4.4.MULTIVIBRATORS

4.4.1.JUNCTION DIODE—SWITCHING TIMES

4.4.1Diode forward recovery time

When a diode is driven from the: reverse-biased condition to the forward-biased condition or in the opposite direction, the diode response is accompanied by a transient, and an interval of time elapses before the diode recovers to its steady state. The nature of the forward recovery transient depends on the magnitude of the current being driven through the diode and the rise time of the driving signal. Consider the voltage which develops across the diode when the input is a current source supplying a step current I_V as shown in Figure 3,1 (a). If the current amplitude is comparable to or larger than the diode rated current, and if the rise time of the current step is small enough, then the waveform of the voltage which appears across the diode is shown in Figure 3.1(b). The overshoot results from the fact that initially the diode acts not as a p-n junction diffusion device but as a resistor, tn the steady-state condition, the current which flows through the diode is a diffusion current which results from the gradient in the density of minority carriers. If the current is large enough, then there will also be an ohmic drop across the diode. The ohmic drop is initially very large, for immediately after the application of the current, the holes, say, will npn have time to diffuse very far into the n-side in order to build up a minority carrier density. Therefore except near the junction, there will be no minority charge to establish a density gradient, and the current flow through the mechanism of diffusion will not be possible. Indeed, an electric field will be required to achieve current flow by exerting force on the majority carriers. This electric field gives rise to the ohmic drop. With the passage of time, however, the ohmic drop will decrease as more and more minority carriers become available from the junction, and current by diffusion

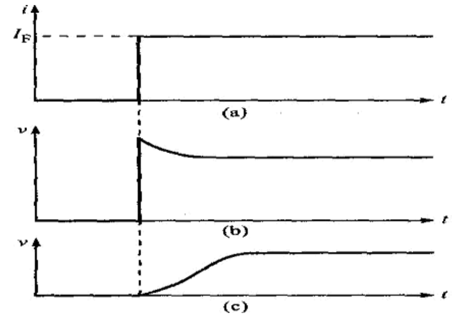


Figure 4.3.1(a)Input step current to a diode, (b) diode voltage when the current is large, and(c) diode voltage when the current is small.

(Source: Microelectronics byJ. Millman and A. Grabel, Page-468)

- The magnitude of the overshoot will increase as the magnitude of the input current increases. At large current amplitudes, the diode behaves as a combination of a resistor and an inductor. At low currents the diode is representable by a parallel resistor-capacitorcombination. At intermediate currents, the diode behaves as a resistor, inductor, and capacitor circuit and oscillations may be produced.
- The forward recovery time f_{fr}, for a specified rise time of the input current is the time difference between the 10% point of the diode voltage and the time when this voltage reaches and remains within 10% of its final value. The forward recovery time does not usually constitute a serious problem.

4.4.2Diode reverse recovery time

- When an external voltage is impressed across a junction in the direction that reverse biases it, very little current called the reverse saturation current flows. This current is because of the minority carriers.
- The density of minority carriers in the neighbourhood of the junction in the steady stateis shown in Figure 3.2(a).
- Here the levels $p_{nl)}$ and n are the thermal equilibrium values of the minority carrier densities on the two sides of the junction in the absence of an externally impressed voltage.

- When a reverse voltage is applied, the density of minority carriers is shown by the solid Sines marked p_n and n_p. Away from the junction, the minority carrier density remains unaltered, but as these carriers approach the junction they are rapidly swept across and the density of minority carriers diminishes to zero at the junction. The reverse saturation current which flows is small because the density of thermally generated minority carriers is very small.

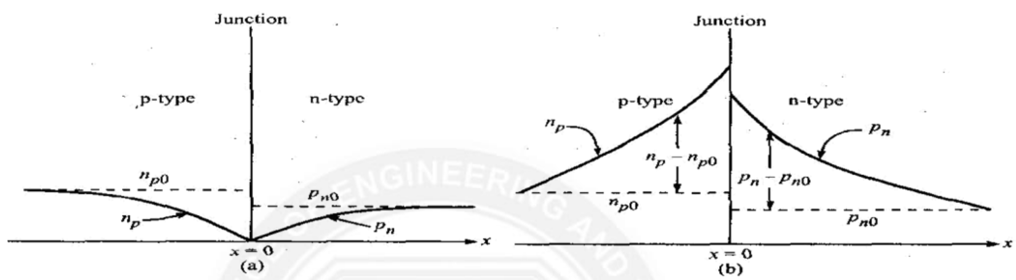


Figure 4.3.2 Minority-carrier density distribution as a function of the distance x from a junction; (a) a reverse-biased junction and (b) a forward-biased junction.

(Source: Microelectronics byJ. Millman and A. Grabel, Page-470)

- When the external voltage forward biases the junction, the steady-state density of minority carriers is as shown in Figure 3.2(b). The injected or excess hole density is (p_n - p_{nQ}) and the excess electron density is (n_p - n_{pQ}).

- In a diode circuit which has been carrying current in the forward direction, if the external voltage is suddenly reversed, the diode current will not immediately fall to its steady-state reverse value. The current cannot attain its steady-state value until the minority carrier distribution changes the form in Figure 3.2(b) to the distribution shown in Figure 3.2(a).

- Until such time as the injected or excess minority carrier density p_n - p_{nQ} (or n_p -n_{p0}) drops nominally to zero, the diode will continue to conduct easily and the current will be determined by the external resistance in the diode circuit.

Storage and transition times

- The sequence of events which occurs when a conducting diode is reverse biased is shownin Figure 3.3. The input voltage shown in Figure 3.3(b) is applied to a diode circuit shown in Figure 3.3(a).
- Up to t = t\, v, = V_f. The resistance R_L is assumed large so that the drop across R_L

is large compared with the drop across the diode.

$$i \approx \frac{V_F}{R_L} = I_F$$

- At the time t ~ t[, the input voltage reverses abruptly to the value V; = - VR, the current reverses,until the time t - t_2. At t ~ t^ as shown in Figure 3.3(c), the injected minority carrier density at the junction drops to zero, that is, the minority carrier density reaches its equilibrium state.
- If the diode ohmic resistance is R_A, then at time t, the diode voltage falls slightly by [(V_F + VR)] but does not reverse as shown in Figure 3.3(e). At t when the excess minority carriers in the immediate neighborhood of the junction have been swept back across the junction, the diode voltage begins to reverse as shown in Figure 3.3(e) and the magnitude of the diode current begins to decrease as shown in Figure 3.3(d). The interval from t1 to t_2 for the minority charge to become zero is called the storage time t_s. The time which elapses between r_2 and the time when the diode has nominally recovered is called the transition time t_t.
- The recovery interval will be completed when the minority carriers which are at some distance from the junction have diffused to the junction, crossed it and then, in addition, the junction transition capacitance across the reverse-biased junction has charged through R_L to the voltage -V_R as shown in Figure 3.3(e).

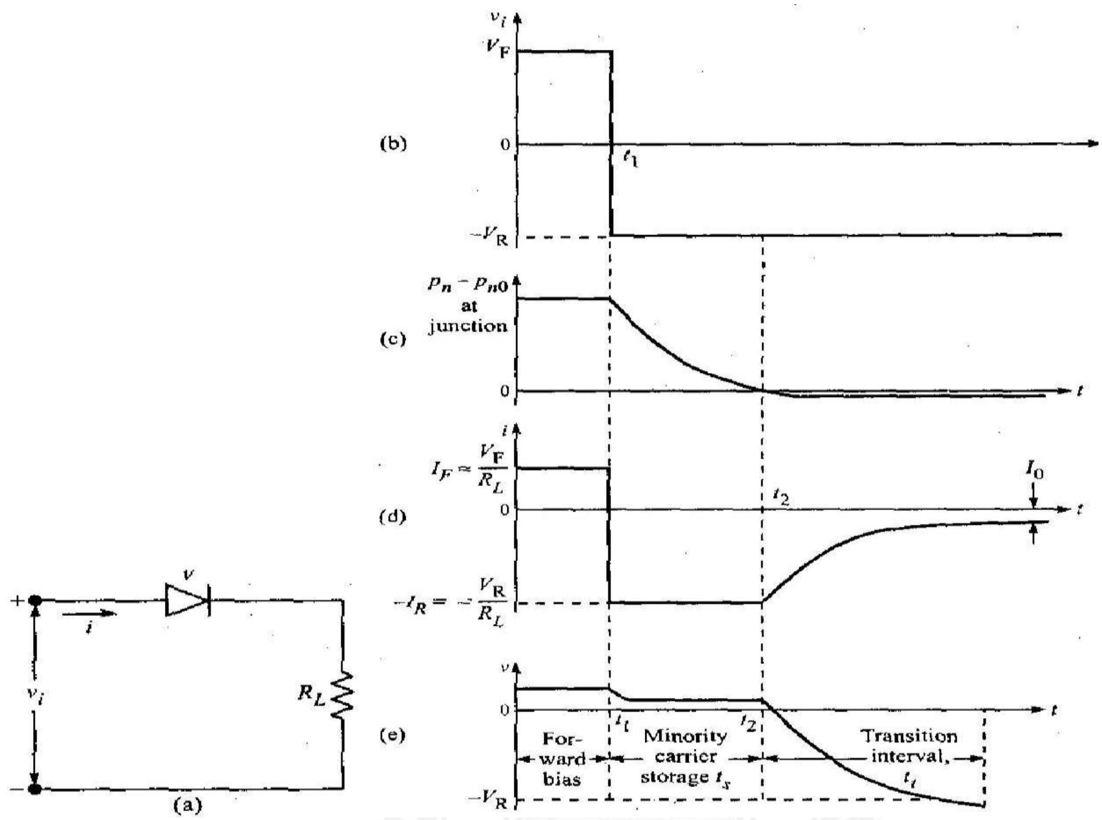


Figure4. 3.3 The waveform in (b) is applied to the diode circuit in (a), (c) the excesscarrier density at the junction, (d) the diode current, and (e) the diode voltage.

(Source: Microelectronics byJ. Millman and A. Grabel, Page-475)

4.4.3.PIECE-WISE LINEAR DIODE CHARACTERISTICS

- A large-signal approximation which often leads to a sufficiently accurate engineeringsolution is the piece-wise linear representation.
- The piece-wise linear approximation for a semiconductor diode characteristic is shown in Figure 3.4. The breakdown is at V_y, which is called the offset or threshold voltage. The diode behaves like an open-circuit if $v < V_r$ The characteristic shows a constant incremental resistance r =dvldi if $v > V_r$ Here r is called the forward resistance. The static resistance $R_f = V_\gamma$ is

not constant and is not useful.

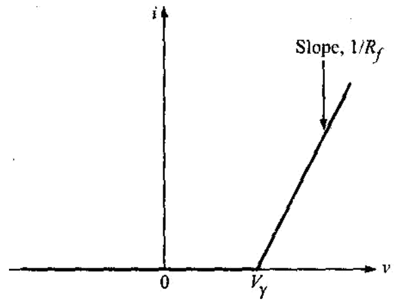


Figure4. 3.4 The piece-wise linear characteristic of a diode.

(Source: Microelectronics byJ. Millman and A. Grabel, Page-479)

The numerical values of Vy and Rf to be used depend upon the type of diode and the contemplated voltage and current swings. Typically: For current swings from cut-off to 10 mA

For Ge,	$V_\gamma = 0.2$ V	and	$R_f = 20\ \Omega$
For Si,	$V_\gamma = 0.6$ V	and	$R_f = 15\ \Omega$

For current swings up to 50 mA

For Ge,	$V_\gamma = 0.3$ V	and	$R_f = 6\ \Omega$
For Si,	$V_\gamma = 0.65$ V	and	$R_f = 5.5\ \Omega$

4.4.4.TRANSISTOR AS A SWITCH

- A transistor can be used as a switch. It has three regions of operation. When both emitter^ base and collector-base junctions are reverse biased, the transistor operates in the cut-off region and it acts as an open switch. When the emitter base junction is forward biased and the collector base junction is reverse biased, it operates in the active region and acts as auf amplifier. When both the emitter-base and collector-base junctions are forward biased, it operates in the saturation region and acts as a closed switch. When the transistor is switched! from cut-off to saturation and from saturation to cut-off with negligible active region, the transistor is operated as a switch. When the transistor is in saturation, junction voltages are very small but the operating currents are large. When the transistor is in cut-off, the currents* are zero (except small leakage current) but the junction voltages are large.

- In Figure 3.6 the transistor Q can be used to connect and disconnect the load R_L from the source Vcc When Q is saturated it is like a closed switch from collector to emitter and when Q is cut- off it is like an open switch from collector to emitter.

$$I_C = \frac{V_{CC} - V_{CE}}{R_L} \quad \text{and} \quad I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

- Referring to the output characteristics shown in Figure 3.6(b), the region below the I_B = 0 curve is the cut-off region. The intersection of the load line with I_B = 0 curve is the cut-off point. At this point, the base current is zero and the collector current is negligible. The emitter diode comes out of forward bias and the normal transistor action is lost, i.e, V_{CE}(cut-off) = V_{CC}. The transistor appears like an open switch.

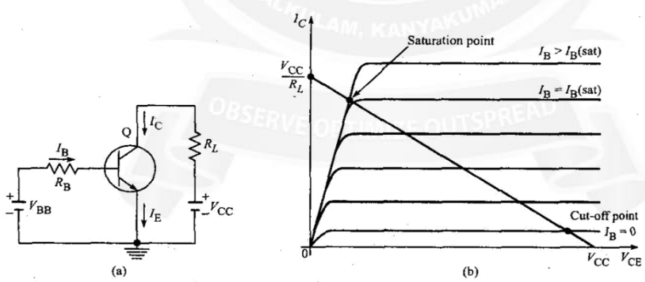


Figure 3.6 (a) Transistor used as a switch and (b) output characteristics with load line (dc).

- The intersection of the load line with the I_B - Ie(sat) curve is called the saturation point. At this point, the base current is I_B(sat) and the collector current is maximum. 'At saturation, the collector diode comes out of cut-off and again the normal transistor action is lost, i.e. Ic(sat) = Vcc/R_L.Ie(sat) represents the minimum base current required to bring the transistor into saturation. For 0 < I_B < I_B(sat), the transistor operates in the active region. If the base current is greater than I_B(sat), the collector current approximately equals

V_{CC}/I_C and the transistor appears like a closed switch.

4.4.5.TRANSISTOR SWITCHING TIMES

- When the transistor acts as a switch, it is either in cut-off or in saturation. To consider the behaviour of the transistor as it makes transition from one state to the other, consider the circuit shown in Figure 3,7(a) driven by the pulse waveform shown in Figure 3.7(b). The pulse waveform makes transitions between the voltage levels V_2 and V_1. At V_2 the transistor is at cut- off and at V the transistor is in saturation. The input waveform v; is applied between the base and the emitter through a resistor R_B.

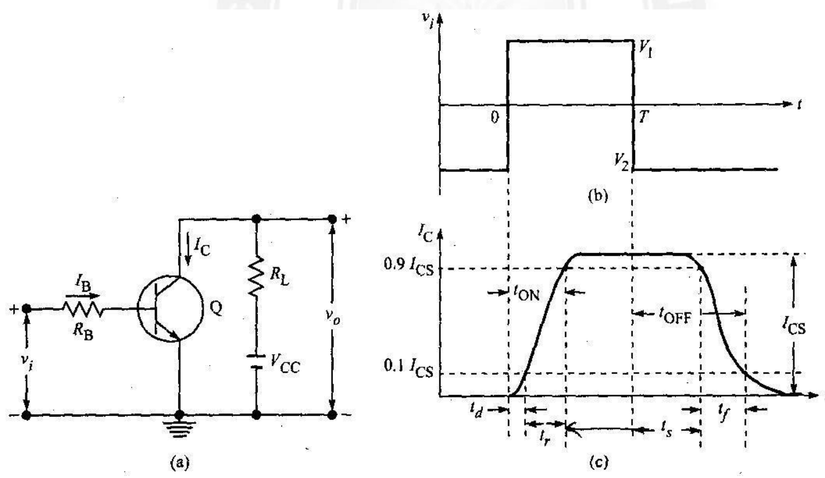


Figure4.3.7 (a) Transistor as a switch, (b) input waveform, and (c) the response of collector current versus time.

(Source: Microelectronics byJ. Millman and A. Grabel, Page-488)

- The response of the collector current ic to the input waveform, together with its time relationship to the waveform is shown in Figure 3.7(c), The collector current does not immediately respond to the input signal. Instead there is a delay, and the time that elapses during this delay, together with the time required for the current to rise to 10% of its maximum (saturation) value (I_{CS} = Vcc/Rc) is called the delay time t_d. The current waveform has a nonzero rise time f_r, which is the rise time required for the current to rise from 10% to 90% of Ics- The total turn-on time T_{ON} is the sum of the delay time and the rise time, i.e. $T_{ON} = t_d + t_r$.

- When the input signal returns to its initial state, the collector current again fails to respond immediately. The interval which elapses between the transition of the input waveform and the time when $/_c$ has dropped to 90% of $/_{C}$s is called the storage time t_s. The storage interval is followed by the fall time ly, which is the time required for 7_C to fall from 90% to 10% of Ics- The turn-off time ^OFF is defined as the sum of the storage and fall times, i.e. $T_{OFF} = t_r + t_f$ We shall now consider the physical reasons for the existence of each of these times.

The delay time

- There are three factors that contribute to the delay time. First there is a delay which results from the fact that, when the driving signal is applied to the transistor input, a non-zero time is required to charge up the junction capacitance so that the transistor may be brought, from cut-off to the active region. Second, even when the transistor has been brought to the point where minority carriers have begun to cross the emitter junction into the base, a nonzero time is required before these carriers can cross the base region to the collector junction and be recorded as collector current. Finally, a nonzero time is required before the collector current can rise to10% of its maximum value. Rise time and fall time The rise time and fall time are due to the fact that, if a base current step is used to saturate the transistor or to return it from saturation into cut- off, the collector current must traverse the active region.
- The collector current increases or decreases along an exponential curve. Storage

time The failure of the transistor to respond to the trailing edge of the driving pulse for the time interval t_S, results from the fact that a transistor in saturation has a saturation charge of excess minority carriers stored in the base. The transistor cannot respond until the saturation excess charge has been removed.

4.4.6.MULTIVIBRATORS

- Multi means many; vibrator means oscillator. A circuit which can oscillate at a number of frequencies is called a multivibrator. Basically there are three types of multivibrators:
    1. Bistable multivibrator
    2. Monostable multivibrator
    3. Astable multivibrator
- Each of these multivibrators has two states. As the names indicate, a bistable multivibrator has got two stable states, a monostable multivibrator has got only one stable state (the other state being quasi stable) and the astable multivibrator has got no stable state (both the states being quasi stable). The stable state of a multivibrator is the state in which the device can stay permanently. Only when a proper external triggering signal is applied, it will change its state. Quasi stable state means temporarily stable state. The device cannot stay permanently in this state. After a predetermined time, the device will automatically come out of the quasistable state.
- In this chapter we will discuss multivibrators with two-stage regenerative amplifiers. They have two cross-coupled inverters, i.e. 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. In bistable circuits both the coupling elements are resistors (i.e. both are dc couplings). In monostable circuits, one coupling element is a capacitor (ac coupling) and the other coupling element is a resistor (dc coupling) In astable multivibrators both the coupling elements are capacitors (i.e. both are ac

couplings).

- A bistable multivibrator requires a triggering signal to change from one stable state to another. It requires another triggering signal for the reverse transition. A monostable multivibrator requires a triggering signal to change from the stable state to the quasi stable state but no triggering signal is required for the reverse transition, i.e. to bring it from the quasi stable state to the stable state. The astable multivibrator does not require any triggering signal at all. It keeps changing from one quasi stable state to another quasi stable state on its own the moment it is connected to the supply.
- A bistable multivibrator is the basic memory element. It is used to perform many digital operations such as counting and storing of binary data. It also finds extensive applications in the generation and processing of pulse type waveforms. The monostable multivibrator finds extensive applications in pulse circuits. Mostly it is used as a gating circuit or a delay circuit. The astable circuit is used as a master oscillator to generate square waves. It is often a basic source of fast waveforms. It is a free running oscillator. It is called a square wave generator. It is also termed a relaxation oscillator.

4.4.7.BISTABLE MULTIVIBRATOR

- A bistable multivibrator is a multivibrator which can exist indefinitely in either of its two stable states and which can be induced to make an abrupt transition from one state to the other by means of external excitation. In a bistable multivibrator both the coupling elements are resistors (dc coupling). The bistable multivibrator is also called a multi, Eccles-Jordan circuit (after its inventors), trigger circuit, scale-of-two toggle circuit, flip-flop, and binary. There are two types of bistable multivibrators:

  1. Collector coupled bistable multivibrator
  2. Emitter coupled bistable multivibrator

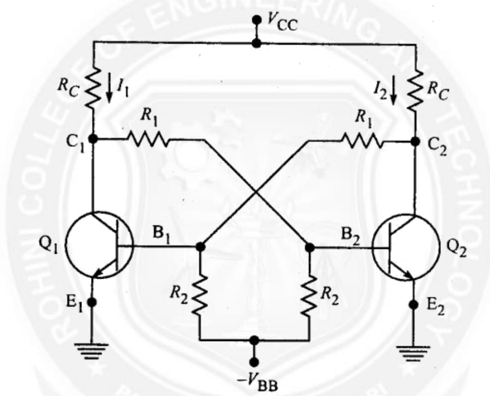
There are two types of collector-coupled bistable multivibrators:

1. Fixed-bias bistable multivibrator
2. Self-bias bistable multivibrator

4.4.8.A FIXED-BIAS BISTABLE MULTIVIBRATOR

- Figure 4.1 shows the circuit diagram of a fixed-bias bistable multivibrator using transistors (inverters). Note, that the output of each amplifier is direct coupled to the input of the other amplifier. In one of the stable states, transistor Q[is ON (i.e. in saturation) and Q2 is OFF (i.e. in cut-off), and in the other stable state Qj is OFF and Q2 is ON. Even though the circuit is symmetrical, it is not possible for the circuit to remain in a stable state with both the transistors conducting (i.e. both operating in the active region) simultaneously and carrying equal currents. The reason is that if we assume that both the transistors are biased equally and are carrying equal currents .suppose there is a minute fluctuation in the current 1 let us say it increases by a small amountthen the voltage at the collector of Qi decreases. This will result in a decrease in voltage at the base of Q2. So Q2 conducts less and decreases and hence the potential at the collector of Q2 increases. This results in an increase in the base potential of Qi. So, Qi conducts still more and is further increased and the potential at the collector of Qt is further reduced, and so on. So, the current I keeps on increasing and the current 2 keeps on decreasing till Q goes into saturation and Q2 goes into cut-off. This action takes place because of the regenerative feedback incorporated into the circuit and will occur only if the loop gain is greater than one. A stable state of a binary is one in which the voltages and currents satisfy the Kirchhoff's laws and are consistent with the device characteristics and in which, in addition, the condition of the loop gain being less than unity is satisfied.
- The condition with respect to loop gain will certainly be satisfied, if either

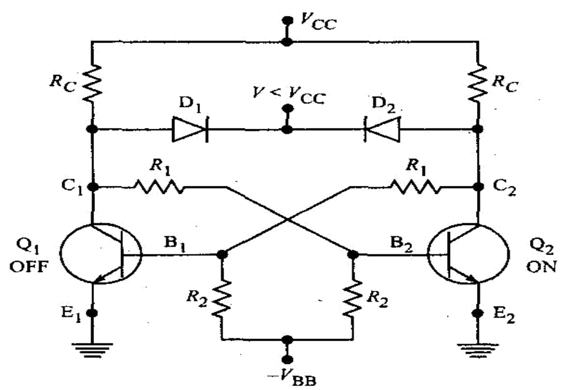
of the two devices is below cut-off or if either device is in saturation. But normally the circuit is designed such that in a stable state one transistor is in saturation and the other one is ir cut-off, because if one transistor is biased to be in cut-off and the other one to be in active region, as the temperature changes or the devices age and the device parameters vary, the quiescent point changes and the quiescent output voltage may also change appreciably Sometimes the drift may be so much that the device operating in the active region may gc into cut-off, and with both the devices in cut-off the circuit will be useless.



Selection of components in the fixed-bias bistable multivibrator

- In the fixed-bias binary shown in Figure 4.1., nearly the full supply voltage V_{CC} will appear across the transistor that is OFF. Since this supply voltage V_{CC} is to be reasonably smaller than the collector breakdown voltage SVce. Vcc *^{S} restricted to a maximum of a few tens of volts. Under saturation conditions the collector current I_C is maximum. Hence RC must be chosen so that this value of 7_C (= VCC/^G) does not exceed the maximum permissible limit. Thevalues of R\, /?2 and V_{BB} must be selected such that in one startle 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 signal at a collector called the output swing V_W is the change in collector voltage resulting from a transistor going from one state to the other, i.e. V_W =

VCi - ^C2- If the loading caused by RI can be neglected, then the collector voltage of the OFF transistor is V_{CC}. Since the collector saturation voltage is few tenths of a volt.The bistable multivibrator may be used to drive other circuits and hence at one or both the collectors there are shunting loads, which are not shown in Figure 4.1. These loads reduce the magnitude of the collector voltage V_{C1} of the OFF transistor. This will result in reduction of the output voltage swing. A reduced VC[will decrease 7B2 and it is possible that Q_2 may not be driven into saturation- Hence the flip-flop circuit components must be chosen such that under the heaviest load, which the binary drives, one- transistor remains in saturation while the other is in cut-off. Since the resistor Rl also loads the OFF transistor, to reduce loading, the value of Rshould 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^ should be selected such that For some applications, the loading varies with the operation being performed. In such cases, the extent to which a transistor is driven into saturation is variable. A constant output swing V\v = V, arid a constant base saturation current I_{B2} can be obtained by clamping the collectors to an auxiliary voltage V < V_{CC} through the diodes DI and D_2 as indicated in Figure 4.2. As Qi cuts OFF, its collector voltage rises and when it reaches V, the "collector catching diode" D| conducts and clamps the output to V.



Transistor as an ON-OFF switchIn digital circuits transistors operate either in the cut-off region or in the saturation region. Specially designed transistors called switching transistors with negligible active region are used. In the cut-off region the transistor does not conduct and acts as a open switch. In the saturation region the transistor conducts heavily and acts as a closed switch-In a binary which uses two cross-coupled transistors, each of the transistors is alternately cut-off and driven into saturation. Because of regenerative feedback provided both the transistors cannot be.ON or both cannot be OFF simultaneously. When one transistor is ON, the other is OFF and vice versa.

4.4.9.THE EMITTER-COUPLED BINARY (THE SCHMITT TRIGGER CIRCUIT)

- Figure 4.29 shows the circuit diagram of an emitter-coupled bistable multivibrator using n-p-n transistors. Quite commonly it is called Schmin trigger after the inventor of its vacuum-tube version. It differs from the basic collector-coupled binary in that the coupling from the output of the second stage to the input of the first stage is missing and the feedback is obtained now through a common emitter resistor R_E. It is a bistable circuit and the existence of only two stable states results form the fact that positive feedback is incorporated into the circuit, and from the further fact that the loop gain of the circuit is greater than unity. There are several ways to adjust the loop gain. One way of adjusting the loop gain is.by varying /?$_{C1}$. Suppose R$_{C}$] is selected such that the loop gain is less than unity. When fl $_{cl}$ is small, regeneration is not possible.

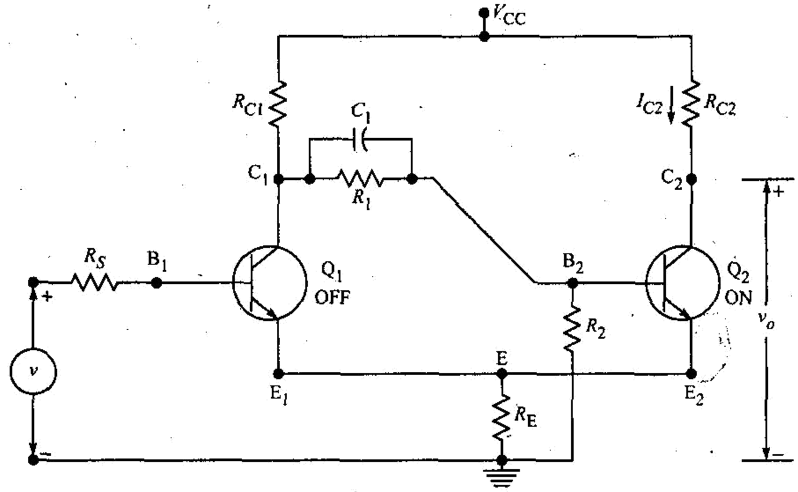


Figure 4.29 An emitter-coupled binary.

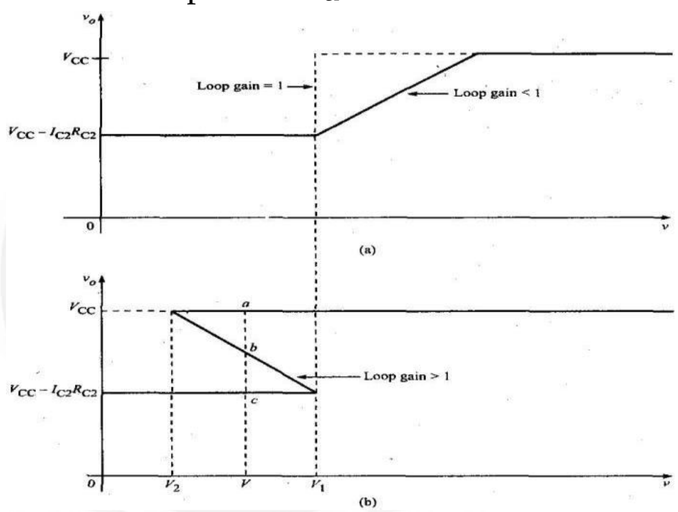
(Source: Microelectronics byJ. Millman and A. Grabel, Page-488)

- For the circuit of Figure 4.29, under quiescent conditions Qi is OFF and Q_2 is ON because it getsthe required base drive from V_Cc through R_Ci andthe output voltage

is at its lower level. With Q_2 conducting, there will be a voltage drop across this will elevate the emitter of Q\. As the input v is increased from zero, the circuit will not respond until Qi reaches the cut-in point (at v = V_t). Until then the output remains at its lower level. With Oj conducting (for v > V|) the circuit will amplify because Q_2 is already conducting and since the gain Av</Av is positive, the output will rise in response to the rise in input. As v continues to rise, C_t and hence B_2 continue to fall and E_2 continues to rise. Therefore a value of v will be reached at which Qa is turned OFF. At this point v_0 = V_Cc and the output remains constant at this value of V_{CC}, even if the input is further increased. A plot of v_a versus v is shown in Figure 4.30(a) for loop gain < 1.

- Suppose the loop gain is increased by increasing the resistance R_{Ci}. Such a change will have negligible effect on the cut-in point V| of Qj. However in the region of amplification (i.e. for v > V{) the amplifier gain Av</Av will increase and so the slope of the rising portion of the plot in Figure 4.30(a) will be steeper. This increase in slope with increase in loop gain continues until at a loop gain of unity where the circuit has just become regenerative the slope will become infinite.

- And finally when the loop gain becomes greater than unity, the¯ slope becomes negative and the plot of v_a versus v assumes the S **Figure 4.30**



Response of emitter-coupled binary for (a) loop gain < 1 and (b) loop gain > 1.

(Source: Microelectronics byJ. Millman and A. Grabel, Page-475)

The behaviour of the circuit may be described by using this S curve. As v rises from **zero** voltage, v_0 will remain at its lower level (= V_{Cc} ~ 'c2 ^ca) unt*l v reaches V\. (This value of v = V, at which the transistor

Qi just enters into conduction is called the upper triggering point, UTP.) As v exceeds V} the output will make an abrupt .transition to its higher level (= V_{CC}). For v > V_h **Qj** is ON and **Q2** is **OFF.** Similarly if v is initially greater than V], then as v is decreased, the output will remain at its upper level until v attains a

definite level V_2 at which point the circuit makes an abrupt transition to its lower level.

- For Qi is **OFF** and **Q2** is **ON.** (This value of v = V2 at which the transistor **Q2** resumes conduction is called the lower triggering point, LTP.)
- This 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.
- A vertical line drawn at v = V which lies between V2 and Vi intersects the S curve at three points a, b and c. The upper and lower points a and c are points of stable equilibrium.
- The S curve is a plot of values which satisfy Kirchhoff's laws and which are consistent with the transistor characteristics. At v = V, the circuit will be at a or c, depending on the direction of approach of v towardsV. When v = V in the range between V2 and V|, the Schmitt circuit is in one of its two possible stable states and hence is a bistable circuit.

Applications of Schmitt trigger circuit

- Schmitt trigger is also a bistable multivibrator. Hence it can be used in applications where a normal binary is used. However for applications where the circuit is to be triggered back-and-forth between stable states, the normal binary is preferred because of its symmetry. Since the base of Q] is not involved in regenerative switching, the Schmitt trigger is preferred for applications in which the advantage of this free terminal can be taken. The resistance KC2 m me output circuit of Q2 is not required for the operation of the binary. Hence this resistance may be selected over a wide range to obtain different output signal amplitudes.
- A most important application of the Schmitt trigger is its use as an amplitude comparator to mark the instant at which an arbitrary waveform attains a particular reference level. As input v rises to Vi or falls to V2, the circuit makes a fast regenerative transfer to its other state.
- Another important application of the Schmitt trigger is as a squaring circuit. It can convert a sine wave

into a square wave. In fact, any slowly varying input waveform can be converted into a square wave with faster leading and trailing edges as shown in Figure 4.31, if the input has large enough excursions to carry the input beyond the limits of the hysteresis range, V_H = V\ - V_2.

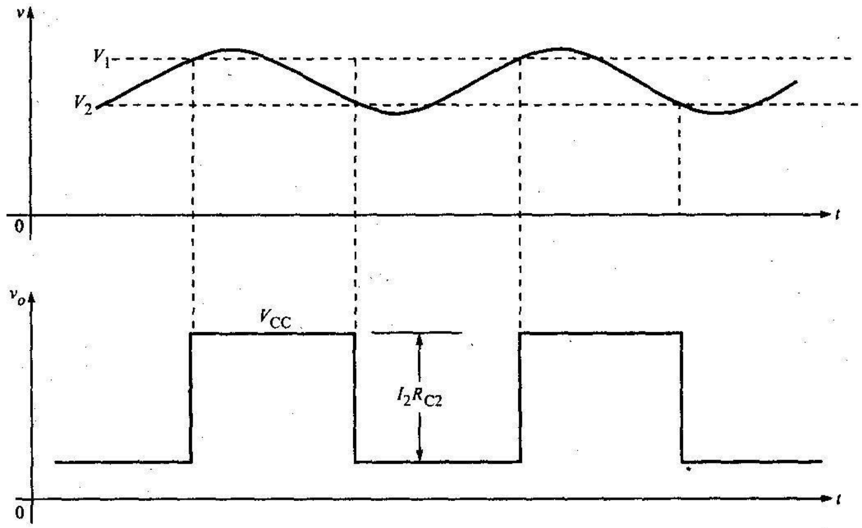


Figure 4.31 Response of the emitter-coupled binary to an arbitrary input waveform.

(Source: Microelectronics byJ. Millman and A. Grabel, Page-488)

- In another important application, the Schmitt trigger circuit is triggered between its two stable states by alternate positive and negative pulses. If the input is biased at a voltage V between V_2 and V\ and if a positive pulse of amplitude greater than V\ - V is coupled to the input, then Qj will conduct and Q_2 will be OFF. If now a negative pulse of amplitude larger than V - V_2 is coupled to the input, the circuit will be triggered back to the state where Qj is OFF and Q_2 is ON.

Hysteresis

- If the amplitude of the periodic input signal is large compared with the hysteresis range V_H, then the hysteresis of the Schmitt trigger is not a matter of concern. In some applications, a large hysteresis range will not allow the circuit to function properly.
- Hysteresis may be eliminated by adjusting the loop gain of the circuit to unity.

Such an adjustment may be made in a number of ways:

(1) The loop gain may be increased or decreased by increasing or decreasing the resistance

(2) The loop gain may be increased or decreased by adding a resistance in series with the emitter of Qi, or by adding a resistance 7?^ in series with the emitter of Q_2 and then decreasing or increasing R_{El} and R_{E2}. Since /?$_{C1}$ and $R_{E]}$ are in series with Qi, these resistors will have no effect on the circuit when Qi is OFF. Therefore, these resistors will not change V\ but may be used to move V_2 closer to or coincident with V\. Similarly, R_{E2} will affect V\ but not V_2.

(3) The loop gain may also be varied by varying the ratio R[/(Ri + /?$_2$). Such an adjustment will change both V\ and V_2.

(4) The loop gain may be increased by increasing the value of R$.

- If $_{E1}$ or R_{E2} is larger than the value required to give zero hysteresis, then the gain will be less than unity and the circuit will not change state. So, usually $R_{E\backslash}$ or /?$_{E2}$ is chosen so that a small amount of hysteresis remains in order to ensure that the loop gain is greater than unity.
- Vi is independent of R_S but V_2 depends on R$ and increases with an increase in the value of R_S. So for a large value of R_S it is possible for V_2 to be equal to V\, Hysteresis is thus eliminated and the gain is unity.
- If R_S exceeds this critical value, the loop gain falls below unity and the circuit cannot bs triggered. If R_S is too small, the speed of operation of the circuit is reduced.

Derivation of expression for UTP

- The upper triggering point UTP is defined as the input voltage V_l at which the transistor Qi just enters into conduction. To calculate V_b we have to first find the current in Q_2 when Q! just enters into conduction. For this we have to find the

Thevenin's equivalent voltage V and the Thevenin's equivalent resistance tfB at the base of Q2, where

$$V' = V_{CC}\frac{R_2}{R_2 + R_{C1} + R_1} \quad \text{and} \quad R_B = R_2 \parallel (R_{C1} + R_1) = \frac{R_2(R_{C1} + R_1)}{R_2 + R_{C1} + R_1}$$

It is possible for Q2 to be in its active region or to be in saturation. Assuming that Q2 is in its active region

$$I_{C2} = h_{FE} I_{B2} \qquad \therefore\ I_{E2} = I_{C2} + I_{B2} = (h_{FE} + 1) I_{B2}$$

- In the circuit shown in Figure 4.32, to calculate V\, we replace V_{CC}, KCI> ^i anc* ^2 of Figure 4.29 by V and R_B at the base of Q2.

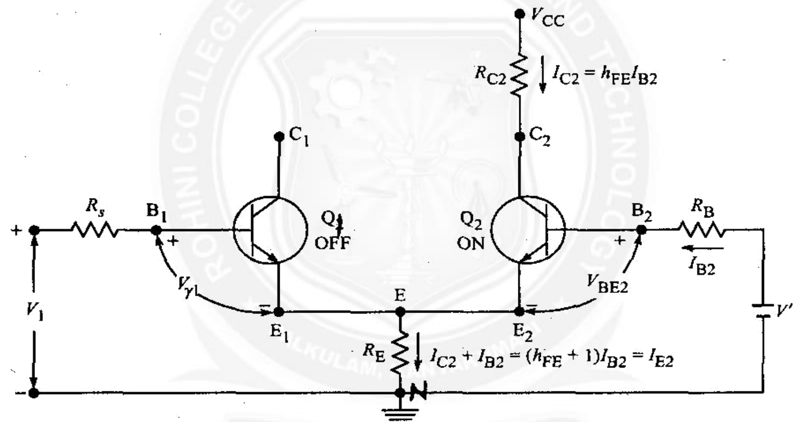


Figure 4.32 The equivalent circuit of Figure 4.29 with Q| just at cut-in.

Writing KVL around the base loop of Q2,

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

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

Hence $\qquad V_{EN} = I_{B2}(h_{FE} + 1)\ R_E = \dfrac{(V' - V_{BE2})(h_{FE} + 1) R_E}{R_B + R_E\ (h_{FE} + 1)}$

Also $\qquad V_{EN1} = V_{EN} = V_{EN2}$

Since Q_1 is just at cut-in, $I_{B1} = 0$ and $V_{BE1} = V_{\gamma 1}$

$$\therefore \qquad V_1 = V_{EN1} + V_{BE1} + I_{B1}R_S = V_{EN} + V_{\gamma 1}$$

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

$$\therefore \qquad V_{EN} = V' - V_{BE2}$$

and $\qquad V_1 = V' - V_{BE2} + V_{\gamma 1}$

Since VyJ is the voltage from base to emitter at cut-in where the loop gain just exceeds unity, it differs from V_{BE2} in the active region by only 0.1 V for either Ge or Si. $V_1 = V' - 0.1$

- This indicates that V, may be made almost independent of h^, of the emitter resistance R_E, of the temperature and of whether or not a silicon or germanium transistor is used. Hence the discriminator level V_t is stable with transistor replacement, ageing, temperature changes, provided that R_B and that V" » 0.1. Since V depends on V_{CC}, RCI, R\ and R_2, where stability is required it is necessary that a stable supply and stable resistors are selected.

Derivation of expression for LTP

- The lower triggering point LTP is defined as the input voltage V_2 at which the transistor Q_2 resumes conduction. Vi can be calculated from the circuit shown in Figure 4.33 which is obtained by replacing V_{CC}, J?C_1, RI and R_2 of Figure 4.29 by Thevenin's equivalent voltage VTH and Thevenin's equivalent resistance R at the collector of Q(, where

$$V_{Th} = V_{CC}\frac{R_1 + R_2}{R_{C1} + R_1 + R_2} \quad \text{and} \quad R = R_{C1} \| (R_1 + R_2) = \frac{R_{C1}(R_1 + R_2)}{R_{C1} + R_1 + R_2}$$

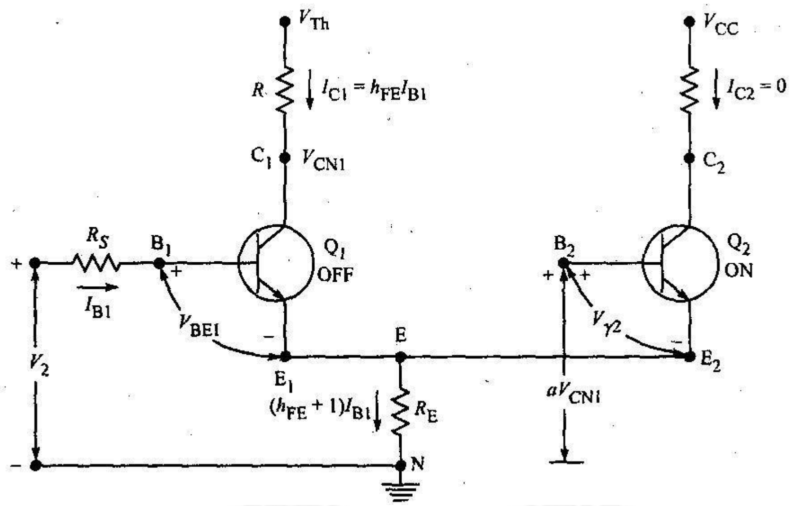


Figure 433 The equivalent circuit of Figure 4.29 when Q2 just resumes conduction.

- The voltage ratio from the collector of Qi to the base of Q2 is $a = R_2/(R_1 + R_2)$. Figure 4.33, the input signal to Qi is decreasing, and when it reaches V2 then Q2 comes out of cut-off.
- Writing KVL around the base circuit of Q2,

$$aV_{CN1} - V_{\gamma 2} - (I_{B1} + I_{C1})R_E = 0$$

where $$V_{CN1} = V_{Th} - I_{C1}R$$

$$\therefore \quad aV_{Th} - aI_{C1}R - V_{\gamma 2} - I_{C1}\left(1 + \frac{1}{h_{FE}}\right)R_E = 0$$

or $$I_{C1} = \frac{aV_{Th} - V_{\gamma 2}}{aR + R_E\left(1 + \frac{1}{h_{FE}}\right)}$$

$$\therefore \quad aV_{Th} = \frac{R_2}{R_1 + R_2} \cdot V_{CC}\frac{R_1 + R_2}{R_1 + R_2 + R_{C1}} = V_{CC}\frac{R_2}{R_2 + R_{C1} + R_1} = V'$$

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

$$\therefore \quad I_{C1} = \frac{V' - V_{\gamma 2}}{aR + R'_E}$$

Therefore from Figure 4.33,

$$V_2 = I_{B1}R_S + V_{BE1} + (I_{B1} + I_{C1})R_E$$

$$= V_{BE1} + I_{C1}\left(R_E\left(1 + \frac{1}{h_{FE}}\right) + \frac{R_S}{h_{FE}}\right)$$

$$= V_{BE1} + I_{C1}\left(R'_E + \frac{R_S}{h_{FE}}\right)$$

$$= V_{BE1} + \frac{V' - V_{\gamma 2}}{aR + R'_E}\left(R'_E + \frac{R_S}{h_{FE}}\right)$$

Since h_{FE} is a large number, $R'_E \approx R_E$ and usually $\frac{R_S}{h_{FE}} << R_E$

$$\therefore \quad V_2 = V_{BE1} + (V' - V_{\gamma 2})\frac{R_E}{aR + R_E}$$

- Since VBE| is higher for silicon than germanium, the LTP Va is a few tenths of a volt higher for a Schmitt trigger using silicon transistors than for one using germanium transistors.

4.4.10.MONOSTABLE MULTIVIBRATOR

- As the name indicates, a monostable multivibrator has got only one permanent stable state, the other state being quasi stable. Under quiescent conditions, the monostable multivibrator will be in its stable state only. A triggering signal is required to induce a transition from the stable state to the quasi stable state. Once triggered properly the circuit may remain in its quasi stable state for a time which is very long compared with the time of transition between the states, and after that it will return to its original state. No external triggering signal is required to induce this reverse transition. In a monostable multivibrator one coupling element is a resistor and another coupling element is a capacitor.
- When triggered, since the circuit returns to its original state by itself after a time T, it is known as a one- shot, a single-step, or a univibrator. Since it generates a rectangular waveform which can be used to gate other circuits, it is also called a gating circuit. Furthermore, since it generates a fast transition at a predetermin6d time T after the input trigger, it is also

referred to as a delay circuit. The monostable multivibrator may be a collector-coupled one, or an emitter-coupled one.

THE COLLECTOR COUPLED MONOSTABLE MULTIVIBRATOR

- Figure 4.41 shows the circuit diagram of a collector-to-base coupled (simply called collector- coupled) monostable multivibrator using n-p-n transistors. The collector of Q_2 is coupled to the base of Qi by a resistor R} (dc coupling) and the collector of Q_t is coupled to the base of Q_2 by a capacitor C (ac coupling). Ci is the commutating capacitor introduced to increase the speed of operation. The base of Qiis connected to $-V_{BB}$ through a resistor R_2, to ensure that Q! is cut off under quiescent conditions.

- The base of Q_2 is connected to V_{Cc} through R to ensure that Q_2 is ON under quiescent conditions. In fact, R may be returned to even a small positive voltage but connecting it to V_{CC} is advantageous.

- The circuit parameters are selected such that under quiescent conditions, the monostable multivibrator finds itself in its permanent stable state with Q_2ON (i.e. in saturation) and Q! OFF (i.e. in cut-off)- The multivibrator may be induced to make a transition out of its stable state by the application of a negativetrigger at the base of Q_2 or at the collector of Q|. Since the triggering signal is applied to only one deviceand not to both the devices simultaneously, unsymmetrical triggering is employed.

- When a negative signal is applied at the base of Q_2 at t ~ 0, due to regenerative action Q_2 goes to OFF state and Qi goes to ON state. When Q, is ON, a current /i flows through its R_C and hence its collector voltage drops suddenly by $I\backslash R_C$ This drop will be instantaneously

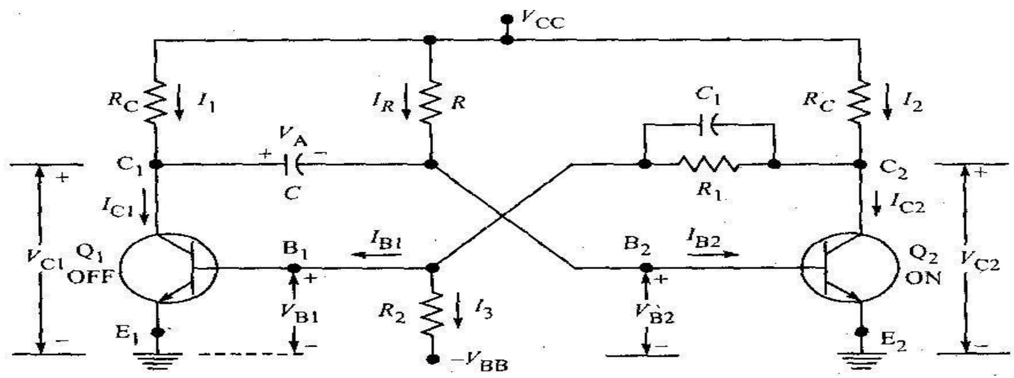


Figure 4.41 Circuit diagram of a collector-coupled monostable multivibrator.

transmitted through the coupling capacitor C to the base of Q2. So at $t = 0^+$, the base voltage of Q2 is

$$V_{BE}(sat) - I_1 R_C.$$

- The circuit cannot remain in this state for a long time (it stays in this state only for a finite time T) because when Qt conducts, the coupling capacitor C charges from V_{CC} through the conducting transistor Qi and $(R + R_o)C \approx RC,$

  hence the potential at the base of Q2 rises exponentially with a time constant
- where R_0 is the conducting transistor output impedance including the resistance R_C. When it passes the cut-in voltage V_γ of Q2 (at a time t = T), a regenerative action takes place turning Q| OFF and eventually returning the multivibrator to its initial stable state.

- The transition from the stable state to the quasi-stable state takes place at t = 0, and the reverse transitionfrom the quasi-stable state to the stable state takes place at t = T. The time T for which the circuit is in its quasi-stable state is also referred to as the delay time, and also as the gate width, pulse width, or pulse duration. The delay time may be varied by varying the time constant t(= RC).

Expression for the gate width T of a monostable multivibrator neglecting the

reverse saturation current /CBO

- Figure 4.42(a) shows the waveform at the base of transistor Q2 of the monostable multivibrator shownin Figure 4.41.
- For t < 0, Q2 is ON and so vB2 = VBE(sat). At t = 0, a negative signal applied brings Q2 to OFF state and Q[into saturation. A current /| flows through Rc of Qt and hence vci drops abruptly by /|7? c volts and so vB2 also drops by I\RC instantaneously. So at t - 0, vB2 = VBE(sat) - I}RC. For t > 0, the capacitor charges with a time constant RC, and hence the base voltage of Q2 rises exponentially towards VCc with the same time constant. At t = T, when this base voltage rises to the cut-in voltage level Vy of the transistor, Q2 goes to ON state, and Qj to OFF state and the pulse ends.

In the interval 0 < t < 7", the base voltage of Q2, i.e. vB2 is given by

$$v_{B2} = V_{CC} - (V_{CC} - \{V_{BE}(\text{sat}) - I_1 R_C\})e^{-t/\tau}$$

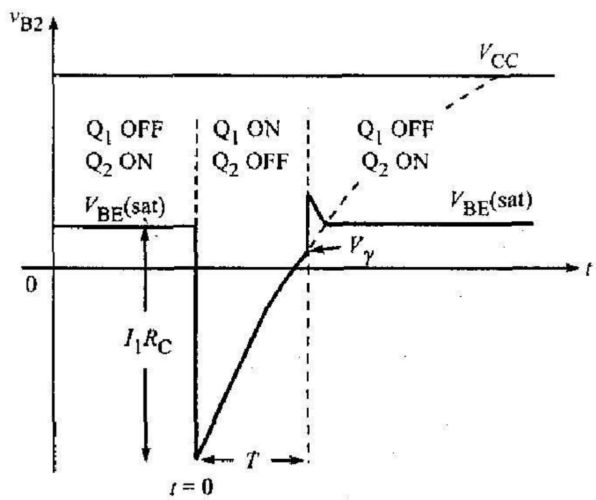


Figure 4.42(a) Voltage variation at the base of Q2 during the quasi-stable state (neglecting /cuoX

But $I_1R_C = V_{CC} - V_{CE}(\text{sat})$ (because at $t = 0^-$, $v_{C1} = V_{CC}$ and at $t = 0^+$, $v_{C1} = V_{CE}(\text{sat})$)

$$\therefore \quad v_{B2} = V_{CC} - [V_{CC} - \{V_{BE}(\text{sat}) - (V_{CC} - V_{CE}(\text{sat}))\}]e^{-t/\tau}$$

$$= V_{CC} - [2V_{CC} - \{V_{BE}(\text{sat}) + V_{CE}(\text{sat})\}]e^{-t/\tau}$$

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

$$\therefore \quad V_\gamma = V_{CC} - [2V_{CC} - \{V_{CE}(\text{sat}) + V_{BE}(\text{sat})\}]e^{-T/\tau}$$

i.e.
$$e^{T/\tau} = \frac{2V_{CC} - [V_{CE}(\text{sat}) + V_{BE}(\text{sat})]}{V_{CC} - V_\gamma}$$

$$\therefore \quad \frac{T}{\tau} = \frac{\text{In}\left[2\left(V_{CC} - \dfrac{V_{CE}(\text{sat}) + V_{BE}(\text{sat})}{2}\right)\right]}{V_{CC} - V_\gamma}$$

i.e.
$$T = \tau \text{ In } 2 + \tau \text{ In} \frac{V_{CC} - \dfrac{V_{CE}(\text{sat}) + V_{BE}(\text{sat})}{2}}{V_{CC} - V_\gamma}$$

Normally for a transistor, at room temperature, the cut-in voltage is the average of the saturation junction

voltages for either Ge or Si transistors, i.e. $V_\gamma = \dfrac{V_{CE}(\text{sat}) + V_{BE}(\text{sat})}{2}$

Neglecting the second term in the expression for T

$$T = \tau \ln 2$$

i.e.
$$T = (R + R_o)C \ln 2 = 0.693(R + R_o)C$$

but for a transistor in saturation Ra « R.

Gate width, T = 0.693KC

- The larger the V_{CC} is, compared to the saturation junction voltages, the more accura the result is.

The gate width can be made very stable (almost independent of transistor

characteristic supplyvoltages, and resistance values) if Ql is driven into

saturation during the quasi-stab state.

Expression for the gate width of a monostable multivibrator considering th

reverse saturation current /CBO

- In the derivation of the expression for gate width T above, we neglected the effect of tt reverse saturation current /CBO on the gate width T. In fact, as the temperature increases, tt reverse saturation current increases and the gate width decreases.

- In the quasi-stable state when Q2 is OFF, /CBO flows out of its base through R to th supply V_{CC}. Hencethe base of Q2 will be not at V_{CC} but at V_{CC} + /CBO^> ^ C *S disconnect from the junction of the base of Q2 with the resistor R. It therefore appears that the capacitt C in effect charges through R from a source V_{CC} + /CBO^- See Figure 4.42(b).

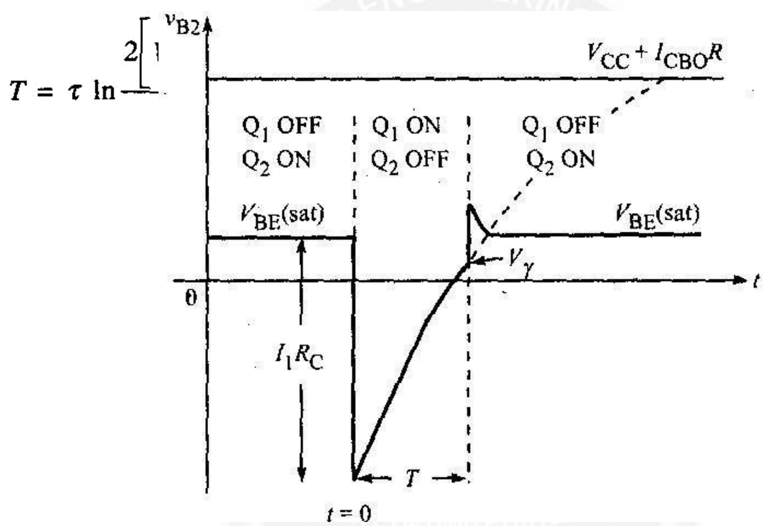


Figure 4.42(b) Voltage variation at the base of Q2 during the quasirstable state

So, the expression for the voltage at the base of Q_2 is given by

$$v_{B2} = (V_{CC} + I_{CBO}R) - [(V_{CC} + I_{CBO}R) - (V_{BE}(\text{sat}) - I_1R_C)]e^{-t/\tau}$$

$$= (V_{CC} + I_{CBO}R) - [(V_{CC} + I_{CBO}R) - (V_{BE}(\text{sat}) - (V_{CC} - V_{CE}(\text{sat}))]e^{-t/\tau}$$

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

$$\therefore \quad V_\gamma = V_{CC} + I_{CBO}R - [2V_{CC} + I_{CBO}R - (V_{CE}(\text{sat}) + V_{BE}(\text{sat}))]e^{-T/\tau}$$

$$\therefore \quad e^{T/\tau} = \frac{2V_{CC} + I_{CBO}R - (V_{CE}(\text{sat}) + V_{BE}(\text{sat}))}{V_{CC} + I_{CBO}R - V_\gamma}$$

(considering

Neglecting the junction voltages and the cut-in voltage of the transistor,

$$T = \tau \ln \frac{2\left[V_{CC} + \frac{I_{CBO}R}{2}\right]}{V_{CC} + I_{CBO}R}$$

$$= \tau \ln 2 + \tau \ln \frac{1+\frac{\phi}{2}}{1+\phi}, \quad \text{where } \phi = \frac{I_{CBO}R}{V_{CC}}$$

$$T = \tau \ln 2 - \tau \ln \frac{1+\phi}{1+\frac{\phi}{2}}$$

- Since /CBO increases with temperature, we can conclude that the delay time T decreases as temperature increases.

Waveforms of the collector-coupled monostable multivibrator

- The waveforms at the collectors and bases of both the transistors Q] and Q2 of the monostable multivibrator of Figure 4.41 are shown in Figure 4.44. The triggering signal is applied at t = 0, and the reverse transition occurs at t = T.

The stable state. For t < 0, the monostable circuit is in its stable state with Q2 ON and Q, OFF. Since Q2 is ON, the^ase voltage of Q2 is vB2 = VBE2(sat) and the collector voltage of Q2 is vC2 = VCE2(sat). Since Q, is OFF, there is no current in Rc of Q! and its base voltage must be negative. Hence the voltage at the collector of Q| is, vC1 = VCC

and the voltage at the base of Q] using the superposition theorem is

$$v_{B1} = -V_{BB}\frac{R_1}{R_1+R_2} + V_{CE2}(\text{sat})\frac{R_2}{R_1+R_2}$$

The quasi-stable state.

- A negative triggering signal applied at t = 0 brings Q2 to OFF state and Qi to ON state.

A current /, flows in tfc of Q]. So, the collector voltage of Qj drops suddenly by I}RC volts. Since the

voltage across the coupling capacitor C cannot change instantaneously, the voltage at the base of Q2 also drops by /itf$_C$, where I{R$_C$ = V$_{CC}$ -VcE2(^{sat})- Since Qi is ON,

$$v_{B1} = V_{BE1}(\text{sat}) \quad \text{and} \quad v_{C1} = V_{CE1}(\text{sat})$$

$$\text{Also,} \quad v_{B2} = V_{BE2}(\text{sat}) - I_1R_C \quad \text{and} \quad v_{C2} = V_{CC}\frac{R_1}{R_1 + R_C} + V_{BE1}(\text{sat})\frac{R_C}{R_1 + R_C}$$

In the interval 0 < t < T, the voltages VGI, VBI and Vc2 remain constant at their values at f = 0, but the voltage at the base of. Q2, i.e. v$_{B2}$ rises exponentially towards V$_{CC}$ with a time constant, t - RC, until at t = T, v$_{B2}$ reaches the cut-in voltage V$_X$ of the transistor.

Waveforms for t > T. At , reverse transition -takes place. Q2 conducts and Qi is cut-off. The collector voltage of Q2 and the base voltage of Qi return to their voltage levels for / < 0. The voltage v$_{Cl}$ now rises abruptly since Q$_t$ is OFF. This increase in voltage is transmitted to the base of Q2 and drives Q2 heavily into saturation. Hence an overshoot develops in v$_{B2}$ at t = 7**", which decays as the capacitor recharges because of the base current. The magnitude of the base current may be calculated as follows.

Replace the input circuit of Q2 by the base spreading resistance r$_{BB}$ in series with the voltage VsE(sat) as shown in Figure 4.43. Let 7$_B$ be the base current at t = 1*. The current in R may be neglected compared to /'$_B$.

From Figure 4.43,

$$V'_{BE} = I'_B r'_{BB} + V_{BE}(\text{sat}) \quad \text{and} \quad V_C = V_{CC} - I'_B R_C - V'_{BE}$$

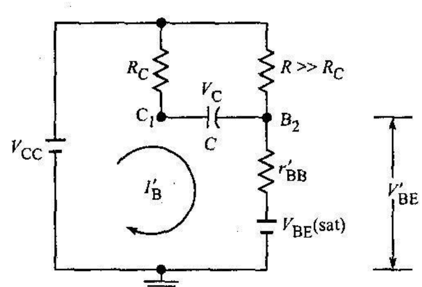


Figure 4.43 Equivalent circuit for calculating the overshoot at base 62 of Q3.

The jumps in voltages at B2 and C| are, respectively, given by

$\delta = V'_{BE} - V_\gamma = I'_B r'_{BB} + V_{BE}(\text{sat}) - V_\gamma$ and $\delta' = V_{CC} - V_{CE}(\text{sat}) - I'_B R_C$

Since C] and B2 are connected by a capacitor C and since the voltage across the capacitts cannotchange instantaneously, these two discontinuous voltage changes 5 and 5' must bl equal.

Equating them,

$$I'_B r'_{BB} + V_{BE}(\text{sat}) - V_\gamma = V_{CC} - V_{CE}(\text{sat}) - I'_B R_C$$

$$I'_B = \frac{V_{CC} - V_{BE}(\text{sat}) - V_{CE}(\text{sat}) + V_\gamma}{R_C + r'_{BB}}$$

vB2 and vcl decay to their steady-state values with a time constant $\tau' = (R_C + r'_{BB})C$

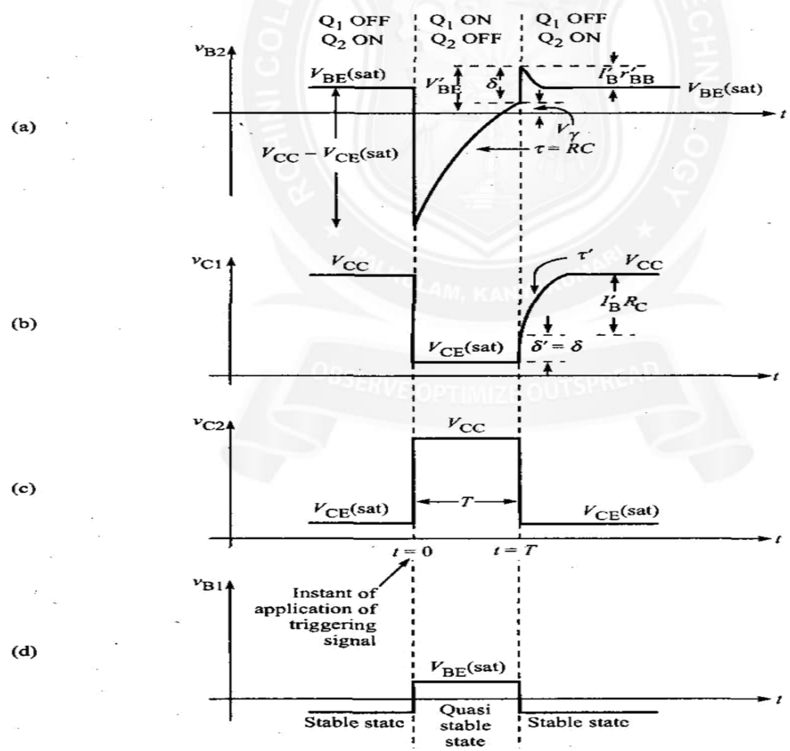


Figure 4.44 Waveforms at the collectors and bases of the collector-coupled monostable multivibrator. (a) at the base of Q_2, (b) at the collector of Q_t, (c) at the collector of Q_2, and (d) at the base

4.4.11.ASTABLE MULTIVIBRATOR

- As the name indicates an astable multivibrator is a multivibrator with no permanent stable state. Both of its states are quasi stable only. It cannot remain in any one of its states indefinitely and keeps on oscillating between its two quasi stable states the moment it is connected to the supply. It remains in each of its two quasi stable states for only a short designed interval of time and then goes to the other quasi stable state. No triggering signal is required. Both the coupling elements are capacitors (ac coupling) and hence both the states are quasi stable. It is a free running multivibrator. It generates square waves. It is used as a master oscillator.

There are two types of astable multivibrators:

1. Collector-coupled astable multivibrator
2. Emitter-coupled astable multivibrator

THE COLLECTOR-COUPLED ASTABLE MULTIVIBRATOR

- Figure 4.53 shows the circuit diagram of a collector-coupled astable multivibrator using n-p-n transistors. The collectors of both the transistors Qj and Q2 are connected to the bases

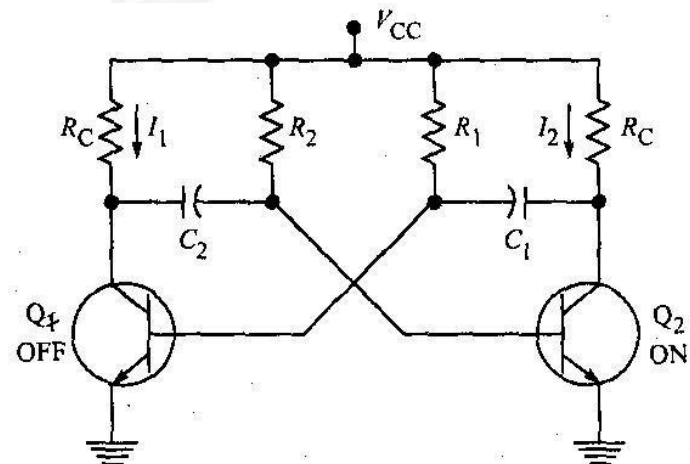


Figure 4.53 A collector-coupled astable multivibrator.

of the other transistors through the coupling capacitors C_s and C_2. Since both are ac couplings, neither transistor can remain permanently at cut-off. Instead, the circuit has two quasi-stable states, and it makes periodic transitions between these states. Hence it is used as a master oscillator. No triggering signal is required for this multivibrator. The component values are selected such that, the moment it is connected to the supply, due to supply transients one transistor will go into saturation and the other into cut-off, and also due to capacitive couplings it keeps on-oscillating between its two quasi stable states.

The waveforms at the bases and collectors for the astable multivibrator, are shown in Figure 4.54. Let us say at t = 0, Q_2 goes to ON state and Q] to OFF state. So, for t < 0, Q_2 was OFF and Qi was ON. Hence

for t < 0, v_{B2} is negative, $v_{C2} = V_{cc}$, $V_{B!} = V_{BE}(sat)$ and $v_{cj} = V_{CE}(sat)$. 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_y and Q_2

conducts. As Q_2 conducts, its collector voltage V_{c2} drops by /2/?c - ^cc ~ VcE(^{sa}O- This drop in v_{c2} is
transmitted to the base of Qj through the coupling capacitor C_2 and hence v_{B1} also falls by /2/?c- Qi goes to OFF state. So, $V_{B]} = V_{BE}(sat)$ - /2tf$_c$, and its collector voltage v_{cl} rises towards V_{Cc}- This rise in $v_{c]}$ is coupled through the coupling capacitor C_2 to the base of Q_2, causing an overshoot § in v_{B2} and the abrupt rise by the same amount 8 in VCL as shown in Figure 4.51(c). Now since Q_2 is ON, C\ charges from V_{cc} through R_{lt} and hence $V_{B]}$ rises exponentially. At t = 7"], when $V_{B!}$ rises to V_Y, Qi conducts and due to regenerative action Qi goes into saturation and Q_2 to cut-off. Now, for t > T\, the coupling capacitor C_2 charges from V_{cc} through R_2 and when v_{B2} rises to the cut-in voltage V_r, Q_2

conducts and due to regenerative feedback Q2 goes to ON state and Q| to OFF state. The cycle of events repeats and the circuit keeps on oscillating between its two quasi-stable states. Hence the output is a square wave. It is called a square wave generator or square wave oscillator or relaxation oscillator. It is a free running oscillator.

Expression for the frequency of oscillation of an astable multivibrator

Consider the waveform at the base of Q_1 shown in Figure 4.54(d). At $t = 0$,

$$v_{B1} = V_{BE}(\text{sat}) - I_2R_C$$

But $$I_2R_C = V_{CC} - V_{CE}(\text{sat})$$

$\therefore$ $$\text{At } t = 0,\ v_{B1} = V_{BE}(\text{sat}) - V_{CC} + V_{CE}(\text{sat})$$

For $0 < t < T_1$, v_{B1} rises exponentially towards V_{CC} given by the equation,

$$v_o = v_f - (v_f - v_i)e^{-t/\tau}$$

$\therefore$ $$v_{B1} = V_{CC} - [V_{CC} - (V_{BE}(\text{sat}) - V_{CC} + V_{CE}(\text{sat}))]e^{-t/\tau_1}, \text{ where } \tau_1 = R_1C_1$$

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

$\therefore$ $$V_\gamma = V_{CC} - [2V_{CC} - (V_{BE}(\text{sat}) + V_{CE}(\text{sat}))]e^{-T_1/R_1C_1}$$

or $$e^{T_1/R_1C_1} = \frac{2\left[V_{CC} - \dfrac{V_{BE}(\text{sat}) + V_{CE}(\text{sat})}{2}\right]}{V_{CC} - V_\gamma}$$

$$T_1 = R_1C_1 \ln \frac{2\left[V_{CC} - \dfrac{V_{CE}(\text{sat}) + V_{BE}(\text{sat})}{2}\right]}{V_{CC} - V_\gamma}$$

$$T_1 = R_1C_1 \ln 2 + R_1C_1 \ln \frac{\left[V_{CC} - \dfrac{V_{CE}(\text{sat}) + V_{BE}(\text{sat})}{2}\right]}{V_{CC} - V_\gamma}$$

At room temperature for a transistor,

$$V_\gamma = \frac{V_{CE}(\text{sat}) + V_{BE}(\text{sat})}{2}$$

$\therefore$ $$T_1 = R_1C_1 \ln 2 = 0.693R_1C_1$$

On similar lines considering the waveform of Figure 4.54(b), we can show that the time T2 for which Q2 is

OFF and Qj is ON is given by $T_2 = R_2C_2 \ln 2 = 0.693R_2C_2$ The period of the waveform,

The frequency ofoscillation,

If R{ = R2 = R, and Cs = C2 = C, then TI = T2 = 772

$$T = 2 \times 0.693RC = 1.386RC \quad \text{and} \quad f = \frac{1}{1.386RC}$$

The frequency of oscillation may be varied over the range from cycles to mega cycles by varying RC. It is also possible to vary the frequency electrically by connecting R\ and R2 to an auxiliary voltage source V (the collector supply remains +VCC) and then varying this voltage V.

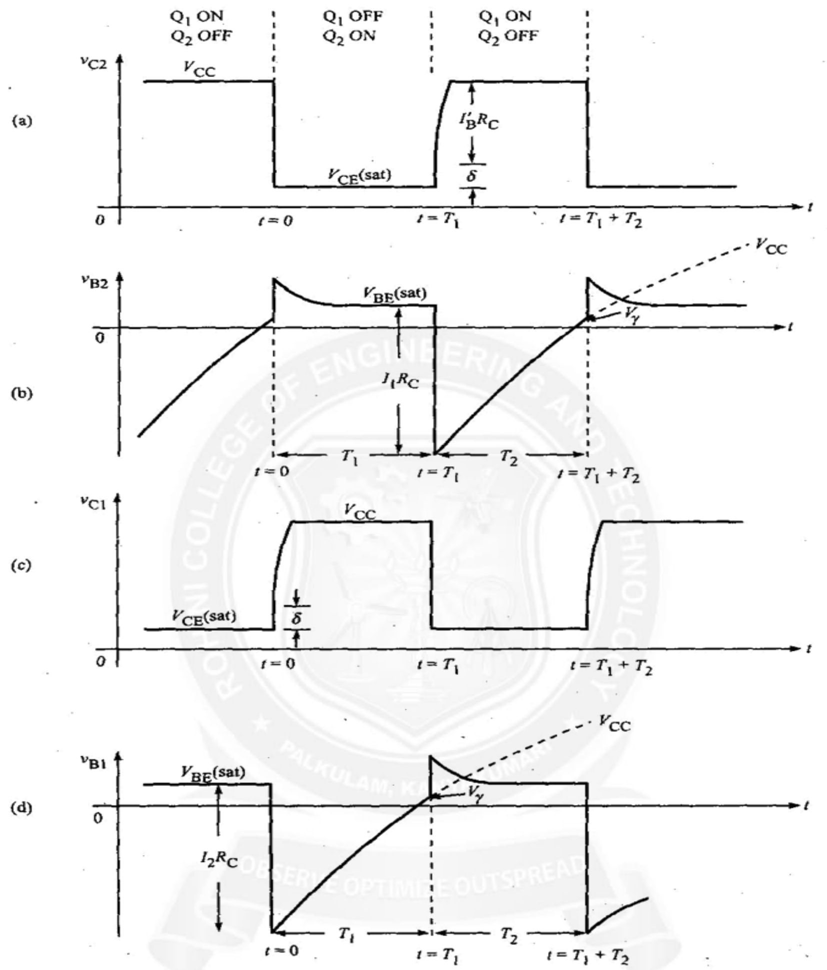


Figure 4.54 Waveforms at the bases and collectors of a collector-coupled astable multivibrator.

THE EMITTER-COUPLED ASTABLE MULTIVIBRATOR

- An emitter-coupled astable multivibrator may be obtained by using three power supplies or a single power supply.

Figure 4.63 shows the circuit diagram of a free-running emitter coupled multivibrator using n-p-n transistors. Figure 4.64 shows its waveforms. Three power supplies are indicated for the sake of simplifying the analysis. A more practical circuit using a single supply is indicated in Figure 4.65. Let us assume that the circuit operates in such a manner that Qi switches between cut-off and saturation and Q_2 switches between cut-off and its active region.

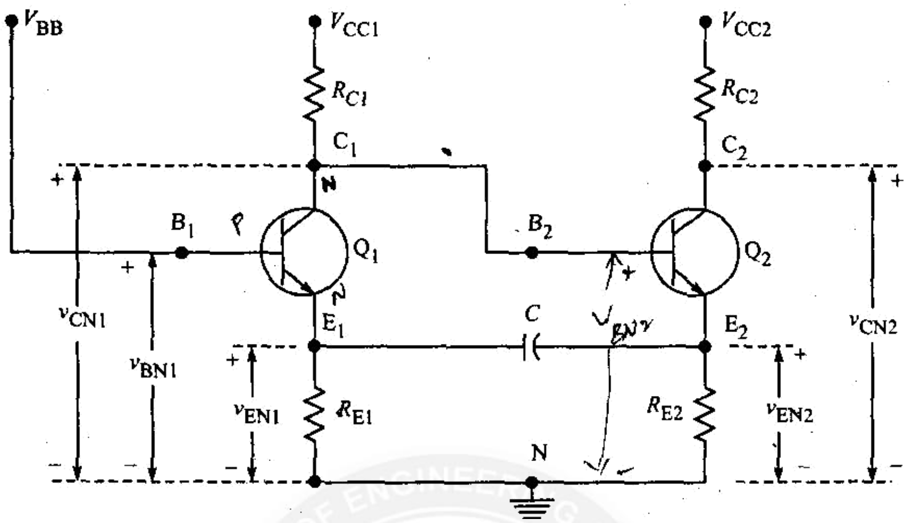


Figure 4.63 The astable emitter-coupled multivibrator.

(Source: Microelectronics byJ. Millman and A. Grabel, Page-498)

Calculations at $t = t_1^-$

Since Q_1 is ON and Q_2 is OFF just before the transition at $t = t_1^-$, we have

$$v_{CN2}(t_1^-) = V_{CC2}$$
$$v_{EN1}(t_1^-) = V_{BB} - V_{BE}(\text{sat}) = V_{BB} - V_\sigma$$
$$v_{CN1}((t_1^-) = v_{BN2} = v_{EN1} + V_{CE}(\text{sat}) = V_{BB} - V_\sigma + V_{CE}(\text{sat})$$

During the interval preceding t = t\, the capacitor C charges from a fixed voltage ^BB ~ V0 through the resistor R_{E2}. All circuit voltages remain constant except

$$v_{EN2}(t_1^-) = v_{BN2} - V_\sigma + V_{CE}(\text{sat}) - V_\gamma$$

v_{EN2}, which falls asymptotically towards zero.

The transistor Q_2 will begin to conduct when v_{EN2} falls to

$$R_{C1} = \frac{R'R''}{R'+R''}$$

and

$$V_{CC1} = V_{CC}\frac{R''}{R'+R''} + V_{BB}\frac{R'}{R'+R''}$$