ch. Priyanka

Introduction:

→ Any circuit which is used to generate a periodic voltage without an a.c Input signal is called an oscillator.

→ To generate the periodic voltage, the circuit is supplied with energy from a dc source.

→ If the output voltage is a sine wave function of time, the oscillator is called a "sinusoidal" or "Harmonic" oscillator.

→ positive feedback and negative resistance oscillators belong to this category.

→ There is another category of oscillators which generate a non-sinusoidal waveforms such as square, rectangular, triangular or sawtooth waves.

Classification of oscillators:

Oscillators are classified in the following different ways.

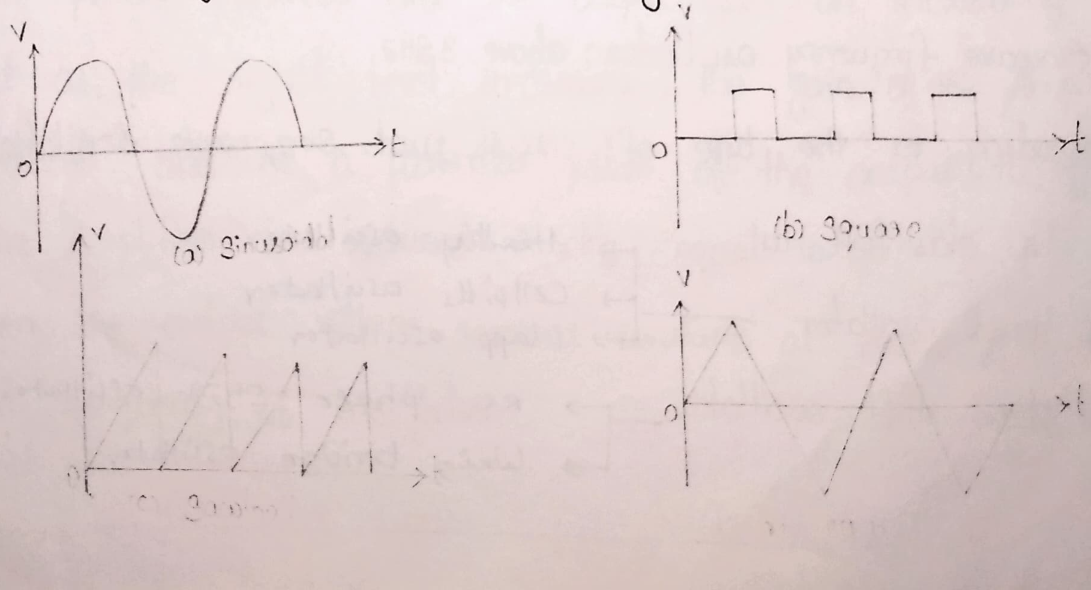
1. According to the waveforms generated:

(a) Sinusoidal oscillator

(b) Relaxation oscillator

(a) Sinusoidal oscillator:

It generates sinusoidal voltages or currents as shown in fig.



(b) Relaxation oscillator:

It generates voltages or currents which vary abruptly one or more times in a cycle of oscillation.

2. According to the fundamental mechanisms involved:

(a) Negative Resistance oscillators

(b) Feedback oscillators

(a) Negative Resistance oscillators:

It uses Negative Resistance of the ~~Amplifying~~ Amplifying device to neutralize the positive Resistance of the oscillator.

(b) Feedback oscillator:

It uses positive feedback in the feedback Amplifier to satisfy the Barkhausen criterion.

3. According to the frequency generated:

(a) Audio frequency oscillator (AFO): up to 20 kHz

(b) Radio frequency oscillator (RFO): 20 kHz to 30 MHz

(c) very high frequency (VHF) oscillator: 30 MHz to 300 MHz

(d) ultra high frequency (UHF) oscillator: 300 MHz to 3 GHz

(e) Microwave frequency oscillator: above 3 GHz

4. According to the type of circuit used, sine-wave oscillators may be classified as

(a) LC tuned oscillator
- Hartley oscillator
- Colpitts oscillator
- Clapp oscillator

(b) RC phase shift oscillator
- RC phase shift oscillator
- Wein bridge oscillator

Conditions for oscillation (BARKHAUSEN CRITERION):

Mechanism for start of oscillations:

→ The oscillator circuit is set into oscillations by a Random variation caused in the base current due to noise component or a small variation in the d.c power supply.

→ The noise components i.e. extremely small Random Electrical voltages and currents are always present in any conductor, tube or transistor.

→ Even when no external signal is Applied, the ever-present noise will cause some small signal at the output of the Amplifier.

→ when the Amplifier is tuned at a particular frequency f_r, the output signal caused by noise signals will be predominantly at f_r.

→ If a small fraction (β) of the output signal is fed back to the Input with proper phase Relation, then this feedback signal will be Amplified by the Amplifier.

→ If the Amplifier has a gain of more than $1/\beta$, then the o/p increases and thereby the feedback signal becomes larger.

→ This process continues and the output goes on increasing.

→ But as the signal level increases, the gain of the Amplifier is reduced and at a particular value of the output, the gain of the Amplifier is reduced exactly equal to $1/\beta$.

→ Then the output voltage remains constant at frequency f_r, called frequency of oscillation.

The essential conditions for maintaining oscillations are:

1. $|A\beta| = 1$, i.e. the magnitude of loop gain must be unity.

2. The total phase shift around the closed loop is zero or 360 degrees.

Practical considerations:

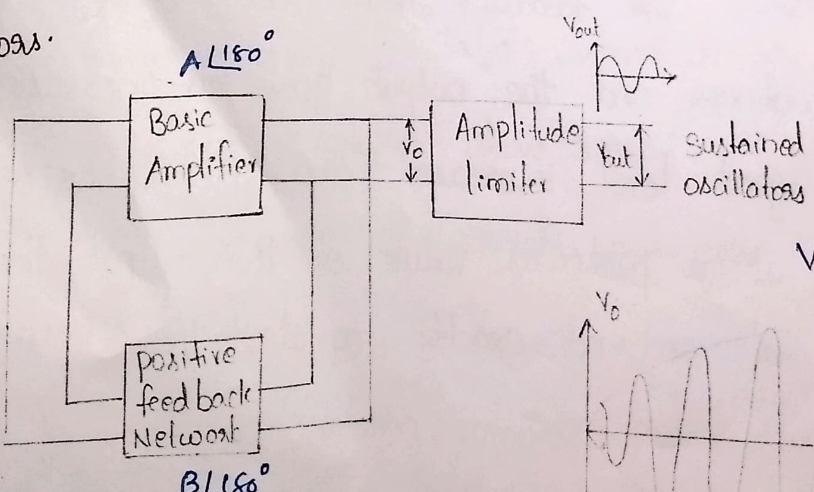
→ The condition $|A\beta| = 1$ gives a single and precise value of $A\beta$ which should be set through out the operation of the oscillator circuit.

→ But in practice, as transistor characteristics and performance of other circuit components change with time, $|A\beta|$ will become greater or less than unity.

→ Hence, in all practical circuits $|A\beta|$ should be set greater than unity so that the Amplitude of oscillation will continue to increase without limit but such an increase in Amplitude is limited by the onset of the nonlinearity of operation in the active devices associated with the Amplifier as shown in fig.

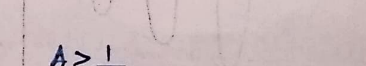
→ In this circuit, $A\beta$ is larger than unity for positive feed back.

→ This onset of nonlinearity is an essential feature of all practical oscillators.



$V_f = \beta V_o$ |V
$= A\beta V_{in}$

$V_o = A(V_f + V_{in})$
$= A(\beta V_o + V_{in})$
$= A\beta V_o + V_{in}$
$V_o(1 - A\beta) = 2$

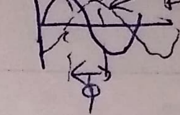


$A > \frac{1}{\beta} \Rightarrow A\beta > 1$

$A\beta = 1\angle 360^\circ$

Block diagram of an oscillator

Voltage leads current → positive phase
Voltage lags by current → -ve phase



General form of an LC oscillator:

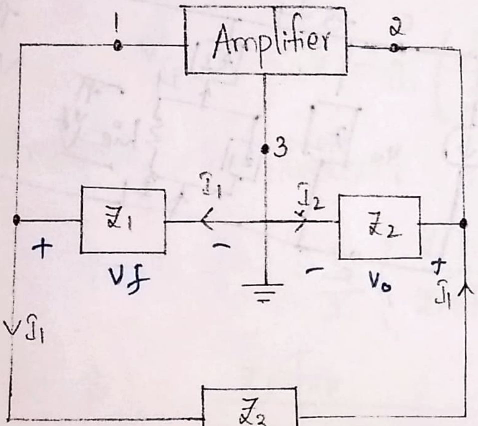
→ In the general form of oscillator, any of the Active devices such as vaccum tube, Transistor, FET and operational Amplifier may be used in the Amplifier section.

→ Z_1, Z_2 and Z_3 are the reactive elements constituting the feedback tank circuit which determines the frequency of oscillation.

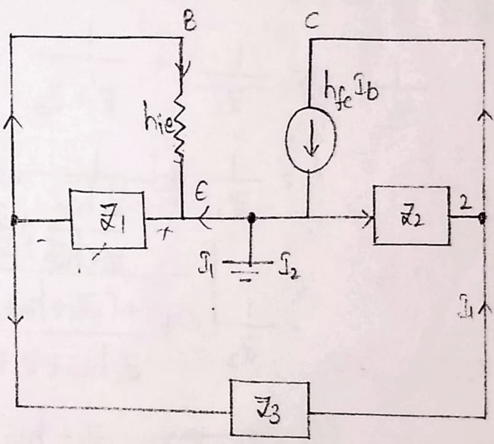
→ Here Z_1 and Z_2 serve as an ac voltage divider for the output voltage and feedback signal.

→ Therefore, the voltage across Z_1 is the feedback signal.

→ The frequency of oscillation of the LC oscillator is



(a) General form of an oscillator



(b) Its equivalent circuit

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

The Inductive or capacitive Reactances are represented by Z_1, Z_2 and Z_3. The output terminals are 2 and 3, and Input terminals are 1 and 3 as shown in fig(a).

The fig (b) gives the equivalent circuit of General form of an oscillator.

Load Impedance:

Since Z_1 and the Input Resistance h_{ie} of the transistor are in parallel, their equivalent Impedance Z' is given by

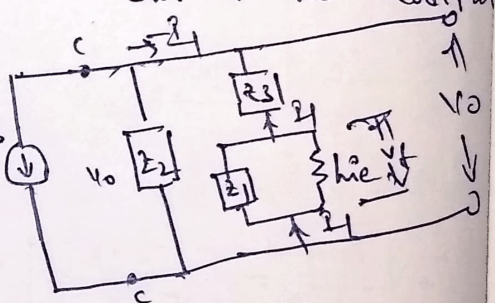
$$\frac{1}{Z'} = \frac{1}{Z_1} + \frac{1}{h_{ie}}$$

From this equation, we get

$$Z' = \frac{Z_1 h_{ie}}{Z_1 + h_{ie}} \longrightarrow (1)$$

Now the load Impedance Z_L between the output terminals 2 & 3 is the equivalent Impedance of Z_2 in parallel with the series combination of Z' and Z_3.

Ckt for llc modification



Therefore,

$$\frac{1}{Z_L} = \frac{1}{Z_2} + \frac{1}{Z' + Z_3}$$

$$= \frac{1}{Z_2} + \frac{1}{\frac{Z_1 h_{ie}}{Z_1 + h_{ie}} + Z_3}$$

$$= \frac{1}{Z_2} + \frac{Z_1 + h_{ie}}{Z_1 h_{ie} + Z_1 Z_3 + h_{ie} Z_3}$$

$$= \frac{1}{Z_2} + \frac{Z_1 + h_{ie}}{h_{ie}(Z_1 + Z_3) + Z_1 Z_3}$$

$$= \frac{h_{ie}(Z_1 + Z_3) + Z_1 Z_3 + Z_2(Z_1 + h_{ie})}{Z_2[h_{ie}(Z_1 + Z_3) + Z_1 Z_3]}$$

$$= \frac{h_{ie}(Z_1 + Z_2 + Z_3) + Z_1 Z_2 + Z_1 Z_3}{Z_2[h_{ie}(Z_1 + Z_3) + Z_1 Z_3]}$$

Therefore,

$$Z_L = \frac{Z_2[h_{ie}(Z_1 + Z_3) + Z_1 Z_3]}{h_{ie}(Z_1 + Z_2 + Z_3) + Z_1 Z_2 + Z_1 Z_3} \longrightarrow (2)$$

Voltage gain without feedback:

This is given by

$$A_{ve} = -\frac{h_{fe} Z_L}{h_{ie}} \longrightarrow (3)$$

Feedback fraction (β):

The output voltage between the terminals 3 & 2 in terms of the current I_1 is given by

$$V_o = -I_1 (Z' + Z_3) = -I_1 \left(\frac{Z_1 h_{ie}}{Z_1 + h_{ie}} + Z_3 \right)$$

$$= -I_1 \left(\frac{h_{ie}(Z_1 + Z_3) + Z_1 Z_3}{Z_1 + h_{ie}} \right) \longrightarrow (4)$$

The voltage feedback to the input terminals 3 & 1 is given by

$$V_{fb} = -I_1 Z' = -I_1 \left(\frac{Z_1 h_{ie}}{Z_1 + h_{ie}} \right) \longrightarrow (5)$$

Therefore, the feedback ratio β is given by

$$\beta = \frac{V_{fb}}{V_o} = \frac{I_1}{I_1} \left(\frac{Z_1 h_{ie}}{Z_1 + h_{ie}} \right) \left[\frac{Z_1 + h_{ie}}{h_{ie}(Z_1 + Z_3) + Z_1 Z_3} \right]$$

$$\beta = \frac{Z_1 h_{ie}}{h_{ie}(Z_1 + Z_3) + Z_1 Z_3} \longrightarrow (6)$$

Equation of the oscillator:

For oscillation, we must have

$$A_{ve} \beta = 1$$

Substituting the values of A_{ve} and β, we get

$$\left(-\frac{h_{fe} Z_L}{h_{ie}} \right) \left[\frac{Z_1 h_{ie}}{h_{ie}(Z_1 + Z_3) + Z_1 Z_3} \right] = 1$$

$$\left\{ \frac{h_{fe} Z_2 \left[h_{ie}(Z_1 + Z_3) + Z_1 Z_3 \right]}{h_{ie}(Z_1 + Z_2 + Z_3) + Z_1 Z_2 + Z_1 Z_3} \right\} \left[\frac{Z_1}{h_{ie}(Z_1 + Z_3) + Z_1 Z_3} \right] = -1$$

$$\frac{h_{fe} Z_2 Z_1}{h_{ie}(Z_1 + Z_2 + Z_3) + Z_1 Z_2 + Z_1 Z_3} = -1$$

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

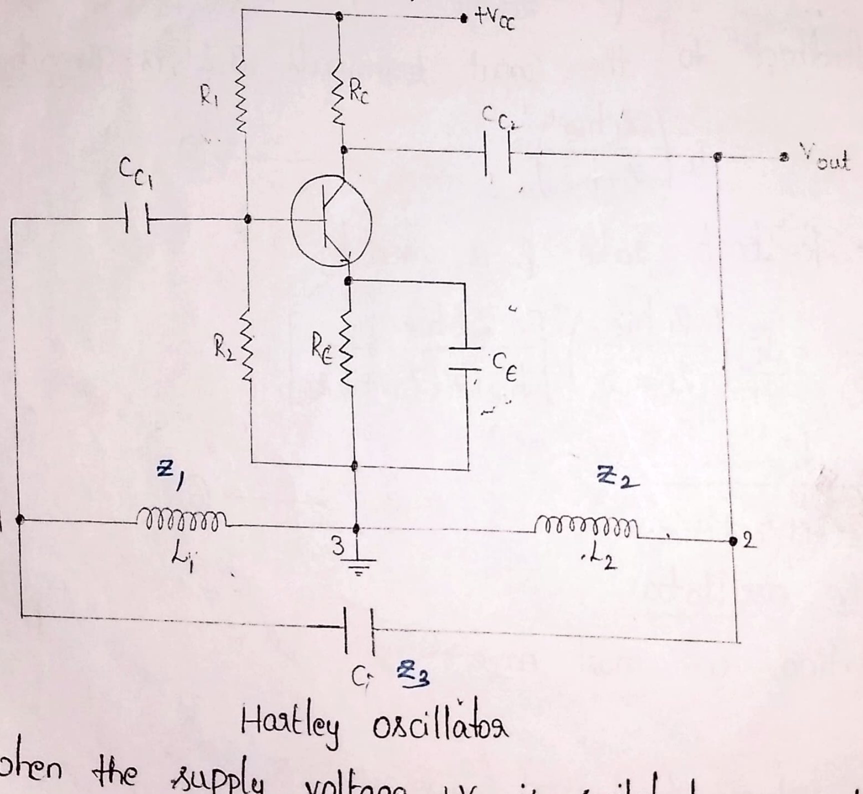
$$h_{ie}(Z_1+Z_2+Z_3)+Z_1Z_2(1+h_{fe})+Z_1Z_3=0 \longrightarrow (1)$$

- This is the general Equation for the oscillator.

Hartley oscillator:

→ In the Hartley oscillator Z_1 and Z_2 are Inductors and Z_3 is a capacitor. Resistors R_1, R_2 and R_E provide the necessary d.c bias to the transistor C_E is a bypass capacitor. C_{C_1} and C_{C_2} are coupling capacitors.

→ The feedback network consisting of Inductors L_1 and L_2, and capacitor C determines the frequency of the oscillator.



Hartley oscillator

→ when the supply voltage +Vcc is switched ON, a transient current is produced in the tank circuit and consequently, damped harmonic oscillations are set up in the circuit.

→ The oscillatory current in the tank circuit produces a.c voltages across L_1 and L_2.

frequency at which the response of amplitude is Max known as resonant frequency, at which large amp of oscill[illegible]

→ As terminal 3 is earthed, it is at zero potential.

→ If terminal 1 is at a positive potential with respect to 3 at any instant, terminal 2 will be at a negative potential with respect to 3 at the same instant.

→ Thus the phase difference between the terminals 1 and 2 is always 180°.

→ In the CE mode, the transistor provides the phase difference of 180° between the input and output.

→ Therefore, the total phase shift is 360°. Thus, at the frequency determined for the tank circuit, the necessary condition for unstained oscillations is satisfied.

→ If the feedback is adjusted so that the loop gain $A\beta = 1$, the ckt acts as an oscillator.

→ The frequency for oscillation is $f_r = \frac{1}{2\pi\sqrt{LC}}$

where $L = L_1 + L_2 + 2M$

M = The value of Mutual Inductance between coils L_1 and L_2.

→ The condition for sustained oscillation is

$$h_{fe} \geq \frac{L_1 + M}{L_2 + M}$$

Analysis:

→ In the Hartley oscillator, Z_1 and Z_2 are Inductive Reactances and Z_3 is the capacitive Reactance.

→ Suppose M is the Mutual Inductance between the Inductors, then

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

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

$$Z_3 = \frac{1}{j\omega C} = \frac{-j}{\omega C}$$

→ we know, the general equation for the oscillator is

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

$j\omega L$, $\frac{1}{j\omega C}$

→ substitute Z_1, Z_2 and Z_3 values in eq ①

$$j\omega h_{ie}\left[L_1+L_2+2M-\frac{1}{\omega^2 C}\right]-\omega^2(L_1+M)\left[(L_2+M)(1+h_{fe})-\frac{1}{\omega^2 C}\right]=0 \longrightarrow ②$$

→ The frequency of oscillation $f_r=\frac{\omega_r}{2\pi}$ can be determined by equating the imaginary part of eq ② to zero.

Therefore,

$$\left[L_1+L_2+2M-\frac{1}{\omega_r^2 C}\right]=0 \qquad \Rightarrow L_1+L_2+2M=\frac{1}{\omega_r^2 C}$$

$$\Rightarrow L_1+L_2+2M=\frac{1}{4\pi^2 f_r^2 C}$$

Simplifying this equation, we obtain

$$f_r=\frac{\omega_r}{2\pi}=\frac{1}{2\pi\sqrt{(L_1+L_2+2M)C}}=\frac{1}{2\pi\sqrt{LC}} \longrightarrow ③$$

$L=L_1+L_2+2M$

→ The condition for maintanance of oscillation is obtained by substituting eq ③ into eq ②. Now the imaginary part becomes zero and hence,

frequency of oscillation

$f_1 \rightarrow Z_1+Z_2+Z_3=0$

$$\left[(L_2+M)(1+h_{fe})-\frac{1}{\omega_r^2 C}\right]=0$$

$h_{fe\,min}=\frac{Z_1}{Z_2}$

Substituting eq ③ into above equation and simplifying, we get

$$h_{fe}=\frac{L_1+M}{L_2+M}$$

$$\boxed{h_{fe\,min}=\frac{Z_1}{Z_2}} \longrightarrow ④$$

Colpitts oscillator: → design: are two centre tapped capacitor in series, parallel inductor forms resonant tank

→ In the colpitts oscillator Z_1 and Z_2 are capacitors and Z_3 is an inductor.

frequency stability increased, simple design

→ The resistors R_1, R_2 and R_E provide the necessary d.c bias to the transistor.

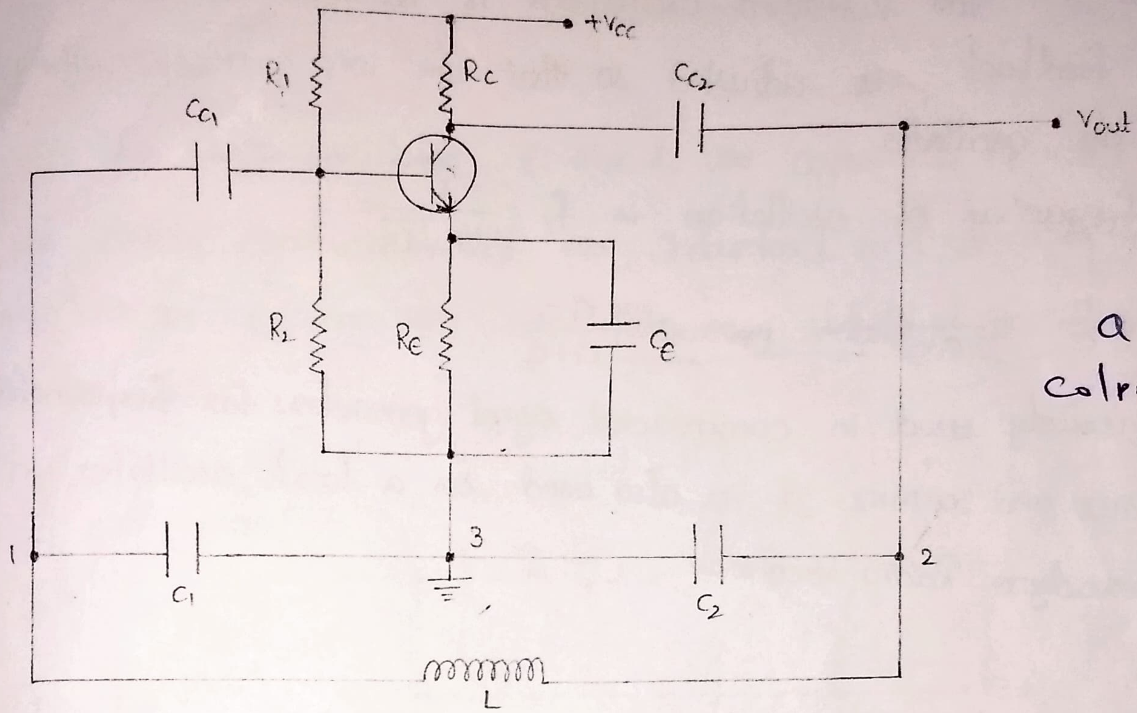
In this capacitive voltage divider ckt is used for feed back n/w

Quality factor → energy stored / energy lost →

→ C_E is a bypass capacitor. C_{C_1} and C_{C_2} are coupling capacitors.

→ The feedback network consisting of capacitors C_1 and C_2 and an inductor L determines the frequency of the oscillator.

→ The colpitts oscillator is as shown in the figure.



colpitts oscillator

Q is good
Colpitts compare to Hartley

→ when the supply voltage $+V_{cc}$ is switched ON, a transient current is produced in the tank circuit and consequently, damped harmonic oscillations are set up in the circuit.

→ The oscillatory current in the tank circuit produces a.c voltages across C_1 and C_2.

→ As terminal 3 is earthed, it will be at zero potential.

→ If terminal 1 is at a positive potential with respect to 3 at any instant, terminal 2 will be at a negative potential with respect to 3 at the same instant.

→ Thus the phase difference between the terminals 1 and 2 is always 180°.

→ In the CE mode, the transistor provides the phase difference of 180° between the Input and output.

→ Therefore, the total phase shift is 360°.

→ Thus, at the frequency determined for the tank circuit, the necessary condition for sustained oscillations is satisfied.

→ If the feedback is adjusted so that the loop gain $A\beta = 1$, the ckt acts as an oscillator.

→ The frequency of oscillation is $f_r = \frac{1}{2\pi\sqrt{LC}}$

where $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$ i.e. $C = \frac{C_1 C_2}{C_1 + C_2}$

→ It is widely used in commercial signal generators for frequencies between 1MHz and 500MHz. It is also used as a local oscillator in super heterodyne Radio Receiver.

Analysis:

→ For this oscillator,

$$Z_1 = \frac{1}{j\omega C_1} = -\frac{j}{\omega C_1}$$

$$Z_2 = \frac{1}{j\omega C_2} = -\frac{j}{\omega C_2}$$

$$Z_3 = j\omega L$$

→ we know that, the general equation for the oscillator is

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

→ Substitute Z_1, Z_2 and Z_3 values in eq ①

$$j h_{ie}\left(\frac{1}{\omega C_1} + \frac{1}{\omega C_2} - \omega L\right) + \left(\frac{1+h_{fe}}{\omega^2 C_1 C_2} - \frac{L}{C_1}\right) = 0 \longrightarrow ②$$

→ The frequency of oscillation, $f_r = \frac{\omega_r}{2\pi}$, is found by equating the imaginary part of eq ② to zero. Thus we get

$$f_r = \frac{\omega_r}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{C_1+C_2}{LC_1C_2}} \longrightarrow ③ \qquad f_r = \frac{1}{2\pi\sqrt{LC}} \qquad C = \frac{C_1C_2}{C_1+C_2}$$

Substitute eq ③ in eq ② and simplifying, we get the condition for maintenance of oscillation as

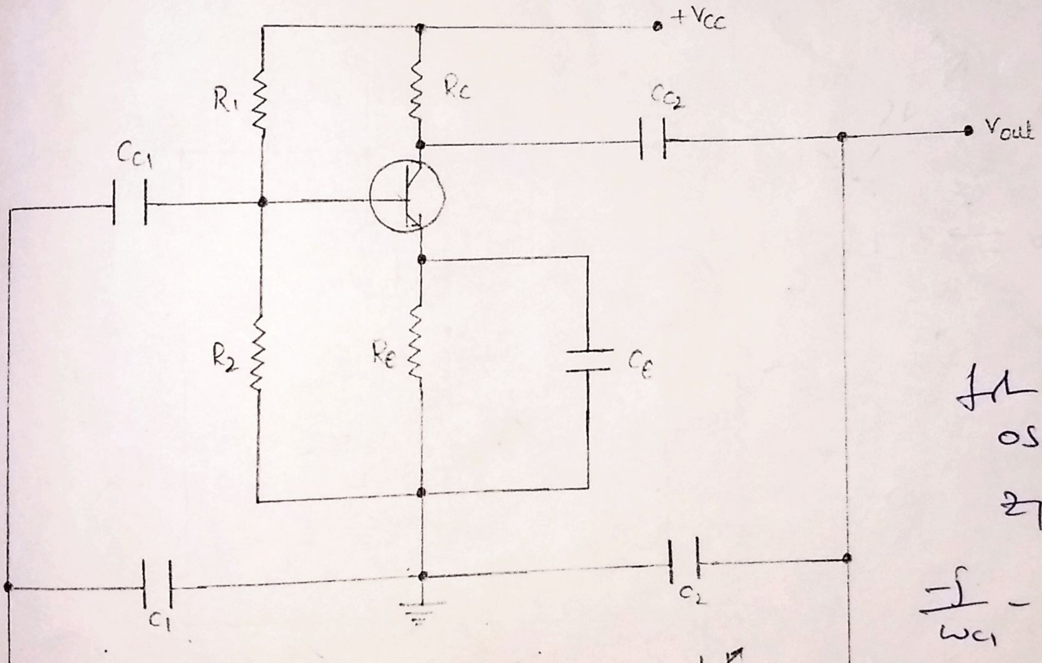
$$h_{fe} = \frac{C_2}{C_1} \longrightarrow ④$$

Clapp oscillator:

→ In the clapp oscillator, Z_1 and Z_2 are capacitors C_1 and C_2, and Z_3 is the series combination of an inductor L and a capacitor C_3.

→ Addition of C_3 improves the frequency stability. The frequency of oscillation is

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



for frequency of oscillation oscillator

$$Z_1 + Z_2 + Z_3 = 0$$

$$\frac{-j}{\omega C_1} - \frac{j}{\omega C_2} + j\omega L - \frac{j}{\omega C_3} = 0$$

$$j\left[-\frac{1}{\omega C_1} - \frac{1}{\omega C_2} - \frac{1}{\omega C_3} + \omega L\right] = 0$$

Clapp oscillator $\underbrace{\qquad}_{Z_3}$

$$\boxed{Z_1 = \frac{-j}{\omega C_1} \quad Z_2 = \frac{-j}{\omega C_2} \quad Z_3 = j\omega L - \frac{j}{\omega C_3}}$$

where $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$

$\frac{1}{}$

$$h_{fe} = \frac{Z_1}{Z_2}$$

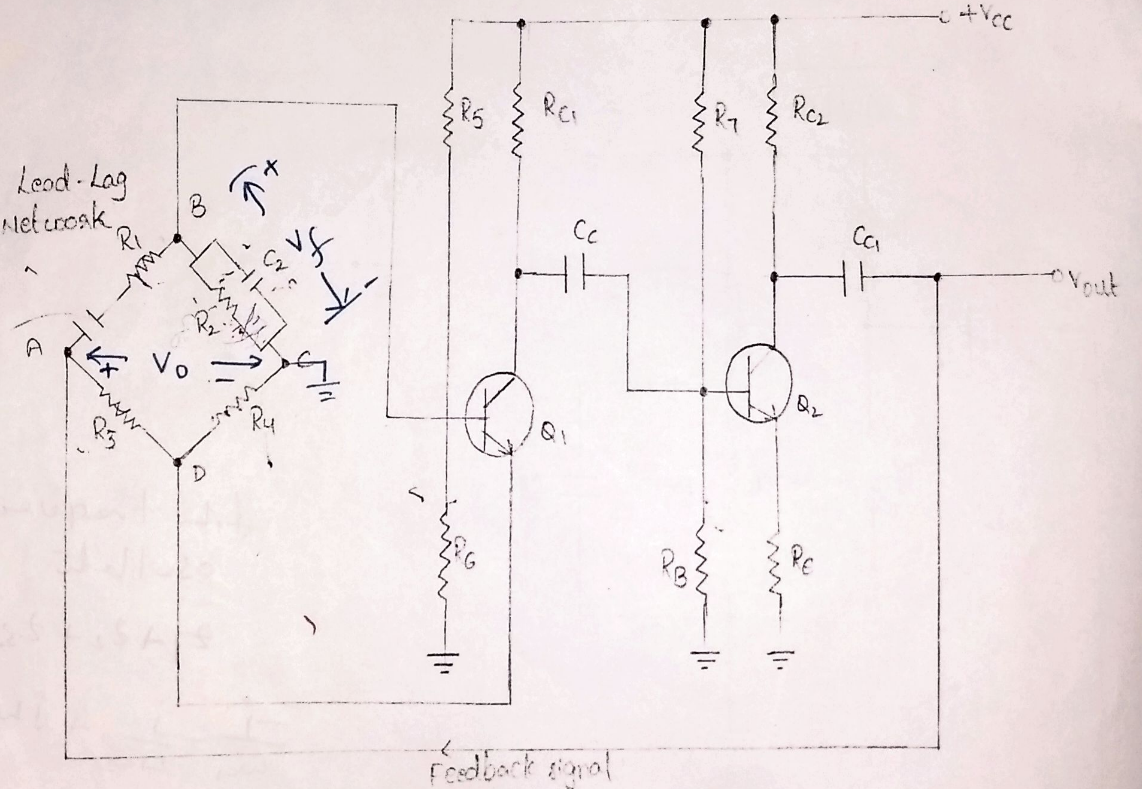
Wein - Bridge oscillator:

→ The circuit consists of a two-stage Rc coupled Amplifier which provides a phase shift of 360° or 0°.

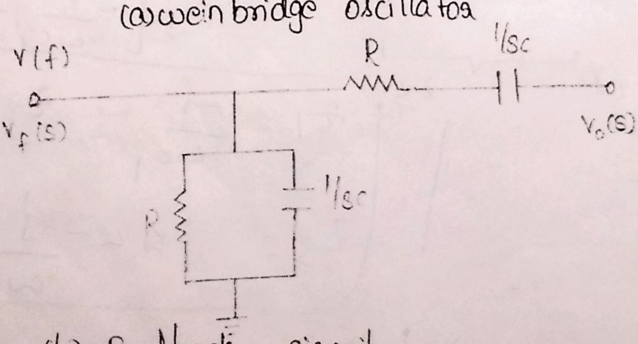
→ A balanced bridge is used as the feedback network which has no need to provide any additional phase shift.

→ The feedback network consists of a lead-lag network (R_1-C_1 & R_2-C_2) and a voltage divider (R_3-R_4).

→ The lead-lag network provides a positive feedback to the input of the first stage and the voltage divider provides a negative feedback to the emitter of Q_1.



(a) wein bridge oscillator



(b) Feedback circuit

If the bridge is balanced,

$$\frac{R_3}{R_4} = \frac{R_1 - jX_{C_1}}{\left[\frac{R_2(-jX_{C_2})}{R_2 - jX_{C_2}}\right]} \longrightarrow ①$$

where X_{C_1} and X_{C_2} are the Reactances of the capacitors.

→ simplifying eq ① and equating the real and imaginary parts on both sides we get the frequency of oscillation as,

$$f_r = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}$$

$$= \frac{1}{2\pi RC}, \text{ if } R_1 = R_2 = R \text{ and } C_1 = C_2 = C$$

→ The ratio of R_3 to R_4 being greater than 2 will provide a sufficient gain for the circuit to oscillate at the desired frequency. This oscillator is used in commercial audio signal generators.

To determine the gain of wien bridge oscillator using BJT Amplifier:

Assume that $R_1 = R_2 = R$ and $C_1 = C_2 = C$

Therefore,

$$V_f(S) = V_o(S) \frac{R // \frac{1}{SC}}{R + \frac{1}{SC} + R // \frac{1}{SC}}$$

$$V_f(S) = V_o(S) \frac{\frac{R}{1+SRC}}{R + \frac{1}{SC} + \frac{R}{1+SRC}}$$

$$= V_o(S) \frac{SRC}{S^2R^2C^2 + 3SRC + 1}$$

Hence, the feedback factor is

$$\beta = \frac{V_f(S)}{V_o(S)} = \frac{SRC}{S^2R^2C^2 + 3SRC + 1}$$

$A\beta = 1$

$A \left[\dfrac{j\omega RC}{-\omega^2 c^2 R^2 + 3j\omega RC + 1} \right] = 1$

$A j\omega RC = -\omega^2 c^2 R^2 + 3j\omega RC + 1$

equaly imaginary & real

$-\omega^2 c^2 R^2 + 1 = 0$

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

we know that $A\beta = 1$

Therefore, the gain of the Amplifier,

$$A = \frac{1}{\beta} = \frac{s^2R^2C^2 + 3sRC + 1}{sRC}$$

→ substituting $s = j\omega_r$, where the frequency of oscillation $f_r = \frac{1}{2\pi RC}$

i.e. $\omega_r = \frac{1}{RC}$, in the above equation and simplifying, we get $A = 3$.

Hence the gain of the wien bridge oscillator using BJT Amplifier is at least equal to 3 for oscillations to occur.

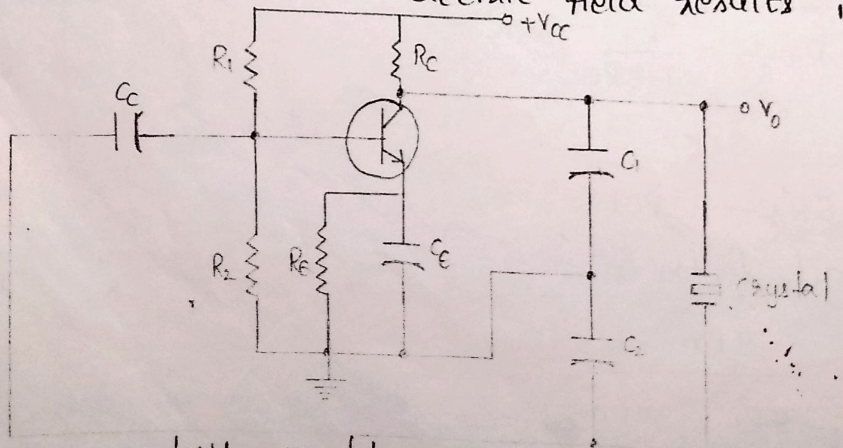
Crystal oscillators:

→ Here, it is a colpitts crystal oscillator in which the Inductor is replaced by the crystal.

→ In this type, a piezo-electric crystal, usually quartz, is used as a resonant circuit replacing an LC circuit.

→ The crystal is a thin slice of piezo-electrica material, such as quartz, tourmaline and rochelle salt, which exhibit a property called piezo-electric effect.

→ The piezo-electric effect represents the characteristics that the crystal reacts to any mechanical stress by producing an electric charge; in the reverse effect, an electric field results in mechanical strain



Colpitts crystal oscillator

Crystal construction:

→ In order to obtain high degree of frequency stability, crystal oscillators are essentially used.

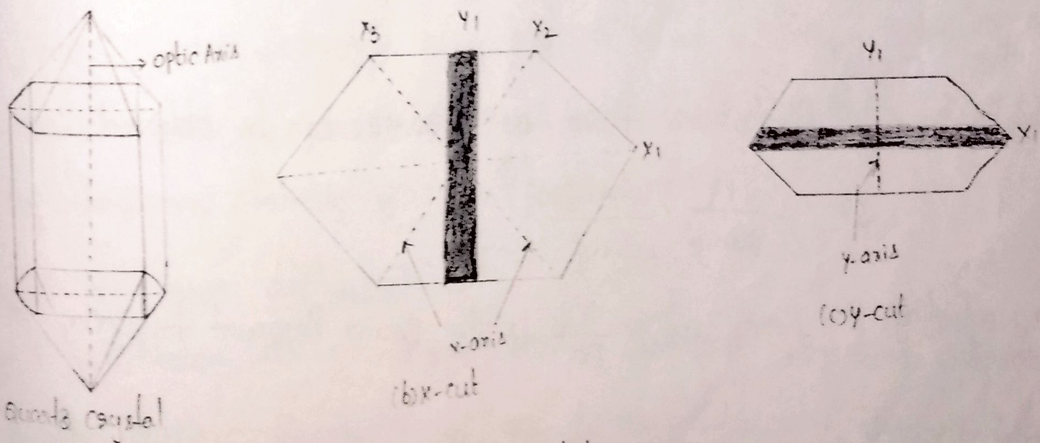
→ Generally, the crystal is ground wafer of translucent quartz or tourmaline stone placed between two metal plates and housed in a lamp sized package.

→ There are two different methods of cutting this crystal wafer from the crude quartz.

→ The method of cutting determines the natural Resonant frequency and temperature coefficient of the crystal.

→ when the wafer is cut in such a way that its flat surfaces are perpendicular to its electrical axis (x-axis), it is called an x-cut crystal.

→ when the wafer is cut in such a way that its flat surfaces are perpendicular to its mechanical axis (y-axis), it is called y-cut crystal as shown in figure.



Piezoelectric crystal

→ If an Alternating voltage is applied, then the crystal wafer is set into vibration.

→ The frequency of vibration equal to the resonant frequency of the crystal is determined by its structural characteristics.

→ If the frequency of the applied a.c voltage is equal to the natural resonant frequency of the crystal, then the maximum Amplitude of vibration will be obtained.

→ In general, the frequency of vibration is inversely proportional to the thickness of the crystal.

→ The frequency of vibration is $f = \frac{P}{2l}\sqrt{\frac{Y}{\rho}}$

where Y is the young Modulus.

ρ is the density of the materal and $P = 1, 2, 3, \ldots$

→ The crystal is suitably cut and polished to vibrate at a certain frequency and mounted between two metal plates.

→ The equivalent circuit of the crystal is shown in fig (b).

→ The ratio of C_p to C_s may be several hundred or more so that series Resonance frequency is very close to parallel Resonant frequency.

→ The Resonant frequency is inversely proportional to the thickness of the crystal.

→ Resonant frequencies from 0.5 to 30 MHz can be obtained.

$$jX = \frac{1}{j\omega C_p} \cdot \frac{\omega^2 - \omega_s^2}{\omega^2 - \omega_p^2}$$

→ Neglecting R. Here $\omega_s^2 = \frac{1}{LC_s}$ is the series Resonant frequency and

$$\omega_p^2 = \frac{1}{L\left(\frac{1}{C_s} + \frac{1}{C_p}\right)}$$

is the parallel Resonant frequency.

→ since $C_p >> C_s$, $\omega_p = \omega_s$. For $\omega_s < \omega < \omega_p$, the reactance is inductive and for ω out of the above range, it is capacitive.

→ The frequency stability is defined as

$$S_\omega = \frac{d\theta}{d\omega}$$

where $d\theta$ is the phase shift introduced for a small frequency change in nominal frequency f_r.

→ The circuit giving the larger value of $\frac{d\theta}{d\omega}$ has the more stable oscillator frequency.

→ If the Q is infinite (an ideal inductor with zero series Resistance), this phase change in phase is abrupt, $\frac{d\theta}{d\omega} \to \infty$ because the phase changes abruptly from -90° to $+90^\circ$.

→ For tuned oscillators, S_ω is directly proportional to the Q of a tuned circuit.

→ A frequency stability of one part in 10^4 can be achieved with LC circuits.

→ For LC oscillators, a tuned circuit must be lightly loaded to preserve high Q value.

→ As piezo-electric crystals have high Q values of the order of 10^5, they can be used as parallel Resonant circuits in oscillators to get very high frequency stability of 1ppm (part per million).

Negative-Resistance oscillators:

→ All oscillators do not require positive feedback for their operation.

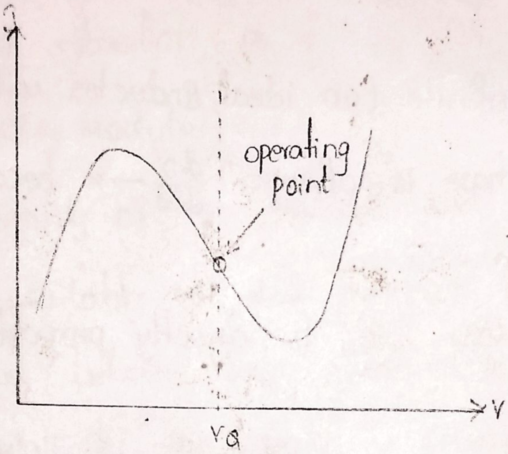
→ If the positive Resistance of the LC tank circuit is cancelled by introducing the right amount of negative resistance across the tank ckt, then the steady oscillation can be maintained.

→ There are several devices such as dynatron, transitron, UJT and tunnel diode that exhibit a region of negative Resistance within the

V-I characteristics as shown in figure.

→ Such devices operated in the negative Resistance Region are placed across a high Q parallel LC circuit as the frequency determining section.

→ For oscillation to occur the negative Resistance should be numerically less than the dynamic resistance of the tuned circuit.

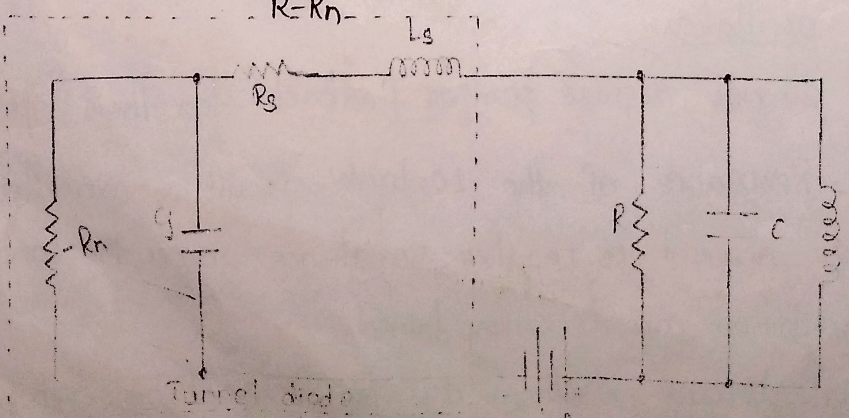


V-I characteristics of negative Resistance Oscillators

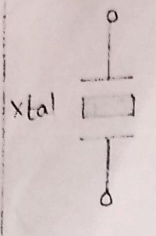
Tunnel diode oscillator:

If the parallel tank circuit with a Resistance R, a capacitance C and an Inductance L is connected across the tunnel diode whose negative Resistance is $-R_n$, the net Resistance R_{eq} represents R and $-R_n$ in parallel and is given by

$$R_{eq} = \frac{-R_n \cdot R}{R - R_n}$$

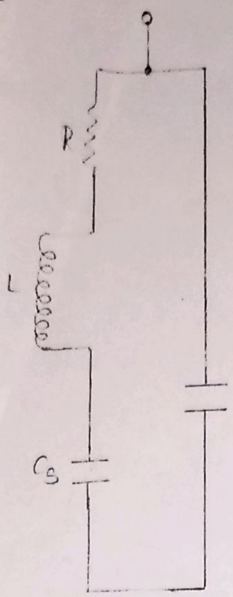


Tunnel diode oscillator



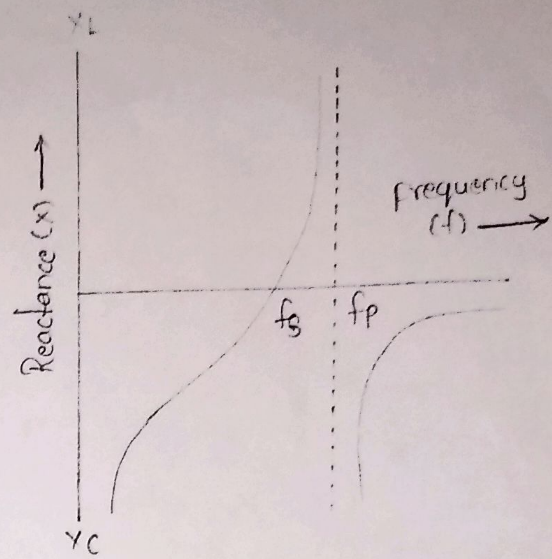
(a)

symbol



(b)

electrical equivalent ckt



(c)

The Reactance function when R = 0

A Piezo electric crystal

→ For crystal Hartley oscillator, the capacitors C_1 and C_2 are replaced with Inductors L_1 and L_2 respectively, so that the Reactance of the crystal is capacitive.

→ Hence, its oscillation frequency is $\frac{1}{2\pi\sqrt{(L_1+L_2)C}}$

→ The Advantage of the crystal is its very high Q as a resonant circuit, which results in good frequency stability for the oscillator.

→ However, since the resonant frequencies of the crystals are temperature dependent, it is necessary to enclose the crystal in a temperature controlled oven to achieve the frequency stability of the order of 1 part in 10^{10}.

<u>Frequency stability of oscillator:</u>

→ The frequency stability of an oscillator is a measure of its ability to maintain the required frequency as precisely as possible over as long a time Interval as possible.

→ The accuracy of frequency calibration required may be anywhere between 10^{-2} and 10^{-10}.

→ The main drawback in transistor oscillators is that the frequency of oscillation is not stable during a long time operation.

→ The following are the factors which contribute to the change in frequency.

1. Due to change in temperature, the values of the frequency determining components, viz., resistor, Inductor and capacitor change.
2. Due to variation in the power supply, unstable transistor parameters, change in climatic conditions and aging.
3. The effective Resistance of the tank circuit is changed when the load is connected.
4. Due to variation in biasing conditions and loading conditions.

→ The variation of frequency with temperature is given by

$$S_{\omega,T} = \frac{\Delta\omega/\omega_0}{\Delta T/T_0} \text{ ppmc (Parts per million per}^\circ\text{c)}$$

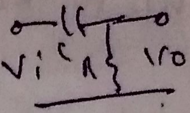
where ω_0, T_0 are the desired frequency of oscillation and the operating temperature respectively.

→ In the Absence of Automatic temperature control, the effect of temperature on the resonant LC circuit can be reduced by selecting an Inductance L with positive temperature coefficient and a capacitance C with negative temperature coefficient.

→ The loading effect may be minimised if the oscillator is coupled to the load loosely or by a circuit with high Input Resistance and low output Resistance properties.

RC phase shift oscillator

Phase shift of one RC $\pi/4$



$$\frac{V_o}{V_i} = \frac{R}{R - j/\omega C}$$

$$= \frac{1}{1 - \frac{j}{\omega CR}}$$

$$\theta = \tan^{-1}\left(\frac{1}{\omega CR}\right)$$

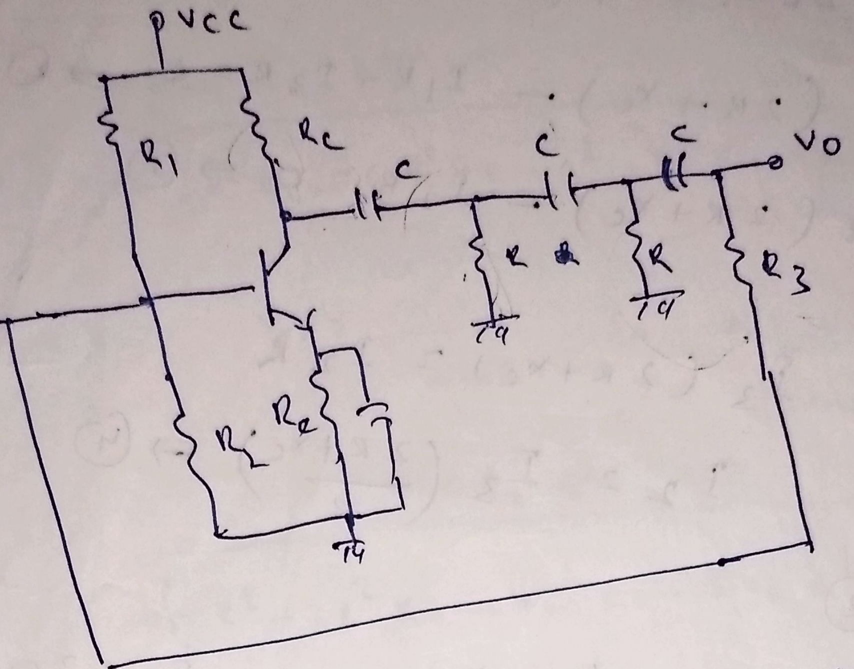
$$= \tan^{-1}\left(\frac{X_C}{R}\right)$$

$R = 0$

$$\theta = \tan^{-1}(\infty) = 90$$

$X_C = 0$

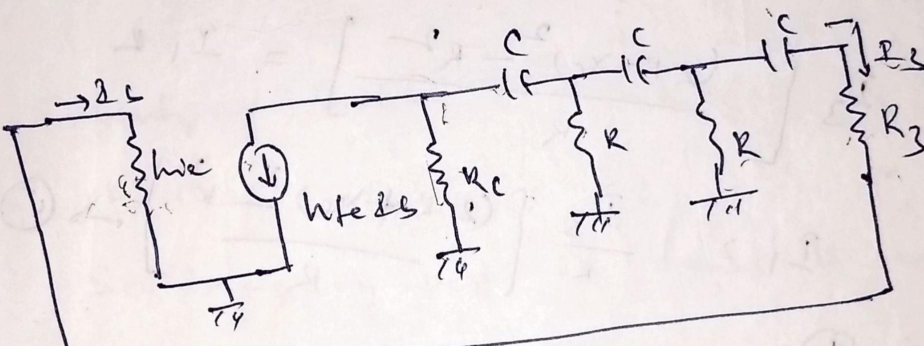
$$\theta = 0^{\circ}$$

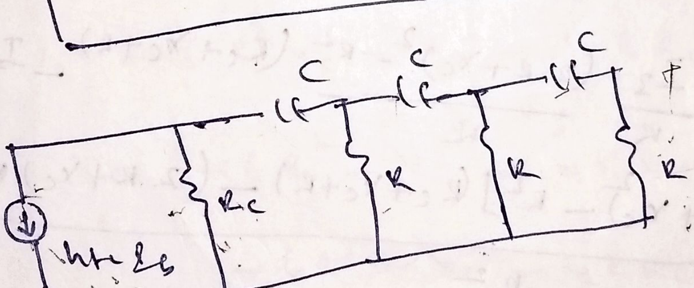


Transistor is replaced by h parameter model

$$Z = \sqrt{R^2 + X_C^2}$$

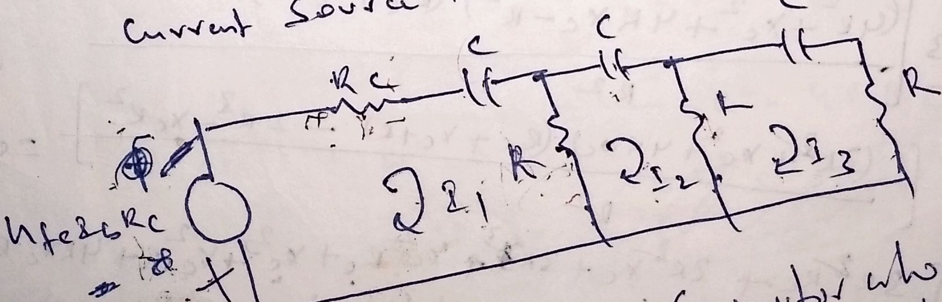
$$\phi = \tan^{-1}\left(\frac{X_C}{R}\right)$$





$R = R_3 + h_{ie}$

Current source is replaced by voltage source



Capacitor whose voltage leads by 90°.

$$-h_{fe} I_b R_c = I_1 (R_c + X_c + R) - I_2 R$$

$$h_{fe} I_b R_c + I_1 (R_c + X_c + R) - I_2 R = 0 \rightarrow (1)$$

$$I_2 (2R + X_c) - I_1 R - I_3 R = 0 \rightarrow (2)$$

$$I_3 (2R + X_c) - I_2 R = 0 \rightarrow (3)$$

from (3)

$$I_3 (2R + X_c) = I_2 R$$

$$I_2 = I_3 \left(\frac{2R + X_c}{R}\right) \rightarrow (4)$$

(4) in (2)

$$I_3 \left(\frac{2R + X_c}{R}\right)(2R + X_c) - I_1 R - I_3 R = 0$$

$$I_3 \left[\frac{(2R + X_c)^2 - R^2}{R}\right] = I_1 R$$

$$I_1 = \frac{I_3}{R}\left[\frac{(2R + X_c)^2 - R^2}{R}\right] \rightarrow (5)$$

(4) & (5) in (1)

$$h_{fe} I_b R_c + \frac{I_3}{R}\,\frac{(2R + X_c)^2 - R^2}{R}(R_c + X_c + R) - I_3\left(\frac{2R + X_c}{\cancel{R}}\right)\cancel{R} = 0$$

$$h_{fe} I_b R_c + I_3 \left\{\frac{[(2R + X_c)^2 - R^2](R_c + X_c + R) - (2R + X_c)R^2}{R^2}\right\} = 0$$

$$h_{fe} I_b R_c + I_3 \left[\frac{(4R^2 + X_c^2 + 4RX_c - R^2)(R_c + X_c + R) - 2R^3 - X_c R^2}{R^2}\right] = 0$$

$$h_{fe} I_b R_c + I_3 \left[\frac{(3R^2 + X_c^2 + 4RX_c)(R_c + X_c + R) - 2R^3 - X_c R^2}{R^2}\right] = 0$$

$$h_{fe} I_b R_c + I_3 \left[\frac{3R^2 R_c + 3R^2 X_c + 3R^3 + X_c^2 R_c + X_c^3 + X_c^2 R + 4RX_c R_c + 4RX_c^2 + 4R^2 X_c - 2R^3 - X_c R^2}{R^2}\right] = 0$$

③ $h_{fe} I_b R_c + I_3 \left[\frac{3R^2 R_c + 6R^2 x_c + R^3 + x_c^2 R_c + x_c^3 + \cancel{x_c} \; + 4R x_c R_c + 5 x_c^2 R}{R^2} \right] = 0$ → ①

$$\frac{I_3}{I_b} = \frac{h_{fe} R_c R^2}{-3R^2R_c - 6R^2 x_c - R^3 - x_c^2 R_c - x_c^3 - 4R x_c R_c - 5 x_c^2 R}$$

We know $x_c = \frac{1}{j\omega c}$ So all odd power of x_c is imaginary

$$\frac{I_3}{I_b} = \frac{h_{fe} R_c R^2}{\underbrace{[-R^3 - 3R^2 R_c - x_c^2 R_c - 5x_c^2 R]}_{\text{real}} + \underbrace{[-6R^2 x_c - x_c^3 - 4R x_c R_c]}_{\text{imaginary}}}$$

Satisfying Barkhausen criteria I_3 & I_b are in phase

So imaginary part is equal to zero.

$$-6R^2 x_c - x_c^3 - 4R R_c x_c = 0$$

$$x_c [-6R^2 - x_c^2 - 4RR_c] = 0$$

$$-6R^2 - x_c^2 - 4RR_c = 0$$

$$x_c^2 = -6R^2 - 4RR_c \qquad x_c = \frac{1}{j\omega c}$$

$$\frac{-1}{\omega^2 c^2} = -6R^2 - 4RR_c$$

$$\cancel{\frac{1}{\omega^2 c^2} - 6R^2 c^2 - 4R_c R c}$$

$$\frac{1}{w^2c^2} = 6R^2 + 4RR_C \rightarrow (2)$$

$$w^2c^2 = \frac{1}{6R^2 + 4RR_C}$$

$$w^2 = \frac{1}{c^2(6R^2 + 4RR_C)}$$

$$w = \frac{1}{c\sqrt{6R^2 + 4RR_C}}$$

$$f = \frac{1}{2\pi c\sqrt{6R^2 + 4RR_C}}$$

$$= \frac{1}{2\pi Rc\sqrt{6 + 4\left(\frac{R_C}{R}\right)}} \qquad \frac{R_C}{R} = k$$

$$f = \frac{1}{2\pi Rc\sqrt{6 + 4k}}$$

Condition for min" oscillation $\qquad k = \frac{R_C}{R}$

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

for min" value of h_{fe}

$$\frac{dh_{fe}}{dk} = 0$$

$$4 - \frac{29}{k^2} = 0$$

$$k = 2.69$$

$k = 2.69 \rightarrow h_{fe}(min)$

$$h_{fe}(min) = 23 + 4(2.69) + \frac{29}{2.69}$$

$$= 44.55$$

$$h_{fe} \geq 23 + 4k + \frac{29}{k}$$

R.C Phase Shift oscillator:
Conditions for stable oscillator h_{fe} min.

in equation (1) imaginary part is zero. Then rewrite equation (1) $\quad X_c = -j/\omega C$

$$h_{fe} R_c R^2 + 3R^2 R_c + X_c^2 R_c + 5X_c^2 R + R^3 = 0$$

$$h_{fe} R_c R^2 + 3R^2 R_c + R^3 - \frac{R_c}{\omega^2 C^2} - \frac{5R}{\omega^2 C^2} = 0$$

We know $\frac{1}{\omega^2 C^2} = 6R^2 + 4RR_c$ from eq (2)

substitute above equation

$$h_{fe} R_c R^2 + 3R^2 R_c + R^3 - R_c(6R^2 + 4RR_c) - 5R(6R^2 + 4RR_c) = 0$$

$$h_{fe} R_c R^2 + 3R^2 R_c + R^3 - 6R^2 R_c - 4RR_c^2 - 30R^3 - 20R^2 R_c = 0$$

$$h_{fe} R_c R^2 - 23R^2 R_c - 29R^3 - 4RR_c^2 = 0$$

$$h_{fe} R_c R^2 = 23R^2 R_c + 29R^3 + 4RR_c^2$$

$$h_{fe} = \frac{23R^2 R_c}{R_c R^2} + \frac{29R^3}{R_c R^2} + \frac{4RR_c^2}{R_c R^2}$$

$$= 23 + 29\frac{R}{R_c} + 4\frac{R_c}{R}$$

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

for h_{fe} min

$$\frac{d h_{fe}}{dk} = \frac{-29}{k^2} + 4 = 0$$

$$k = 2.69$$

If $k = 2.69$

$$h_{fe\,min} = 23 + 4(2.69) + \frac{29}{2.69} = 44.55$$