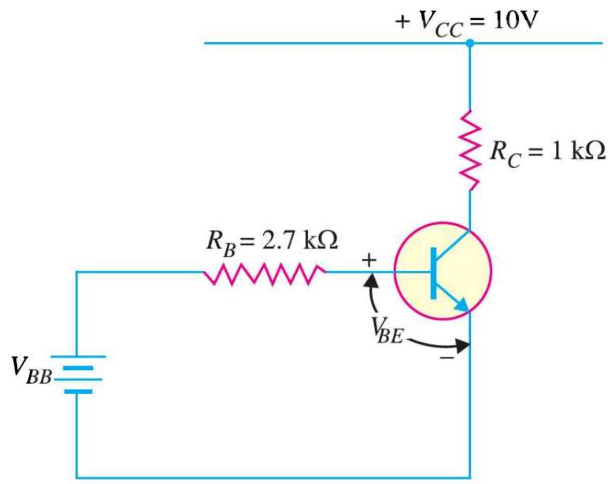


Fig. 18.9

$$= \frac{10\text{V} - 0.7\text{V}}{1\text{ k}\Omega} = \frac{9.3\text{V}}{1\text{ k}\Omega} = 9.3\text{ mA}$$

∴ $$\text{Minimum } \beta = \frac{I_{C(sat)}}{I_B} = \frac{9.3\text{ mA}}{0.48\text{ mA}} = \mathbf{19.4}$$

(*ii*) $$I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

$$= \frac{1\text{V} - 0.7\text{V}}{2.7\text{ k}\Omega} = \frac{0.3\text{V}}{2.7\text{ k}\Omega} = 0.111\text{ mA}$$

∴ $$I_C = \beta I_B = 50 \times 0.111 = 5.55\text{ mA}$$

Since the collector current is less than saturation current (= 9.3 mA), **the transistor will not be saturated.**

18.10 Multivibrators

An electronic circuit that generates square waves (or other non-sinusoidals such as rectangular, saw-tooth waves) is known as a ***multivibrator.**

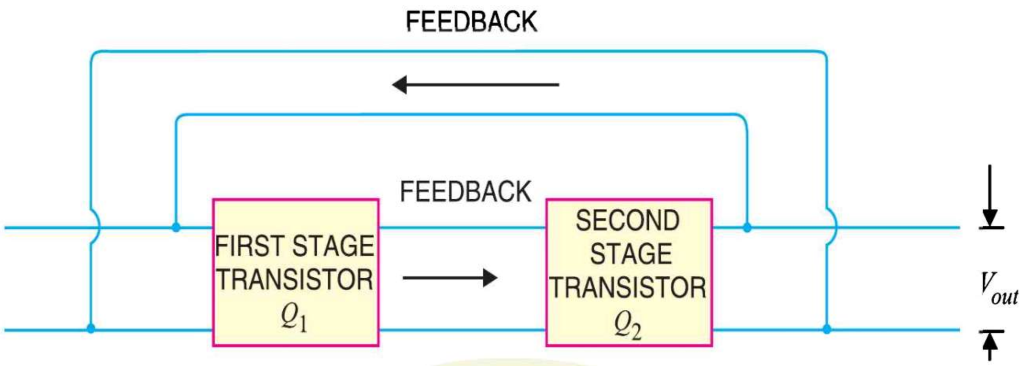


Fig. 18.10

A multivibrator is a switching circuit which depends for operation on positive feedback. It is basically a two-stage amplifier with output of one fedback to the input of the other as shown in Fig. 18.10.

* The name multivibrator is derived from the fact that a square wave actually consists of a large number of (fourier series analysis) sinusoidals of different frequencies.

The circuit operates in two states (*viz* ON and OFF) controlled by circuit conditions. Each amplifier stage supplies feedback to the other in such a manner that will drive the transistor of one stage to saturation (ON state) and the other to cut off (OFF state).

After a certain time controlled by circuit conditions, the action is reversed *i.e.* saturated stage is driven to cut off and the cut off stage is driven to saturation. The output can be taken across either stage and may be rectangular or square wave depending upon the circuit conditions.

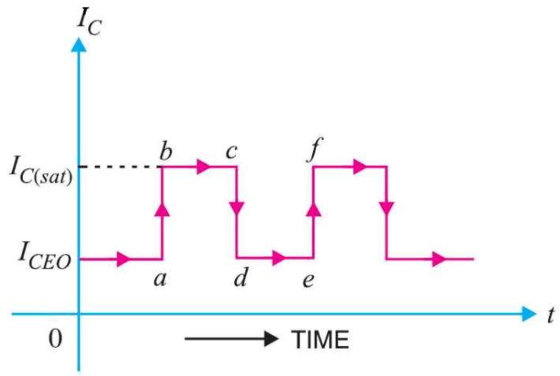


Fig. 18.11

Fig. 18.10 shows the block diagram of a multivibrator. It is a two-stage amplifier with 100% positive feedback. Suppose output is taken across the transistor Q_2. At any particular instant, one transistor is ON and conducts $I_{C(sat)}$ while the other is OFF. Suppose Q_2 is ON and Q_1 is OFF. The collector current in Q_2 will be $I_{C(sat)}$ as shown in Fig. 18.11. This condition will prevail for a time (*bc* in this case) determined by circuit conditions. After this time, transistor Q_2 is cut off and Q_1 is turned ON. The collector current in Q_2 is now I_{CEO} as shown. The circuit will stay in this condition for a time *de*. Again Q_2 is turned ON and Q_1 is driven to cut off. In this way, the output will be a square wave.

18.11 Types of Multivibrators

A multivibrator is basically a two-stage amplifier with output of one fedback to the input of the other. At any particular instant, one transistor is ON and the other is OFF. After a certain time depending upon the circuit components, the stages reverse their conditions – the conducting stage suddenly cuts off and the non-conducting stage suddenly starts to conduct. The two possible states of a multivibrator are :

	ON	**OFF**
First State	Q_1	Q_2
Second State	Q_2	Q_1

Depending upon the manner in which the two stages interchange their states, the multivibrators are classified as :

(*i*) Astable or free running multivibrator

(*ii*) Monostable or one-shot multivibrator

(*iii*) Bi-stable or flip-flop multivibrator

Fig. 18.12 shows the input/output relations for the three types of multivibrators.

(*i*) The astable or free running multivibrator alternates automatically between the two states and remains in each for a time dependent upon the circuit constants. Thus it is just an oscillator since it requires no external pulse for its operation. Of course, it does require a source of d.c. power. Because it continuously produces the square-wave output, it is often referred to as a *free running multivibrator*.

(*ii*) The monostable or one-shot multivibrator has one state stable and one quasi-stable (*i.e.* half-stable) state. The application of input pulse triggers the circuit into its quasi-stable state, in which it remains for a period determined by circuit constants. After this period of time, the circuit returns to its initial stable state, the process is repeated upon the application of each trigger pulse. Since the monostable multivibrator produces a single output pulse for each input trigger pulse, it is generally called *one-shot multivibrator*.

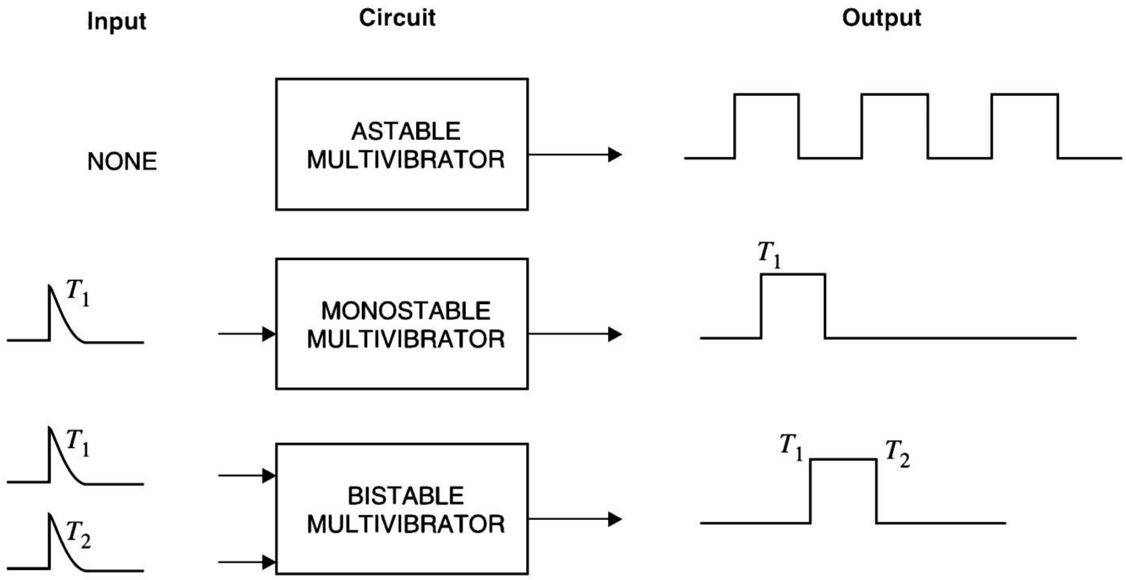


Fig. 18.12

(iii) The bistable multivibrator has both the two states stable. It requires the application of an external triggering pulse to change the operation from either one state to the other. Thus one pulse is used to generate half-cycle of square wave and another pulse to generate the next half-cycle of square wave. It is also known as a *flip-flop multivibrator* because of the two possible states it can assume.

18.12 Transistor Astable Multivibrator

A multivibrator which generates square waves of its own (i.e. without any external triggering pulse) is known as an **astable** *or* **free running multivibrator.**

The *astable multivibrator has no stable state. It switches back and forth from one state to the other, remaining in each state for a time determined by circuit constants. In other words, at first one transistor conducts (*i.e.* ON state) and the other stays in the OFF state for some time. After this period of time, the second transistor is automatically turned ON and the first transistor is turned OFF. Thus the multivibrator will generate a square wave output of its own. The width of the square wave and its frequency will depend upon the circuit constants.

Circuit details. Fig. 18.13 shows the circuit of a typical transistor astable multivibrator using two identical transistors Q_1 and Q_2. The circuit essentially consists of two symmetrical *CE* amplifier stages, each providing a feedback to the other. Thus collector loads of the two stages are equal *i.e.* $R_1 = R_4$ and the biasing resistors are also equal *i.e.* $R_2 = R_3$. The output of transistor Q_1 is coupled to the input of Q_2 through C_1 while the output of Q_2 is fed to the input of Q_1 through C_2. The square wave output can be taken from Q_1 or Q_2.

Operation. When V_{CC} is applied, collector currents start flowing in Q_1 and Q_2. In addition, the coupling capacitors C_1 and C_2 also start charging up. As the characteristics of no two transistors (*i.e.* β, V_{BE}) are *exactly* alike, therefore, one transistor, say Q_1, will conduct more rapidly than the other. The rising collector current in Q_1 drives its collector more and more positive. The increasing positive output at point *A* is applied to the base of transistor Q_2 through C_1. This establishes a reverse

* A means not. Hence astable means that it has no stable state.

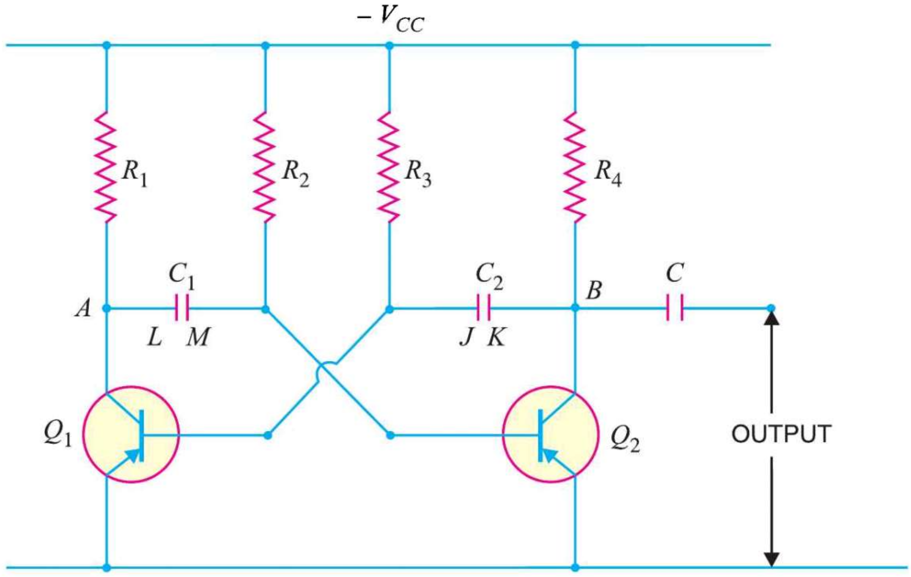


Fig. 18.13

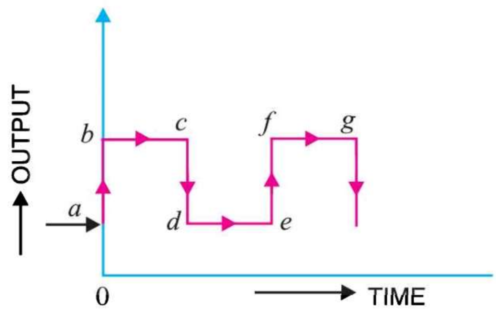


Fig. 18.14

bias on Q_2 and its collector current starts decreasing. As the collector of Q_2 is connected to the base of Q_1 through C_2, therefore, base of Q_1 becomes more negative *i.e.* Q_1 is more forward biased. This further increases the collector current in Q_1 and causes a further decrease of collector current in Q_2. This series of actions is repeated until the circuit drives Q_1 to saturation and Q_2 to cut off. These actions occur very rapidly and may be considered practically instantaneous. The output of Q_1 (ON state) is approximately zero and that of Q_2 (OFF state) is approximately V_{CC}. This is shown by *ab* in Fig. 18.14.

When Q_1 is at saturation and Q_2 is cut off, the full voltage V_{CC} appears across R_1 and voltage across R_4 will be zero. The charges developed across C_1 and C_2 are sufficient to maintain the saturation and cut off conditions at Q_1 and Q_2 respectively. This condition is represented by time interval *bc* in Fig. 18.14. However, the capacitors will not retain the charges indefinitely but will discharge through their respective circuits. The discharge path for C_1, with plate L negative and Q_1 conducting, is $LAQ_1V_{CC}R_2M$ as shown in Fig. 18.15 (*i*).

The discharge path for C_2, with plate K negative and Q_2 cut off, is KBR_4R_3J as shown in Fig. 18.15 (*ii*). As the resistance of the discharge path for C_1 is lower than that of C_2, therefore, C_1 will discharge more rapidly.

As C_1 discharges, the base bias at Q_2 becomes less positive and at a time determined by R_2 and C_1, forward bias is re-established at Q_2. This causes the collector current to start in Q_2. The increasing positive potential at collector of Q_2 is applied to the base of Q_1 through the capacitor C_2. Hence the base of Q_1 will become more positive *i.e.* Q_1 is reverse biased. The decrease in collector current in Q_1 sends a negative voltage to the base of Q_2 through C_1, thereby causing further increase in the collector current of Q_2. With this set of actions taking place, Q_2 is quickly driven to saturation and Q_1 to cut off. This condition is represented by *cd* in Fig. 18.14. The period of time during which Q_2 remains at saturation and Q_1 at cut off is determined by C_2 and R_3.

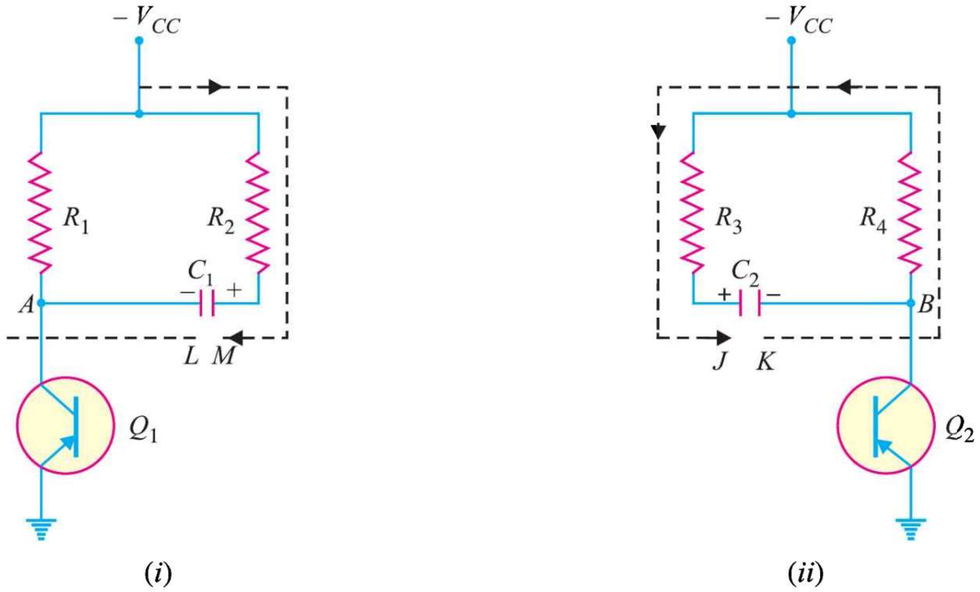


Fig. 18.15

ON or OFF time. The time for which either transistor remains ON or OFF is given by :

ON time for Q_1 (or OFF time for Q_2) is

$$T_1 = 0.694 R_2 C_1$$

OFF time for Q_1 (or ON time for Q_2) is

$$T_2 = 0.694 R_3 C_2$$

Total time period of the square wave is

$$T = T_1 + T_2 = 0.694\,(R_2 C_1 + R_3 C_2)$$

As $R_2 = R_3 = R$ and $C_1 = C_2 = C$,

$$\therefore \quad T = 0.694\,(RC + RC) \simeq 1.4\,RC \text{ seconds}$$

Frequency of the square wave is

$$f = \frac{1}{T} \simeq \frac{0.7}{RC}\,\text{Hz}$$

It may be noted that in these expressions, R is in ohms and C in farad.

Example 18.4. *In the astable multivibrator shown in Fig. 18.13, $R_2 = R_3 = 10\ k\Omega$ and $C_1 = C_2 = 0.01\ \mu F$. Determine the time period and frequency of the square wave.*

Solution.

Here $R = 10\ \text{k}\Omega = 10^4\ \Omega$; $C = 0.01\ \mu\text{F} = 10^{-8}$ F

Time period of the square wave is

$$T = 1.4\,RC = 1.4 \times 10^4 \times 10^{-8} \text{ second}$$
$$= 1.4 \times 10^{-4} \text{ second} = 1.4 \times 10^{-4} \times 10^3 \text{ m sec}$$
$$= \mathbf{0.14\ m\ sec}$$

Frequency of the square wave is

$$f = \frac{1}{T \text{ in second}}\,\text{Hz} = \frac{1}{1.4 \times 10^{-4}}\,\text{Hz}$$
$$= 7 \times 10^3\ \text{Hz} = \mathbf{7\ kHz}$$

18.13 Transistor Monostable Multivibrator

A multivibrator in which one transistor is always conducting (i.e. in the ON state) and the other is non-conducting (i.e. in the OFF state) is called a **monostable multivibrator.**

A *monostable multivibrator has only one state stable. In other words, if one transistor is conducting and the other is non-conducting, the circuit will remain in this position. It is only with the application of external pulse that the circuit will interchange the states. However, after a certain time, the circuit will automatically switch back to the original stable state and remains there until another pulse is applied. Thus a monostable multivibrator cannot generate square waves of its own like an astable multivibrator. Only external pulse will cause it to generate the square wave.

Circuit details. Fig. 18.16 shows the circuit of a transistor monostable multivibrator. It consists of two similar transistors Q_1 and Q_2 with equal collector loads *i.e.* $R_1 = R_4$. The values of V_{BB} and R_5 are such as to reverse bias Q_1 and keep it at cut off. The collector supply V_{CC} and R_2 forward bias Q_2 and keep it at saturation. The input pulse is given through C_2 to obtain the square wave. Again output can be taken from Q_1 or Q_2.

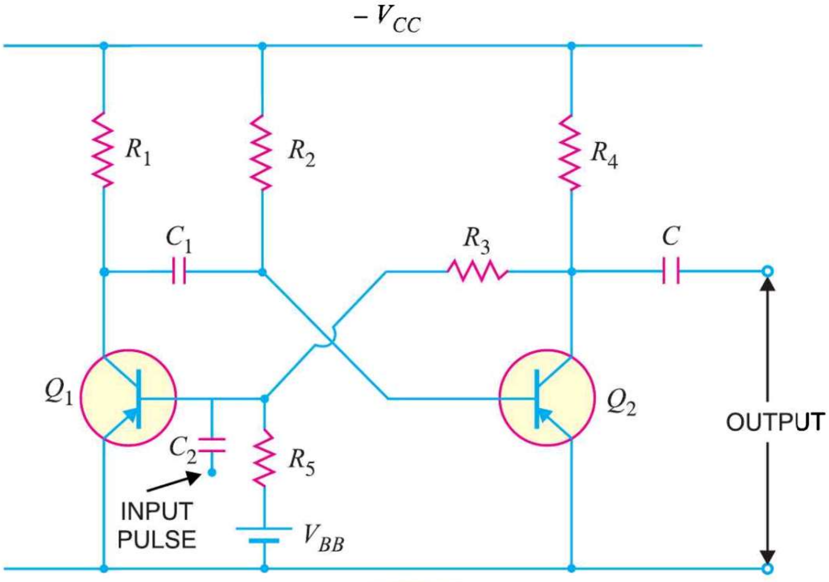
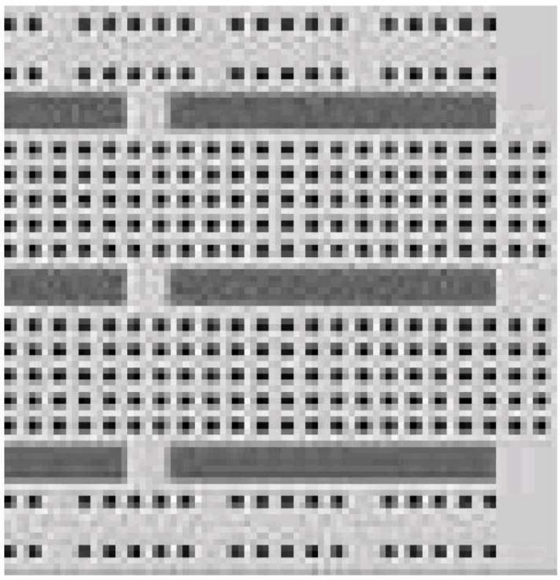


Fig. 18.16

Operation. With the circuit arrangement shown, Q_1 is at cut off and Q_2 is at saturation. This is the stable state for the circuit and it will continue to stay in this state until a triggering pulse is applied at C_2. When a negative pulse of short duration and sufficient magnitude is applied to the base of Q_1 through C_2, the transistor Q_1 starts conducting and positive potential is established at its collector. The positive potential at the collector of Q_1 is coupled to the base of Q_2 through capacitor C_1. This decreases the forward bias on Q_2 and its collector current decreases. The increasing negative potential on the collector of Q_2 is applied to the base of Q_1 through R_3. This further increases the forward bias on Q_1 and hence its collector current. With this set of actions taking place, Q_1 is quickly driven to saturation and Q_2 to cut off.



Monostable Multivibrator

* Mono means single.

With Q_1 at saturation and Q_2 at cut off, the circuit will come back to the original stage (*i.e.* Q_2 at saturation and Q_1 at cut off) after some time as explained in the following discussion. The capacitor C_1 (charged to approximately V_{CC}) discharges through the path $R_2 V_{CC} Q_1$. As C_1 discharges, it sends a voltage to the base of Q_2 to make it less positive. This goes on until a point is reached when forward bias is re-established on Q_2 and collector current starts to flow in Q_2. The step by step events already explained occur and Q_2 is quickly driven to saturation and Q_1 to cut off. This is the stable state for the circuit and it remains in this condition until another pulse causes the circuit to switch over the states.

18.14 Transistor Bistable Multivibrator

A multivibrator which has both the states stable is called a **bistable multivibrator.**

The bistable multivibrator has both the states stable. It will remain in whichever state it happens to be until a trigger pulse causes it to switch to the other state. For instance, suppose at any particular instant, transistor Q_1 is conducting and transistor Q_2 is at cut off. If left to itself, the bistable multivibrator will stay in this position forever. However, if an external pulse is applied to the circuit in such a way that Q_1 is cut off and Q_2 is turned on, the circuit will stay in the new position. Another trigger pulse is then required to switch the circuit back to its original state.

Circuit details. Fig. 18.17 shows the circuit of a typical transistor bistable multivibrator. It consists of two identical *CE* amplifier stages with output of one fed to the input of the other. The feedback is coupled through resistors (R_2, R_3) shunted by capacitors C_1 and C_2. The main purpose of capacitors C_1 and C_2 is to improve the switching characteristics of the circuit by passing the high frequency components of the square wave. This allows fast rise and fall times and hence distortionless square wave output. The output can be taken across either transistor.

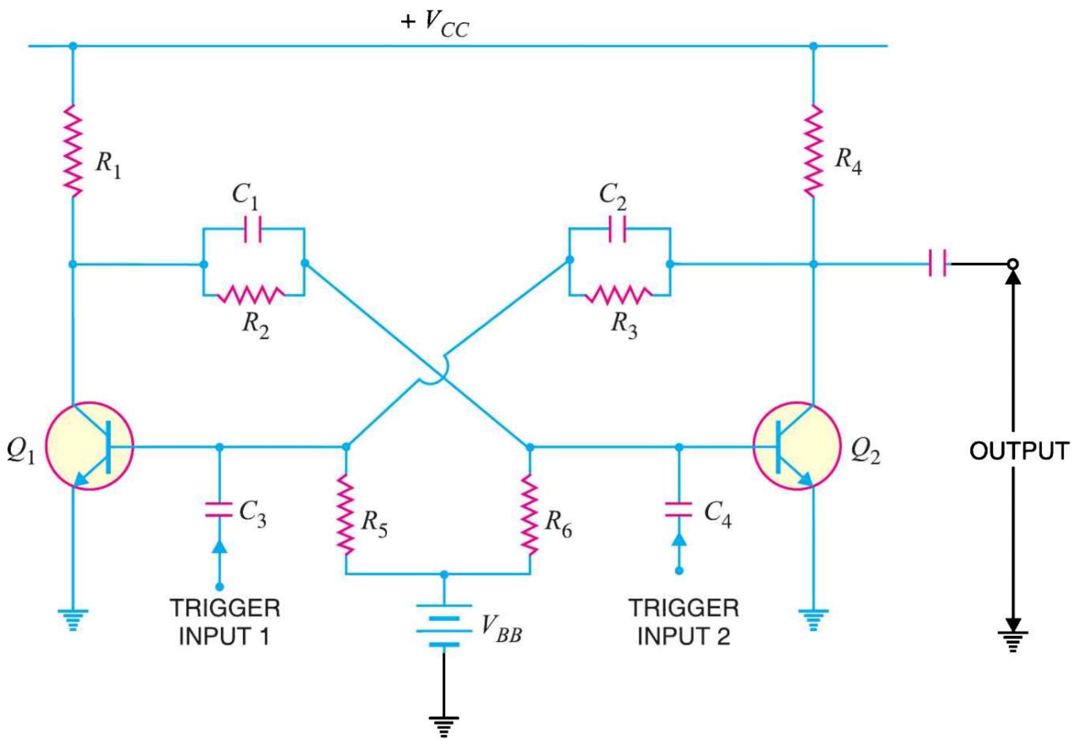


Fig. 18.17

Operation. When V_{CC} is applied, one transistor will start conducting slightly ahead of the other due to some differences in the characteristics of the transistors. This will drive one transistor to saturation and the other to cut off in a manner described for the astable multivibrator. Assume that Q_1 is turned ON and Q_2 is cut OFF. If left to itself, the circuit will stay in this condition. In order to switch the multivibrator to its other state, a trigger pulse must be applied. A negative pulse applied to the base of Q_1 through C_3 will cut it off or a positive pulse applied to the base of Q_2 through C_4 will cause it to conduct.

Suppose a negative pulse of sufficient magnitude is applied to the base of Q_1 through C_3. This will reduce the forward bias on Q_1 and cause a decrease in its collector current and an increase in collector voltage. The rising collector voltage is coupled to the base of Q_2 where it forward biases the base-emitter junction of Q_2. This will cause an increase in its collector current and decrease in collector voltage. The decreasing collector voltage is applied to the base of Q_1 where it further reverse biases the base-emitter junction of Q_1 to decrease its collector current. With this set of actions taking place, Q_2 is quickly driven to saturation and Q_1 to cut off. The circuit will now remain stable in this state until a negative trigger pulse at Q_2 (or a positive trigger pulse at Q_1) changes this state.

18.15 Differentiating Circuit

A circuit in which output voltage is directly proportional to the derivative of the input is known as a **differentiating circuit.**

$$\text{Output} \propto \frac{d}{dt}(\text{Input})$$

A differentiating circuit is a simple *RC* series circuit with output taken across the resistor *R*. The circuit is suitably designed so that output is proportional to the derivative of the input. Thus if a d.c. or constant input is applied to such a circuit, the output will be zero. It is because the derivative of a constant is zero.

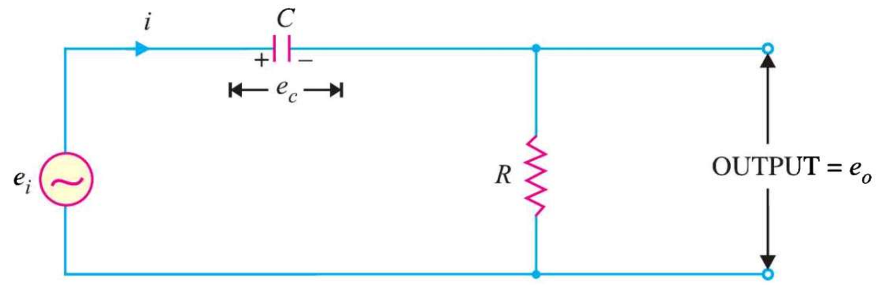


Fig. 18.18

Fig. 18.18 shows a typical differentiating circuit. The output across *R* will be the derivative of the input. It is important to note that merely using voltage across *R* does not make the circuit a differentiator; it is also necessary to set the proper circuit values. In order to achieve good differentiation, the following two conditions should be satisfied :

(i) The time constant *RC* of the circuit should be much smaller than the time period of the input wave.

(ii) The value of X_C should be 10 or more times larger than *R* at the operating frequency.

Fulfilled these conditions, the output across *R* in Fig. 18.18 will be the derivative of the input.

Let e_i be the input alternating voltage and let *i* be the resulting alternating current. The charge *q* on the capacitor at any instant is

$$q = C\,e_c$$

Now $$i = \frac{dq}{dt} = \frac{d}{dt}(q) = \frac{d}{dt}(C\,e_c)$$