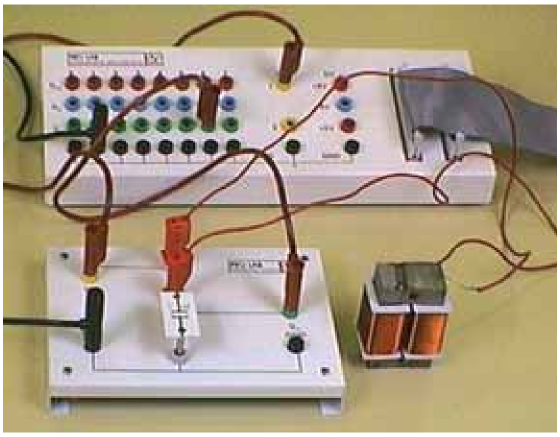
Contents

14

Sinusoidal Oscillators



INTRODUCTION

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

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

14.1 Sinusoidal Oscillator

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

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

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

Advantages

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

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

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

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

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

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

(*vi*) It has very high efficiency.

14.2 Types of Sinusoidal Oscillations

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

(*i*) **Damped oscillations.** The electrical oscillations whose amplitude goes on decreasing with time are called *damped oscillations*. Fig. 14.1 (*i*) shows waveform of damped electrical oscillations. Obviously, the electrical system in which these oscillations are generated has losses and some energy is lost during each oscillation. Further, no means are provided to compensate for the losses and consequently the amplitude of the generated wave decreases gradually. It may be noted that frequency of oscillations remains unchanged since it depends upon the constants of the electrical system.

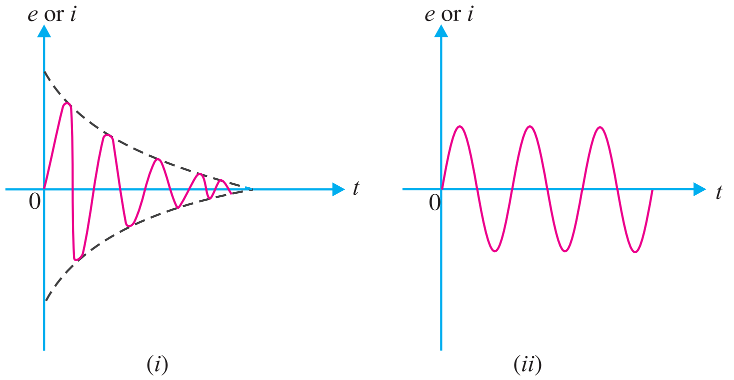


Fig. 14.1

* Note that oscillations are produced without any external signal source. The only input power to an oscillator is the d.c. power supply.

***(ii)* Undamped oscillations.** The electrical oscillations whose amplitude remains constant with time are called *undamped oscillations*. Fig. 14.1 (*ii*) shows waveform of undamped electrical oscillations. Although the electrical system in which these oscillations are being generated has also losses, but now right amount of energy is being supplied to overcome the losses. Consequently, the amplitude of the generated wave remains constant. It should be emphasised that an oscillator is required to produce undamped electrical oscillations for utilising in various electronics equipment.

14.3 Oscillatory Circuit

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

A simple oscillatory circuit consists of a capacitor (*C*) and inductance coil (*L*) in parallel as shown in Fig. 14.2. This electrical system can produce electrical oscillations of frequency determined by the values of *L* and *C*. To understand how this comes about, suppose the capacitor is charged from a d.c. source with a polarity as shown in Fig. 14.2 (*i*).

(*i*) In the position shown in Fig. 14.2 (*i*), the upper plate of capacitor has deficit of electrons and the lower plate has excess of electrons. Therefore, there is a voltage across the capacitor and the capacitor has electrostatic energy.

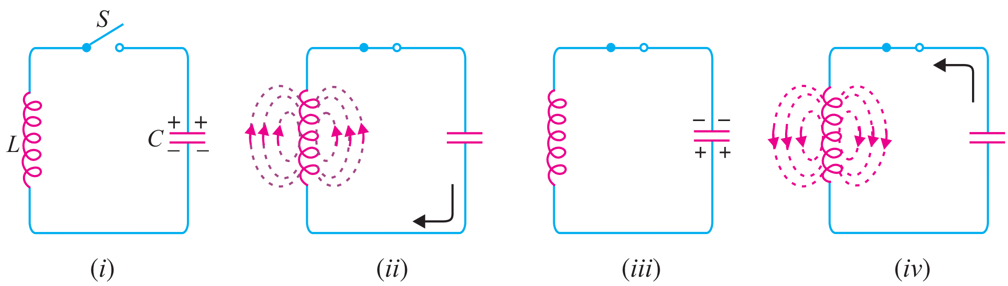


Fig. 14.2

(*ii*) When switch *S* is closed as shown in Fig. 14.2 (*ii*) , the capacitor will discharge through inductance and the electron flow will be in the direction indicated by the arrow. This current flow sets up magnetic field around the coil. Due to the inductive effect, the current builds up slowly towards a maximum value. The circuit current will be maximum when the capacitor is fully discharged. At this instant, electrostatic energy is zero but because electron motion is greatest (*i.e.* maximum current), the magnetic field energy around the coil is maximum. This is shown in Fig. 14.2 (*ii*). Obviously, the electrostatic energy across the capacitor is completely converted into magnetic field energy around the coil.

(*iii*) Once the capacitor is discharged, the magnetic field will begin to collapse and produce a counter e.m.f. According to Lenz's law, the counter e.m.f. will keep the current flowing in the same direction. The result is that the capacitor is now charged with opposite polarity, making upper plate of capacitor negative and lower plate positive as shown in Fig. 14.2 (*iii*).

(*iv*) After the collapsing field has recharged the capacitor, the capacitor now begins to discharge; current now flowing in the opposite direction. Fig. 14.2 (*iv*) shows capacitor fully discharged and maximum current flowing.

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

Waveform. If there were no losses in the tank circuit to consume the energy, the interchange of energy between L and C would continue indefinitely. In a practical tank circuit, there are resistive and radiation losses in the coil and dielectric losses in the capacitor. During each cycle, a small part of the originally imparted energy is used up to overcome these losses. The result is that the amplitude of oscillating current decreases gradually and eventually it becomes zero when all the energy is consumed as losses. Therefore, the tank circuit by itself will produce *damped oscillations* as shown in Fig. 14.3.

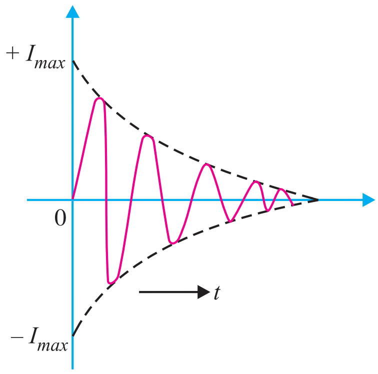


Fig. 14.3

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

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

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

14.4. Undamped Oscillations from Tank Circuit

As discussed before, a tank circuit produces damped oscillations. However, in practice, we need continuous undamped oscillations for the successful operation of electronics equipment. In order to make the oscillations in the tank circuit undamped, it is necessary to supply correct amount of energy to the tank circuit at the proper time intervals to meet the losses. Thus referring back to Fig. 14.2, any energy which would be applied to the circuit must have a polarity conforming to the existing polarity at the instant of application of energy. If the applied energy is of opposite polarity, it would oppose the energy in the tank circuit, causing stoppage of oscillations. Therefore, in order to make the oscillations in the tank circuit undamped, the following conditions must be fulfilled :

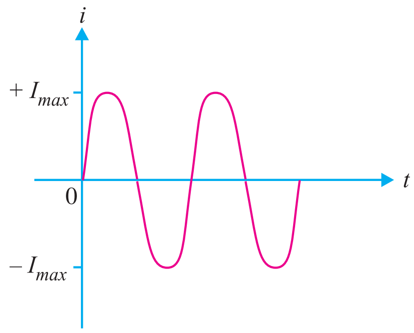


Fig. 14.4

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

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

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

receiver makes use of an LC tuned circuit with L_1 = 58.6 µH and C_1 = 300 pF. Calculate the frequency of oscillations.

Solution.

$$L_1 = 58.6\ \mu\text{H} = 58.6 \times 10^{-6}\ \text{H}$$

$$C_1 = 300\ \text{pF} = 300 \times 10^{-12}\ \text{F}$$

Frequency of oscillations,
$$f = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

$$= \frac{1}{2\pi\sqrt{58.6 \times 10^{-6} \times 300 \times 10^{-12}}}\ \text{Hz}$$

$$= 1199 \times 10^3\ \text{Hz} = \textbf{1199 kHz}$$

Example 14.2. *Find the capacitance of the capacitor required to build an LC oscillator that uses an inductance of L_1 = 1 mH to produce a sine wave of frequency 1 GHz (1 GHz = 1 × 10^{12} Hz).*

Solution.

Frequency of oscillations is given by ;

$$f = \frac{1}{2\pi\sqrt{L_1 C_1}}$$

or
$$C_1 = \frac{1}{L_1 (2\pi f)^2} = \frac{1}{(1 \times 10^{-3})(2\pi \times 1 \times 10^{12})^2}$$

$$= 2{\cdot}53 \times 10^{-23}\ \text{F} = \mathbf{2{\cdot}53 \times 10^{-11}\ pF}$$

The LC circuit is often called *tuned circuit* or *tank circuit.*

14.10 Colpitt's Oscillator

Fig. 14.10 shows a Colpitt's oscillator. It uses two capacitors and placed across a common inductor *L* and the centre of the two capacitors is tapped. The tank circuit is made up of C_1, C_2 and *L*. The frequency of oscillations is determined by the values of C_1, C_2 and *L* and is given by ;

$$f = \frac{1}{2\pi\sqrt{LC_T}} \quad \text{....}(i)$$

where
$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

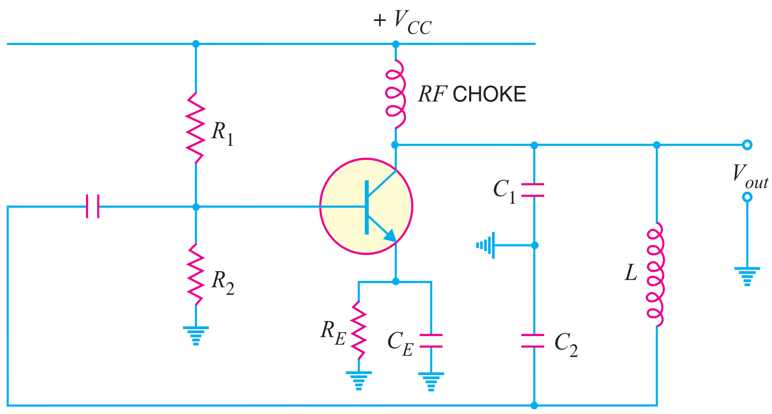


Fig. 14.10

*Note that $C_1 - C_2 - L$ is also the feedback circuit that produces a phase shift of 180°.

Circuit operation. When the circuit is turned on, the capacitors C_1 and C_2 are charged. The capacitors discharge through L, setting up oscillations of frequency determined by exp.** (*i*). The output voltage of the amplifier appears across C_1 and feedback voltage is developed across C_2. The voltage across it is 180° out of phase with the voltage developed across C_1 (V_{out}) as shown in Fig. 14.11. It is easy to see that voltage fedback (voltage across C_2) to the transistor provides positive feedback. A phase shift of 180° is produced by the transistor and a further phase shift of 180° is produced by $C_1 - C_2$ voltage divider. In this way, feedback is properly phased to produce continuous undamped oscillation.

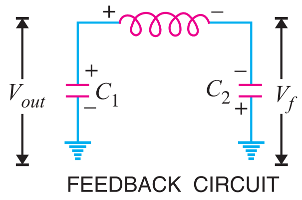


Fig. 14.11

Feedback fraction m_v. The amount of feedback voltage in Colpitt's oscillator depends upon feedback fraction m_v of the circuit. For this circuit,

$$\text{Feedback fraction, } m_v = \frac{V_f}{V_{out}} = \frac{X_{c2}}{X_{c1}} = \frac{C_1}{C_2}^{***}$$

or $$m_v = \frac{C_1}{C_2}$$

Example 14.3. *Determine the (i) operating frequency and (ii) feedback fraction for Colpitt's oscillator shown in Fig. 14.12.*

Solution.

(*i*) Operating Frequency. The operating frequency of the circuit is always equal to the resonant frequency of the feedback network. As noted previously, the capacitors C_1 and C_2 are in series.

$$\therefore \quad C_T = \frac{C_1 C_2}{C_1 + C_2} = \frac{0.001 \times 0.01}{0.001 + 0.01} = 9.09 \times 10^{-4}\ \mu\text{F}$$

$$= 909 \times 10^{-12}\ \text{F}$$

$$L = 15\ \mu\text{H} = 15 \times 10^{-6}\ \text{H}$$

$$\therefore \quad \text{Operating frequency, } f = \frac{1}{2\pi\sqrt{LC_T}}$$

$$= \frac{1}{2\pi\sqrt{15 \times 10^{-6} \times 909 \times 10^{-12}}}\ \text{Hz}$$

$$= 1361 \times 10^3\ \text{Hz} = \mathbf{1361\ kHz}$$

(*ii*) Feedback fraction

$$m_v = \frac{C_1}{C_2} = \frac{0.001}{0.01} = \mathbf{0.1}$$

* The RF choke decouples any ac signal on the power lines from affecting the output signal.

** Referring to Fig. 14.11, it is clear that C_1 and C_2 are in series. Therefore, total capacitance C_T is given by;

$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

*** Referring to Fig. 14.11, the circulating current for the two capacitors is the same. Futher, capacitive reactance is inversely proportional to capacitance.

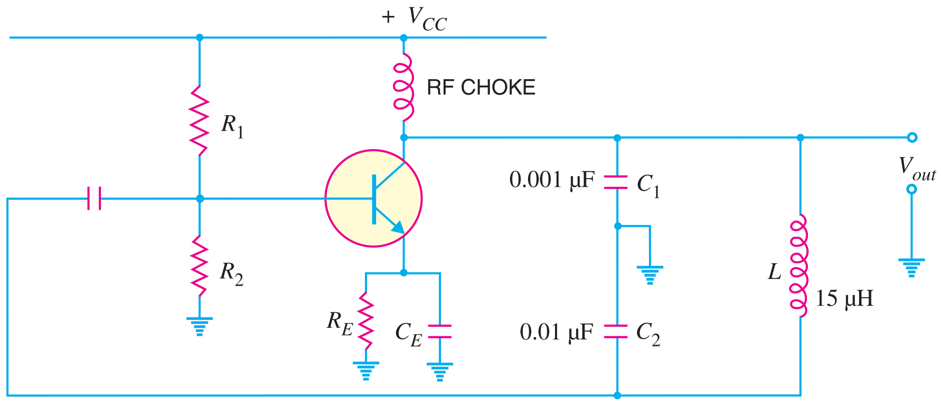


Fig. 14.12

Example 14.4. *A 1 mH inductor is available. Choose the capacitor values in a Colpitts oscillator so that f = 1 MHz and m_v = 0.25.*

Solution.

Feedback fraction, $m_v = \dfrac{C_1}{C_2}$

or $0.25 = \dfrac{C_1}{C_2}$ $\qquad \therefore \; C_2 = 4C_1$

Now $f = \dfrac{1}{2\pi\sqrt{LC_T}}$

or $C_T = \dfrac{1}{L(2\pi f)^2} = \dfrac{1}{(1\times10^{-3})\,(2\pi\times1\times10^6)^2} = 25.\,3\times10^{-12}$ F

$= 25.3$ pF

or $\dfrac{C_1 C_2}{C_1 + C_2} = 25.3$ pF $\qquad \left[\because C_T = \dfrac{C_1 C_2}{C_1 + C_2}\right]$

or $\dfrac{C_2}{1+\dfrac{C_2}{C_1}} = 25.3$

or $\dfrac{C_2}{1+4} = 25.3$ $\qquad \therefore \; C_2 = 25.3 \times 5 =$ **126.5 pF**

and $C_1 = C_2/4 = 126.5/4 =$ **31.6 pF**

14.11 Hartley Oscillator

The Hartley oscillator is similar to Colpitt's oscillator with minor modifications. Instead of using tapped capacitors, two inductors L_1 and L_2 are placed across a common capacitor C and the centre of the inductors is tapped as shown in Fig. 14.13. The tank circuit is made up of L_1, L_2 and C. The frequency of oscillations is determined by the values of L_1, L_2 and C and is given by :

$$f = \frac{1}{2\pi\sqrt{CL_T}} \qquad ...(i)$$

where $L_T = L_1 + L_2 + 2M$

Here M = mutual inductance between L_1 and L_2

Note that $L_1 - L_2 - C$ is also the feedback network that produces a phase shift of 180°.

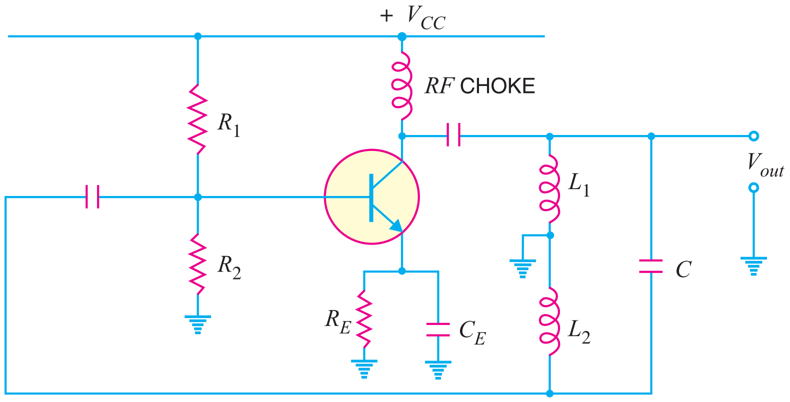


Fig. 14.13

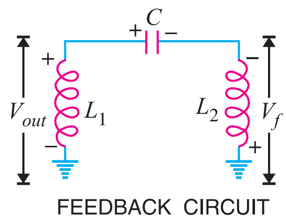


Fig. 14.14

Circuit operation. When the circuit is turned on, the capacitor is charged. When this capacitor is fully charged, it discharges through coils L_1 and L_2 setting up oscillations of frequency determined by *exp. (*i*). The output voltage of the amplifier appears across L_1 and feedback voltage across L_2. The voltage across L_2 is 180° out of phase with the voltage developed across L_1 (V_{out}) as shown in Fig. 14.14. It is easy to see that voltage fedback (*i.e.*, voltage across L_2) to the transistor provides positive feedback. A phase shift of 180° is produced by the transistor and a further phase shift of 180° is produced by $L_1 - L_2$ voltage divider. In this way, feedback is properly phased to produce continuous undamped oscillations.

Feedback fraction m_v. In Hartley oscillator, the feedback voltage is across L_2 and output voltage is across L_1.

$$\therefore \qquad \text{Feedback fraction, } m_v = \frac{V_f}{V_{out}} = \frac{X_{L_2}}{X_{L_1}} = {}^{**}\frac{L_2}{L_1}$$

$$\text{or} \qquad m_v = \frac{L_2}{L_1}$$

Example 14.5. *Calculate the (i) operating frequency and (ii) feedback fraction for Hartley oscillator shown in Fig. 14.15. The mutual inductance between the coils, M = 20 μH.*

Solution.

(*i*) $L_1 = 1000\ \mu\text{H}\ ;\quad L_2 = 100\ \mu\text{H}\ ;\quad M = 20\ \mu\text{H}$

$$\therefore \quad \text{Total inductance, } L_T = L_1 + L_2 + 2M$$

$$= 1000 + 100 + 2 \times 20 = 1140\ \mu\text{H} = 1140 \times 10^{-6}\text{H}$$

$$\text{Capacitance, } C = 20\ \text{pF} = 20 \times 10^{-12}\ \text{F}$$

* Referring to Fig. 14.14, it is clear that L_1 and L_2 are in series. Therefore, total inductance L_T is given by : $L_T = L_1 + L_2 + 2M$

** Referring to Fig. 14.14, the circulating current for the two inductors is the same. Further, inductive reactance is directly proportional to inductance.

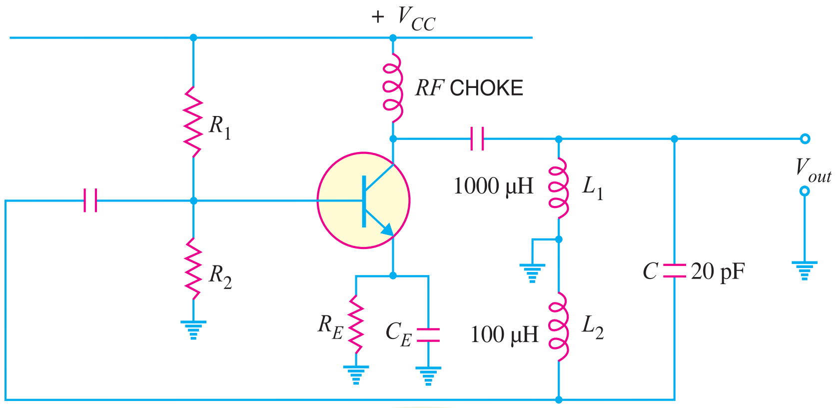


Fig. 14.15

$$\therefore \quad \text{Operating frequency, } f = \frac{1}{2\pi\sqrt{L_T C}} = \frac{1}{2\pi\sqrt{1140 \times 10^{-6} \times 20 \times 10^{-12}}} \text{ Hz}$$

$$= 1052 \times 10^3 \text{ Hz} = \mathbf{1052 \text{ kHz}}$$

(*ii*) $$\text{Feedback fraction, } m_v = \frac{L_2}{L_1} = \frac{100\ \mu H}{1000\ \mu H} = \mathbf{0.1}$$

Example 14.6. *A 1 pF capacitor is available. Choose the inductor values in a Hartley oscillator so that f = 1 MHz and m_v = 0.2.*

Solution.

$$\text{Feedback fraction, } m_v = \frac{L_2}{L_1}$$

or $$0.2 = \frac{L_2}{L_1} \qquad \therefore L_1 = 5L_2$$

Now $$f = \frac{1}{2\pi\sqrt{L_T C}}$$

or $$L_T = \frac{1}{C(2\pi f)^2} = \frac{1}{(1 \times 10^{-12})(2\pi \times 1 \times 10^6)^2}$$

$$= 25.3 \times 10^{-3} \text{ H} = 25.3 \text{ mH}$$

or $$L_1 + L_2 = 25.3 \text{ mH} \qquad (\because L_T = L_1 + L_2)$$

or $$5L_2 + L_2 = 25.3 \qquad \therefore L_2 = 25.3/6 = \mathbf{4.22 \text{ mH}}$$

and $$L_1 = 5\,L_2 = 5 \times 4.22 = \mathbf{21.1 \text{ mH}}$$

14.12 Principle of Phase Shift Oscillators

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