Unit-II - Sine Wave Oscillators -

An electronic oscillator is defined as -

① It is a circuit which converts dc energy into ac energy at a very high frequency.

② It is an electronic source of alternating current or voltage having sine, square or sawtooth or pulse shapes.

③ It is a circuit which generates an ac output signal without requiring any externally-applied input-signal.

④ It is an unstable amplifier.

Classification -

Electronic oscillator is divided in to following two groups -

(1) Sinusoidal (or harmonic) oscillators.
 - which produces an output having sine waveform

(2) Non-sinusoidal (or relaxation) oscillators.
 - which produces an output having square, rectangul or sawtooth waveform or is of pulse shape.

Sinusoidal oscillators are again sub-divided in to -

(1) tuned circuits or LC-feedback oscillators for ex Hartley, Colpitts and Clapp etc

(2) RC- Phase shift Oscillators like Wien-bridge Oscillator.

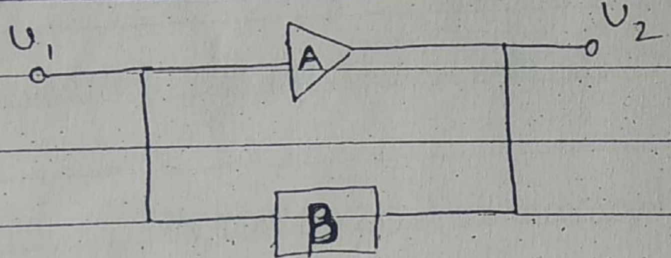
(3) negative-resistance oscillators such as tunnel diode oscillator.

(4) crystal oscillators such as pierce oscillator

(5) heterodyne or beat-frequency oscillator (BFO) -

Introduction to positive and negative Feedback -

A feedback arrangement is shown in figure. "When the output of a circuit is fed-back



in the correct phase and magnitude at the input of the circuit is called feedback network."

Let A be the gain in the above circuit and let B is the fraction of the output fed-back to the input by the feedback network B. Then, the input to the circuit in the presence of feedback is $v_1 + B \cdot v_2$ and is related to the output by the eqn -

$$v_2 = A(v_1 + Bv_2)$$

$$\therefore \frac{V_2}{V_1} = \frac{A}{1-A\beta} \quad \text{i.e.} \quad A_f = \frac{A}{1-A\beta}$$

If AB is negative, we have a negative feedback and if AB is positive it is positive feedback.

"If the voltage derived from the output i.e. feedback voltage is 180° out of phase with the input voltage the feedback is said to be negative feedback." The feedback network does not introduce any ~~change~~ phase change so that the feedback remains 180° out of phase with the signal input. The gain of the circuit when there is a feedback is given by the equation -

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

For negative feedback, AB is negative and the amplifier gain is reduced by feedback.

"If the voltage derived from the output i.e. feedback voltage is 180° in phase with the input voltage (It requires a network designed to produce an additional phase shift of 180°) the feedback is said to be positive feedback."

" In this case, the gain becomes infinitely large till the active device becomes saturated when the gain falls to a low value. This type of feedback is also known as regenerative feedback.

<1> It is used in most of the oscillators. If the feedback network produces a phase shift of 180° at a particular frequency only, the gain of the amplifier becomes infinite at this frequency and electrical oscillations are produced at this frequency. The amplitude of oscillations stabilise at a level when the loss in power in the circuit is equal to the power developed by the active device. •

Requirement of an oscillator –

Every oscillator consists of the following three basic constituents –

① Internal Amplifier
② Feedback network or Negative resistance property
③ Amplitude limiting device

① Internal Amplifier –

An oscillator is essentially an amplifier with infinite voltage gain. An amplifier forms, therefore, an essential part of any oscillator. The voltage gain of this amplifier is made infinite by proper feedback arrangement (adequate positive feedback) or by inclusion of a suitable negative resistance effect.

Negative Resistance Property or Effect –

In a circuit, d.c. resistance R is a positive quantity. The power loss is due to this resistance. A negative resistance is required to neutralize the effect of this resistance. This negative resistance is provided by the amplifying device or by some means in a oscillator so that it neutralizes the positive resistance of the oscillator circuit. This resistance is called negative resistance effect or property.

② Feedback Effect -

There is a loss of energy in the input circuit. Hence positive feedback is applied to compensate this loss. The voltage gain of the amplifier with feedback is given by -

$$A_f = \frac{A}{1+A\beta}$$

where, A = is the complex voltage gain of the internal amplifier and β is the complex feedback ratio. The voltage gain must be infinite in an amplifier to work as an oscillator.

$$\therefore 1+A\beta = 0$$

$$\text{or} \quad A\beta = -1.$$

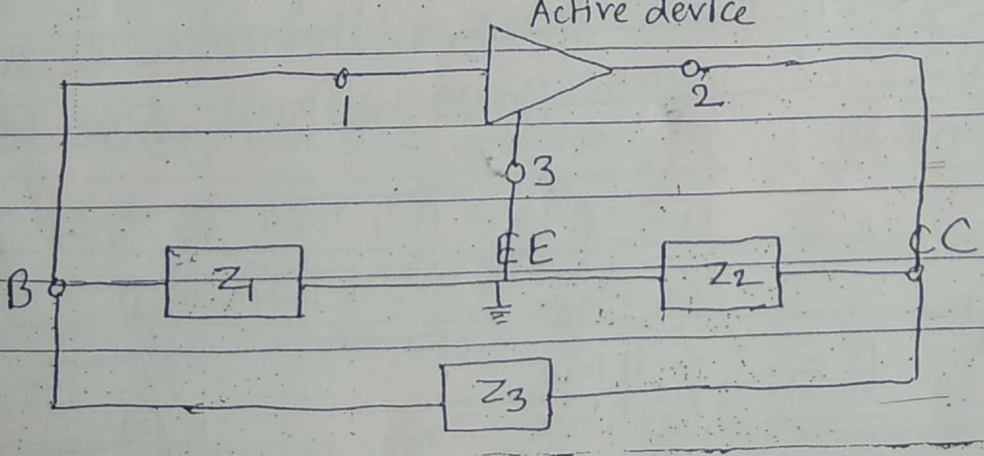
such, an oscillator is called a "feedback oscillator". A network is needed to apply feedback. In some oscillators, the network is a tuned circuit or an application of negative resistance effect.

③ Amplitude limiting device-

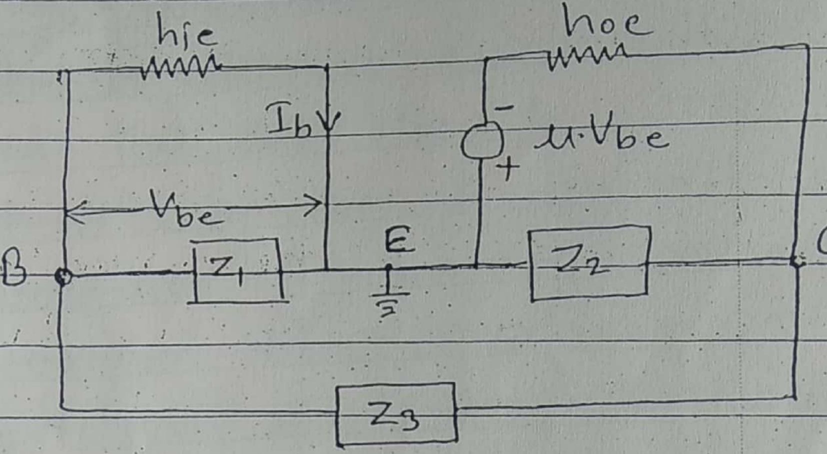
When the circuit is switched on, oscillation are built up gradually and the amplitude increases During this process overall resistance of the oscillator is negative. When the amplitude of oscillation has built up considerably, the increase in amplitude is checked by the non-linearity of operations in the active device (transistor or ~~tube~~ vacuum tube) associated with the basic amplifier. This non-linearity becomes more as the amplitude of oscillations increases. The non-linearity reduce (gm) transconductance which reduces the gain of the basic amplifier. The amplitude of oscillation thus continues to build up until $|A\beta|$ equals to unity. This produces constant amplitude oscillation in a oscillator.

Circuit Requirements for oscillations-

The following circuit shows a basic form of



an oscillator using a resonant circuit as the load. The active device may be a transistor, a vacuum tube or an FET. The circuit is analysed here and the results are then applied to the specific circuit. The following figure shows the linear equivalent circuit with transistor as the active device.



Consider the circuit is a feedback amplifier with output taken from terminals 2 and 3 (i.e. C and E) and input taken from terminals 1 and 3 (i.e. B and E).

The load impedance Z_L consists of Z_2 in parallel with the series combination of Z_3 and $Z_1 \| hie$. This voltage gain without feedback is given by −

$$A = \frac{\mu \cdot Z_L}{Z_L + hoe} \quad \text{———} ①$$

and $$\beta = \frac{-Z_1 \| hie}{-(Z_1 \| hie + Z_3)} \quad \text{———} ②$$

Hence, loop gain is given by -

$$-A\beta = \frac{-\mu Z_L}{Z_L + hoe} \cdot \frac{Z_1 || hie}{Z_3 + Z_1 || hie} \quad \text{———} ③$$

$$V_{be} = I_b \cdot hie$$

If the impedances are purely reactive (i.e. either inducti or capacitive), then we can write -

$Z_1 = jX_1$, $Z_2 = jX_2$, and $Z_3 = jX_3$

Neglecting hie in eqn ③ it reduces to -

$$-A\beta = \frac{\mu \cdot X_1 X_2}{j hoe(x_1 + x_2 + x_3) - X_2(x_1 + X_2)}$$

for loop gain to be real, (i.e. with zero phase shift) we have,

$$X_1 + X_2 + X_3 = 0 \quad \text{———} ④$$

Then $$-A\beta = \frac{\mu \cdot X_1 \cdot X_2}{-X_2(x_1 + X_2)} = \frac{\mu \cdot X_1}{-(X_1 + X_2)} \quad — ⑤$$

eqn ④ determines the frequency of oscillations.

Combining eqn ④ and ⑤ we get -

$$-A\beta = \frac{\mu(X_1)}{\mu_2}$$

This equation shows that for sustained oscillations $-A\beta$ must be positive and unity in magnitude. It is also clear that X_1 and X_2 must have the same sign i.e the two reactances must be of the same type, either both inductive or capacitive.
Again from eq^n ⑤ we have-

$$X_1 + X_2 + X_3 = 0$$

$$\therefore X_3 = -(x_1 + x_2)$$

It means that, if X_1 and X_2 are inductive, X_3 is capacitive and vice-versa.

An oscillatory circuit -

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

A oscillatory circuit is shown below -

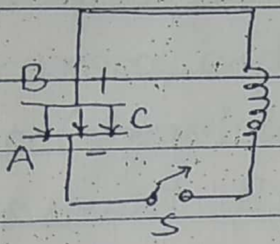


fig-①

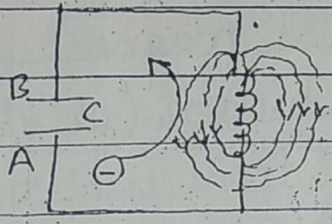


fig-②

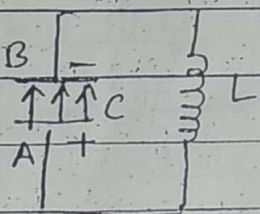


fig ③

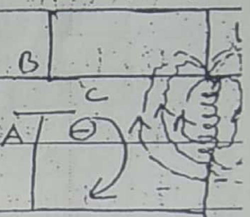


fig-④

Let, the capacitor is fully changed from a dc-source since S is open, it can not dischange through L. when S is closed electrons move from Plate A to Plate B. Through coil L. (conventional current flows from B to A). This electron flow reduces the strength of the electric field and hence the amount of energy stored in it.

② As electronic current starts flowing, the self induced emf in the coil opposes the current flow. Hence, rate dischage of electrons is somewhat slowed down.

③ Due to the flow of current, magnetic field is set which stores the energy given out by the electric fi as shown in fig ②.

④ Since Plate A looses its electrons by discharge, The elec current has a tendency to die down and will actually reduce to 0 (zero), when all excess electrons on A are driven over to plate B. so that, both plates are reduced to the same potential. At this stage, there is n electric field but the magnetic field has maximum v

⑤ But, due to self induction (or electrical inertia) of the c more electrons are transferred to plate B. than are nece to make up the electron deficiency there. It means now Plate B has more electrons than A. Hence, capacitor becomes changed again though in opposite direction as sh in fig ③.

⑥ The magnetic field collapses and the energy given ou it is stored in the electric field of the capacitor.

⑦ After this, the capacitor starts dischanging in the opposite So that, now the electron move from Plate B to Plate A a shown in fig ③. The electric field starts collapsing whe magnetic field starts building up again though in oppo direction as shown in fig ④. Thus the capacitor becomes fully changed once again.

These discharging electrons over shoots and again an excess amount of electrons flow to plate A; thereby charging the capacitor once more. This sequence of charging and discharging continues. The to and fro motion of electrons between the two plates of the capacitor constitutes an oscillatory current.

Thus, the electrical energy of the capacitor is converted in to magnetic energy and vice-versa..

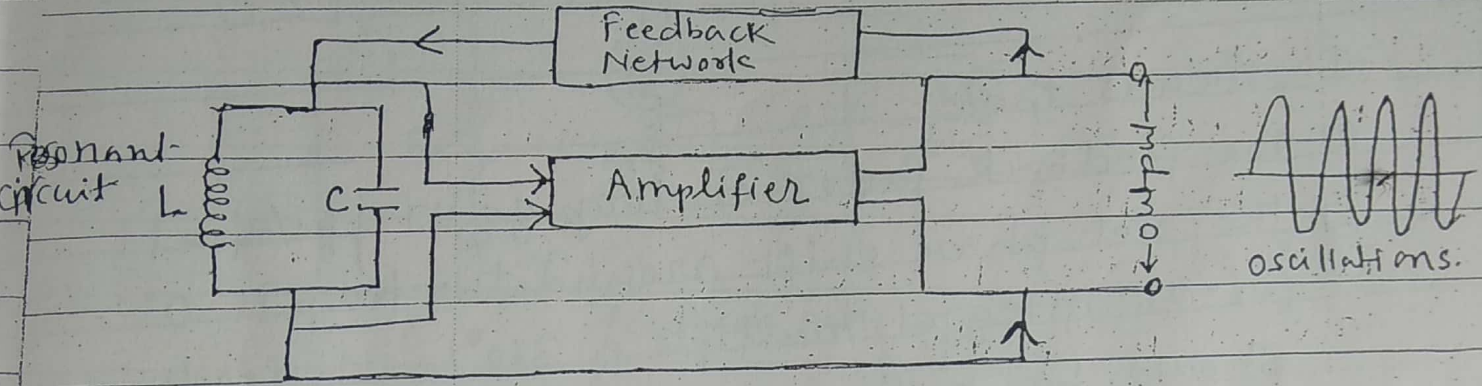
~~The oscillations~~

Scanned by CamScanner

Perrfect

① Hartley Oscillator:-

Hartley oscillator is a LC-feedback oscillator. A simple arrangement of a feedback oscillator is shown below-



The circuit consists of -

① A resonator which consists of an LC circuit. It is also known as frequency determining network (FDN) or tank circuit.

② An amplifier whose function is to amplify the oscillations produced by the resonator.

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

The essential condition for mainta
oscillations and for finding the valu
frequency is –

$$\beta A = 1 + j0 \quad \text{or} \quad \beta A \angle \phi =$$

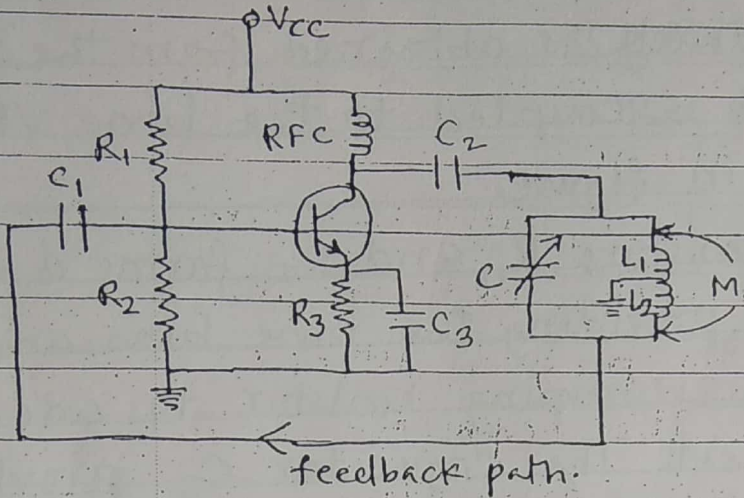
It means that :-

① The feedback factor or loop gain |

② The net phase shift around the lo
(or an integral multiple of 360°), i.
should be positive.

The above two conditions form
criterion for maintaining a steady
oscillation at a specific frequency.

A transistor Hartley oscillator using CE configuration is shown below -



(1) It uses a single tapped coil having two parts maked L_1 and L_2 instead of two separate coils. ② One side of L_2 is connected to the base via C_1 and the other to emitter via ground and C_3. ③ Similarly, one end of L_1 is connected to collector via C_2 and the other to common-emitter terminal via C_3. In other words, L_1 is in the output circuit i.e. collector-emitter circuit whereas, L_2 is in the input circuit i.e. base emitter circuit. These two parts are inductively coupled and form an auto-transformer or a split-tank inductor. The feedback between the output and input circuit is provided by autotransformer action which also introduces a phase reversal of 180°.

The total phase shift becomes 360°, thus makin the feedback positive or regenerative. which is the essential condition for oscillations. Thus, the positive feedback is obtained from the tank circuit and is coupled to the base via C_1 as shown in figure.

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

When V_{cc} is switched on an Initial bias is given by $R_1 - R_2$ and oscillations are produced because of positive feedback from LC-tank circuit. The frequency of oscillation is given by -

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

Where $L = L_1 + L_2 + 2M$ - self inductance in μH and C - is capacitance in μF. M-is mutual inductance betn two section of the coils

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

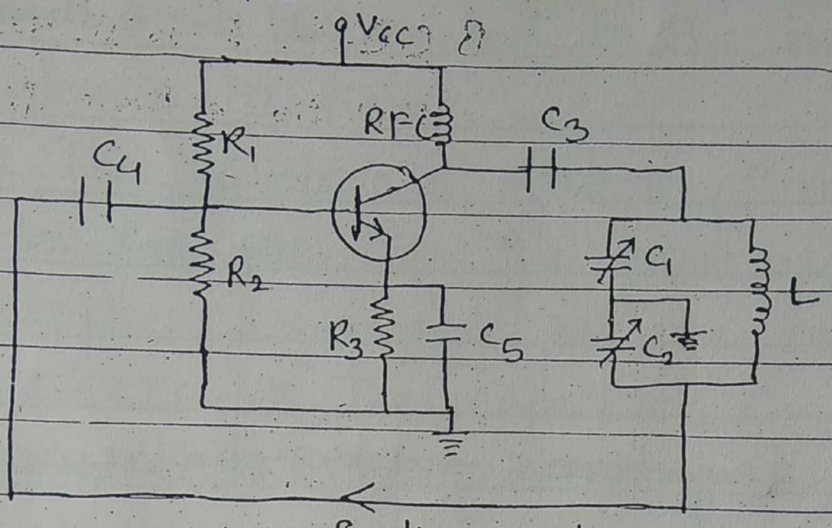
B.S.E.S. I to III year
Roll No. & Name list.

~~Pen drivers are not strictly not~~
~~allowed~~

Y

② Colpitt's Oscillator —

A transistor Colpitt's oscillator circuit using CE-configuration is shown below —



feedback path.

The tank circuit in Colpitt's Oscillator is a tapped ~~cap~~ capacitance type. The two series capacitors C_1 and C_2 forms the voltage divider ~~using~~ used for providing feedback voltage (The voltage drop across C_2 constitutes the feedback voltage). The feedback fraction is C_1/C_2. The minimum value of amplifier gain for maintaining oscillation is —

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

The tank circuit consists of two ganged capacitors C_1 and C_2 and a single fixed coil. The frequency of

oscillation (which does not depend on mutual inductan
is given by.

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

The transistor itself produces a phase shift of 180°. Another phase shift of 180° is provided by the capacitiv feedback thus giving a total phase shift of 360° betwe the emitter-base and collector emitter base circuits. Thus, Positive feedback or regenative feedback is produced in the circuit.

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

When V_{cc} is made on, a sudden surge of collector current shock-excites the tank circuit in to oscillations which are sustained by the feedback and the amplifying action of the transistor.

Colpitts oscillator is widely used in commercial signal generators up to 1 MHz. The frequency of oscillations is varied by gang tunning the two capacitors C_1 and C_2.

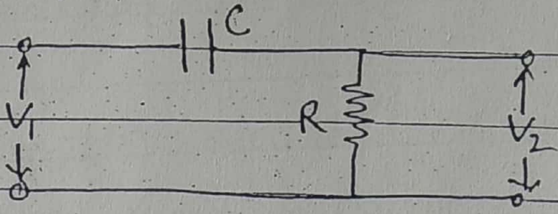
Scanned by CamScanner

③ R-C Network:-

A oscillator circuit requires a passi which produces a phase shift of 180° so that par of the output of an amplifier can be fed back to the amplifier. The positive feedback causes oscillations.

A R-C Network can be used for phase-shift.

Consider a resistance R connected in series with a capacitor C as shown in figure. If an



alternating voltage V_1 is applied to the terminals of the network. The current in the circuit is given by -

$$i = \frac{V_1 \cdot j\omega C}{1+j\omega CR}$$

The voltage across R has a value,

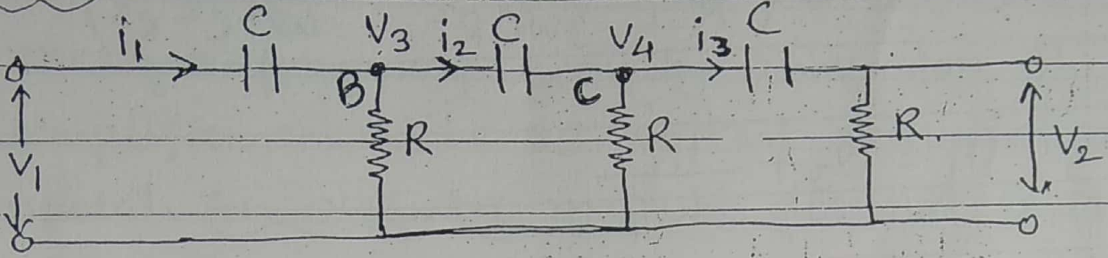
$$V_2 = iR = \frac{V_1 \cdot j\omega C \cdot R}{1+j\omega CR}$$

The input voltage V_1 and the output voltage V_2 have a phase difference ϕ.

where, $\tan\phi = \frac{1}{\omega CR}$

The phase shift depends on the frequency and the value of C and R.

Let us consider the following circuit. It consists of three CR-sections and is also called a ladder network.



Let V_1 be the input voltage and V_2 be the output. If V_3 and V_4 are the voltages at the points B and C we have,

I^{st} $v_4 - v_2 - \frac{i_3}{j\omega C} = 0$

II^{nd} $v_4 = v_2 + \frac{i_3}{j\omega C}$

$= v_2 + \frac{v_2}{j\omega CR}$ ∴ since $i_3 = \frac{V_2}{R}$ Hint

$\frac{V_2}{R} + \frac{V_2 + \frac{V_2}{j\omega CR}}{R}$

$i_2 = i_3 + \frac{v_4}{R}$

$= V_2\left(\frac{2}{R} + \frac{1}{j\omega CR^2}\right)$

$\frac{V_2}{R} + \frac{V_2 j\omega CR + V_2}{j\omega CR^2}$

$\frac{V_2}{R} + \frac{V_2}{R} + \frac{V_2}{j\omega CR^2}$

$\frac{2V_2}{R} + \frac{V_2}{j\omega CR^2}$

$v_3 = v_4 + \frac{i_2}{j\omega C}$

$= v_2\left(1 + \frac{3}{j\omega CR} - \frac{1}{\omega^2C^2R^2}\right)$ ⇒ $V_2\left[\frac{2}{R} + \frac{1}{j\omega CR^2}\right.$

$$i_1 = i_2 + \frac{V_3}{R}$$

$$= V_2\left(\frac{3}{R} + \frac{4}{j\omega CR^2} - \frac{1}{\omega^2C^2R^3}\right)$$

$$v_1 = v_3 + \frac{i_1}{j\omega C}$$

$$= v_2\left(1 + \frac{6}{j\omega CR} - \frac{5}{\omega^2C^2R^2} - \frac{1}{j\omega^3C^3R^3}\right)$$

The output voltage is real at a frequency making the factor.

$$\left(\frac{6}{j\omega CR} - \frac{1}{j\omega^3C^3R^3}\right)$$

$$\therefore \quad \omega = \frac{1}{\sqrt{6}\,CR}$$

At this frequency —

$$v_1 = v_2(1-30)$$

$$= -29\,v_2$$

The output voltage is $\frac{1}{29}$ times the input and is 180° out of phase with the input at the frequency given by the equation.-

$$\omega = \frac{1}{\sqrt{6}\,CR}$$

~~If~~ this passive network is connected between the output and Input of an amplifier, the feedback will be positive and the amplifier will generate oscillations of a frequency given by above eqn. The gain of the amplifier should be 29. so that oscillation may be generated. An oscillator may be designed to provide sinusoidal oscillations of low frequency using a R-C network.

* Question =

In R-C Network, show that output voltage $\frac{1}{29}$ time's the input voltage and 180° out of phase with input

① Phase Shift Oscillator :-

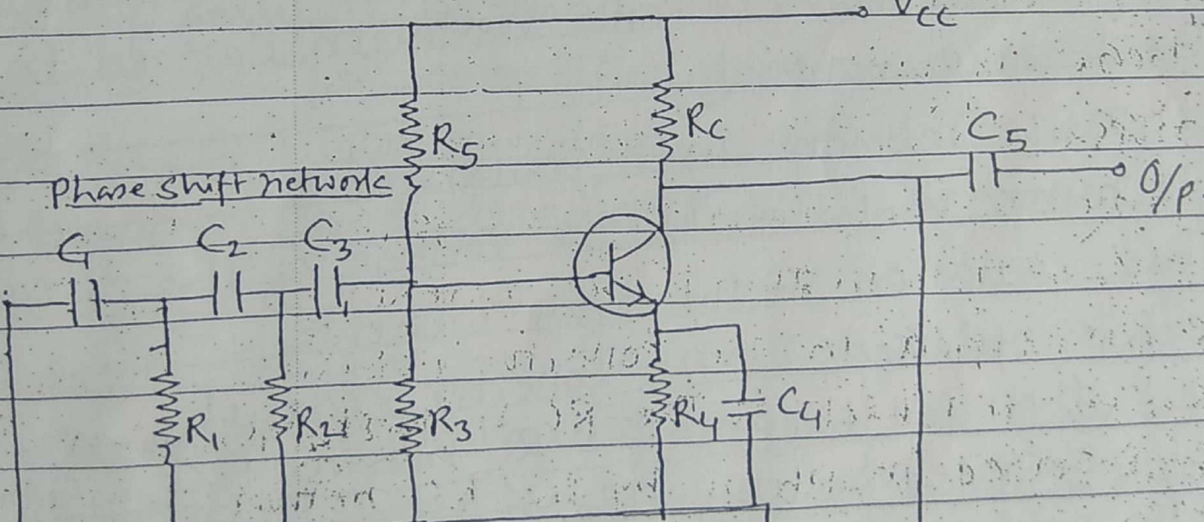
A phase shift oscillator is R-C oscillator. In an oscillator two conditions are to be satisfied.

① there should be a 180° phase shift around the feedback network. (The total phase shift required is 360°, However the balance of 180° is provided by the active device of the amplifier itself). and.

② The loop gain should be greater than unity.

In phase shift oscillator, the 180° phase shift in the feedback signal is achieved by using a suitable R-C network consisting of three ~~of~~ R-C sections. The sine wave oscillators which use R-C feedback network are called phase-shift-oscillators.

The following figure shows a transistor phase shift oscillator which uses a three section R-C



feedback network for producing a total phase shift of 180° (i.e. 60° per section). in the signal is fed back to the base. Since CE amplifier ~~proces~~ produces a phase reversal of the input signal, total phase shift becomes 360° or 0° which is essential for regeneration and hence for sustained oscillations.

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

Circuit action-

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

(i) noise inherent in a transistor or

(ii) minor variation in the voltage of the dc source

This variation in the base current:

- is amplified in the collector circuit
- is then fed back to the RC-network R_1C_1, R_2C_2 and R_3C_3
- is reversed in phase by the RC network.
- is next applied to the base in phase with initial change in base current.

and hence is used to sustain cycles of variation in collector current between saturation and cut-off values.

The voltage divider R_5 and R_3 provides dc emitter base bias. Resistor R_4 controls collector voltage and Resistor R_4 and Capacitor C_4 provides temperature stability and prevents ac signal degeneration. The oscillator output voltage is capacitively coupled to the load by C_5.

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

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

Analytically, it is found that the value of $\beta = \frac{1}{29}$. It means that amplifier gain must be more than 29 for oscillator operation.

Advantages and disadvantages:-

① Since, they do not require any bulky and expensive high value inductors, such oscillators are well suited for frequencies below 10KHz.

② Since only one frequency can fulfill Barkhausen phase shift requirement; positive feedback occurs only for one frequency. Hence pure sine-wave output is possible.

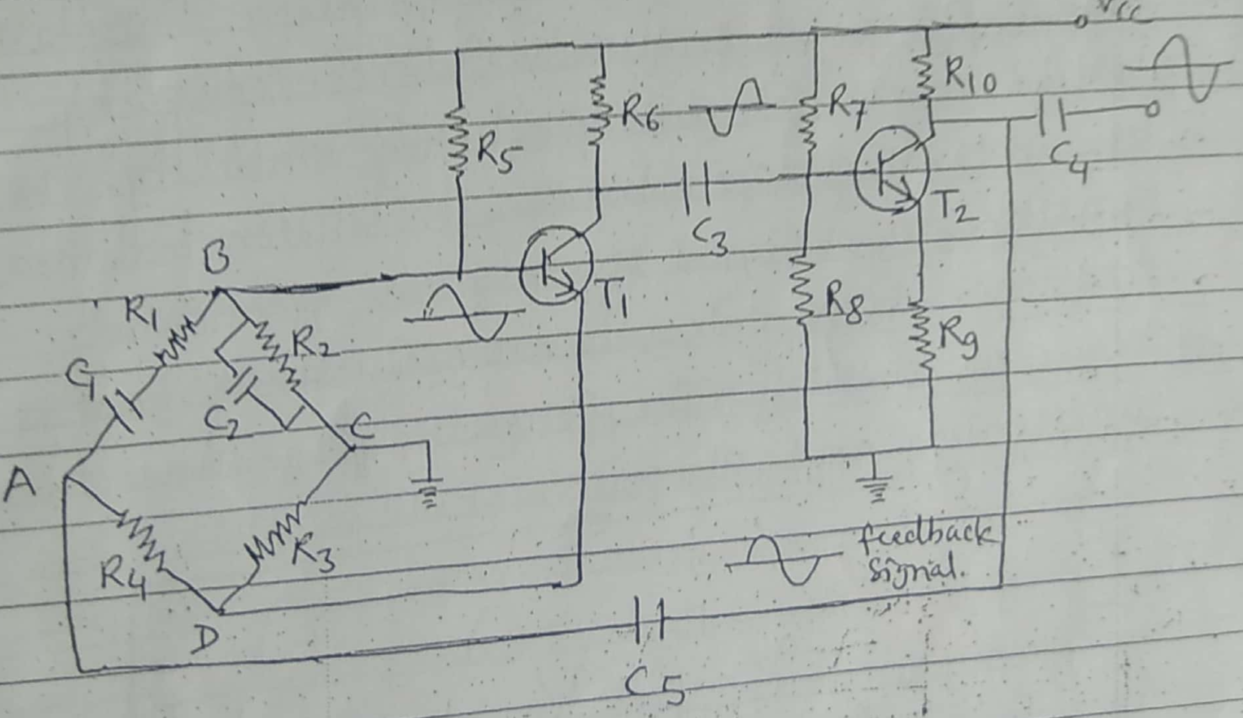
③ It is not suited to variable frequency range because a large number of capacitors will have to be ~~vary~~ varied. Also, gain adjust would be necessary every time frequency change is made.

④ It produces a distortion level of nearly 5 in the output signal.

⑤ It is necessary to use a high β transisto to overcome losses in the R-C Network.

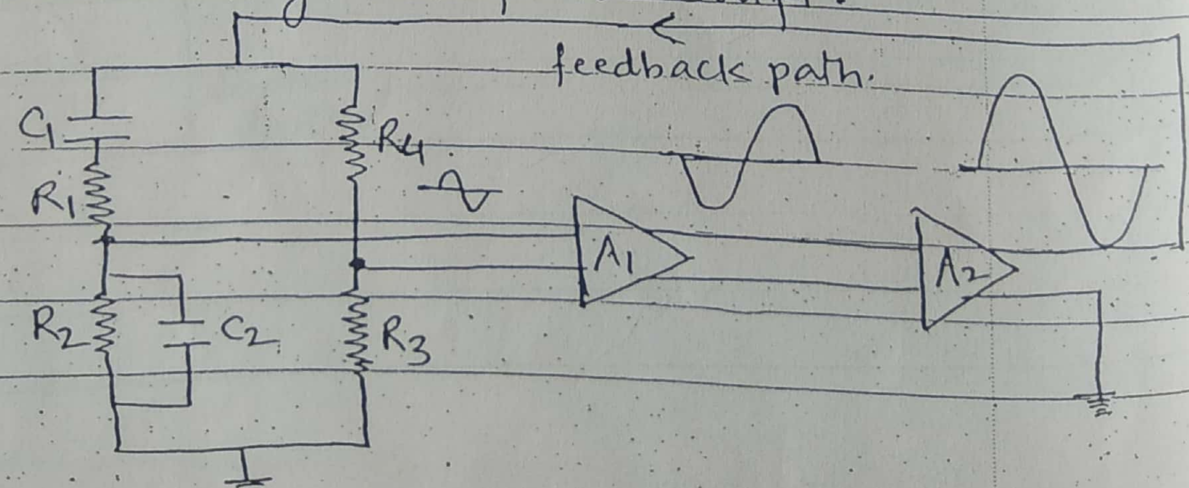
) Wien Bridge Oscillator:

A wien bridge oscillator is a low frequen (5 Hz – 500 kHz), low distortion, tunable, high purity sine wave generator. This oscillator uses two CE-connected, RC coupled transistor amplifiers an one R-C bridge called Wien bridge network to provide feedback. A circuit of Wien-bridge oscillat is shown below. In the circuit, T_1 serves as amplific oscillator and T_2 provides phase reversal and additional amplification. The bridge circuit is used to control the phase of the feedback signal at T_1.



Phase-shift principle.

Any input signal at the base of T_1 appears in the amplified but phase-reversed form across collector resistor R_6. It is further inverted by T_2 in order to provide a total phase reversal of 360° for positive feedback. Obviously, the signal at R_{10} is an amplified replica of the input signal at Q_1 and is of the same phase since it has been inverted twice. This signal is fed back to the base of T_1 directly to provide regeneration needed for oscillator operation. But since T_1 will amplify signals over a wide range of frequencies, direct coupling would result in poor frequency stability. Then, by adding a wien bridge, oscillator becomes sensitive to a signal of only one particular frequency. Hence we get an oscillator of good frequency stability. The following fig. shows the functioning and phase shift.



Circuit-action -

Any random change in base current of T_1 can start oscillations. If the base current of T_1 is increased due to some reason. (by applying a positive going signal to T_1). Then, -

① An amplified but phase-reversed signal will appear at the collector of T_1.

② A still further amplified and twice phase-reversed signal will appear at the collector of T_2. Since it is inverted twice, this output signal will be in phase with the input signal at T_1.

③ A part of the out-put signal at T_2 is fed back to the input points of the bridge circuit (point A-C A part of this feedback signal is applied to emitter resistor R_3. where it produces degenerative effect. similarly, a part of the feedback signal is applied across base-bias resistor R_2 where it produces regenerative effect.

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

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

The balance conditions are—

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

and $$\omega_0 = \frac{1}{\sqrt{R_1C_1 \cdot R_2C_2}}$$

and $$f_0 = \frac{1}{2\pi\sqrt{R_1C_1 \cdot R_2C_2}}$$

If $R_1 = R_2 = R$ and $C_1 = C_2 = C$ then,

$$f_0 = \frac{1}{2\pi\sqrt{RC}} \quad \text{and} \quad \frac{R_4}{R_3} = 2.$$

Advantages—

This circuit has—

① highly stabilized amplitude and Voltage amplification.

② Provides good sinewave output.

③ has good frequency stability.