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CHAPTER 65

SINUSOIDAL AND NON-SINUSOIDAL OSCILLATORS

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- Classification of Oscillators
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An oscillator is an electronic device used for the purpose of generating a signal. Oscillators are found in computers, wireless receivers and transmitters, and audiofrequency equipment particularly music synthesizers

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65.1. What is an Oscillator ?

An electronic oscillator may be defined in any one of the following four ways :

1. It is a circuit which converts dc energy into ac energy at a very high frequency;
2. It is an electronic source of alternating current or voltage having sine, square or sawtooth or pulse shapes;
3. It is a circuit which generates an ac output signal without requiring any externally applied input signal;
4. It is an unstable amplifier.

Oscillator

These definitions exclude electromechanical alternators producing 50 Hz ac power or other devices which convert mechanical or heat energy into electric energy.

65.2. Comparison Between an Amplifier and an Oscillator

As discussed in Chapter-10, an amplifier produces an output signal whose waveform is similar to the input signal but whose power level is generally high. This additional power is supplied by

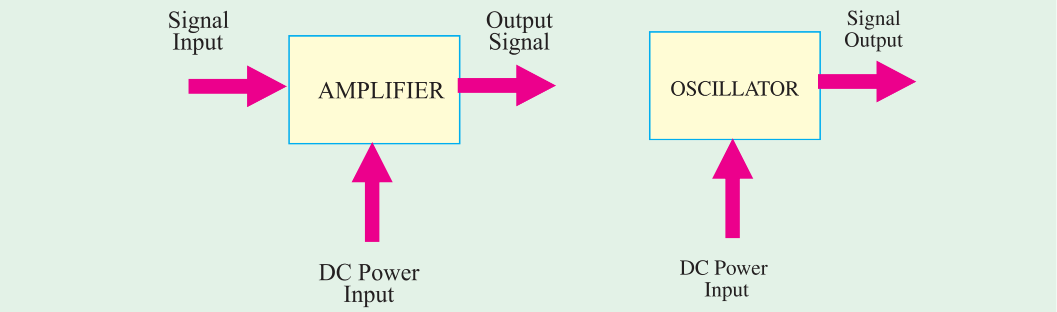


Fig. 65.1

the external dc source. Hence, an amplifier is essentially an energy convertor *i.e.* it takes energy from the dc power source and converts it into ac energy at signal frequency. The process of energy conversion is controlled by the input signal. If there is no input signal, there is no energy conversion and hence there is no output signal.

An oscillator differs from an amplifier in one basic aspect : the oscillator ***does not require an external signal*** either to start or maintain energy conversion process (Fig. 65.1). It keeps producing an output signal so long as the dc power source is connected.

Moreover, the frequency of the output signal is determined by the passive components used in the oscillator and can be varied at will.

65.3. Classification of Oscillators

Electronic oscillators may be broadly divided into following two groups :

(*i*) Sinusoidal (or harmonic) oscillators—which produce an output having sine waveform;
(*ii*) Non-sinusoidal (or relaxation) oscillators—they produce an output which has square, rectangular or sawtooth waveform or is of pulse shape.

Sinusoidal oscillators may be further subdivided into :

(*a*) Tuned-circuits or LC feedback oscillators such as Hartley, Colpitts and Clapp etc.;
(*b*) *RC* phase-shift oscillators such as Wien-bridge oscillator;
(*c*) Negative-resistance oscillators such as tunnel diode oscillator;
(*d*) Crystal oscillators such as Pierce oscillator;

(*e*) Heterodyne or beat-frequency oscillator (BFO).

The active devices (bipolars, FETs or unijunction transistors) in the above mentioned circuits may be biased class-A, B or C. Class-A operation is used in high-quality audio frequency oscillators. However, radio frequency oscillators are usually operated as class-C.

65.4. Damped and Undamped Oscillations

Sinusoidal oscillations produced by oscillators may be (*i*) damped or (*ii*) undamped.

(*i*) Damped Oscillations

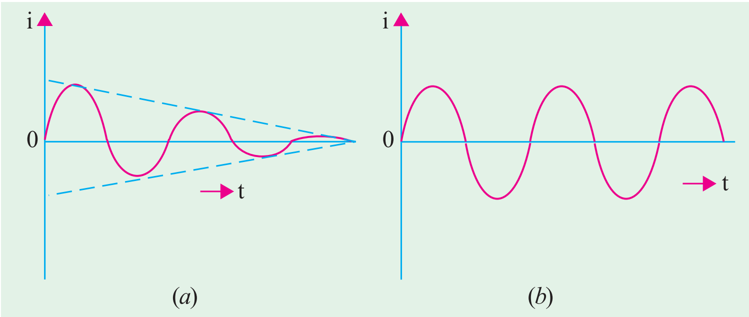


Fig. 65.2

Oscillations whose amplitude keeps decreasing (or decaying) with time are called **damped** or **decaying** oscillations. The waveform of such oscillations is shown in Fig. 65.2 (*a*). These are produced by those oscillator circuits in which I^2R losses take place continuously during each oscillation without any arrangement for compensating the same. Ultimately, the amplitude of the oscillations decays to zero when there is not enough energy to supply circuit losses. However, the frequency or time-period remains constant because ***it is determined by the circuit parameters.***

Sinusoidal oscillators serve a variety of functions in telecommunications and in electronics. The most important application in telecommunication is the use of sine waves as carrier signal in both radio and cable transmissions.

Sine wave signals are also used in frequency response testing of various types of systems and equipment including analogue communication channels, amplifiers and filters and closed-loop control systems.

(*ii*) Undamped Oscillations

Oscillations whose amplitude remains constant *i.e.* does not change with time are called undamped oscillations. These are produced by those oscillator circuits which have no losses or if they have, there is provision for compensating them. The constant-amplitude and constant-frequency sinusoidal waves shown in Fig. 65.2 (*b*) are called ***carrier waves*** and are used in communication transmitters for transmitting low-frequency audio information to far off places.

65.5. The Oscillatory Circuit

It is also called *LC* circuit or tank circuit. The oscillatory circuit (Fig. 65.3) consists of two reactive elements *i.e.* an inductor and a capacitor. Both are capable of storing energy. The capacitor stores energy in its electric field whenever there is potential difference across its plates. Similarly, a coil or an inductor stores energy in its magnetic field whenever current flows through it. Both *L* and *C* are supposed to be loss-free (*i.e.* their *Q*-factors are infinite).

As shown in Fig. 65.3 (*a*), suppose the capacitor has been fully-charged from a dc source. Since *S* is open, it cannot discharge through *L*. Now, let us see what happens when *S* is closed.

1. When *S* is closed [Fig. 65.3 (*b*)] ***electrons*** move from plate *A* to plate *B* through coil *L* as shown by the arrow (or conventional current flows from *B* to *A*). This electron flow reduces the strength of the electric field and hence the amount of energy stored in it.
2. As electronic current starts flowing, the self-induced emf in the coil opposes the current flow. Hence, rate of discharge of electrons is somewhat slowed down.
3. Due to the flow of current, magnetic field is set up which stores the energy given out by

the electric field [Fig. 65.3 (*b*)].

4. As plate *A* loses its electrons by discharge, the electron current has a tendency to die down and will actually reduce to zero when all excess electrons on *A* are driven over to plate *B* so that both plates are reduced to the same potential. At that time, there is no electric field but the magnetic field has maximum value.

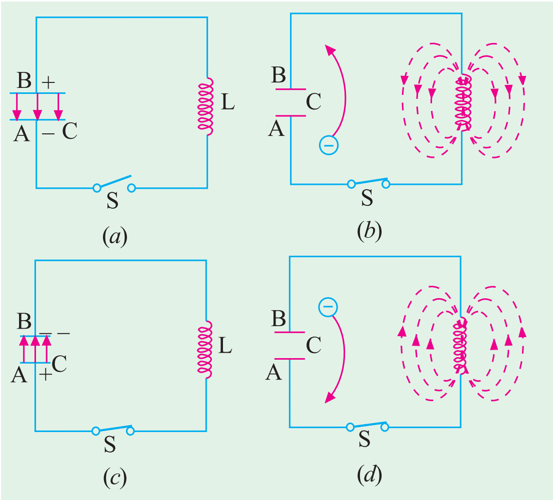


Fig. 65.3

5. However, due to self-induction (or electrical inertia) of the coil, more electrons are transferred to plate *B* than are necessary ***to make up the electron deficiency there.*** It means that now plate *B* has more electrons than *A*. Hence, capacitor becomes charged again though in opposite direction as shown in Fig. 65.3 (*c*).

6. The magnetic field *L* collapses and the energy given out by it is stored in the electric field of the capacitor.

7. After this, the capacitor starts discharging in the opposite direction so that, now, the electrons move from plate *B* to plate *A* [Fig. 65.3 (*d*)]. The electric field starts collapsing whereas magnetic field starts building up again though in the opposite direction. Fig. 65.3 (*d*) shows the condition when the capacitor becomes fully discharged once again.

8. However, these discharging electrons overshoot and again an excess amount of electrons flow to plate *A*, thereby charging the capacitor once more.

9. This sequence of charging and discharging continues. The to and fro motion of electrons between the two plates of the capacitor constitutes an oscillatory current.

It may be also noted that during this process, the electric energy of the capacitor is converted into magnetic energy of the coil and ***vice versa.***

These oscillations of the capacitor discharge are damped because energy is dissipated away gradually so that their amplitude becomes zero after sometime. There are two reasons for the loss of the energy :

(*a*) Some energy is lost in the form of heat produced in the resistance of the coil and connecting wires ;

(*b*) and some energy is lost ***in the form of electromagnetic (EM) waves*** that are radiated out from the circuit through which an oscillatory current is passing.

Both these losses subtract energy from the circuit with the result that circuit current decreases gradually till it becomes zero. The waveform of the oscillatory discharge is similar to that shown in Fig. 65.2 (*a*).

65.6. Frequency of Oscillatory Current

The frequency of time-period of the oscillatory current depends on two factors :

(*a*) Capacitance of the Capacitor

Larger the capacitor, greater the time required for the reversal of the discharge current *i.e.* lower its frequency.

(*b*) Self-inductance of the Coil

Larger the self-inductance, greater the internal effect and hence longer the time required by the current to stop flowing during discharge of the capacitor.

The frequency of this oscillatory discharge current is given by

$$f = \frac{1}{2\pi\sqrt{LC}} = \frac{159}{\sqrt{LC}} \text{ kHz}$$

where L = self-inductance in μH and C = capacitance in μF

It may, however, be pointed out here that damped oscillations so produced are not good for radio transmission purpose because of their ***limited range and excessive distortion.*** For good radio transmission, we need undamped oscillations which can be produced if some additional energy is supplied in correct phase and correct direction to the LC circuit for making up the I^2R losses continually occuring in the circuit.

65.7. Frequency Stability of an Oscillator

The ability of an oscillator to maintain a constant frequency of oscillation is called its frequency stability. Following factors affect the frequency stability :

1. Operating Point of the Active Device

The Q-point of the active device (*i.e.* transistor) is so chosen as to confine the circuit operation on the linear portion of its characteristic. Operation on non-linear portion varies the parameters of the transistor which, in turn, affects the frequency stability of the oscillator.

2. Inter-element Capacitances

Any changes in the inter-element capacitances of a transistor particularly the collector- to-emitter capacitance cause changes in the oscillator output frequency, thus affecting its frequency stability. The effect of changes in inter-element capacitances, can be neutralized by adding a swamping capacitor across the offending elements—the added capacitance being made part of the tank circuit.

3. Power Supply

Changes in the dc operating voltages applied to the active device shift the oscillator frequency. This problem can be avoided by using regulated power supply.

4. Temperature Variations

Variations in temperature cause changes in transistor parameters and also change the values of resistors, capacitors and inductors used in the circuit. Since such changes take place slowly, they cause a slow change (called drift) in the oscillator output frequency.

5. Output Load

A change in the output load may cause a change in the Q-factor of the LC tuned circuit thereby affecting the oscillator output frequency.

6. Mechanical Vibrations

Since such vibrations change the values of circuit elements, they result in changes of oscillator frequency. This instability factor can be eliminated by isolating the oscillator from the source of mechanical vibrations.

65.8. Essentials of a Feedback LC Oscillator

The essential components of a feedback LC oscillator shown in Fig. 65.4 are :

1. A resonator which consists of an LC circuit. It is also known as frequency-determining network (FDN) or tank circuit.
2. An amplifier whose function is to amplify the oscillations produced by the resonator.

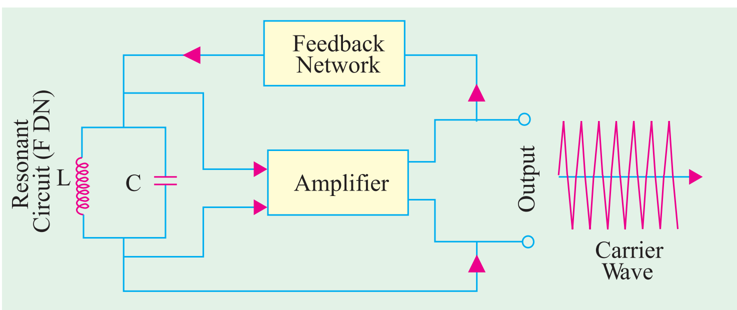


Fig. 65.4

3. A positive feedback network (*PFN*) whose function is to transfer part of the output energy to the resonant *LC* circuit in ***proper phase.*** The amount of energy fed back is sufficient to meet I^2R losses in the *LC* circuit.

The essential condition for maintaining oscillations and for finding the value of frequency is

$$\beta A = 1 + j\,0 \quad \text{or} \quad \beta A \angle \phi = 1 \angle 0$$

It means that

(i) The feedback factor or loop gain $|\beta A| = 1$,

(ii) The net phase shift around the loop is 0° (or an integral multiple of 360°). In other words, ***feedback should be positive.***

The above conditions form Barkhausen criterion for maintaining a steady level of oscillation at a specific frequency.

Majority of the oscillators used in radio receivers and transmitters use tuned circuits with positive feedback. Variations in oscillator circuits are due to the different way by which the feedback is applied. Some of the basic circuits are :

1. *Armstrong or Tickler or Tuned-base Oscillator* — it employs inductive feedback from collector to the tuned *LC* circuit in the base of a transistor.

2. *Tuned Collector Oscillator*—it also employs inductive coupling but the *LC* tuned circuit is in the collector circuit.

3. *Hartley Oscillator*—Here feedback is supplied inductively.

4. *Colpitts Oscillator*—Here feedback is supplied capacitively.

5. *Clapp Oscillator*—It is a slight modification of the Colpitts oscillator.

65.9. Tuned Base Oscillator

Such an oscillator using a transistor in *CE* configuration is shown in Fig. 65.5. Resistors R_1, R_2 and R_3 determine the dc bias of the circuit. The parallel R_3—C_2 network in the emitter circuit is a stabilizing circuit to prevent signal degeneration. As usual, C_1 is the dc blocking capacitor. The mutually-coupled coils L_1 and *L* forming primary and secondary coils of an *RF* transformer provide the required feedback between the collector and base circuits. The amount of feedback depends on the coefficient of coupling between the two coils. The *CE* connected transistor itself provides a phase shift of 180° between its input and output circuits. The transformer provides another 180° phase shift and thus producing a ***total phase shift of 360° which is an essential condition for producing oscillations.***

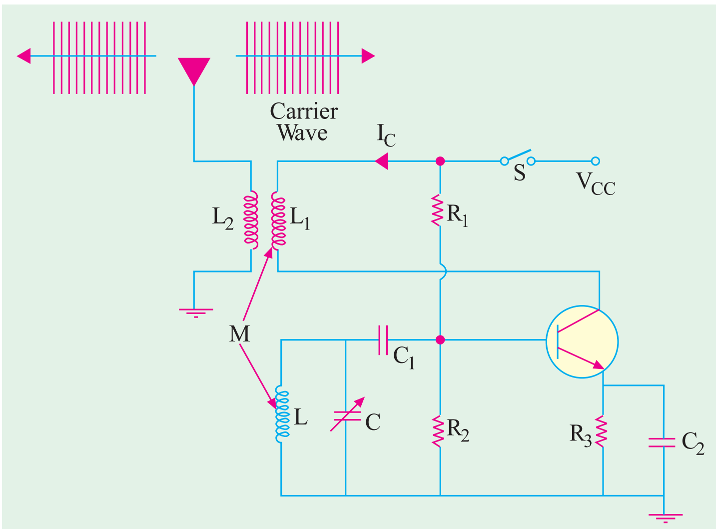


Fig. 65.5

The parallel-tuned *LC* circuit connected between base and emitter is the frequency determining network (*FDN*) *i.e.* it generates the oscillations at its resonant frequency.

Circuit Action

The moment switch *S* is closed, collector current is set up which tends to rise to its quiescent value. This increase in I_C is accompanied by :

1. An expanding magnetic field through L_1 which links with L and
2. An induced *e.m.f.* called feedback voltage in L.

Two immediate reactions of this feedback voltage are:

(*i*) Increase in emitter-base voltage (and base current) and
(*ii*) A further increase in collector current I_C .

It is followed by a succession of cycles of

1. An increase in feedback voltage,
2. An increase in emitter-base voltage and
3. An increase in I_C until saturation is reached.

Meanwhile, C gets charged. As soon as I_C ceases to increase, magnetic field of L_1 ceases to expand and thus no longer induces feedback voltage in L. Having been charged to maximum value, C starts to discharge through L. However, decrease in voltage across C causes the following sequence of reactions :

1. A decrease in emitter-base bias and hence in I_B , 2. A decrease in I_C;
3. A collapsing magnetic field in L_1;
4. An induced feedback voltage in L though, this time, in ***opposite*** direction;
5. Further decrease in emitter-base bias and so on till I_C reaches its cut-off value.

During this time, the capacitor having lost its original charge, again becomes fully charged though with ***opposite*** polarity. Transistor being in cut-off, the capacitor will again begin to discharge through L. Since polarity of capacitor charge is opposite to that when transistor was in saturation, the sequence of reactions now will be

1. An increase in emitter-base bias,
2. An increase in I_C,
3. An expanding magnetic field in L_1,
4. An induced feedback voltage in L,
5. A further increase in emitter-base bias and
6. So on till I_C increases to its saturation value.

This cycle of operation keeps repeating so long as enough energy is supplied to meet losses in the LC circuit.

The output can be taken out by means of a third winding L_2 magnetically coupled to L_1. It has approximately the same waveform as collector current.

The frequency of oscillation is equal to the resonant frequency of the LC circuit.

65.10. Tuned Collector Oscillator

Such an oscillator using a transistor in CE configuration is shown in Fig. 65.6.

(*i*) Frequency Determining Network (FDN)

It is made up of a variable capacitor C and a coil L which forms primary winding of a step-down transformer. The combination of L and C forms an oscillatory tank circuit to set the frequency of oscillation.

Resistors R_1, R_2 and R_3 are used to dc bias the transistor. Capacitors C_1 and C_2 act to bypass R_3 and R_2 respectively so that they have no effect on the ac operation of the circuit. Moreover, C_2 provides ac ground for transformer secondary L_1.

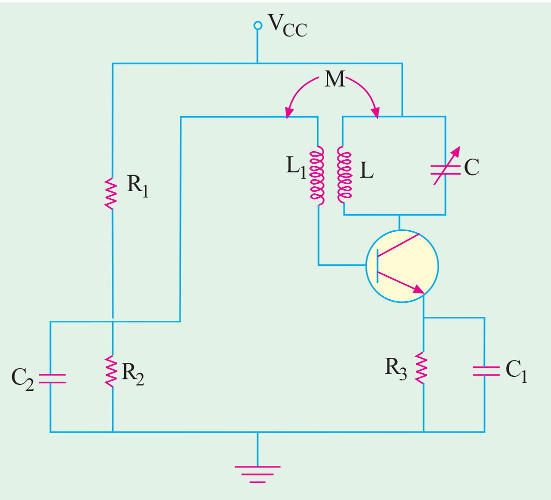


Fig. 65.6

(*ii*) Positive Feedback

Feedback between the collector-emitter circuit and base-emitter circuit is provided by the transformer secondary winding L_1 which is mutually-coupled to L. As far as ac signals are concerned, L_1 is connected to emitter *via* low-reactance capacitors C_2 and C_1.

Since transistor is connected in CE configuration, it provides a phase shift of 180° between its input and output circuits. Another phase shift of 180° is provided by the transformer thus producing a total phase shift of 360° between the output and input voltages resulting in ***positive feedback*** between the two.

(*iii*) Amplifying Action

The transistor amplifier provides sufficient gain for oscillator action to take place.

(*iv*) Working

When the supply is first switched on, a transient current is developed in the tuned *LC* circuit as the collector current rises to its quiescent value. This transient current initiates natural oscillations in the tank circuit. These natural oscillations induce a small emf into L_1 by mutual induction which causes corresponding variations in base current. These variations in I_B are amplified β times and appear in the collector circuit. Part of this amplified energy is used to meet losses taking place in the oscillatory circuit and ***the balance is radiated out in the form of electromagnetic waves.***

The frequency of oscillatory current is almost equal to the resonant frequency of the tuned circuit.

$$\therefore \qquad f_0 = \frac{1}{2\pi\sqrt{LC}}$$

65.11. Tuned Drain Oscillator (FET)

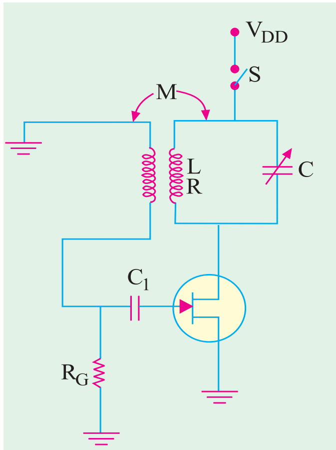


Fig. 65.7

The basic circuit is illustrated in Fig. 65.7. It is similar to the tuned collector oscillator of Fig. 65.6. Because of its high input impedance and high voltage amplification, a FET can be used to construct very simple and efficient oscillator circuit. This frequency of oscillation is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}} = \sqrt{\left(1+\frac{R}{r_d}\right)}$$

where r_d = ac drain resistance

The value of mutual inductance required for maintaining oscillations is $M = \dfrac{r_d\, RC + L}{\mu}$.

Example 65.1. *A tuned-collector oscillator has a fixed inductance of 100 μH and has to be tunable over the frequency band of 500 kHz to 1500 kHz. Find the range of variable capacitor to be used.* **(Principles of Telecom. Engg. Pune Univ.)**

Solution. Resonant frequency is given by

$$f_0 = 1/2\pi\sqrt{LC} \qquad \text{or} \qquad C = 1/4\pi^2 f_o^2 L$$

where *L* and *C* refer to the tank circuit.

When fo = 500 kHz

$C = 1/4\pi^2 \times (500 \times 10^3)^2 \times 100 \times 10^{-6}$= **1015 pF**

When fo = 1500 kHz

$C = 1015/(1500/500)^2$=113 pF

Hence, capacitor range required is **113 – 1015 pF**

Example 65.2. *The resonant circuit of a tuned-collector transistor oscillator has a resonant frequency of 5 MHz. If value of capacitance is increased by 50%, calculate the new resonant frequency.*

Solution. Using the equation for resonant frequency, we have

$$5 \times 10^6 = 1/2\pi\sqrt{LC} \qquad \text{— 1st case}$$

$$f_0 = 1/2\pi\sqrt{L \times 1.5C} \qquad \text{— 2nd case}$$

$$\therefore \quad \frac{f_0}{5\times10^6} = \frac{1}{\sqrt{1.5}} \quad \text{or} \quad f_o = \mathbf{4.08\ MHz}$$

65.12. Hartley Oscillator

In Fig. 65.8 (*a*) is shown a transistor Hartley oscillator using *CE* configuration. Its general principle of operation is similar to the tuned-collector oscillator discussed in Art. 65.10.

It uses a single tapped-coil having two parts marked L_1 and L_2 instead of two separate coils. So far as ac signals are concerned, one side of L_2 is connected to base *via* C_1 and the other to emitter *via* ground and C_3. Similarly, one end of L_1 is connected to collector *via* C_2 and the other to common emitter terminal *via* C_3. In other words, L_1 is in the output circuit *i.e.* collector-emitter circuit whereas L_2 is in the base-emitter circuit *i.e.* input circuit. These two parts are inductively-coupled and form an auto-transformer or a split-tank inductor. Feedback between the output and input circuits is accomplished through autotransformer action which also introduces a phase reversal of 180°. This phase reversal

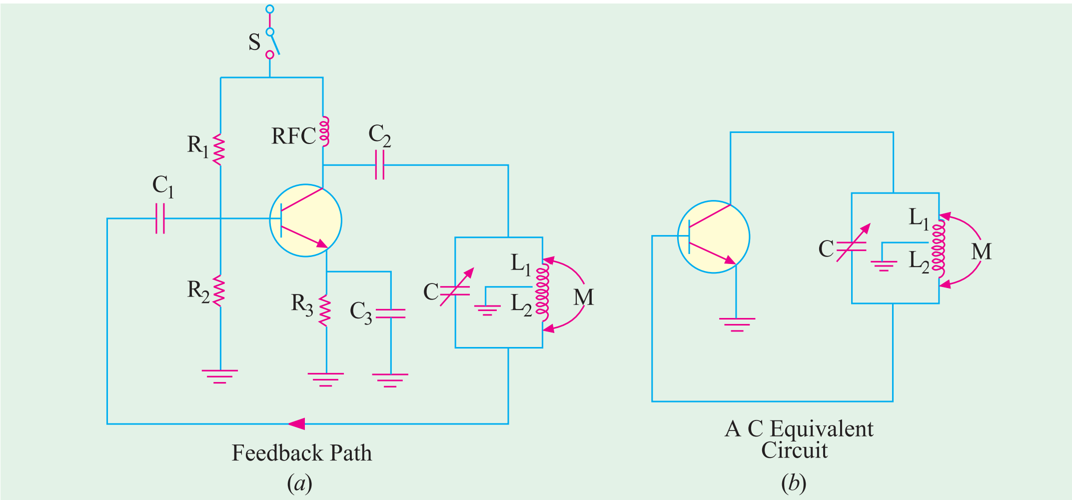


Fig. 65.8

Hartley oscillator

between two voltages occurs because they are taken from ***opposite ends*** of an inductor (L_1 - L_2 combination) with respect to the tap which is tied to common transistor terminal *i.e*. emitter which is ac grounded *via* C_3. Since transistor itself introduces a phase shift of 180°, the total phase shift becomes 360° thereby making the ***feedback positive* or *regenerative*** which is essential for oscillations (Art 65.8). As seen, positive feedback is obtained from the tank circuit and is coupled to the base *via* C_1. The feedback factor is given by the ratio of turns in L_2 and L_1 *i.e.* by N_2/N_1 and its value ranges from 0.1 to 0.5. Fig. 65.8 (*b*) shows the equivalent circuit of Hartley oscillator.

Resistors R_1 and R_2 form a voltage divider for providing the base bias and R_3 is an emitter swamping resistor to add stability to the circuit. Capacitor C_3 provides ac ground thereby preventing any signal degeneration while still providing temperature stabilisation. Radio-frequency choke (RFC) provides dc load for the collector and also keeps ac currents out of the dc supply V_{CC}.

When V_{CC} is first switched on through S, an initial bias is established by R_1 - R_2 and oscillations are produced because of positive feedback from the LC tank circuit (L_1 and L_2 constitute L). The frequency of oscillation is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \qquad \text{where} \quad L = L_1 + L_2 + 2M$$

The output from the tank may be taken out by means of another coil coupled either to L_1 or L_2.

Example 65.3. *Calculate the oscillation frequency for the transistor Hartley oscillator circuit (refer to Fig. 65.8). Given the circuit values: L_{RFC} = 0.5 mH, L_1 = 750 µH, L_2 = 750 µH, M = 150 µH and C = 150 pF.*

Solution. $f_0 = \dfrac{1}{2\pi\sqrt{LC}}$ where $L = L_1 + L_2 + 2M$

$\therefore$ $L = 750\ \mu\text{H} + 750\ \mu H + 2 + 150\ \mu\text{H} = 1800\ \mu\text{H}$

and $f_0 = \dfrac{1}{2\pi\sqrt{1800\mu\text{H} \times 150\text{pF}}}$ = **320kHz**

Example 65.4. *In an Hartley oscillator if L_1 = 0.1 mH and mutual inductance between the coils equal to 20 µH . Calculate the value of capacitor C of the oscillating circuit to obtain frequency of 4110 kHz.* **(Bangalore University 2001)**

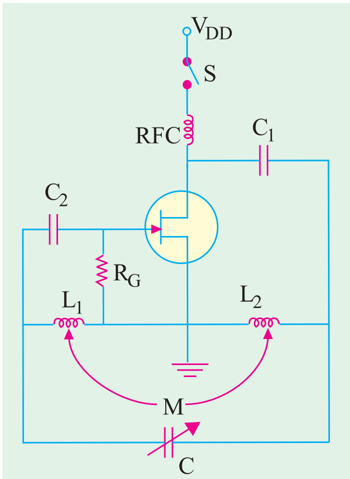


Fig. 65.9

Solution. $L = L_1 + L_2 + 2\text{M} = 0.1\ \text{mH} + 10\ \mu\text{H} + 20\ \mu\text{H} = 130\ \mu\text{H}$

Now the resonant frequency is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad \text{or} \quad C = \frac{1}{4\pi^2 f_0^2 L} = \frac{1}{4\pi^2 \times 4110^2 \times 130\mu\text{H}}$$

C = **11.5 pF**

65.13. FET Hartley Oscillator

The basic circuit is shown in Fig. 65.9. R_G is the gate biasing resistor. There is mutual induction between the two parts L_1 and L_2 of the coil.

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

where $L = L_1 + L_2 + 2M$

Example 65.5. *Calculate the oscillator frequency for a FET Hartley oscillator (refer to Fig. 65.9), for the following circuit values: C = 250 pF, L_1 = 1.5 mH, L_2 = 1.5 mH, and M = 0.5 mH.*

Solution. $f_0 = \dfrac{1}{2\pi\sqrt{LC}}$ where $L = L_1 + L_2 + 2\text{M}$

$\therefore$ $L = 1.5\ \text{mH} + 1.5\ \text{mH} + 2 \times 0.5\ \text{mH} = 4\ \text{mH}$

and $f_0 = \dfrac{1}{2\pi\sqrt{4\,mH \times 250\ pF}}$ = **159.1 kHz**

65.14. Colpitts Oscillator

This oscillator is essentially the same as Hartley oscillator except for one difference. Colpitts oscillator uses **tapped capacitance** whereas Hartley oscillator uses **tapped inductance*. Fig. 65.10** (*a*)

* As an aid to memory, remember that Hartley begins with letter H for Henry *i.e.* coil and Colpitts begins with *C* for Capacitor.

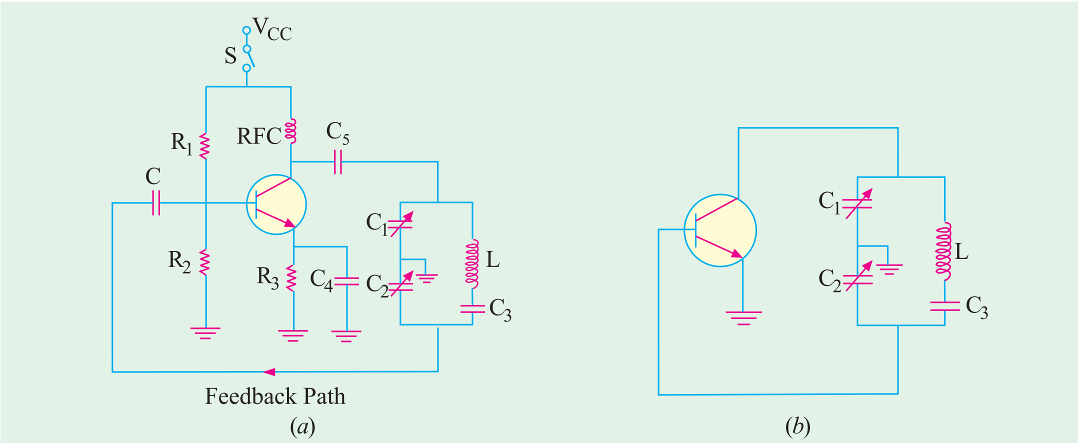


Fig. 65.10

shows the complete circuit with its power source and dc biasing circuit whereas Fig. 65.10 (*b*) shows its ac equivalent circuit. The two series capacitors C_1 and C_2 form the voltage divider used for providing the feedback voltage (the voltage drop across C_2 constitutes the feedback voltage). The feedback factor is C_1/C_2. The minimum value of amplifier gain for maintaining oscillations is

$$A_{v(min)} = \frac{1}{C_1/C_2} = \frac{C_2}{C_1}$$

The tank circuit consists of two ganged capacitors C_1 and C_2 and a single fixed coil. The frequency of oscillation (which does not depend on mutual inductance) is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \qquad \text{where} \qquad C = \frac{C_1 C_2}{C_1 + C_2}$$

Transistor itself produces a phase shift of 180°. Another phase shift of 180° is provided by the capacitive feedback thus giving a total phase shift of 360° between the emitter-base and collector-base circuits.

Resistors R_1 and R_2 form a voltage divider across V_{CC} for providing base bias, R_3 is for emitter stabilisation and *RFC* provides the necessary dc load resistance R_C for amplifier action. It also prevents ac signal from entering supply dc V_{CC}. Capacitor C_5 is a bypass capacitor whereas C_4 conveys feedback from the collector-to-base circuit.

When *S* is closed, a sudden surge of collector current **shock-excites** the tank circuit into oscillations which are sustained by the feedback and the amplifying action of the transistor.

Colpitts oscillator is widely used in commercial signal generators upto 1 MHz. Frequency of oscillation is varied by gang-tuning the two capacitors C_1 and C_2.

Example 65.6. *Determine the circuit oscillation frequency for a transistor Colpitts oscillator shown in Fig. 65.10(a). Given,*

$L = 100\ \mu H$, $L_{RFC} = 0.5$ mH, $C_1 = 0.005\ \mu F$, $C_2 = 0.01\ \mu F$. $C_6 = 10\ \mu$F

Solution. For a transistor Colpitts oscillator, the oscillation frequency,

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \qquad \text{where} \qquad C = \frac{C_1 C_2}{C_1 + C_2}$$

$$\therefore \quad C = \frac{0.005\,\mu F \times 0.01\,\mu F}{0.005\,\mu F + 0.01\mu F} = 3.3\,nF$$

$$\text{and} \quad f_0 = \frac{1}{2\pi \times \sqrt{100\,\mu H \times 3.3\,nF}} = \textbf{277 kHz}$$

Example 65.7. *For the Colpitts oscillator circuit shown in Fig. 65.11, find the values of*

(a) feedback fraction,

(b) minimum gain to sustain oscillations,

(c) emitter resistor R_E.

(Electronics-I, Bangalore Univ.)

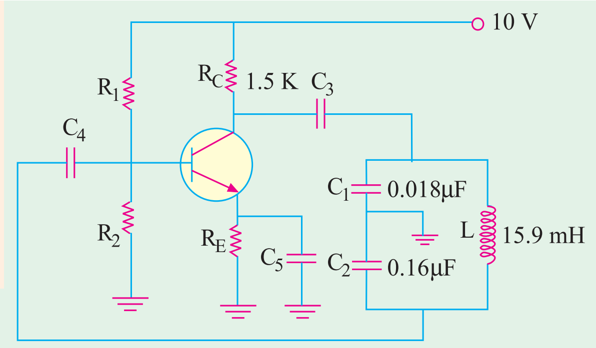


Fig. 65.11

Solution. (*a*) The voltage drop across C_2 is feedback to the input circuit.

feedback fraction

$$= \frac{\text{drop across } C_2}{\text{drop across } C_1} = \frac{IX_2}{IX_1} = \frac{C_1}{C_2} = \frac{0.018}{0.16} = \mathbf{0.11}$$

(*b*) $A_{v(min)} = \dfrac{1}{\text{feedback fraction}} = \dfrac{1}{0.11} = \mathbf{9}$

(*c*) Now, $A_v \cong \dfrac{R_C}{R_E}$ $\quad\therefore\quad$ $R_E = \dfrac{R_C}{A_v} = \dfrac{1500}{9} = \mathbf{167\ \Omega}$

It should be noted that the above calculations do not take into account the losses in the coil and the loading effect of the amplifier input impedance.

65.15. Clapp Oscillator

It is a variation of Colpitts oscillator and is shown in Fig. 65.12 (*a*). It differs from Colpitts oscillator in respect of capacitor C_3 only which is joined in series with the tank inductor. Fig. 65.12 (*b*) shows the ac equivalent circuit.

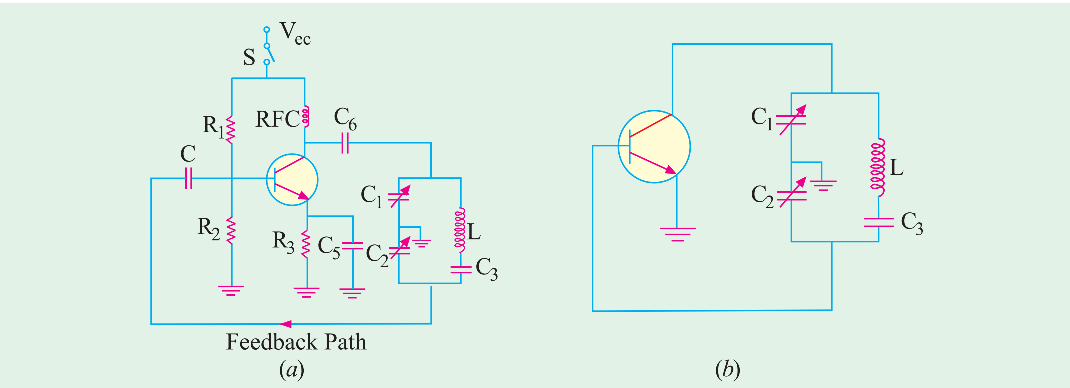


Fig. 65.12

Addition of C_3 (*i*) improves frequency stability and (*ii*) eliminates the effect of transistor's parameters on the operation of the circuit.

The operation of this circuit is the same as that of the Colpitts oscillator.

The frequency of oscillation is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad \text{where} \quad \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

65.16. FET Colpitts Oscillator

The circuit is shown in Fig. 65.13. It is similar to the transistor circuit of Fig. 65.10. Here, R_G is the gate biasing resistor. The radio-frequency coil choke (R_{FC}) performs two functions :

(*i*) It keeps ac current out of the dc drain supply and

(*ii*) It provides drain load.

As seen, C_1 is in the input circuit whereas C_2 is in the output circuit.

The frequency of oscillation is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \text{ ; where, } C = \frac{C_1 C_2}{C_1 + C_2}$$

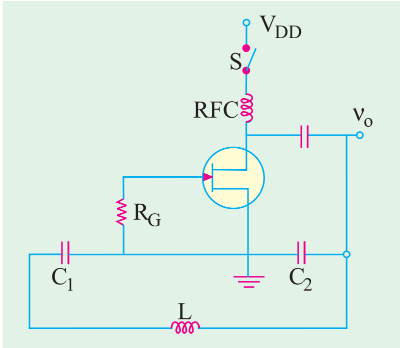


Fig. 65.13

Example 65.8. *Determine the circuit oscillation frequency for the FET Colpitts oscillator (refer to Fig. 65.13), given C_1 = 750 pF, C_2 = 2500 pF and L = 40 μH.*

Solution. For a Colpitts oscillator, the oscillation frequency,

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad \text{where} \quad C = \frac{C_1 C_2}{C_1 + C_2}$$

$$\therefore \quad C = \frac{750\text{ pF} \times 2500\text{ pF}}{750\text{ pF} + 2500\text{ pF}} = \mathbf{576.9\ pF}$$

$$\text{and} \quad f_0 = \frac{1}{2\pi \times \sqrt{40\mu H \times 576.9\ pF}} = \mathbf{1.048\ MHz}$$

65.17. Crystals

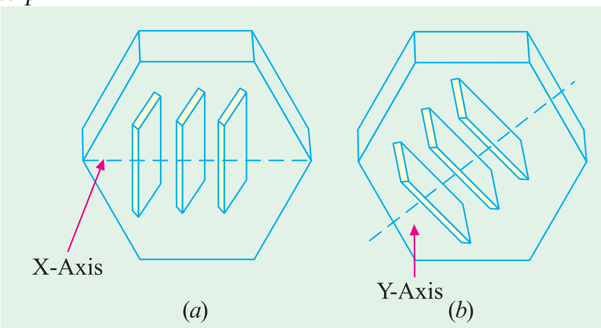


Fig. 65.14

For an exceptionally high degree of frequency stability, use of crystal oscillators is essential. The crystal generally used is a finely-ground wafer of translucent quartz (or tourmaline) stone held between two metal plates and housed in a package about the size of a postal stamp. The crystal wafers are cut from the crude quartz in two different ways. The method of 'cutting' determines the crystal's natural resonant frequency and its temperature coefficient. When the wafer is cut so that its flat surface are perpendicular to its **electrical axis**, it is called an **X-cut** crystal (Fig. 65.14). But if the wafer is so cut that its flat surfaces are perpendicular to its **mechanical axis**, it is called **Y-cut** crystal.

(a) Piezoelectric Effect

The quartz crystal described above has peculiar properties. When mechanical stress is applied across its two opposite faces, **a potential difference is developed across them.** It is called ***piezo-electric effect.*** Conversely, when a potential difference is applied across its two opposite faces, it causes the crystal to ***either expand or contract.*** If an alternating voltage is applied, the crystal wafer is set into vibrations. The frequency of vibration is equal to the resonant frequency of the crystal as determined by its structural characteristics. Where the frequency of the applied ac voltage equals the natural resonant frequency of the crystal, the amplitude of vibration will be maximum. As a general rule, thinner the crystal, ***higher its frequency of vibration.***

(b) Equivalent Electrical Circuit

The electrical equivalent circuit of the crystal is shown in Fig. 65.15 (*b*). It consists of a series RLC_1 circuit in parallel with a capacitor C_2.

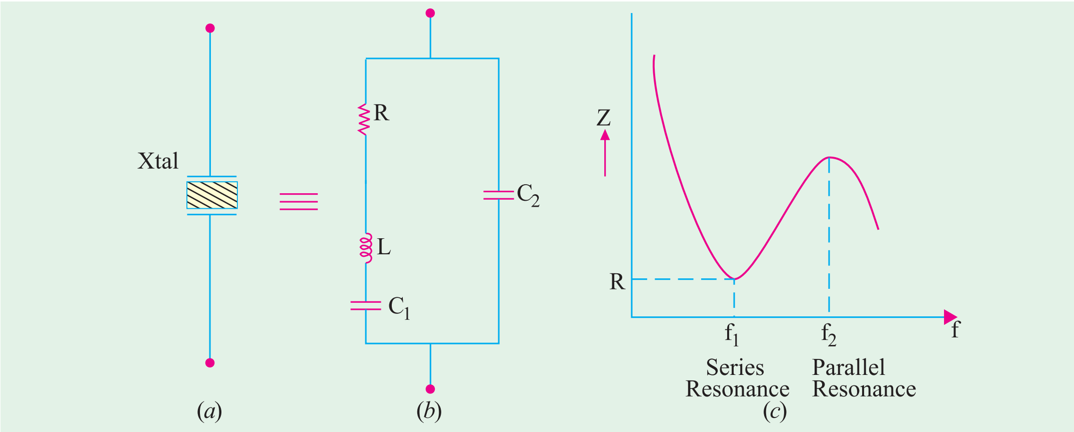


Fig. 65.15

The circuit has two resonant frequencies :

(*i*) one is the lower series resonance frequency f_1 which occurs when $X_L = X_{C1}$. In that case, $Z = R$ as shown in Fig. 65.15 (*c*).

$$f_1 = \frac{1}{2\pi\sqrt{LC_1}}$$

(*ii*) the other is the parallel resonance frequency f_2 which occurs when reactance of the series leg equals the reactances of C_2. At this frequency, the crystal offers very high impedance to the external circuit.

$$f_2 = \frac{1}{2\pi\sqrt{LC}}\ ; \quad \text{where} \quad C = \frac{C_1 C_2}{C_1 + C_2}$$

The impedance versus frequency graph of the crystal is shown in Fig. 65.15 (*c*). Crystals are available at frequencies of 15 kHz and above. However, at frequencies above 100 MHz, they become so small that handling them becomes a problem.

(*c*) Q-factor

The equivalent inductance of a crystal is very high as compared to either its equivalent capacitance or equivalent resistance. Because of high *L/R* ratio, the *Q*-factor of a crystal circuit is 20,000 as compared to a maximum of about 1000 for high-quality *LC* circuits. Consequently, greater frequency stability and frequency discrimination are obtained because of extremely high *Q* (upto 10^6) and high *L/R* ratio of the series RLC_1 circuit.

(*d*) Temperature Coefficient

Temperature variations affect the resonant frequency of a crystal. The number of cycles change per million cycles for a 1°C change in temperature is called the **temperature coefficient** (TC) of the crystal. It is usually expressed in parts per million (ppm) per °C. For example, a TC of 10 ppm per °C means that frequency variation is 0.001 per cent* per °C change in temperature. It can also be expressed as 10 Hz/MHz/°C. When kept in temperature-controlled ovens, crystal oscillators have frequency stability of about ±1 ppm.

Usually, X-cut crystals have negative TC whereas *Y*-cut crystals have positive TC.

Example 65.9. *A 600 kHz X-cut crystal when calibrated at 50°C has a TC of 20 ppm/°C. What will be its resonant frequency when its temperature is raised to 60°C ?*

Solution. A TC of 20 ppm/°C is the same thing as 20 Hz/MHz/°C. Since temperature rise is 10°C and original frequency is 600 kHz = 0.6 MHz, the total change as calculated by ratio propor-

* Since 10 ppm means a change of 10 in 10^6, hence percentage change is

$$= \frac{10}{10^6} \times 100 = 10^{-3} = 0.001$$

tion is = 20 × 10 × 0.6 = 120 Hz.

Since TC is negative, the new resonance frequency of the crystal is

= 600,000 – 120 = 599,880 = **599.88 kHz**.

Example 65.10. *A certain X-cut quartz crystal resonates at 450 kHz. It has an equivalent inductance of 4.2 H and an equivalent capacitance of 0.0297 pF. If its equivalent resistance is 60 Ω, calculate its Q-factor.*

Solution. $$Q = \frac{\omega L}{R} = \frac{2\pi fL}{R}$$

$$= \frac{2\pi \times 450 \times 10^3 \times 4.2}{600} = \mathbf{19{,}790}$$

Example 65.11. *The parameters of a crystal oscillator equivalent circuit are : L_1 = 0.8H; C_1 = 0.08 pF, R = 5 kΩ and C_2 = 1.0 pF. Determine the resonant frequencies f_1 and f_2*

(UPSC Engg. Services 1999)

Solution. $$f_1 = \frac{1}{2\pi\sqrt{LC_1}} = \frac{1}{2\pi\sqrt{0.8 \times 0.08 \times 10^{-12}}} = \frac{1}{2\pi \times 0.253 \times 10^{-6}}$$

$$= \frac{1}{1.5895 \times 10^{-6}} = 0.629 \times 10^6 \text{ Hz} = \mathbf{629\ kHz}$$

$$f_2 = \frac{1}{2\pi\sqrt{LC}} \text{ where } C = \frac{C_1 C_2}{C_1 + C_2} = \frac{0.08 \times 1}{0.08 + 1} = 0.074\,\text{pF}$$

$$\therefore \quad f_2 = \frac{1}{2\pi\sqrt{0.8 \times 074 \times 10^{-12}}} = \frac{1}{2\pi \times 0.0243 \times 10^6}\,(\text{Hz})$$

$$f_2 = \frac{1}{2\pi\sqrt{0.8 \times 074 \times 10^{-12}}} = \frac{1}{2\pi \times 0.0243 \times 10^6}\,(\text{Hz})$$

$= 0.654 \times 10^6$ Hz = **654 kHz.**

65.18. Crystal Controlled Oscillator

Fig. 65.16, shows the use of a crystal to stabilise the frequency of a tuned-collector oscillator which has a crystal (usually quartz) in the feedback circuit.

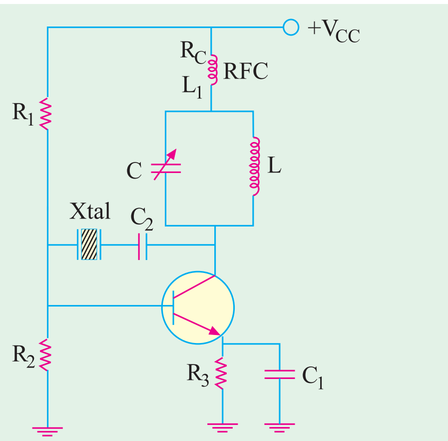
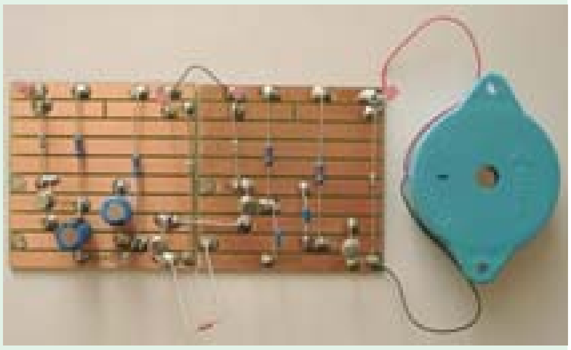


Fig. 65.16



Crystal Controlled oscillator

The *LC* tank circuit has a frequency of oscillation

$$f_0 = 1/2\pi\sqrt{LC}$$

The circuit is adjusted to have a frequency nearabout the desired operating frequency but the exact frequency is set by the crystal and stabilized by the crystal. For example, if natural frequency of vibration of the crystal is 27 MHz, the *LC* circuit is made to resonate at this frequency.

As usual, resistors R_1, R_2 and R_3 provide a voltage-divider stabilised dc bias circuit. Capacitor C_1 by-passes R_3 in order to maintain large gain. *RFC* coil L_1 prevents ac signals from entering dc line whereas R_C is the required dc load of the collector. The coupling capacitor C_2 has negligible impedance at the operating frequency but prevents any dc link between collector and base. Due to extreme stability of crystal oscillations, such oscillators are widely used in communication transmitters and receivers where frequency stability is of prime importance.

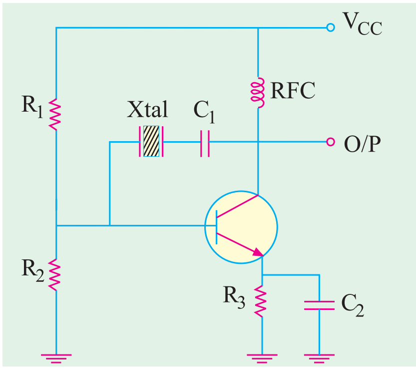


Fig. 65.17

65.19. Transistor Pierce Crystal Oscillator

A typical circuit originally suggested by Pierce is shown in Fig. 65.17. Here, the crystal is excited in the series-resonance mode because it is connected as a series element in the feedback path from collector to the base. Since, in series resonance, crystal impedance is the smallest, the amount of positive feedback is the largest. The crystal not only provides the feedback but also the necessary phase shift.

As usual, R_1, R_2 and R_3 provide a voltage-divider stabilized dc bias circuit. C_2 bypasses R_3 to avoid degeneration. The *RFC* coil provides dc collector load and also prevents any ac signal from entering the dc supply. The coupling capacitor C_1 has negligible reactance at circuit operating frequency but ***blocks any dc flow between collector and base.*** The oscillation frequency equals the series-resonance frequency of the crystal and is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC_1}} \qquad \text{— Fig 65.15 } (b)$$

Advantages

1. It is a very simple circuit because no tuned circuit other than the crystal itself is required.
2. Different oscillation frequencies can be obtained by simply replacing one crystal with another. It makes it easy for a radio transmitter to work at different frequencies.
3. Since frequency of oscillation is set by the crystal, it remains unaffected by changes in supply voltage and transistor parameters etc.

65.20. FET Pierce Oscillator

It is shown in Fig. 65.18. Use of FET is desirable because its high input impedance results in light loading of the crystal which

1. results in good stability and
2. does not lower the *Q*-value.

The circuit shown in Fig. 65.18 is essentially a Colpitts oscillator in which

(i) crystal has replaced the inductor and
(ii) inherent FET junction capacitance provide the split capacitance as shown in the figure.

The circuit can be made to operate at different frequencies simply by plugging in different crystals between points *A* and *B* of the circuit.

The circuit oscillation frequency is given by the series-resonance frequency of the crystal (Art. 65.17)

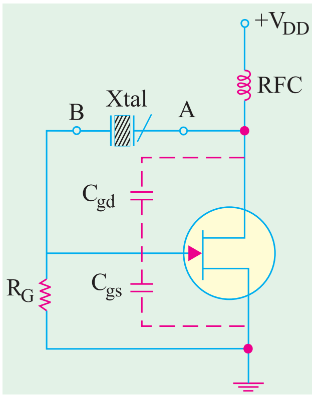


Fig. 65.18

65.21. Phase Shift Principle

Tuned circuits are ***not an essential requirement for oscillation.*** What is essential is that there should be a 180° phase shift around the feedback network* and loop gain should be greater than unity. The 180° phase shift in the feedback signal can be achieved by using a suitable *R-C* network

* Total phase shift required is 360°. However, the balance of 180° is provided by the active device of the amplifier itself.

consisting of three or four *R-C* sections. The sine wave oscillators which use *R-C* feedback network are called **phase-shift oscillators**.

65.22. RC Phase Shift Oscillator

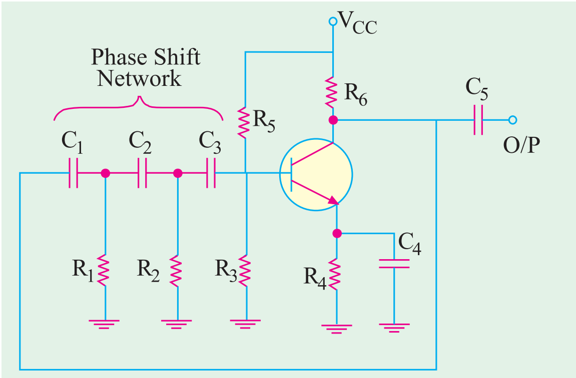


Fig. 65.19

Fig. 65.19, shows a transistor phase-shift oscillator which uses a three-section *R-C* feedback network for producing a total phase shift of 180° (*i.e.* 60° per section) in the signal fed back to the base. Since *CE* amplifier produces a phase reversal of the input signal, total phase shift becomes 360° or 0° which is essential for **regeneration and hence for sustained oscillations.**

Values of *R* and *C* are so selected that each *RC* section produces a phase advance of 60°. Addition of a fourth section improves oscillator stability. It is found that phase shift of 180° occurs ***only at one frequency*** which becomes the oscillator frequency.

(*a*) Circuit Action

The circuit is set into oscillations by any random or chance variation caused in the base current by

(*i*) noise inherent in a transistor or
(*ii*) minor variation in the voltage of the dc source.

This variation in the base current

1. is amplified in the collector circuit,
2. is then fed back to the *RC* network R_1C_1, R_2C_2 and R_3C_3,
3. is reversed in phase by the *RC* network,
4. is next applied to the base in phase with initial change in base current,
5. and hence is used to sustain cycles of variations in collector current between saturation and cut-off values.

Obviously, the circuit will stop oscillating the moment phase shift differs from 180°.

As is the case with such transistor circuits **(*i*)** voltage divider R_5 - R_3 provides dc emitter-base bias, **(*ii*)** R_6 controls collector voltage and **(*iii*)** R_4, C_4 provide temperature stability and prevent ac signal degeneration. The oscillator output voltage is capacitively coupled to the load by C_5.

(*b*) Frequency of Oscillation

The frequency of oscillation for the three-section *RC* oscillator when the three *R* and *C* components are equal is roughly given by

$$f_0 = \frac{1}{2\pi\sqrt{6}.RC}\,\text{Hz} = \frac{0.065}{RC}\,\text{Hz}$$

Moreover, it is found that value of β is 1/29. It means that amplifier gain must be more than 29 for oscillator operation.

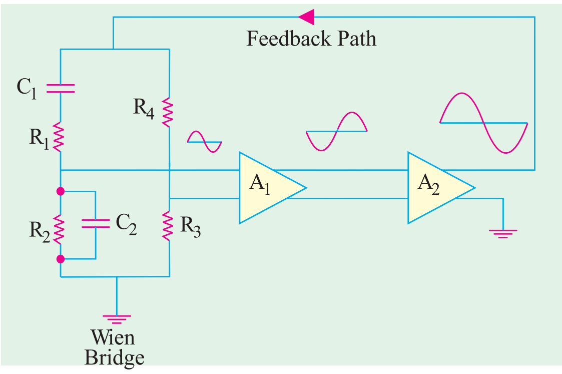


Fig. 65.20

(*c*) Advantages and Disadvantages

1. Since they do not require any bulky and expensive high-value inductors, such oscillators are well-suited for frequencies below 10 kHz.
2. Since only one frequency can fulfil Barkhausen phase-shift requirement, positive feedback occurs only for one frequency. Hence, pure sine wave output is possible.

3. It is not suited to variable frequency usage because a large number of capacitors will have to be varied. Moreover, gain adjustment would be necessary every time frequency change is made.
4. It produces a distortion level of nearly 5% in the output signal.
5. It necessitates the use of a high β transistor to overcome losses in the network.

Example 65.12. *It is desired to design a phase-shift oscillator using a BJT and R = 10 kΩ.. Select the value of C for oscillator operation at 1 kHz.*

Solution. $f_0 = \dfrac{0.065}{RC}$ or $C = \dfrac{0.065}{Rf_0} = \dfrac{0.065}{10K \times 1KHz}$

$= 0.0065 \times 10^{-6}$ F $=$ **6.5 nF**

65.23. Wien Bridge Oscillator

It is a low-frequency (5 Hz — 500 kHz), low-distortion, tunable, high-purity sine wave generator, often used in laboratory work. As shown in the block diagrams of Fig. 65.20 and Fig. 65.21, this oscillator uses two *CE*-connected *RC*-coupled transistor amplifiers and one *RC*-bridge (called Wien bridge) network to provide feedback. Here, Q_1 serves as amplifier-oscillator and Q_2 provides phase reversal and additional amplification. The bridge circuit is used to control the phase of the feedback signal at Q_1.

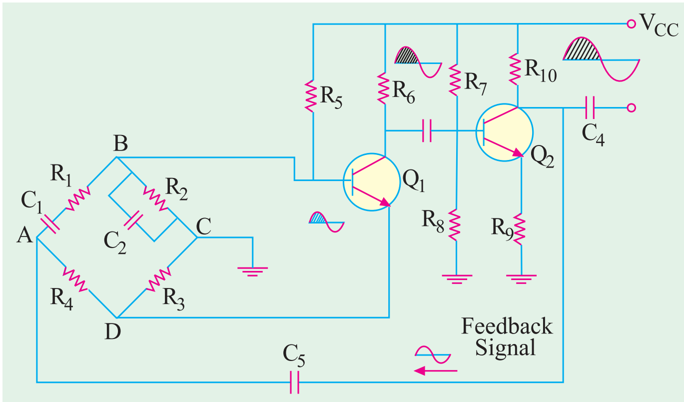


Fig. 65.21

(*a*) Phase Shift Principle

Any input signal at the base of Q_1 appears in the amplified but phase-reversed form across collector resistor R_6 (Fig. 65.21). It is further inverted by Q_2 in order to provide a total phase reversal of 360° for positive feedback. Obviously, the signal at R_{10} is an amplified replica of the input signal at Q_1 and is of the same phase since it has been inverted twice. We could feed this signal back to the base of Q_1 directly to provide regeneration needed for oscillator operation. But because Q_1 will amplify signals over a wide range of frequencies, direct coupling would result in poor frequency stability. By adding the Wien bridge, oscillator becomes sensitive to a signal of ***only one particular frequency***. Hence, we get an oscillator of good frequency stability.

(*b*) Bridge Circuit Principle

It is found that the Wien bridge would become balanced at the signal frequency for which phase shift is exactly 0° (or 360°),

The balance conditions are

$$\frac{R_4}{R_3} = \frac{R_1}{R_2} + \frac{C_2}{C_1} \quad \text{and} \quad \omega_0 = \frac{1}{\sqrt{R_1C_1R_2C_2}} \quad \text{or} \quad f_0 = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}$$

$$\text{If } R_1 = R_2 = R \quad \text{and} \quad C_1 = C_2 = C, \quad \text{then} \quad f_0 = \frac{1}{2\pi RC} \quad \text{and} \quad \frac{R_4}{R_3} = 2$$

(*c*) Circuit Action

Any random change in base current of Q_1 can start oscillations. Suppose, the base current of Q_1 is increased due to some reason. It is equivalent to applying a positive going signal to Q_1. Following sequence of events will take place :

1. An amplified but phase-reversed signal will appear at the collector of Q_1;
2. A still further amplified and twice phase-reversed signal will appear at the collector of Q_2. Having been inverted twice, this output signal will be in phase with the input signal at Q_1;
3. A part of the output signal at Q_2 is fed back to the input points of the bridge circuit (point A-*C*). A part of this feedback signal is applied to emitter resistor R_3 where it produces degenerative effect. Similarly, a part of the feedback signal is applied across base-bias resistor R_2 where it produces regenerative effect.

At the rated frequency f_o, effect of ***regeneration is made slightly more than that of degeneration*** in order to maintain continuous oscillations.

By replacing R_3 with a thermistor, amplitude stability of the oscillator output voltage can be increased.

(*d*) Advantages

Such a circuit has

1. highly stabilized amplitude and voltage amplification,
2. exceedingly good sine wave output,
3. good frequency stability.

Example 65.13. *Calculate the resonant frequency of a Wien Bridge oscillator (shown in Fig. 65.21) when R = 10 k Ω and C = 2400 pF.*

Solution. $f_0 = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi \times 10\,K \times 2400\,pF} =$ **6.63 kHz**

Example 65.14. *Design RC elements of a Wien Bridge oscillator (shown in Fig. 65.21), for operation at 2.5 kHz.*

Solution. Using equal values of R_1 and R_2, let us select R = 100 kΩ (you can chose any value in kilo ohms). Then from the relation,

$$f_0 = \frac{1}{2\pi RC} \quad \text{we get} \quad C = \frac{1}{2\pi f_0 R} = \frac{1}{2\pi \times 2.5\text{ kHz} \times 100\text{ K}}$$

or C = **636 pF**

65.24. Non-sinusoidal Waveforms

Any waveform whose shape is different from that of a standard sine wave is called ***non-sinusoidal waveform.*** Examples are : square, rectangular, sawtooth, triangular waveforms and pulses as shown in Fig. 65.22.

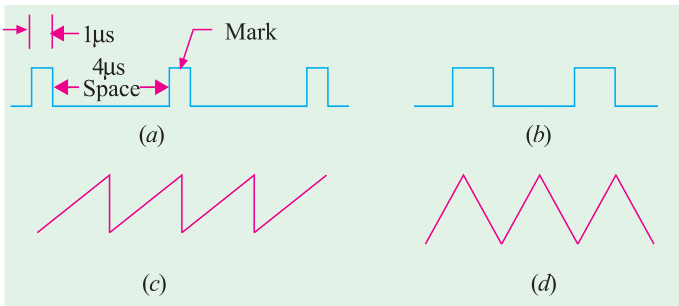


Fig. 65.22

(*a*) Pulses

Fig. 65.22 (*a*) shows a pulse train *i.e.* a stream of pulses at regular intervals. A pulses may, in general, be defined as a voltage or current that changes rapidly from one level of amplitude to another ***i.e.* it is an abrupt discontinuity in voltage or current**. These pulses are extensively used in digital electronics.

1. Mark-to-Space Ratio (MSR)

$$MSR = \frac{\text{pulse width}}{\text{time between pulses}} = \frac{1\,\mu s}{4\,\mu s} = \mathbf{0.25} \qquad \text{— Fig. 65.22 } (a)$$

Hence, mark-to-space ratio of the pulse shown in Fig. 65.22 (*a*) is 1 : 4.

This name has come from early morse-code transmission systems where a pulse was used to cause a pen to mark the paper.

2. Pulse Repetition Time (PRT)

It may be defined as ***the time between the beginning of one pulse and that of the other.***

As seen from Fig. 65.22 (*a*), $PRT = 5\ \mu s$

3. Pulse Repetition Frequency (PRF)

It is given by ***the number of pulses per second.***

$$PRF = \frac{1}{PRT} = \frac{1}{5\mu s} = \frac{10^6}{5} = 200{,}000\,\text{Hz} = 200\,\text{kHz}$$

Pulse circuits find applications in almost all electronic-based industries. Various types of pulse code modulations are employed in communication systems whereas radars utilize pulses to track targets. Digital computers require circuits that can be switched very rapidly between two states by using appropriate pulses.

(*b*) Square Wave

It is shown in Fig. 65.22 (*b*) and is, in fact, a pulse waveform with a mark-to-space ratio of 1:1

Such square waves or pulses are used

1. for audio frequency note generation,
2. for digital electronic switching as in computers, 3, in radars,
4. as synchronizing pulses in TV,
5. for switching of high-power electronic circuits such as thyristor circuits.

(*c*) Sawtooth Wave

It is shown in Fig. 65.22 (*c*). Such waves are used

1. in the scanning circuits of cathode-ray tubes (CRT),
2. in timing circuits where the time for the wave to proceed from one level to another is measured, such as that produced in an integrating circuit.

(*d*) Triangular Wave

It is shown in Fig. 65.22 (*d*). Such waves are often used

1. in scanning circuits where a uniform left-to-right scan is required as in computer displays,
2. for audio frequency note generation,
3. in timing circuits for electronic applications.

65.25. Classification of Non-sinusoidal Oscillators

Those oscillators which generate waveforms other than sine waveform are called **non-sinusoidal oscillators** or **relaxation oscillators**. Non-sinusoidal waveforms include: square, rectangular, sawtooth and pulse-shaped waves as shown in Fig. 65.22.

A relaxation oscillator may be defined ***as a circuit in which voltage or current changes abruptly from one value to another*** and which continues to oscillate between these two values as long as dc power is supplied to it.

We will consider the following three types of such oscillators :

1. Sawtooth generators **2.** Blocking oscillators **3.** Multivibrators (MV)

65.26. Pulse Definitions

Due to capacitive effects in a transistor (or to circuit elements external to it), its **output does not directly follow its input**. For example, if we apply a square input pulse to its *E/B* junction, some amount of time lapses be-

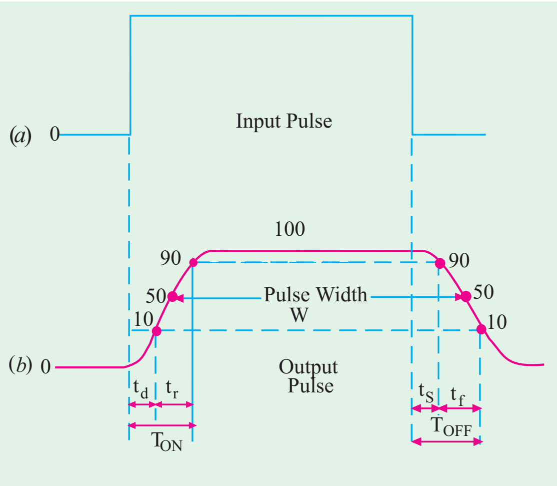


Fig. 65.23

fore I_C starts to rise. Similarly, when the input becomes zero, there is some time lapse before I_C starts to decrease. There is always some time delay between the application of input and change in the output. In order to measure how quickly the output changes *i.e.* in order to define the switching (*i.e.* OFF/ON) characteristics of a transistor, we will define the following few terms. It will be assumed that perfect square wave, as shown in Fig. 65.23 (*a*), has been applied at the input. The output wave and the various time delays are shown in Fig. 65.23 (*b*).

1. Time delay, t_d

It is the time interval between the beginning of the input pulse and the time the output voltage (or current) reaches 10 per cent of its maximum value.

It depends on ***(i)*** depletion region capacitances, ***(ii)*** turn-on base current and ***(iii)*** value of transistor β.

2. Rise time, t_r

It is the time taken by the output voltage (or current) to rise from 10% to 90% of its maximum value.

It primarily depends on diffusion capacitance C_D of the transistor (Art. 1.4).

3. Turn-on time T_{ON}

It is equal to the sum of the delay time and rise time *i.e.* $T_{ON} = t_d + t_r$

4. Storage time, T_s

It is the time interval between the end of the input pulse (trailing edge) and the time when output voltage (or current) falls to 90% of its initial maximum value.

It depends on the degree of saturation. Deeper the transistor is driven into saturation, more the stored charge that has to be removed and hence longer the storage time. That is why non-saturated switching is often preferred.

5. Fall time, t_f

It is the time interval during which the output voltage (or current) falls from 90% of its maximum value to 10%.

In simple words, it is the time interval between 90% and 10% levels of the output pulse.

6. Turn-off time, TO_{FF}

It is equal to the sum of storage time and fall time *i.e.* $T_{OFF} = t_s + t_f$

For a fast switching transistor, T_{ON} and T_{OFF} must be of the order of nanoseconds.

7. Pulse Width, *W*

It is the time duration of the output pulse measured between two 50% levels of the rising and falling waveform.

65.27. Basic Requirements of a Sawtooth Generator

The essential requirements of a sawtooth generator are :

1. a dc power source,
2. a switching device (neon tube, thyratron, thyristor, UJT etc.),
3. a capacitor,
4. a resistor.

Circuit Action

The *V/I* characteristics of the *RC* circuit play an important role in the operation of such a generator. By restricting the time interval equal to the time constant $\lambda = CR$, only the rising portion of the characteristic (*OA* in Fig. 65.24) which is almost a straight line, is utilized. For periods of time greater than λ , the rising portion of the characteristic is no longer a straight line and hence cannot be utilized.

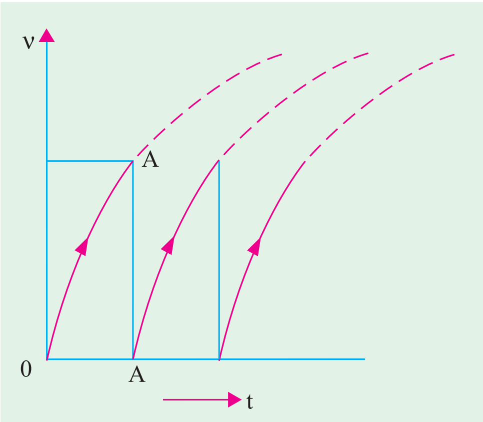


Fig. 65.24

The frequency of the wave is given by the reciprocal of time which elapses between the two waves. In Fig. 65.24, $f = 1/\lambda$.

65.28. UJT Sawtooth Generator

The circuit is shown in Fig. 65.25. It consists of a power source, a unijunction transistor and an *R-C* network.

Circuit Action

When *S* is initially closed, following chain of events takes place :

1. a small current is set up through R_2 and R_1 *via* B_2 and B_1 and an initial reverse bias is established across the E/B_1 junction;
2. at the same time, *C* begins to get charged through R_E and voltage across it increases exponentially with time towards the target voltage *V*;
3. when capacitor voltage equals the emitter firing (or peak point) voltage V_P, E/B_1 junction becomes forward-biased and the emitter goes into the negative region of its characteristic;
4. being forward-biased, E/B_1 junction offers very low resistance. Hence, *C* starts discharging through B_1 and R_1 at a rate determined mainly by E/B_1 junction resistance and R_1;
5. as capacitor voltage approaches zero, the E/B_1 junction again becomes reverse-biased and so stops conducting;
6. we revert to the initial state where *C* begins to charge and the whole cycle of circuit actions is repeated.

The emitter voltage waveform is shown in Fig. 65.25 (*b*). As seen, V_E rises exponentially towards the target voltage *V* but drops to a very low value after it reaches the value V_P due to sudden conduction through E/B_1 junction. Since R_E is large (10 *K* or so) charging rate is comparatively slow but discharge is much quicker since R_1 is very small (50 Ω or less). ***This slow charge and fast discharge produces a sawtooth wave.***

The time required for v_E to rise to V_P is given by

$$T = kR\,C \qquad \text{where} \quad k = \log_e{}^{1/(1-\eta)} \text{ and}$$

$$\eta = \text{intrinsic stand-off ratio} = \frac{R_{B1}}{R_{B1}+R_{B2}} \qquad \text{...Art 64.2}$$

Here, R_{B1} and R_{B2} are the internal inter-base resistances.

The frequency of oscillation of the *UJT* or of the output sawtooth wave is

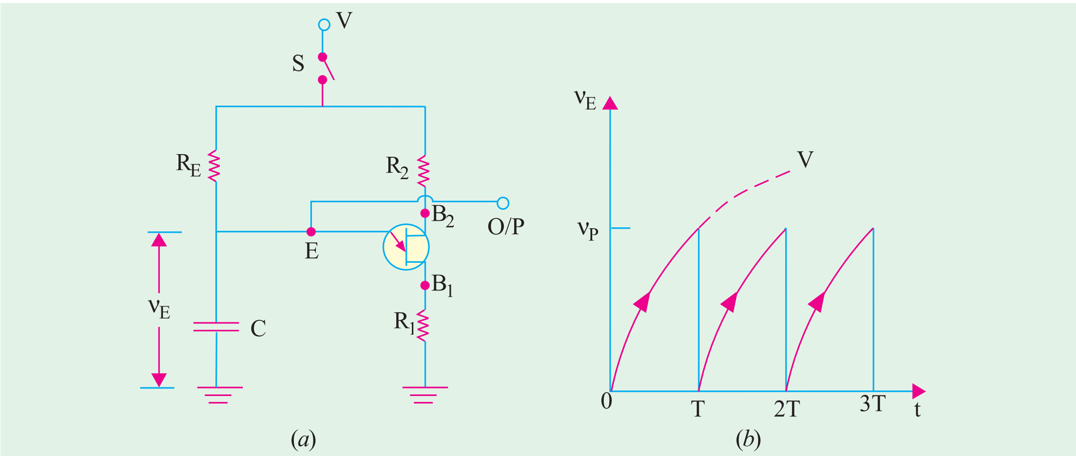


Fig. 65.25

$$f_0 = \frac{1}{T} = \frac{1}{kRC}$$

Its amplitude is determined primarily by applied voltage V and V_P.

Applications

Sawtooth voltage waves are commonly used as

1. sweep voltages at the picture tubes of TV receivers,
2. as sweep voltages of the viewing screens of oscilloscopes and radar equipment.

Example 65.15. *For the UJT oscillator circuit shown in Fig. 65.25, R_E = 10 K, η = 0.75. If the required oscillator frequency is 1 kHz, find the value of C.*

(Components and Devices, Pune Univ.)

Solution. $k = \log_e 1/(1-0.75) = \log_e 4 = 2.3 \log_{10} 4 \cong 1.4$

Now, $f_0 = \dfrac{1}{kRC}$ $\quad\therefore\quad$ $1 \times 10^3 = \dfrac{1}{1.4 \times 10 \times 10^3 \times C}$ or C = **0.07 μF**

65.29. Multivibrators (MV)

These devices are very useful as pulse generating, storing and counting circuits. They are basically **two-stage amplifiers with positive feedback from the output of one amplifier to the input of the other**. This feedback (Fig. 65.26) is supplied in such a manner that one transistor is driven to saturation and the other to cut-off. It is followed by new set of conditions in which the saturated transistor is driven to cut-off and the cut-off transistor is driven to saturation.

There are three basic types of *MVs* distinguished by the type of coupling network employed.

1. astable multivibrator (*AVM*),
2. monostable multivibrator (*MMV*),
3. bistable multivibrator (*BMV*).

The first one is the *non-driven type* whereas the other two are the *driven type* (also called triggered oscillators).

1. Astable Multivibrator (AMV)

It is also called ***free-running relaxation oscillator***. It has no stable state but only two quasi-stable (half-stable) states between which it keeps oscillating continuously of its own accord without any external excitation.

In this circuit, neither of the two transistors reaches a stable state. When one is ON, the other is OFF and they continuously switch back and forth at a rate depending on the *RC* time constant in the circuit. Hence, it oscillates and produces pulses of certain mark-to-space ratio. Moreover, two outputs (180° out of phase with each other) are available.

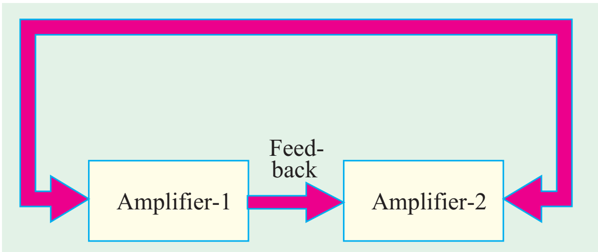


Fig. 65.26

It has two energy-storing elements ***i.e. two capacitors.***

2 . Monostable Multivibrator (MMV)

It is also called a **single-shot** or **single swing** or a **one-shot** multivibrator. Other names are : ***delay multivibrator and univibrator.*** It has

(i) one absolutely stable (stand-by) state and ***(ii)*** one quasi-stable state.

Multivibrator

It can be switched to the quasi-stable state by an external trigger pulse but it returns to the stable condition after a time delay determined by the value of circuit components. It supplies a single output pulse of a desired duration for every input trigger pulse.

It has one energy-storing element *i.e.* **one-capacitor**.

3. Bistable Multivibrator (BMV)

It is also called Eccles-Jordan or flip-flop multivibrator. It has **two absolutely stable states**. It can remain in either of these two states unless an external trigger pulse switches it from one state to the other. Obviously, ***it does not oscillate***. It has **no energy storage element**.

Detailed discrete circuits for the above MVs are discussed below after listing their uses.

65.30. Uses of Multivibrators

Some of their uses are :

1. as frequency dividers,
2. as sawtooth generators,
3. as square wave and pulse generators,
4. as a standard frequency source when synchronized by an external crystal oscillator,
5. for many specialised uses in radar and TV circuits,
6. as memory elements in computers.

65.31. Astable Multivibrator

Fig. 65.27 shows the circuit of a symmetrical collector-coupled AMV using two similar transistors. It, in fact, consists of two *CE* amplifier stages, each providing a feedback to the other. The feedback ratio is unity and positive because of 180° phase shift in each stage. Hence, the circuit oscillates. Because of the very strong feedback signal, the transistors are driven either to saturation or to cut-off (they do not work on the linear region of their characteristics).

The transistor Q_1 is forward-biased by V_{CC} and R_1 whereas Q_2 is forward-biased by V_{CC} and R_2. The collector-emitter voltages of Q_1 and Q_2 are determined respectively by R_{L1} and R_{L2} together with V_{CC}. The output of Q_1 is coupled to the input of Q_2 by C_2 whereas output of Q_2 is coupled to Q_1 by C_1.

Note that it is not essential to draw the coupling leads at 45° to the vertical as shown but it is usually done because it helps to identify the circuit immediately as MV.

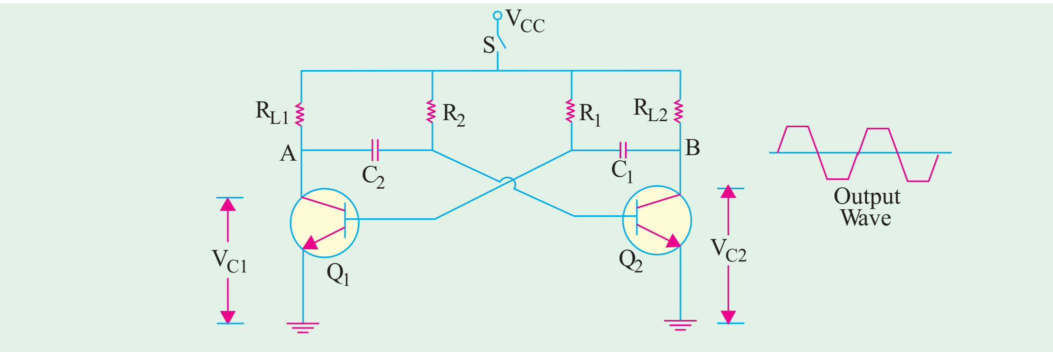


Fig. 65.27

The output can be taken either from point *A* or *B* though these would be phase-reversed with respect to each other as shown in Fig. 65.27.

Circuit Operation

The circuit operation would be easy to understand if it is remembered that due to feedback **(*i*)** when Q_1 is ON, Q_2 is OFF and **(*ii*)** when Q_2 is ON, Q_1 is OFF.

When the power is switched on by closing *S*, one of the transistors will start conducting before the other does (or slightly faster than the other). It is so because characteristics of no two seemingly similar transistors can be exactly alike. Suppose that Q_1 starts conducting before Q_2 does. The feedback system is such that Q_1 will be very rapidly driven to saturation and Q_2 to cut-off.

The following sequence of events will occur :

1. Since Q_1 is in saturation, whole of V_{CC} drops across R_{L1}. Hence, V_{C1} = 0 and point A is at zero or ground potential.
2. Since Q_2 is in cut-off *i.e.* it conducts no current, there is no drop across R_{L2}. Hence, point B is at V_{CC}.
3. Since A is at 0 V, C_2 starts to charge through R_2 towards V_{CC}.
4. When voltage across C_2 rises sufficiently (*i.e.* more than 0.7 V), it biases Q_2 in the forward direction so that it starts conducting and is soon driven to saturation.
5. V_{C2} decreases and becomes almost zero when Q_2 gets saturated. The potential of point B decreases from V_{CC} to almost 0 V. This potential decrease (negative swing) is applied to the base of Q_1 through C_1. Consequently, Q_1 is pulled out of saturation and is soon driven to cut-off.
6. Since, now, point B is at 0 V, C_1 starts charging through R_1 towards the target voltage V_{CC}.
7. When voltage of C_1 increases sufficiently, Q_1 becomes forward-biased and starts conducting. In this way, the whole cycle is repeated.

It is seen that the circuit alternates between a state in which Q_1 is ON and Q_2 is OFF and a state in which Q_1 is OFF and Q_2 is ON. The time in each state depends on RC values. Since each transistor is driven alternately into saturation and cut-off the voltage wavefrom at either collector (points A and B in Fig. 65.27) is essentially a square waveform with a peak amplitude equal to V_{CC} (Fig. 65.28).

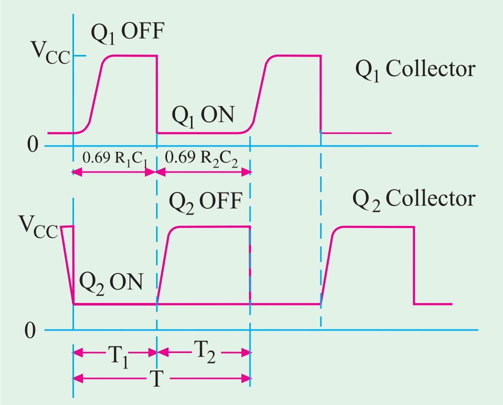


Fig. 65.28

Switching Times

It can be proved that off-time for Q_1 is $T_1 = 0.69\, R_1C_1$ and that for Q_2 is $T_2 = 0.69\, R_2C_2$.

Hence, total time-period of the wave is

$$T = T_1 + T_2 = 0.69\,(R_1C_1 + R_2\,C_2)$$

If $R_1 = R_2 = R$ and $C_1 = C_2 = C$ *i.e.* the two stages are symmetrical, then T = 1.38 RC

Frequency of Oscillation

It is given by the reciprocal of time period,

$$\therefore \quad f = \frac{1}{T} = \frac{1}{1.38\,RC} = \frac{0.7}{RC}$$

Minimum Values of β

To ensure oscillations, the transistors must saturate for which minimum values of β are as under :

$$\beta_1 = \frac{R_1}{R_{L1}} \qquad \text{and} \qquad \beta_2 = \frac{R_2}{R_{L2}}$$

If $R_1 = R_2 = R$ and $R_{L1} = R_{L2} = R_L$. then $\beta_{min} = \dfrac{R}{R_L}$

Example 65.16. *Determine the period and frequency of oscillation for an astable multivibrator with component values: R_1 = 2 K, R_2 = 20 K, C_1 = 0.01 μF and C_2 = 0.05 μF.*

Solution. T_1 = 0.69 × 2 K × 0.01 μF = 13.8 μs

and T_2 = 0.69 × 20 k × 0.05 μF = 690 μs

∴ $T = T_1 + T_2$ = 13.8 μs + 690 μs = 703.8 μs

$$\therefore \quad f_0 = \frac{1}{703.8\,\mu s} = \mathbf{1.42\ kHz}$$

Example. 65.17. *In the AMV circuit of Fig. 65.27, $R_1 = R_2 = 10$ K, $C_1 = C_2 = 0.01$ μF and $R_{L1} = R_{L2} = 1$ K. Find*

(a) frequency of circuit oscillation, *(b) minimum value of transistor β.*

(Digital Electronics, Bombay Univ.)

Solution. (*a*) $T_1 = T_2 = 0.69 \times 10 \times 10_3 \times 0.01 \times 10^{-6} = 69$ μs

$\therefore \quad T = T_1 + T_2 = 2 \times 69 = 138$ μs $\quad \therefore$

$$f_0 = \frac{1}{138 \times 10^{-6}} = \mathbf{7.25\ kHz}$$

$$(b) \quad \beta_{min} = \frac{R}{R_L} = \frac{10 \times 10^3}{1 \times 10^3} = \mathbf{10}$$

Example 65.18. *Determine the value of capacitors to be used in an astable multivibrator to provide a train of pulses 1μs side at a repetition rate of 100 kHz. Given $R_1 = R_2 = 10$ K.*

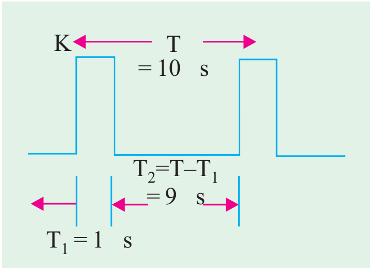


Fig. 65.29

Solution. Fig. 65.29 shows the waveform to be generated by the astable multivibrator. Note that the desired pulse width is actually the time interval $T_1 = 1$ μs and the time period T which equals 10 μs (*i.e.* 1/100 kHz) is the desired repetition time.

Now $\quad T_1 = 0.69\, R_1 C_1, \quad \therefore \quad C_1 = \dfrac{1\ \mu s}{0.69 \times 10\,K} = \mathbf{145pF}$

and $\quad T_2 = 0.69\, R_2 C_2, \quad \therefore \quad C_2 = \dfrac{9\ \mu s}{0.69 \times 10\,K} = \mathbf{1304\ pF}$

65.32. Monostable Multivibrator (MMV)

A typical *MMV* circuit is shown in Fig. 65.30. Here, Q_1 is coupled to Q_2 base as in an *AMV* but the other coupling is different. In this multivibrator, a single narrow input trigger pulse produces a single rectangular pulse whose amplitude, pulse width and wave shape depend upon the values of circuit components rather than upon the trigger pulse.

Initial Condition

In the absence of a triggering pulse at C_2 and with S closed,

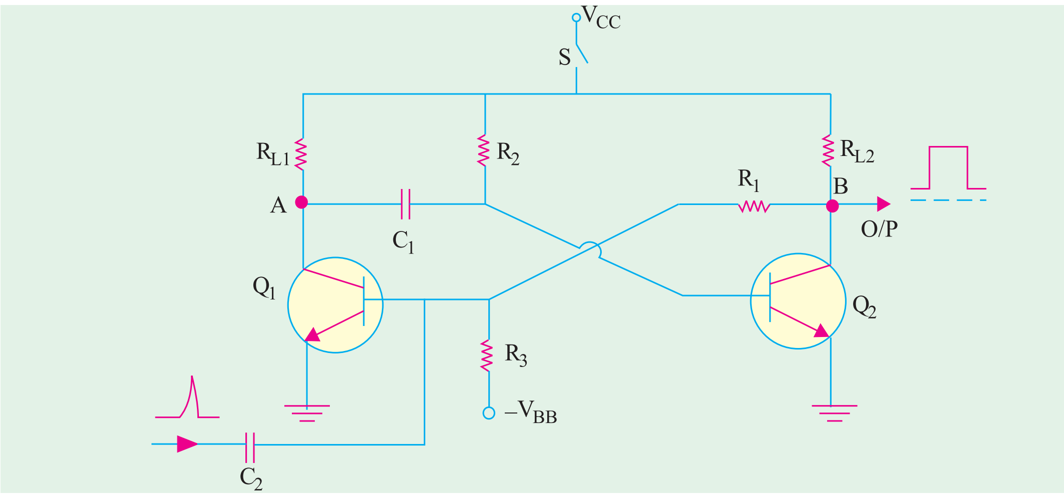


Fig. 65.30

1. V_{CC} provides reverse bias for *C/B* junctions of Q_1 and Q_2 but forward-bias for *E/B* junction of Q_2 only. Hence, Q_2 conducts at saturation.
2. V_{BB} and R_3 reverse bias Q_1 and keep it cut off.
3. C_1 charges to nearly V_{CC} through R_{L1} to ground by the low-resistance path provided by saturated Q_2.

As seen, the initial stable state is represented by

(i) Q_2 conducting at saturation and ***(ii)*** Q_1 cut-off.

When Trigger Pulse is Applied

When a trigger pulse is applied to Q_1 through C_2, *MMV* will switch to its opposite unstable state where Q_2 is cut-off and Q_1 conducts at saturation. The chain of circuit actions is as under :

1. If positive trigger pulse is of sufficient amplitude, it will override the reverse bias of the *E/B* junction of Q_1 and give it a forward bias. Hence, Q_1 will start conducting.
2. As Q_1 conducts, its collector voltage falls due to voltage drop across R_{L1}. It means that potential of point *A* falls (negative-going signal). This negative-going voltage is fed to Q_2 *via* C_1 where it decreases its forward bias.
3. As collector current of Q_1 starts decreasing, potential of point *B* increases (positive-going signal) due to lesser drop over R_{L2}. Soon, Q_2 comes out of conduction.
4. The positive-going signal at *B* is fed *via* R_1 to the base of Q_1 where it increases its forward bias further. As Q_1 conducts more, potential of point *A* approaches 0 V.
5. This action is cumulative and ends with Q_1 conducting at saturation and Q_2 cut-off.

Return to Initial Stable State

1. As point A is at almost 0 V, C_1 starts to discharge through saturated Q_1 to ground.
2. As C_1 discharges, the negative potential at the base of Q_2 is decreased. As C_1 discharges further, Q_2 is pulled out of cut-off.
3. As Q_2 conducts further, a negative-going signal from point *B via* R_1 drives Q_1 into cut-off.

Hence, the circuit reverts to its original state with Q_2 conducting at saturation and Q_1 cut-off. It remains in this state till another trigger pulse comes along when the entire cycle repeats itself.

As shown in Fig. 65.30, the output is taken from the collector of Q_2 though it can also be taken from point A of Q_1. The width of this pulse is determined by the time constant of C_1R_2. Since this MV produces one output pulse for every input trigger pulse it receives, it is called ***mono or one-shot multivibrator.***

The width or duration of the pulse is given by $T = 0.69\ C_1R_2$

It is also known as the one-shot period.

Uses

1. The falling part of the output pulse from *MMV* is often used to trigger another pulse generator circuit thus producing a pulse delayed by a time *T* with respect to the input pulse.
2. *MMV* is used for regenerating or rejuvenating old and worn out pulses. Various pulses used in computers and telecommunication systems become somewhat distorted during use. An *MMV* can be used to generate new, clean and sharp pulses from these distorted and used ones.

Example 65.19. *A 20 kHz, 75% duty cycle square (t_p) wave is used to trigger continuously, a monostable multivibrator with a triggered pulse duration of 5μs. What will be the duty cycle of the waveform at output (B) of the monostable multivibrator (refer to Fig. 65.30).*

Solution. Time period of the square wave

$$T = \frac{1}{f} = \frac{1}{20\,\text{kHz}} = 50\,\mu\text{s}$$

Since the duty cycle of the square wave is 75%, therefore the time interval during which the input waveform is at a higher voltage level is, 0.75 × 50 µs = 37.5 µs. Fig. 65.31 (*a*) shows a sketch of the input waveform which is used to trigger the monostable multivibrator.

Now the monostable multivibrator is triggered once each time a new pulse arives. The monostable multivibrator remains triggered only for a duration, t_p = 5 µs. A sketch of the waveform at the output (B) of the monostable multivibrator is as shown in Fig. 65.31(*b*).

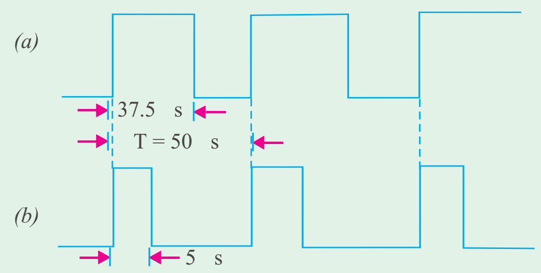


Fig. 65.31

Example 65.20. *A monostable multivibrator is required to convert a 100 kHz, 30% duty cycle square wave to a 100 kHz, 50% duty cycle square wave. Find the values of R_2 and C_2.*

Solution. Fig. 65.32 (*a*) shows a sketch of the input waveform. In order to convert it to a square waveform with 50% duty cycle, we want that the monostable multivibrator must remain triggered for 50% of the time period.

Now time period of 100 kHz square wave,

$$T = \frac{1}{f} = \frac{1}{100\,\text{kHz}} = 10\,\mu\text{s}$$

∴ The duration for which the monostable multivibrator must remain triggered = 50% × 10 µs= 5 µs.

Fig. 65.32 (*b*) shows a sketch of the required waveform at the output of the monostable multivibrator.

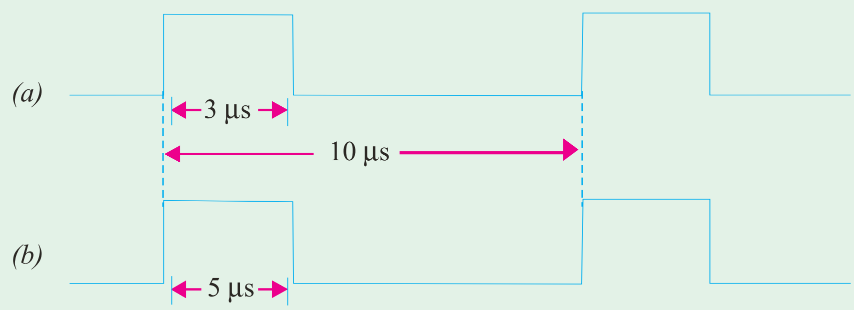


Fig. 65.32

Now width or duration of the pulse,

$T = 0.69\, C_1 R_2$

Let us select *C_1 = 0.001µF, then from the above equation.

* You can chose any value of *C* which could result in the value of R_2 in kilohms. The reason for this is that we want the current in the circuit to be limited to few milliamperes.

$$R_2 = \frac{T}{0.69C_1} = \frac{5\mu s}{0.69 \times 0.001\mu F} = \mathbf{7.2\ K}$$

65.33. Bistable Multivibrator (BMV)

The basic circuit is shown in Fig. 65.33. As stated earlier, it has **two absolutely stable** states. It can stay ***in one of its two states indefinitely*** (as long as power is supplied) changing to the other state only when it receives a trigger pulse from outside. When it receives another triggering pulse, only then it goes back to its original state. Since one trigger pulse causes the *MV* to 'flip' from one state to another and the next pulse causes it to ***'flop'*** back to its original state, the *BMV* is also popularly known as **'flip-flop'** circuit.

The *BMV* circuit shown in Fig. 65.33 differs from the *AMV* circuit of Fig. 65.27 in the following respects :

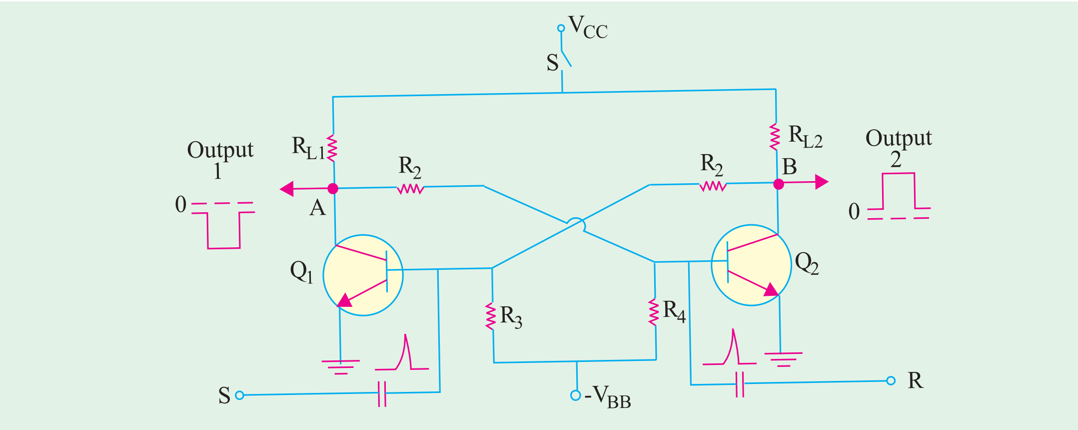


Fig. 65.33

1. the base resistors are not joined to V_{CC} but to a common source–V_{BB},
2. the feedback is coupled through two resistors (not capacitors).

Circuit Action

If Q_1 is conducting, then the fact that point *A* is at nearly 0 V makes the base of Q_2 negative (by the potential divider $R_2 - R_4$) and holds Q_2 off.

Similarly, with Q_2 OFF, the potential divider from V_{CC} to $-V_{BB}$ (R_{L2}. R_1, R_3) is designed to keep base of Q_1 at about 0.7 V ensuring that Q_1 conducts. It is seen that Q_1 holds Q_2 OFF and Q_3 holds Q_1 ON.

Suppose, now, a positive pulse is applied momentarily to *R*, it will cause Q_2 to conduct. As collector of Q_2 falls to zero, it cuts Q_1 OFF and, consequently, the *BMV* switches over to its other state.

Similarly, a positive trigger pulse applied to *S* will switch the *BMV* back to its original state.

Uses

1. in timing circuits as a frequency divider,
2. in counting circuits,
3. in computer memory circuits.

65.34. Schmitt Trigger

The Schmitt trigger (after the name of its invertor) is a **binary circuit** and **closely resembles an MV**. It has two bistable states and the magnitude of the input voltage determines which of the two is possible. It is also called emitter-coupled binary oscillator because positive feedback occurs by coupling through emitter resistor R_E.

The Quiescent Condition

As shown in Fig. 65.34, it consists of two similar transistors Q_1 and Q_2 coupled through R_E. Resistors R_1, R_3 and R_4 form a voltage divider across V_{CC} and $-V_{BB}$ which places a small positive voltage (forward bias) on the base of Q_2. Hence, when power is first switched ON, Q_2 starts conducting. The flow of its current through R_E places a small reverse bias on the base of Q_1, thereby cutting it OFF. Consequently, collector of Q_1 rises to V_{CC}. This positive voltage, coupled to the base of Q_2 through R_3, drives Q_2 into saturation and holds it there.

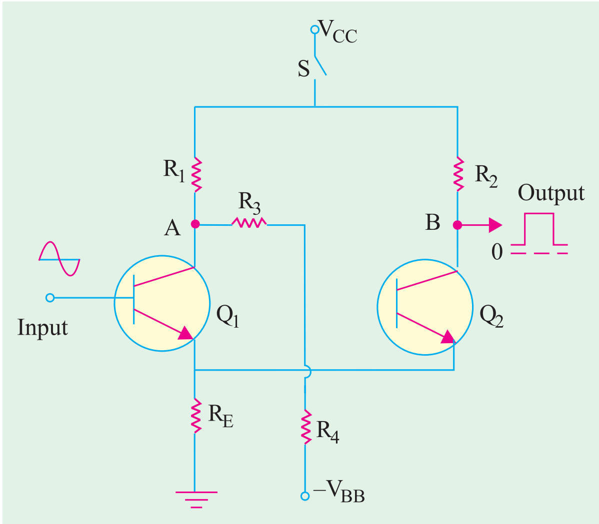


Fig. 65.34

Hence, in the initial static or quiescent condition of the Schmitt trigger,

1. Q_2 is in saturation,
2. Q_1 is cut-off,
3. collector of Q_2 is at 0 V,
4. collector of Q_1 is at V_{CC}.

Circuit Action

Suppose, positive half-cycle of the input ac voltage is applied to the trigger input first. Let us further suppose that this positive voltage is sufficient to overcome the reverse bias on the base of Q_1 placed there by the voltage drop across R_E. Then, the chain of events that follows is as under :

1. Q_1 comes out of cut-off and starts to conduct;
2. as it does so, its collector voltage drops (swings negative);
3. this negative-swinging voltage coupled to the base of Q_2 *via* R_3 reduces its forward bias and hence its emitter current;
4. with reduced emitter current, voltage drop across R_E is reduced;
5. consequently, reverse bias of Q_1 is further lowered and it conducts more heavily;
6. as a result, collector voltage of Q_1 falls further, thereby driving Q_2 still closer to cut-off.

This process is cumulative and ends up with

(*a*) Q_1 conducting at saturation with its collector voltage almost zero;
(*b*) Q_2 becoming cut-off with its collector voltage nearly V_{CC}.

Negative Half-cycle of the Input Voltage

Now, when the negative half-cycle of the input voltage is applied

1. Q_1 becomes reverse-biased. Consequently, its collector current falls and collector voltage rises (*i.e.* potential of point A increases towards V_{CC}) ;

2. this positive-swinging voltage is coupled to the base of Q_2 through R_3 and, as a result, Q_2 is driven to saturation;

3. this re-establishes the original conditions of

(*a*) Q_1 cut off with collector voltage at V_{CC} and
(*b*) Q_2 at saturation with collector voltage at 0 V.

It completes one cycle. This cycle is repeated as the input voltage rises and falls again. Hence, each cycle of the Schmitt trigger produces a positive-going pulse at its output which is taken out from the collector of Q_2 *i.e.* from point *B* in Fig. 65.34.

Output Pulse Width

It depends on the time during which Q_2 is conducting. It, in turn, depends on the input voltage, within the limits imposed by emitter resistor R_E.

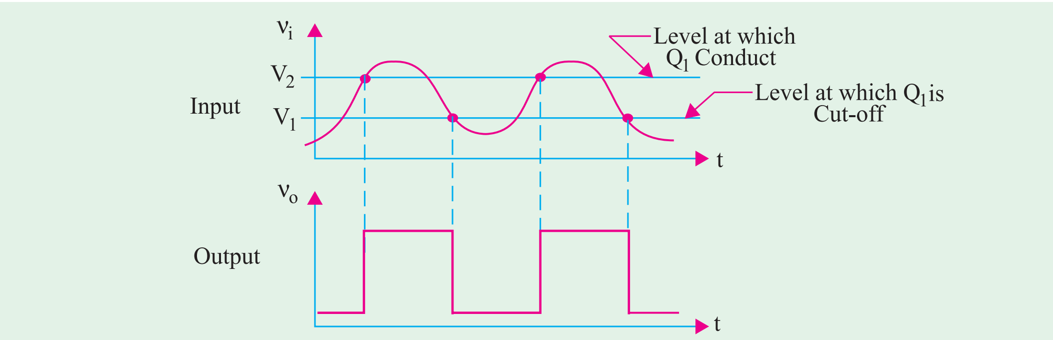


Fig. 65.35

Uses

1. It is frequently used for wave-shaping purposes. As shown in Fig. 65.35, it can convert inputs with any waveshape into output pulses having rectangular or square waveshapes. That is why Schmitt trigger is often called a **'squaring' circuit** or a **'squarer'** circuit.
2. It can reshape worn-out pulses by giving them sharp leading and trailing edges.
3. Since a change of state occurs whenever the input crosses a trigger point, the Schmitt trigger is often used as a **level detector** *i.e.* as a pulse height discriminator.

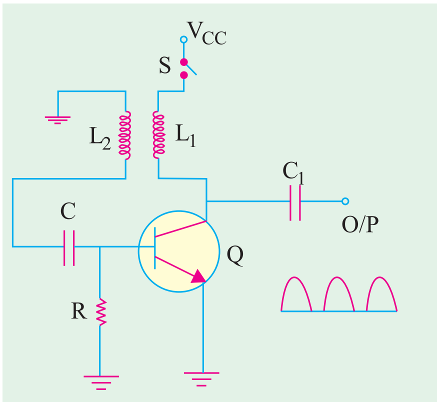


Fig. 65.36

65.35. Transistor Blocking Oscillator

The basic circuit is shown in Fig. 65.36. When *S* is closed, base current rises rapidly due to forward-bias placed by V_{CC} on the *E/B* junction of *Q*. It causes a corresponding increase in its collector current. This rising flow of I_C through L_1 produces an induced *e.m.f.* in L_2. Coupling between L_1 and L_2 is such that lower end of L_2 becomes positive and the grounded end negative.

The positive voltage from L_2 is applied to the base of *Q* through *C*. It further increases the forward-bias of the *E/B* junction which leads to further increase in I_C. Since this process is cumulative, *Q* is quickly driven to saturation. At that point, there is no further increase in I_C and hence, no induced *e.m.f.* in L_2 to be applied to *Q*.

Now, *C* which had been charged earlier, places a negative charge on the base of *Q* which reverse-biases its *E/B* junction and ultimately drives it to cut-off.

The transistor remains at cut-off as *C* now starts to discharge through *R*. When sufficient amount of charge leaks off *C* so that reverse bias of *E/B* junction is removed and forward bias is re-established, *Q* comes out of cut-off and its collector current starts rising once again. Then, the entire cycle of operation is repeated. As shown, the output consists of sharp and narrow pulses.

Tutorial Problems No. 65.1

1. A tuned collector oscillator circuit is tuned to operate at 22 kHz by a variable capacitor set to 2 nF. Find the value of tuned circuit inductance. **(0.026 H)**

2. A tuned collector oscillator operates at 2.2 MHz frequency. At what frequency will it work if its tuned circuit capacitance is reduced by 50% ? **(3.11 MHz)**

3. In a transistorized Hartley oscillator, the tank circuit has the capacitance of 100 pF. The value of inductance between the collector and tapping point is 30 μH and the value of inductance between the tapping point and the transistor base is 100 μH. Determine the frequency of oscillators. Neglect the mutual inductance. **(2.9 MHz)**

4. For the transistor Hartley oscillator circuit shown in Fig. 65.37, find the frequency of operation. Neglect the mutual inductance between the coils. **(73.1 kHz)**

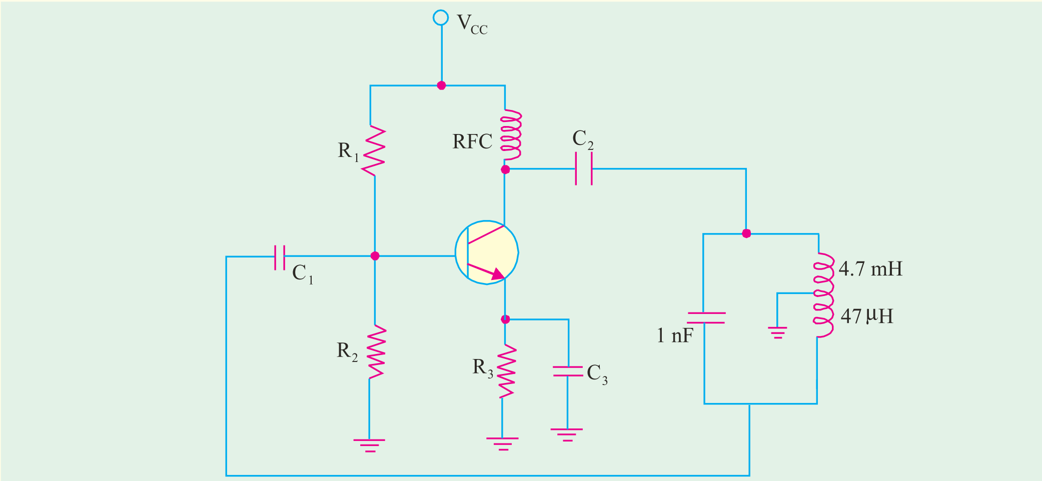


Fig. 65.37

5. A transistor Hartley oscillator is designed with L_1 = 2 mH, L_2 = 20 μH and a variable capacitance. Determine the range of capacitance values if the frequency of operation is varied from 950 kHz to 2050 kHz. **(2.98 pF to 13.9 pF)**

6. In a transistor Colpitts oscillator, C_1 = 0.001μF, C_2 = 0.01 μF and L = 5 μH. Find the required gain for oscillation and the frequency of oscillations. **(0.91 nF and 2.37 MHz)**

7. Determine the frequency of oscillations for the transistor Colpitts oscillator circuit shown in Fig. 65.38. **(24.4 kHz)**

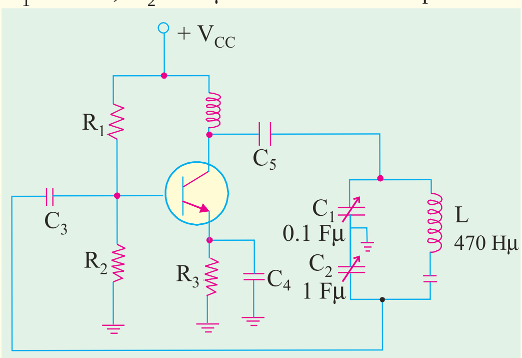


Fig. 65.38

8. A Colpitts oscillator is designed with C_1 = 100 pF, C_2 = 7500 pF. The inductance is variable. Determine the range of inductance values if the frequency of oscillation is to vary between 950 kHz and 2050 kHz. **(61 μH to 284 μH)**

9. The frequency of oscillation of a Colpitts oscillator is given by,

$$f_0 = \frac{1}{2\pi\sqrt{L\left(\dfrac{C_1C_2}{C_1+C_2}\right)}}$$

where L, C_1 and C_2 are the frequency-determining components. Such a circuit operates at 450 kHz with $C_1 = C_2$. What will be the oscillation frequency if the value of C_2 is doubled.

(389.7 kHz)

10. Calculate the frequency of oscillations for the Clapp oscillator shown in Fig. 65.39. **(734.5 kHz)**

11. A crystal has the following parameters : L = 0.33 H, C_1 = 0.065 pF, C_2 = 1 pF and R = 5.5 KΩ. Find the series resonant frequency and Q-factor of the crystal. **(1.09 MHz and 411)**

12. A Wien Bridge oscillator is used for operation at f_0 = 10 kHz. The value of R is 100 K, find the value of capacitor, C. Assume $R_1 = R_2 = R$ and $C_1 = C_2 = C$. **(159 pF)**

13. *A RC* phase shift oscillator has R = 1kΩ and C = 0.01 μF. Calculate the frequency of oscillations **(*Electronics Engg, Annamalai Univ. 2002*)**

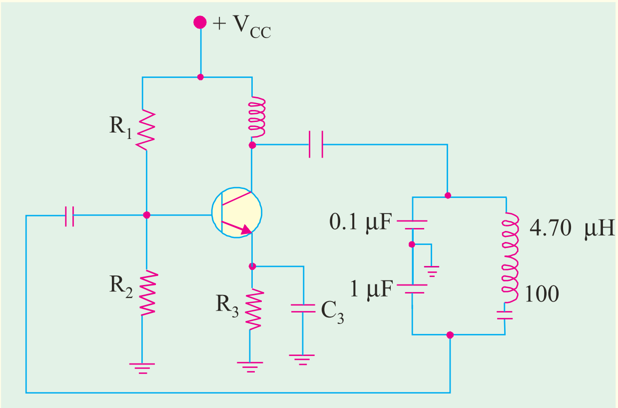


Fig. 65.39

14. Calculate the frequency and the duty cycle of the output of stable multivibrator and draw the waveform obtained across the capacitor C_T. as shown in Fig. 65.40. **(*Electronics Engg. Bangalore Univ. 2001*)**

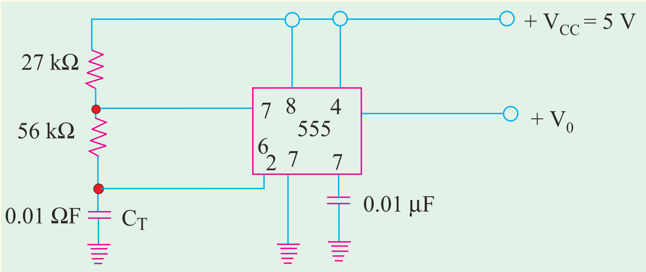


Fig. 65.40

15. In an Hartey oscillator if L_1 = 0.1 mH, L_2 = 10 μH and mutual inductance between the coils equal to 20 μH. Calculate the value of capacitor C of the oscillatory circuit to obtain frequency of 4110 kHz and also find the condition for sustained oscillations. **(*Electronics Engg: Bangalore Univ. 2001*)**

16. Calculate the frequency of oscillation of a colpit oscillator with $C_1 = C_2$ = 400 pF and L = 2mH. **(*Electronics Engg., Bangalore Univ. 2002*)**

17. In an R-C phase shift oscillator R = 5000 Ω and C = 0.1 MF. Calculate the frequency of oscillations. **(Electronics Engg., Bangalore Univ. 2002**

OBJECTIVE TESTS – 65

1. An electronic oscillator is
(*a*) just like an alternator
(*b*) nothing but an amplifier
(*c*) an amplifier with feedback
(*d*) a converter of ac to dc energy.

2. The frequency of oscillation of an elementary *LC* oscillatory circuit depends on
(*a*) coil resistance
(*b*) coil inductance
(*c*) capacitance
(*d*) both (*b*) and (*c*).

3. For sustaining oscillations in an oscillator
(*a*) feedback factor should be unity
(*b*) phase shift should be 0°
(*c*) feedback should be negative
(*d*) both (*a*) and (*b*).

4. If Barkhausen criterion is not fulfilled by an oscillator circuit, it will
(*a*) stop oscillating
(*b*) produce damped waves continuously
(*c*) become an amplifier
(*d*) produce high-frequency whistles.

5. In a transistor Hartley oscillator
(*a*) inductive feedback is used
(*b*) untapped coil is used
(*c*) entire coil is in the output circuit
(*d*) no capacitor is used

6. A Hartley oscillator is used for generating
(*a*) very low frequency oscillation
(*b*) radio-frequency oscillation
(*c*) microwave oscillation
(*d*) audio-frequency oscillation

7. A Colpitts oscillator uses
(*a*) tapped coil
(*b*) inductive feedback
(*c*) tapped capacitance
(*d*) no tuned *LC* circuit

8. In *RC* phase-shift oscillator circuits.
(*a*) there is no need for feedback
(*b*) feedback factor is less than unity
(*c*) pure sine wave output is possible
(*d*) transistor parameters determine osci- llation frequency.

9. Wien bridge oscillator is most often used whenever
(*a*) wide range of high purity sine waves is to be generated
(*b*) high feedback ratio is needed
(*c*) square output waves are required
(*d*) extremely high resonant frequencies are required.

10. The RC network shown in Fig 65.40 can provide a maximum theoretical phase shift of

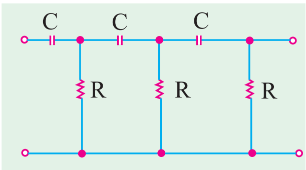


Fig. 65.41

(*a*) 90° (*b*) 180° (*c*) 270° (*d*) 360°
(UPSC Engineering Services 2002)

11. A *CE* amplifier can be converted into oscillator by
(*a*) providing adequate positive feedback
(*b*) phase shifting the output by 180° and feeding this phase-shifted output to the input.
(*c*) using only a series tuned circuit as a load on the amplifier
(*d*) using a negative resistance device as a load on the amplifier
(*e*) all of the above
(UPSC Engineering Service, 2002)

12. The primary advantage of a crystal oscillator is that
(*a*) it can oscillate at any frequency
(*b*) it gives a high output voltage
(*c*) its frequency of oscillation remains almost constant
(*d*) it operates on a very low dc supply voltage.

13. Non-sinusoidal waveforms
(*a*) are departures from sine waveform
(*b*) have low mark-to-space ratio
(*c*) are much easier to generate
(*d*) are unfit for digital operation.

14. A relaxation oscillator is one which
(*a*) has two stable states
(*b*) relaxes indefinitely
(*c*) produces non-sinusoidal output
(*d*) oscillates continuously.

15. A square pulse has a mark-to-space ratio of
(*a*) 1 : 1 (*b*) 1 : 2 (*c*) 2 : 1 (*d*) 1 : 4.

16. Apart from a dc power source, the essential requirements of a sawtooth generator are
(*a*) a resistor (*b*) a capacitor
(*c*) a switching device (*d*) all of the above.

17. Which of the following statement is WRONG ? In a multivibrator
(*a*) output is available continuously
(*b*) feedback between two stages is 100%
(*c*) positive feedback is employed
(*d*) when one transistor is ON, the other is OFF.

18. An MMV circuit
(*a*) has no stable state
(*b*) gives two output pulses for one input trig ger pulse
(*c*) returns to its stand-by states automatically
(d) has no energy-storage element.

19. A BMV circuit
(*a*) has two unstable states
(*b*) has one energy-storage element
(*c*) switches between its two states automatically
(*d*) is not an oscillator.

20. The digital circuit using two inverters shown in Fig. 65.42 will act as
(*a*) a bistable multi-vibrator
(*b*) an astable multi-vibrator
(*c*) a monostable multi-vibrator
(*d*) an oscillator

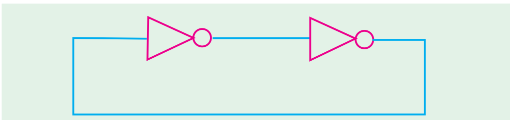


Fig. 65.42

21. In the Schmitt trigger circuit shown in Fig. 65.43 if $V_{CE(sat)} = 0.1$ *V*, the output logic low level (V_{OL}) is

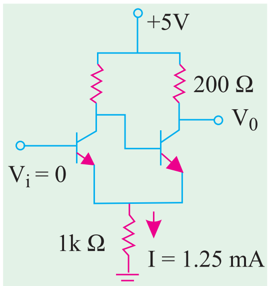


Fig. 65.43

(*a*) 1.25 V
(*b*) 1.35 V
(*c*) 2.50 V
(*d*) 5.00 V

ANSWERS

1. (*c*)	**2.** (*d*)	**3.** (*d*)	**4.** (*a*)	**5.** (*a*)	**6.** (*b*)	**7.** (*c*)	**8.** (*c*)	**9.** (*a*)	**10.** (*b*)	**11.** (*b*)
12. (*c*)	**13.** (*a*)	**14.** (*c*)	**15.** (*a*)	**16.** (*d*)	**17.** (*a*)	**18.** (*c*)	**19.** (*a*)	**20.** (*a*)	**21.** (*b*)	

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