regenerative

OSCILLATORS
UNIT - III

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If the o/p voltage is a sine wave function of time, the oscillator is called a 'Sinusoidal' or 'Harmonic' oscillat

There is another category of oscillators which generates non-sinusoidal waveforms such as square, rectangul triangular or sawtooth waves.

Classification of Oscillators:-

Based on o/p waveform:
① sinusoidal
② non-sinusoidal
Based on circuit component: RC oscillator, LC oscillator, crystal "
Based on operating freq:

Oscillators are classified in the following different way

① According to the waveform generated: (i) Sinusoidal oscillator
(ii) Relaxation oscillator.

Sinusoidal oscillator generates sinusoidal voltage or currents.

Relaxation oscillator generates voltages or currents which may vary one or moore times in a cycle of oscillation.

② According to the fundamental mechanisms involved:
(i) Negative resistance oscillators. (non-feedback osci) UJT
(ii) Feedback oscillators.

Relaxation osci

Negative resistance oscillator uses negative resistance of the amplifing device to ~~not~~ neutralize the positive resistance of the oscillator.

Feedback oscillator uses positive feedback in the feedback amplifier to satisfy the Barkhausen criterion.

③ According to the frequency generated:
(i) Audio frequency oscillator (AFO): up to 20 KHz
(ii) Radio " " (RFO): 20 KHz to 30 MHz
(iii) Very high frequency (VHF) oscillator: 30 MHz to 300 MHz

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(iv) Ultra high frequency (UHF) oscillator : 300 MHz to 3

(v) Microwave frequency oscillator : above 3 GHz.

(5) According to the type of circuit used, sine-wave oscillators may be classified as (a) LC tuned oscillator

(b) RC Phase shift oscillator.

Conditions for oscillations:-

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°

Positive feedback:-

As the phase of the feedback signal is same as that of the i/p applied, the feedback is called positive feedback.

→ The open loop gain of the amplifier is $A = \frac{V_0}{V_i}$ —— (1)

→ The closed loop gain of the amplifier is $A_f = \frac{V_0}{V_s}$ —— (2)

→ Input signal of an amplifier is $V_i = V_f + V_s$ —— (3)

→ The feedback voltage V_f depends on the feedback gain β

$\therefore V_f = \beta V_0$ —— (4)

Substituting eq (4) in eq (3), $V_i = \beta V_0 + V_s$

$\therefore V_s = V_i - \beta V_0$ —— (5)

$$\therefore A_f = \frac{V_0}{V_s} = \frac{V_0/V_i}{1 - \beta \left(\frac{V_0}{V_i}\right)} = \frac{A}{1 - \beta A} \quad \text{—— (6)}$$

The loop gain of the feedback circuit is $T = A\beta$ —— (7)

→ We know that the loop gain T is positive for negative feedback, which means that the feedback signal V_{fb} subtracts from the i/p signal V_s.

→ If the loop gain T becomes negative, then the feedback signal phases causes V_{fb} to add to the i/p signal ...

→ If $T = -1$, the closed loop gain transfer function goes to infinity, which means that the circuit can have a finite o/p for a zero i/p signal.

→ As T approaches −1, an actual circuit becomes nonlinear, which means the gain does not go to infinity.

→ Assume $T \simeq -1$ so that positive feedback exist over a perticular frequency range.

→ If a spontaneous signal is created at V_s in this frequency range, the resulting feedback signal V_{fb} is in phase with V_s and the error signal V_e is reinforced and increased.

→ This reinforcement process continues at only thoes frequencies for which the total phase shift around the feedback loop is zero.

→ Therefore, the condition for oscillation is that, at a specific frequency, we have $T(j\omega_0) = A(j\omega_0)\beta(j\omega_0) = -1$

→ The condition that $T(j\omega_0) = -1$ is called Barkhausen criterion.

→ Two conditions must be satisfied to sustain oscillation

① The total phase shift through the amplifier and feedback network must be $N \times 360°$ where $N = 0, 1, 2, \ldots$

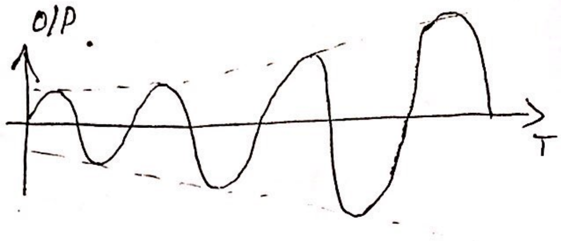
② The magnitude of the loop gain must be unity.

Thus without an i/p, the o/p will continue to oscillate whose frequency depends upon the feedback n/w or the amplifier or both. Such a circuit is called as an oscillator.

Satisfying these conditions, the circuit works as oscillator producing sustained oscillations of constant frequency and amplitude.

① $|A\beta| > 1$

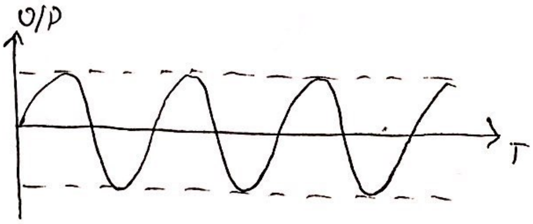
When the total phase shift around a loop is $0°$ or $360°$ and $|A\beta| > 1$ then the O/P oscillates but the oscillations are of growing type. The amplitude of oscillations goes on increasing shown in fig(1)



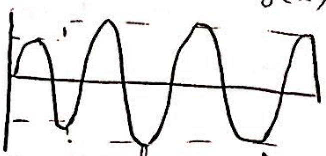
Fig(1)

② $|A\beta| = 1$

As stated by Barkhausen criterion, when total phase shift around a loop is $0°$ or $360°$ ensuring positive feedback and $|A\beta| = 1$ then the oscillations are with constant freq and amplitude called sustained oscillations.

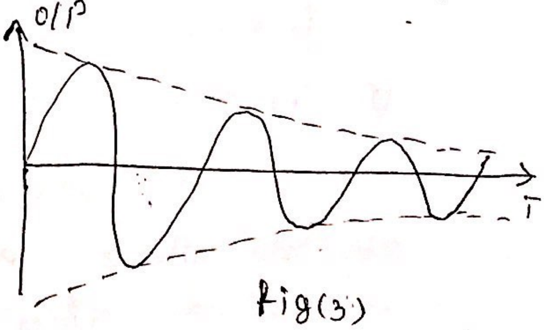


Fig(2)



③ $|A\beta| < 1$

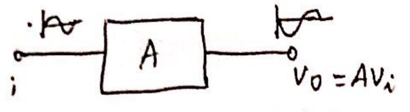
When total phase shift around a loop is $0°$ or $360°$ but $|A\beta| < 1$ then the oscillations are of decaying type. i.e such oscillation amplitude decreases exponentially. Thus the circuit works as an amplifier without oscillations.



Fig(3)

Barkhausen Criterion:-

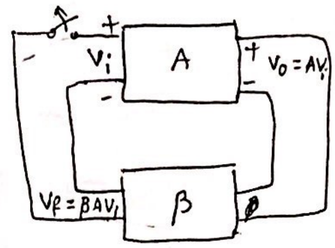
As a basic amplifier is inverting, it produces a phase shift of 180° between i/p and o/p.



Inverting Amp.

If the feedback is positive, then the voltage derived from output using feedback n/w must be inphase with V_i. Thus the feedback n/w must introduce a phase shift of 180° while feed~~back~~ing back the voltage from o/p to i/p.

Consider the feedback circuit as shown in fig. when the switch is open, no oscillations are produced. Imagine an i/p voltage V_i at the i/p terminals of the amplifier. It produces an o/p voltage AV_i.



Feedback circuit as an oscillator

The feedback n/w reduces this voltage to $V_f = \beta A V_i$ —①

The factor βA is called loop gain.

For the oscillator, we want that feedback should drive the amplifier and hence V_f must act as V_i.

Now V_f is equal to V_i

$$\therefore V_i = \beta A V_i$$

$$\beta A = 1 \quad —②$$

Let us now close the switch and remove V_i. The circuit continues to operate. The feedback voltage is sufficient to drive the amplifier and the feedback n/w. The amplifier produces an o/p if $\beta A = 1$

This is known as Barkhausen criterion for oscillations.

In practice no i/p signal is needed to start operation of the oscillator. The system starts oscillat amplifying noise voltage.

(or) The gain of an amplifier with negative feedback is $A_f = \frac{A}{1+\beta A}$ —— ③

if $\beta A = -1$, $A_f \to \infty$ i.e, there will be O/P voltage ev when the i/P voltage is zero.

The amplifier provides its own i/p voltage. It behaves as a generator.

The condition $\beta A = -1$ indicates that

(a) The magnitude of βA i.e $|\beta A| = 1$ and

(b) its phase angle is $-180°$.

For sustained oscillations two conditions must be satisfied. They are:

① The phase shift caused by the amplifier and the feedback n/w must be 360°.

i.e amplifier phase shift (180°) + feedback n/w Phase shift (180°)

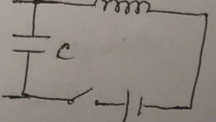
② The magnitude of the product of the gain of the amplifier and feedback factor must be unity.

Wave - Forming Networks :-

In electronic oscillator used wave - forming n/ws. Two types of wave - forming N/ws. They are LC n/w and RC.

LC Network :

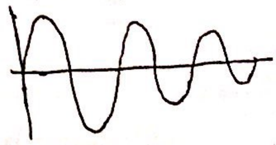
It consists of an inductance (L) and capacitance (C) connected in parallel. It is also called as tank circuit.



LC circuit.

start oscillating

when voltage is switched ON or OFF, the current in the circuit oscillates harmonically but the oscillations are damped due to resistance in the circuits.



waveform

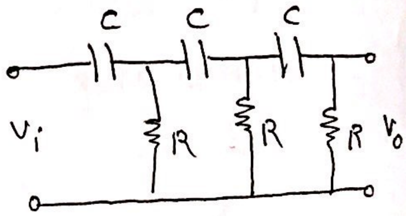
Thus, the LC circuit generates a waveform (sinusoidal) whose freqy is given by $\boxed{f = \frac{1}{2\pi\sqrt{LC}}}$

→ Tuned circuits are used in radio-freqy oscillators.

② RC Networks:-

In general, an amplifier produced a phaseshift of 180°. An additional phase shift of 180°, to satisfy Barkhausen Criterion, is provided by the RC network.

It couples o/p and i/p of the amplifier. The network shown is a series of high pass filters. Each of the filters shift the phase of the feedback signal.



RC Network

The amount of phase shift depends on the freqy and total phase shift required is 180°.

The phase shift n/w thus satisfies the oscillations condition only at one frequency. That frequency is given by

$$\boxed{f = \frac{1}{2\pi RC\sqrt{6}}}$$

→ This is called RC phase-shift oscillator.

→ Audio freqy oscillators are used this type feedback.

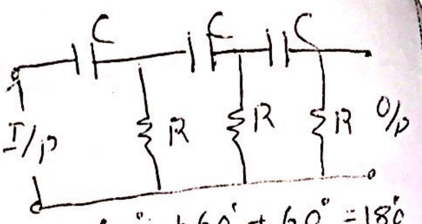
LC oscillators are colpitts and Hartly oscillators & Clapp

RC oscillators are RC phase shift and wainbridge oscillators.

using (FET, BJT, OP-AMP)

RC Phase-shift oscillator:-

In Oscillators, feedback network must introduce phaseshift of 180° to obtain total phase shift around loop as 360°. Thus if one RC n/w produces phaseshift 60° then to produce phaseshift of 180° such three RC n/w must be connected in cascade.



RC Network

Hence in RC phase shift oscillator the feedback n/w consists of three RC sections each producing a phase shift of 60°, thus total phaseshift due to feedback is 180°.

The frequency of the oscillator o/p depends upon the values of capacitors C and resistors R used in the phaseshift n/w. Using basic RC circuit analysis techniques, it can be shown that the network phase shift is 180° when $X_C = \sqrt{6} \cdot R$

$$\frac{1}{2\pi fC} = \sqrt{6}R$$

$$\boxed{f = \frac{1}{2\pi RC\sqrt{6}}} \quad \text{——— } ①$$

As well as phase shifting, the R-C n/w attenuates the amplifier o/p. 'Network' analysis shows that when the necessary phase shift of 180° is obtained, this n/w attenuates the o/p voltage by a factor of $\frac{1}{29}$. This means that the amplifier must have a voltage gain of 29 or more.

$\therefore$ $A = 29$ and $\beta = \frac{1}{29}$ then loopgain $= A\beta = 29 \times \frac{1}{29} = \underline{1}$

The amplifier phaseshift of $-180°$ combined with the n/w phaseshift of $+180°$ give loop phase shift of zero. Both of these conditions are necessary to satisfy the Barkhausen criteria.

Advantages:-

① It is cheap and simple circuit circuit as it contains resistors and capacitors.

② It provides good frequency stability.

③ It is simpler than the wien bridge oscillator circuit.

④ The O/P is sinusoidal that is quite distortion free.

⑤ They have a wide frequency range (Hz to 100KHz).

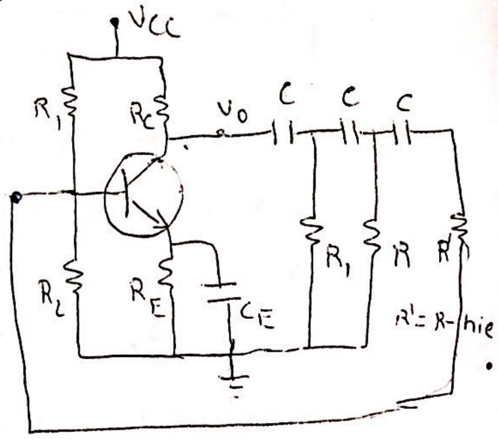
Disadvantages:-

① The O/P is small. It is due to smaller feedback.

② It is difficult for the circuit to start oscillations as the feedback is usually small.

③ It needs high voltage (12 V) battery so as to develop sufficiently large feedback voltage.

Transistor Phase shift oscillator:-



Transistor phase shift Oscillator

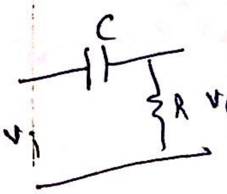
→ R_1, R_2 provides dc emitter base bias.

→ R_E and C_E combination provides temperature stability and prevent ac signal degeneration.

→ R_C controls the collector voltage.

→ In the circuit, the feedback signal is coupled through the feedback Resistor R' in series with the amplifier stage i/p resistance hie.

∴ The value of R' should be such that when added with amplifier stage i/p resistance hie. $\boxed{\therefore R = R' + h_{ie}}$



$$\frac{V_o}{V_i} = \frac{R}{R + \frac{1}{j\omega C}} = \frac{1}{1 + \frac{1}{j\omega RC}} = \frac{1}{1 - \frac{j}{\omega RC}}$$

$$\angle\phi = 0 - \tan^{-1}\left(\frac{-1}{\omega RC}\right) = \tan^{-1}\left(\frac{X_C}{R}\right)$$

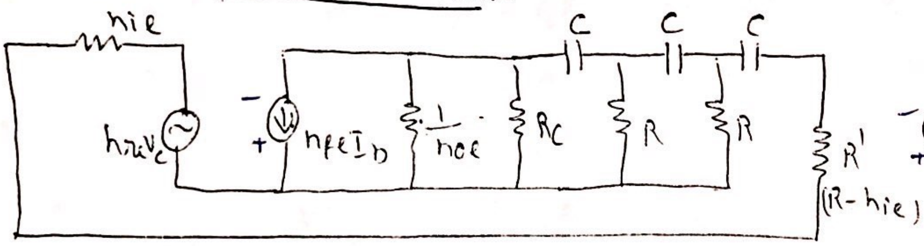
if X_C = small then $\angle\phi = 0°$

if $R = 0$ or small then $\angle\phi = \alpha = 90°$

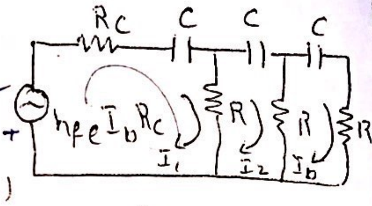
[illegible] circuit / Phase lead circuit (O/P voltage is lead the i/p voltage)

Operation:- The circuit is set into oscillations by an or variation caused in the base current, that may be due to noise inherent in the transistor or minor var... in dc power supply. This variation in base current is amplified in collector circuit. The O/P of the amplifier supplied to an RC n/w. The RC n/w produces a phase shift 180°. Since CE amplifier produces a phase reversal of the i/p signal, total phase shift becomes 360° or 0° which is essential for regeneration or for sustained oscillations.

Frequency of oscillations:-



fig(2) equivalent circuit



fig(3)

→ h_{re} of the transistor is negligibly small and therefore, $h_{re}V_o$ is omitted from the circuit.

→ h_{oe} of the transistor is very small i.e. $\frac{1}{h_{oe}}$ is much larger than R_C. Thus the effect of h_{oe} can be neglected.

→ Apply KVL to the 3 loops shown in fig(3) we have,

$$I_1\left(R+R_C+\frac{1}{j\omega C}\right)-I_2R+h_{fe}I_bR_C=0 \quad \text{—— (1)}$$

$$-I_1R+\left(2R+\frac{1}{j\omega C}\right)I_2-RI_b=0 \quad \text{—— (2)}$$

$$0-RI_2+\left(2R+\frac{1}{j\omega C}\right)I_b=0 \quad \text{—— (3)}$$

→ As the currents I_1, I_2 and I_b are non-vanishing, the determinant of the coefficients of I_1, I_2 and I_b must be '0'. Substituting $\frac{1}{\omega C}=X_C$ we have,

$$\begin{vmatrix} (R+R_c - jX_c) & (-R) & (h_{fe}R_c) \\ (-R) & (2R - jX_c) & (-R) \\ 0 & (-R) & (2R - jX_c)\end{vmatrix} = 0$$

$$(R+R_c-jX_c)[(2R-jX_c)^2 - R^2] + R[-R(2R-jX_c)] + h_{fe}R_c(R^2) = 0$$

$$(R+R_c-jX_c)[4R^2 - X_c^2 - 4RjX_c - R^2] - R[2R^2 - jRX_c - h_{fe}R_cR] = 0$$

$$3R^3 - RX_c^2 - j4R^2X_c + R_c3R^2 - R_cX_c^2 - j4RR_cX_c - j3R^2X_c + jX_c^3 - 4RX_c^2$$
$$- 2R^3 + jR^2X_c + h_{fe}R_cR^2 = 0$$

$$\therefore R^3 + R^2R_c(h_{fe}+3) - 6jR^2X_c - 5RX_c^2 - R_cX_c^2 - j4RR_cX_c + jX_c^3 = 0$$

Equating the imaginary components of the above equation to zero, we have,

$$6R^2X_c + 4RR_cX_c - X_c^3 = 0$$

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

$$6R^2 + 4RR_c = X_c^2$$

$$X_c = \sqrt{6R^2 + 4RR_c} \qquad \because X_c = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

$$\therefore \frac{1}{2\pi f C} = \sqrt{6R^2 + 4RR_c}$$

$$f = \frac{1}{2\pi RC\sqrt{6 + \frac{4R_c}{R}}}$$

if $R_c = R$, then $f = \dfrac{1}{2\pi R_c\sqrt{10}}$ —— (4)

The above equation gives frequency of oscillation.

Equating the real component to zero, we have.

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

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

$$R^3 + R^2R_c3 + h_{fe}R^2R_c - 30R^3 - 6R^2R_c - 20R^2R_c - 4RR_c^2 = 0$$

$$-29R^3 - 23R^2R_C + h_{fe}R^2R_C - 4RR_C^2 = 0$$

dividing with R^2R_C, $\frac{-29R}{R_C} - 23 + h_{fe} - 4\frac{R_C}{R} = 0$

$$\therefore \; h_{fe} = 23 + 29\frac{R}{R_C} + 4\frac{R_C}{R} \quad \text{--- (5)}$$

For the loop gain to be greater than unity, the requirement of the current gain of the transistor is found to be

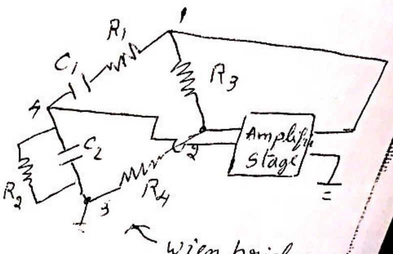
$$h_{fe} > 23 + 29\frac{R}{R_C} + 4\frac{R_C}{R} \quad \text{--- (6)}$$

if $R = R_C$ then $h_{fe} > (23 + 29 + 4)$ i.e 56 --- (7)

Wien Bridge Oscillator:-

Wien bridge oscillator uses a noninverting amplifier and hence does not provide any phase shift during amplifier stage. As total phase shift required is 0° or 360°, in wien bridge type no phase shift is necessary through feedback. Thus the total phase shift around a loop is 0°.

→ The O/P of the amplifier is applied between the terminals 1 and 3, which is the i/p to the feedback n/w.

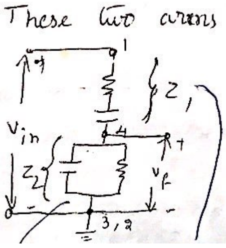


wien bridge

→ 2 and 4 are the O/P from the feedback n/w.

→ The two arms of the bridge, namely R_1, C_1 in series and R_2, C_2 in parallel are called frequency sensitive arms.

→ These two arms are decide the frequency of the oscillator.



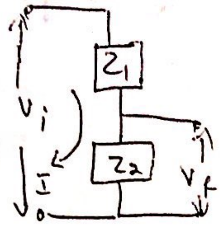
--> 1 and 3 are V_{in} to the F.B n/w.

--> 4 and 2 are V_f of the F.B n/w

--> Such a feed back n/w is called as lead-lag n/w.

$$Z_1 = R_1 + \frac{1}{j\omega C_1} = \frac{1 + j\omega R_1 C_1}{j\omega C_1}$$

$$Z_2 = R_2 \,||\, \frac{1}{j\omega C_2} = \frac{R_2 \times \frac{1}{j\omega C_2}}{R_2 + \frac{1}{j\omega C_2}} = \frac{R_2}{1 + j\omega R_2 C_2}$$



Simplified circuit

Replacing $j\omega = s$,

$$Z_1 = \frac{1 + sR_1C_1}{sC_1} \quad \text{and} \quad Z_2 = \frac{R_2}{1 + sR_2C_2}$$

$$I = \frac{V_{in}}{Z_1 + Z_2} \quad \text{and} \quad V_f = I Z_2$$

$$\therefore V_f = \frac{V_{in} Z_2}{Z_1 + Z_2}$$

$$\beta = \frac{V_f}{V_i} = \frac{Z_2}{Z_1 + Z_2}$$

Substituting the values of Z_1 and Z_2

$$\frac{V_f}{V_i} = \frac{\left[R_2 / 1 + sR_2C_2\right]}{\left[\frac{1 + sR_1C_1}{sC_1}\right] + \left[\frac{R_2}{1 + sR_2C_2}\right]}$$

$$= \frac{sC_1R_2}{(1 + sR_1C_1)(1 + sR_2C_2) + sC_1R_2}$$

$$= \frac{sC_1R_2}{1 + s(R_2C_2 + R_1C_1 + C_1R_2) + s^2 R_1C_1R_2C_2}$$

Replacing s by $j\omega$, $s^2 = -\omega^2$

$$\therefore \frac{V_f}{V_i} = \frac{j\omega C_1 R_2}{(1 - \omega^2 R_1C_1R_2C_2) + j\omega(R_1C_1 + R_2C_2 + C_1R_2)}$$

Rationalizing the expression,

$$\therefore \beta = \frac{j\omega C_1 R_2\left[(1 - \omega^2 R_1C_1R_2C_2) - j\omega(R_1C_1 + R_2C_2 + C_1R_2)\right]}{(1 - \omega^2 R_1C_1R_2C_2)^2 + \omega^2(R_1C_1 + R_2C_2 + C_1R_2)^2}$$

$$\beta + j0 = \beta = \frac{\omega^2 C_1 R_2 (R_1C_1 + R_2C_2 + C_1R_2) + j\omega C_1 R_2 (1 - \omega^2 R_1 R_2 C_1 C_2)}{(1 - \omega^2 R_1 R_2 C_1 C_2)^2 + \omega^2 (R_1C_1 + R_2C_2 + C_1R_2)^2}$$

To have zero phase shift of the feedback n/w, it's imaginary part must be zero.

$$\therefore \omega C_1 R_2 (1 - \omega^2 R_1 R_2 C_1 C_2) = 0$$

$$1 - \omega^2 R_1 R_2 C_1 C_2 = 0$$

$$+\omega^2 R_1 R_2 C_1 C_2 = +1$$

$$\omega^2 = \frac{1}{R_1 R_2 C_1 C_2}$$

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

$$\therefore f = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

→ This is the frequency of the oscillator and it shows that the components of the freq sensitive arms are deciding factors; for the freq.

In practice, $R_1 = R_2 = R$ and $C_1 = C_2 = C$ are selected.

$$\therefore f = \frac{1}{2\pi\sqrt{R^2C^2}} = \boxed{\frac{1}{2\pi RC} = f}$$

At $R_1 = R_2 = R$ and $C_1 = C_2 = C$, the gain of feedback n/w becomes,

$$\beta = \frac{\omega^2 RC(3RC) + j\omega RC(1 - \omega^2 R^2 C^2)}{(1 - \omega^2 R^2 C^2)^2 + \omega^2 (3RC)^2}$$

substituting $f = \frac{1}{2\pi RC}$ i.e $\omega = \frac{1}{RC}$.

we get the magnitude of the feedback n/w at the resonating frequency of the oscillator as

$$\beta = \frac{3}{0+9} = \frac{3}{9} = \frac{1}{3} \qquad \boxed{\therefore \beta = \frac{1}{3}}$$

The +ve sign of β indicates that the phase shift by the feedback n/w is 0°. Now to satisfy the Barkhausen criterion for the sustained oscillations, we can write,

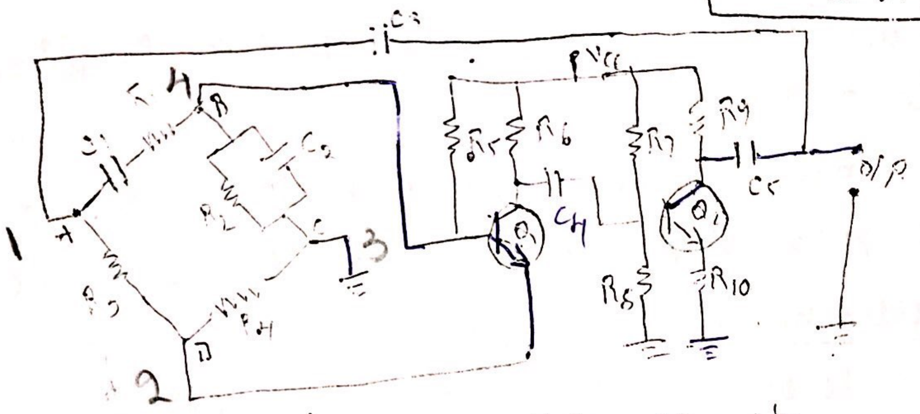
$$|A\beta| \geq 1$$

$$\therefore |A| \geq \frac{1}{|\beta|} \geq \frac{1}{\frac{1}{3}}$$

$$\boxed{\therefore |A| \geq 3}$$

→ This is required gain of the amplifier stage, without any phase shift.

If $R_1 \neq R_2$ and $C_1 \neq C_2$ then $\boxed{f = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}}$



Wien bridge oscillator circuit

→ It is essentially a two-stage amplifier with an RC bridge circuit. Wien bridge circuit is a lead-lag n/w. The phase shift across the n/w lags with increasing freq and leads with decreasing freq.

→ It is also a phase-shift oscillator. It has two transistors each producing a phase shift of 180° and thus producing a total phase-shift of 360° or 0°.

→ By adding wien bridge feedback network, the oscillator becomes sensitive to a signal of only one particular freq.

→ This particular freq is that at which wien bridge is balanced and for which the phase-shift is 0°.

→ In bridge circuit the o/p will be in phase with i/p only when the bridge is balanced i.e., at resonant freqn given by $\boxed{f = \frac{1}{2\pi RC}}$.

Advantages:-

① It provides a stable low distortion sinusoidal o/p over a wide range of freqn.

② The freqn of oscillation can be easily varied by varying capacitance C_1 and C_2 simultaneously.

③ The overall gain is high because of two transistors.

Disadvantages:-

① The circuit needs two transistors and a large number of other components.

② The maximum frequency o/p is limited because of amplitude and the phase shift characteristics of the amplifier.

L-C Oscillators:-

Oscillators, which use inductance-capacitance (L-C) circuits as their tank or oscillator circuits are called L-C oscillators.

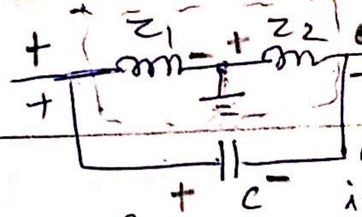
L-C oscillators are very popular for generating high freqn o/ps (10 KHz to 100 MHz).

There is a large variety of LC oscillators such as tuned-collector oscillators, tuned-base oscillators, Colpitts oscillators, Hartley oscillators, Clapp oscillators, crystal oscillators etc...

The frequency of oscillations generated by LC tank circuit depends on the values L and C and is given by,

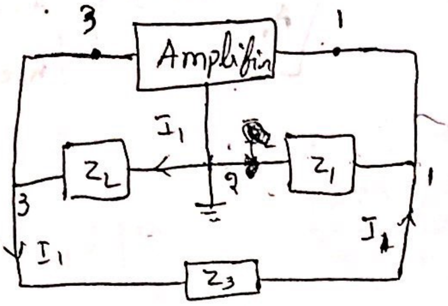
$$\boxed{f = \frac{1}{2\pi\sqrt{LC}}} \text{ Hz}$$

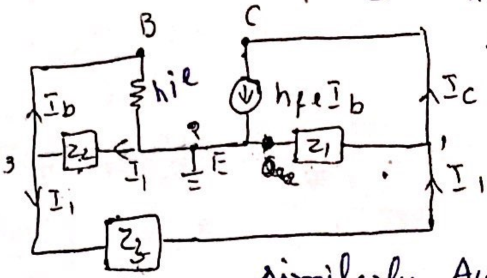
where L is in Henries and C is in Farads.



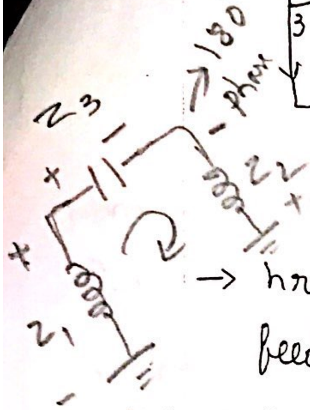
This is a as auto inductance i.e. one side +ve & other side -ve Polarity.

Generalized Analysis of LC oscillators:-





similarly Auto capacitance



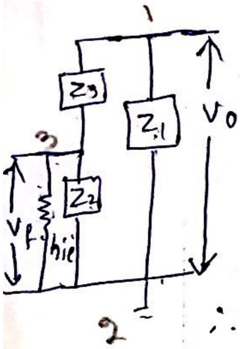
General form of an oscillator and it's equivalent circuit

→ h_{re} of transistor is negligibly small and therefore, the feedback source $h_{re}V_0$ is negligible.

→ h_{oe} of the transistor is very small i.e. the o/p resistance $\frac{1}{h_{oe}}$ is very large and therefore $1/h_{oe}$ is omitted from the equivalent circuit.

→ Let us determine the load impedance between o/p terminals 1 and 2. Here Z_2 and h_{ie} are in parallel and their resultant impedance is in series with Z_3. The equivalent impedance ~~between~~ is in parallel with impedance Z_1.

→ Thus load impedance between output terminals is given as



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

$$= Z_1 \| \left[Z_3 + \frac{Z_2 h_{ie}}{Z_2 + h_{ie}}\right]$$

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

$$\therefore \frac{1}{Z_L} = \frac{1}{Z_1} + \frac{Z_2 + h_{ie}}{h_{ie}(Z_2+Z_3) + Z_2 Z_3} = \frac{h_{ie}(Z_2+Z_3) + Z_2 Z_3 + Z_1 Z_2 + h_{ie} Z_1}{Z_1[h_{ie}(Z_2+Z_3) + Z_2 Z_3]}$$

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

$$Z_L = \frac{Z_1[h_{ie}(Z_2+Z_3) + Z_2 Z_3]}{h_{ie}(Z_1+Z_2+Z_3) + Z_1 Z_2 + Z_2 Z_3} \quad \text{— (1)}$$

$$V_f = \frac{V_0 (Z_2 \| h_{ie})}{(Z_2 \| h_{ie}) + Z_3}$$

$$\frac{V_f}{V_0} = \beta = \frac{Z_2 \| h_{ie}}{(Z_2 \| h_{ie}) + Z_3}$$

→ The voltage gain of a CE amplifier without feedback is as $A = \frac{-h_{fe} Z_L}{h_{ie}}$ —— (2) $\left[A_v = \frac{A_i R_L}{R_i}\right]$ $\left[A_i = \frac{-h_{fe}}{1+h_{oe}R_L}, \; h_{oe} \ll 1 \to A_i \simeq \right]$

→ The O/P voltage between terminals 1 and 2 is given as

$V_f = V_0 \frac{Z_2 \| h_{ie}}{(Z_2 \| h_{ie}) + Z_3}$

$$v_{out} = I_1\left[Z_3 + \frac{Z_2 h_{ie}}{Z_2 + h_{ie}}\right] = \left[\frac{h_{ie}(Z_2+Z_3) + Z_2 Z_3}{Z_2 + h_{ie}}\right] I_1$$

→ The voltage feedback to the input terminals 2 and 3 is given as

$\frac{V_f}{V_0} = \beta =$

$$v_f = \left[\frac{Z_2 h_{ie}}{Z_2 + h_{ie}}\right] I_1$$

→ So feedback fraction,

$$\beta = \frac{v_f}{v_0} = \frac{\left[\frac{Z_2 h_{ie}}{Z_2 + h_{ie}}\right]\cancel{I_1}}{\left[\frac{h_{ie}(Z_2+Z_3) + Z_2 Z_3}{Z_2 + h_{ie}}\right]\cancel{I_1}} = \frac{Z_2 h_{ie}}{h_{ie}(Z_2+Z_3) + Z_2 Z_3}$$

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

→ Applying the criterion of oscillation i.e, $A\beta = 1$, we have

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

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

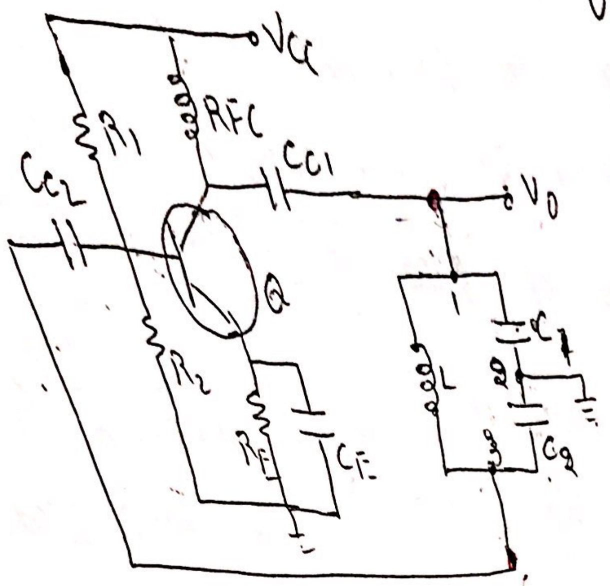
$$\frac{h_{fe} Z_1 Z_2}{h_{ie}[Z_1+Z_2+Z_3] + Z_1 Z_2 + Z_2 Z_3} = -1.$$

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

$$\boxed{\therefore \; h_{ie}(Z_1+Z_2+Z_3) + Z_1 Z_2 (1+h_{fe}) + Z_2 Z_3 = 0} \quad \text{—— (3)}$$

This is the general equation for the oscillator.

Colpitts Oscillator:-



Transistorised colpitts oscillator

The basic circuit of a transistor colpitts oscillator is shown in fig. It basically consists of a single stage inverting amplifier and L-C phase shift network.

The two series capacitors C_1 and C_2 form the potential divider used for providing the feedback voltage - the voltage developed across capacitor C_2 provides the regenerative feedback required for sustained oscillations.

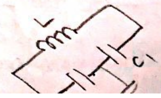
→ The collector supply voltage Vcc is applied to the collector through a radio-freq. chock (RFC) which permits an easy flow of direct current but at the same time it offers very high impedance to the high frequency current.

→ Transistor itself produces a phase shift of 180° and another phase shift of 180° is provided by the capacitor feedback. Thus a total phase shift of 360° is obtained which is an essential condition for developing oscillations.

→ The frequency is determined by the tank circuit and is varied by gang-tuning the two capacitors C_1 and C_2.

→ The capacitor C_1 and C_2 are ganged.

→ As the tuning is varied, values of both capacitors vary simultaneously, the ratio of the two capacitances remaining the same.



Working:-

-> When the collector supply voltage V_{cc} is switched on, capacitors C_1 and C_2 are charged.

-> These capacitors C_1 and C_2 discharge through the coil L setting up oscillations of freq $\boxed{f = \frac{1}{2\pi}\sqrt{\frac{1}{LC_1} + \frac{1}{LC_2}}}$

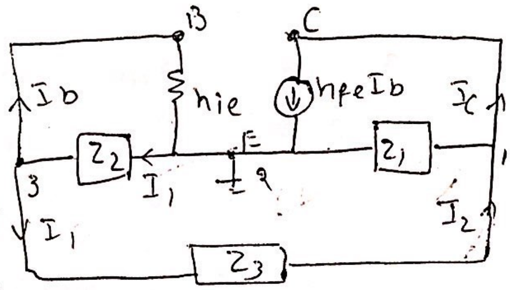
-> The oscillations across capacitor C_2 are applied to the base - emitter junction and appear in the amplified form in the collector circuit.

-> This amplified o/p in the collector circuit is supplied to the tank circuit in order to meet the losses.

-> Thus the tank circuit is getting continously energy from the circuit and ensures undamped oscillations.

-> The energy supplied to the tank circuit is of correct phase and if $A\beta$ exceeds unity, oscillations are sustained in the circuit.

Frequency of oscillation:-



The general equation for the oscillator is

$$h_{ie}(Z_1+Z_2+Z_3)+Z_1Z_2(1+h_{fe})+Z_2Z_3=0 \quad -(1)$$

where $Z_1 = \frac{1}{jwC_1} = -\frac{j}{wC_1}$; $Z_2 = \frac{1}{jwC_2} = -\frac{j}{wC_2}$ and $Z_3 = jwL$

Substituting these values in eqn (1), we have

$$h_{ie}\left[\frac{-j}{wC_1} - \frac{j}{wC_2} + jwL\right] + \left[-\frac{j}{wC_1} \cdot -\frac{j}{wC_2}\right](1+h_{fe}) + \left[\frac{-j}{wC_2}\right]jwL = 0$$

$$-jh_{ie}\left[\frac{1}{wC_1} + \frac{1}{wC_2} + wL\right] - \frac{1+h_{fe}}{w^2C_1C_2} + \frac{L}{C_2} = 0 \quad —— (2)$$

Equivaling the imaginary components of the eqn (2) to zero, we get,

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

$$\frac{1}{\omega C_1}+\frac{1}{\omega C_2}=\omega L$$

$$\frac{C_1+C_2}{\omega C_1C_2}=\omega L$$

$$\omega^2=\frac{C_1+C_2}{LC_1C_2}$$

$$\therefore \omega=\sqrt{\frac{C_1+C_2}{LC_1C_2}}=\sqrt{\frac{1}{LC_1}+\frac{1}{LC_2}}$$

$$\boxed{\therefore f=\frac{1}{2\pi}\sqrt{\frac{1}{LC_1}+\frac{1}{LC_2}}} \quad \text{—— (3)}$$

The above eqn gives the freqn of oscillations.

Equivating real components to zero, we have,

$$-\frac{1+h_{fe}}{\omega^2C_1C_2}+\frac{L}{C_2}=0$$

$$\frac{1+h_{fe}}{\omega^2C_1C_2}=\frac{L}{C_2}$$

$$1+h_{fe}=\omega^2LC_1=\frac{C_1+C_2}{\cancel{L}C_1C_2}\cdot\cancel{L}C_1$$

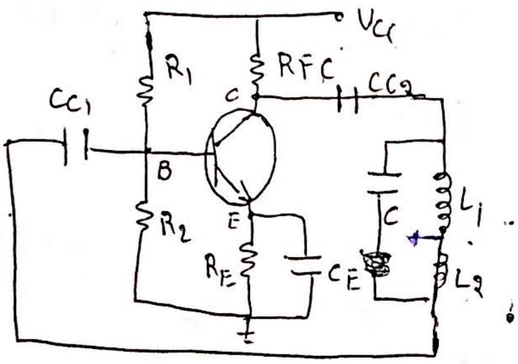
$$=\frac{C_1+C_2}{C_2}=1+\frac{C_1}{C_2}$$

$$\therefore h_{fe}=\frac{C_1}{C_2} \quad \text{—— (4)}$$

As for other oscillator circuits, the loop gain must be greater than unity to ensure that the oscillates.

$$\text{So } A\beta\geq 1 \text{ or } A\geq\frac{1}{\beta}\geq\frac{C_2}{C_1} \quad \text{—— (5)}$$

Hartley Oscillator :-



Basic circuit for Hartley oscillator

The transistor Hartley oscillator is as popular as colpitt's oscillator and is widely used as a local oscillator in radio receivers.

It consists of two inductors L_1 and L_2 and a capacitor C instead of two capacitors and one inductor.

The o/p of the amplifier is applied across inductor L_1 and L_2 forms the feedback voltage. The operation of the circuit is similar to that of the colpitt's oscillator circuit.

Considering the fact that there exist mutual inductance between coils L_1 and L_2 because the coils are wound on the same core, their net effective inductance is increased by mutual inductance M.

So in this case effective inductance is given by the eq

$$\boxed{L = L_1 + L_2 + 2M} \quad \text{—— (1)}$$

and resonant or oscillation frequency is given by the equation

$$\boxed{f = \frac{1}{2\pi\sqrt{C(L_1+L_2+2M)}}} \quad \text{—— (2)}$$

Frequency of oscillations:-

The general equation for the oscillator is

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

Here $Z_1 = j\omega L_1 + j\omega M$; $Z_2 = j\omega L_2 + j\omega M$ and $Z_3 = \frac{1}{j\omega C} = -\frac{j}{\omega C}$

Substituting these values in general eqn (1), we get

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

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

equating the imaginary part of above eqn (2) to zero, —(2)

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

$$L_1+L_2+2M - \frac{1}{\omega^2 C} = 0$$

$$L_1+L_2+2M = \frac{1}{\omega^2 C}$$

$$\omega^2 C = \frac{1}{L_1+L_2+2M}$$

$$\therefore \omega^2 = \frac{1}{C(L_1+L_2+2M)}$$

$$\boxed{\therefore f = \frac{1}{2\pi\sqrt{C(L_1+L_2+2M)}}} \quad \text{—— (3)}$$

The above equation gives the freqn of oscillation.

equating the real component eqn(2) to zero, we get

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

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

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

$$1+h_{fe} = 1 + \frac{L_2+M}{L_1+M}$$

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

So $A\beta \geq 1$ $\therefore$ $\boxed{A \geq \frac{1}{\beta} \geq \frac{L_1+M}{L_2+M}}$ —(4)

Crystal oscillator:-

-> In crystal oscillators, the usual electrical resonant circuit is replaced by a mechanically vibrating crystal.

-> The crystal oscillators are used for to get great stability.

-> Hence crystals are used in transmitters, receivers, digital clocks etc..

-> A quartz crystal exhibits a very important property known as piezoelectric effect.

-> The piezoelectric effect means under the influence of the ~~crystal~~ mechanical pressure, the voltage gets generation across the opposite faces of the crystal. If the mechanical force is applied in such a way to force the crystal to vibrate, the ac voltage gets generated across it.

-> An alternating voltage applied to a crystal causes it to vibrate at its natural frequency.

-> Besides quartz, the other substances that exhibit the piezoelectric effect are Rochelle salt and tourmaline.

-> Rochelle salt exhibits the greatest piezoelectric effect, but its applications are limited to manufacture of microphones, headsets and loudspeakers. It is because the Rochelle salt is mechanically the weakest and strongly affected by moisture and heat.

-> Tourmaline is most rugged but shows the least piezoelectric effect.

-> Quartz is a compromise between the piezoelectric effect of Rochelle salt and the mechanical strength of tourmaline.

-> It is inexpensive and readily available in nature. It is mainly the quartz crystal that is used in radio-frequ (RF) oscillators.

Characteristics of oscillators:-

-> An oscillator circuit does not have i/p signal.

-> It produces a.c. waveform using dc source.

-> It contains either positive feedback or a negative resistance device or tuned circuit.

-> It contains an amplifier circuit.