Introduction

In order to predict the behaviour of a small-signal transistor amplifier, it is important to know its operating characteristics *e.g.*, input impedance, output impedance, voltage gain *etc.* In the text so far, these characteristics were determined by using *β and circuit resistance values. This method of analysis has two principal advantages. Firstly, the values of circuit components are readily available and secondly the procedure followed is easily understood. However, the major drawback of this method is that accurate results cannot be obtained. It is because the input and output circuits of a transistor amplifier are not completely independent. For example, output current is affected by the value of load resistance rather than being constant at the value βI_b. Similarly, output voltage has an effect on the input circuit so that changes in the output cause changes in the input.

One of the methods that takes into account all the effects in a transistor amplifier is the hybrid parameter approach. In this method, four parameters (one measured in ohm, one in mho, two dimensionless) of a transistor are measured experimentally. These are called hybrid or h parameters of the transistor. Once these parameters for a transistor are known, formulas can be developed for input impedance, voltage gain *etc.* in terms of h parameters. There are two main reasons for using h parameter method in describing the characteristic of a transistor. Firstly, it yields exact results because the inter-effects of input and output circuits are taken into account. Secondly, these parameters can be measured very easily. To begin with, we shall apply h parameter approach to general circuits and then extend it to transistor amplifiers.

26·1. Hybrid Parameters

*Every *linear circuit having input and output terminals can be analysed by four parameters (one measured in ohm, one in mho and two dimensionless) called* **hybrid** *or h* **parameters**.

Hybrid means "mixed". Since these **parameters have mixed dimensions, they are called hybrid parameters. Consider a linear circuit shown in Fig. 26·1. This circuit has input voltage and current labeled v_1 and i_1. This circuit also has output voltage and current labelled v_2 and i_2. Note that both input and output currents (i_1 and i_2) are assumed to flow *into* the box ; input and output voltages (v_1 and v_2) are assumed *positive* from the upper to the lower terminals. These are standard conventions and do not necessarily correspond to the actual directions and polarities. When we analyse circuits in which the voltages are of opposite polarity or where the currents flow out of the box, we simply treat these voltages and currents as negative quantities.

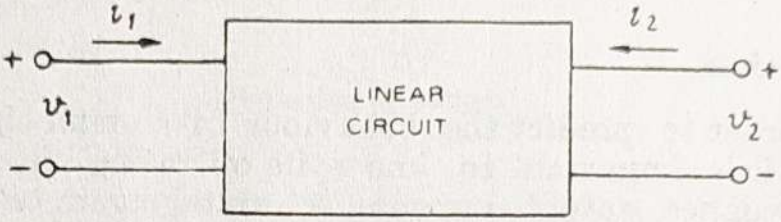

Fig. 26·1

It can be proved by advanced circuit theory that voltages and currents in Fig. 26·1 can be related by the following sets of equations :

$$v_1 = h_{11}\, i_1 + h_{12}\, v_2 \qquad \ldots(i)$$

$$i_2 = h_{21}\, i_1 + h_{22} v_2 \qquad \ldots(ii)$$

In these equations, the *hs* are fixed constants for a given circuit and are called *h* parameters. Once these parameters are known, we can use equations (*i*) and (*ii*) to find the voltages and and currents in the circuit. If we look at eq. (*i*), it is clear that ***h_{11} has the dimension of ohm and h_{12} is dimensionless. Similarly. from eq. (*ii*), h_{21} is dimensionless and h_{22} has the dimension of mho. The following points may be noted about *h* parameters :

(*i*) Every linear circuit has four *h* parmeters ; one having dimension of ohm, one having dimension of mho and two dimensionless.

(*iii*) The *h* parameters of a given circuit are constant. If we change the circuit, *h* parameters would also change.

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*A linear circuit is one in which resistances, inductances and capacitances remain fixed when voltage across them changes.

**A parameter of a circuit is a constant that enters into a functional equation and corresponds to some characteristic of the circuit such as resisance, capacitance, inductance *etc*.

***The two parts on the R.H.S. of eq. (*i*) must have the unit of voltage. Since current (amperes) must be multiplied by resistance (ohms) to get voltage (volts), h_{11} should have the dimension of resistance *i.e.* ohms.

(*iii*) Suppose that in a particular linear circuit, voltages and currents are related as under :

$$v_1 = 10 i_1 + 6 v_2$$
$$i_2 = 4 i_1 + 3 v_2$$

Here we can say that the circuit has h parameters given by $h_{11} = 10\ \Omega$; $h_{12} = 6$; $h_{21} = 4$ and $h_{22} = 3\ \mho$.

26·2. Determination of h parameters

The major reason for the use of h parameters is the relative ease with which they can be measured. The h parameters of a circuit shown in Fig. 26·1 can be found out as under :

(*i*) If we short-circuit the output terminals (see Fig. 26·2), we can say that output voltage $v_2 = 0$. Putting $v_2 = 0$ in equations (*i*) and (*ii*), we get,

$$v_1 = h_{11} i_1 + h_{12} \times 0$$
$$i_2 = h_{21} i_1 + h_{22} \times 0$$

$$\therefore \qquad h_{11} = \frac{v_1}{i_1} \qquad \text{for } v_2 = 0 \text{ i.e., output shorted}$$

and

$$h_{21} = \frac{i_2}{i_1} \qquad \text{for } v_2 = 0 \text{ i.e., output shorted}$$

Let us now turn to the physical meaning of h_{11} and h_{21}. Since h_{11} is a ratio of voltage and current (*i.e.* v_1/i_1), it is an impedance and is called *"*input impedance with output shorted*". Similarly, h_{21} is the ratio of output and input current (*i.e.*, i_2/i_1), it will be dimensionless and is called "*current gain with output shorted*":

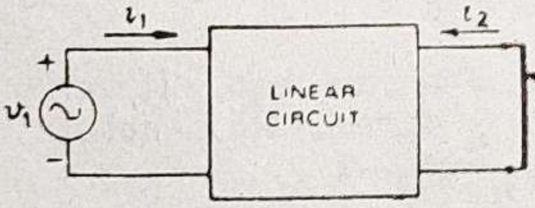


Fig. 26·2

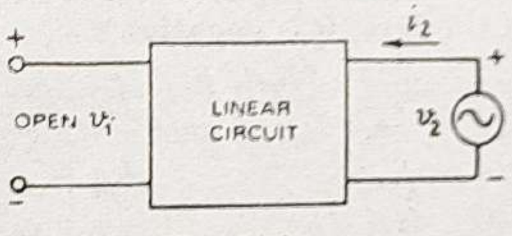


Fig. 26·3

(*ii*) The other two h parameters (*viz* h_{21} and h_{22}) can be found by making $i_1 = 0$. This can be done by the arrangement shown in Fig. 26·3. Here, we drive the output terminals with voltage v_2, keeping the input terminals open. With this set up, $i_1 = 0$ and the equations become :

$$v_1 = h_{11} \times 0 + h_{12} v_2$$
$$i_2 = h_{21} \times 0 + h_{22} v_2$$

$$\therefore \qquad h_{12} = \frac{v_1}{v_2} \qquad \text{for } i_1 = 0 \text{ i.e. input open}$$

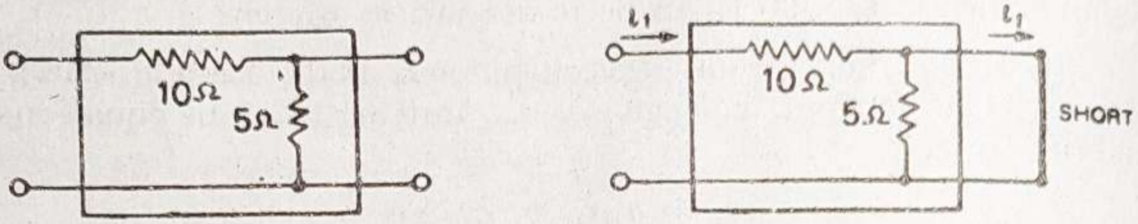
---

*Note that v_1 is the input voltage and i_1 is the input current. Hence v_1/i_1 is given the name input impedance.

and $$h_{22} = \frac{i_2}{v_2} \quad \text{for } i_1 = 0 \text{ i.e. input open}$$

Since h_{12} is a ratio of input and output voltages (*i.e.* v_1/v_2), it is dimensionless and is called *"voltage feedback ratio with input terminals open"*. Similarly, h_{22} is a ratio of output current and output voltage (*i.e.* i_2/v_2), it will be admittance and is called *output admittance with input terminals open.*

Example 26·1. *Find the h parameters of the circuit shown in Fig. 26·4 (i).*



(i) (ii)

Fig. 26·4

Solution. The h parameters of the circuit shown in Fig. 26·4(*i*) can be found as under :

(*i*) To find h_{11} and h_{21}, short-circuit the output terminals as shown in Fig. 26·4 (*ii*). It is clear that input impedance of the circuit is 10Ω because 5Ω resistance is shorted out.

$$\therefore \qquad h_{11} = \mathbf{10\ \Omega}$$

Now current i_1 flowing into the box will flow through 10Ω resistor and then through the shorted path as shown. It may be noted that in our discussion i_2 is the output current flowing into the box. Since output current in Fig. 26·4 (*ii*) is actually flowing out of the box, i_2 is negative *i.e.*,

$$i_2 = -i_1$$

$$\therefore \qquad h_{21} = \frac{i_2}{i_1} = \frac{-i_1}{i_1} = \mathbf{-1}$$

(*ii*) To find h_{12} and h_{22}, make the arrangement as shown in Fig. 26·4 (*iii*). Here we are driving the output terminals with a voltage v_2. This sets up a current i_2. Note that input terminals are open. Under this condition, there will be no current in 10 Ω resistor and therefore there can be no voltage drop across it. Consequently, all the voltage appears across input terminals *i.e.*

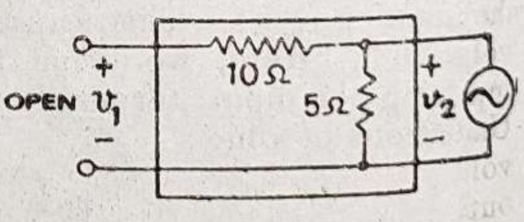


Fig. 26·4. (*iii*)

$$v_1 = v_2$$

$$\therefore \qquad h_{12} = \frac{v_1}{v_2} = \frac{v_2}{v_2} = \mathbf{1}.$$

Now the output impedance looking into the output terminals with input terminals open is simply 5Ω. Then h_{22} will be the reciprocal of it because h_{22} is the output admittance with input terminals open.

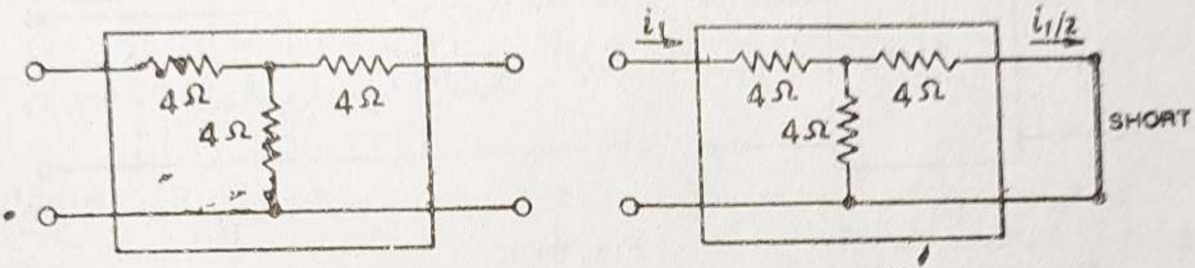
$$\therefore \qquad h_{22} = 1/5 = 0{\cdot}2 \ \mho$$

The h parameters of the circuit are :

$$h_{11} = 10\ \Omega \ ; \ h_{21} = -1$$
$$h_{12} = 1 \ ; \qquad h_{22} = 0{\cdot}2\ \mho$$

It may be mentioned here that in practice, dimensions are not written with h parameters. It is because it is understood that h_{11} is always in ohms, h_{12} and h_{21} are dimensionless and h_{22} is in mhos.

Example 26·2. *Find the h parameters of the circuit shown in Fig. 26·5 (i).*



(i) (ii)

Fig. 26·5

Solution.

(*i*) First of all imagine that output terminals are short-circuited as shown in Fig. 25·6 (*ii*). The input impedance under this condition is the parameter h_{11}.

Obviously, $$h_{11} = 4 + 4 \parallel 4$$
$$= 4 + \frac{4 \times 4}{4+4} = 6\Omega$$

Now the input current i_1 in Fig. 26·5 (*ii*) will divide equally at the junction of 4Ω resistors so that output current is $i_1/2$ *i.e.*

$$i_2 = -i_1/2 = -0{\cdot}5\ i_1$$

$$\therefore \qquad h_{21} = \frac{i_2}{i_1} = \frac{-0{\cdot}5\ i_1}{i_1} = -0{\cdot}5$$

(*ii*) In order to find h_{12} and h_{22}, imagine the arrangement as shown in Fig. 26·5(*iii*). Here we are driving the output terminals with voltage v_2, keeping the input terminals open. Under this condition, any voltage v_2 applied to the output will divide by a factor 2 *i.e.*

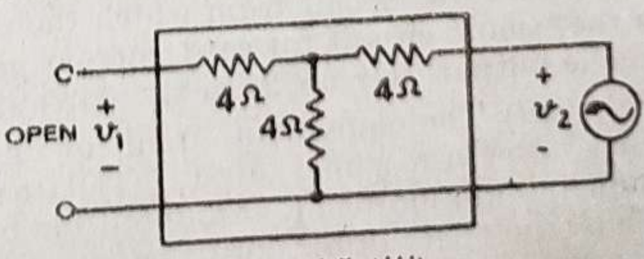


Fig. 26·5 (*iii*)

$$v_1 = \frac{v_2}{2} = 0{\cdot}5\ v_2$$

$$\therefore \qquad h_{12} = \frac{v_1}{v_2} = \frac{0{\cdot}5\ v_2}{v_2} = 0{\cdot}5$$

Now the output impedance looking into the output terminals

15·1 Feedback

The process of injecting a fraction of output energy of some device back to the input is known as **feedback**.

The principle of feedback is probably as old as the invention of first machine but it is only some 30 years ago that feedback has come into use in connection with electronic circuits. It has been found very useful in reducing noise in amplifiers and making amplifier operation stable. Depending upon whether the feedback energy aids or opposes the input signal, there are two basic types of feedback in amplifiers *viz positive feedback* and *negative feedback*.

(*i*) **Positive feedback**. When the feedback energy (voltage or current) is in phase with the input signal and thus aids it, it is called *positive feedback*. Positive feedback increases the gain of amplifier. However, it has the disadvantage of increased distortion and instability. Therefore, positive feedback is seldom employed in

Introduction

Many electronic devices require a source of energy at a specific frequency which may range from a few Hz to several MHz. This is achieved by an electronic device called an *oscillator*. Oscillators are extensively used in electronic equipment. For example, in radio and television receivers, oscillators are used to generate high frequency wave (called *carrier wave*) in the tuning stages. Audio-frequency and radio-frequency signals are required for the repair of radio, television and other electronic equipment. Oscillators are also widely used in radar, electronic computers and other electronic devices.

Oscillators can produce sinusoidal or non-sinusoidal (*e.g.* square wave) waves. In this chapter, we shall confine our attention to sinusoidal oscillators *i.e.* those which produce sine-wave signals.

16·1 Sinusoidal oscillator

An electronic device that generates sinusoidal oscillations of desired frequency is known as a **sinusoidal oscillator**.

Although we speak of an oscillator as "generating" a frequency, it should be noted that it does not create energy, but merely acts as an energy converter. It receives d.c. energy and changes it into a.c. energy of desired frequency. The frequency of oscillations depends upon the constants of the device.

It may be mentioned here that although an alternator produces sinusoidal oscillations of 50 Hz, it cannot be called an oscillator. Firstly, an alternator is a mechanical device having rotating parts whereas an oscillator is a non-rotating electronic device. Secondly, an alternator converts mechanical energy into a.c. energy while an oscillator converts d.c. energy into a.c. energy. Thirdly, an alternator cannot produce high frequency oscillations whereas an oscillator can produce oscillations ranging from a few *Hz* to several *MHz*.

Advantages

Although oscillations can be produced by mechanical devices (*e.g.* alternators), but electronic oscillators have the following advantages :

(*i*) An oscillator is a non-rotating device. Consequently, there is little wear and tear and hence longer life.

(*ii*) Due to the absence of moving parts, the operation of an oscillator is quite silent.

(*iii*) An ocillator can produce from small (20 Hz) to extremely high frequencies (> 100 MHz).

(*iv*) The frequency of oscillations can be easily changed when desired.

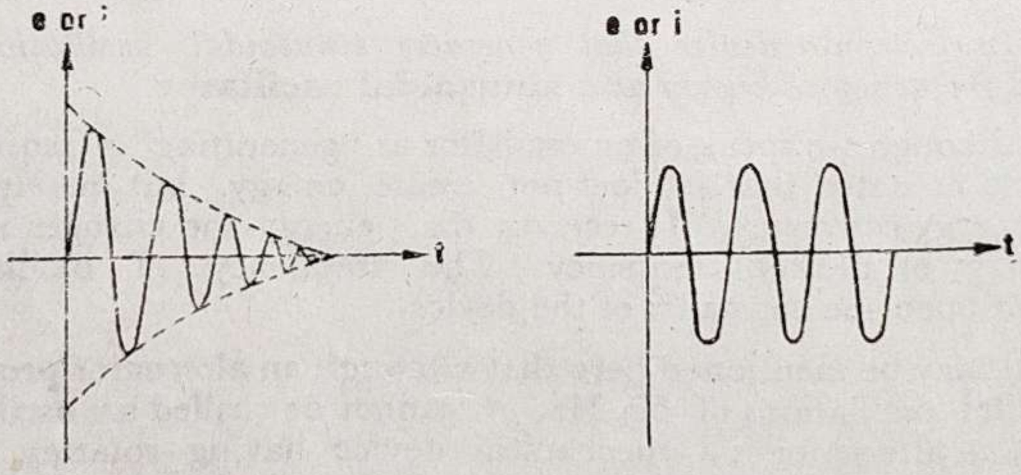
(*v*) It has good frequency stability *i.e.* frequency once set remains constant for a considerable period of time.

(*vi*) It has very high efficiency.

16·2 Types of sinusoidal oscillations

Sinusoidal electrical oscillations can be of two type *viz damped oscillations* and *undamped oscillations*.

(*i*) *Damped oscillations*. The electrical oscillations whose amplitude goes on decreasing with time are called *damped oscillations*. Fig. 16·1 (*i*) shows wave form of damped electrical oscillations. Obviously, the electrical system in which these oscillations are generated has losses and some energy is lost during each oscillation. Further, no means are provided to compensate for the losses and consequently the amplitude of the generated wave decreases gradually. It may be noted that frequency of oscillations remains unchanged since it depends upon the constants of the electrical system.



Damped oscillations
(*i*)

Undamped oscillations
(*ii*)

Fig. 16·1

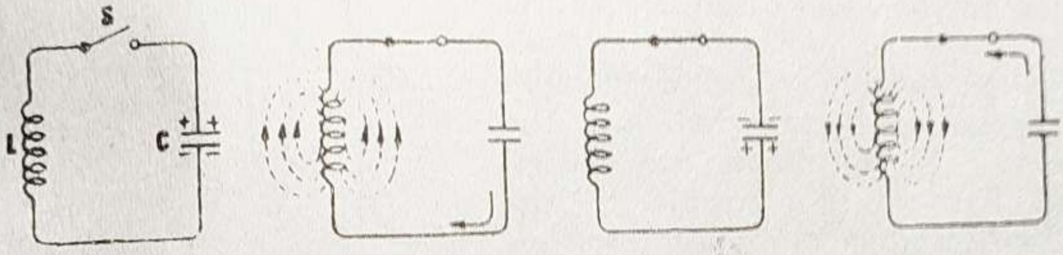
(*ii*) *Undamped oscillations*. The electrical oscillations whose amplitude remains constant with time are called *undamped oscillations*. Fig. 16·1 (*ii*) shows wave form of undamped electrical oscillations. Although the electrical system in which these oscillations are being generated has also losses, but now right amount of energy is being supplied to overcome the losses. Consequently, the amplitude of the generated wave remains constant. It should be emphasised that an oscillator is required to produce undamped electrical oscillations for utilising in various electronics equipment.

16·3. Oscillatory circuit

A circuit which produces electrical oscillations of any desired frequency is known as an **ocillatory circuit** *or* **tank circuit**.

A simple oscillatory circuit consists of a capacitor (C) and inductance coil (L) in parallel as shown in Fig. 16·2. This electrical system can produce electrical oscillations of frequency determined by the values of L and C. To understand how this comes about, suppose the capacitor is charged from a d.c. source with a polarity as shown in Fig. 16·2 (*i*).

(*i*) In the position shown in Fig. 16·2 (*i*), the upper plate of capacitor has defecit of electrons and the lower plate has excess of electrons. Therefore, there is a voltage across the capacitor and the capacitor has electro-static energy.



(*i*) (*ii*) (*iii*) (*iv*)

Fig. 16·2

(*ii*) When switch S is closed as shown in Fig. 16·2 (*ii*), the capacitor will discharge through inductance and the electron flow will be in the direction indicated by the arrow. This current flow sets up magnetic field around the coil. Due to the inductive effect, the current builds up slowly towards a maximum value. The circuit current will be maximum when the capacitor is fully discharged. At this instant, electrostatic energy is zero but because electron motion is greatest (*i.e.* maximum current), the magnetic field energy around the coil is maximum. This is shown in Fig. 16·2 (*ii*). Obviously, the electro-static energy across the capacitor is completely converted into magnetic field energy around the coil.

(*iii*) Once the capacitor is discharged, the magnetic field will begin to collapse and produce a counter e.m.f. According to Lenz's law, the counter e.m.f. will keep the current flowing in the same direction. The result is that the capacitor is now charged with opposite polarity, making upper plate of capacitor negative and lower plate positive as shown in Fig. 16·2 (*iii*).

(*iv*) After the collapsing field has recharged the capacitor, the capacitor now begins to discharge current flowing in the opposite direction. Fig. 16·2 (*iv*) shows capacitor fully charged and maximum current flowing.

The sequence of charge and discharge results in alternating motion of electrons or an oscillating current. The energy is alternately stored in the electric field of the capacitor (C) and the magnetic field of the inductance coil (L). This intercharge of energy between L and C is repeated over and again resulting in the production of oscillations.

Wave form. If there were no losses in the tank circuit to consume the energy, the interchange of energy between L and C would continue indefinitely. In a practical tank circuit, there are resistive and radiation losses in the coil and dielectric losses in the capacitor. During each cycle, a small part of the originally imparted energy is used up to overcome these losses. The result is that the amplitude of oscillating current decreases gradually and eventually it becomes zero when all the energy is consumed as losses. Therefore, the tank circuit by itself will produce *damped oscillations* as shown in Fig. 16·3.

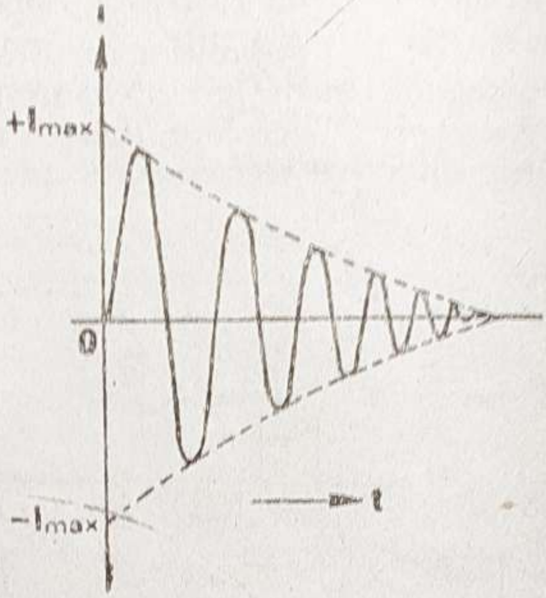


Fig. 16·3

Frequency of oscillations. The frequency of oscillations in the tank circuit is determined by the constants of the circuit *viz* L and C. The actual frequency of oscillations is the resonant frequency (or natural frequency) of the tank circuit given by ;

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

It is clear that frequency of oscillations in the tank circuit is inversely proportional to L and C. This can be easily explained. If a large value of capacitor is used, it will take longer for the capacitor to charge fully, and also longer to discharge. This will lengthen the period of oscillations in the tank circuit, or equivalently, lower its frequency. With a large value of inductance, the opposition to change in current flow is greater and hence the time required to complete each cycle will be longer. Therefore, the greater the value of inductance, the longer is the period, or the lower is the frequency of oscillations in the tank circuit.

16·4 Undamped oscillations from tank circuit

As discussed before, a tank circuit produces damped oscillations. However, in practice, we need continuous undamped oscillations for the successful operation of electronics equipment. In order to make the oscillations in the tank circuit undamped, it is necessary to supply correct amount of energy to the tank circuit at the proper time intervals to meet the losses. Thus referring back to Fig. 16·2, any energy which would be applied to the circuit must have a polarity conforming to the existing polarity at the instant of application of energy. If the applied energy is of opposite polarity, it would oppose the energy in the tank circuit, causing stoppage of oscillations. Therefore, in order to make the oscillations in the tank circuit undamped, the following conditions must be fulfilled :

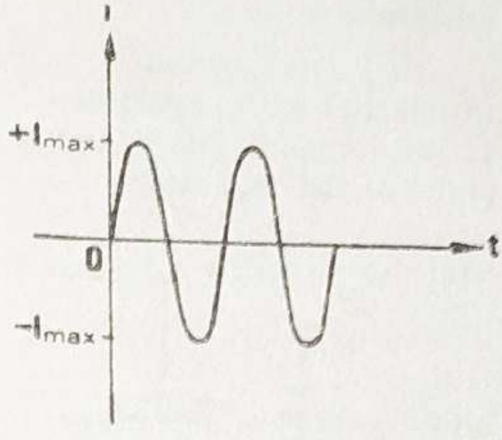


Fig. 16·4

(*i*) The amount of energy supplied should be such so as to meet the losses in the tank circuit and the a.c. energy removed from the circuit by the load. For instance, if losses in LC circuit amount to $5 mW$ and a.c. output being taken is 100 mW, then power of 105 mW should be continuously supplied to the circuit.

(*ii*) The applied energy should have the same frequency as that of the oscillations in the tank circuit.

(*iii*) The applied energy should be in phase with the oscillations set up in the tank circuit *i.e.* it should aid the tank circuit oscillations.

If these conditions are fulfilled, the circuit will produce continuous undamped output as shown in Fig. 16·4.

16·5 Transistor oscillator

In order to obtain continuous undamped a.c. output from the tank circuit, it is necessary to supply the correct amount of power to the circuit. The most practical way to do this is to supply d.c. power to some device which should convert it to necessary a.c. power for supply to the tank circuit. This can be achieved by employing a transistor circuit. Because of its ability to amplify, a transistor is very efficient energy converter *i.e.* it converts d.c. power to a.c. power. If the damped oscillations in the tank circuit are applied to base of transistor, it will result in an amplified reproduction of oscillations in the collector circuit. Because of this amplification, more energy is available in the collector circuit than in the base circuit. If a part of this collector-circuit energy is feed back by some means to the base circuit in proper phase to aid the oscillations in the tank circuit, then its losses will be overcome and continuous undamped oscillations will occur.

16·6 Essentials of transistor oscillator

Fig. 16·5 shows the block diagram of an oscillator. Its essential components are :

(*i*) *Tank circuit.* It consists of inductance coil (L) connected in parallel with capacitor (C). The frequency of oscillations in the circuit depends upon the values of inductance of the coil and capacitance of the capacitor :

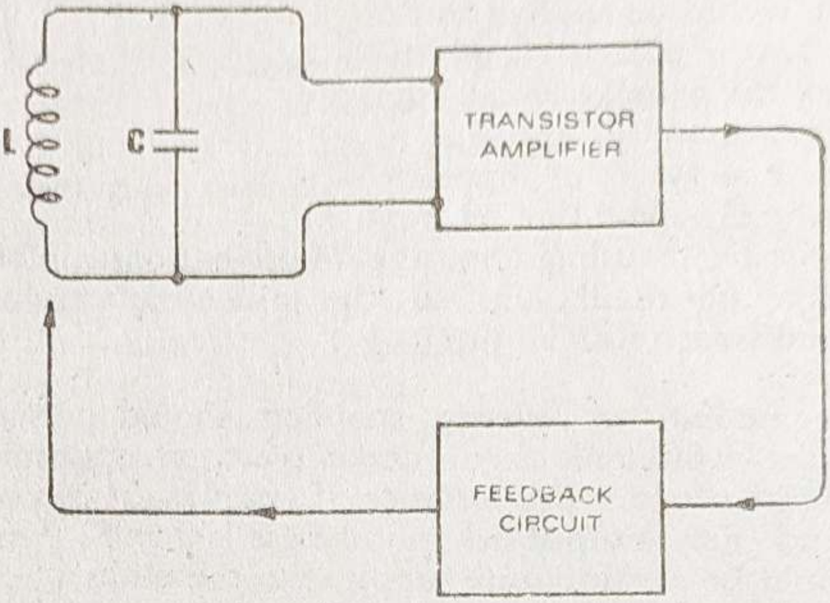


Fig. 16·5

(*ii*) *Transistor amplifier.* The transistor amplifier receives d.c. power from the battery and changes it into a.c. power for supplying to the tank circuit. The oscillations occuring in the tank circuit are applied to the input of the transistor amplifier. Because of the amplifying properties of the transistor, we get increased output of these oscillations.

This amplified output of oscillations is due to the d.c. power supplied by the battery. The output of the transistor can be supplied to the tank circuit to meet the losses.

(*iii*) *Feedback circuit.* The feedback circuit supplies a part of collector energy to the tank circuit in correct phase to aid the oscillations *i.e.* it provides positive feedback.

16·7 Different types of transistor oscillators

A transistor can work as an oscillator to produce continuous undamped oscillations of any desired frequency if tank and feedback circuits are properly connected to it. All oscillators under different names have similar function *i.e.* they produce continuous undamped output. However, the major difference between these oscillators lies in the method by which energy is supplied to the tank circuit to meet the losses.

16·9 Hartley oscillator

Hartley oscillator is very popular and is commonly used as a local oscillator in radio receivers. It has two main advantages *viz* adaptability to a wide range of frequencies and is easy to tune. Fig. 16·7 shows the circuit of Hartley oscillator. The tank circuit is made up of C_T, L_1 and L_2. The coil L_1 is inductively coupled to coil L_2, the combination functions as autotransformer. The resistance R_b between the collector and base provides the necessary biasing. The capacitor C blocks the d.c. component. The frequency of oscillations is determined by the values of L_1, L_2 and C_T and is

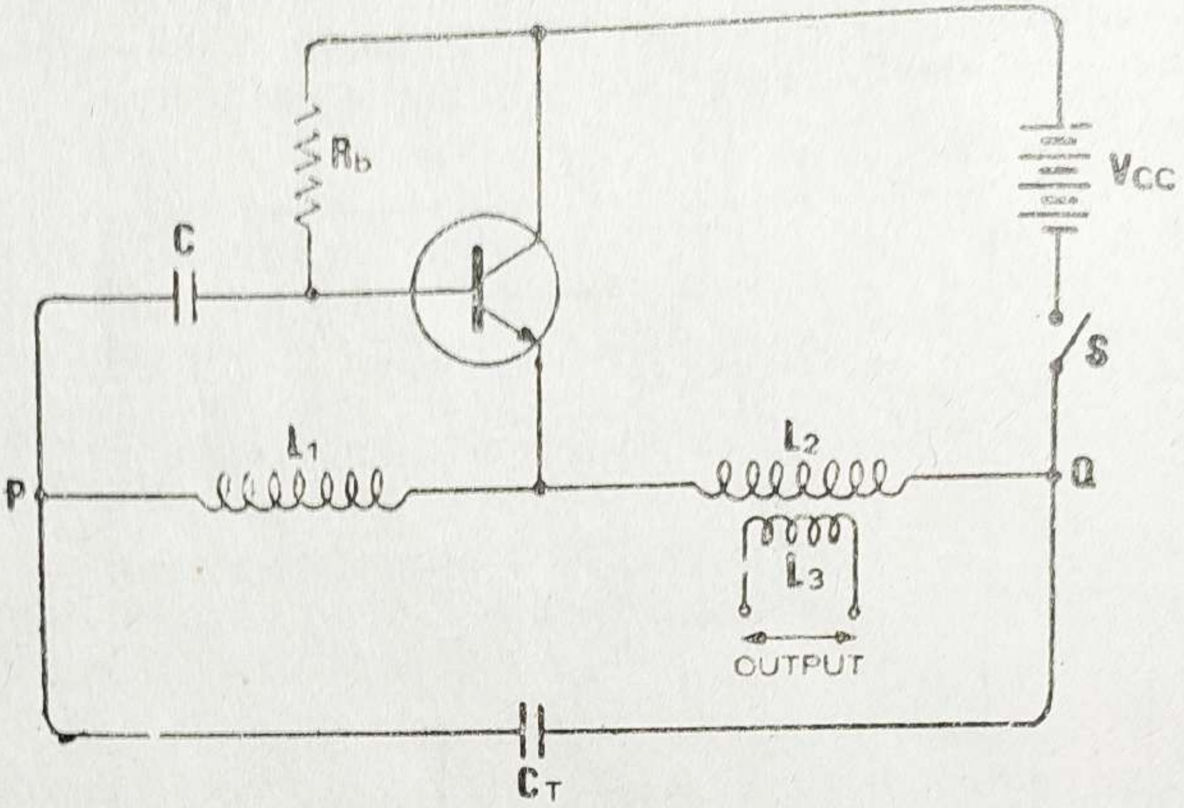


Fig. 16·7

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*All transformers introduce a phase shift of 180° between primary and secondary.

given by ;

$$f = \frac{1}{2\pi\sqrt{C_T(L_1+L_2)}} \qquad \text{...(}i\text{)}$$

Circuit operation. When switch S is closed, collector current starts rising and charges the capacitor C_T. When this capacitor is fully charged, it discharges through coils L_1 and L_2, setting up oscillations of frequency determined by exp. (*i*). The oscillations across L_1 are applied to the base-emitter junction and appear in the amplified form in the collector circuit. The coil L_2 couples the collector circuit energy back into the tank circuit by means of mutual inductance between L_1 and L_2. In this way, energy is being continuously supplied to the tank circuit to overcome the losses occurring in it. Consequently, continuous undamped output is obtained.

It may be seen that energy supplied to the tank circuit is of correct phase. The ends P and Q of the autotransformer $L_1 - L_2$ are 180° out of phase. A further of 180° is produced by base and collector ciruit of transistor. In this way, energy fedback to the tank circuit is in phase with the generated oscillations.

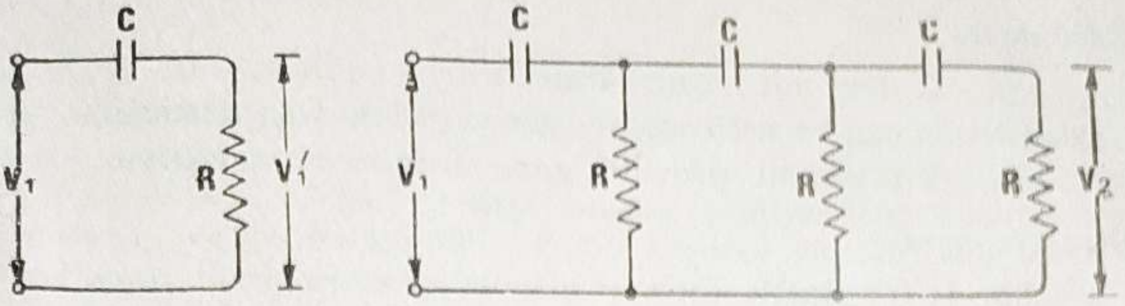
16·11 Principles of phase shift oscillators

One desirable feature of an oscillator is that it should feedback energy of correct phase to the tank circuit to overcome the losses occuring in it. In the oscillator circuit discussed so far, the tank circuit employed inductive (L) and capacitive (C) elements. In such circuits, a phase shift of 180° was obtained due to inductive or capacitive coupling and a further phase shift of 180° was obtained due to transistor properties. In this way, energy supplied to the tank circuit was in phase with the generated oscillations. The oscillator circuits employing L-C elements have two general drawbacks. Firstly, they suffer from frequency instability and poor wave form. Secondly, they cannot be used for very low frequencies, because they become too much bulky and expensive.

Good frequency stability and wave form can be obtained from oscillators employing resistive and capacitive elements Such amplifiers are called *R-C or phase shift oscillators* and have the additional advantage that they can be used for very low frequencies. In a phase shift oscillator, a phase shift of 180° is obtained with a phase shift circuit instead of inductive or capacitive coupling. A further phase shift of 180° is introduced due to the transistor properties. Thus, energy supplied back to the tank circuit is assured of correct phase.

Phase shift circuit. A phase-shift circuit essentially consists of an R-C network. Fig. 16·9 *i*) shows a single section of RC network. From the elementary theory of electrical engineering it can be shown that alternating voltage V'_1 across R leads the applied voltage V_1 by $\phi°$. The value of ϕ depends upon the values of R and C. If resistance R is varied, the value of ϕ also changes. If R were reduced to zero, V'_1 will lead V_1 by 90° *i.e.* $\phi = 90°$. However, adjusting R to zero would be impracticable because it would lead to no voltage across R. Therefore, in practice R is varied to such a value that makes V'_1 to lead V_1 by 60°.

Fig. 16·9 (*ii*) shows the three sections of RC network. Each section produces a phase shift of 60°. Consequently, a total phase shift of 180° is produced *i.e.* voltage V_2 leads the voltage V_1 by 180°.



(*i*) (*ii*)

Fig. 16·9

16·12 Phase shift oscillator

Fig. 16·10 shows the circuit of a phase shift oscillator. It consists of a conventional single transistor amplifier and a *RC* phase shift network. The phase shift network consists of three sections R_1C_1, R_2C_2, and R_3C_3. At some particular frequency f_0, the phase shift in each *RC* section is 60°, so that the total phase-shift produced by the *RC* network is 180°. The fr quency of oscillations is given by ;

$$f_0 = \frac{1}{2\pi RC\sqrt{6}} \qquad \ldots(i)$$

where
$$R_1 = R_2 = R_3 = R,$$
$$C_1 = C_2 = C_3 = C$$

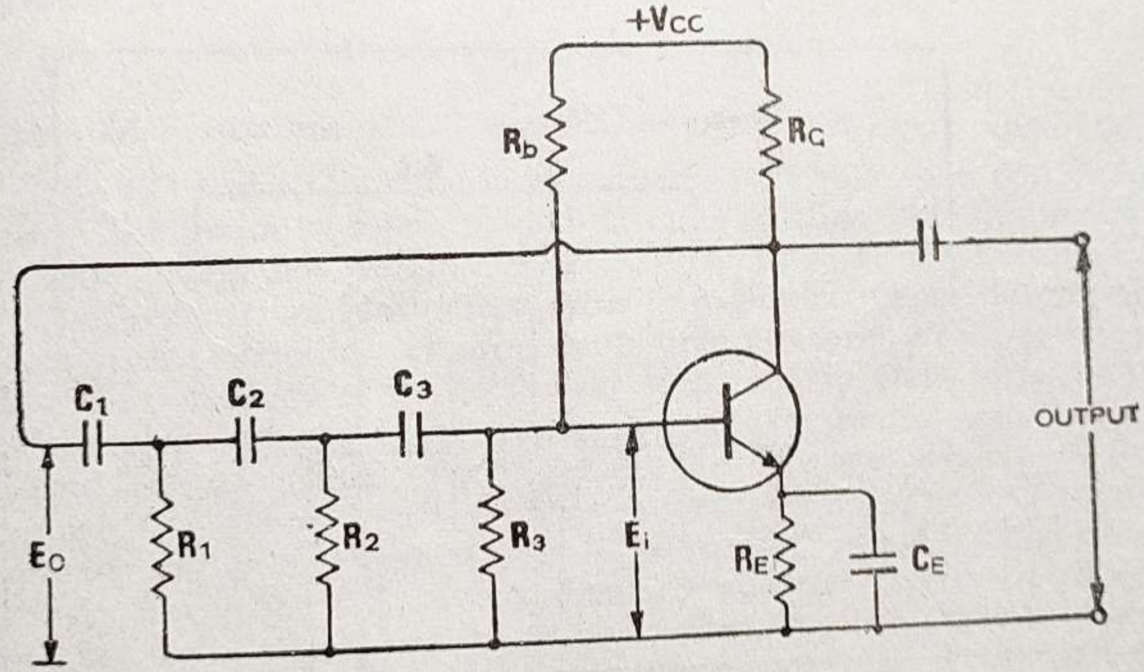


Fig. 16·10

Circuit operation. When the circuit is switched on, it produces oscillations of frequency determined by exp. (*i*). The output E_0 of the amplifier is fedback to *RC* feedback network. This network produces a phase shift of 180° and a voltage E_i appears at its output which is applied to the transistor amplifier.

Obviously, the feedback fraction $m = E_i/E_0$. The feedback phase is correct. A phase shift of 180° is produced by the transistor amplifier. A further phase shift 180° is produced by the *RC* network. As a result, the phase shift around the entire loop is 360°.

Advantages

(*i*) It does not require transformers or inductors.
(*ii*) It can be used to produce very low frequencies.
(*iii* The circuit provides good frequency stability.

Disadvantages

(*i*) It is difficult for the circuit to start oscillations as the feedback is generally small.

(*ii*) The circuit gives small output.

20·6. Multivibrators

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

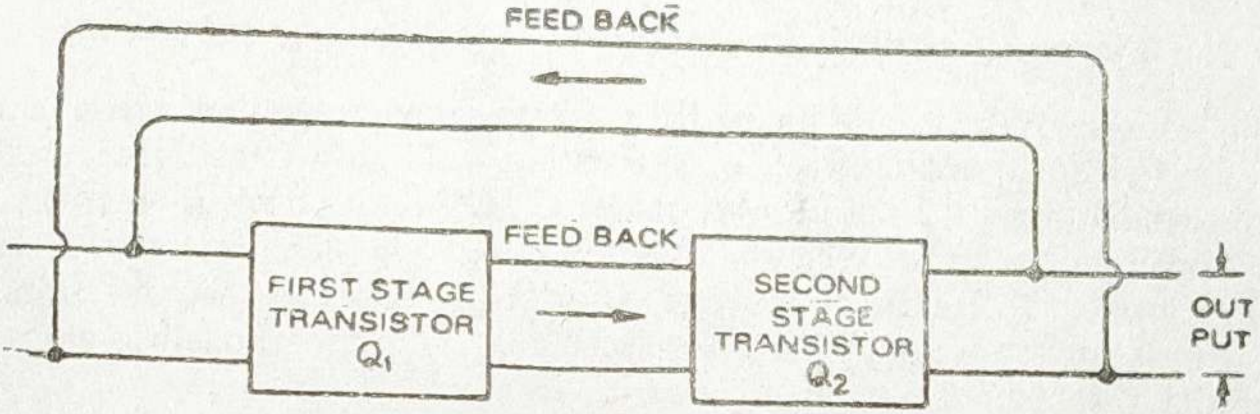


Fig. 20·6.

A multivibrator is a switching circuit which depends for operation on positive feedback. It is basically a two-stage amplifier with output of one fed back to the input of the other as shown in fig. 20·6.

The circuit operates in two states (*viz. ON* and *OFF*) controlled by circuit conditions. Each amplifier stage supplies feed back 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).

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*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.

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 a rectangular or square wave depending upon the circuit conditions.

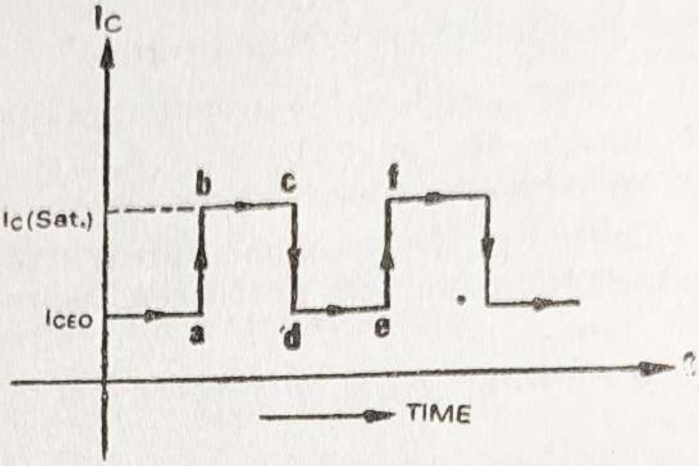

Fig. 20·7.

Fig. 20·6 shows the block dragram 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_{Csat} while the other is OFF. Suppose Q_2 is ON and Q_1 is OFF. The collector current in Q_2 will be I_{Csat} as shown in fig. 20·7. 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.

20·7. Types of multivibrators

A multivibrator is basically a two-stage amplifier with output of one fed back 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.

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.

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.

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 because of the two possible states it can assume.

20·8 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 of its own. The width of the square wave and its frequency will depend upon the circuit constants.

Circuit details. Fig. 20·8 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 feed back 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

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

This establishes a reverse 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. 20·9.

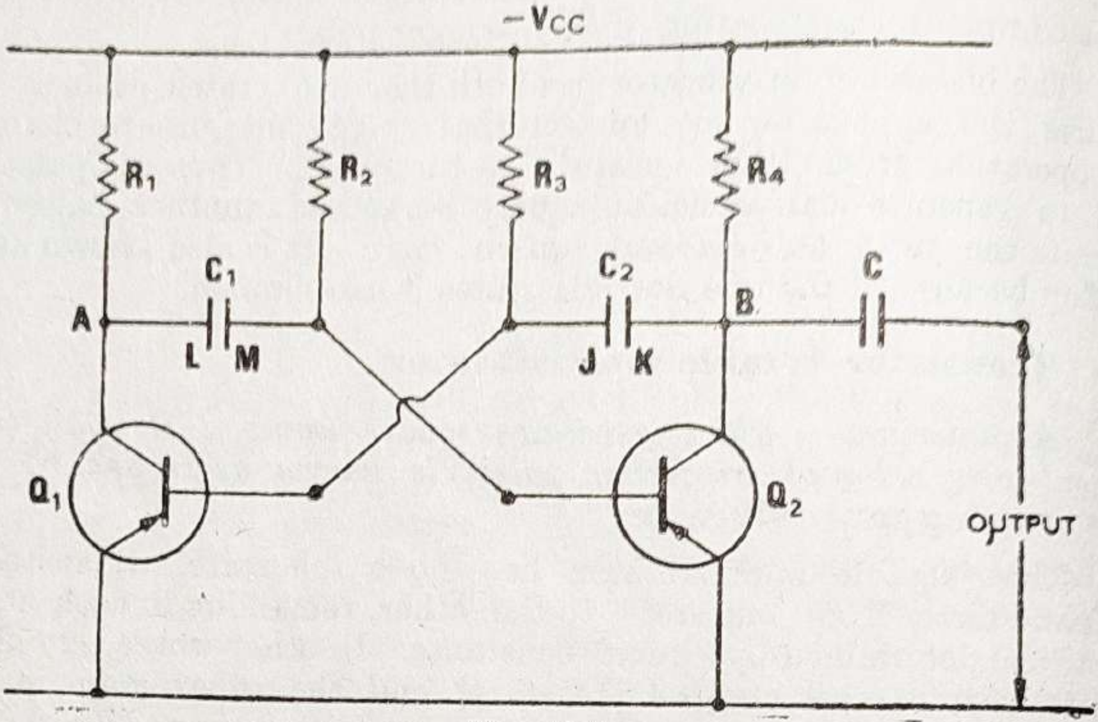


Fig. 20·8.

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

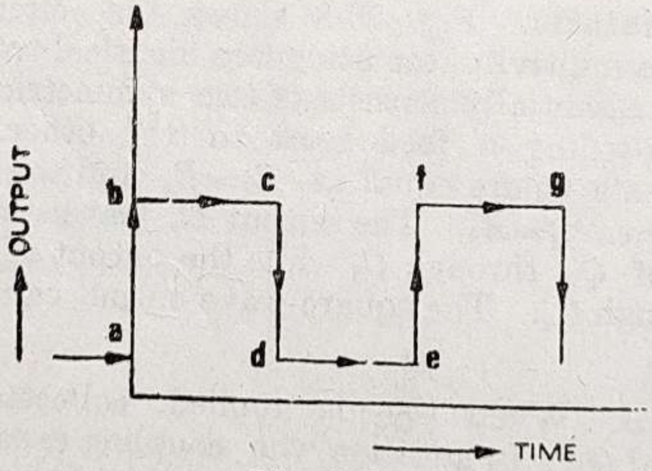
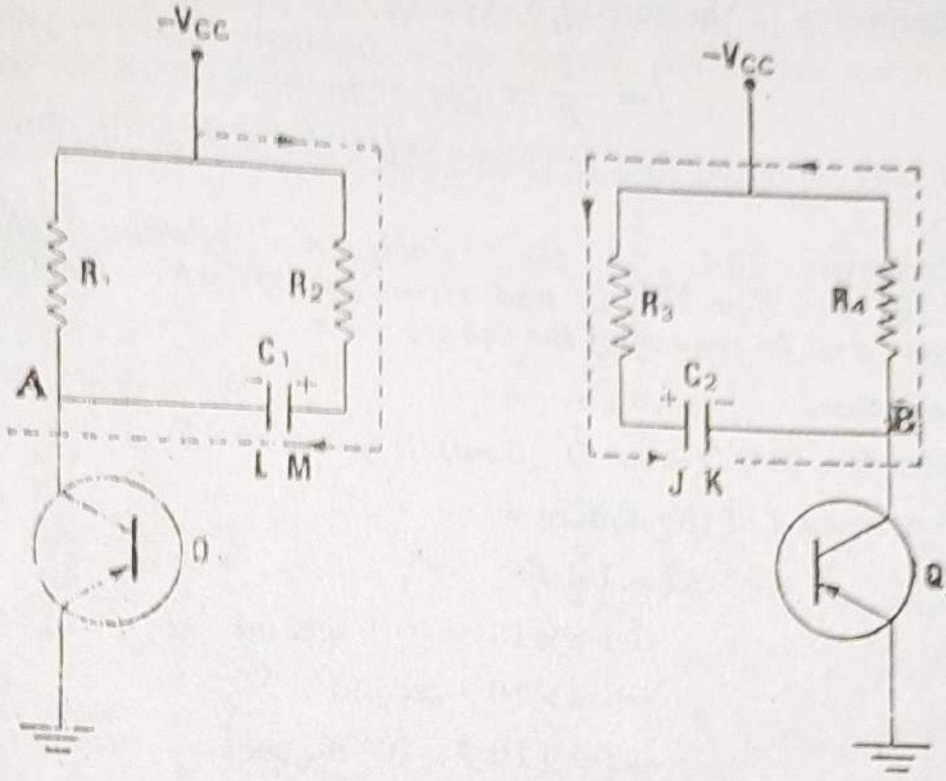


Fig. 20·9.

epresented by time interval *bc* in Fig. 20·9. However, the capacitors vill 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_1 V_{CC} R_2M as shown in Fig. 20·10 (*i*).

The discharge path for C_2, with plate K negative and Q_2 cut off, is KBR_4R_3J as shown in Fig. 20·10 (*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.



(*i*) (*ii*)

Fig. 20·10.

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. 20·9. 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.

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)

$$T_1 = 0{\cdot}694\ R_2C_1$$

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

$$T_2 = 0{\cdot}694\ R_3C_2$$

Total time period of the square wave

$$T = T_1 + T_2$$
$$= 0{\cdot}694\ (R_2C_1 + R_3C_2)$$

As $R_1 = R_2 = R$ and $C_1 = C_2 = C$,

$$\therefore \quad T = 0{\cdot}694\ (RC + RC)$$

$$\simeq 1{\cdot}4\ RC \text{ seconds}$$

Frequency of the square wave,

$$f = \frac{1}{T} \simeq \frac{0{\cdot}7}{RC}\ Hz$$

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

Example 20·1. *In the astable multivibrator, shown in Fig. 20·10, $R_2 = R_3 = 10\ k\,\Omega$ and $C_1 = C_2 = 0{\cdot}01\ \mu F$. Determine the time period and frequency of the square wave.*

Solution

Here $R = 10\ \text{k}\,\Omega = 10^4\ \Omega$; $C = 0{\cdot}01\ \mu F = 10^{-8} F$

Time period of the square wave

$$T = 1{\cdot}4\ RC$$

$$= 1{\cdot}4 \times 10^4 \times 10^{-8} \text{ second}$$

$$= 1{\cdot}4 \times 10^{-4} \text{ second}$$

$$= 1{\cdot}4 \times 10^{-4} \times 10^3 \text{ m. sec.}$$

$$= \mathbf{0{\cdot}14\ m\ sec} \qquad (Ans.)$$

Frequency of the square wave

$$f = \frac{1}{T \text{ in second}}\ Hz$$

$$= \frac{1}{1{\cdot}4 \times 10^{-4}}\ Hz$$

$$= \mathbf{7 \times 10^3}\ Hz$$

$$= \mathbf{7\ KHz} \qquad (Ans.)$$

20·9 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.

***Mono means single.**

Circuit details. Fig. 20·11 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.

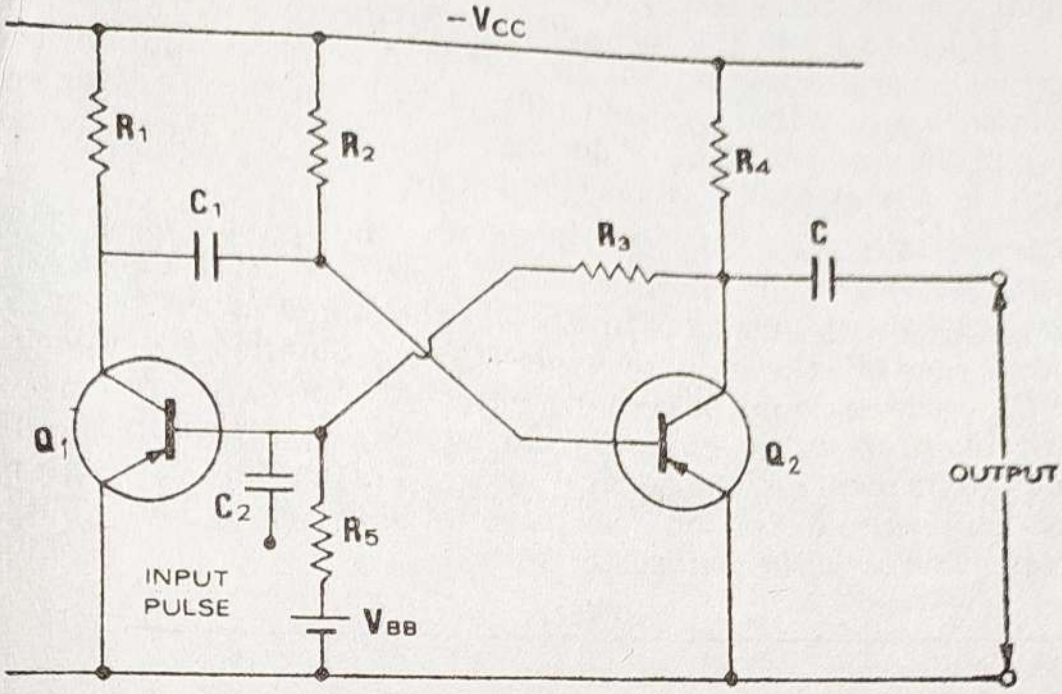


Fig. 20·11.

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.

With Q_1 at saturation and Q_2 at cut off, the circuit will come back to the original state (*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 remains in this condition until another pul be causes the circuit to switch over the states.

20·10 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 for ever. 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. 20·12 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 transistors.

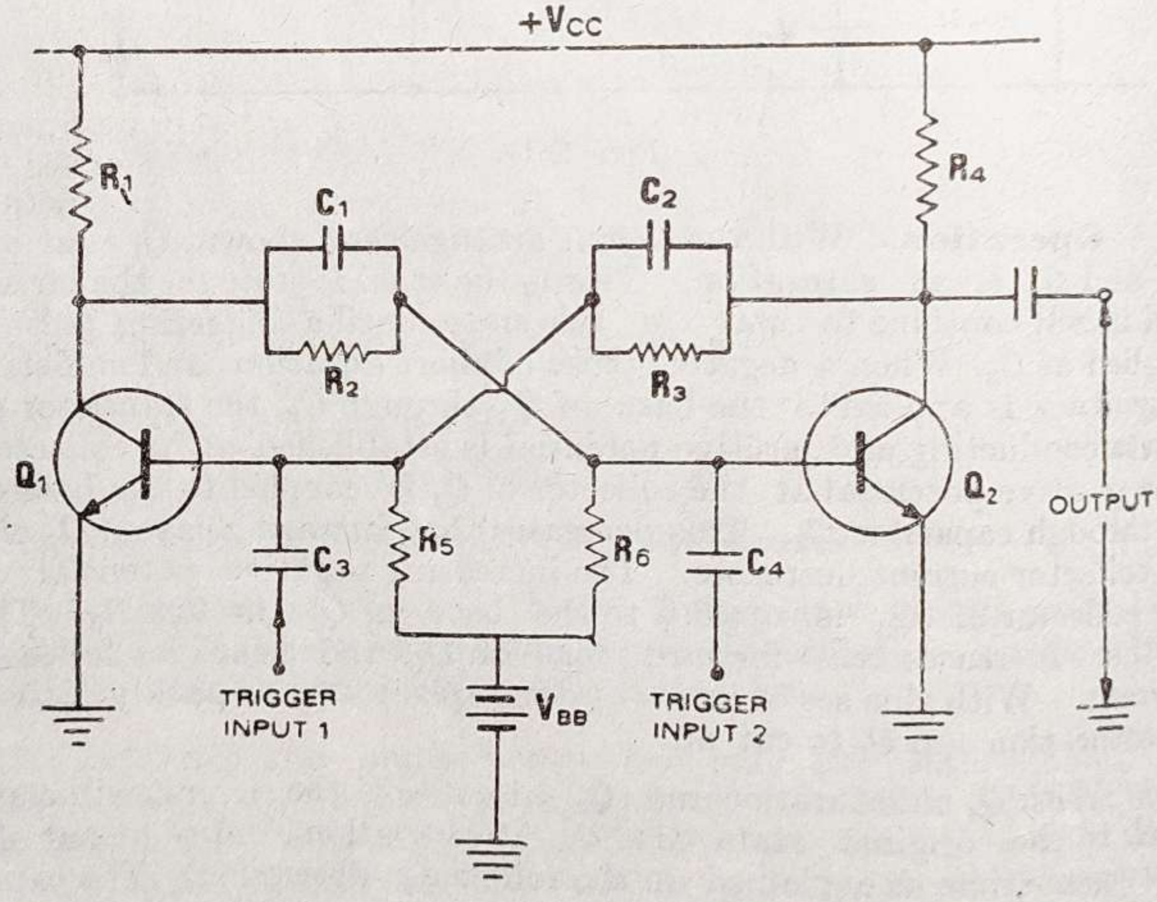


Fig. 20·12

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. *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.