INTRODUCTION:

- An oscillator is an electronic system.
- It comprises active and passive circuit elements and produces repetitive waveforms at the output without the application of a *direct external input signal to the circuit.*
- *It* converts the dc power from the source to ac power in the load. A rectifier circuit converts ac to dc power, but an oscillator converts dc noise signal/power to its ac equivalent.

Need of an Oscillator

- An oscillator circuit is capable of producing ac voltage of desired frequency and waveshape.
- To test performance of electronic circuits, it is called signal generator.
- It can produce square, pulse, triangular, or sawtooth waveshape.
- High frequency oscillator are used in broadcasting.
- Microwave oven uses an oscillator.
- Used for induction heating and dielectric heating.

Using Positive Feedback

- The gain with positive feedback is given as

$$\boxed{A_f = \frac{A}{1 - A\beta}}$$

- By making $1 - A\beta = 0$, or $A\beta = 1$, we get gain as infinity.

- This condition ($A\beta = 1$) is known as Barkhausen Criterion of oscillations.

- It means you get output without any input !

Types of Oscillators

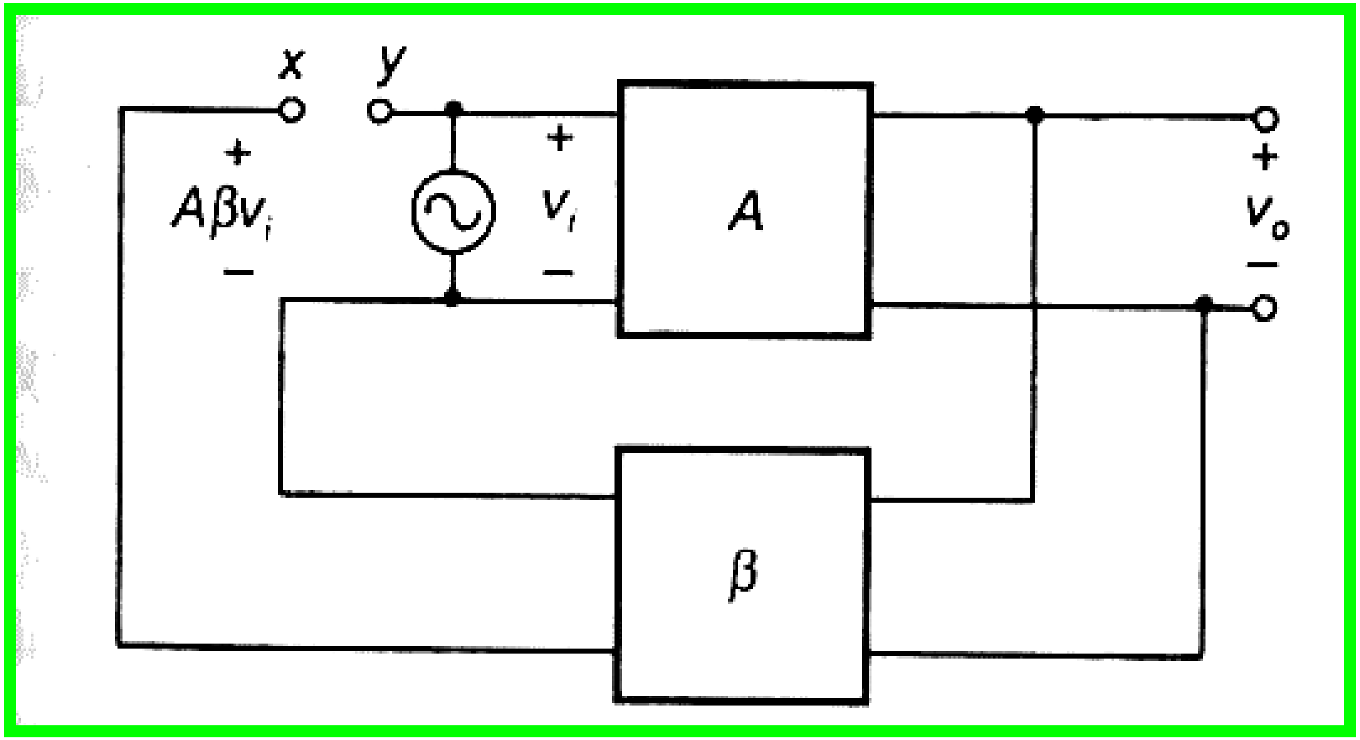
Depending on waveshape:

- Sinusoidal
- non-sinusoidal.

Depending upon type of feedback, we have

1. Tuned Circuit (*LC*) oscillators.
2. *RC* oscillators, and
3. Crystal oscillators.

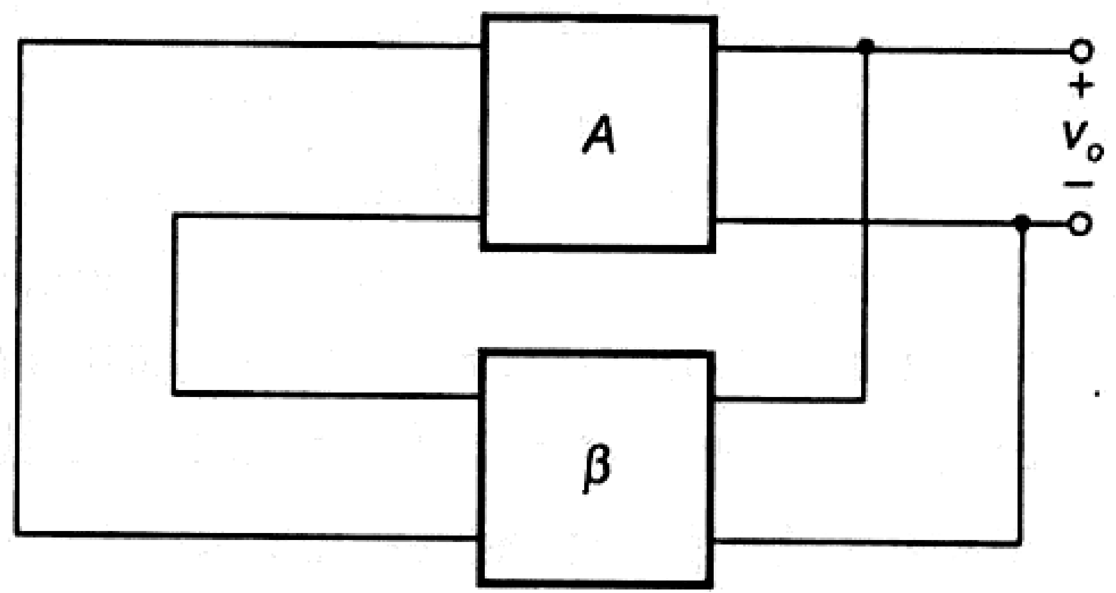
How is it Possible ?



Connecting point *x* to *y*, feedback voltage drives the amplifier.

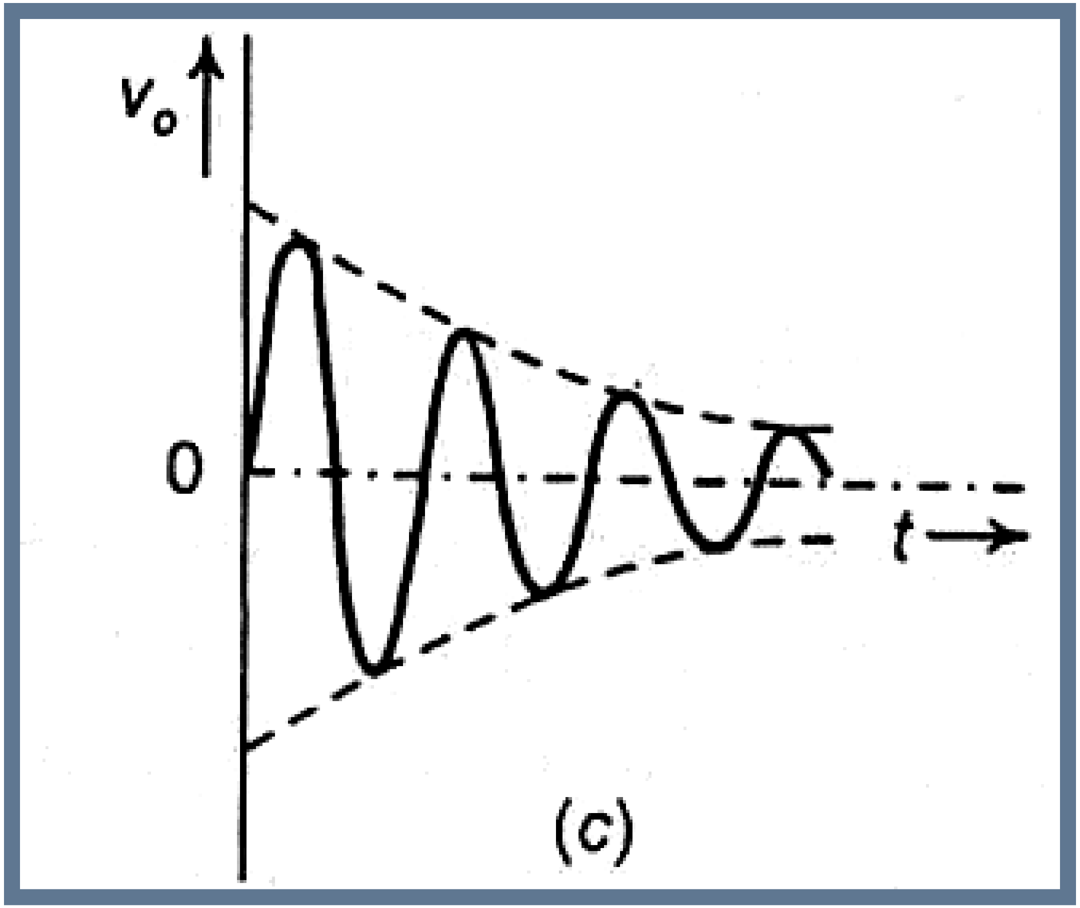
Wherefrom comes the starting voltage ?

- Each resistor is a noise generator.
- The feedback network is a resonant circuit giving maximum feedback voltage at frequency f_0, providing phase shift of 0° only at this frequency.
- The initial loop gain $A\beta > 1$.
- The oscillations build up only at this frequency.
- After the desired output is reached, $A\beta$ reduces to unity.

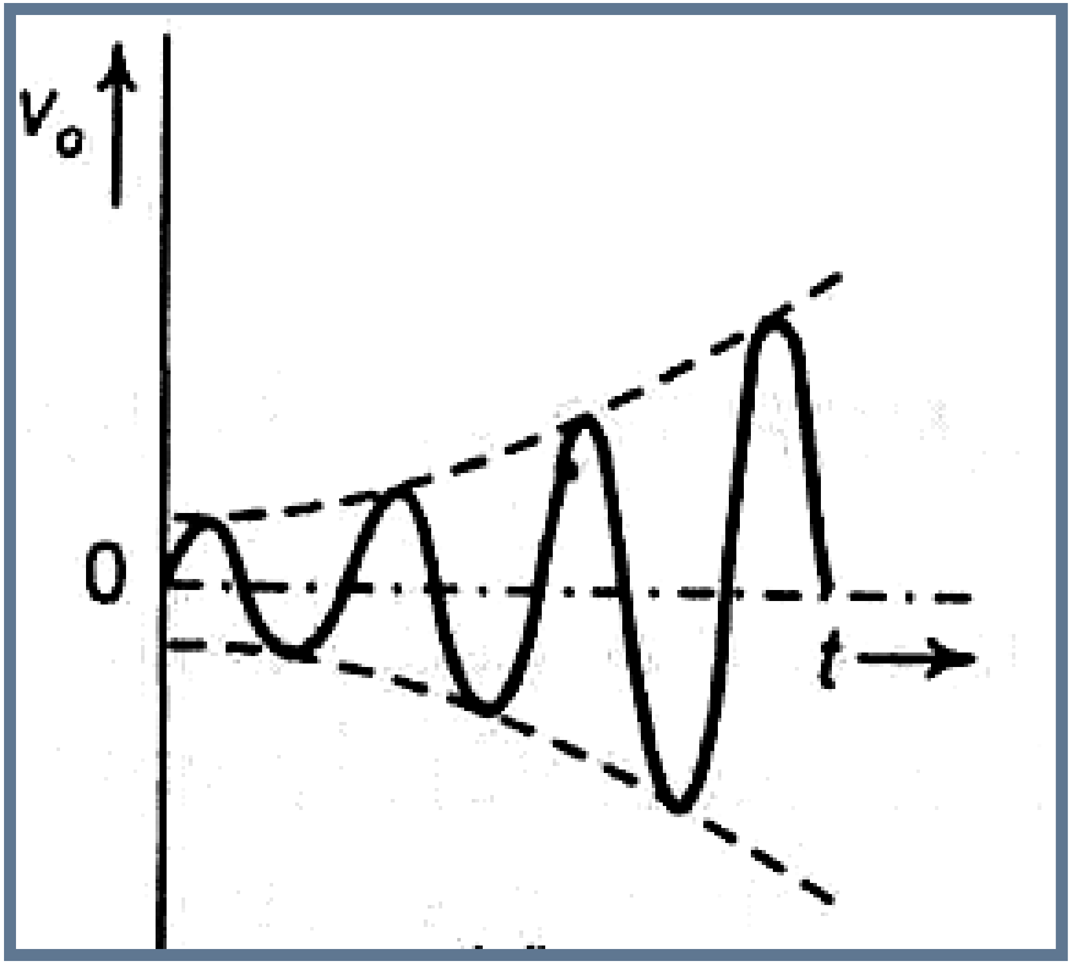


- What happens to the output ?
- There are three possibilities.

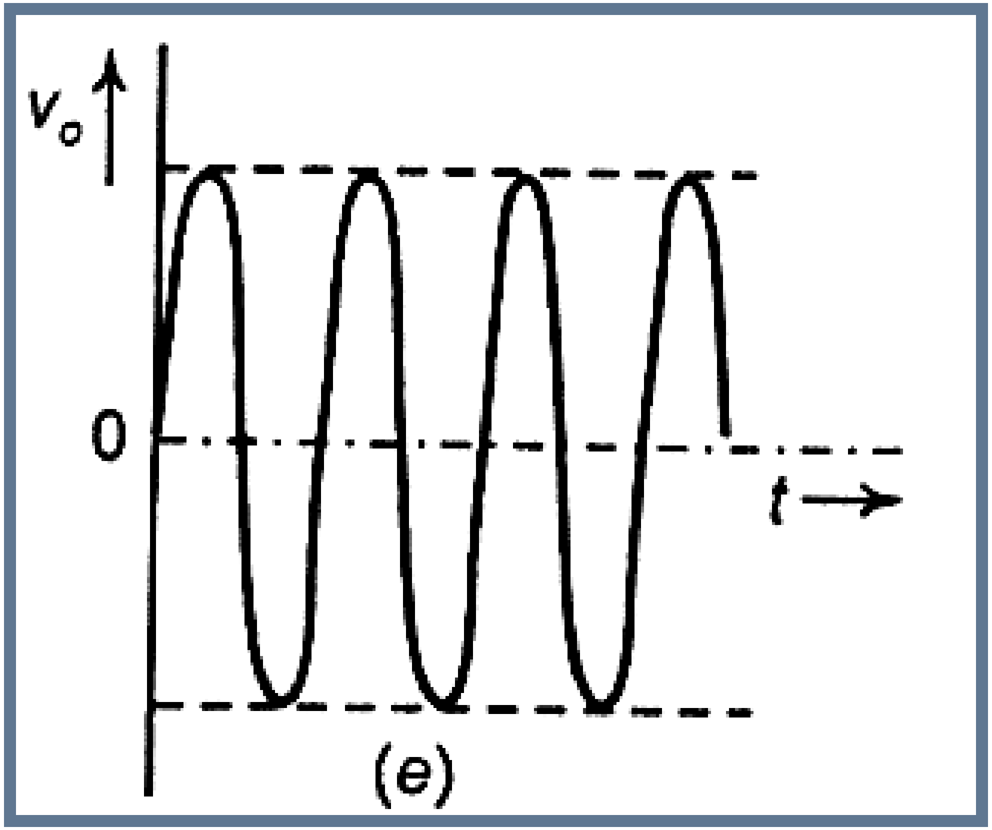
(1) If $A\beta < 1$, we get decaying of damped oscillations.



(2) If $A\beta > 1$, we get growing oscillations.



(3) If $A\beta = 1$, we get sustained oscillations. In this case, the circuit supplies its own input signal.



CLASSIFICATIONS OF OSCILLATORS:

- Oscillators are classified based on the type of the output waveform.
- If the generated waveform is *sinusoidal or close to sinusoidal* (with a certain frequency) then the oscillator is said to be a *Sinusoidal Oscillator*.

  If the output waveform is *non-sinusoidal*, which refers to square/saw-tooth waveforms, the oscillator is said to be a *Relaxation Oscillator*.
- An oscillator has a positive feedback with the loop gain infinite. Feedback-type sinusoidal oscillators can be classified as *LC (inductor-capacitor) and RC (resistor-capacitor) oscillators.*

CLASSIFICATIONS OF OSCILLATORS:

- The classification of various oscillators is shown in Table 12-1.

Table 12-1 Different types of oscillators and their frequency ranges

Type of Oscillator	*Frequency Range Used*
1. Audio-frequency oscillator	20 Hz – 20 kHz
2. Radio-frequency oscillator	20 kHz – 30 MHz
3. Very-high-frequency oscillator	30 MHz –300 MHz
4. Ultra-high-frequency oscillator	300 MHz – 3 GHz
5. Microwave oscillator	3 GHz – 30 GHz
6. Millimeter wave oscillator	30 GHz – 300 GHz

Difference between an amplifier and an oscillator:

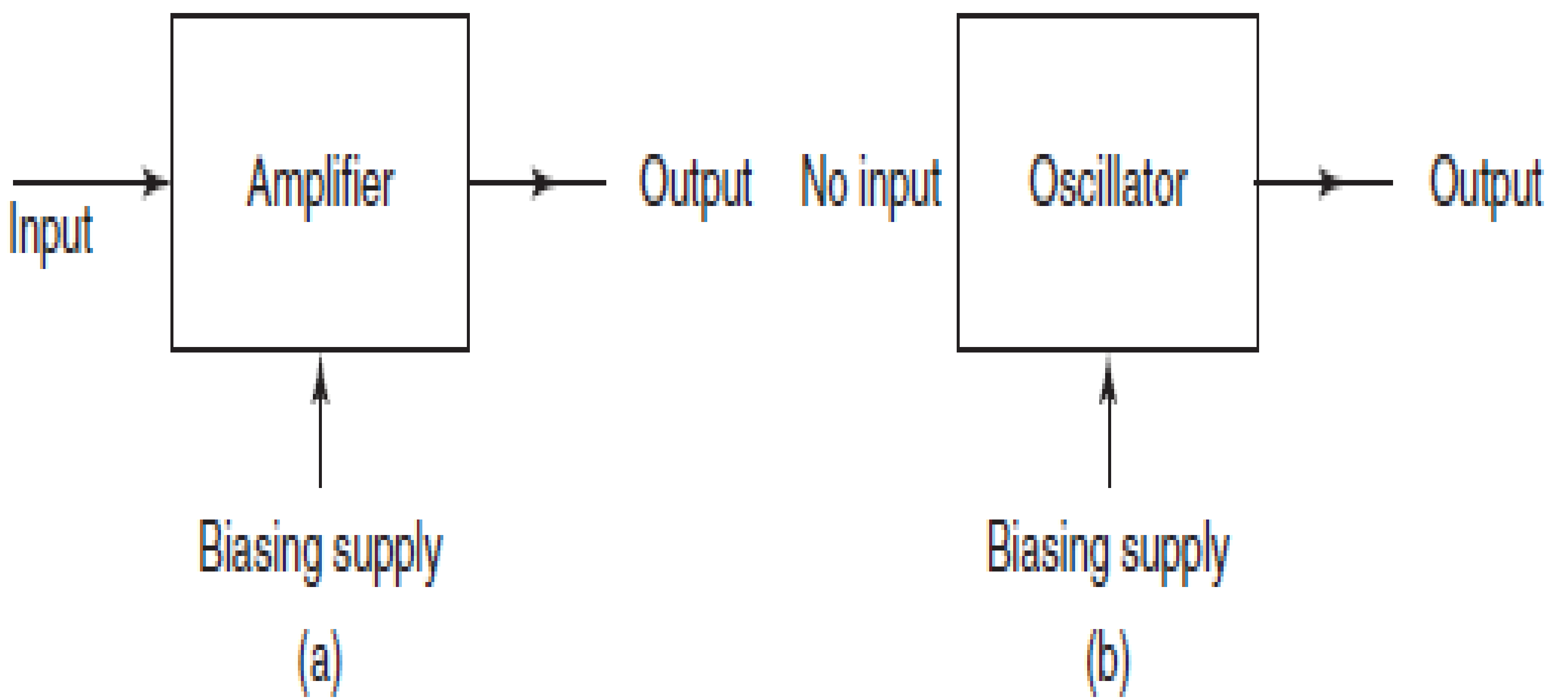
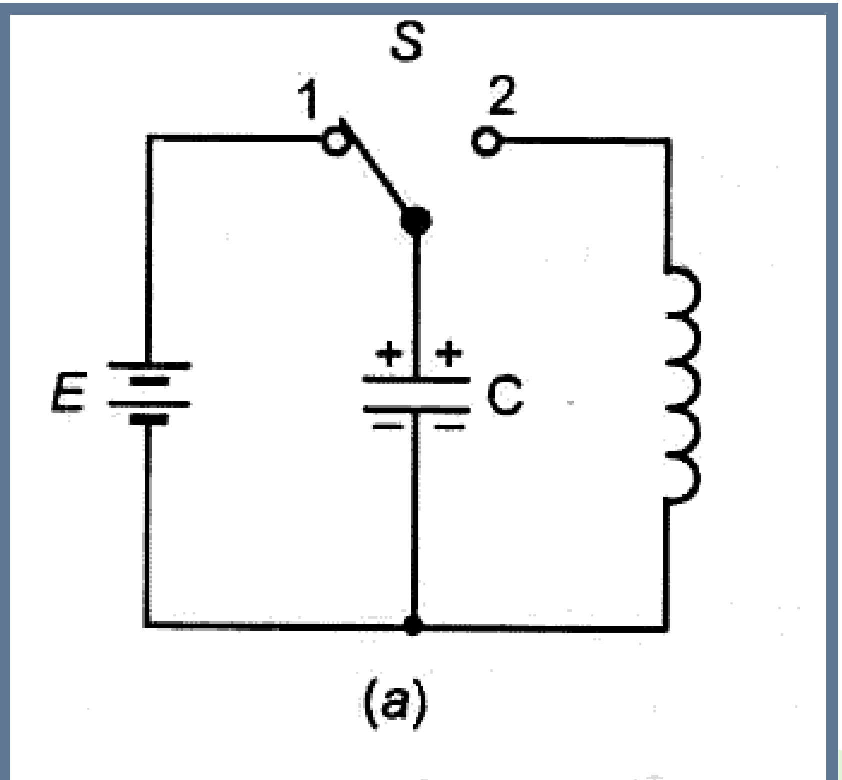


Figure 12-1 Schematic block diagrams showing the difference between an amplifier and an oscillat

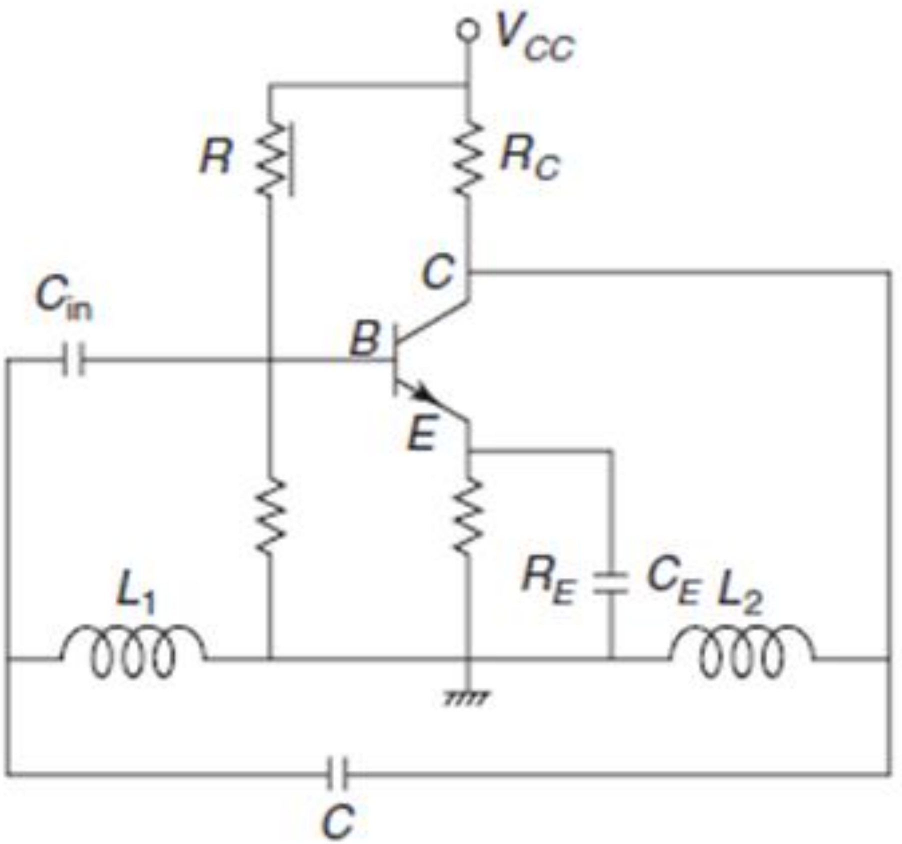
Tank Circuit

- *LC* parallel circuit is called tank circuit.
- Once excited, it oscillates at



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

Hartley Oscillator:



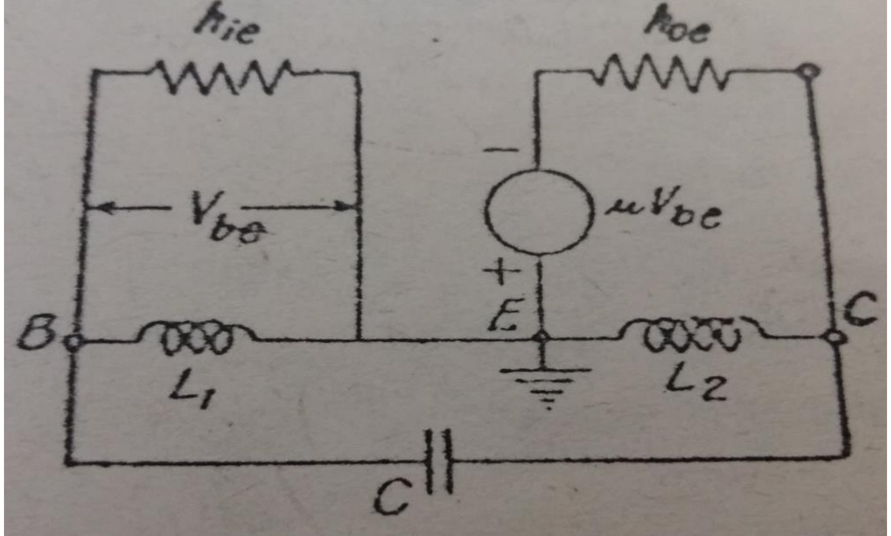


Fig. 6. (b) Equivalent circuit of Hartley oscillator.

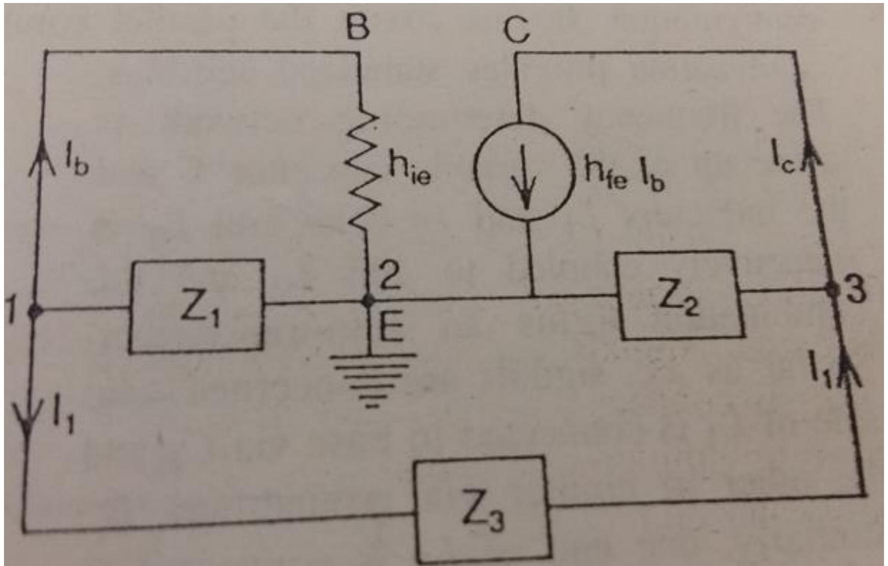


Fig. 7. General equivalent circuit of Hartley oscillator

General Equation:

$$h_{ie}(Z_1+Z_2+Z_3)+Z_1Z_2(1+h_{fe})+Z_1Z_3=0$$

Hartley Oscillator: General Equation

$$h_{ie}\ (Z_1+Z_2+Z_3)+Z_1Z_2(1+h_{fe})+Z_1Z_3=0$$

$$Z_1=j\omega L_1+ j\omega M$$

$$Z_2=j\omega L_2+ j\omega M$$

$$Z_3=1/j\omega C= -j/ \omega C$$

$$h_{ie}\ [(j\omega L_1+ j\omega M)+(j\omega L_2+ j\omega M)- j/ \omega C]+(j\omega L_1+ j\omega M)(j\omega L_2+ j\omega M)(1+h_{fe})+(j\omega L_1+ j\omega M)(-j/ \omega C)=0$$

$$h_{ie}\, j\omega[L_1+ L_2+ 2M-(1/ \omega^2C)] - \omega^2[L1+M)(L_2+M)(1+h_{fe}) + (L_1+ M)/ C=0$$

Hartley Oscillator:

$$h_{ie}\, j\omega[L_1 + L_2 + 2M - (1/\omega^2 C)] - \omega^2[L1 + M)(L_2 + M)(1 + h_{fe}) + (L_1 + M)/C = 0$$

Equating the imaginary part to zero, we get

$$L_1 + L_2 + 2M - (1/\omega^2 C) = 0$$

$$\omega^2 C = 1/(L_1 + L_2 + 2M)$$

$$\omega^2 = 1/(L_1 + L_2 + 2M)C$$

$$\omega = {}^{1}\Big/_{\sqrt{(L_1 + L_2 + 2M)c}}$$

$$\therefore f = \frac{1}{2\pi} \cdot \frac{1}{\sqrt{(L_1 + L_2 + 2M)c}}$$

Frequency of oscillations

Hartley Oscillator:

$$h_{ie}\, j\omega[L_1+ L_2+ 2M-(1/\ \omega^2C)] - \omega^2[L1+M)(L_2+M)(1+h_{fe}) + (L_1+ M)/\ C=0$$

Equating the real part to zero, we get

$$- \omega^2[L1+M)(L_2+M)(1+h_{fe}) + (L_1+ M)/\ C=0$$

$$1+h_{fe}=1/(L_2+M)\ \omega^2\ C = \{(L_1+ L_2+ 2M)C\} / \{(L_2+M)C\}$$

$$h_{fe}= \{(L_1+ L_2+ 2M)C\} / \{(L_2+M)C\} -1$$

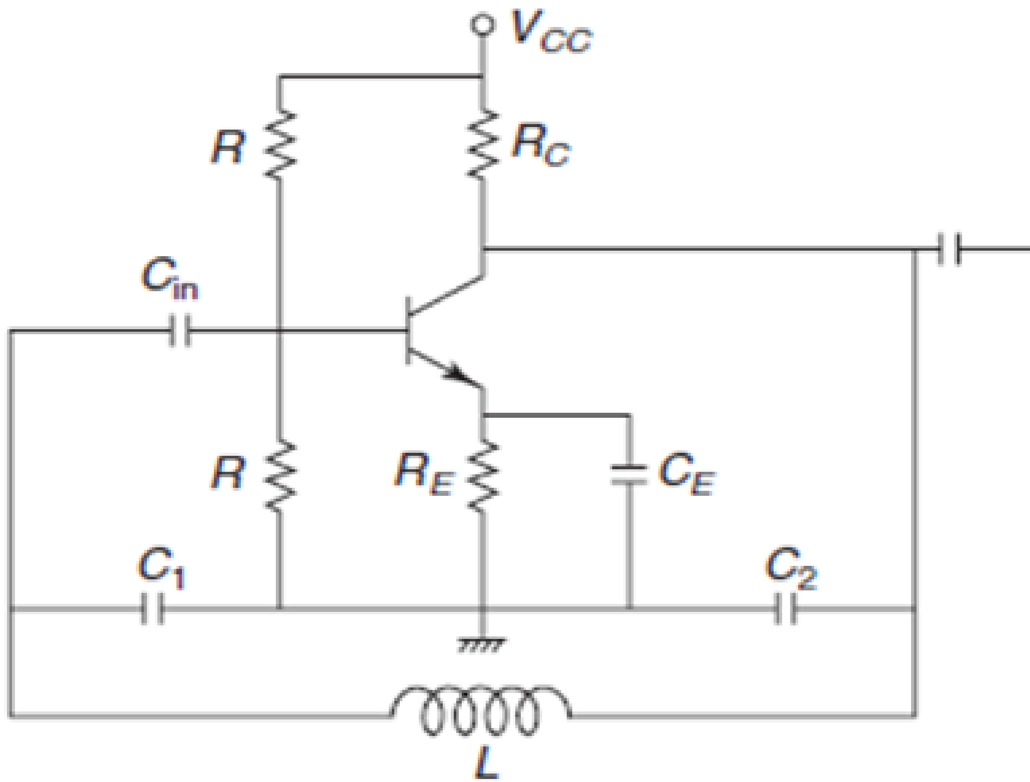
$$h_{fe}= (L_1+ M) / (L_2+M)$$

Condition for the maintenance of oscillations

Example

Example: Find the operating frequency of a transistor Hartley oscillator if $L_1 = 100\ \mu H$, $L2 = 1\ mH$, mutual inductance between the coils $M = 20\ \mu H$ and $C = 20\ pF$

Colpitt's oscillator:



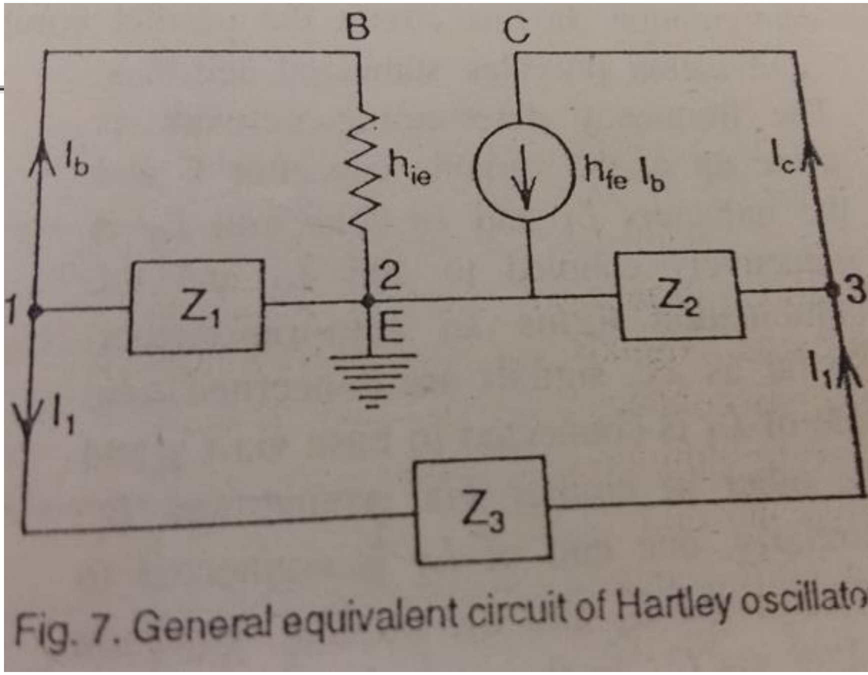


Fig. 7. General equivalent circuit of Hartley oscillato

General Equation:

$$h_{ie}(Z_1+Z_2+Z_3)+Z_1Z_2(1+h_{fe})+Z_1Z_3=0$$

Colpitt's Oscillator: General Equation

$$h_{ie}\ (Z_1+Z_2+Z_3)+Z_1Z_2(1+h_{fe})+Z_1Z_3=0$$

$$Z_1=1/j\omega C_1= -j/\ \omega C_1$$

$$Z_2=1/j\omega C_2 = -j/\ \omega C_2$$

$$Z_3=j\omega L$$

$$h_{ie}\ [-(j/\ \omega C_1)-(j/\ \omega C_2\ )+ j\omega L]+(-j/\ \omega C1)(-j/\ \omega C_2\ )(1+h_{fe})+(-j/\ \omega C_1)\ j\omega L=0$$

$$jh_{ie}\,[-(1/\ \omega C_1)-(1/\ \omega C_2\ )+ j\omega L] – [(1+h_{fe})/\omega^2\ C_1\ C_2]+(L/\ C_1\ )=0$$

Colpitt's Oscillator:

$$jh_{ie}\left[-(1/\omega C_1)-(1/\omega C_2)+j\omega L\right]-\left[(1+h_{fe})/\omega^2 C_1 C_2\right]+(L/C_1)=0$$

Equating the imaginary part to zero, we get

$$(1/\omega C_1)+(1/\omega C_2)-\omega L=0$$

$$(1/\omega C_1)+(1/\omega C_2)=\omega L$$

$$\omega^2=(C_1+C_2)/LC_1C_2$$

$$\omega=\sqrt{\frac{(C_1+C_2)}{LC_1C_2}}$$

$$\omega=\sqrt{\frac{1}{LC}}$$

$$(1/C_1)+(1/C_2)=1/C$$

$$\therefore f=\frac{1}{2\pi}\cdot\frac{1}{\sqrt{LC}}$$

Frequency of oscillations

Colpitt's Oscillator:

$$jh_{ie}\,[-(1/\ \omega C_1)-(1/\ \omega C_2\ )+ j\omega L] - [(1+h_{fe})/\omega^2\ C_1\ C_2]+(L/\ C_1\ )=0$$

Equating the real part to zero, we get

$$-[(1+h_{fe})/\omega^2\ C_1\ C_2]+(L/\ C_1\ )=0$$

$$1+h_{fe} = \omega^2\ C_2\ L$$

$$h_{fe} = (\omega^2\ C_2\ L)-1$$

$$h_{fe} =[\{(C_1+C_2)/LC_1C_2\}X\ C_2\ L]-1$$

$$h_{fe} =1 + (C_2/C_1) - 1$$

$$\boxed{h_{fe} = (C_2/C_1)}$$

Condition for the maintenance of oscillations

Example

Example: Find the operating frequency of a transistor Colpitt's oscillator if $C_1 = 0.001\ \mu F$, $C_2 = 0.01\ \mu F$, $L = 15\ \mu H$.

AUDIO OSCILLATORS

- An audio oscillator is useful for testing equipment that operates in the audio-frequency range. Such instruments always produce a sine-wave signal, variable in both amplitude and frequency, and usually provide a square-wave output as well. The maximum amplitude of the output waveform is typically on the order of 25 V_{rms}. whereas the range of frequencies covers at least the audio-frequency range from 20 Hz to 20 kHz. The most common output impedances for audio oscillators are 75 Ω and 600 Ω.

- The two most common audio-oscillator circuits are the Wien bridge oscillator and the phase-shift oscillator, both of which employ RC feedback networks. The Wien bridge offers some very attractive features, including a straightforward design, a relatively pure sine-wave output, and a very stable frequency.

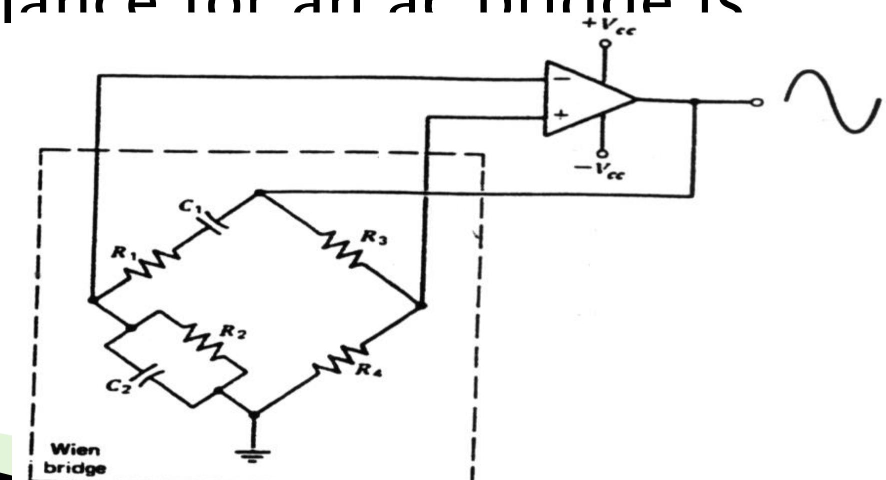
Wien Bridge

- The Wien bridge oscillator is essentially a feedback amplifier in which the Wien bridge serves as the phase-shift network. The Wien bridge is an ac bridge, the balance of which is achieved at one particular frequency.

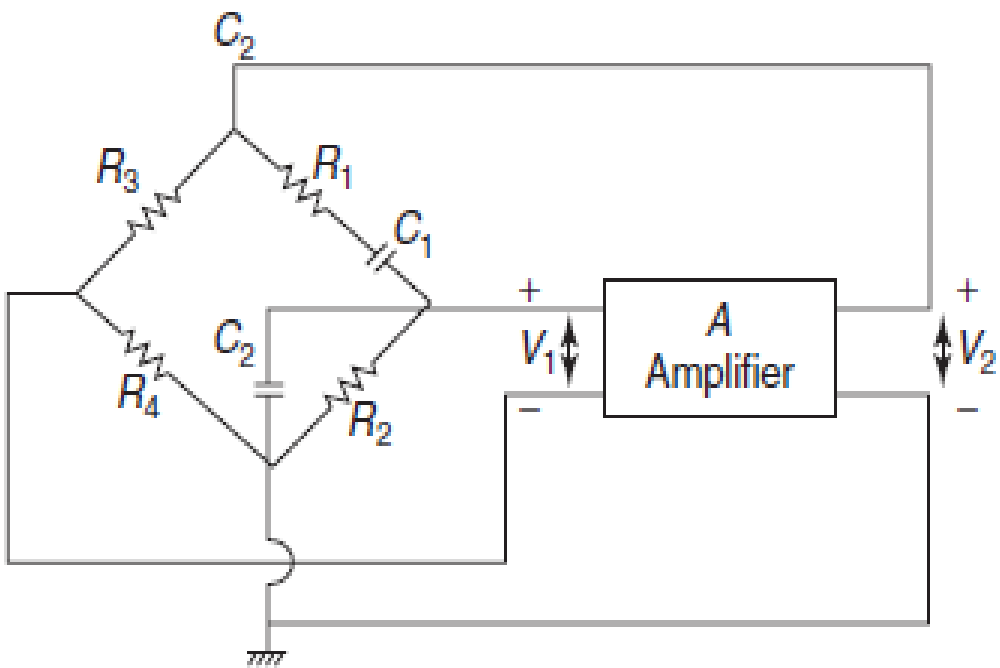
Cont'd

- The basic Wien bridge oscillator is shown in Fig. 1-2. as can be seen. the Wien bridge oscillator consists of a Wien bridge and an operational amplifier represented by the triangular symbol. Operational amplifiers are integrated circuit amplifiers and have high-voltage gain, high input impedance, and low output impedance. The condition for balance for an ac bridge is

$$Z_1 Z_4 = Z_2 Z_3 \quad (1\text{-}2)$$



Circuit Diagram of Wien-Bridge Oscillator:



Wien-bridge oscillator with an amplifier

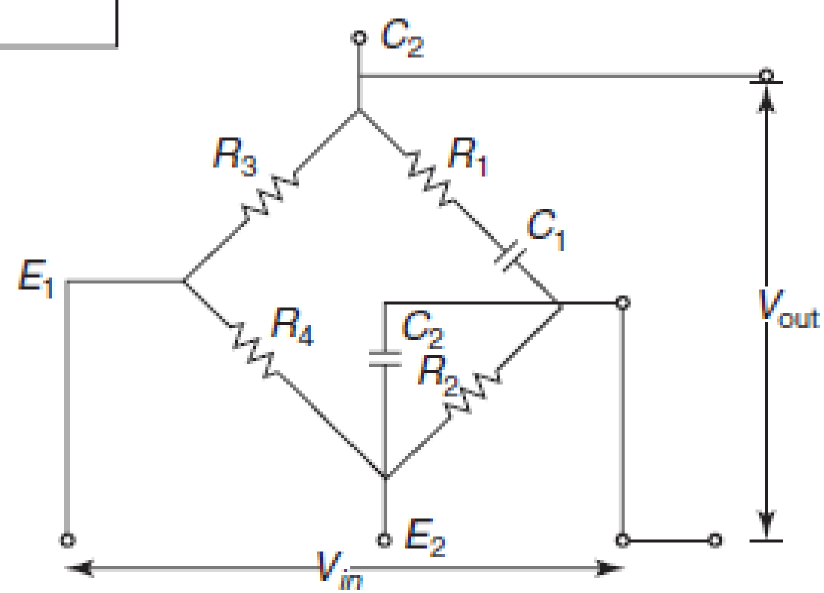


Figure 12-7 Wien-Bridge oscillator

Cont'd

Where

$$Z_1 = R_1 - j/\omega C_1$$

$$Z_2 = \frac{R_2\,(-j/\omega C_2)}{R_2 - j/\omega C_2} = \frac{-jR_2}{-j + R_2\omega C_2}$$

$$\mathrm{Z}_3 = \mathrm{R}_3$$

$$\mathrm{Z}_4 = \mathrm{R}_4$$

Substituting the appropriate expressions into Eq. 1-2 yields

$$\left(R_1 - \frac{j}{\omega C_1}\right)R_4 = \left(\frac{-jR_2}{-j + R_2\omega C_2}\right)R_3 \qquad (1\text{-}3)$$

Cont'd

- if the bridge is balanced both the magnitude and phase angle of the impedances must be equal. These conditions are best satisfied by equating real terms and imaginary terms. Separating and equating the real terms in Eq. 1-3 yields.

$$\frac{R_3}{R_4} = \frac{R_1}{R_2} + \frac{C_2}{C_1}$$

(1-4)

Separating and equating imaginary terms in Eq. 1-3 yields

$$\omega C_1 R_2 = \frac{1}{\omega C_2 R_1}$$

(1-5)

Cont'd

- Where $\omega = 2\pi f$. Substituting for to in Eq. 1-5, we can obtain an expression for frequency which is

$$f = \frac{1}{2\pi (C_1 R_1 C_2 R_2)^{1/2}}$$ (1-6)

- If $C_1 = C_2 = C$ and $R_1 = R_2 = R$ then Eq. 1-4 simplifies yield

$$\frac{R_3}{R_4} = 2$$ (1-7)

Cont'd

- and from Eq. 1-6 we obtain

$$f = \frac{1}{2\pi RC} \qquad (1\text{-}8)$$

Where

f = frequency of oscillation of the circuit in Hertz

C = capacitance in farads

R = resistance in ohms

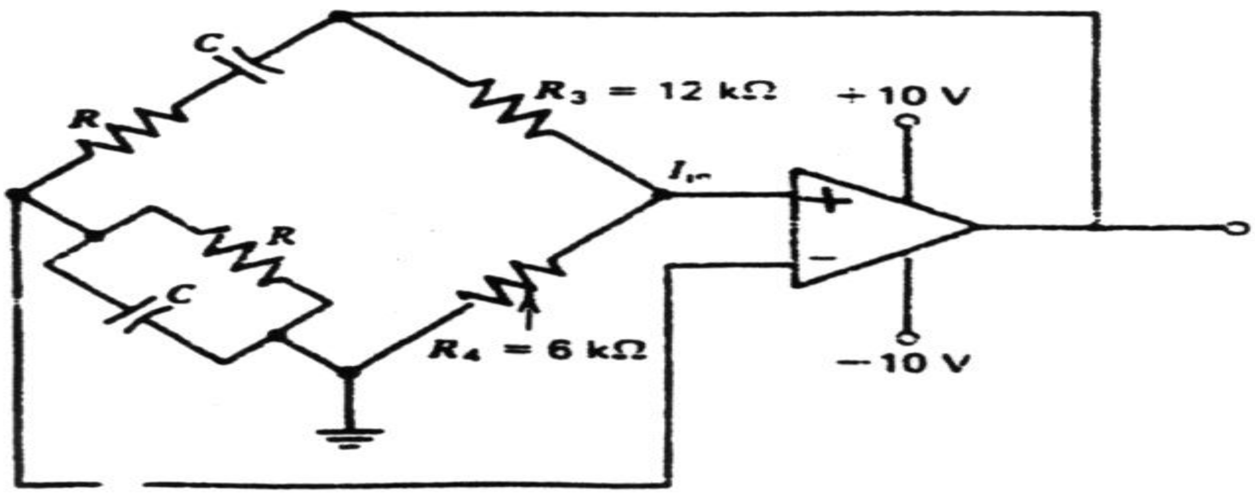
Wien-Bridge Oscillator:

- **Advantages of Wien-Bridge Oscillator:**
- 1. The frequency of oscillation can be easily varied just by changing *RC network*
- 2. High gain due to two-stage amplifier
- 3. Stability is high

- **Disadvantages of Wien-Bridge Oscillator**
- The main disadvantage of the Wien-bridge oscillator is that a high frequency of oscillation cannot be generated.

EXAMPLE 1-1

- Determine the frequency of oscillation of the Wien bridge oscillator shown in Fig. 1-3 if R = 6Ω and C = 0.003 F.



Solution

- Using Eq. 1-8. we compute the frequency as

$$f = \frac{1}{2\pi RC}$$

$$= \frac{1}{(2\pi)(6k\Omega)(0.003\,\mu F)}$$

$$= 8.885\,kHz$$

Wein Bridge

- It can be shown, by using ordinary ac circuit analysis techniques, that Eq. 1-2 is satisfied by the value of the components in the circuit in Fig. 1-3. The design of a Wien bridge oscillator can be approached by selecting an operating frequency and level of current that will be acceptable through each arm of the bridge. The bridge currents are typically larger by at least a factor of 100 than the maximum input current to the amplifier, and the peak value of the sinusoidal output voltage is typically on the order of 90% of V_{cc}.

EXAMPLE 1-2

- Design a Wien bridge oscillator around the following specifications:
- F = 15 kHz
- V_{cc} = 10V
- $/_{in} = 1$
- $/R_4 = 100/_{in}$

Solution

- If the peak value of the sinusoidal waveform is 90% of V_{cc}, we can solve for the value of $R_3 + R_4$ as

$$R_3 + R_4 = \frac{0.9V_{cc}}{100\ \mu A}$$

Using Eq. 1-7, we can say that

$$R_3 = 2R_4$$

$$= \frac{9V}{100\ \mu A} = 90\ k\Omega$$

Cont'd

Therefore

$$3R_4 = 90$$
$$R_4 = 30$$

and

$$R_3 = 2R_4 = 60$$

Wein Bridge

- We arrived at Eq. 1–7 by letting $R_1 = R_2 = R$. It is generally convenient to let $R_1 = R_2 = R_4$: therefore,

$$R_1 = R_2 = 30$$

Using Eq. 1–8. we can now solve for the capacitance C as

$$C = \frac{1}{2\pi f R}$$

$$= \frac{1}{(2\pi)(15kHz)(30k\Omega)} = 354\, pF$$

Cont'd

- The Wien bridge oscillator is widely used in audio oscillators because of its relatively small amount of distortion, excellent frequency stability, comparatively wide frequency range, and ease of changing frequency. A typical commercial Wien bridge oscillator can have a frequency range extending from 5 Hz to 500 kHz in decade steps.

Phase Shift Oscillator

- The second audio-oscillator circuit of interest is the phase-shift oscillator.
- The phase-shift network for the phase-shift oscillator, is an RC network made up of equal-value capacitors and resistors connected in cascade. Each of the three *RC* stages shown provides a 60^o phase shift. with the total phase shift equal to the required 180^o.

Phase Shift Oscillator

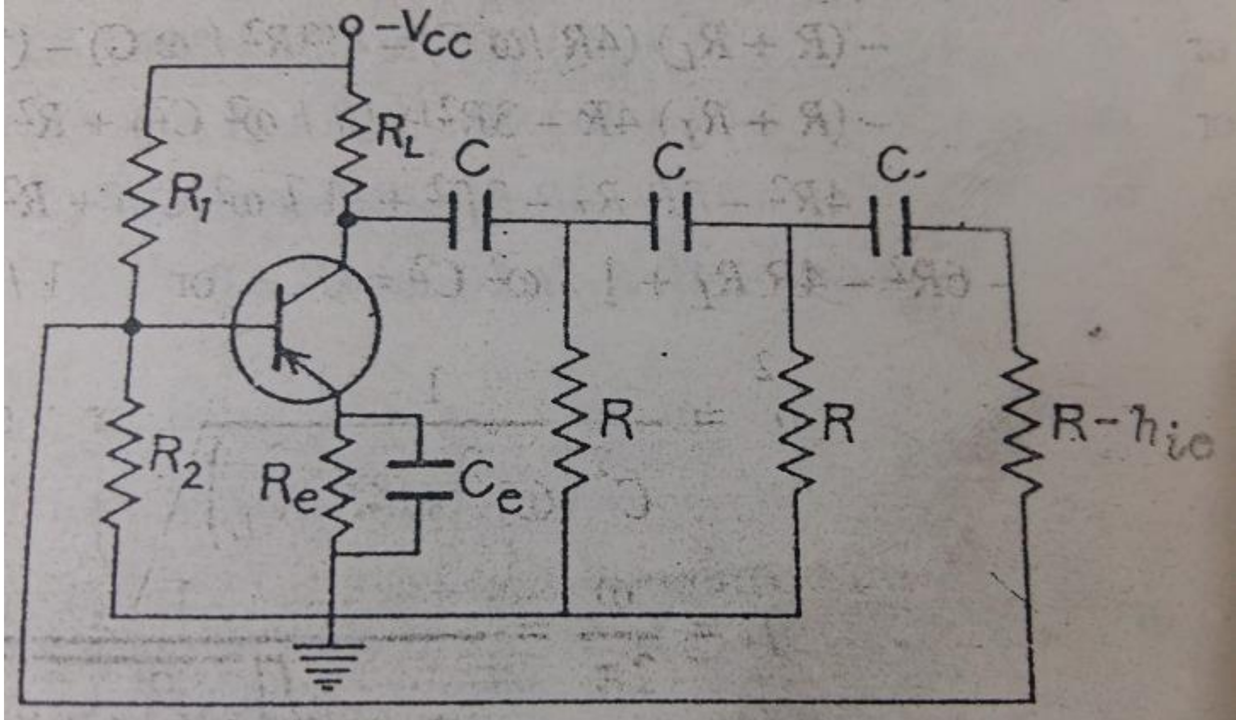
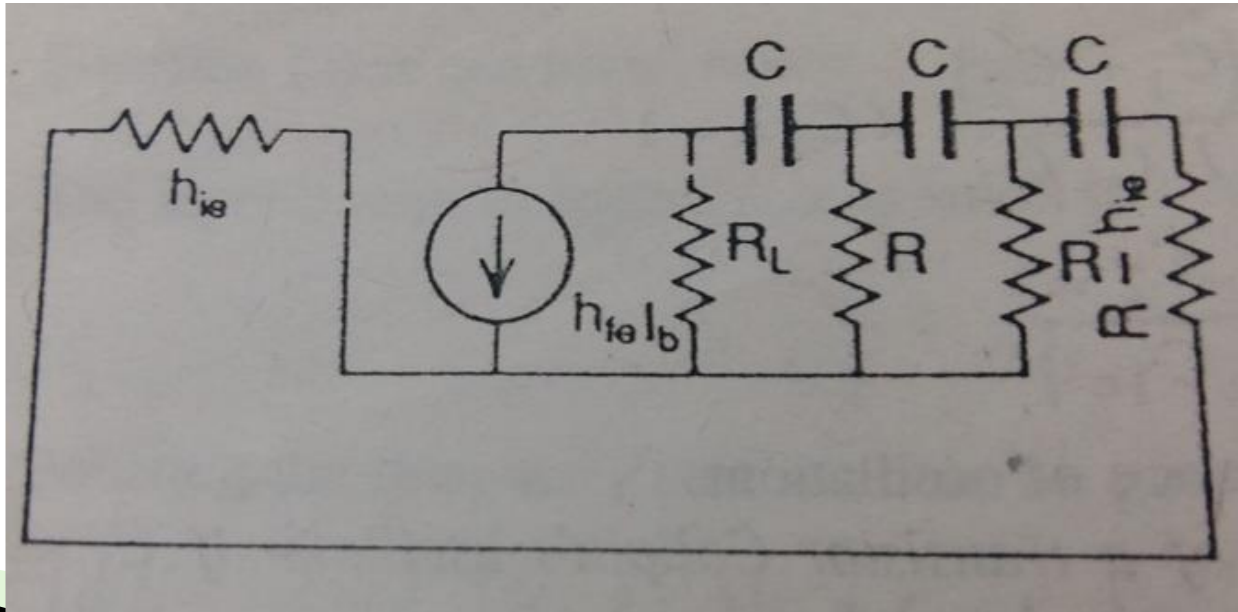
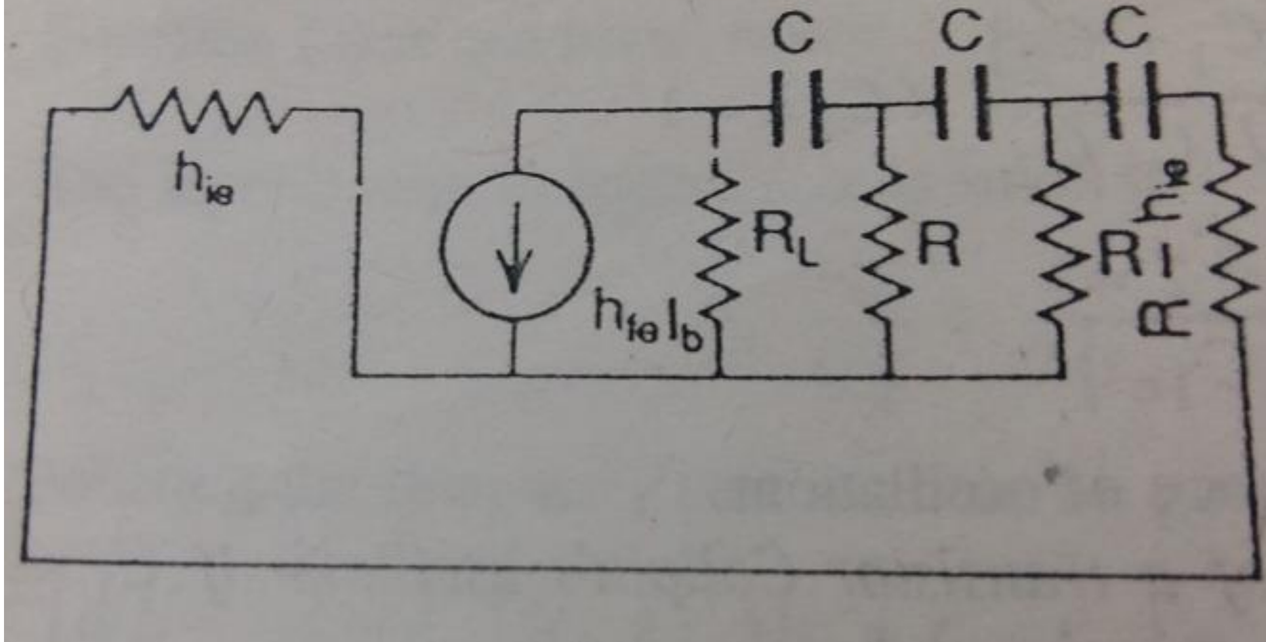


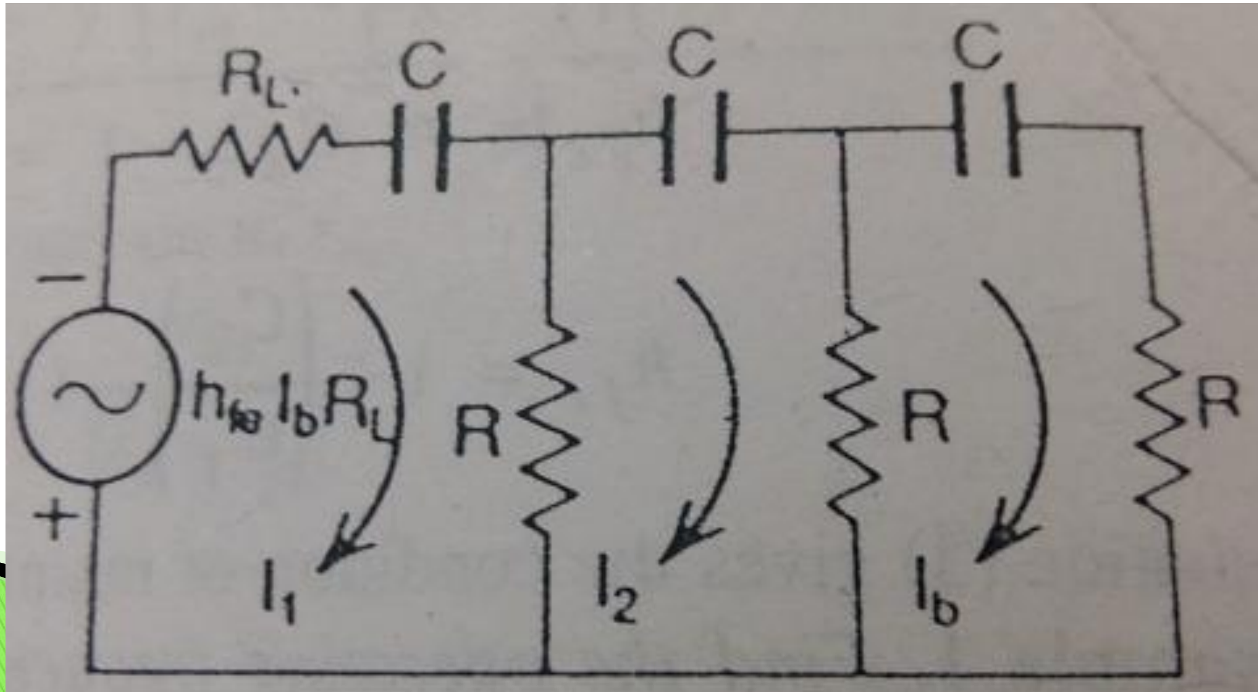
Fig. 10. Phase shift oscillator.

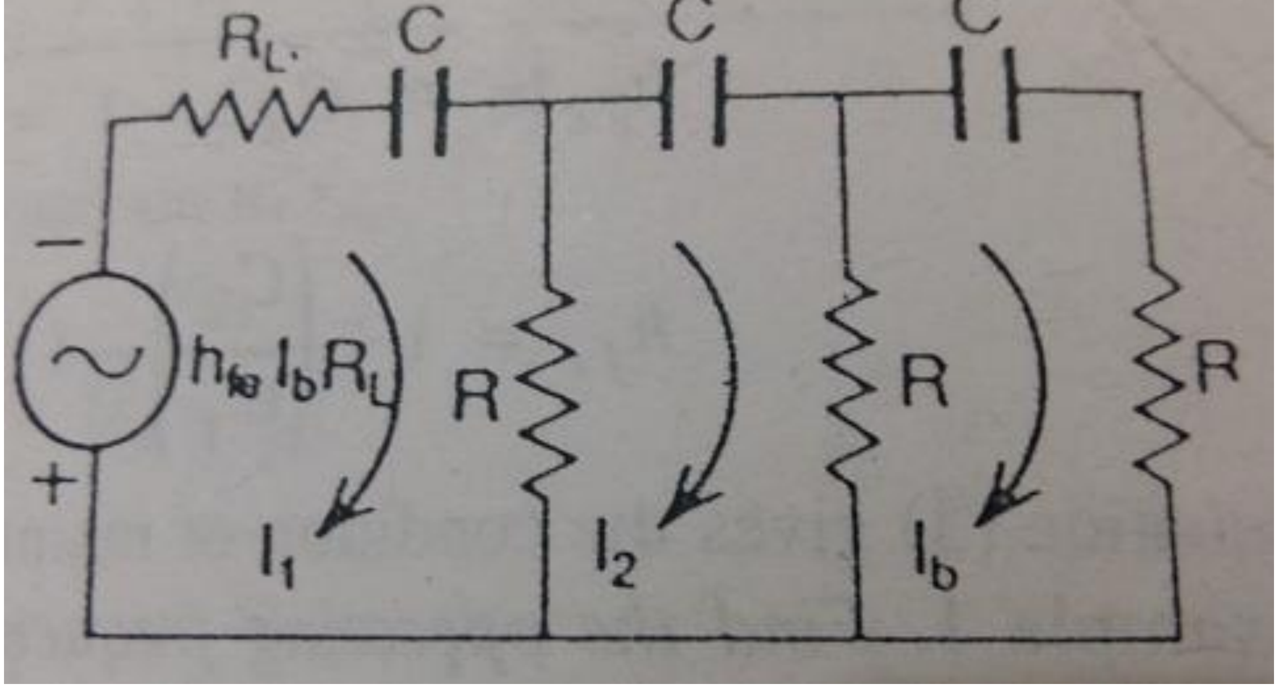


(a)



(a)





- Appying KVL for 3 loops in fig

$$\left\{R + R_L + \left({}^{1}\!/_{j\omega C}\right)\right\} I_1 \; - \quad R I_2 \; + \quad h_{fe} R_L I_b = 0$$

$$-R I_1 + \left(2R + {}^{1}\!/_{j\omega C}\right) I_2 \; - \; R I_b = 0$$

$$-R I_2 + \; \left(2R + {}^{1}\!/_{j\omega C}\right) I_b \; = 0$$

$$\left\{R + R_L + \left({}^{1}/_{j\omega C}\right)\right\} I_1 \quad - \quad R I_2 \quad + \quad h_{fe} R_L I_b = 0$$

$$-R I_1 + \left(2R + {}^{1}/_{j\omega C}\right) I_2 \; - \; R I_b = 0$$

$$-R I_2 + \quad \left(2R + {}^{1}/_{j\omega C}\right) I_b \; = 0$$

- The determinant of the above equations

$$\begin{vmatrix} R + R_L + \left({}^{1}/_{j\omega C}\right) & -R & h_{fe} R_L \\ -R & \left(2R + {}^{1}/_{j\omega C}\right) & -R \\ 0 & -R & \left(2R + {}^{1}/_{j\omega C}\right) \end{vmatrix} = 0$$

$$\boldsymbol{\left(R + R_L + {}^{1}/_{j\omega C}\right)\left\{3R^2 + {}^{4R}/_{j\omega C} - {}^{1}/_{\omega^2 C^2}\right\} - R^2\left(2R + {}^{1}/_{j\omega C}\right) + h_{fe} R_L R^2 = 0}$$

$$\boldsymbol{(R + R_L)\left\{3R^2 - {}^{1}/_{\omega^2 C^2}\right\} - (R + R_L)\left({}^{j4R}/_{\omega C}\right) - j\left({}^{3R^2}/_{\omega C} - {}^{1}/_{\omega^3 C^3}\right) - {}^{4R}/_{\omega^2 C^2} - 2R^3 - \left({}^{jR^2}/_{\omega C}\right) + h_{fe} R_L R^2 = 0}$$

$$(R+R_L)\left\{3R^2 - {}^{1}\!/_{\omega^2C^2}\right\} - (R+R_L)\left({}^{j4R}\!/_{\omega C}\right)$$
$$- j\left({}^{3R^2}\!/_{\omega C} - {}^{1}\!/_{\omega^3C^3}\right) - {}^{4R}\!/_{\omega^2C^2} - \quad 2R^3 - \left({}^{jR^2}\!/_{\omega C}\right) + h_{fe}R_LR^2 = 0$$

Equating the imaginary part to zero, we get

$$-(R+R_L)\left({}^{4R}\!/_{\omega C}\right) - \left\{\left({}^{3R^2}\!/_{\omega C}\right) - \left({}^{1}\!/_{\omega^3C^3}\right)\right\} + {}^{R^2}\!/_{\omega C} = 0$$

$$-(R+R_L)4R - 3R^2 + \left({}^{1}\!/_{\omega^2C^2}\right) + R^2 = 0$$

$$-4R^2 - 4RR_L - 3R^2 + \left({}^{1}\!/_{\omega^2C^2}\right) + R^2 = 0$$

$$-6R^2 - 4RR_L + \left({}^{1}\!/_{\omega^2C^2}\right) = 0$$

$${}^{1}\!/_{\omega^2C^2} = 6R^2 + 4RR_L$$

$$\omega^2 = {}^{1}\!/_{C^2(6R^2+4RR_L)}$$

$$\omega = {}^{1}\!/_{C\sqrt{(6R^2+4RR_L)}}$$

$$f = {}^{1}\!/_{2\pi C\sqrt{(6R^2+4RR_L)}} = {}^{1}\!/_{2\pi\sqrt{10}RC}$$

Equating the real part to zero, we get

$$(R+R_L)\left\{3R^2-{}^{1}\!/_{\omega^2C^2}\right\}\ -{}^{4R}\!/_{\omega^2C^2}-\ 2R^3+h_{fe}R_LR^2=0$$

$$3R^3-{}^{R}\!/_{\omega^2C^2}+3R^2R_L-{}^{R_L}\!/_{\omega^2C^2}\ -{}^{4R}\!/_{\omega^2C^2}-\ 2R^3+h_{fe}R_LR^2=0$$

$$\begin{aligned}3R^3-R\left(6R^2{+}4RR_L\right)+3R^2R_L\\ -R_L\left(6R_LR^2{+}4RR_L\right)\ -4R\left(6R^2{+}4RR_L\right)-\ 2R^3+h_{fe}R_LR^2=0\end{aligned}$$

$$3R^3-6R^3-4R^2R_L+3R^2R_L-6R^2R_L-4RR_L^2-24R^3-16R^2R_L\ -2R^3+h_{fe}\,R_LR^2=0$$

$$h_{fe}R_LR^2=29R^3+23R^2R_L+4RR_L^2$$

$$h_{fe}=29\frac{R}{R_L}\ \ +23+4\frac{R_L}{R}$$

$$h_{fe}=56$$

EXAMPLE 1-3

- Determine the frequency of oscillation of a phase-shift oscillator with a three-section feedback network consisting of 13-Ω resistors and 100- F capacitors.

Cont’d

- The phase-shift oscillator is useful for noncritical applications. particularly at medium and low frequencies, even down to 1Hz, because of its simplicity.
- However, its frequency stability is not as good as that of the Wien bridge oscillator, distortion is greater, and changing frequency is inconvenient because the value of each capacitor must be adjusted.
- The choice of an oscillator circuit to operate in the audio-frequency range is determined by the particular application.

Wien-Bridge Oscillator:

- **Advantages of Wien-Bridge Oscillator:**
- 1. The frequency of oscillation can be easily varied just by changing *RC network*
- 2. High gain due to two-stage amplifier
- 3. Stability is high

- **Disadvantages of Wien-Bridge Oscillator**
- The main disadvantage of the Wien-bridge oscillator is that a high frequency of oscillation cannot be generated.

APPLICATIONS OF OSCILLATORS:

- Oscillators are a common element of almost all electronic circuits. They are used in various applications, and their use makes it possible for circuits and subsystems to perform numerous useful functions.
- In oscillator circuits, oscillation usually builds up from zero when power is first applied under linear circuit operation.
- The oscillator's amplitude is kept from building up by limiting the amplifier saturation and various non-linear effects.
- Oscillator design and simulation is a complicated process. It is also extremely important and crucial to design a good and stable oscillator.
- Oscillators are commonly used in communication circuits. All the communication circuits for different modulation techniques—AM, FM, PM—the use of an oscillator is must.
- Oscillators are used as stable frequency sources in a variety of electronic applications.
- Oscillator circuits are used in computer peripherals, counters, timers, calculators, phase-locked loops, digital multi-metres, oscilloscopes, and numerous other applications.