2} - (-V_{BB})}{R_1 + R_2} = \frac{V_{BB}}{R_1 + R_2} \quad [\because V_{C_2} \simeq 0V]$$

$$V_{B_1} = V_{C_2} - IR_1 = V_{C_2} - \frac{V_{BB}R_1}{R_1 + R_2} = -\frac{V_{BB}R_1}{R_1 + R_2}$$

Generally V_{BB} is +ve for NPN transistor.
But in this case V_{B_1} is −ve i.e $V_{B_1} < 0$ i.e $V_{BE(cut\,off)}$

∴ Transistor Q_1 is OFF state.

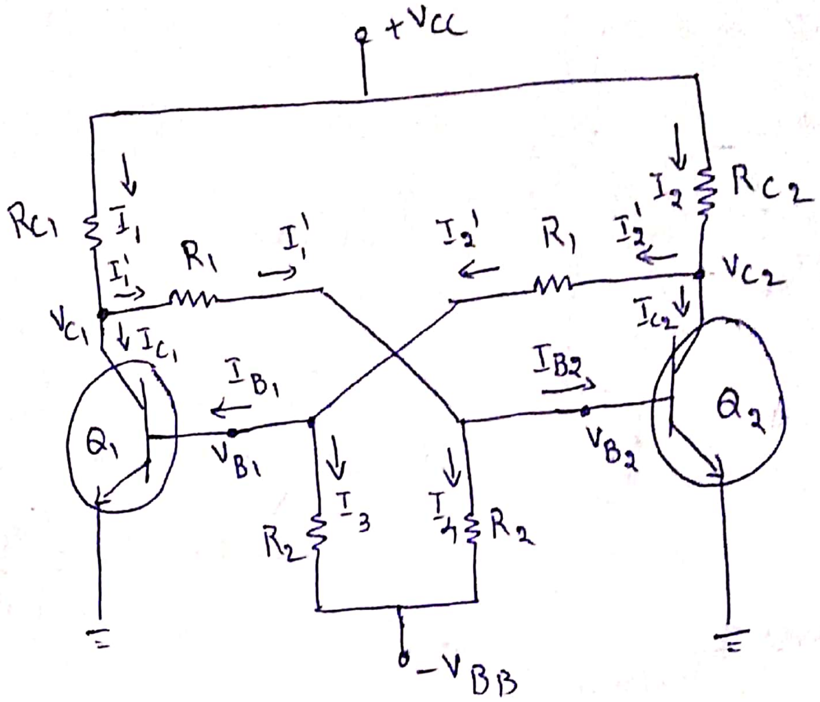
→ If Q_1 is OFF, there no o/p current I_{C_1} and hence $V_{C_1} = V_{CC}$.

→ This large +ve voltage V_{C_1} is sufficient to overcome the −ve bias of $-V_{BB}$ and force a current through the base of transistor Q_2.

→ ∴ $I_{B_2} > I_{B_2(min)}$. where $I_{B_2(min)}$ is the minimum base current needed to keep Q_2 in saturation.

→ Similarly $Q_1 = ON$, $Q_2 = OFF$. Thus the binary has two stable states.

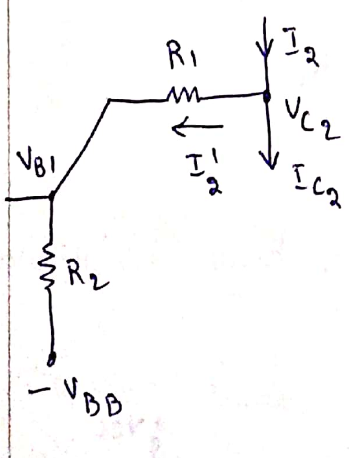
To evaluate the stable state currents and voltages:-



Assume $Q_1 = OFF$ and $Q_2 = ON$

$V_{C1} = V_{CC}$ $\quad V_{C2} = V_{CE\,sat}$ and $V_{B2} = V_{BE\,sat}$

To find I_2, I_2' and I_{C2}:-



where $I_2 = \frac{V_{CC} - V_{C2}}{R_{C2}}$

Since Q_1 is OFF, $I_{B1} = 0$ as Q_1 forms open circuit. $\therefore I_3 = I_2'$

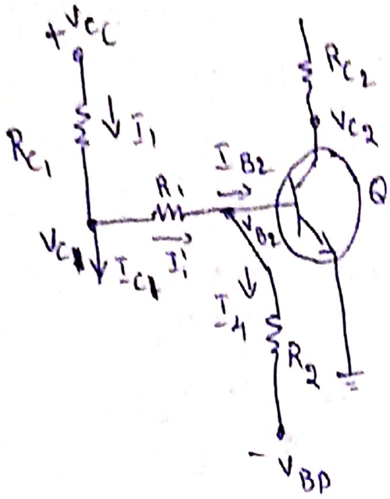
$$I_2' = \frac{V_{C2} - (-V_{BB})}{R_1 + R_2} = \frac{V_{C2} + V_{BB}}{R_1 + R_2}$$

$$I_2 = I_2' + I_{C2}$$

$$\therefore I_{C2} = I_2 - I_2'$$

Thus currents I_2, I_2' and I_{C2} are evaluated.

To find I_{B2} :-



Since Q_1 = OFF , $I_{C1} = 0$

$\therefore I_1 = I_1'$

$\therefore I_{B2} = I_1 - I_4$

We have $I_1 = \dfrac{V_{CC} - V_{B2}}{R_{C1} + R_1}$

$$I_4 = \frac{V_{B2} - (-V_{BB})}{R_2} = \frac{V_{B2} + V_{BB}}{R_2}$$

$$\therefore I_{B2} = I_1 - I_4 = \left[\frac{V_{CC} - V_{B2}}{R_{C1} + R_1}\right] - \left[\frac{V_{B2} + V_{BB}}{R_2}\right]$$

→ We have $I_{B2(min)} = \dfrac{I_{C2}}{h_{fe(min)}}$

→ If the calculated value of $I_{B2} > I_{B2(min)}$ then it implies that Q_2 is indeed ON.

→ Now, verify whether Q_1 is indeed OFF.

from the circuit, $V_{B1} = V_{C2} - I_2' R_1$

→ But $V_{B1} = V_{BE}$ of Q_1

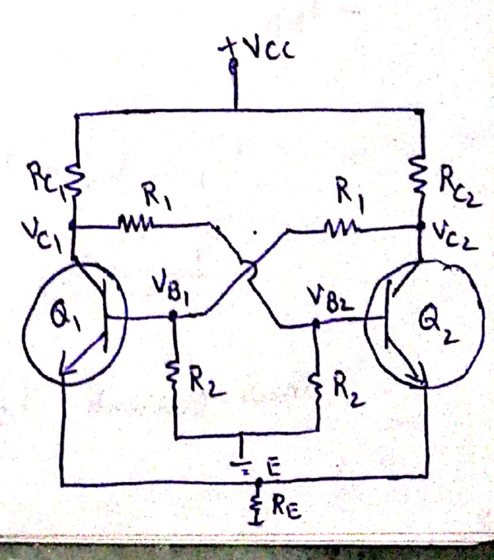
It would be found that $V_{B1} < 0$, hence this proves that Q_1 is indeed OFF.

$\therefore V_{C1} = V_{CC} - I_1 R_{C1}$.

Self Bias Bistable Multivibrator

Self bias circuit which removes the negative supply voltage $-V_{BB}$.

A Common Emitter Resistor R_E Provides the necessary selfbias.



Triggering of Bistable multivibrator :-

To change the states of Q_1 and Q_2, a pulse voltage or step voltage from an external source needs to be applied to one of the transistors. This process of bringing about a change of state of the binary by appling an external pulse is termed as "Triggering".

Transition Time :- The duration of time when conduction transfers from one transistor to other is called as Transition Time.

Usually a -ve pulse of short duration is applied suitably to the collector of the OFF transistor to cause triggering.

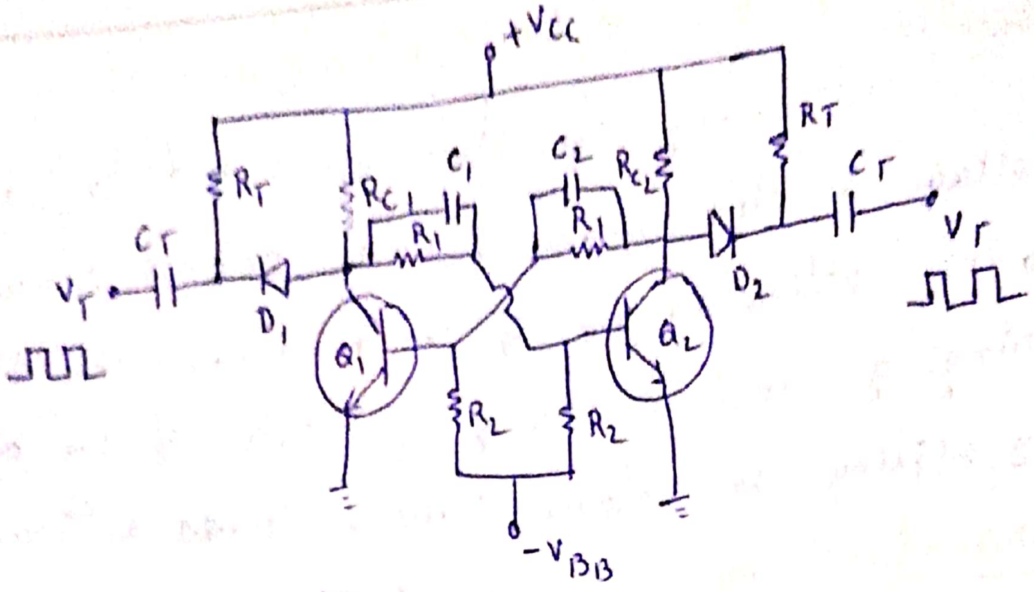
Two types of Triggerings.

① Unsymmetrical or asymmetrical Triggering, and
② Symmetrical Triggering.

① Unsymmetrical Triggering :-

In this, two triggering pulses from two seperate sources are needed to change the states of the binary.

When triggering pulse from a source is applied to one of the transistors, suppose Q_2 which is ON, Q_2 becomes 'OFF' and Q_1 which was OFF becomes 'ON'. Now, Q_2 continues to be 'OFF' and Q_1 continues to be 'ON' until another triggering pulse from another source is applied to Q_1.



Asymmetrical or Unsymmetrical Triggering

→ Trigger circuit has Resistor R_T, capacitor C_T and Diode D. where C_1 and C_2 are commiutating capacitors.

Commutating capacitors:- In order to increase the switching speed of multivibrators, it is added to shunt the coupling resistors R_1 by suitable capacitors (C_1 and C_2). These capacitors are also called as speed up capacitors or transpose capacitors.

In order to change the state of the binary, a -ve spike voltage is applied to the collector of the OFF transistor Q_1 and this appears at the base of Q_2. Since Q_2 goes +ve, the voltage at it's collector terminal is rises. This increase of voltage at the collector Q_2 must be quickly transmitted to the base of Q_1 so as to change it's state from OFF to ON as quickly as possible. This is achived by providing a suitable capacitor C_2 accross R_1. These $C_1 R_1 C_2, R_1$ together constitute a perfectly compensated attenuator, and the full voltage rise at collector Q_2 would be immediately transmitted to the base of Q_1 and and Q_1 would be ON.

The main feature of commutating capacitors is that they reduce the transition time and increase the switching speed. Hence the name <u>speed-up capacitors.</u>

In trigger circuit C_T and R_T together constitute a differentiator circuit and when pulse is applied as input to such circuit, the output is in the form of spikes.

These voltage spikes are alternately +ve and -ve w.r.t V_{CC}. The Diode D_1 can transmit only -ve spikes.

A -ve spike appearing at collector Q_1, is transmitted through the commutating capacitor C_1 and it appears at the base of Q_2. As a result, the base of Q_2 goes -ve and Q_2 becomes OFF. When Q_2 becomes OFF, Q_1 becomes ON.

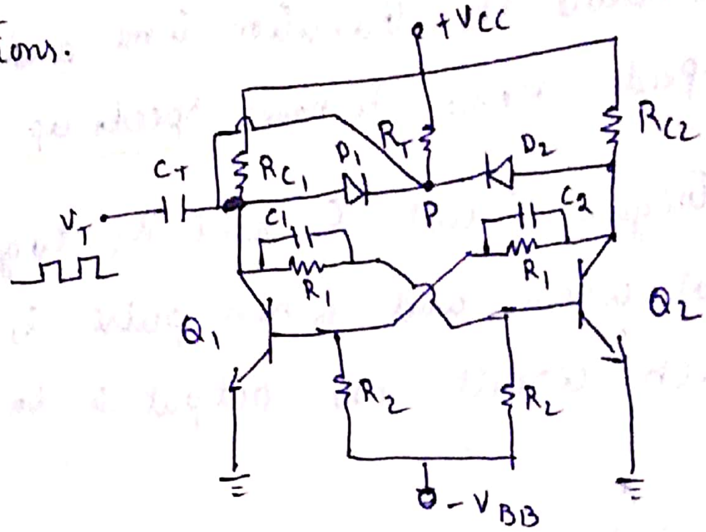
In order to restore the binary to the original state i.e Q_1 OFF and Q_2 ON, a similar triggering arrangement is provided at the collector of Q_2.

<u>Note</u>:- Asymmetrical binary triggering requires two triggering pulses from two separate sources.

Scanned with CamScanner

(2) Symmetrical Triggering :-

In symmetrical triggering, only one triggering pulse is needed to bring about change of state. Thus from a single source, triggering can be effected in both directions.



→ Let it be assumed that Q_2 is ON and Q_1 is OFF.

→ Q_2 is ON i.e $V_{C2} = V_{CE\,sat} = 0V$. Hence the supply voltage V_{CC} which is positive reverse biases diode D_2.

→ when -ve trigger pulse is appears at P, diode D_1 is forword biased and readily conducts.

→ Hence the -ve spike gets applied to V_{C1}. It is transmitting through capacitor C_T and it appers at the base of Q_2.

→ The result of it is that the base Q_2 goes -ve and it becomes OFF and it makes Q_1 is ON.

→ Now Q_1 is ON, Q_2 is OFF.

Since Q_1 is ON, $V_{C1} = V_{CE\,sat} = 0V$. Hence D_1 is reverse bias

→ when next -ve spike appears at P, the diode D_2 is forword biased and it conducts.

→ Hence -ve spike is applied to V_{C2}, it is transmitted through C_2 and appears at the base of Q_1.

→ The base Q_1 goes -ve with the result that Q_1 becomes OFF and it makes Q_2 is ON.

Loading Considerations:-

The bistable multivibrators is used to drive other circuits and hence most of the times there are shunting load resistors connected to both the collectors of the transistor.

Such loads reduce the magnitude of V_{C1} and V_{C2} of the OFF transistors in respective alternate stable states. This reduces the output voltage swing.

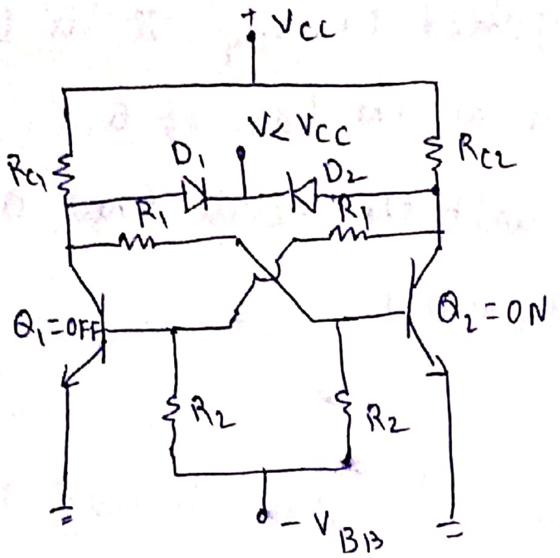
If V_{C1} decreases I_{B2} also decreases and hence the Q_2 cannot be ensures in the saturation. Hence the loading effect must be considered while designing.

Since R_1 also loads the OFF transistor to read the loading, the value of R_1 should be as large as possible compared to the value of R_C. But to ensure a loop gain ~~is~~ excess of unity during the transistor between the states.

∴ R_1 should be selected such that

$$\boxed{R_1 < h_{fe} R_C \;\; \& \;\; R_1 > R_C}$$

the modified circuit to maintain $V = V_W = V_{CC}$



→ Where D_1 and D_2 are col Catching Diodes.

→ These are used to clamp the collector voltage to a voltage $V < V_{CC}$.

→ Let Q_1 = OFF and Q_2 = ON.

→ Since V is positive, diode D_2 is reverse biased, as the potential of V_{C2} is equal to $V_{CE\,sat}$ i.e zero.

→ Since Q_1 is OFF, the potential of V_{C1} tends to rise to almost V_{CC}.

→ Since $V_{CC} > V$, diode D_1 becomes forward biased and conducts readily. Due to reference voltage V, it is seen that the collector voltage V_C of Q_1 is clamped to 'V' volts.

→ Thus irrespective of what resistor R_L is shunted accross the collector of Q_1, the collector voltage 'V_C' remains steady at 'V'.

→ The collector voltage is thus made independent of R_L.

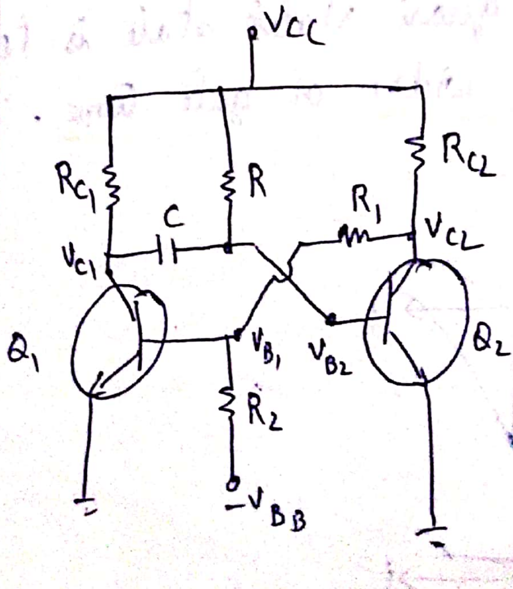
② Monostable Multivibrators :-

It has only one stable state and one quasi-stable state. Normally the multivibrator is in the stable state, and when an external triggering pulse is applied, it switches from the stable to quasi stable state. It remains in the quasi state for T sec, after that automatically switches back to its original stable state without any triggering pulse. T value depends upon the circuit components. Hence the monostable multi is called a 'Pulse Generator'.

It is also called as 'one shot' or 'univibrator'. Since it generates a rectangular waveform and hence can be used to gate other circuits, it is also called a 'gating circuit'.

Since it generates a fast transition at a predetermined time T after the i/p trigger, it is also referred to as a 'delay circuit'.

Operation:-



→ Under normal conditions the supply voltage V_{CC} provides enough base drive to the transistor Q_2 through resistor R, with the result that Q_2 goes into saturation.

→ with Q_2 ON, Q_1 goes to OFF.

→ If a -ve triggering pulse is applied to the collector of Q_1, it is transmitted to the base of Q_2 through the capacitor and hence makes the base of Q_2 -ve. Immediately Q_2 goes to OFF and Q_1 becomes ON.

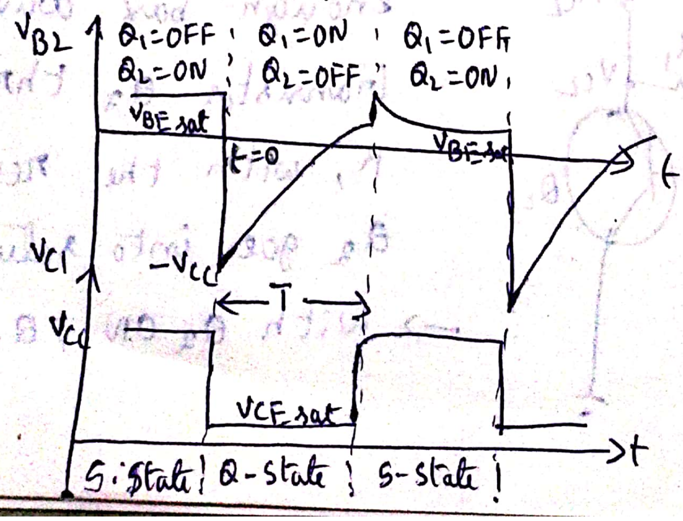
→ The multivibrator is now in it's quasi-stable state.

→ The circuit will remain in this quasi-stable state for only a finite time 'T' because base B_2 is connected to V_{cc} through a resistance R.

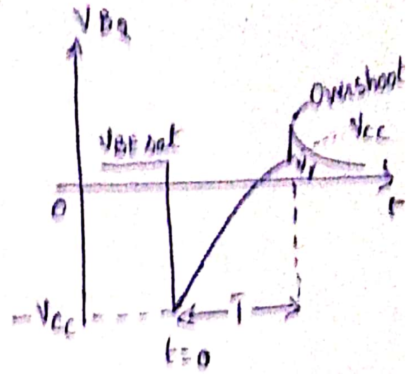
→ Therefore B_2 will rise in voltage and when it passes the cut in voltage V_γ of Q_2 a regenerative action will takes place, turning Q_1 OFF and then return back x multivibrator to its initial stable states.

→ The interval during which the quasi stable state of the multivibrator persists i.e Q_2 remains OFF is dependent upon the rate at which the capacitor C discharges.

→ This duration of the quasi stable state is termed as delay time or pulse width or gate time. It is denoted as T.



Expression for pulse width or delay Time (T) :-



→ Initial value of V_B at $t=0$ is $V_{ini} = -V_{cc}$

→ As capacitor discharges, the voltage V_B rises exponentially and would attain the value $+V_{cc}$.

→ But at $t=T$, Q_2 becomes ON and V_B takes the value $V_B = V_\gamma$ which may be taken as zero.

∴ Final value of V_B (at $t=\infty$), $V_{final} = +V_{cc}$

at $t=T$, $V_B = V_\gamma = 0$

→ The exponentially increasing voltage V_B is mathematically expressed as, $V_B = V_{final} - (V_{final} - V_{initial})\, e^{-t/RC}$

$$\therefore V_B = V_{cc} - (V_{cc} - (-V_{cc})\, e^{-T/RC}$$

At $t=T$, $V_B = V_\gamma = 0$

$$\therefore 0 = V_{cc} - 2V_{cc}\, e^{-T/RC} = 1 - 2e^{-T/RC}$$

$$\therefore 2e^{-T/RC} = 1$$

$$e^{T/RC} = 2$$

$$\frac{T}{RC} = \log_e 2 = 0.69$$

∴ Pulse width or delay Time $\boxed{T = 0.69\,RC}$

→ In above expression reverse current (I_{CBO}) of transistor Q_1 has been ignored. If I_{CBO} is taken into consideration, The expression for T as $T = RC \log_e \left[\frac{2V_{cc} + I_{CBO}R}{V_{cc} + I_{CBO}R}\right]$

if $I_{CBO} = 0$, we get $T = RC \log_e 2 = 0.69\,RC$

Designing steps of Fixed Bias Bistable Multivibrator:-

→ For the design purpose assume that the values of V_{CC}, V_{BB}, $h_{fe(min)}$ and I_{Csat} values are known.

→ Assume Q_1, Q_2 to be npn transistors and assume suitable junction voltages depending on whether transistore are Si or Ge.

→ Under saturation conditions the collector current I_C is maximum. Hence R_C must be chosen so that this value of I_C ($\simeq V_{CC}/R_C$) does not exceed the maxim permissible limit.

→ The values of R_1, R_2 and V_{BB} must be selected such that in one stable state the base current is large enough to drive the transistor into saturation whereas in the second stable state the emitter junction must be below cut-off.

→ The base current of the ON transistor is taken as 1.5 times the minimum value. $I_B = 1.5\, I_{B(min)}$.

→ ~~Reduce~~ Neglect loading effect caused by R_1, then the collector voltage of the OFF transistor is V_{CC}.

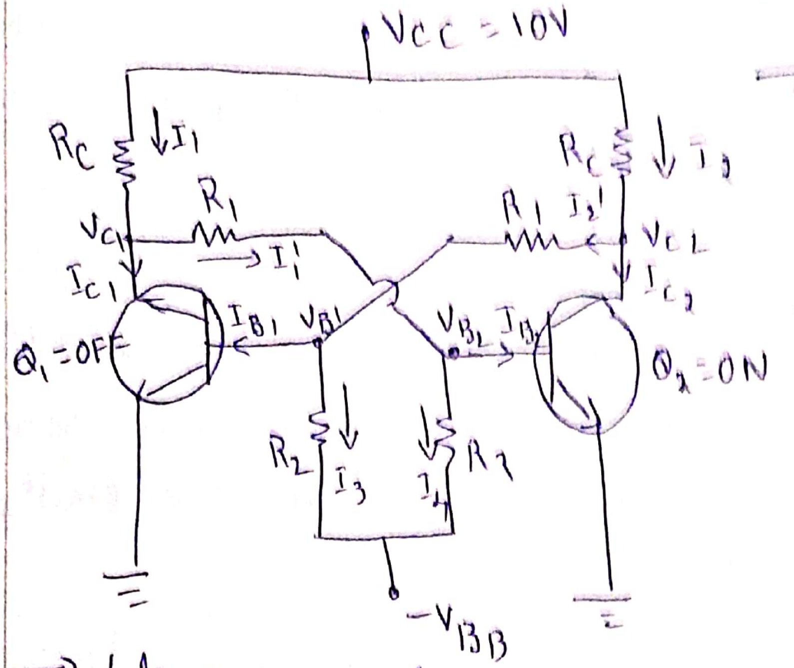
Note:- Voltage swing V_W is the change in collector volt resulting from a transistor going from one state to other, i.e $V_W = V_{C_1} - V_{C_2}$.

→ To reduce loading, the value of R_1 should be as large as possible compared to the value of R_C.

→ But to ensure a loop gain in excess of unity during the transition between the states, R_1 should be selected such that $R_1 < h_{fe} R_C$.

Ex:- Si transistors with $h_{fe(min)}$ equal to 20 are available. If $V_{CC} = V_{BB} = 10V$, design the bistable multivibrator.

(A) **Note:-** For n-p-n type, V_{CC} is +ve & V_{BB} is −ve.



→ Q_1 = OFF & Q_2 = ON

$I_{C1} = 0$ $\quad V_{C2} = V_{CE\,sat} = 0V$

$I_{B1} = 0$ $\quad V_{B2} = V_{BE\,sat} = 0V$

→ Neglect the loading effect of R_1 at collector of Q_2 (i.e neglect I_2' compared to I_2)

→ Let assume saturation current of the ON transistor be $I_{C\,sat} = 5mA$.

→ $I_{B2\,min} = \dfrac{I_{C2}}{h_{fe\,min}} = \dfrac{5m}{20} = 0.25\,mA$

→ Neglecting junction voltages,

$[\because I_2 \simeq I_{C2}$, I_2' is very small$]$

$$R_C = \frac{V_{CC} - V_{C2}}{I_2} = \frac{V_{CC} - V_{CE_2 sat}}{I_{C\,sat}} = \frac{10-0}{5m} = 2K\Omega \quad \text{—(1)}$$

→ Q_1 is to be cut off, let $V_{B1} = -1V$

dure

But $V_{B1} = -V_{BB} \cdot \frac{R_1}{R_1+R_2} + V_{C2}\frac{R_2}{R_1+R_2}$ [Using superposition theorem]

$\therefore -1 = -10 \frac{R_1}{R_1+R_2}$ or $R_2 = 9R_1$ —— (2)

To find I_1, $I_1 = \frac{V_{CC} - V_{B2}}{R_C + R_1}$ $[\because I_{C1} = 0A]$

$\therefore I_1 = \frac{V_{CC} - V_{BE\,sat}}{R_C + R_1} = \frac{10-0}{R_C+R_1} = \frac{10}{2+R_1}$ —— (3)

$I_4 = \frac{V_{B2} - (-V_{BB})}{R_2} = \frac{0-(-10)}{R_2} = \frac{10}{R_2}$ —— (4)

$\therefore I_1 = I_1' = I_{B2} + I_4$

$\therefore I_{B2} = I_1 - I_4$ —— (5)

Let $I_{B2}(\text{actual}) = 1.5\, I_{B2min} = 1.5 \times 0.25\,mA = 0.375\,mA$

From eqn (5), $0.375\,mA = \frac{10}{2+R_1} - \frac{10}{R_2}$

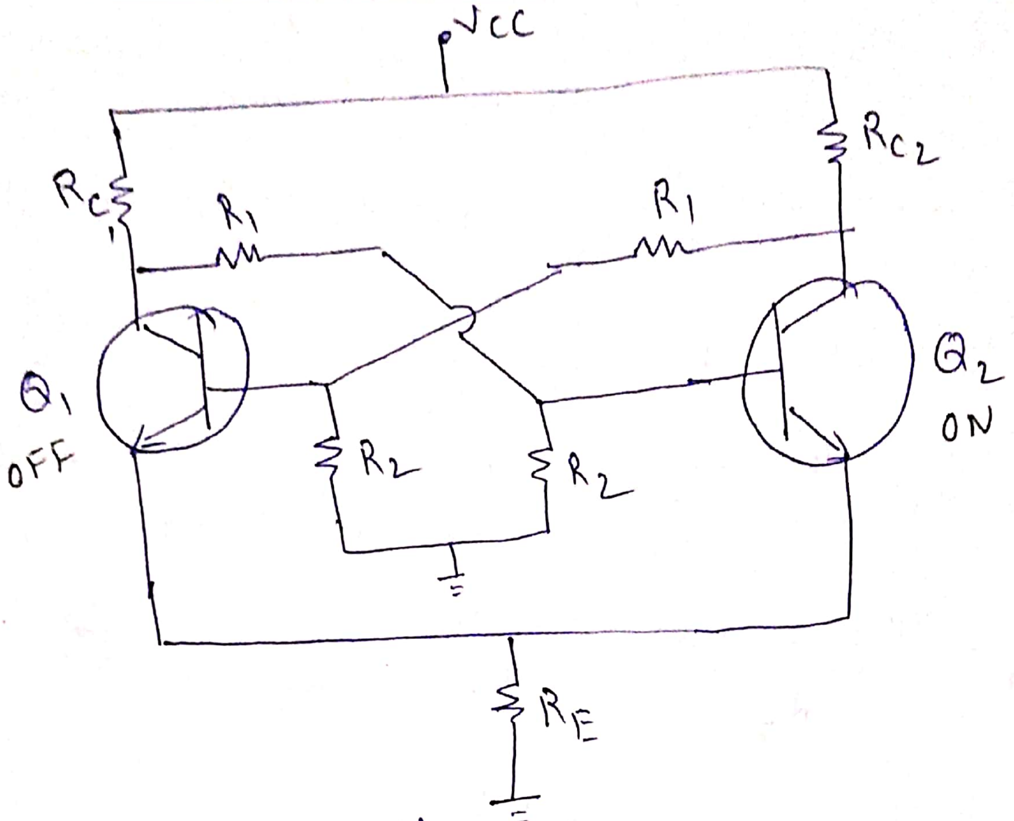
$\therefore 0.375\,mA = \frac{10}{2+R_1} - \frac{10}{9R_1}$

By solving above expressions, $R_1 = 21.423\,\Omega$

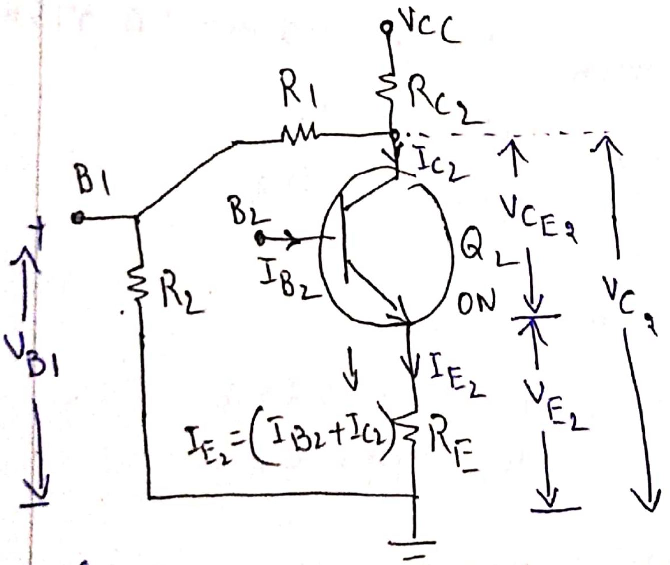
$R_2 = 192.8\,K\Omega$.

Self - Biased Transistor Binary:-

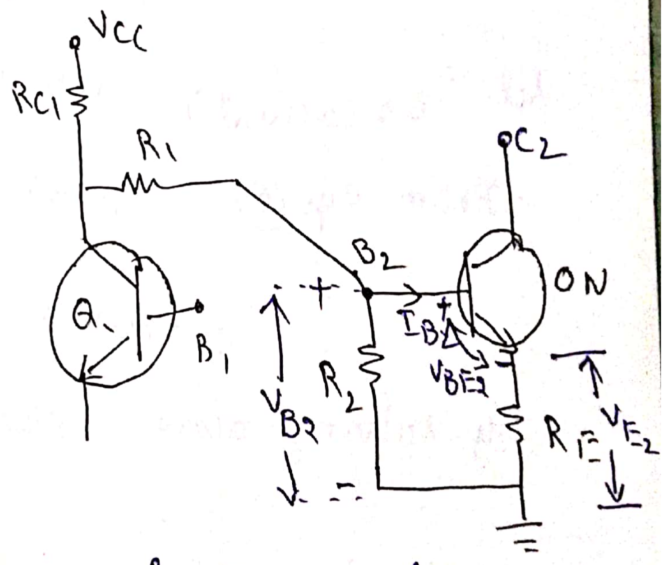
A fixed - biased multivibrator requires two Power supplies. One is positive and one is Negative. The need for the -ve power supply may be eliminated by using a common emitter Resistor R_E. The binary using the R_E to provide self bias is called self biased binary.



Fig(1) Self Biased Binary



Fig(2) equivalent circuit at the Collector of Q_2



Fig(3) Equivalent circuit at the Base of Q_2

→ Collector circuit Q_2 is replaced by Thevenin's equivalent voltage i.e $V_{C_2T} = \dfrac{V_{CC}(R_1 + R_2)}{R_{C_2} + R_1 + R_2}$ —— (1)

Scanned with CamScanner

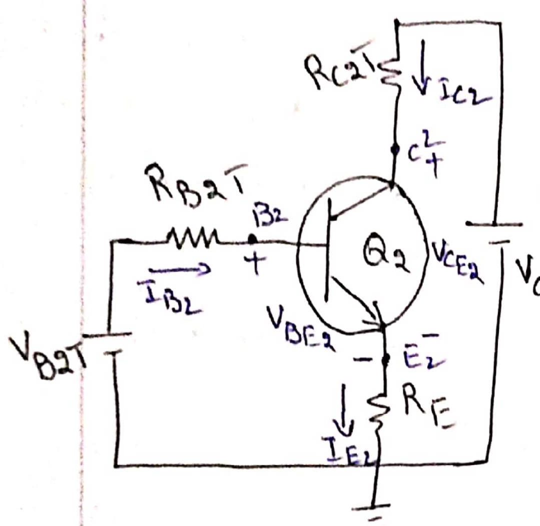
→ and it's Thevenin's Resistance $R_{C2T} = R_{C2} \| (R_1 + R_2)$

$$\therefore R_{C2T} = \frac{R_{C2} \times (R_1 + R_2)}{R_{C2} + R_1 + R_2} \quad \text{—— (2)}$$

→ Base circuit of Q_2 is replaced by it's Thevenin's equivalent voltage $V_{B2T} = \dfrac{V_{CC} R_2}{R_2 + R_{C1} + R_1}$ —— (3)

→ and it's Thevenin's equivalent Resistance $R_{B2T} = R_2 \| (R_{C1} + R_1)$

$$\therefore R_{B2T} = \frac{R_2 \times (R_{C1} + R_1)}{R_2 + R_1 + R_{C1}} \quad \text{—— (4)}$$



Fig(4): equivalent circuit when Q_2 is ON.

→ Apply KVL loop to Base circuit

(5) — $V_{B2T} - I_{B2} R_{B2T} - V_{BE2} - (I_{B2} + I_{C2}) R_E = 0$

→ Apply KVL to collector circuit

(6) → $V_{C2T} - I_{C2} R_{C2T} - V_{CE2} - (I_{B2} + I_{C2}) R_E = 0$

solving eqn (5) & (6) I_{B2} & I_{C2} will be obtained.

→ $I_{B2} > I_{B2(min)}$ then Q_2 is really in Saturation.

→ The voltages in the circuit are

$V_{C2} = V_{CE2} + V_{E2}$

$V_{E2} = (I_{B2} + I_{C2}) R_E$

$V_{B2} = V_{BE2} + V_{E2}$

$V_{B1} = V_{B2} \dfrac{R_2}{R_1 + R_2}$

$V_{BE1} = V_{B1} - V_{E1}$

if V_{BE1} is negative value the Q_1 is really in cutoff.

$$V_{C1} = V_{CC} \times \frac{R_1}{R_1 + R_{C1}} + V_{B2} \times \frac{R_{C1}}{R_{C1} + R_1}$$

(or)

$$V_{C1} = V_{CC} - I_1 R_{C1} \quad \text{where } I_1 = \frac{V_{CC} - V_{B2}}{R_1 + R_{C1}}$$

Ex:- A Self biased bistable multivibrator using NPN transistors having $V_{CE\,sat} = 0.4V$, $V_{BE\,sat} = 0.8V$, $R_C = 4.7k$, $R_1 = 30K$, $R_2 = 15K$, $R_E = 0.39K$, $h_{FE} = 25$, $V_{CC} = 20V$. and zero base to emitter voltage for cut-off ($V_{BE} = 0V$). Find (a) the stable state voltages and currents (b) the maximum load that the binary can drive. (c) the maximum value of I_{CBO} required to reach the condition that neither device is OFF.

(A) To find stable state voltages and currents :-

$$V_{C2T} = \frac{V_{CC}(R_1 + R_2)}{R_1 + R_2 + R_{C2}} = 18.108V$$

$$R_{C2T} = R_{C2} \| (R_1 + R_2) = 4.255 K\Omega$$

$$V_{B2T} = \frac{V_{CC} R_2}{R_2 + R_1 + R_{C1}} = 6.036V$$

$$R_{B2T} = R_2 \| (R_1 + R_C) = 10.473 K\Omega$$

KVL to Base $\rightarrow$ $V_{B2T} - I_{B2} R_{B2T} - V_{BE2} - R_E(I_{B2} + I_{C2}) = 0$

$$10.863 I_{B2} + 0.39 I_{C2} = 5.236 \quad \text{--- (1)}$$

KVL to collector $\rightarrow$ $V_{C2T} - I_{C2} R_{C2T} - V_{CE2} - (I_{B2} + I_{C2}) R_E = 0$

$$0.39 I_{B2} + 4.645 I_{C2} = 17.708 \quad \text{--- (2)}$$

Solving eqn (1) & (2), $I_{B2} = 0.225 mA$ & $I_{C2} = 3.793 mA$

$\rightarrow I_{B2(min)} = \frac{I_{C2}}{h_{FE}} = 0.1517 mA$

$\because I_{B2} > I_{B2(min)}$, so Q_2 is in saturation.

$\rightarrow V_{E2} = (I_{B2} + I_{C2}) R_E = 1.567V$

$V_{C2} = V_{CE2} + V_{E2} = 1.967V$

$V_{B2} = V_{BE2} + V_{E2} = 2.367V$

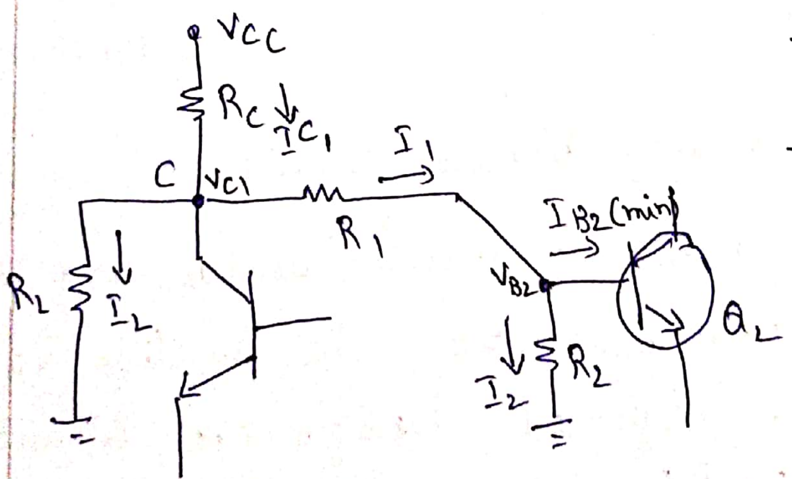
$V_{B1} = V_{C2} \cdot \frac{R_2}{R_1 + R_2} = 0.656V$

$V_{BE1} = V_{B1} - V_{E2} = -1.007V$ $\rightarrow$ $-ve$ means Q_1 is cut-off.

$V_{C1} = V_{CC} \frac{R_1}{R_1 + R_C} + V_{B2} \frac{R_C}{R_C + R_1} = 15.548V$

$I_{C1} = 0 mA$ & $I_{B1} = 0 mA$

(b) To find $R_L(max)$ can drive binary :-



$\rightarrow I_{B2} = I_{B2(min)} = 0.1517 mA$

$\rightarrow I_2 = \frac{V_{B2}}{R_2} = 0.1578 mA$

$\rightarrow V_{C1} = I_1 R_1 + V_{B2}$

$\therefore I_1 = I_{B2} + I_2$

$\therefore V_{C1} = 11.652V$

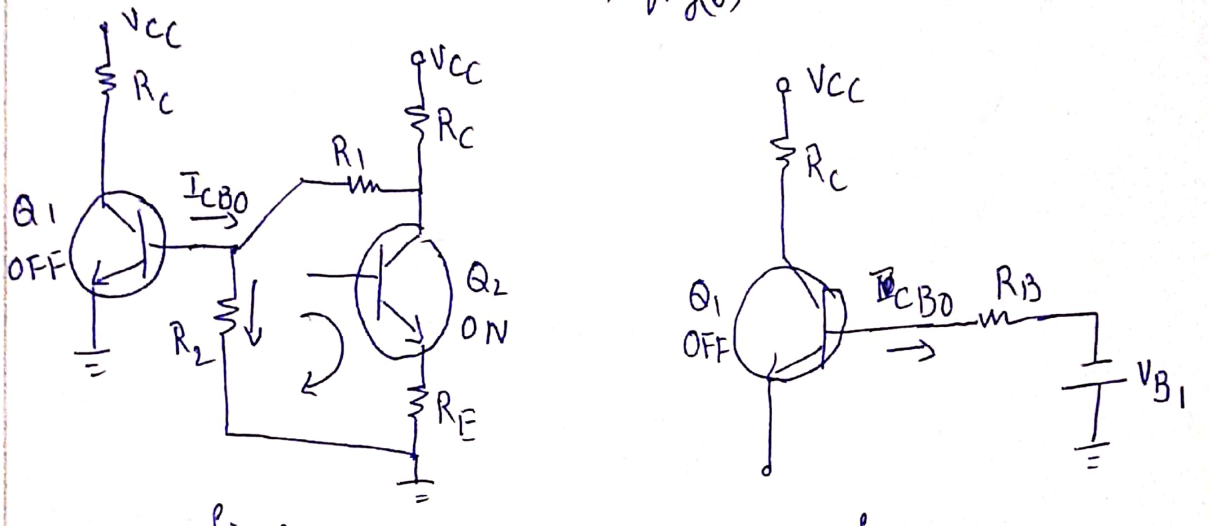
$I_{C1} = \frac{V_{CC} - V_{C1}}{R_C} = 1.776 mA$

$\therefore I_{C1} = I_L + I_1$

$I_L = I_{C1} - I_1 = 1.467 mA$

$R_{L(max)} = \frac{V_{C1}}{I_{L(max)}} = 7.942 k\Omega$

(C) The maximum I_{CBO} the bistable multivibrator withstand so that one device is still OFF can be found by finding the equivalent resistance looking into the base as shown in fig(b)



fig(b) fig(c)

$$R_B = \frac{R_2(R_1+R_E)}{R_2+R_1+R_E} = \frac{15(30+0.39)}{15+30+0.39} = 10.04\,K\Omega$$

The $I_{CBO(max)}$ can be found using fig(c),

Since $V_{BE1} = -1.007V$

Limiting value of $I_{CBO} = \frac{V_{BE1}}{R_B} = \frac{1.007}{10.04K} = 0.1003mA = 100$

Design of Self biased binary circuit:-

Ex:- The self biased bistable multivibrator uses Si transistors with $h_{FE(min)} = 20$. The junction voltages and I_{CBO} may be neglected. Design the circuit subject to the condition $V_{CC} = 18V$, $R_1 = R_2$, $I_{C(max)} = 10$. The base current of ON transistor is twice the minimum base current, and V_{BE} of the OFF transistor is equal to $-1V$.

8(A) $h_{FE(min)} = 20$

Junction voltages & I_{CBO} are neglected.

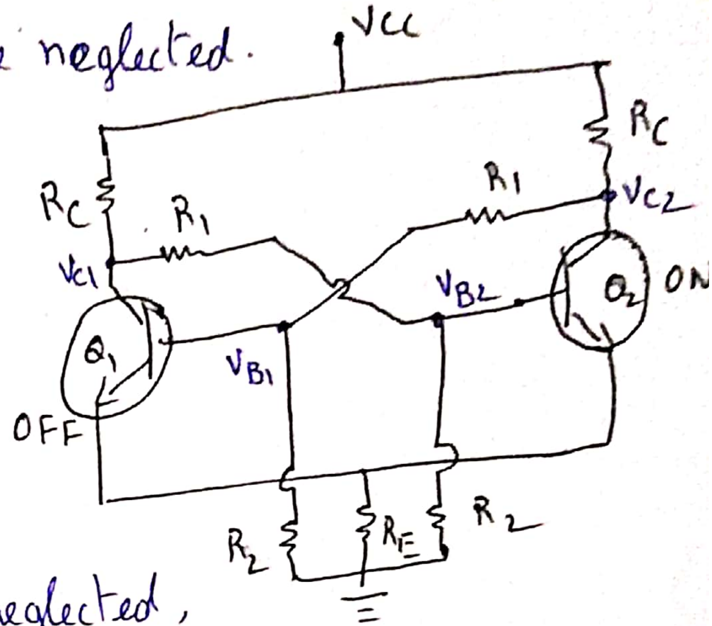
$V_{CC} = 18V$

$R_1 = R_2$

$I_{C(max)} = I_{C sat} = 10 mA$

$I_B = 2 I_{B min}$

$V_{BE_1} = -1V$



if junction voltages are neglected,

then $V_{C2} = V_{B2} = V_{E2} = V_E$ — (1)

$$V_{B_1} = V_{C2} \cdot \frac{R_2}{R_2 + R_1 \cancel{+R_E}} = V_{C2} \cdot \frac{R/2}{2R/2} = \frac{V_{C2}}{2} \quad \text{— (2)} \quad [\because R_1 = R_2]$$

$V_{B_1} = V_{BE_1} + V_{E_1}$

$V_{B_1} - V_{E_1} = -1 \quad [\because V_{BE_1} = -1V]$

$V_{B_1} = V_{E_1} - 1$

$V_{C2} = 2(V_{E_1} - 1) = 2V_{E_1} - 2$

$V_E - 2V_{E} = -2$

$-V_E = -2 \quad \therefore V_E = 2V = V_{C2}$ — (3)

Neglecting the loading effect of R_1 & R_2 at C_2,

$$R_C = \frac{V_{CC} - V_{C2}}{I_{C2}} = \frac{18 - 2}{10} = 1.6 k\Omega \quad \text{— (4)}$$

$I_B = 2 I_{B min}$

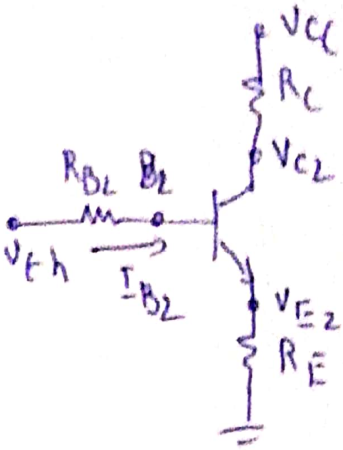
$$I_{B min} = \frac{I_{C2}}{h_{FE min}} = \frac{10}{20} = 0.5 mA$$

$I_{B2} = 2 \times I_{B2\,min} = 1\,mA$

$V_E = I_{E2} R_E = (I_{C2} + I_{B2}) R_E = 11 R_E$

$\therefore 2 = 11 R_E \qquad \therefore R_E = \frac{2}{11} = 0.182\,K\Omega$

Using Thevenin's equivalent at the base of Q_2,



$$V_{B2} = V_{th} = V_{CC} \cdot \frac{R_2}{R_2 + R_1 + R_C} = \frac{V_{CC} R_1}{2R_1 + R_C}$$

$$V_{th} = \frac{18 R_1}{2R_1 + 1.6K}$$

$$R_{th} = R_2 \| (R_1 + R_C) = \frac{R_2 (R_1 + R_C)}{R_2 + R_1 + R_C}$$

Apply KVL to the base circuit,

$$V_{th} = I_{B2} R_{th} + \cancel{V_{BE2}} + V_{E2}$$

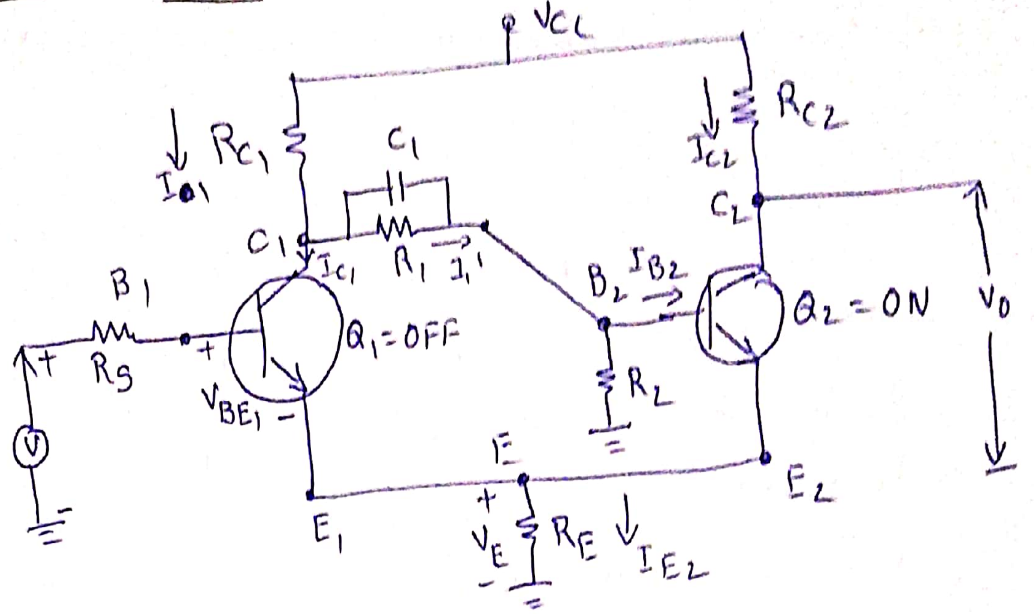
$$\frac{18 R_1}{2R_1 + 1.6K} = 1 \times \frac{R_1 (R_1 + 1.6K)}{2R_1 + 1.6K} + 2$$

Solving above expression, $R_1 = 12.2\,K\Omega = R_2$

$R_C = 1.6\,K\Omega$

$R_E = 0.182\,K\Omega$

Emitter coupled Binary (Schmitt Trigger circuit) :-



if $V_i = 0$, $Q_1 = OFF$ then $I_{B_1} = 0$ & $I_{C_1} = 0$

$$V_{B2} = V_{CC} \cdot \frac{R_2}{R_2 + R_{C_1} + R_1}$$

if $V_{B2} > V_{BE2}$ then $Q_2 = ON$, then $V_0 = V_{CC} - I_{C2} R_{C2}$ — ①

$I_{C2} = I_{E2}$ $\left[\because I_E = I_B + I_C \simeq I_C\right]$

$\therefore V_E = I_{E_2} R_E = I_{C_2} R_E$

This V_E is present at Emitter of Q_1.

$\therefore$ $\boxed{V_1 = V_{BE_1} + V_E}$ = UTP — 1st Ref level.

To turn on Q_1, apply $V_i >$ UTP then $Q_1 = ON$.

if $Q_1 = ON$ then $I_{B_1} \uparrow$ & $I_{C_1} \uparrow$.

$I_1 = I_{C_1} + I_1'$, $V_{C_1} = V_{CE\,sat}$ hence V_{B2} is $\downarrow$

hence $Q_2 = OFF$ then $I_{C2} = 0$ $\therefore$ $V_0 = V_{CC}$

$\therefore I_{E_1} = I_{C_1}$ $\rightarrow$ $\boxed{V_2 = V_{BE_1} + V_E'}$ = LTP — II Ref level

where $V_E' = I_{C_1} R_E$

→ As V_i rises from zero voltage, V_o will remain at it's lower level $= V_{CC} - I_{C2} R_{C2}$ until V_i reaches V_1.

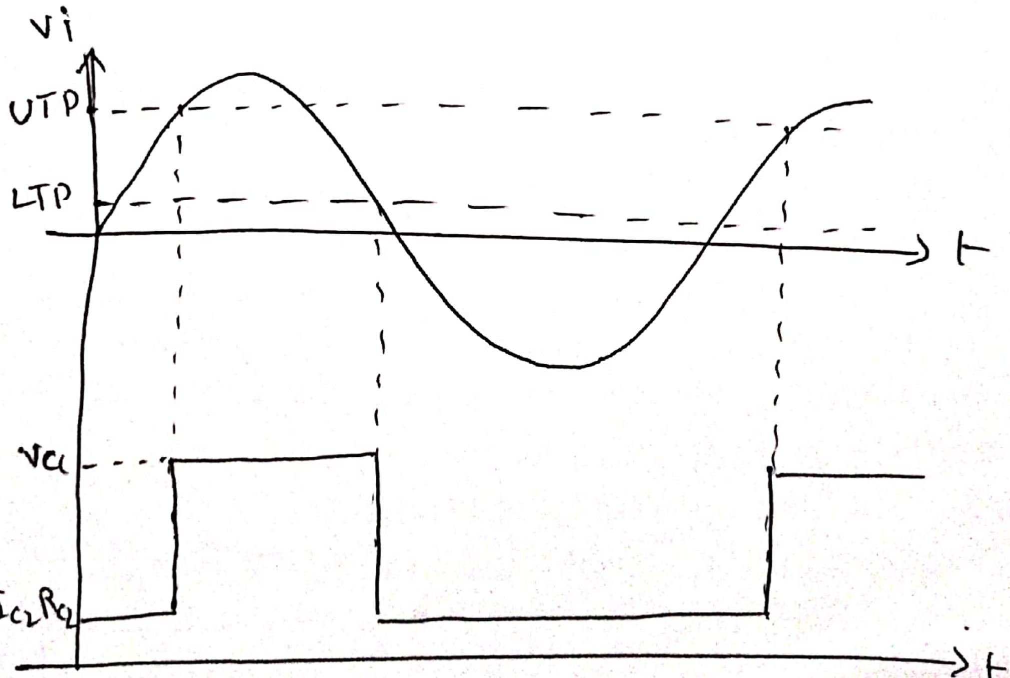
→ At which Q_1 enters into conduction (i.e $V_i = V_1$) is called Upper Triggering point, UTP).

→ For $V_i > V_1$, Q_1 is ON and Q_2 is OFF.

→ V_i is initially greater than V_1, then as V_i is decreased, the O/P will remain at it upper level until V_i attains a definite level V_2.

→ $V_i = V_2$ at which the Q_2 resumes conduction is called the lower Triggering point, LTP.

→ The circuit exhibits hysteresis, that is, to effect a transition in one direction we must first pass beyond the voltage at which the reverse transition took place.



Applications of schmitt Trigger circuit :-

→ It is used as an Amplitude comparator to mark the instant at which an arbitary waveform attains a particular reference level.

→ It is a squaring circuit. It can convert any type of wave into square wave.

→ The schmitter Trigger circuit is triggered between it's two stable states by alternate +ve & -ve pulses.

Derivation of expression for UTP :-

→ The UTP is defined as the i/p volt V_1 at which the transistor Q_1 just enters into conduction.

→ To calculate V_1, we have to calculate current in Q_2. For this we have to find the Thevenins equivalent voltage V' & equivalent resistance R_B at the base of Q_2.

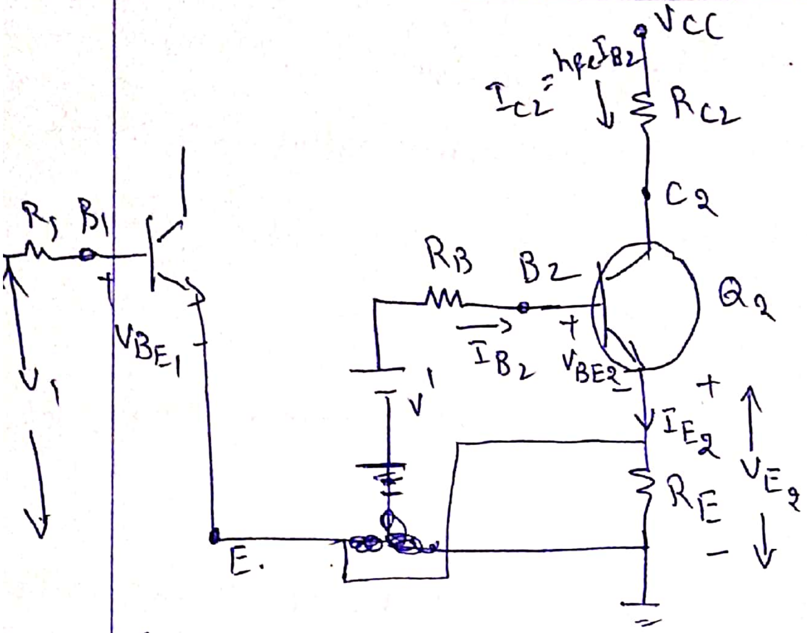
$$\therefore \; V' = V_{CC} \cdot \frac{R_2}{R_2 + R_{C_1} + R_1} \quad \& \quad R_B = R_2 \,\|\, (R_{C_1} + R_1)$$

→ Assume Q_2 is in its active region.

$$\therefore \; I_{C2} = h_{fe} I_{B2}$$

$$\therefore \; I_{E2} = I_{B2} + I_{C2} = I_{B2} + h_{fe} I_{B2} = I_{B2}(1 + h_{fe})$$

→ Replace circuit with thevenin's equivalent model.



$\rightarrow I_{E_2} = I_{B_2} + I_{C_2}$

$= (1+h_{fe}) I_{B_2}$

$\rightarrow$ Apply KVL to base loop of Q_2

$$V' - I_{B2}R_B - V_{BE2} - (1+h_{fe})I_{B2}R_E = 0$$

$$\therefore I_{B2} = \frac{V' - V_{BE2}}{R_B + R_E(1+h_{fe})}$$

Since $V_{E1} = V_E = V_{E2}$, Q_1 is just cut-in, $I_{B1} = 0$, $V_{BE1} = V_\gamma$

$$\therefore V_{E2} = I_{E2}R_E = (1+h_{fe})I_{B2} \cdot R_E$$

$$V_{E2} = \frac{V' - V_{BE2}}{R_B + R_E(1+h_{fe})} \cdot (1+h_{fe}) \cdot R_E$$

$\therefore V_1 = V_{E1} + V_{BE1} + I_{B1}R_S$

$$\boxed{\therefore V_1 = V_{BE1} + V_{E2}}$$

If $R_E(1+h_{fe}) >> R_B$, the drop across R_B may be neglected compared with R_E drop.

$$\therefore V_{E2} = V' - V_{BE2}$$

$$\therefore V_1 = V_{BE1} + V' - V_{BE2}$$

Since V_{BE1} is the cut in volt where the loop gain just exceeds unity, it differs from V_{BE2} in the active region by only 0.1V. for Ge or Si.

$$\boxed{\therefore V_1 = V' - 0.1}$$

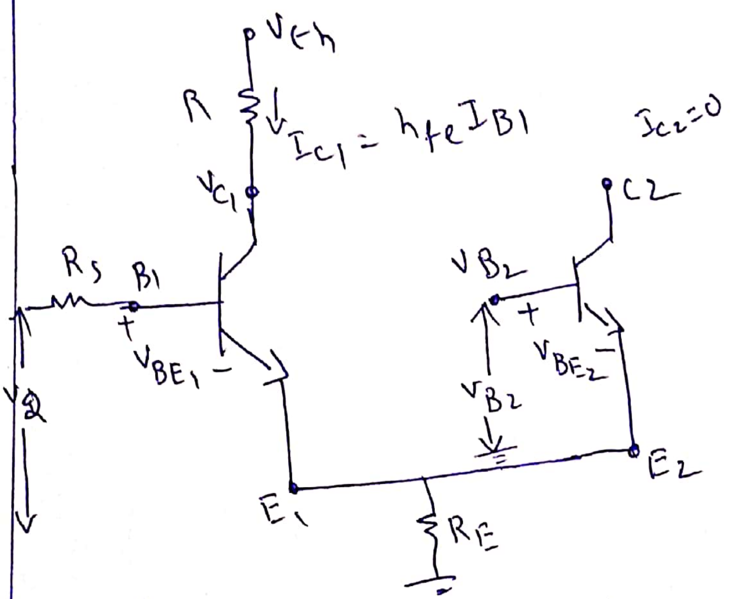
[V_1 made almost independent of h_{FE} & R_E & Temp]

Derivation of expression for LTP :-

→ The LTP is defined as the i/p voltage V_2 at which the transistor Q_2 resumes conduction.

→ Replace circuit with Thevenins voltage & resistace at the collector of Q_1.

$$\therefore V_{th} = V_{CC} \cdot \frac{R_1 + R_2}{R_1 + R_2 + R_{C1}} \quad \& \quad R_{th} = R_{C1} \| (R_1 + R_2)$$



$$R = \frac{V_{th} - V_{C1}}{I_{C1}}$$

$$V_{th} = V_{C1} - I_{C1} R$$

$$V_{C1} = V_{th} - I_{C1} R$$

$$V_{B2} = V_{C1} \cdot \frac{R_2}{R_2 + R_1}$$

$$= \alpha V_{C1}$$

where $\alpha = \frac{R_2}{R_2 + R_1}$

Apply KVL around the base circuit of Q_2,

$$V_{B2} - V_{BE2} - I_{E2} R_E = 0$$

$$V_{C1} \cdot \frac{R_2}{R_2 + R_1} - V_{BE2} - (I_{B1} + I_{C1}) R_E = 0$$

$$\frac{R_2}{R_2 + R_1} (V_{th} - I_{C1} R) - V_{BE2} - \left(\frac{I_{C1}}{h_{fe}} + I_{C1}\right) R_E = 0$$

$$'' \quad - V_{BE2} - I_{C1}\left(1 + \frac{1}{h_{fe}}\right) R_E = 0$$

$$\therefore I_{C1} = \frac{\frac{R_2}{R_2 + R_1} (V_{th}) - V_{BE2}}{\frac{R_2}{R_2 + R_1} \cdot R + R_E \left(1 + \frac{1}{h_{fe}}\right)}$$

$$\therefore \frac{R_2}{R_1+R_2} \cdot V_{th} = \frac{R_2}{R_1+\cancel{R_2}} \cdot V_{CC} \frac{\cancel{R_1+R_2}}{R_{C_1}+R_1+R_2} = V_{CC}\frac{R_2}{R_2+R_1+R_{C_1}} = V'$$

Let $R_E\left(1+\frac{1}{h_{fE}}\right) = R_E'$

$$\therefore I_{C_1} = \frac{V' - V_{BE_2}}{\frac{R_2 R}{R_1+R_2} + R_E'}$$

$$\therefore V_2 = I_{B_1} R_S + V_{BE_1} + (I_{B_1}+I_{C_1})R_E$$

$$= V_{BE_1} + \frac{I_{C_1}}{h_{fe}} R_S + \frac{I_{C_1}}{h_{fe}} R_E + I_{C_1} R_E$$

$$= V_{BE_1} + I_{C_1}\left[R_E\left(1+\frac{1}{h_{fe}}\right) + \frac{R_S}{h_{fe}}\right]$$

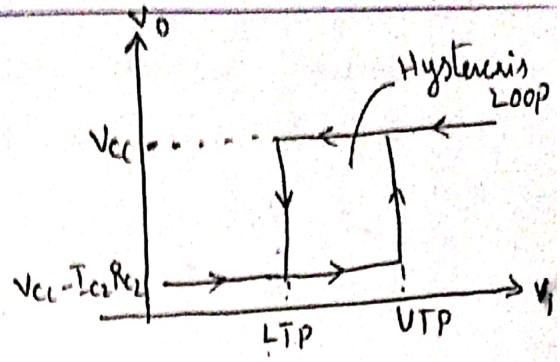
$$= V_{BE_1} + I_{C_1}\left[R_E' + \frac{R_S}{h_{fe}}\right]$$

$$= V_{BE_1} + \frac{V' - V_{BE_2}}{\frac{R_2 R}{R_1+R_2} + R_E'}\left[R_E' + \frac{R_S}{h_{fe}}\right]$$

Since h_{fe} is large, $R_E' \approx R_E$ and $\frac{R_S}{h_{fe}} << R_E$

$$\therefore V_2 = V_{BE_1} + (V' - V_{BE_2}) \frac{R_E'}{\frac{R_2 R}{R_1+R_2} + R_E'}$$

Hysteresis:-



Transfer function of schmitt Trigger circuit is called hysteresis.

x - axis → switching Thresholds.
Y - axis → o/p voltage levels.

When the i/p is below the UTP reference level, the o/p is low, and when the i/p is between the two levels i.e UTP & LTP, the o/p retains it value. This dual threshold action is called hysteresis.

The difference between UTP and LTP is called width of hysteresis. $\boxed{W = UTP - LTP}$

→ Hysteresis may be eliminated by adjusting the loop gain of the circuit to unity.

→ Loop gain adjustment may be made in a no. of ways:

① The loop gain may be increased or decreased by ~~adding~~ increasing or decreasing the R_{C1}.

② by adding R_{E1} & R_{E2} in series with Q_1 & Q_2 and then decreasing or increasing R_{E1} & R_{E2}.

③ The loop gain may also be varied by varying the ratio of $R_1/(R_1+R_2)$. Such an adjustment will change both V_1 & V_2.

④ Increased by increasing the value of R_S.

⑤ V_1 is independent of R_S but V_2 is depends on R_S and increases with an increase in the value of R_S. So for large value of R_S it is possible for V_2 to be equal to V_1.

Thus Hysteresis is eliminated and gain is unity.
If R_s exceeds this critical value, the loop gain falls below unity and circuit cannot be triggered.
If R_s is too small, the speed of operation of the circuit is reduced.

Ex:- Consider emitter-coupled bistable multivibrator with $h_{fe} = 20$, $V_{CC} = 10V$, $R_S = 1K\Omega$, $R_E = 4K\Omega$, $R_{C_1} = 6K\Omega$, $R_{C_2} = 1$, $R_1 = 2K\Omega$, $R_2 = 8K\Omega$. Calculate the UTP & LTP and plot o/p wave when the i/p is $10 \sin \omega t$.

(A) Determination of UTP :-   Approximate $V_1 = V' - 0.1$

Exact

$$V_1 = V_{BE1} + V_E = V_{BE1} + \frac{(V' - V_{BE2})(1+h_{fe})R_E}{(1+h_{fe})R_E + R_B}$$

$$V' = V_{CC} \cdot \frac{R_2}{R_2 + R_{C_1} + R_1} = 5V$$

Assume $V_{BE2}^{(ON)} = 0.7V$

$V_{BE1} = 0.6V$ (OFF)

$$R_B = R_2 \| (R_{C_1} + R_1) = 4K\Omega$$

$$\therefore V_1 = 0.6 + \frac{(5-0.7)(1+20)4K}{(1+20)4K + 4K} = \boxed{4.704V = UTP}$$

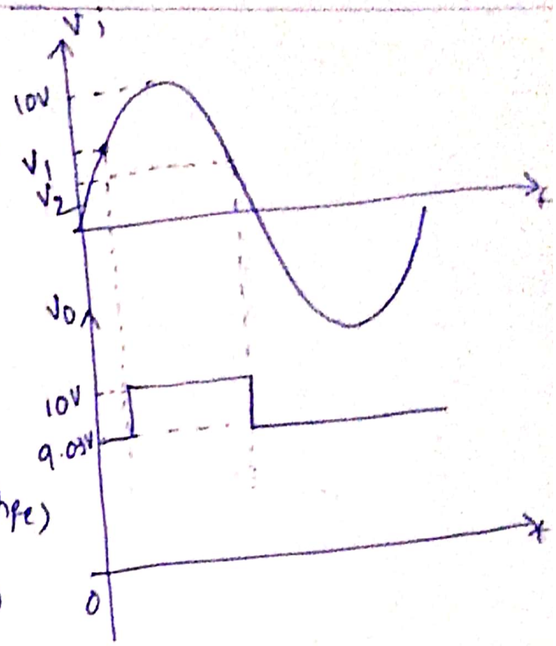
LTP :-

$$V_2 = V_{BE1} + \frac{(V' - V_{BE2})}{\alpha R + R_E'} \cdot \left[R_E' + \frac{R_s}{h_{FE}}\right]$$

where $\alpha = \frac{R_2}{R_1 + R_2} = 0.8$, $R_E' = R_E\left(1 + \frac{1}{h_{fe}}\right) = 4.2K\Omega$

$$R = R_{C_1} \| (R_1 + R_2) = 3.75K\Omega$$

$$\therefore V_2 = 0.7 + \frac{(5-0.6)}{(0.8)(3.75K) + 4.2K} \cdot \left[4.2K + \frac{1K}{20}\right] = \boxed{3.3V = LTP}$$



If $Q_1 = ON$ & $Q_2 = OFF$ then

$V_0 = V_{CC} = 10V$ – Higher level of o/p

If $Q_1 = OFF$ & $Q_2 = ON$ then

$$V_0 = V_{CC} - I_{C2} R_{C2}$$

$$\therefore I_{C2} = h_{fe} I_{B2} = h_{fe} \cdot \frac{V' - V_{BE2}}{R_B + R_E(1+h_{fe})}$$

$$\therefore I_{C2} = 20 \times \frac{5 - 0.7}{4 + 4(20+1)} = 0.977 mA$$

$\therefore V_0 = 10 - 0.977m \times 1K = 9.023V$ – Lower level of o/p

Designing of Schmitt Trigger :-

→ $I_2 = I_{C2}/10$ because R_2 is large value.

→ Soure Resistance R_S must be selected such that

$$R_S << h_{fe} R_E$$

→ Assume Q_2 to be in active region.

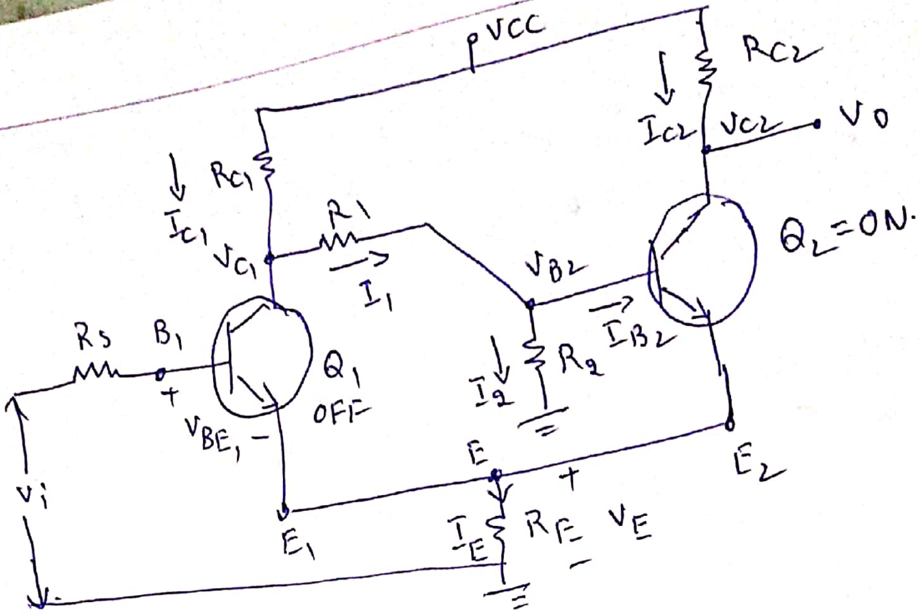
$$V_{CE(active)} = \frac{1}{3} V_{CC}.$$

→ Assume junction voltages like V_{BE1}, V_{BE2}, etc--

Ex:- Design a schmitt trigger circuit to have $V_{CC} = 12V$, UTP = 6V, LTP = 3V, using two silicon NPN transistors with $h_{fe(min)} = 60$.

(A) The circuit to be designed is shown in fig.

Let $I_{C2} = 2mA$ and $I_2 = I_{C2}/10 = 0.2mA$.



<u>Calculation of R_E</u>:- $R_E = \frac{V_E}{I_E}$

$UTP = V_1 = V_E + V_{BE_1} = 6V$ $[\because V_{BE_1} = 0.5V]$

$\therefore V_E = 6 - V_{BE_1} = 6 - 0.5 = 5.5V$

$I_E = I_{E_2} = I_{C_2} = 2mA$

$\therefore R_E = \frac{5.5}{2m} = 2.75 K\Omega$ ——— (1)

<u>Calculation of R_S</u>:-

R_S must be selected such that $R_S << h_{fe} R_E$

$\therefore R_S << 60 \times 2.75K \approx 165 K\Omega$

Let $\therefore R_S = 2K\Omega$ (arbitary value)

<u>Calculation of R_{C2}</u>:-

Assume Q_2 to be in the active region.

$V_{CE(active)} = \frac{1}{3} V_{CC} = \frac{12}{3} = 4V$

$\therefore V_{CC} - I_{C2} R_{C2} - V_{CE(active)} - I_{C2} R_E = 0$

$$\therefore R_{C2} = \frac{V_{CC} - V_{CE(active)} - \overset{V_E}{\boxed{I_{C2}R_E}}}{I_{C2}} = \frac{12-4-5.5}{2} = 1.25\,K\Omega$$

Calculation of R_2:-

$$R_2 = \frac{V_{B2}}{I_2} = \frac{V_{BE2}+V_E}{I_{C2}/10} = \frac{0.7+5.5}{0.2} = 31\,K\Omega$$

$[\because V_{BE2} = 0.7]$

Calculation of R_{C1}:-

$$I_1 = \frac{V_{CC} - V_{B2}}{R_{C1}+R_1} = \frac{12-6.2}{R_{C1}+R_1}$$

$I_{B2} = \frac{I_{C2}}{h_{fe}} = \frac{2m}{60} = 33.3\mu$

$I_2 = \frac{I_{C2}}{10} = 0.2m$

Generally $I_1 = I_{B2} + I_2 = 0.2m + 0.033\,mA$

$= 0.233\,mA$

$$R_{C1}+R_1 = \frac{12-6.2}{0.233m} = 24.89\,K\Omega$$

$$\therefore LTP = V_2 = V_{BE1} + (v' - V_{BE2})\frac{R_E' + \frac{R_S}{h_{fe}}}{\alpha R + R_E'}$$

~~wb~~ if h_{fe} is large, $R_E' = R_E$

and $\frac{R_S}{h_{fe}} << R_E$

$\left[\because R_E' = R_E\left(1+\frac{1}{h_{fe}}\right)\right]$

$\left[\alpha = \frac{R_2}{R_1+R_2}\right]$

$$\therefore LTP = V_2 = V_{BE1} + (v' - V_{BE2})\frac{R_E}{\alpha R + R_E}$$

where $v' = V_1 + 0.1$ $\quad [\because V_1 = v' - 0.1]$

$v' = 6+0.1 = 6.1$

$v' = V_{CC}\frac{R_2}{R_2+R_{C1}+R_1}$

$\frac{6.1}{12} = \frac{R_2}{R_2+R_{C1}+R_1}$

$$3V = 0.7 + (6+0.1-0.5) \times \frac{2.75K}{\alpha R + 2.75K}$$

Where $\alpha R = \frac{R_2}{R_1+R_2} \times \frac{R_{C1}(R_1+R_2)}{R_{C1}+R_1+R_2} = \frac{R_2}{R_{C1}+R_1+R_2} \times R_{C1} = 0.508\,R_{C1}$

$\therefore R_{C_1} = 5.465 K\Omega$

<u>calculation</u> of R_1 :-

$$R_1 = (R_{C_1} + R_1) - R_{C_1} = 24.89 - 5.465K = 19.425$$

The design values are :-

$R_E = 2.75 K\Omega$

$R_{C2} = 1.25 K\Omega$

$R_2 = 31 K\Omega$

$R_{C1} = 5.465 K\Omega$

$R_1 = 19.425 K\Omega$

$R_S = 2 K\Omega$

Generally R_1 should be 3 to 5 times larger than R_{C1}

Take $R_1 = 4 \times R_{C1} = 21.86 K\Omega$

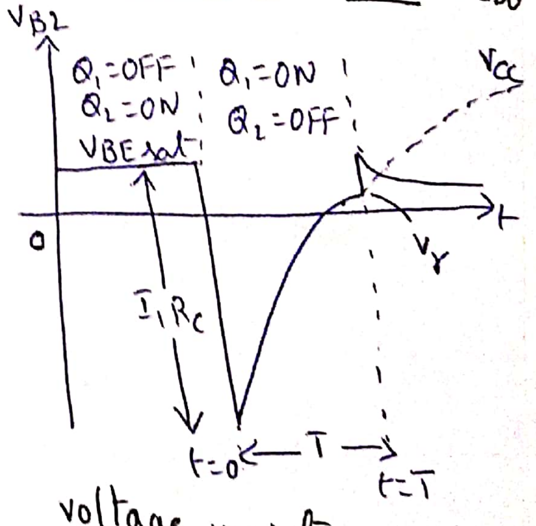
Expression for the gate width T of a monostable Multivibrator neglecting the reverse saturation current I_{CBO}

-> To derive the its expression, consider the voltage variation at base of Q_2.

-> Initially Q_2 = ON, so $V_{B_2} = V_{BEsat}$

-> At $t=0$, -ve signal applied brings Q_2 to OFF & Q_1 into ON.

-> A current I_1 flows through R_C of Q_1 and hence V_{C_1} drops by $I_1 R_C$ and so V_{B2} also drops by $I_1 R_C$ instantaneously.



voltage variation at the base of Q_2 during quasi stable state.

-> At $t=0$, $V_{B2} = V_{BEsat} - I_1 R_C$

-> $t>0$, the capacitor 'C' charges with time constant RC and hence base voltage of Q_2 rises exponentially towards Vcc.

→ At $t = T$ when this base voltage rises to the cut in voltage level V_γ of the transistor, Q_2 goes to ON. and Q_1 to OFF state.

∴ $0 \le t < T$, the base voltage of Q_2 is

$$V_{B2} = V_{CC} - (V_{CC} - [V_{BEsat} - I_1 R_C])\, e^{-t/RC}$$

where $V_f = V_{CC}$, $V_{in} = V_{BEsat} - I_1 R_C$

But $I_1 R_C = V_{CC} - V_{CEsat}$ because at $t = 0^-$, $V_{C1} = V_{CC}$

at $t = 0^+$, $V_{C1} = V_{CEsat}$

$$\therefore V_{B2} = V_{CC} - (V_{CC} - [V_{BEsat} - (V_{CC} - V_{CEsat})])\, e^{-t/RC}$$
$$= V_{CC} - [2V_{CC} - (V_{BEsat} + V_{CEsat})]\, e^{-t/RC}$$

At $t = T$, $V_{B2} = V_\gamma$

$$\therefore V_\gamma = V_{CC} - [2V_{CC} - (V_{BEsat} + V_{BEsat})]\, e^{-T/RC}$$

$$e^{-T/RC} = \frac{V_{CC} - V_\gamma}{2V_{CC} - [V_{CEsat} + V_{BEsat}]}$$

$$e^{T/RC} = \frac{2V_{CC} - [V_{CEsat} + V_{BEsat}]}{V_{CC} - V_\gamma}$$

$$\frac{T}{RC} = \ln \left[\frac{2\left(V_{CC} - \frac{V_{cesat} + V_{Besat}}{2}\right)}{V_{CC} - V_\gamma} \right]$$

$$T = RC \ln 2 + RC \ln \frac{V_{CC} - \frac{V_{CEsat} + V_{BEsat}}{2}}{V_{CC} - V_\gamma}$$

Note: Normally for a transistor, at room temp, the cut in volt is the average of the saturation junction voltages for Ge or Si transistors.

$\therefore V_\gamma = \dfrac{V_{CE\,sat} + V_{BE\,sat}}{2}$

$\therefore T = RC \ln 2 + RC \ln \dfrac{\cancel{V_{CC}} - V_\gamma}{\cancel{V_{CC}} - V_\gamma}$ $\quad [\because \ln(1) = 0]$

$$\boxed{T = RC \ln 2 = 0.693\, RC}$$

→ The gate width can be made very stable (almost independent of transistor characteristics, supply volt, and Resistance values) if Q_1 is driven into saturation during the quasi-stable state.

→ If I_{CBO} is taken into consideration, the expression for $T = RC \ln \left[\dfrac{2[V_{CC} + I_{CBO} R]}{V_{CC} + I_{CBO} R}\right]$

$T = RC \ln 2 - RC \ln \dfrac{1+\phi}{1+\phi/2}$

when $\phi = \dfrac{I_{CBO} R}{V_{CC}}$

if $I_{CBO} = 0$, we get $T = RC \ln 2 = 0.693\, RC$.

Waveforms of the collector-coupled monostable multivibrator:-

→ The triggering signal is applied at $t = 0$, & the reverse transition occures at $t = T$.

(i) **Stable state:-**

For $t < 0$, $Q_1 = OFF$ & $Q_2 = ON$

$I_{C_1} = 0$ $\qquad V_{B2} = V_{BE2(sat)}$

$V_{B1} = -ve$ $\qquad V_{C2} = V_{CE2(sat)}$

$V_{C_1} = V_{CC}$

$\therefore V_{B_1} = V_{CE2(sat)} \dfrac{R_2}{R_1 + R_2} - V_{BB} \dfrac{R_1}{R_1 + R_2}$

Quasi stable state:-

$Q_2 = OFF$

$V_{B2} = \downarrow I_1 R_C$

$I_1 R_C = V_{CC} - V_{CE\,sat}$

$V_{B2} = V_{BE\,sat} - I_1 R_C$

$Q_1 = ON$

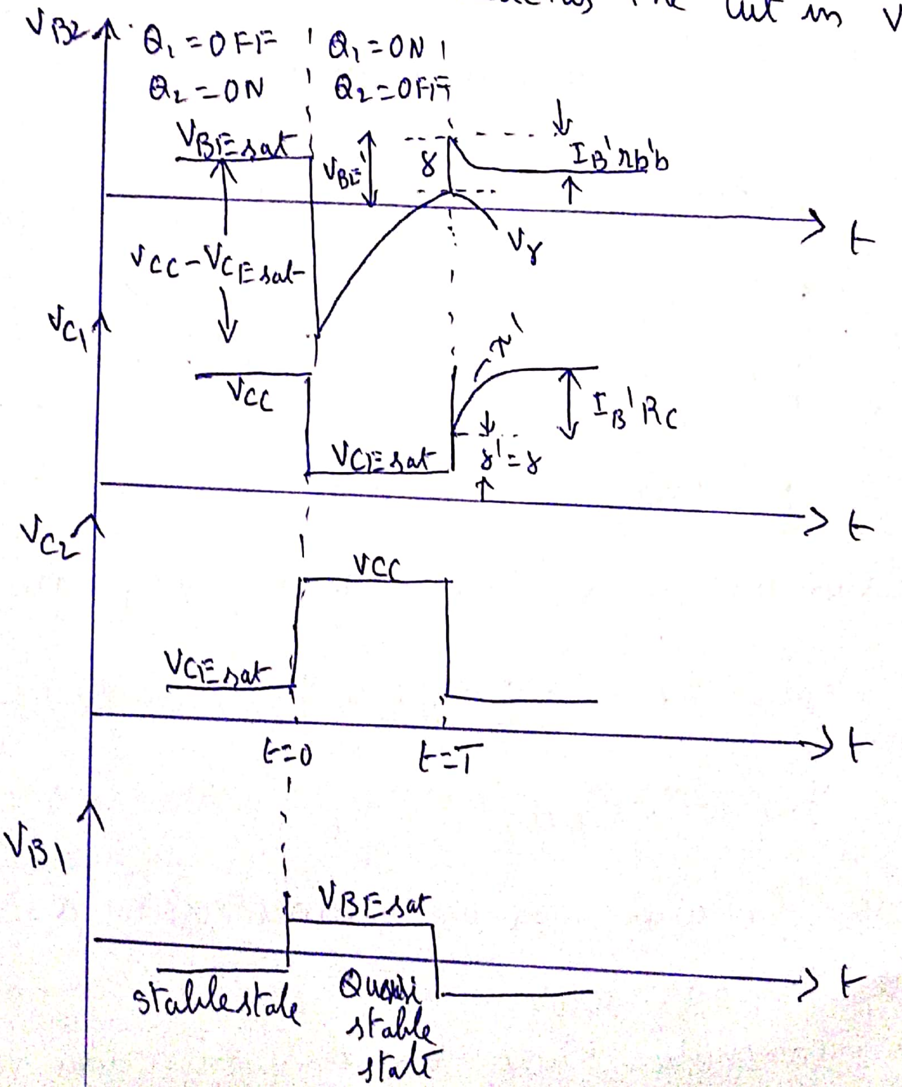
$I_{C_1} = \uparrow$

$V_{C_1} = V_{CC} - I_1 R_C = V_{CE\,sat}$

$V_{B_1} = V_{BE_1(sat)}$

$$V_{C2} = V_{CC} \frac{R_1}{R_1 + R_C} + V_{BE1(sat)} \frac{R_C}{R_1 + R_C}$$ (Using superposition Theorem)

→ In the interval $0 < t < T$, $V_{C_1}, V_{B_1}, V_{C_2}$ remain constant at their values at $t = 0$. But V_{B_2} rises exponentially towards V_{CC} with time const $\tau = RC$ until $t = \tau$. V_{B_2} reaches the cut in volt V_γ of the tran.



Waveforms for $t > T$:-

At $t = T^+$, reverse transition takes place.

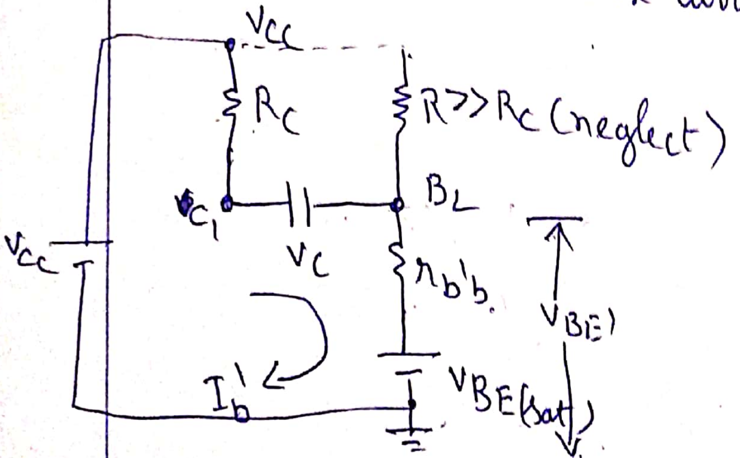
i.e $Q_1 = OFF$ & $Q_2 = ON$

$\therefore$ The V_{C_1} now rises abruptly. This increase in volt. is transmitted to the base of Q_2 and drives Q_2 heavily into saturation.

→ Hence an overshoot develops in V_{B_2} at $t = T^+$, which decays as the capacitor recharges because of the base current.

→ Replace the i/p circuit of Q_2 by base spreading resistance $r_{b'b}$ in series with the volt. $V_{BE\,sat}$.

→ Let I_b' be the base current at $t = T^+$



$$V_{BE}' = I_b' r_{b'b} + V_{BE\,sat}$$

$$V_c = V_{cc} - I_b' R_c - V_{BE}'$$

→ The jumps in voltages at B_2 & C_1 are respectively

$$\delta = V_{BE}' - V_\gamma = I_b' r_{b'b} + V_{BE\,sat} - V_\gamma$$

$$\delta' = V_{CC} - V_{CE(sat)} - I_b' R_C$$

→ Since C_1 and B_2 are connected by a capacitance hence voltage across the capacitor cannot change instantaneously, these two discontinuous voltage

δ and δ' must be equal.

$\therefore$ Equating them,

$$I_b' r_{b'b} + V_{BE(sat)} - V_\gamma = V_{CC} - V_{CE(sat)} - I_b' R_C$$

$$\boxed{\therefore I_b' = \frac{V_{CC} - V_{BE(sat)} - V_{CE(sat)} + V_\gamma}{R_C + r_{b'b}}}$$

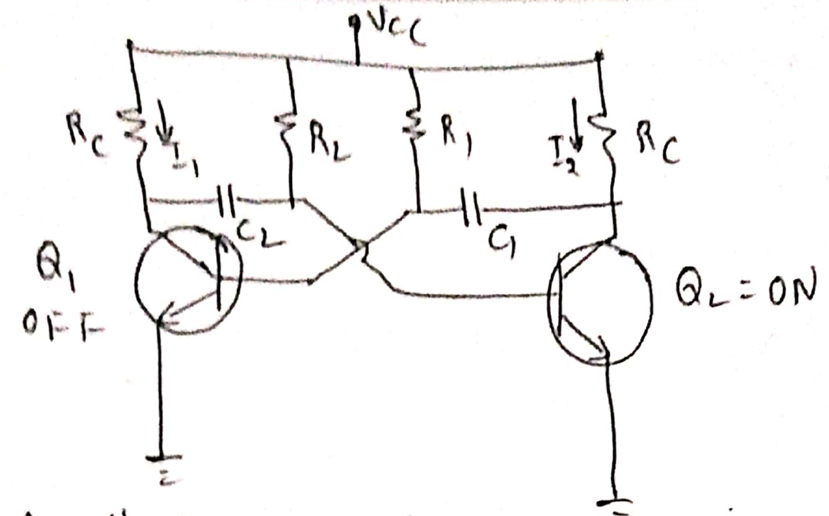
→ V_{B2}, V_{C1} decay to their steady state values with a time const $\boxed{\tau' = (R_C + r_{b'b})C}$.

Applications:-

→ It is a voltage to time converter.
→ Pulse width modulator.
→ Rectangular pulse generator
→ Used in delay circuits.
→ Used as a gating circuit.

Astable Multivibrator:-

→ No stable states. Both of its states are quasi stable only.
→ No triggering signal is required.
→ Both coupling elements are capacitors (ac coupling)
→ It is a free running multivibrator.
→ It generates square waves.
→ It is used as a master oscillator.
→ There are two types of astable multivibrators:
(i) collector coupled " "
(ii) Emitter " " "



A collector coupled Astable multivibrator.

→ The component values are selected such that, the moment it is connected to supply, due to supply transients one transistor will go into saturation & other into cut off and also due to capacitive coupling it keeps on oscillating between it's two quasi stable states.

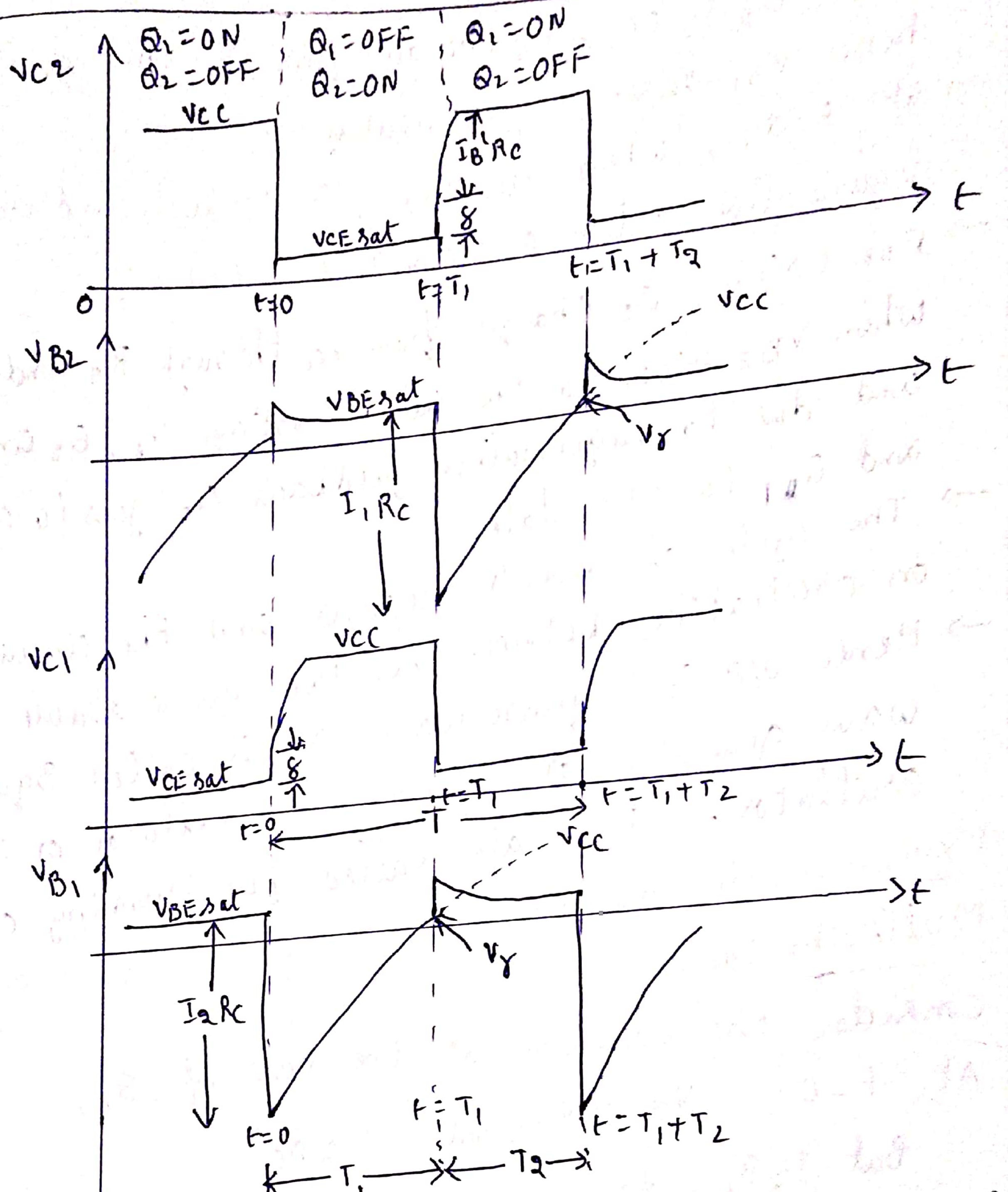
→ For $t<0$, Q_2 = OFF & Q_1 = ON. Hence V_{B2} is negative $V_{C2} = V_{CC}$, $V_{B1} = V_{BE\,sat}$ and $V_{C1} = V_{CE\,sat}$.

→ The capacitor C_2 charges from V_{CC} through R_2 and V_{B2} rises exponentially towards V_{CC}.

→ At $t=0$, V_{B2} reaches the cut-in voltage V_γ and Q_2 conducts.

→ As Q_2 = ON, it's collector voltage(V_{C2}) drops by $I_2 R_C = V_{CC} - V_{CE\,sat}$. This drop, in V_{C2} is transmitted to the base of Q_1 through C_1 and hence V_{B1} also falls by $I_2 R_C$. Q_1 goes to OFF state.

→ So, $V_{B1} = V_{BE\,sat} - I_2 R_C$ and V_{C1} rises towards V_{CC}.



Wave forms at bases & collectors of a collector coupled Astable multivibrator

→ This rise in V_{C1} is coupled through the coupling capacitor C_2 to the base of Q_2, causing an overshoo[t] 'δ' in V_{B2} and the abrupt rise by the same amoun[t] 'δ' in V_{C1}.

→ Now Q_2 is ON, C_1 charges from V_{CC} through R_1 and hence V_{B1} rises exponentially.

→ At $t = T_1$, when $V_{B1} = V_\gamma$, Q_1 conducts and due to regenerative action $Q_1 = ON$ & $Q_2 = OFF$.

→ For $t > T_1$, C_2 charges from V_{CC} through R_2 and $t = T_1 + T_2$ when V_{B2} rises to the cut in voltage V_γ, Q_2 conducts and due to regenerative feedback Q_2 goes to ON state and Q_1 to OFF state.

→ The cycle of events repeats and the circuit keeps on oscillating between its two quasi stable states.

→ Hence O/P is square wave. It is called square wave generator or square wave oscillator or relaxation oscillator. It is also called free running oscillator.

Expression for the frequency of oscillation of an astable Multivibrator:-

Consider the waveform at the base of Q_1,

At $t = 0$, $V_{B1} = V_{BE\,sat} - I_2 R_C$

But $I_2 R_C = V_{CC} - V_{CE\,sat}$ because at $t = 0^-$, $V_{C1} = V_{CE\,sat}$

at $t = 0^+$, $V_{C1} = V_{CC}$

∴ At $t = 0$, $V_{B1} = V_{BE\,sat} - V_{CC} + V_{CE\,sat}$.

For $0 < t < T_1$, V_{B1} rises exponentially towards V_{CC} given by the equation, $V_0 = V_f - (V_f - V_i)\, e^{-t/\tau}$

$$\therefore V_{B1} = V_{CC} - (V_{CC} - V_{BE\,sat} + V_{CC} - V_{CE\,sat})\, e^{-t/\tau_1}$$

where $\tau_1 = R_1 C_1$

At $t=T_1$, when V_{B1} rises to V_γ, then Q_1 conducts

$\therefore V_{B1} = V_\gamma$ at $t = T_1$

$$V_\gamma = V_{CC} - [2V_{CC} - V_{BEsat} - V_{CEsat}]\, e^{-T_1/R_1C_1}$$

$$e^{T_1/R_1C_1} = \frac{2\left[V_{CC} - \left(\frac{V_{BEsat} + V_{CEsat}}{2}\right)\right]}{V_{CC} - V_\gamma}$$

$$\therefore T_1 = R_1C_1 \ln \frac{2\left[V_{CC} - \left(\frac{V_{BEsat} + V_{CEsat}}{2}\right)\right]}{V_{CC} - V_\gamma}$$

(or) $$T_1 = R_1C_1 \ln 2 + R_1C_1 \ln \frac{\left[V_{CC} - \left(\frac{V_{BEsat} + V_{CEsat}}{2}\right)\right]}{V_{CC} - V_\gamma}$$

At room temp for a transistor, $V_\gamma = \frac{V_{BEsat} + V_{CEsat}}{2}$

$$\therefore T_1 = R_1C_1 \ln 2 + R_1C_1 \ln 1 = R_1C_1 \ln 2$$

$$\boxed{\therefore T_1 = 0.693\, R_1C_1} \quad \text{—— (1)}$$

consider the waveform at the base of Q_2, we can show that the time $t = T_2$ for which $Q_1 = ON$ & $Q_2 = OFF$ is given by $\boxed{T_2 = 0.693\, R_2C_2}$ —— (2)

$\therefore$ The period of the waveform, $T = T_1 + T_2 = 0.693(R_1C_1 + R_2C_2)$

$$\boxed{T = 0.693(R_1C_1 + R_2C_2)} \quad \text{—— (3)}$$

The freq of oscillation, $f = \frac{1}{T} = \frac{1}{0.693(R_1C_1 + R_2C_2)}$

If $R_1 = R_2 = R$ & $C_1 = C_2 = C$, then $T_1 = T_2 = \frac{T}{2}$

$$\boxed{\therefore T = 2 \times 0.693\, RC = 1.386\, RC} \quad \& \quad \boxed{f = \frac{1}{1.386\, RC}}$$

Applications of Astable multivibrator:-

→ Voltage to freqn converter

→ Square wave generator

→ Used as Master oscillator

Ex:- For astable Multivibrator, if $R_1 = 20\,K\Omega$, $R_2 = 10\,K\Omega$, $C_1 = 0.02\mu F$ and $C_2 = 0.015\,\mu F$, find the freqn of oscillation and duty cycle of the o/p waveform.

(A) $T_1 = 0.693 R_1 C_1 = 277.2\,\mu s$

$T_2 = 0.693 R_2 C_2 = 103.95\,\mu s$

$T = T_1 + T_2 = 381.15\,\mu s$

$F = \frac{1}{T} = 2.623\,KHz$.

$$\text{Duty cycle} = \frac{T_1}{T_1 + T_2} = 0.727$$

Scanned with CamScanner