UNIT - III

PART - B OSCILLATORS

Topics to be Covered:

1. oscillator definition
2. classification of oscillators.
3. List of oscillators to be discussed and Analysis.
4. Conditions for obtaining oscillations (or) Barkhausen Criterion.
5. (a) RC oscillator ckts using FET and BJT and Analysis
   (b) Derivation for frequency of oscillations.
   (c) Condition on minimum gain required for active devices (h_{fe}, μ)
   (d) Design Considerations and variable frequency of oscillations.
6. Generalized LC oscillators
   (a) Colpitts oscillators
   (b) Hartley oscillator.
7. Wien-Bridge oscillator
8. crystal oscillator
9. stability of oscillations
   (a) Frequency stability
   (b) Amplitude stability
10. Problems.

① **OSCILLATOR:**

An oscillator is an electronic circuit which (produces) generates ~~a~~ periodic ac signal at its output ~~wh~~ without any external input signal.

Note: ① oscillator converts DC power into AC power.
② oscillator is a switch which ~~selects~~ generates a periodic signal with a single frequency desired.

② **CLASSIFICATION OF OSCILLATORS:**

The oscillators are classified based on various parameters as given below:

ⓐ Based on the shape of the waveform:

① Sinusoidal oscillators → o/p is sine (or) cosine wave [uses RC (or) LC or crystal ckt]

② Non-sinusoidal osc. or Relaxation osci → o/p is square, triangle, sawtooth etc. [uses UJT (or) Multivibrators]

ⓑ Based on Fundamental Mechanism involved:

① Negative Resistance osci's → These ckt uses 2/3-terminal devices like Tunnel diode or UJT, which exhibit negative resistance region.

② Feedback oscillators (to be discussed here) → These circuits uses positive feedback for generating sinusoidal oscillations.

(P.T.O.)...

ⓒ Based on Frequency generated:

1. Audio Frequency Oscillators (AFO) : upto 20kHz
2. Radio Frequency Oscillators (RFO) : 20kHz to 30MHz
3. Very High Frequency osc. (VHF) : 30MHz to 300MHz
4. Ultra High Frequency osc. (UHF) : 300MHz to 3GHz
5. Micro Wave Frequency osc. (MWFO) : above 3GHz

③ List of oscillators to be discussed and Analysized:

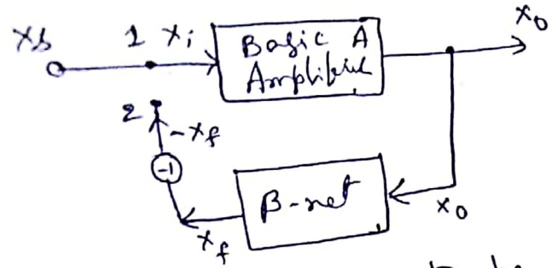
Sinusoidal oscillators are further classified based on the Components used in β-network, which provides positive feedback to the basic amplifier.

~~Singu~~ Sinusoidal oscillators

- RC-phaseshift osc.
  - eg: ① using FET
  - ② Using BJT
  - ③ Wien Bridge
- LC oscillators (Tuned osc)
  - eg: ① Colpitts
  - ② Hartley
- crystal oscillators

(4) BARKHUSEN CRITERION/CONDITIONS (or) Conditions for obtaining oscillations:

The block diagram of a feedback amplifier can be drawn as shown below. To complete the feedback loop



points 1 and 2 are to be joined together, then

$$x_i = x_s - x_f$$

Basic amplifier amplifies x_i and produces x_o.
Suppose if $x_i = -x_f$ then also Basic amplifier produces x_o, because it cannot distinguish how x_i is generated whether due to x_s (or) due to FB signal.
So, if we set $-x_f = x_i$ then it is possible to obtain x_o without x_s, the external source.

$$\therefore -x_f = x_i$$

$$-\beta x_o = x_i$$

$$-A\beta x_i = x_i$$

$$\boxed{\therefore -A\beta = 1}$$

Therefore if the loop gain $(-A\beta)$ is equal to unity then output x_o can be obtained without any external source signal. This is the condition to be satisfied by any feed back ckt for obtaining oscillations.

(P.T.O.)

Barkhusen Conditions:

To obtain oscillations the condition is

$$-A\beta = 1$$

The gain of the amplifier A is a complex quantity (except in Mid Band region), so the LHS expression is a complex quantity. hence the above expression can be expressed as (a) Magnitude part and (b) phase part.

Condition : 1

$$|-A\beta| = 1$$

i.e. Magnitude of loop gain should be unity.

Condition : 2

$$\angle -A\beta = 0 \text{ or } 2n\pi \quad \text{for } n = 1, 2, 3, \ldots$$

i.e. the loop phase shift should be 0° or 360° or integer multiple of 360°.

The above 2 conditions are called as Barkhusen conditions.

Note: (1) If any ckt satisfies above two conditions it produces sinusoidal oscillations without any external signal.

(2) For any circuit to produce oscillations it should satisfy the Barkhusen conditions.

(3) We know the β-net in -ve FB amplifiers does not produce any additional phase-shift.

(4) To obtain oscillations the loop phase-shift should be 360°, The basic amplifier produces 180° phase shift. Therefore β-network should provide another 180° phase shift.

P.T.O.

(5) To produce additional phase-shift of 180°, β-network should consist of reactive elements like capacitors and inductors along with resistors.

(6) If β-network consists of RC circuits then the oscillator is called as RC oscillator.

(7) If β-network consists of LC circuits then it is called as LC oscillator or Tuned oscillator.

(8) In Wien-Bridge oscillator, β-network consists of Wien-Bridge ckt with RC elements. Oscillations will be obtained when the bridge is balanced. Wien-Bridge oscillator is the one in which both negative and positive feedback are used.

Range 10Hz to 1MHz

(9) In crystal oscillators, β-network consists of a crystal which exhibits piezo-electric effect.

(10) Frequency stability of RC oscillators is poor and for LC oscillators it is good. Freq stability of crystal oscillators is very high (1 part in 10^{10})

Applications (11) RC oscillators are used for audio Range
LC oscillators are used for above audio Range
Crystal oscillators can be used for the frequency range of 0.5 to 30 MHz.

Practical consideration (12) In oscillator ckts β-net consists of passive element (R, L, C) hence power dissipation occurs, so the output amplitude gradually decays and the oscillations become damped oscillations. To overcome this problem the magnitude of the loop gain is set 5% larger than unity in all practical circuits.

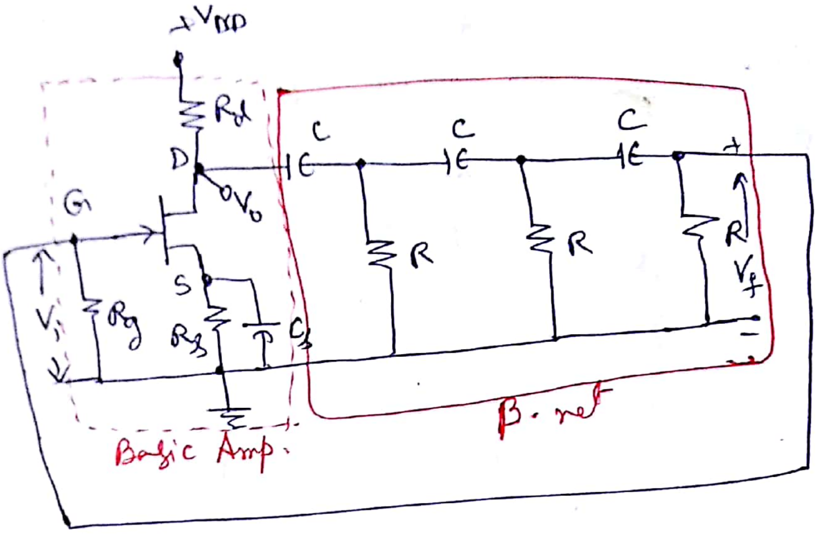
$$\boxed{\therefore |-A\beta| = 1.05 \text{ for practical ckt.}}$$

(13) The maximum amplitude of the output is limited by the non-linearity of the active device.

(P.T.O.)

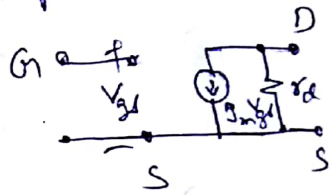
5 (a) RC phase-shift oscillator using FET :

(a) The RC phase-shift oscillator ckt is as shown below using FET



Explanation

1. Common source amplifier is used as basic amplifier. During analysis ground V_{DD}, short ckt C_s, so R_s is bypassed and ignore R_g the biasing ckt. Replace the FET with its low frequency model



2. β-network consists of 3 identical RC stages. Each RC circuit is designed to produce 60° phase shift such that the total phase-shift is 180°.

3. CS configuration provides 180° phase-shift and if β-network provides another 180° then total loop phase-shift would be equal to 360°.

4. Basic Amplifier input impedance is very high so, it does load the β-network. Hence the Basic amplifier and β-network can be analyzed separately.

5. Gain of the β-network is given by

$$\boxed{\beta = \frac{V_f}{V_o}}$$

(P.T.O.)

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(6) the gain of the Basic amplifier A_v is given by

$$A_v = \frac{V_o}{V_i} = -g_m R_d' \quad \text{(known)}$$

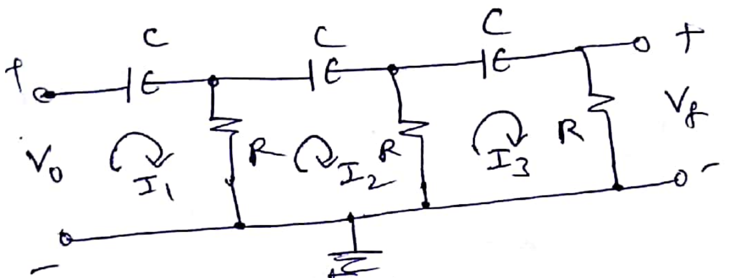
$$= -\frac{g_m r_d R_d}{r_d + R_d}$$

$$\boxed{A_v = -\frac{\mu R_d}{r_d + R_d}}$$

(b) Derivation for frequency of oscillations:

The β-network should provide 180° phase shift, the ~~gain~~ gain of the β-network is given ~~is given~~ by

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



write the 3 loop equations

$$V_o - (-jx_c)I_1 - R(I_1 - I_2) = 0$$

$$\therefore -I_1(R - jx_c) + I_2 R = -V_o$$

$$\boxed{\therefore I_1(R - jx_c) - I_2 R = V_o} \quad \text{— I}$$

divide with R

$$I_1(1 - j\alpha) - I_2 = \frac{V_o}{R}$$

$$-R(I_2 - I_1) - (-jx_c)I_2 - R(I_2 - I_3) = 0$$

$$\boxed{I_1 R - I_2(2R - jx_c) + I_3 R = 0} \quad \text{— II}$$

divide with R

$$I_1 - I_2(2 - j\alpha) + I_3 = 0$$

$$-R(I_3 - I_2) - (-jx_c)I_3 - RI_3 = 0$$

$$\therefore I_2 R - I_3(2R - jx_c) = 0$$

$$\boxed{\therefore I_2 = I_3(2 - j\alpha)} \quad \text{— III}$$

where $\boxed{\alpha = \frac{x_c}{R} = \frac{1}{\omega CR}}$

(P.T.O.)

Substitute III in II

$$\therefore I_1 = I_3(2-j\alpha)^2 - I_3$$
$$= I_3[4-\alpha^2-j4\alpha-1]$$
$$I_1 = I_3[3-\alpha^2-j4\alpha] \quad \text{—— IV}$$

Substitute III & IV in I

$$I_3(1-j\alpha)(3-\alpha^2-j4\alpha) - I_3(2-j\alpha) = \frac{V_o}{R}$$
$$\therefore I_3R[3-\alpha^2-j4\alpha-j3\alpha+j\alpha^3-4\alpha^2-2+j\alpha] = V_o$$
$$\therefore V_f[1-5\alpha^2+j(\alpha^3-6\alpha)] = V_o$$
$$\therefore \beta = \frac{V_f}{V_o} = \frac{1}{1-5\alpha^2+j(\alpha^3-6\alpha)}$$

the condition to obtain oscillations is $\angle\beta = 180^0$

$$\therefore \angle\beta = -\tan^{-1}\left(\frac{\alpha^3-6\alpha}{1-5\alpha^2}\right) = 180^0$$
$$\therefore \alpha^3-6\alpha = 0 \Rightarrow \boxed{\alpha^2 = 6}$$
$$\therefore \boxed{\alpha = \sqrt{6}}$$

but $\alpha = \frac{1}{\omega CR} = \frac{1}{2\pi f RC}$

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

for this frequency only the β-network will provide 180° phase shift. To btain sustained oscillations the magnitude condition should also be satisfied at this frequency.

(P.T.O.)...

(c) Condition on Minimum gain Required:

There phase at this frequency the magnitude of β-network is given by

$$|\beta| = \left|\frac{1}{1-5\alpha^2}\right| = \frac{1}{29}$$

So, to obtain sustained oscillations

$$|A\beta| = 1$$

$$\Rightarrow |A| = \frac{1}{|\beta|}$$

$$\boxed{\therefore |A| = 29}$$

So a FET CS amplifier with amplification factor (μ) less than 29 cannot produce sustained oscillations.

$$\boxed{\therefore |A| \simeq \mu > 29}$$

$|A| = g_m R_d'$
$\simeq \mu$ if $R_d \to \infty$.

(d) Design Considerations:

① Select a FET with $\mu = g_m r_d > 29$ and operate in CS mode.

② During design the frequency of oscillations f will be given then to complete the design procede as follows:

(a) Select $C \leq 1\mu F$ (depending on availablity in the market)

(b) Calculate R using the formula

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

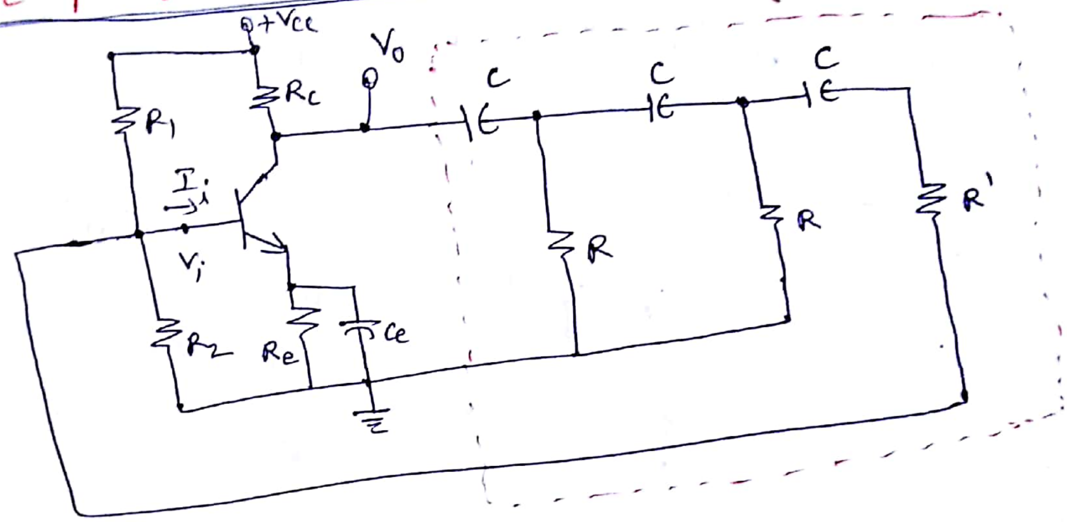
(c) Exact value of the resistance above may not be available in the market, then select a ~~the~~ potentiometer with appropriate value and adjust the as per the requirement.

(P.T.O.)

(e) Frequency Variability:

Once the design is completed for a given frequency f_1, to design an oscillator with f_2 frequency, use 3-Ganged capacitors, [in which the 3 capacitors are connected to a single shaft] and vary all the capacitor values simultaneously, till the desired frequency is obtained.

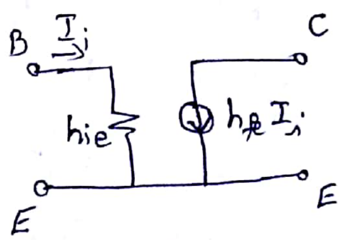
5(a)(b) RC phase-shift oscillator using BJT:



Explanation: BJT is as shown above.

① The RC phase-shift oscillator using BJT is used as basic amplifier.

② Common Emitter amplifier is used as basic amplifier. During analysis Vcc is grounded, Ce is to be short ckted then Re is bypassed. The effect of biasing resistances R_1 & R_2 is neglected. BJT is to be replaced with its approximate h-parameter model.



③ The β-network consists of 3 identical RC stages. Each RC circuit is designed to produce 60° phase-shift such that total phase-shift is 180°.

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(4) CE Configuration provides 180° phase-shift and β-network provides another 180° phase shift and the total loop phase-shift would be equal to 180°.

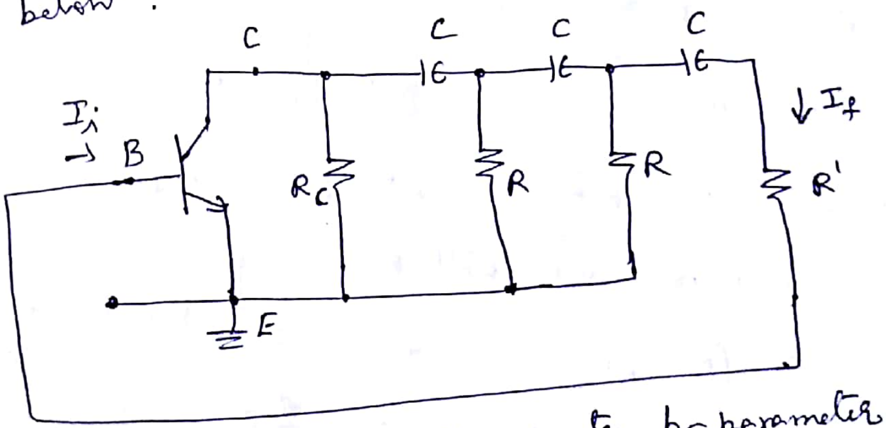
(5) In this circuit the basic amplifier input impedance is low, so the loading effect of the β-network should be considered and BJT is a current controlled device. Hence it is convenient to calculate the loop gain (I_f/I_i) by considering basic amplifier and β-network combinedly as a single circuit.

(6) The loop gain $(-A\beta)$ is obtained as (I_f/I_i)

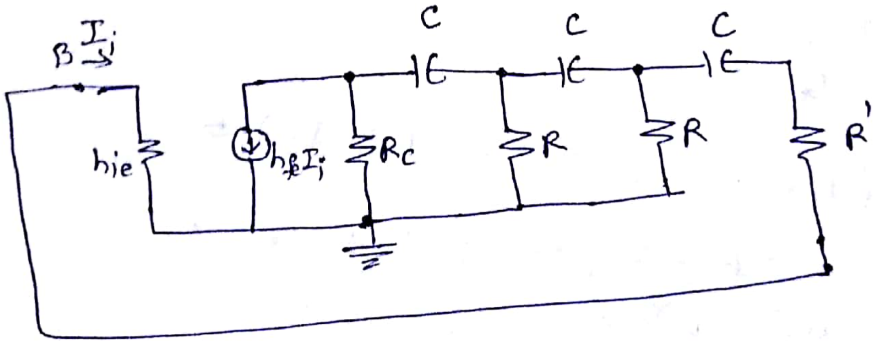
$$\therefore \boxed{-A\beta = \frac{I_f}{I_i}}$$

(8) Derivation ~~of~~ for frequency of oscillations:

The basic amplifier with β-network, after V_{cc} is grounded and C_e shorted to ground and by neglecting R_1 & R_2, ~~the~~ is as shown below.



Replace the BJT with approximate h-parameter model.



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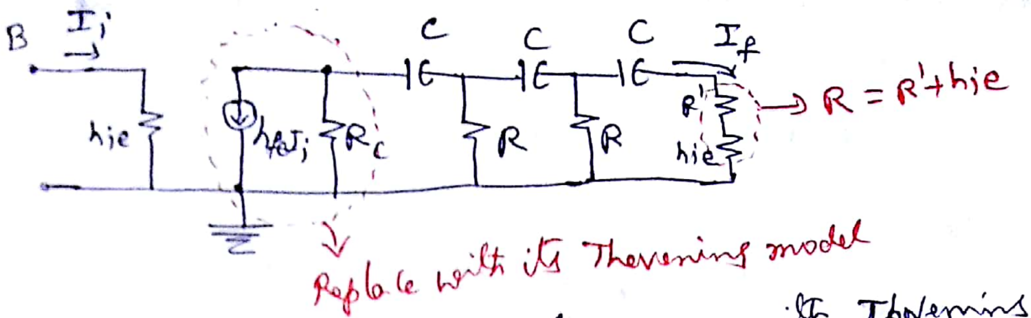
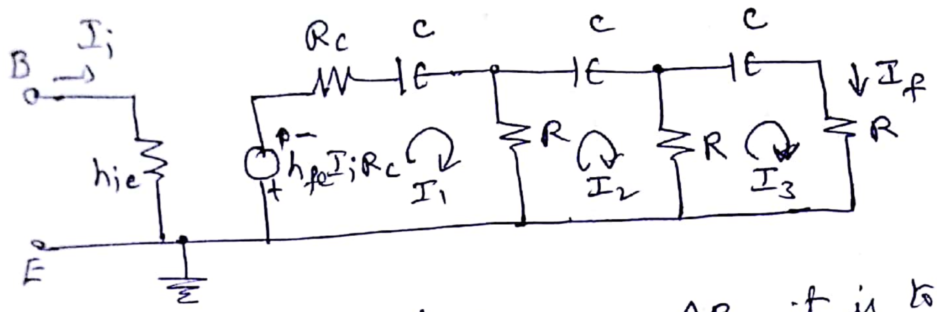
After the input and output circuits are separated



After Replacing the current source with Thevenins model



To determine the loop gain $-A\beta$, it is to be calculated the ratio of I_f to I_i and equated to unity

$$\therefore -A\beta = \frac{I_f}{I_i} = \frac{I_3}{I_i} = 1$$

write KVL's to the three loops and solve for I_3

First loop

$$-h_{fe} I_i R_c - R_c I_1 - (-jX_c) I_1 - R(I_1 - I_2) = 0$$

$$\therefore -I_1(R_c + R - jX_c) + I_2 R = h_{fe} \cdot I_i \cdot R_c$$

devide both sides with R

$$\therefore I_1\left(\frac{R_c}{R} + 1 - j\alpha\right) - I_2 = -h_{fe} I_i \frac{R_c}{R}$$

let $k = \frac{R_c}{R}$ and $\alpha = \frac{X_c}{R} = \frac{1}{\omega CR}$

$$\therefore I_1(1 + k - j\alpha) - I_2 = -h_{fe} k I_i \quad \text{— I}$$

Second loop

$$-(I_2 - I_1)R - I_2(-jX_c) - R(I_2 - I_3) = 0$$

$$\therefore I_1 R - I_2(2R - jX_c) + I_3 R = 0$$

devide with R

$$\therefore I_1 - I_2(2 - j\alpha) + I_3 = 0 \quad \text{— II}$$

Third loop

$$-R(I_3 - I_2) - I_3(-jX_C) - I_3 R = 0$$

$$\therefore I_2 R - I_3(2R - jX_C) = 0$$

$$\therefore I_2 = I_3(2 - j\alpha) \quad \text{— III}$$

Substitute III (I_2) in II

$$\therefore I_1 = I_3(2-j\alpha)(2-j\alpha) - I_3$$

$$= I_3[4 - \alpha^2 - j4\alpha - 1]$$

$$\therefore I_1 = I_3[3 - \alpha^2 - j4\alpha] \quad \text{— IV}$$

Substitute III & IV in eq: I.

$$I_3(3-\alpha^2 - j4\alpha)(1+K-j\alpha) - I_3(2-j\alpha) = -h_{fe} K I_i$$

$$\therefore I_3\left[3+3K - j3\alpha - \alpha^2 - K\alpha^2 + j\alpha^3 - j4\alpha - j4K\alpha - 4\alpha^2 - 2 + j\alpha\right] = -h_{fe} K I_i$$

$$\therefore I_3\left[1 + 3K - 5\alpha^2 - K\alpha^2 + j\alpha^3 - j(6+4K)\alpha\right] = -h_{fe} K I_i$$

$$\therefore \frac{I_3}{I_i} = \frac{I_f}{I_i} = \frac{-h_{fe} K}{\left[1+3K - \alpha^2(5+K) + j\left[\alpha^3 - \alpha(6+4K)\right]\right]} = -A\beta$$

For obtaining ~~sustained~~ oscillations according to Barkhausen criteria the loop phase shift should be equal to $0°$ or $2n\pi$.

$$\therefore \angle -A\beta = \angle \frac{I_f}{I_i} = -\tan^{-1}\left[\frac{\alpha^3 - \alpha(6+4K)}{1+3K - \alpha^2(5+K)}\right] = 0$$

$$\Rightarrow \alpha^3 - \alpha(6+4K) = 0$$

$$\therefore \alpha^2 = 6 + 4K$$

$$\therefore \alpha = \sqrt{6+4K}$$

$$\boxed{\therefore f = \frac{1}{2\pi RC\sqrt{6+4K}}}$$

(P.T.O.)

So, at this frequency the loop phase shift is equal to $0°$ (or) $360°$.

Condition on loop gain & Minimum gain required for active device:

The magnitude of the loop gain at this frequency is given by

$$|-A\beta| = \left|\frac{I_f}{I_i}\right| = \left|\frac{-h_{fe}K}{1+3K-\alpha^2(5+K)}\right|$$

but $\alpha^2 = (6+4K)$

$$\therefore |-A\beta| = \cancel{\left|\frac{-h_{fe}K}{1+3K-30-6K}\right|} = \left|\frac{-h_{fe}K}{1+3K-(6+4K)(5+K)}\right|$$

$$= \cancel{\left|\frac{-h_{fe}K}{-29-3K}\right|}$$

$$= \left|\frac{-h_{fe}K}{1+3K-(30+26K+4K^2)}\right|$$

$$= \left|\frac{-h_{fe}K}{-(29+23K+4K^2)}\right|$$

$$\therefore |-A\beta| = \frac{h_{fe}K}{29+23K+4K^2}$$

where h_{fe} is +ve or $K = \frac{R_C}{R}$ is +ve.

To obtain sustained oscillations the loop gain should be little more than unity.

$$\therefore \frac{h_{fe}K}{29+23K+4K^2} \geq 1$$

$$\boxed{\therefore h_{fe} \geq 23 + 4K + \frac{29}{K}}$$

This is the condition on gain i.e. h_{fe}.

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Note: $f(K) = h_{fe} = 23 + 4K + \frac{29}{K}$; To know for what value of K, f(K) is minimum, $f'(K) = 0$

$$\therefore f'(K) = 4 - \frac{29}{K^2} = 0$$

$$\Rightarrow K^2 = \frac{29}{4}$$

$$\therefore K = 2.693$$

$$\therefore K = 2.7$$

Hence for $K = 2.7$ h_{fe} value will be minimum.

(P.T.O.)

$\therefore$ for $\boxed{K = 2.7}$

$$h_{fe} = 23 + 10.8 + 10.77$$

$$h_{fe} = 44.57$$

$$\boxed{\therefore h_{fe\,min} = 44.5}$$

Therefore for obtaining sustained oscillations using BJT, the h_{fe} value of the transistor should be greater than 44.5. ~~For~~ ~~A~~ A BJT with $h_{fe} \leq 44.5$ no oscillations can be obtained.

Design Considerations:

① During Design the frequency(f) of oscillations will be given so, select $C \leq 1MF$ and calculate R using the formula

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

② If exact value of resistance is not available then select a potentiometer with proper value and set it equal to R.

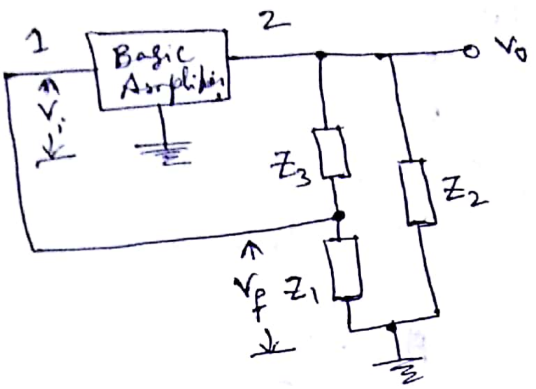
③ select a BJT, with $h_{fe} > 44.5$, and operate in CE Configuration with $R_C = KR = 2.7R\,\Omega$ for obtaining sustained oscillations.

④ Draw the full ckt with design values.

Note: Advantages & disadvantages of RC phase-shift oscillators is on Page: 9.a

6. Generalized LC oscillators: (Tuned oscillators)

A generalized LC oscillator can be shown as below



Explanation ~~Note~~: ① The Basic Amplifier may be a CE or CS amplifier. Z_1, Z_2 & Z_3 are reactance of either inductive or capacitive type.

② $Z_1 = jX_1$
$Z_2 = jX_2$
$Z_3 = jX_3$
if any of Z_1, Z_2, Z_3 are inductive reactance then $\boxed{X_1 = \omega L}$ & if capacitive then $\boxed{X = -\frac{1}{\omega C}}$.

③ Z_1, Z_2 & Z_3 forms the β-network and the voltage across Z_1 is feedback to the basic amplifier.

④ When the Basic Amplifier is a FET amplifier then Basic Amp ~~β-network~~ does not load the β-network, because its input impedance is very high.

⑤ If Basic amplifier is a BJT then Basic Amp loads the β-network due to its low input impedance.

~~Deriv~~ **Derivation for loop gain:**

⑥ It is convinient to calculate the loop gain $-A\beta$ and equate it to unity for getting the expression for frequency of oscillations.

⑦ Hence calculate the voltage gain of the Basic Amplifier and β separately and substitute in $-A\beta = 1$.

⑧ Assume a FET is used in CS configuration as ~~ckt~~ the basic amplifier. The equivalent circuit will be as shown below.

(P.T.O.).

RC phase shift

Advantages:

1. The ckt is simple to design
2. Produces pure sinusoidal output waveform
3. Provides the output over audio frequency range.
4. It needs high 'β' ~~the~~ hfe transistor to over come losses in the network.

disadvantage:

1. To change the frequency of oscillations, all the capacitors are to be varied simultaneously.
2. The frequency stability is poor due to change in parameter values with temperature, aging etc.

Wien-Bridge:

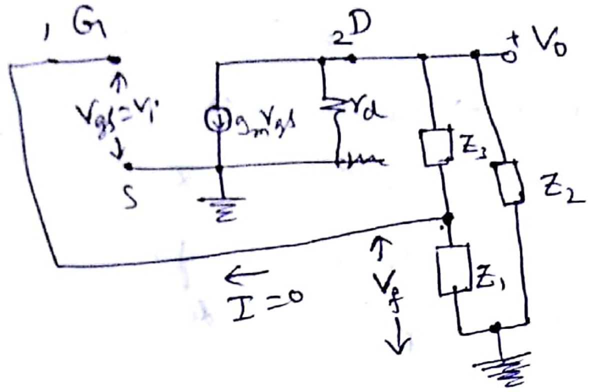
Advantages:

1. It provides a stable low distortion output over a wide range of frequency.
2. It provides better stability as it uses both positive and negative feedback.
3. Overall gain is high because two stage amplifier is used.
4. Frequency can be easily adjusted by varying either a resistor or capacitors.

disadvantages,

1. It is costlier because more components are used.
2. It can not be used to generate very high frequencies.

Derivation for β and gain A_v.



① $\beta = \dfrac{x_f}{x_o} = \dfrac{V_f}{V_o}$

$V_f = -\dfrac{V_o}{Z_1+Z_3} \times Z_1$ $\quad (\because I=0)$ & [$\because$ V_o & V_f are out of phase]

$$\therefore \boxed{\beta = -\frac{Z_1}{Z_1+Z_3}}$$

② Basic Amplifier voltage gain

$Z_L = Z_2 \parallel (Z_1+Z_3) = \dfrac{Z_2(Z_1+Z_3)}{Z_1+Z_2+Z_3}$

$\therefore V_o = -g_m V_{gs} \times \dfrac{r_d Z_L}{r_d + Z_L}$

$\therefore A_v = \dfrac{V_o}{V_{gs}} = -\dfrac{g_m r_d Z_L}{r_d + Z_L}$

$$= \frac{-\mu\, Z_2(Z_1+Z_3)/(Z_1+Z_2+Z_3)}{r_d + \dfrac{Z_1Z_2+Z_2Z_3}{Z_1+Z_2+Z_3}}$$

$$\boxed{A_v = -\frac{\mu\, \cancel{(Z_1+Z_2+Z_3)}\, Z_2(Z_1+Z_3)}{Z_1Z_2+Z_2Z_3+r_d(Z_1+Z_2+Z_3)}}$$

③ Therefore the loop gain $-A\beta$ is given by

$$-A\beta = -\left[\frac{-\mu\, \cancel{(Z_1+Z_2+Z_3)}\, Z_2\, \cancel{(Z_1+Z_3)}}{Z_1Z_2+Z_2Z_3+r_d(Z_1+Z_2+Z_3)}\right] \times \left[-\frac{Z_1}{\cancel{Z_1+Z_3}}\right]$$

This should be equal to unity.

$$\therefore +-\frac{\mu Z_1 \cancel{(Z_1+Z_2+Z_3)}\, Z_2}{(Z_1+Z_3)\left[Z_1Z_2+Z_2Z_3+r_d(Z_1+Z_2+Z_3)\right]} = 1$$

(11)

(P.T.O.)

Now substitute $Z_1 = jX_1$, $Z_2 = jX_2$ and jX_3

$$\therefore \Rightarrow -\frac{\mu \times j^2 X_1 X_2 \cancel{(X_1X_2 + X_2X_3)}}{-X_1X_2 - X_2X_3 + j\gamma_d(X_1 + X_2 + X_3)} = 1$$

$$\Rightarrow \frac{\mu X_1 X_2 \cancel{(X_1X_2 + X_2X_3)}}{X_1X_2 + X_2X_3 - j\gamma_d(X_1 + X_2 + X_3)} = 1$$

To obtain the oscillations the phase of the LHS should be zero and the loop magnitude should be unity.

$$\therefore \tan^{-1}\left(\frac{\gamma_d(X_1 + X_2 + X_3)}{X_1X_2 + X_2X_3}\right) = 0$$

$$\boxed{\therefore X_1 + X_2 + X_3 = 0} \quad \text{— I}$$

Therefore the magnitude is given by

$$-A\beta = -\frac{\mu X_1 \cancel{X_2}}{\cancel{X_2}(X_1 + X_3)}$$

$$-A\beta = -\frac{\mu X_1}{-X_2}$$

$$\therefore \text{loop gain magnitude} = \frac{\mu X_1}{X_2}$$

$$\boxed{\therefore -A\beta = \frac{\mu X_1}{X_2}} \quad \text{— II}$$

This loop gain should be equal to unity and +ve reactances should be of same type

Therefore X_1 and X_2 both should be either inductors or both means both should be of capacitors.

Case 1: Colpitts oscillator:

If X_1 and X_2 are capacitors then the circuit is called as Colpitts oscillator. From eqn: I

$$X_3 = -X_1 - X_2$$

$$\therefore X_3 = -(X_1 + X_2)$$

means X_3 should of ~~or~~ inductive type.

Therefore

$$X_1 = -\frac{1}{WC_1} \quad ; \quad X_2 = -\frac{1}{WC_2} \quad \text{and} \quad X_3 = WL$$

$$\therefore WL = \frac{1}{WC_1} + \frac{1}{WC_2}$$

$$= \frac{1}{W}\left[\frac{1}{C_1} + \frac{1}{C_2}\right]$$

$$WL = \frac{1}{W C_{eq}} \qquad \text{where } C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

$$\therefore W^2 = \frac{1}{L C_{eq}}$$

$$\boxed{\therefore f = \frac{1}{2\pi\sqrt{L C_{eq}}}}$$

Therefore the circuit will oscillate with this frequency.

From equation II we have

$$-A\beta = \frac{\mu X_1}{X_2} = \frac{\mu \cancel{W} C_2}{\cancel{W} C_1} = \frac{\mu C_2}{C_1}$$

To obtain oscillations the magnitude of the loop gain should be more than ~~equal~~ unity

$$\therefore \frac{\mu C_2}{C_1} \geq 1$$

$$\boxed{\therefore \mu \geq \frac{C_1}{C_2}}$$

(P.T.O.)

Case 2: Hartley oscillator:

If X_1 and X_2 are inductors then the circuit is called as Hartley oscillator. From eqn: I

$$X_3 = -(X_1 + X_2)$$

when X_1 & X_2 are inductors then X_3 should be a capacitor.

Therefore

$$X_1 = WL_1 + WM \; ; \; X_2 = WL_2 + WM \text{ and } X_3 = -\frac{1}{WC_3}$$

$$\therefore -\frac{1}{WC} = -W(L_1 + L_2 + 2M)$$

$$= -W L_{eq}.$$

$$W^2 = \frac{1}{L_{eq}C} \quad \text{where } L_{eq} = L_1 + L_2 + 2M$$

$$\boxed{\therefore f = \frac{1}{2\pi\sqrt{L_{eq}C}}}$$

The circuit will oscillate with this frequency. And we know that

$$-A\beta = \frac{\mu X_1}{X_2}.$$

$$= \frac{\mu \cancel{W}(L_1+M)}{\cancel{W}(L_2+M)}$$

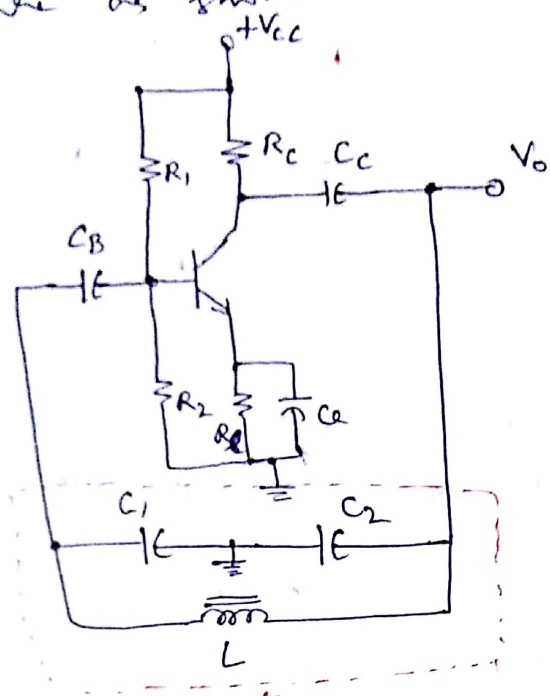
$$= \frac{\mu(L_1+M)}{(L_2+M)}$$

To obtain oscillations the magnitude of loop gain should be more than unity.

$$\therefore \mu \frac{L_1+M}{L_2+M} \geq 1$$

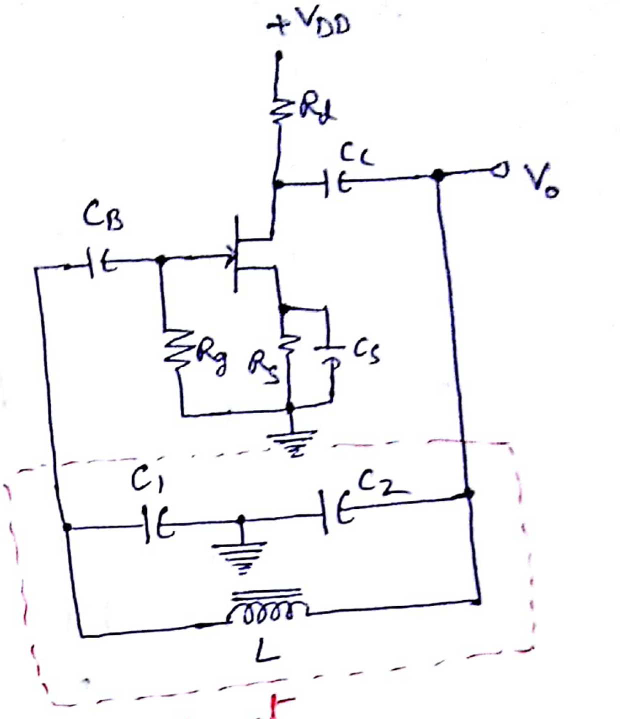
$$\boxed{\therefore \mu \geq \frac{L_2+M}{L_2+M}}$$

The Hartley and Colpitts oscillators usings FET and BJTs are as shown below.



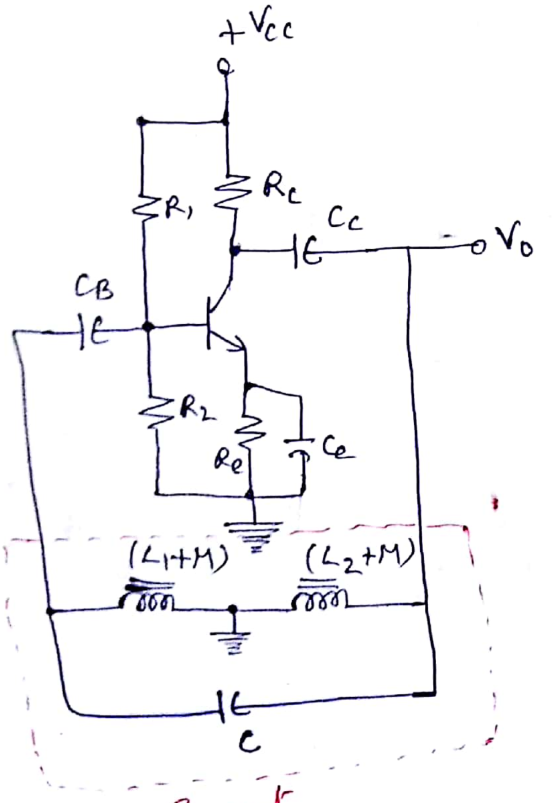
β-net

① Colpitts oscillator using BJT



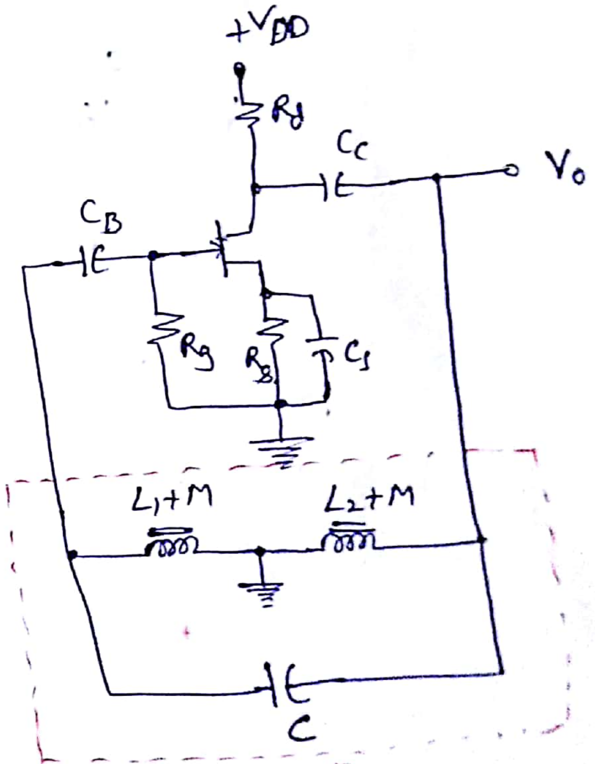
β-net

② Colpitts oscillator using FET



β-net

③ Hartley oscillator using BJT



β-net

④ Hartley oscillator using FET

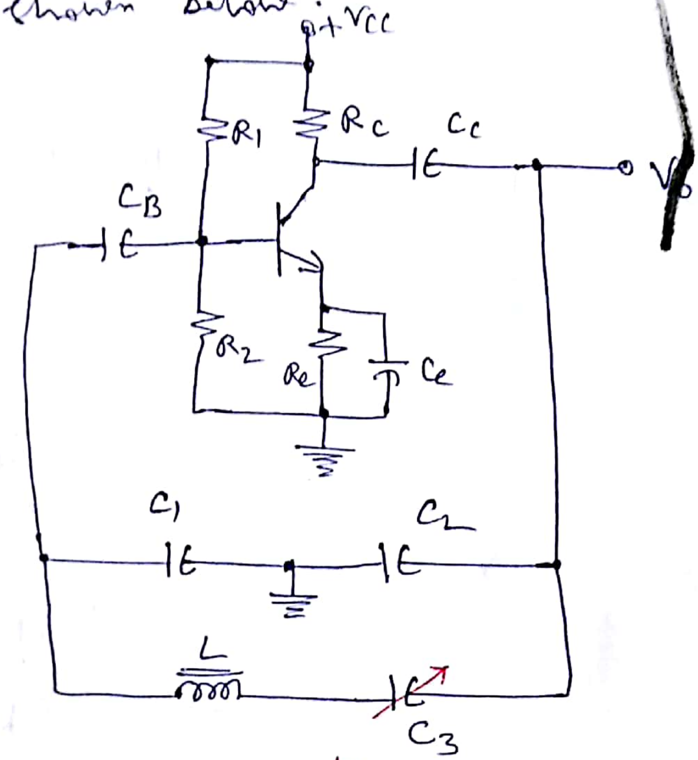
Note: ① In the above circuits C_B & C_C behave as short circuit at the frequency of oscillations.

② The frequency of oscillations is given by

ⓐ For Hartley oscillator → $\boxed{f = \frac{1}{2\pi\sqrt{L_{eq}C}}}$; $L_{eq} = L_1 + L_2 + 2M$

ⓑ For Colpitts oscillator → $\boxed{f = \frac{1}{2\pi\sqrt{LC_{eq}}}}$; $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$

③ To improve the frequency stability a capacitor C_3 is connected in series with inductor in Colpitts oscillator and the circuit is named as CLAPP oscillator as shown below.

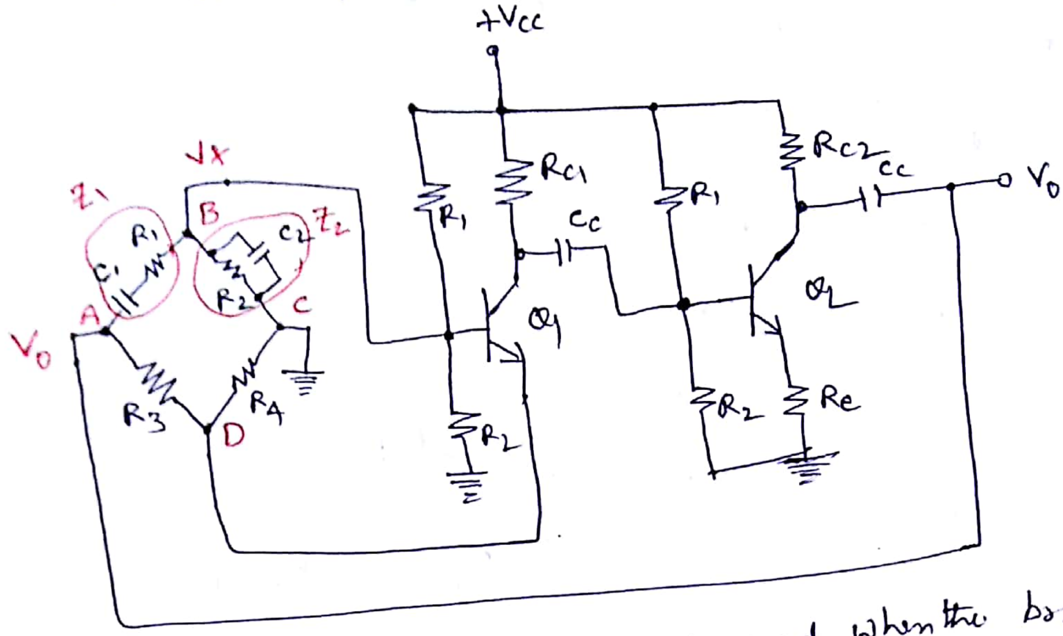


CLAPP oscillator

$\boxed{f = \frac{1}{2\pi\sqrt{L\,C_{eq}}}}$ where $\boxed{\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$

7 Wien-Bridge oscillator:

The circuit of Wien-Bridge



1. Bridge ckt behaves as β-network and when the bridge is balanced it does not provide any phase shift and behave as a perfect resistive circuit.
2. The transistors Q_1 and Q_2 are operated in CE configuration hence the overall voltage gain will be very large and hence the combinedly both stages provide 360°. Hence β-network need not provide any additional phase shift.
3. Here β-network provides +ve feedback when it is balanced and Re provides -ve feedback to reduce the gain.
4. When the bridge is balanced

$$\boxed{\frac{R_3}{R_4} = \frac{Z_1}{Z_2}}$$

where $Z_1 = R_1 - jX_{C1}$

$$Z_2 = \frac{R_2(-jX_{C2})}{R_2 - jX_{C2}}$$

Let $R_1 = R_2 = R$; $C_1 = C_2 = C$

$$\therefore \cancel{Z_2} = \frac{-jRX_C}{R - jX_C} = \cancel{\frac{1}{\frac{1}{R} + \frac{j}{X_C}}}$$

$$Z_1 = R - jX_C$$

$$\therefore \frac{Z_1}{Z_2} = \frac{(R - jX_C)(R - jX_C)}{-jRX_C}$$

$$= \frac{R^2 - X_C^2 - j2X_CR}{-jX_CR}$$

$$\therefore \frac{Z_1}{Z_2} = 2 + j\left(\frac{R^2 - X_C^2}{X_CR}\right)$$

(P.T.O.)

$$\therefore \frac{R_3}{R_4} = 2 + j\left(\frac{R^2 - x_C^2}{x_C R}\right)$$

LHS is real hence RHS should ~~be~~ also be Real

$$\therefore R^2 - x_C^2 = 0$$

$$\therefore R^2 = \frac{1}{w^2 C^2}$$

$$\therefore w^2 = \frac{1}{R^2 C^2}$$

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

Therefore the will be balanced only for this frequency f and at this frequency

$$\frac{R_3}{R_4} = 2 \implies \boxed{R_3 = 2R_4}$$

Analysis of β-network:

$V_f \to$ Voltage across Z_2 and

$V_0 \to$ Voltage across $(Z_1 + Z_2)$ because the current flowing through Base is negligibly small and hence neglected.

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

$$\therefore V_f = Z_2 I$$

$$= Z_2 \times \frac{V_0}{Z_1 + Z_2}$$

$$\therefore \beta = \frac{V_f}{V_0} = \frac{Z_2}{Z_1 + Z_2}$$

$$= \frac{-jx_C R/(R - jx_C)}{R - jx_C - \frac{jx_C R}{R - jx_C}}$$

$$= \frac{-jx_C R}{(R - jx_C)^2 - jx_C R} = \frac{-jx_C R}{R^2 - x_C^2 - j2x_C R - jx_C R}$$

$$= \frac{-jx_C R}{R^2 - x_C^2 - j3x_C R}$$

$$= \frac{1}{3 - \left(\frac{R^2 - x_C^2}{-jx_C R}\right)}$$

$$\beta = \frac{1}{3 - j\left(\frac{R^2 - x_C^2}{x_C R}\right)}$$

But β-network need not provide any phase shift. The imaginary part should be equal to zero

$\therefore$

$$R^2 - X_C^2 = 0 \Rightarrow R = X_C \Rightarrow \omega = \frac{1}{RC} \Rightarrow \boxed{f = \frac{1}{2\pi RC}}$$

at this frequency the magnitude of the β-net is given by

$$\boxed{|\beta| = \frac{1}{3}}$$

Therefore the gain of the basic amplifier (2-stage CE amp.) should be greater than or equal to 3, to obtain sustained oscillations.

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

Design Considerations for variable frequency operation:

① For the given frequency f assume $C_1 = C_2 = C \leq 1\mu F$ and calculate R using

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

any value available.

② select $R_3 = 2R_4$ by assuming R_4 any value available.

③ Design 2-stage CE amplifier with voltage gain $A = A_1 \times A_2 = 3$ and take $R_{e1} = R_4$ (as in step 2).

④ Draw the full ckt with design values.

⑤ For obtaining variable frequency of operation the two capacitors should be ganged together.

Note: Advantages of Wien-Bridge oscillators are on Page 9.a (disadv.)

(P.T.O.)

⑧ Crystal oscillator:

Crystal:

① The crystal is a thin slice of piezo-electric material such as quartz, tourmaline and rochelle salt which exhibit Piezo-Electric Effect.

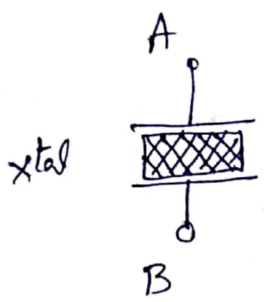
② The Piezo-electric effect means the crystal produces electric charge to any mechanical stress and in reverse effect, it produces mechanical strain to an electric field.

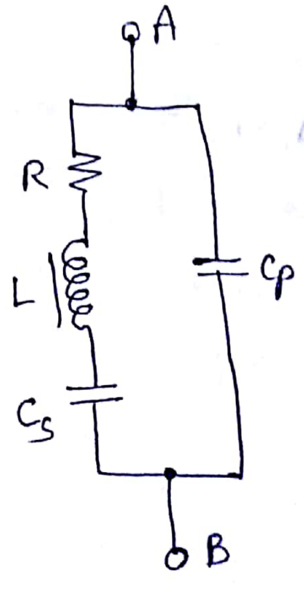
③ The natural frequency of a crystal is inversely proportional to the thickness 't' of the crystal. The frequency is given by

$$\boxed{f = \frac{P}{2t}\sqrt{\frac{Y}{e}}}$$

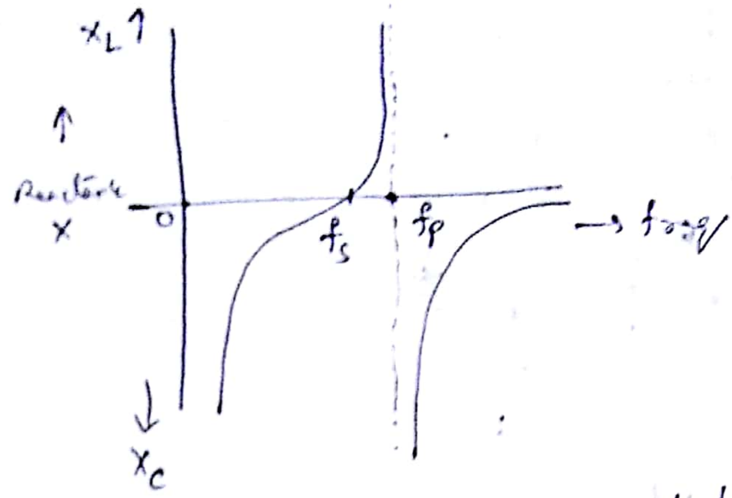
where
$P = 1, 2, 3, \ldots$
t = Thickness of the crystal
Y = Youngs modulus
e = density of the material

④ The crystal symbol, electrical equivalent and reactance graph as given below





R → resistance of the crystal
L → inductance offered by the crystal
Cs → series capacitance
Cp → Parallel capacitance



(5) A crystal exhibits two resonant frequencies, series resonant frequency f_s and parallel resonant frequency f_p, given by

$$\boxed{f_s = \frac{1}{2\pi\sqrt{L C_s}}}$$

$$\boxed{f_p = \frac{1}{2\pi\sqrt{L C_{eq}}}} \quad \text{where} \quad \boxed{\frac{1}{C_{eq}} = \frac{1}{C_s} + \frac{1}{C_p}}$$

(6) For the frequencies between f_s and f_p crystal exhibits inductive reactance, hence crystal can be used in the place of inductor in a Colpitts oscillator.

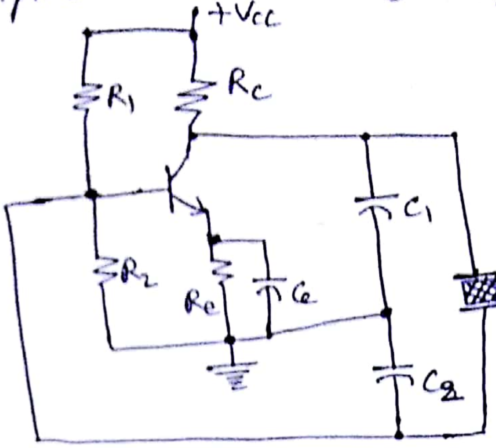
(7) For frequencies less than f_s and more than f_p crystal exhibits capacitive reactance, hence it can be used in the place of capacitor in a Hartley oscillator.

Advantages (8) The Q ~~is~~ for crystal is more than 100. Crystals with Q in the range several thousand to several hundred thousand are available commercially in the frequency range from few Kilo Hz to few MegaHz.

(9) The frequency stability of 1 part in 10^{10} can be obtained in temperature controlled environment.

(P.T.O.)

(10) The Colpitts oscillator using crystal is shown below.



(9) stability of oscillators:

(a) Frequency stability:

The frequency stability of an oscillator is a measure of its ability to maintain as nearly a fixed frequency as possible over as long a time interval as possible.

The allowable variation in frequency may be any where between 10^{-2} to 10^{-10} depending on the area of application.

The deviation (variation) in oscillator frequency occurs due to the following reasons:

① Due to change in temperature, the values of the frequency-determining components, i.e. resistor, inductor capacitor, changes.

② Due to variation in 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 is frequency with temperature is given by

$$S_{W,T} = \frac{\Delta W/W_0}{\Delta T/T_0} \quad ppmC \text{ (Parts per million per } ^\circ C)$$

where W_0 and T_0 are the desired frequency and operating temp. of no temperature Control is available then an inductor with positive temperature coefficient and a capacitor with negative temperature coefficient can reasonably maintain frequency stability.

The frequency stability is ~~is~~ defined as

$$S_W = \frac{d\theta}{dW}$$

where $d\theta$ is the phase shift introduced for a small frequency change in nominal frequency f_0. The ~~test~~ is the circuit giving larger value of $\frac{d\theta}{dW}$ frequency stability. The oscillator with more frequency circuits with larger Q can provide more frequency stability in oscillators. [i.e. $S_W \propto Q$]

(b) Amplitude stability:

The amplitude stability of an oscillator is a measure of its ability to maintain as nearly a fixed amplitude as possible over a long a time interval as possible.

In the case of RC oscillators, the amplitude variations, due to aging of transistors and fluctuations ~~by~~ in circuit components, can be stabilised by replacing the resistors by sensistors which ~~a~~ exhibit positive temperature coefficient of resistance.

(P.T.O.)..

In LC oscillators, the variation in tank circuit resistance can be compensated by connecting negative resistance devices across tank circuit. The devices like dynatron, transitron, thermistor, UJT and Tunnel diode, can be operated in their negative resistance region are placed across a high Q tank circuit for maintaining amplitude stability.

(10) Problems:

(1) A FET phase-shift oscillator has $g_m = 5\,m℧$ and $r_d = 50K\Omega$. The β-network resistance is $100K\Omega$ and capacitance is $64.79pF$. Calculate the frequency of oscillations and value of R_d.
($f_0 = 10KHz$; $R_D = 7.87K\Omega$)

(2) RC phase shift oscillator using BJT has $R_C = 18\Omega$, and $R = 6\Omega$ & $C = 1500pF$ calculate f_0. ($4.168KHz$)

(3) Design an RC phase shift oscillator for $12KHz$. Ignore the effect of R_1, R_2, Re & C_E, C_B, C_C].

(4) In a Hartley oscillator, calculate L_2, if $L_1 = 15mH$ & $C = 50pF$, and $f_0 = 168Hz$ and mutual inductance of $5\mu H$
($L_2 = 2.9394$) H

(5) For a transistorized Hartley oscillator $L_1 = 2mH$ & $L_2 = 20\mu H$ while the frequency is to be changed from $950KHz$ to $2050KHz$. Calculate the range over which the capacitor is to be varied.
(2.98 to $13.89pF$)

(6) A Colpitts oscillator has $C_1 = C_2 = 0.001\mu F$ & $L = 5\mu H$. What is f_0? What is f_0 if L is doubled? What should be inductance to double the frequency?
($f = 3.183MHz$
$L = 1.25\mu H$.)

⑦ A crystal has $L = 0.1\,H$, $C = 0.01\,pF$; $R = 10\,K\Omega$ and $C_p = 1\,pF$. Find series and parallel resonant frequencies and Q factors at both frequencies.

$C_p \rightarrow$ Package or $C_M \rightarrow$ Mounting

⑧ A crystal has $L = 2H$, $C = 0.01\,pF$ and $R = 2K\Omega$, its mounting capacitance is $2\,pF$. Calculate its series and parallel resonant frequencies.

END of UNIT - III

Question Bank for ECA

SSN

UNIT – III FEEDBACK AMPLIFIERS

*① Derive the expression for gain with negative feedback.
*② Prove the gain stabilizes with negative feedback.
③ Explain the general characteristics of negative feedback amplifiers.
*④ Draw the block diagrams of four negative feed back ~~topo~~ topologies and explain.
*⑤ Prove the input impedance decreases for shunt mixing.
⑥ Justify the output impedance increases for current sampling.
*⑦ Derive the expressions for A_{vf}, R_{if} and R_{of} for a voltage series feedback amplifier.
⑧ Draw the circuit of a current shunt feedback amplifier and derive the expression for A_{If}.
*⑨ Draw the circuit of a transresistance amplifier and derive the expression for transresistance gain

$$R_{Mf} = \frac{V_0}{I_s}.$$

*⑩ Compare the four feedback amplifier topologies.

Ans:

Parameter	Voltage-Series	Voltage-Shunt	Current-Series	Current-Shunt
		Topology		
① Gain stabilized	Voltage gain	Transresistance	Trans Conductance	Current gain
② Bandwidth	increases	increases	increases	increases.
③ Input Resistance (R_i)	increases	Decreases	increases	Decreases.
④ Output Resistance (R_o)	Decreases	Decreases	increases	Increases
⑤ Harmonic Distortion	Decreases	Decreases	Decreases	Decreases
⑥ Noise	Decreases	Decreases	Decreases	Decreases.

(PTO)

OSCILLATORS

*① Derive the condition for oscillations and state Barkhausen conditions.

② Prove the minimum h_{fe} required is 44.5, to obtain oscillations using BJT in RC-phase shift oscillator.

*③ Derive the expression for frequency of oscillations and gain required for FET amplifier in RC phase-shift circuit.

④ Draw the circuit of a Hartley oscillator and derive the expression for frequency of oscillations.

*⑤ Design a Colpitts oscillator for 100KHz frequency.

⑥ Write short notes on Wien-Bridge oscillator.

*⑦ Write short notes on crystal.

⑧ Discuss the stability considerations in oscillators.

*⑨ The parameters of a crystal are given as $L = 0.33\,H$, $C = 0.065\,pF$, $C_p = 1.0\,pF$ and $R = 5.5\,K\Omega$. Find the series resonant frequency and Q-factor.

⑩ Compare the advantages and ~~disdan~~ disadvantages of RC, LC and crystal oscillators.

(P.T.O.)

UNIT - III.

A: 05/3/15

Question Bank on Feedback Amplifiers:

Short questions:

1. List the advantages and disadvantages of negative feedback in amplifiers
2. An amplifier has ~~an~~ a open loop gain of 1000, what would be the gain if 10% of the output is feedback in phase opposition.
3. For ~~an~~ a feedback amplifier the gain is 8 ~~10~~ ~~with~~ when ~~for~~ $\beta = 0.1$, Calculate the open loop gain of the amplifier.
4. Proove the gain stabilizates with negative Feedback.
5. Derive the expression for input impedance of a current-shunt feedback amplifier
6. Derive the expression for input impedance of a voltage series feedback amplifier.
7. Derive the expression for o/p impedance of current series [Trans Conductance] FB amplifier.
8. Derive the expression for o/p impedance of Voltage shunt feedback amplifier.
9. For an amplifier the open loop gain is 100 when the source signal of 50 mV is applied. If ~~a~~ 1% of the o/p is ~~fed~~ feedback negatively, what will the output voltage V_o
10. An amplifier has a input resistance of 200kΩ when negative feedback is applied it was found to 20MΩ. Calculate the loop gain and feedback factor if the open loop gain is 1000.

(P.T.O.)

Essay questions:

① Draw the block diagrams of four topologies and define & explain ~~which~~ gain ~~will be~~ that is stabilized and how the input and output impedances are ~~made~~ affected.

② Derive the expressions for input and o/p Impedance for a voltage shunt feedback amplifier.

③ Derive the expressions for both cut off frequencies with feedback ~~and~~ hence prove the Bandwidth increases with negative feedback.

④ Draw the Circuit of CE amplifier without bypass capacitor and check is there any feedback present, if present identify the topology. ~~ignore R_1, R_2 biasing resistances and C_B, C_E are~~ neglect the effect of R_1, R_2 & C_B, C_E.

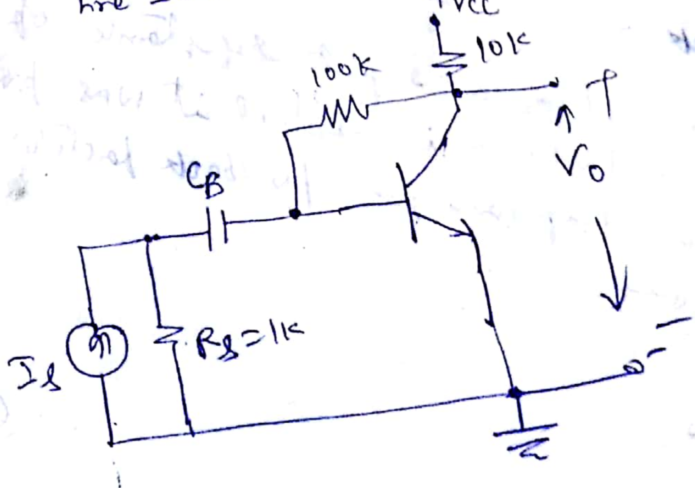
⑤ An amplifier with open-loop voltage gain 1000 ± 100 is available. It is necessary to have an amplifier whose gain varies by no more than ± 0.1 percent.

Find the reverse transmission factor β

ⓐ Find the reverse transmission factor β with Feedback.

ⓑ Find the gain with feedback.

⑥ For the transistor ckt shown below $h_{ie} = 1K$, $h_{fe} = 100$, $h_{re} = h_{oe} = 0$. Determine ① $R_{Mf} = \frac{V_o}{I_s}$, ② R_{if} ③ R_{of} ④ R_{of}'



End.

UNIT-III END of PART-A