Analog Electronics

Part-A

Amplifier: An amplifier is an electronic device that increases the voltage, current and power of a signal.

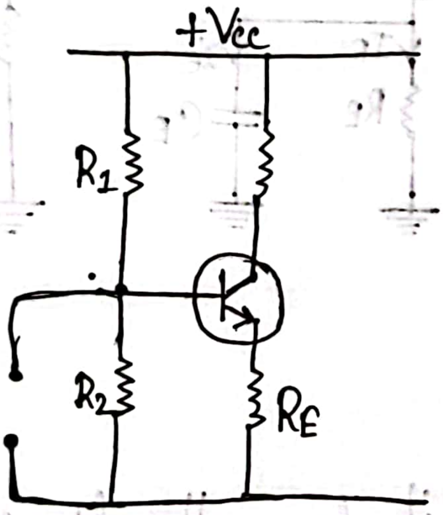
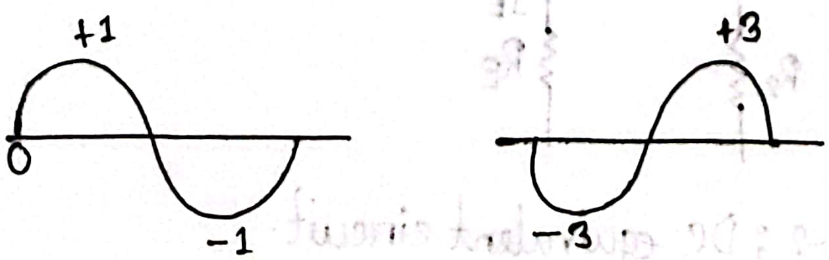


Fig: Single Stage transistor amplifier

Phase Reversal: The phase difference of 180° between the signal voltage and output voltage in a common emmitter amplifier is known as phase reversal.



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⇒ Draw the DC and AC equivalent circuit of an amplifier.

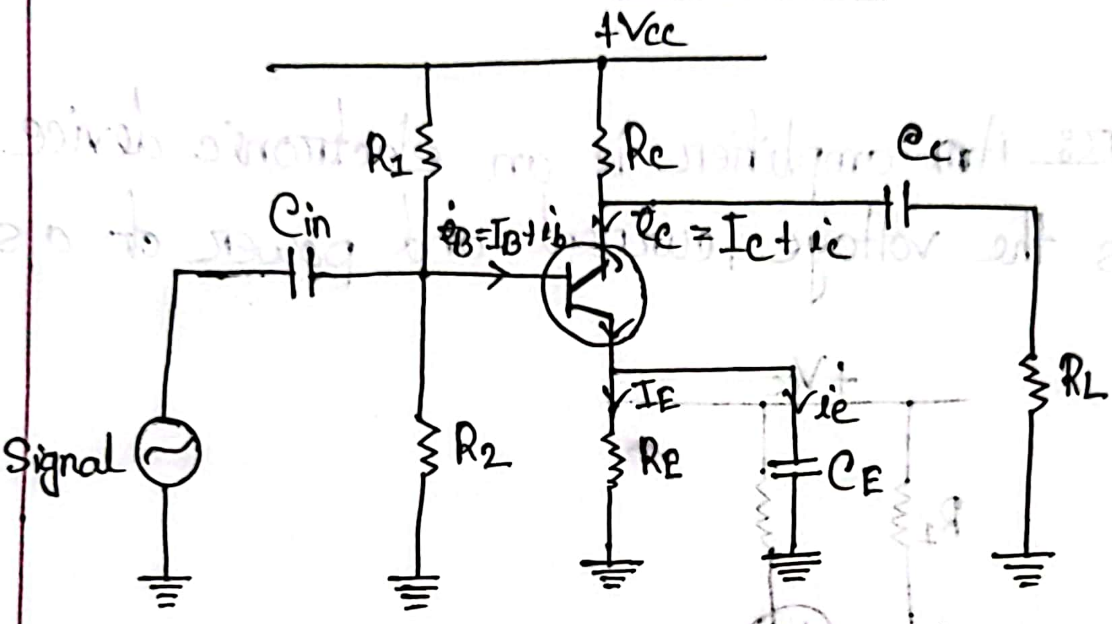


Fig : 1

D.C. equivalent circuit from the fig-1 :

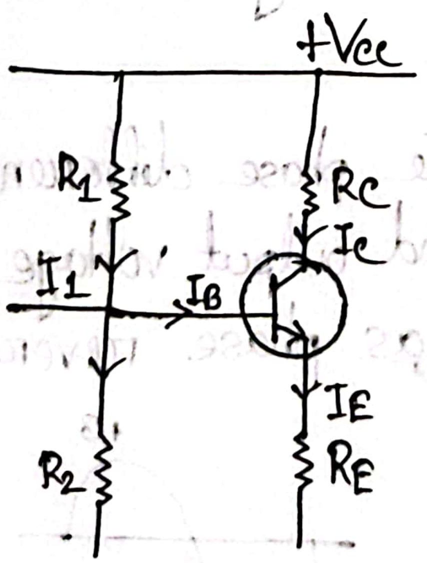


Fig-2 : DC equivalent circuit.

(i) Reduce all ac sources to zero
(ii) Open all the capacitors.

AC equivalent circuit from the circuit:

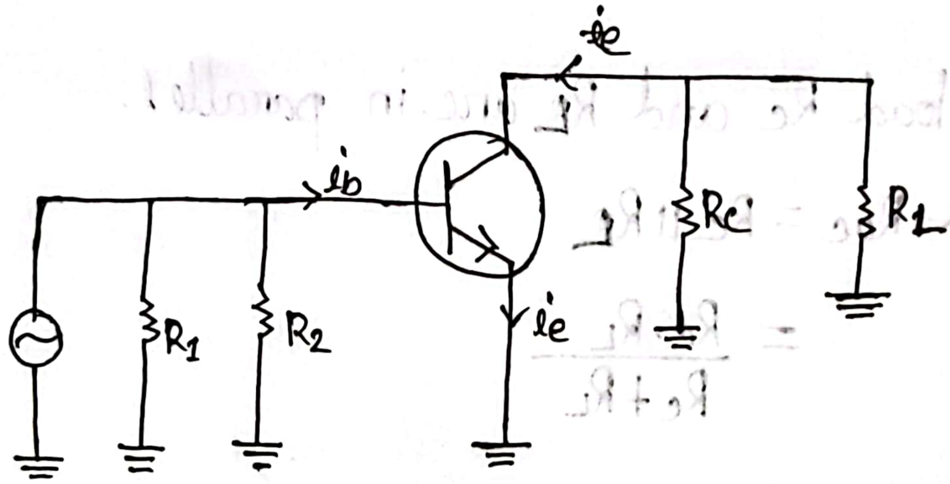


Fig-3: AC equivalent circuit

(i) Reduce al dc sources to zero ($V_{cc}=0$)
(ii) Short all the capacitors.

Example: 10.4

① Dc and AC load:

In dc load R_C and R_E are in series.

$\therefore$ dc load $= R_C + R_E$

In ac load R_C and R_E are in parallel.

AC load: $R_{ac} = R_C \parallel R_L$

$$= \frac{R_C \cdot R_L}{R_C + R_L}$$

⑪ Reffering to d.c. equivalent circuit,

$$V_{CC} = V_{CE} + \frac{I_C}{R_C + R_E}$$

The maximum value will appear when $I_C = 0$

$$\therefore V_{CC} = V_{CE}$$

The maximum collector current will flow when

$V_{CE} = 0$ $\quad \therefore$ Maximum $I_C = \dfrac{V_{CC}}{R_C + R_E}$

(iii) Maximum collector current when ac signal is applied $= I_C$

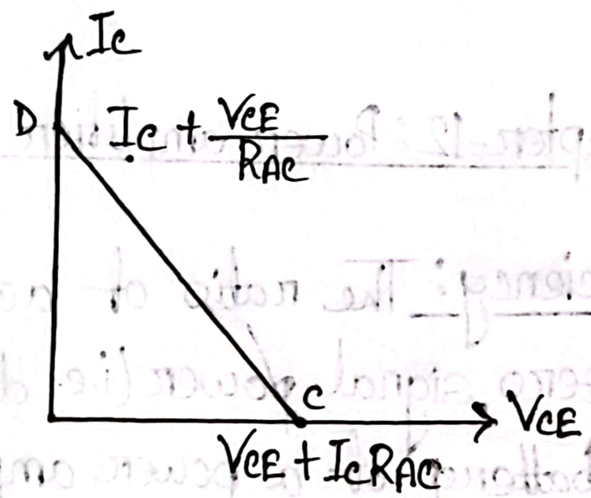
maximum collector-emmiter voltage $= I_C \times R_{AC}$

Total maximum collector-emitter voltage $= V_{CE} + I_C R_{AC}$

Maximum positive swing of ac collector current $= \frac{V_{CE}}{R_{AC}}$

$\therefore$ Total maximum collector current $= I_C + \frac{V_{CE}}{R_{AC}}$.

AC load line:



Voltage Gain:

Output voltage, $V_{out} = i_c \cdot R_{AC}$

Input voltage, $V_{in} = i_b \cdot R_{in}$

Voltage gain, $A_V = \frac{V_{out}}{V_{in}}$

$$= \frac{i_c \cdot R_{AC}}{i_b \cdot R_{in}} = \beta \times \frac{R_{AC}}{R_{in}} \qquad \left[\because \frac{i_c}{i_b} = \beta\right]$$

$\therefore$ Power gain, $A_p = \dfrac{i_c^2 \cdot R_{AC}}{i_b^2 \cdot R_{in}}$

$$= \beta^2 \times \frac{R_{AC}}{R_{in}}$$

⇒ Explain the type of transistor amplifier.(271 page)

⇒ Difference between voltage and power amplifier (page: 309)

Chapter-12: Power amplifier

(i) **Collector efficiency:** The ratio of ac output power to the zero signal power (i.e. dc power) suplied by the battery of a power amplifier is known as collector efficiency.

(ii) **Distortion:** The change of output wave shape from the input wave shape of an amplifier is known as distortion.

(III) Power dissipation capability: The ability of a power transistor to dissipate heat is known as power dissipation capability.

(IV) Class A power amplifier: If the collector current flows at all times during the full cycle of the signal, the power amplifier is known as class A power amplifier.

(V) Class B power amplifier: If the collector current flows only during the positive half-cycle of the input signal, it is called a class B power amplifier.

(VI) Class C power amplifier: If the collector current flows for less than half-cycle of the input signal, it is called class C power amplifier.

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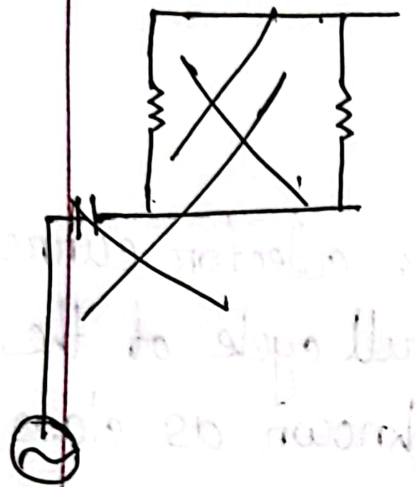
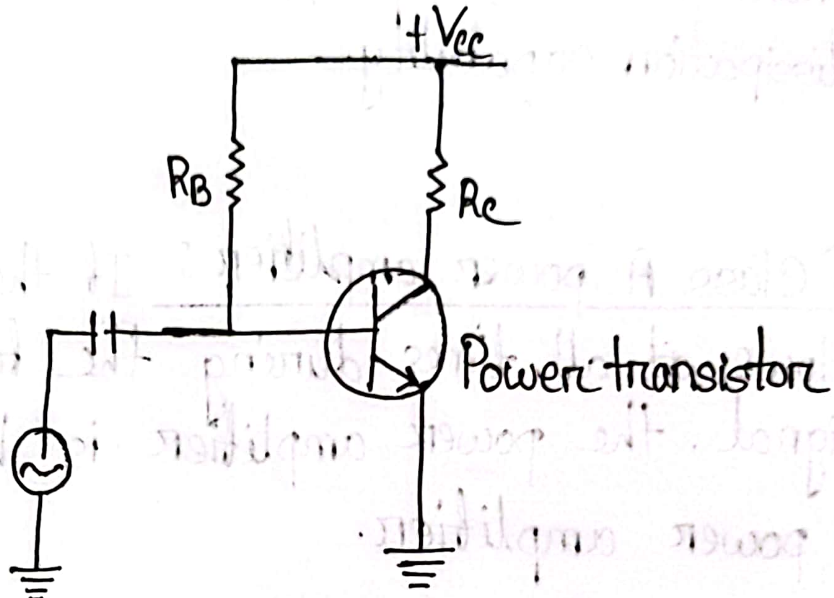
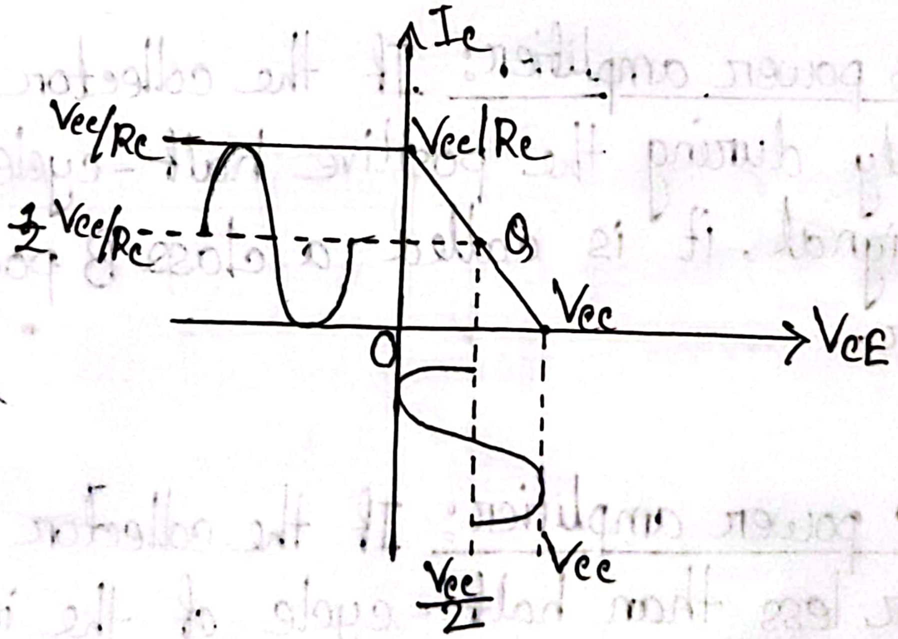
Maximum collector efficiency for series fed class A amplifier:







$$I_C = \frac{V_{CC}}{2R_C}$$

$$V_{CE} = \frac{V_{CC}}{2}$$

maximum output, $P_{o(max)} = \frac{V_{ce(p-p)} \times I_{c(p-p)}}{8}$

$$= \frac{V_{cc} \times V_{cc}/R_c}{8}$$

$$= \frac{V_{cc}^2}{8R_c}$$

Dc power input, $P_{in(dc)} = V_{cc} \times I_c$

$$= V_{cc} \times \frac{V_{cc}}{2R_c}$$

$$= \cancel{V_{cc}}\ \frac{V_{cc}^2}{2R_c}$$

$\therefore$ Maximum collector efficiency, $n = \frac{P_{o(max)}}{P_{dc}} \times 100\%$

$$= \cancel{V_{cc}^2 \times 8}$$

$$= \frac{V_{cc}^2/8R_c}{V_{cc}^2/2R_c} \times 100\%$$

$$= 25\%$$

$$\boxed{\therefore \text{rms value} = \frac{1}{2}\left(\frac{\text{peak to peak value}}{\sqrt{2}}\right) = \frac{1}{2} \times 0.707 \times (p-p) \text{ value}}$$

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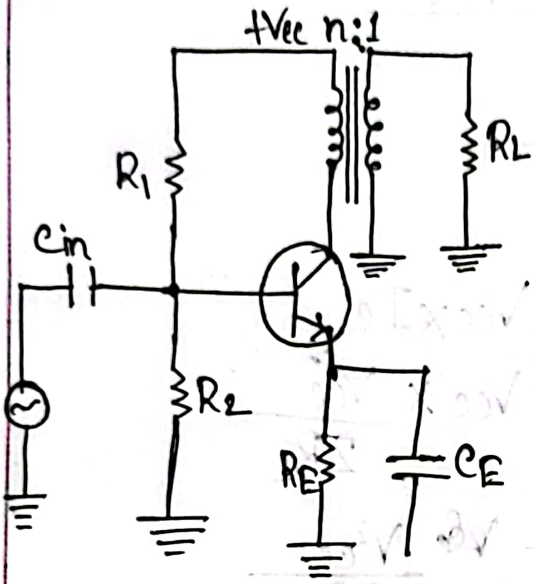
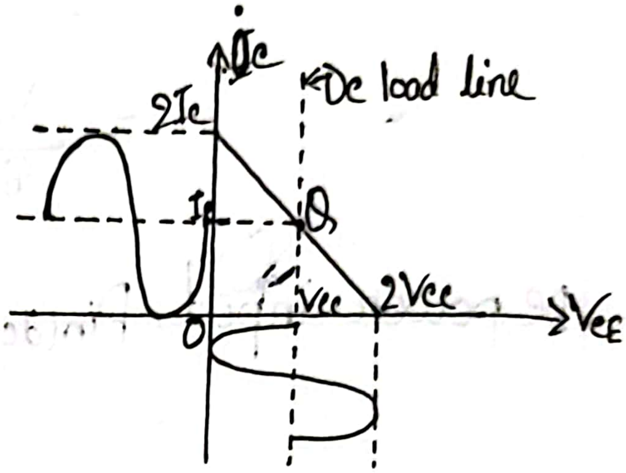
Maximum collector efficiency of transformer coupled class A power amplifier:





$V_{ce(p-p)} = 2V_{cc}$

peak to peak collector current, $i_{c(p-p)} = 2I_c$

$$= \frac{V_{ce(p-p)}}{R_L'}$$

$$= \frac{2V_{cc}}{R_L'}$$

$V_{CE} = V_{cc} - V_T$

$0 = V_{cc} - V_T$

$= V_{cc} - I_c R_L'$

$V_{cc} = I_c R_L'$

maximum output power, $P_{o(max)} = \frac{V_{ce(p-p)} \times 2I_c}{8}$

$$= \frac{2V_{cc} \times 2I_c}{8}$$

$$= \frac{1}{2} V_{cc} I_c$$

$$= \frac{1}{2} I_c^2 R_L'$$

dc power input, $P_{dc} = V_{cc} \times I_c$

$$= I_c \cdot R'_L \times I_c$$

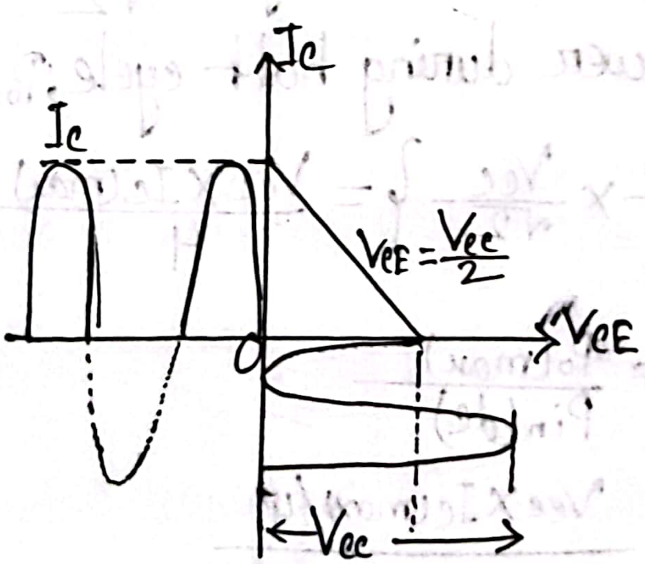
$$= I_c^2 \cdot R'_L$$

$\therefore$ maximu collector $\eta = \frac{P_{o(max)}}{P_{dc}} \times 100\%$

$$= \frac{1/2\, I_c^2 \cdot R'_L}{I_c^2 \cdot R'_L} \times 100\%$$

$$= 50\%$$

Maximum efficiency for class B power amplifier:



$$I_{dc} = \int_0^{\pi} I_{c(max)} \sin\theta \, d\theta$$

$$= \frac{I_{c(max)}}{2\pi} \left[-\cos\theta\right]_0^{\pi}$$

$$= \frac{I_{c(max)}}{2\pi}\left\{-(\cos\pi - \cos 0)\right\}$$

$$= \frac{I_{c(max)}}{2\pi} \times 2$$

$$= \frac{I_{c(max)}}{\pi}$$

$$P_{dc} = \frac{V_{cc} \times I_c}{\pi}$$

$\therefore$ maximum collector efficiency, $\eta = \frac{P_{o(max)}}{P_{in(dc)}}$

rms value of collector current $= \frac{I_{c(max)}}{\sqrt{2}}$

rms value of output voltage $= \frac{V_{cc}}{\sqrt{2}}$

ac output power during half cycle; $P_{o(max)} =$

$$= \frac{1}{2}\left\{\frac{I_{c(max)}}{\sqrt{2}} \times \frac{V_{cc}}{\sqrt{2}}\right\} = \frac{V_{cc} \times I_{c(max)}}{4}$$

$\therefore$ efficiency, $\eta = \frac{P_{o(max)}}{P_{in(dc)}}$

$$= \frac{V_{cc} \times I_{c(max)}/4}{V_{cc} \cdot I_{c(max)}/\pi}$$

$$= \frac{\pi}{4} \times 100\% = 78.4\%$$

⇒ Difference between voltage and power amplifier.

Voltage amplifier	Power amplifier
(I) A voltage amplifier is designed to achieve maximum voltage amplification.	(I) Power amplifier is designed to obtained maximum output power.
(II) The transistor with high β is used in the circuit. In the other word those ~~transmitors~~ transistors are employed whole have thin base.	(II) The base is made thicker to handle larger currents. In the other words, transistor with comparatively smaller β are used.
(III) β range is high (>100)	(III) β range is low (5 to 20).
(IV) RC range is high (4-10kΩ)	(IV) Rc range is low (5-20Ω)
(V) Usually R-C coupling.	(V) Invariably transformer coupling.

Power amplifier: An electronic amplifier which is designed to produce a higher magnitude signal from a given input signal is known as a power amplifier.

03.12.22

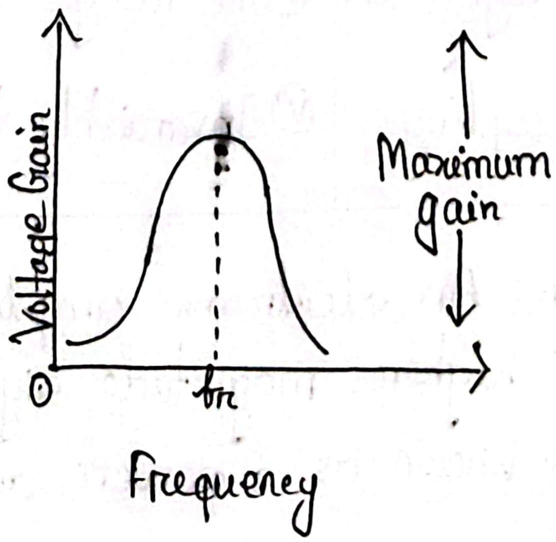
Chapter-11: Multistage transistor amplifier

Definitions: A transistor circuit containing more than one stage of amplification is known as multistage transistor amplifier.

Gain: The ratio of the output electrical quantity to the input one of the amplifier is called its gain.

$$\therefore \text{Total gain, } G = G_1 \times G_2 \times G_3$$

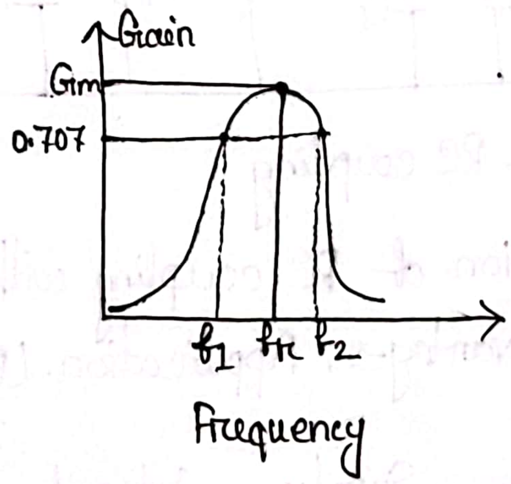
Frequency response: The voltage gain of an amplifier varies with signal frequency.



Decibel gain: Power gain $= \log_{10} \frac{P_{out}}{P_{in}}$ bel

$1\,bel = 10\,db$

Bandwidth: The range of frequency over which the voltage gain is equal to or greater than 70.7% of the maximum gain is known as bandwidth.



Bandwidth $= f_2 - f_1$ [f_2-f_1 inter frequency gap]

There are three types of transistor amplifier:

(i) RC coupling: A capacitor is used as the coupling device.

(ii) Transformer coupling: transformer is used as coupling device

(iii) DC coupling: two stages maybe directly connected

RC coupling:

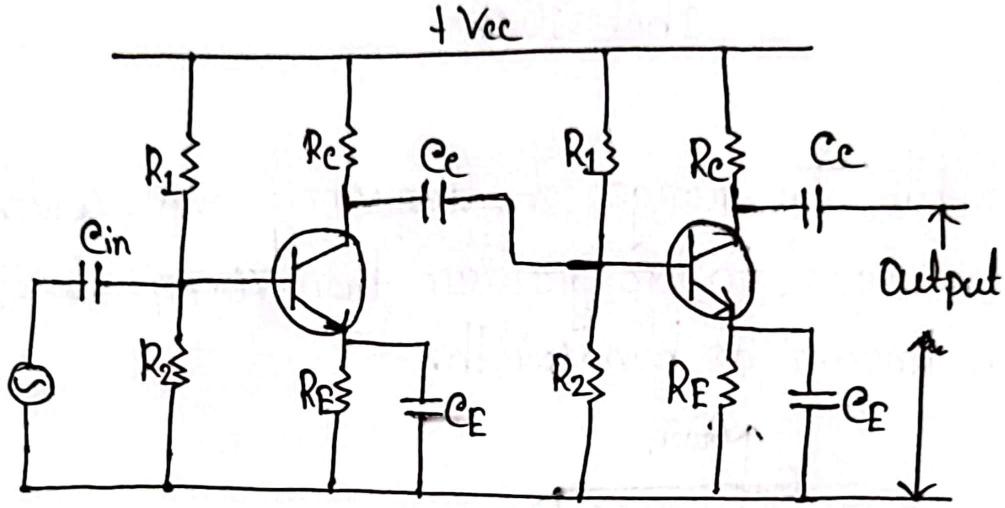


Fig- RC coupling

⇒ Describe operation of RC coupling with diagram.

⇒ Advantages, disadvantages, Application. (Pag-290)

Collector — Supply — 1st coil

Base — resistor — 2nd coupling

Transformer coupling:

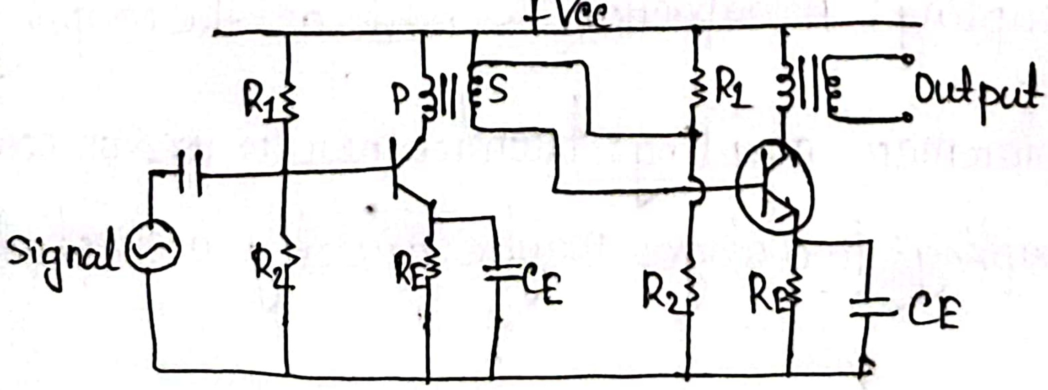


Fig- Transformer coupling

The load R_L' appearing on the primary side will be:

$$R_L' = \left(\frac{N_P}{N_S}\right)^2 \times R_L$$

⇒ Math : 11.16, 11.17 (page - 297)

⇒ Comparison of different types of coupling (301 page)

⇒ 1set question থাকবে math must.

Feedback Amplifier:

Feedback amplifier: The process of sending part of the output signal of an amplifier back to the input of the amplifier is called feedback.

There are four types of feedback amplifier.

1. Voltage series feedback:

Gain, $A_{vsf} = \frac{A_{vs}}{1 + \beta A_{vs}}$

2. Current series feedback:

Voltage gain, $A_{vsf} = \frac{-R_L}{R_e}$

3. Voltage shunt feedback:

Voltage gain, $A_{vsf} = A_v \frac{R_{if}}{R_s + R_{if}}$

4. Current shunt feedback:

Voltage gain, $A_{vsf} = A_v \left[\frac{R_{if}}{(R_{if} + R_s)} \right]$

Positive feedback: When the feedback voltage is so applied that it increases the input voltage (or current) i.e. it is in phase with the input, it is called as positive feedback or regenerative or direct feed back

Amplifier gain $A_f = \frac{A}{1-BA}$

Negative feedback: When the feedback voltage (or current) is so applied that it decreases the input voltage (or current) it is out of phase with the input it is called as negative or degenerative or ~~direct~~ feedback.

Amplifier gain, $A_f = \frac{A}{1+BA}$

⇒ What are the effect on negative feedback:

(1) **Increasing stability:** The gain of the amplifier with negative feedback is given by $A' = \frac{A}{1+BA}$.

In negative feedback amplifiers, the designer deliberately makes the product BA much greater than unity so that 1 may be neglected in comparison to it. Hence,

$$A' \cong \frac{A}{BA} \cong \frac{1}{B}$$

Thus A' depends only on B (feed back ratio) i.e. characteristics of feedback circuit. As feed back circuit is usally a voltage divider (resistive network) and resistors can be selected very precisely with almost zero temperature coefficient of resistance, therefore the gain is uneffected by changes in temperature, variations transistor parameters and frequency. Hence the gain of the amplifier is extremely stable.

(II) <u>Reduction in non-linear distortion:</u> A large signal stage has non-linear distortion because its voltage gain changes at various points in the cycle. The use of negative feedback in large signal amplifiers reduces the non-linear distortion.

Let, D = Distortion voltage generated in amplifiers without feed back.

D' = Distortion voltage generated in amplifier with feedback.

Suppose, $D' = Dx$

Fraction of output distorted voltage feedback to input $= BD' = BDx$

Amplified distorted voltage $= B x D A$

$$D' = D - BxDA$$

$$Dx = D - BxDA$$

$$Dx = D(1 - BxA)$$

$$x = 1 - BxA$$

$$x + BxA = 1$$

$$x(1 + BA) = 1$$

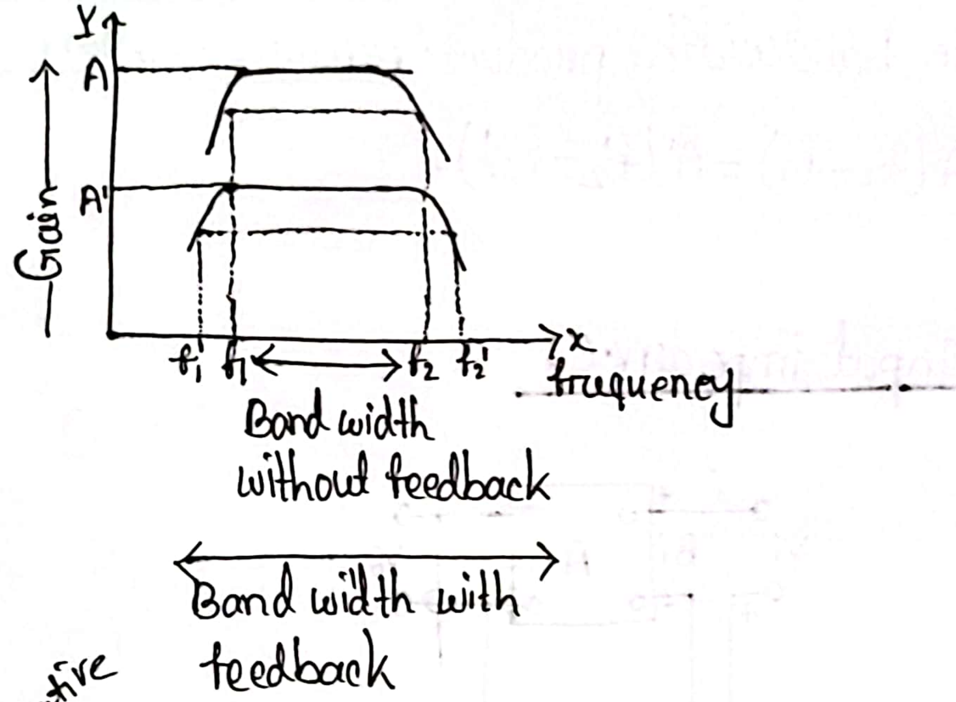
$$x = \frac{1}{1+Bx}$$

$$Dx = \frac{D}{1+Bx}$$

$$D' = \frac{D}{1+Bx}$$

So the negative feedback reduces the amplifier distortion by a factor $(1+BA)$.

(III) Increased bandwidth:



When negative feedback is applied, the gain of the amplifier is decreased but gain bandwidth remains the same. This indicates that the bandwidth must increase to compensate the decrease in gain. It can be shown that with negative feedback, the lower and upper 3dB frequencies are expressed as,

$$f_1' = \frac{f_1}{(1+BA)} \quad \text{--- (1)}$$

$$f_2' = f_2(1+BA) \quad \text{--- (2)}$$

These frequencies are shown in figure (2). It is clear from expression (1) and (2) that f_1' decreases while

f_2' increases. Thus the bandwidth increases, of course gain bandwidth product remain the same i.e.

$$A(f_2 - f_1) = A'(f_2' - f_1').$$

(IV) Input impedence:

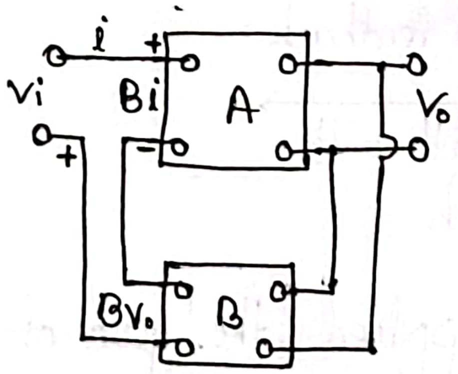


fig: Input impedence increases due to negative feedback

In order to condiser the effect of feedback on input impedence of a transistor amplifier, we assume that A is the normal gain of the amplifier without feedback. BV_o is the fraction of the output voltage which is feed back to the input terminals as shown in fig. Without feedback the input impedence is

$$z_i = \frac{e_1}{i_1} = \frac{V_1}{i_1} \quad (V_1 = e_1)$$

With feedback the input impedence ~~is~~ Z_{if} is given by,

$$Z_{if} = \frac{e_1 - BV_o}{i_1}$$

$$= \frac{V_1 - BV_o}{I_1}$$

$$= \frac{V_1 - BAV_1}{I_1}$$

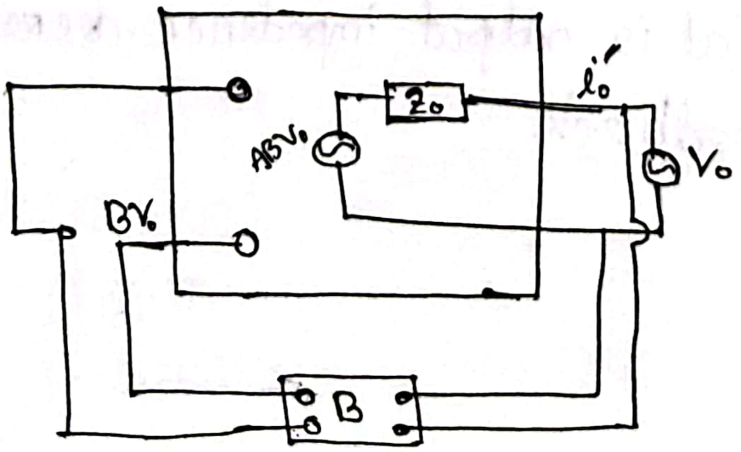
$$= \frac{e_1 - B \times Ae_1}{I_1} \quad [\because V_o = Ae_1]$$

$$= \frac{e_1}{I_1}(1 - BA)$$

$$= Z_i(1 - AB)$$

In negative feedback ~~(β-A~~ $(1-AB)$ is greater than unity and consequently, Z_{if} is greater than Z_i. That is, due to negative feedback, input impedence of a transistor amplifier increases.

(v) Output impedence:



The output impedence without feedback,

$$Z_o = \frac{V_o}{i_o}$$

In order to find ~~the~~ out the output impedence of the amplifier with feedback, we short circuit the source and connect a voltage source V_o at the output terminals as show in fig. The output has been replaced by an equivalent voltage source $A B V_o$. Let i_o' be the current with feedback.

From figure,

$$Z_o i_o' = V_o - ABV_o$$

$$\Rightarrow i_o' = \frac{V_o - ABV_o}{Z_o}$$

$$= \frac{V_o}{Z_o}(1 - AB)$$

So the output impedence is,

$$Z_{of} = \frac{V_o}{i_o'} = \frac{Z_o}{1 - AB}$$

Since the negative feedback $(1-AB) > 1$. Z_{of} is less than Z_o. That is output impedence decreases due to negative feedback.

Example-1:

When the negative feedback is applied to an amplifier of gain 100, the overall gain falls to 50. calculate.

(i) the fraction of output voltage feedback.

(ii) if this fraction is maintained, the value of the amplifier gain required if the overall ~~state~~ stage gain is to be 75.

(i) Sollution: Give that,

$$A' = 50$$
$$A = 100$$

$$A' = \frac{A}{1+BA}$$

$$50 = \frac{100}{1+100B}$$

$$\Rightarrow 50 + 5000B = 100$$

$$\Rightarrow 5000B = 100 - 50$$

$$\Rightarrow B = \frac{100-50}{5000} = 0.01$$

(ii) Solution: $A' = 75$

$$B = 0.01$$

$$A' = \frac{A}{1+BA}$$

$$\Rightarrow 75 = \frac{A}{1+0.01A}$$

$$\Rightarrow 75 = A - 0.75A$$

$$\Rightarrow A(1-0.75) = 75$$

$$\Rightarrow A = \frac{75}{0.25}$$

$$\therefore A = 300$$

Example-2: The gain of the amplifier without feedback is 50 whereas with negative feedback it falls to 25. If due to ageing, the amplifier gain falls to 40, find the percentage reduction in stage gain (i) without feedback and (ii) with negative feedback.

(i) Solution: % reduction in stage gain $= \frac{50-40}{50} \times 100\%$

$= 20\%$

(ii) Solution:

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

$$\Rightarrow 25 = \frac{50}{1+50\beta}$$

$$\Rightarrow \beta = \frac{50-25}{1250} = \frac{1}{50} = 0.02$$

with negative feedback $= \frac{A}{1+\beta A} = \frac{40}{1+40 \times 0.02}$

$= 22.2$

$\therefore$ % reduction in stage gain $= \frac{25-22.2}{25} \times 100\%$

$= 11.2\%$

Example-3: A transistor amplifier has a voltage gain of 50. The input resistance of the amplifier is 1kΩ and the output resistance is 40kΩ. The amplifier is now provided with 10% negative voltage feedback in series with the input. Calculate the voltage gain, input, output resistance with the feedback.

(i) Solution: 10% negative feedback has been provided

$$B = \frac{-10}{100} = -0.1$$

$$A' = \frac{A}{1-(-BA)} = \frac{50}{1+0.1\times 50}$$

$$= \frac{50}{6} = 8.33$$

(ii) Solution:

Input resistance, $Z_{if} = Z_i(1-BA)$

$$= 1\times(1+0.1\times 50)$$

$$= 1\times 6$$

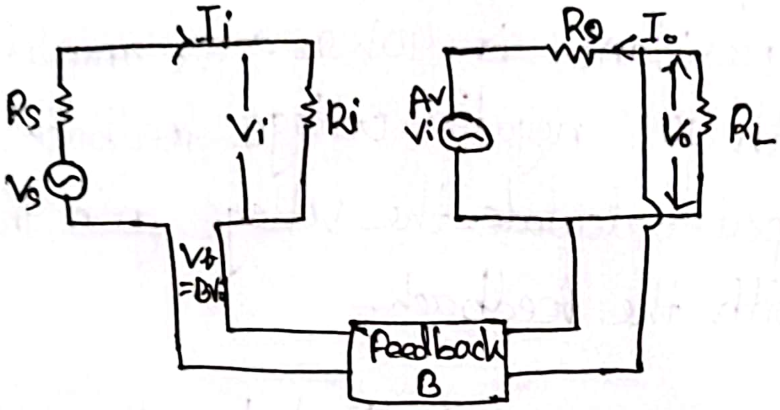
$$= 6K\Omega$$

(iii) Solution:

Output resistance, $Z_{of} = \frac{Z_o}{1-AB} = \frac{40}{1+5}$

$$= \frac{40}{6} = 6.66K\Omega$$

Voltage Series feedback:



From the input circuit,

$V_s - V_i - V_f = 0$

$V_s = V_i + V_f$

$= V_i + BV_o \quad [V_f = BV_o]$

Voltage gain, $A_{vf} = \dfrac{V_o}{V_s}$

$= \dfrac{V_o}{V_i + BV_o}$

$= \dfrac{A_v.V_i}{V_i + B.A_vV_i} \quad [V_o = A_vV_i]$

$= \dfrac{A_v.V_i}{V_i(1+BA_v)}$

$\therefore \quad A_{vf} = \dfrac{A_v}{1+BA_v}$

Input resistance:

$$R_{if} = \frac{V_s}{I_i} \checkmark$$

From input circuit,

$$V_s - V_i - V_f = 0$$

$$V_s = V_i + V_f$$

$$= V_i + BV_o$$

$$\therefore R_{if} = \frac{V_i + BV_o}{I_i}$$

$$= \frac{V_i + B.A_v.V_i}{I_i} \qquad [V_o = A_v.V_i]$$

$$= \frac{V_i}{I_i}(1 + BA_v)$$

$$= R_i(1 + BA_v)$$

Output resistance:

$$R_{of} = \frac{V_o}{I_o} \checkmark$$

From output circuit, $V_o - I_o R_o - A_v V_i = 0$ —— (1)

$$V_s - V_i - BV_o = 0$$

Considering $V_s = 0$

$$-V_i = BV_o$$

$$\therefore V_i = -BV_o$$

putting the value of vi in eqn(i),

$$V_o - I_o R_o - A_v(-BV_o) = 0$$

$$\Rightarrow V_o - I_o R_o + A_v B V_o = 0$$

$$\Rightarrow V_o(1 + A_v B) = I_o R_o$$

$$\Rightarrow \frac{V_o}{I_o} = \frac{R_o}{(1 + A_v B)}$$

$$\Rightarrow R_{of} = \frac{R_o}{1 + A_v B}$$

Part : B

Operational amplifier :

Question-1: What is operational amplifier?

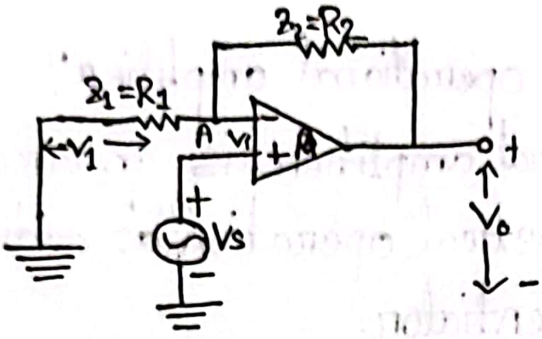
Answer: An operational amplifier is an circuit that can perform ~~such~~ mathmetical operation such as addition, substraction integrator and differentiator.

Question-2: Write down the application of ~~an~~ op-amp.

Answer: Operational amplifier has many different applicatio. They are:

(i) As inverting amplifier
(ii) As non-inverting amplifier
(iii) As differentiator
(iv) As integrator
(v) As phase shifter
(vi) As scale changer
(vii) As adder or summing amplifier
(viii) As voltage or current converter.

⇒ Voltage gain of non-inverting amplifier:



If we assume that we are not at saturation, the potential at point A is the same as V_{in}. Since the input impedance of op-amp is high. All of the current that flows through R_2 also flows through R_1. We have

Voltage across $R_1 = V_{in} - 0$

" " $R_2 = V_{out} - V_{in}$

Now,

$$A = \frac{V_o}{V_1 - V_s}$$

$$\Rightarrow V_1 - V_s = \frac{V_o}{A}$$

$$\Rightarrow V_1 - V_s = 0$$

$$\Rightarrow V_1 = V_s$$

$$V_1 = \frac{V_o}{R_1 + R_2} \cdot R_1$$

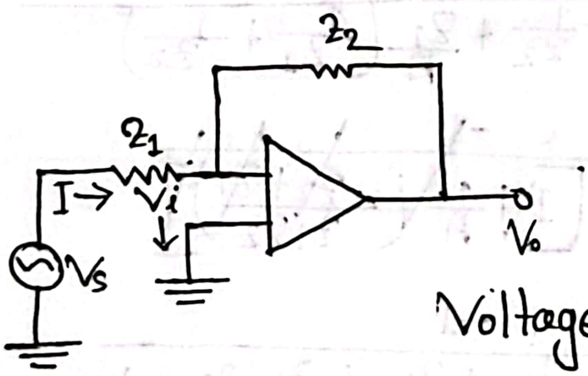
$$V_1 = V_S = \frac{V_o}{R_1 + R_2} \times R_1$$

$$\therefore V_S = \frac{V_o . R_1}{R_1 + R_2}$$

$$\Rightarrow \frac{V_S}{V_o} = \frac{R_1}{R_1 + R_2} \Rightarrow \frac{V_o}{V_S} = \frac{R_1 + R_2}{R_1}$$

$\therefore A = 1 + \frac{R_2}{R_1}$ which is the gain of a non-inverting operational amplifier.

⇒ Voltage gain of an inverting op-amp:



Voltage gain $|A| = \frac{V_o}{V_i}$

Current I flowing through Z_1 will also flow through Z_2.

Thus current through Z_1 is $I = \frac{V_S - V_i}{Z_1}$

Current through Z_2 is $I = \frac{V_i - V_o}{Z_2}$

$$\therefore \frac{V_S - V_i}{Z_1} = \frac{V_i - V_o}{Z_2}$$

$$\Rightarrow \frac{V_S}{Z_1} - \frac{V_i}{Z_1} = \frac{V_i}{Z_2} - \frac{V_o}{Z_2}$$

$$\Rightarrow \frac{V_o}{Z_2} = \frac{V_i}{Z_2} + \frac{V_i}{Z_1} - \frac{V_s}{Z_1}$$

$$\Rightarrow \frac{V_o}{Z_2} = V_i\left(\frac{1}{Z_2} + \frac{1}{Z_1}\right) - \frac{V_s}{Z_1}$$

$$\Rightarrow \frac{V_o}{Z_2} = \frac{-V_o}{A}\left(\frac{1}{Z_1} + \frac{1}{Z_2}\right) - \frac{V_s}{Z_1}$$

[since $A = \frac{-V_o}{V_i}$ so $V_i = -\frac{V_o}{A}$]

$$\Rightarrow \frac{V_o}{Z_2} + \frac{V_o}{A}\left(\frac{1}{Z_1} + \frac{1}{Z_2}\right) = \frac{-V_s}{Z_1}$$

$$\Rightarrow V_o\left\{\frac{1}{Z_2} + \frac{1}{A}\left(\frac{1}{Z_1} + \frac{1}{Z_2}\right)\right\} = \frac{-V_s}{Z_1}$$

$$\Rightarrow \frac{V_o}{V_s} = \frac{-1}{Z_1\left[\frac{1}{Z_2} + \frac{1}{A}\left(\frac{1}{Z_1} + \frac{1}{Z_2}\right)\right]}$$

$$= \frac{-1}{Z_1 \cdot \frac{1}{Z_2} + \frac{Z_1}{A}\left(\frac{1}{Z_1} + \frac{1}{Z_2}\right)}$$

$$= \cancel{\frac{-1}{\frac{Z_1}{Z_2}\left[1 + \frac{1}{A}\left(\frac{Z_2 + Z_1}{Z_1 Z_2}\right)\right]}}$$

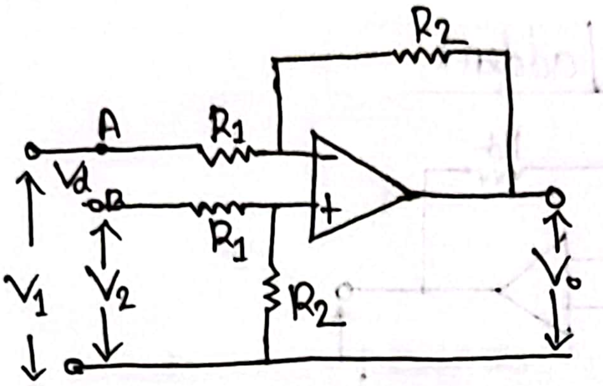
$$= \frac{-1}{Z_1 \cdot \frac{1}{Z_2} + \frac{Z_1}{A}\left(\frac{Z_1 + Z_2}{Z_1 Z_2}\right)}$$

$$= \frac{-1}{\frac{Z_1}{Z_2}\left[1 + \frac{1}{A}\left(1 + \frac{Z_2}{Z_1}\right)\right]}$$

$$\therefore \frac{V_o}{V_s} = -\frac{Z_2}{Z_1}$$

which is the gain of inverting op-amp.

⇒ Differential amplifier:



The voltage $e_2 = \left(\frac{R_2}{R_1+R_2}\right)V_2$. Here $\frac{R_2}{R_1+R_2}$ is termed as the transfer function T(s) of the network involving R_1 and R_2 at the terminal 2. Similarly by the principle of superposition, the voltage at the inverting input terminal 1, is

$$e_1 = \left(\frac{R_2}{R_1+R_2}\right)\cdot V_1 + \frac{R_1}{(R_1+R_2)}\cdot V_0$$

$$e_1 = e_2$$

$$\left(\frac{R_2}{R_1+R_2}\right)\cdot V_1 + \left(\frac{R_1}{R_1+R_2}\right)\cdot V_0 = \left(\frac{R_2}{R_1+R_2}\right)V_2$$

$$\Rightarrow \frac{1}{R_1+R_2}(R_2V_1 + R_1V_0) = \frac{1}{R_1+R_2}(R_2\cdot V_2)$$

$$\Rightarrow R_2V_1 + R_1V_0 = R_2V_2$$

$$\Rightarrow R_1\cdot V_0 = R_2V_2 - R_2V_1$$

$$\Rightarrow R_1V_0 = R_2(V_2 - V_1)$$

$$\therefore V_0 = \frac{R_2}{R_1}(V_2 - V_1) = \frac{R_2}{R_1}\cdot V_d \qquad [\text{Here, } V_2 - V_1 = V_d]$$

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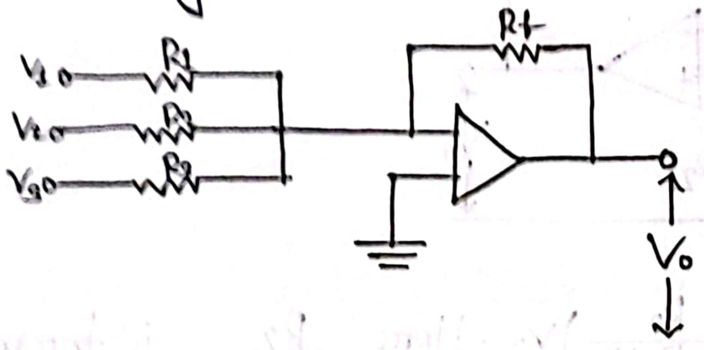
⇒ Application of operational amplifier:

① Summing amplifier/adder:



It is the same as the inverting amplifier except that it has several input terminals. Virtual ground exists at the inverting terminal due to feedback and the input current to the ideal amplifier is zero. Thus the current equation for the node at the inverting terminal is,

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = \frac{-V_o}{R_f}$$

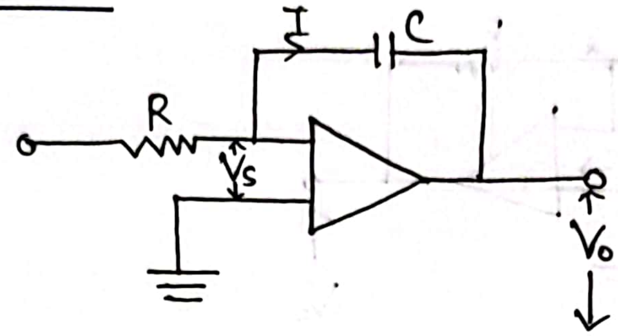
$$\Rightarrow \left\{ \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} \right\} R_f = -V_o$$

$$\Rightarrow \left\{ \frac{V_1}{R} + \frac{V_2}{R} + \frac{V_3}{R} \right\} R_f = -V_o \qquad [\text{If } R_1 = R_2 = R_3 = R]$$

$$\Rightarrow \frac{R_f}{R}(V_1 + V_2 + V_3) = -V_o$$

$$\therefore V_o = \frac{-R_f}{R}(V_1 + V_2 + V_3)$$

(11) Integrator:



In this inverting amplifier feedback resistor R_2 is replaced by a capacitor C. Feedback through the capacitor forces a virtual ground to exist at the inverting input terminal. It means voltage across C is simply the output voltage V_o.
We can write,

$$V_o(t) = -\frac{q}{C}$$
$$= -\frac{1}{C}\int I\,dt$$

$$I = \frac{dq}{dt}$$
$$dq = I\,dt$$
$$q = \int I\,dt$$

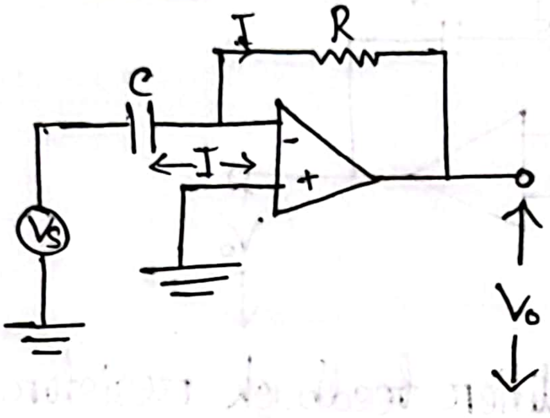
Input current to the ideal amplifier is zero

$$\therefore I = \frac{V_s(t)}{R}$$

$$\therefore V_o(t) = -\frac{1}{C}\int \frac{V_s(t)}{R}\,dt \quad \text{[Keeping the value of I]}$$

$$\therefore V_o(t) = \frac{-1}{CR}\int V_s(t)\,dt$$

(iii) Differentiator:



In inverting operation amplifier, we replace the input resistance by a capacitor to design a differentiator. Because of virtual ground at the inverting terminal, we have,

$$I = \frac{dq}{dt}$$

$$= \frac{d}{dt}(CV_s)$$

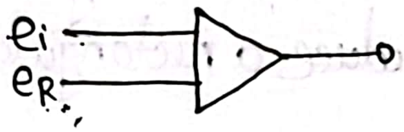
$$= C\frac{dV_s}{dt}$$

~~Vo~~ The output voltage,

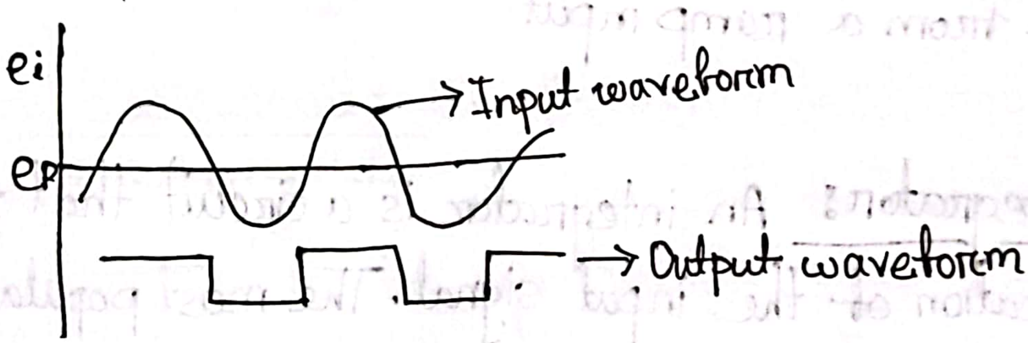
$$V_o = -IR$$

$$= -RC\frac{dV_s}{dt}$$

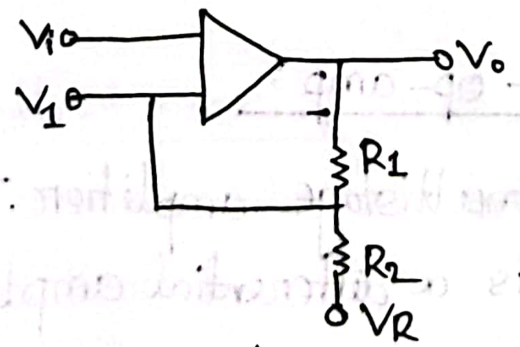
(iv) **Comparator:** The function of voltage comparator is to compare ~~function~~ the time varying voltage at one input with a fixed reference voltage on the other.



e_i = Variable
e_R = fixed



(v) **Schmitt trigger:**



(a) For $V_i < V_1$ and $V_o = +V_o$

$$V_1 = \left(\frac{R_1}{R_1+R_2}\right)V_R + \left(\frac{R_2}{R_1+R_2}\right)V_o$$

(b) For $V_i > V_1$

$$V_2 = \left(\frac{R_1}{R_1+R_2}\right)V_R - \left(\frac{R_2}{R_1+R_2}\right)V_o$$

α

① **Differentiator:** A differentiator is a circuit that performs differentiation of the input signals. A differentiator produces an output voltage that is proportional to the rate of change of the input voltage. It's important application is to produce a rectangular output ~~form~~ from a ramp input.

⑪ **Integrator:** An integrator is a circuit that performs integration of the input signal. The most popular application of an integrator is to produce a ramp output voltage.

→ **Characteristics of op-amp:**

① An op-amp is a multistage amplifier. The input stage of an op-amp is a differential amplifier stage.

⑪ An inverting input and non-inverting output.

(iii) A high input impedence as both input.

(iv) A low output impedence ($<200\Omega$)

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(v) A large open-loop voltage gain.

(vi) The voltage gain remain constant over a wide frequency range.

(vii) Very large CMRR(> 90dB).

Input Bias current: In the real world, tiny amount of current actually do flow into both the inverting and non-inverting input of the components. These currents are reffered to as the input bias currents.

$$I_{bias} = \frac{I_{D1} + I_{D2}}{2}$$

Input offset current: Input offset current is the difference of the currents into the two terminals with the output at zero voltage.

$$I_{iD} = I_{D1} - I_{D2}$$

$$I_{iD} = I_{D1} \sim I_{D2}$$

Input offset voltage: Input offset voltage is defined as the voltage that must be applied between the two input terminals of the op-amp to obtain zero volts at the output.

Slew rate: The slew rate is defined as the maximum rate of output voltage change per unit time.

$$\text{Slew rate, } S = \left(\frac{dV_o}{dt}\right)_{max}$$

The unit of slew rate is volt/μs.

Common mode rejection ratio: Common mode rejection ratio is the measure of a device's ability to reject the signal common to both the positive and negative device input.

$$CMRR = \frac{A_d}{A_c} = \frac{\text{Differential gain}}{\text{Common mode gain}}$$

Transistor Oscillators

Oscillators: Oscillator may be defined as a circuit which generates an a.c output signal without any externally applied input signal or a circuit which converts d.c. energy into a.c. energy at very high frequency.

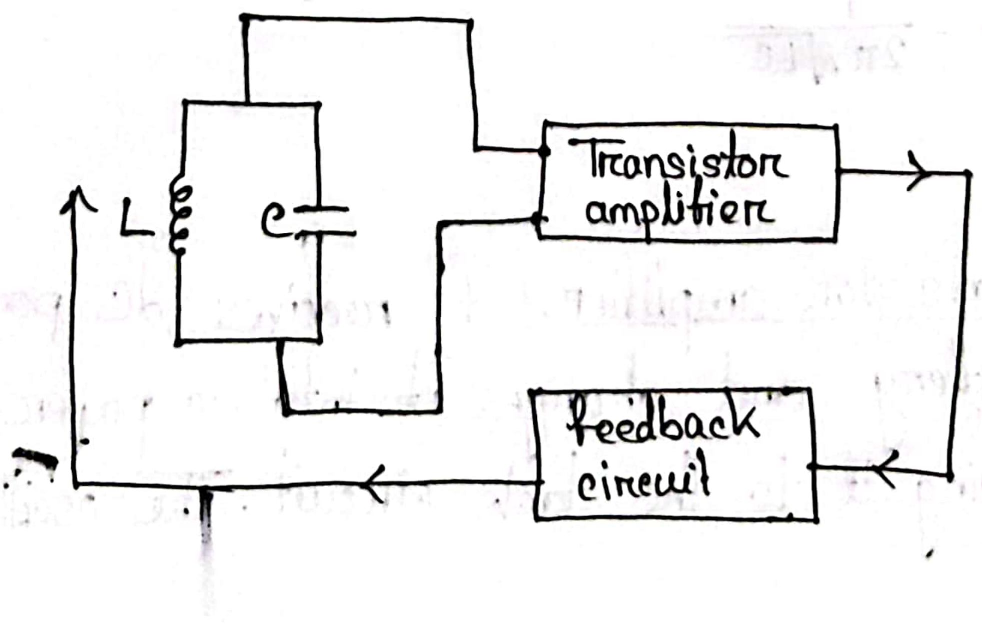
Essential components of oscillator are:

(i) **Tank circuit:** The tank circuit of an inductance coil in parallel with a capacitor. The frequency of oscillations in the circuit depends upon the values of inductance and capacitance. This is given by:

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

(ii) **Transistor amplifier:** It receives dc power from the battery and changes it into ac power for supplying it to the tank circuit. The oscillations of tank circuit are feed to the transistor amplifier which are amplified due to transistor ~~amply~~ amplifying action.

(iii) ~~feet~~ Feedback circuit: The feedback ~~curreit~~ circuit supplies a part of the output energy to tank circuit in correct phase to overcome the losses occuring in the tank circuit and the balance is radiated out in the form of electromagnetic waves. The feedback circuit provides a positive feedback.



Hartley Oscillator:

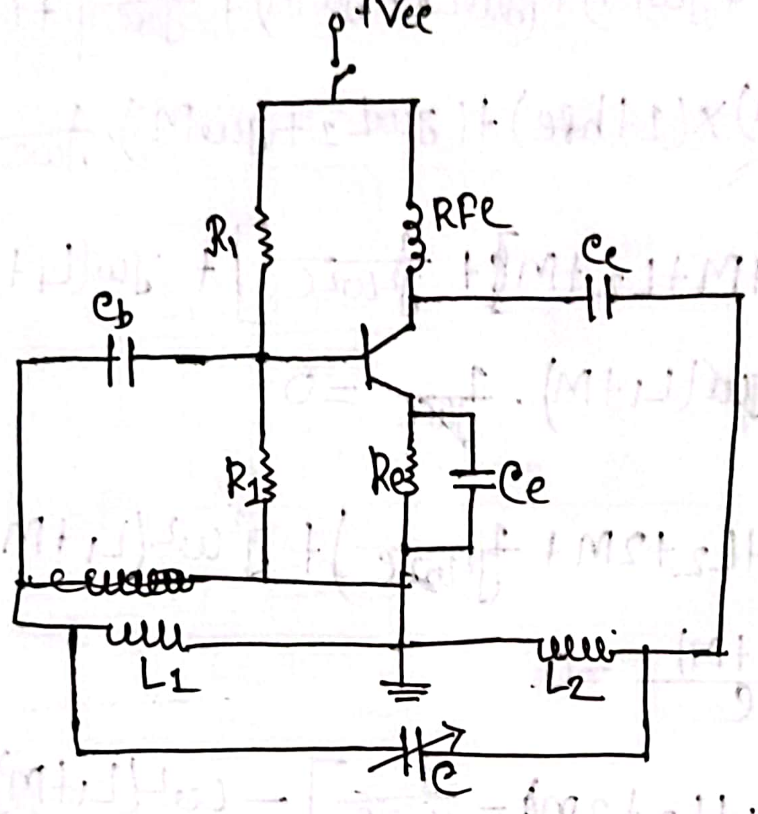


Fig-a: Shunt-feed hartley oscillator

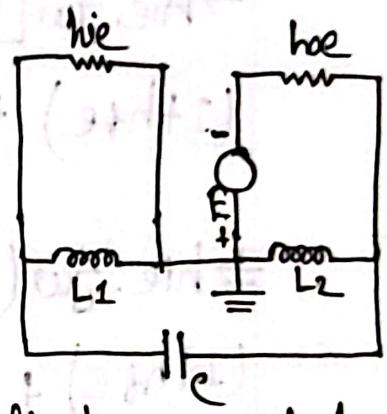


fig-b: Equivalent circuit

The general equation of the oscillator:

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

Here, $Z_1 = j\omega L_1 + j\omega M$;

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

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

Substituting the values into equation (1),

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

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

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

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

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

পরে Now,

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

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

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

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

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

keeping the value of ω^2,

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

$$h_{fe} = \frac{L_1 + L_2 + 2M}{L_2 + M} - 1$$

$$= \frac{L_1 + L_2 + 2M - L_2 - M}{L_2 + M}$$

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

আবার Again,

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

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

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

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

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

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

⇒ What is hybrid parameter?

The constant h_{11}, h_{12}, h_{21} and h_{22} are called the hybrid (or h) parameters of the two port network. h_{11} has the dimention of impedence, h_{12} and h_{21} are dimentionless and h_{22} has the dimention of admittance. Thus, these ~~parate~~ parameters are dimentionally homogeneous. That is why these parameters are called hybrid parameters. These parameters are most suitable for transistor testing.

RC phase shift oscillator:

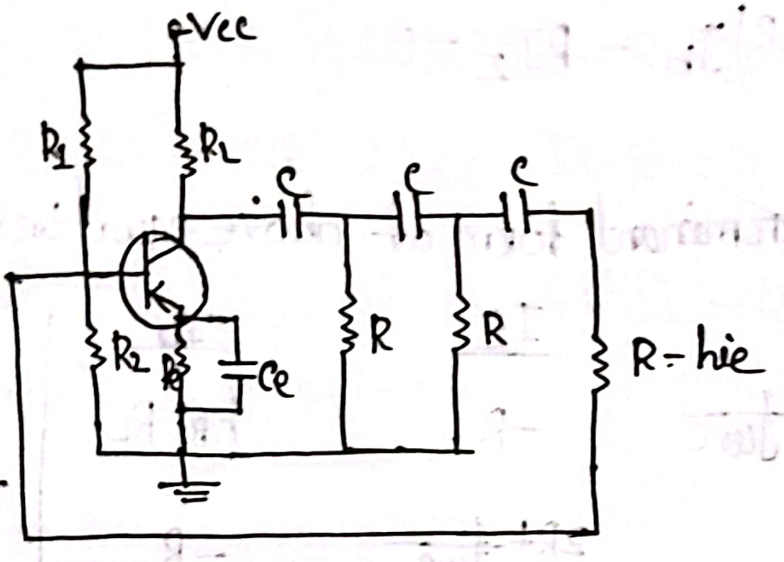


Fig: Phase shifter oscillator.

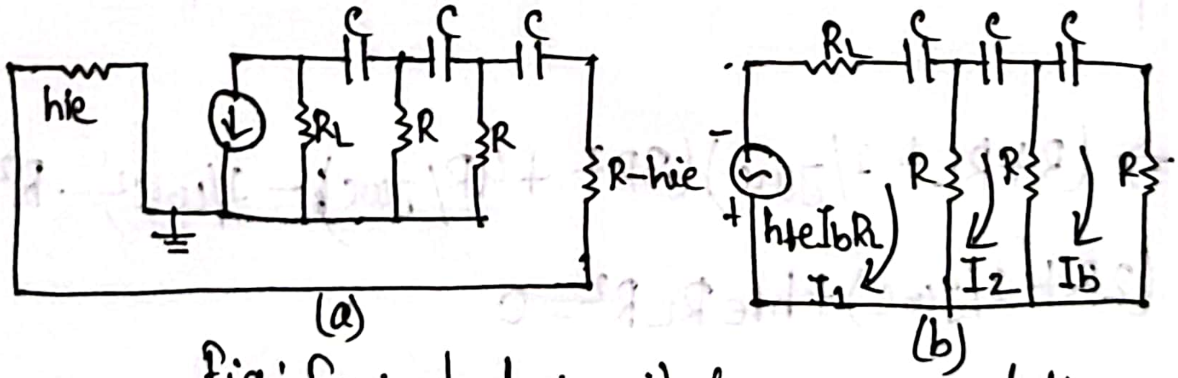


Fig: Equivalent circuit for phase shifter.

Applying KVL for three loops in fig-b:

For 1st loop:

$$\left(R + R_L + \frac{1}{j\omega C}\right)I_1 - RI_2 + h_{fe} R_L I_b = 0$$

For second loop:

$$\left(\frac{1}{j\omega C} + 2R\right)I_2 - RI_b - RI_1 = 0$$

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For third loop,

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

The determinant form of above equation is given by:

$$\begin{array}{ccc} \underline{I_1} & \underline{I_2} & \underline{I_b} \\ \end{array}$$

$$\begin{vmatrix} R+R_L+\frac{1}{j\omega C} & -R & h_{fe} \cdot R_L \\ -R & 2R+\frac{1}{j\omega C} & -R \\ 0 & -R & 2R+\frac{1}{j\omega C} \end{vmatrix} = 0$$

$$\Rightarrow (R+R_L+1/j\omega C)(3R^2+4R/j\omega C - 1/\omega^2C^2) - R^2 (2R+1/j\omega C) + h_{fe}R_LR^2 = 0$$

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

Equating the imaginary part to zero, we get,

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

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

$\Rightarrow 3R^3 - R\{(6R^2 + 4RR_L)\} + 3R^2R_L - R_L(6R^2 + 4R.R_L)$
$- 4R(6R^2 + 4R.R_L) - 2R^3 + h_{fe} \cdot R_L \cdot R^2 = 0$

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

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

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

$$\omega^2 = \frac{1}{C^2(6R^2 + 4R.R_L)}$$

$$\therefore \omega = \frac{1}{C\sqrt{(6R^2 + 4R.R_L)}}$$

$$\therefore f = \frac{1}{2\pi C} \cdot \frac{1}{\sqrt{(6R^2 + 4R.R_L)}}$$

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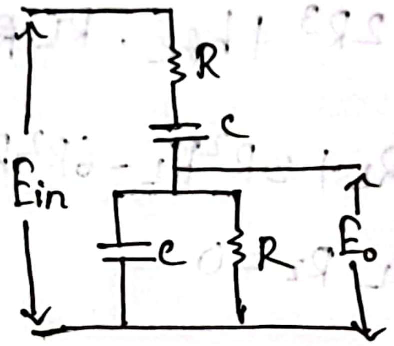
Wien bridge oscillator:



for series circuit, $= R + \frac{1}{jwC}$

$$= R + \frac{j^2}{j^2 wC}$$

$$= R - \frac{j}{wC}$$

for parallel circuit $= \frac{\frac{-R.j}{wC}}{R - j/wC} = E_0$

$\therefore$ Total impedence $= R - \frac{j}{wC} - \frac{Rj/wC}{R - j/wC}$

$$\therefore \frac{E_0}{E_{in}} = \frac{\text{Impedence in parallel combination}}{\text{Total impedence}}$$

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

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

$$= \frac{-Rj/\omega C}{R - \frac{j}{\omega C}} \times \frac{1}{R - \frac{j}{\omega C} - \frac{Rj/\omega C}{R - j/\omega C}}$$

$$= \frac{\frac{-Rj}{\omega C}}{\left(R - \frac{j}{\omega C}\right)^2 - \left(R - \cancel{\frac{j}{\omega C}}\right) \times \left(\frac{Rj/\omega C}{\cancel{R - j/\omega C}}\right)}$$

$$= \frac{-\frac{Rj}{\omega C}}{\left(R - \frac{j}{\omega C}\right)^2 - \frac{jR}{\omega C}}$$

$$= \frac{\frac{-Rj}{\omega C}}{R^2 - 2 \cdot R \cdot \frac{j}{\omega C} + \frac{j^2}{\omega^2 C^2} - \frac{jR}{\omega C}}$$

$$= \frac{\frac{-Rj}{\omega C}}{R^2 + \frac{j^2}{\omega^2 C^2} - \frac{3Rj}{\omega C}}$$

There is zero phase shift if the term in j vanishes.

$$R^2 + \frac{j}{\omega^2C^2} = R^2 - \frac{1}{\omega^2C^2}$$

$$\Rightarrow R^2 - \frac{1}{\omega^2C^2} = 0$$

$$\Rightarrow R^2 = \frac{1}{\omega^2C^2}$$

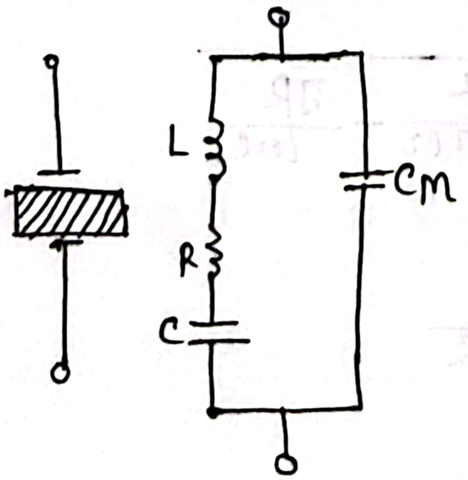
$$\Rightarrow \omega^2 = \frac{1}{R^2C^2}$$

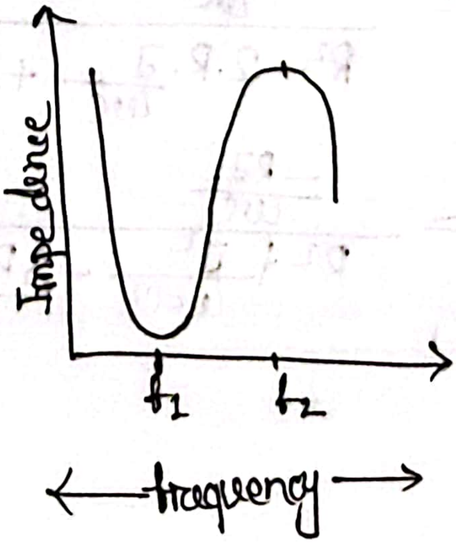
$$\therefore \omega = \frac{1}{RC}$$

$\therefore$ Frequency of oscillation in wien bridge

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

Crystal oscillator:





The impedence vs frequency curve is shown in fig. It is obvious from the figure that there exists one resonant condition when the reactances of the series RLC leg are equal and opposite. At this condition, the series-resonant impedence is very low. Thus at series-resonance:

$$\omega_s L - \frac{1}{\omega_s C} = 0$$

$$\Rightarrow \frac{\omega_s^2 LC - 1}{\omega_s C} = 0$$

$$\Rightarrow \omega_s^2 LC - 1 = 0$$

$$\Rightarrow \omega_s^2 LC = 1$$

$$\Rightarrow \omega_s^2 = \frac{1}{LC}$$

$$\therefore \omega_s = \frac{1}{\sqrt{LC}}$$

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

The other resonant occurs at a higher frequency when the reactance of the series resonant leg equals the reactance of capacitor C_m. This is parallel resonance and or antiresonance condition of the crystal. At the frequency the crystal offers a very high impedence to the external circuit. In this case:

$$\omega_p L - \frac{1}{\omega_p C} = \frac{1}{\omega_p C_m}$$

$$\Rightarrow \omega_p L = \frac{1}{\omega_p C_m} + \frac{1}{\omega_p C}$$

$$\Rightarrow \omega_p L = \frac{C + C_m}{\omega_p C . C_m}$$

$$\Rightarrow \omega_p . \omega_p = \frac{C + C_m}{L C . C_m}$$

$$\Rightarrow \omega_p^2 = \frac{C + C_m}{L C . C_m}$$

$$\therefore \omega_p = \sqrt{\frac{C + C_m}{L C . C_m}}$$

$$\therefore f_p = \frac{1}{2\pi}\sqrt{\frac{C + C_m}{L C . C_m}}$$

Colpitt's Oscillator:

General equation of Oscillator:

$$h_{ie}(Z_1+Z_2+Z_3)+Z_1Z_2(1+h_{fe}) + Z_1.Z_3 = 0 \quad \text{——— (1)}$$

In case of Colpitt's oscillator,

$$Z_1 = 1/j\omega C_1 = \frac{-j}{\omega C_1}, \quad Z_2 = 1/j\omega C_2 = \frac{-j}{\omega C_2}, \quad Z_3 = j\omega L$$

Substituting the values in equation (1)

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

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

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

the frequency of oscillation can be obtained by equating the imaginary part to zero:

$$-jh_{ie}\left(\frac{1}{\omega C_1} + \frac{1}{\omega C_2} - \omega L\right) = 0$$

$$\Rightarrow \frac{C_2 + C_1 - \omega^2 C_1.C_2 L}{\omega C_1.C_2} = 0$$

$$\Rightarrow C_2 + C_1 - \omega^2 C_1 . C_2 . L = 0$$

$$\Rightarrow \omega^2 = \frac{C_2 + C_1}{C_1 . C_2 . L}$$

$$\Rightarrow \omega = \sqrt{\frac{(C_2 + C_1)}{C_1 . C_2 . L}}$$

$$\therefore f = \frac{1}{2\pi} \sqrt{\frac{(C_2 + C_1)}{C_1 . C_2 . L}}$$

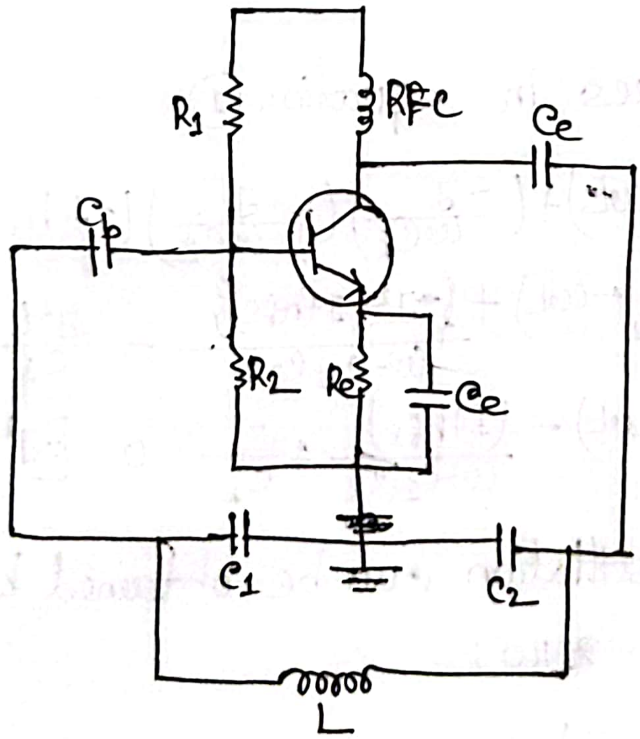


Fig : Colpitt's Oscillator

Filter Circuit

Filter: Filters are electrical networks used to separate alternating from direct current components or to separate a group of a.c. components included within a particular frequency from those lying outside this range.

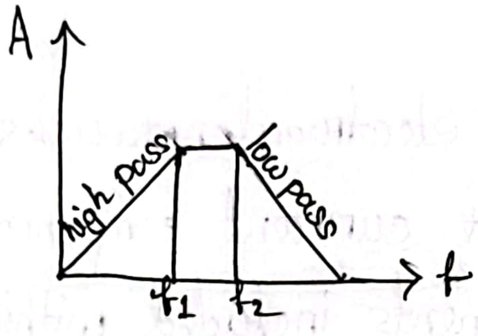
There are two types of filter:

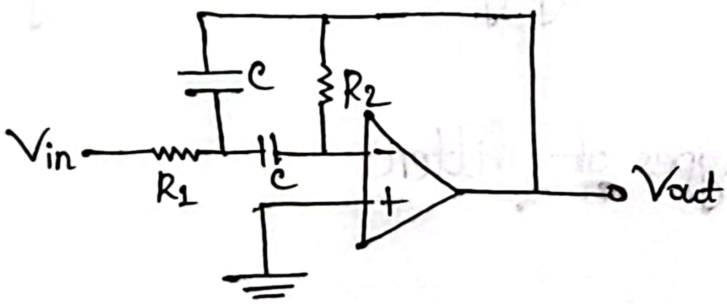
(i) Active filter
(ii) Passive filter

Frequency response এর উপর ভিত্তি করে:

(i) Low pass filter
(ii) High pass filter
(iii) Band pass filter
(iv) Band stop filter.

Band pass filter:





$$\text{Gain } A_v = \frac{-R_2}{2R_1}$$

$$f_0 = \frac{1}{\sqrt{f_1 f_2}}$$

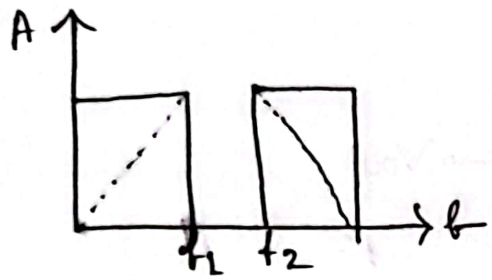
$$f_0 = \frac{1}{2\pi C\sqrt{R_1 R_2}}$$

$$Q = \frac{f_0}{BW} = \frac{1}{2}\sqrt{\frac{R_2}{R_1}}$$ [BW = Bandwidth]

If, $Q>1$ [Narrow band filter]

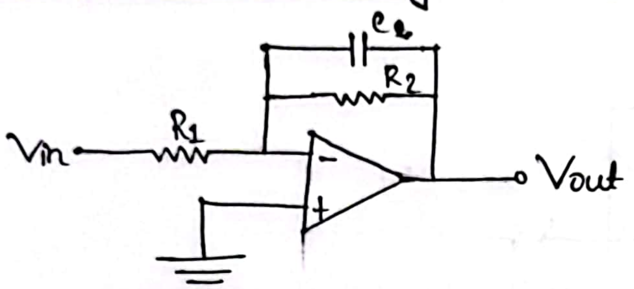
$Q<1$ [wide band filter]

Band stop filter:



frequency response of band pass filter.

Low pass filter (Integrator):

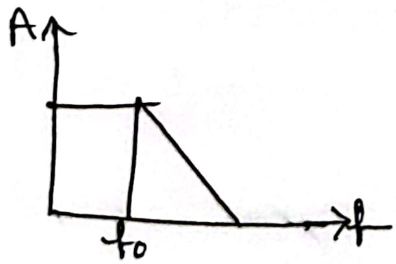


Voltage gain $A_V = \frac{-R_2}{R_1}$

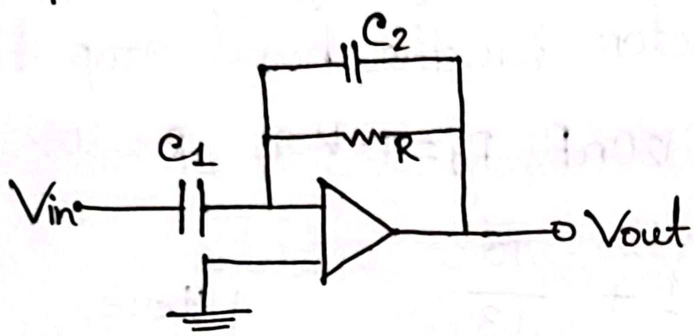
$f_c = \frac{1}{2\pi R_2 C}$

$X_C = \frac{1}{2\pi f_c}$

Frequency response:



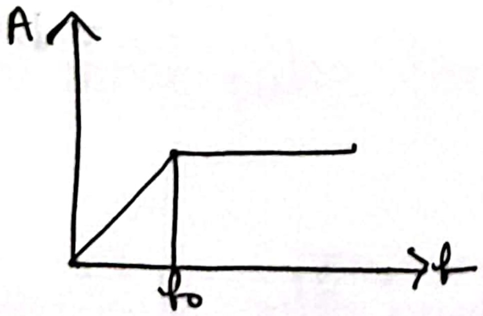
High pass filter (Differentiator):



$$\text{Voltage gain} = \frac{-X_{C_2}}{X_{C_1}}$$

$$= \frac{-R_f}{R_1}$$

Frequency response:



⇒ Operation অবশ্যই আসবে Exam এ।

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Question: What are the voltage gain, centre frequency and Q factor for the band stop filter if, $R = 22K\Omega$, $C = 120nF$, $R_1 = 13K\Omega$, $R = 10K\Omega$

$$A_v = 1 + \frac{R_2}{R_1} = 1 + \frac{10}{13}$$

$$= 1.77$$

Here,

$R_1 = 13\ k\Omega$

$R_2 = 10\ k\Omega$

$A_v = ?$

$f_0 = ?$

$R = 22\ k\Omega$

$= 22 \times 10^3\ \Omega$

$C = 120\ nF$

$= 120 \times 10^{-9} F$

Centre frequency,

$$f_0 = \frac{1}{2\pi RC}$$

$$= \frac{1}{2\pi \times 22 \times 10^3 \times 120 \times 10^{-9}}$$

$$= 60.3\ Hz$$

and,

$$Q = \frac{0.5}{2 - A_v}$$

$$= \frac{0.5}{2 - 1.77}$$

$$= 2.17$$

Multivibrator

Definition: A multivibrator is a two-stage resistance coupled amplifier with positive feedback from the output of one amplifier to the input of the other.
It has two state : ON and off.

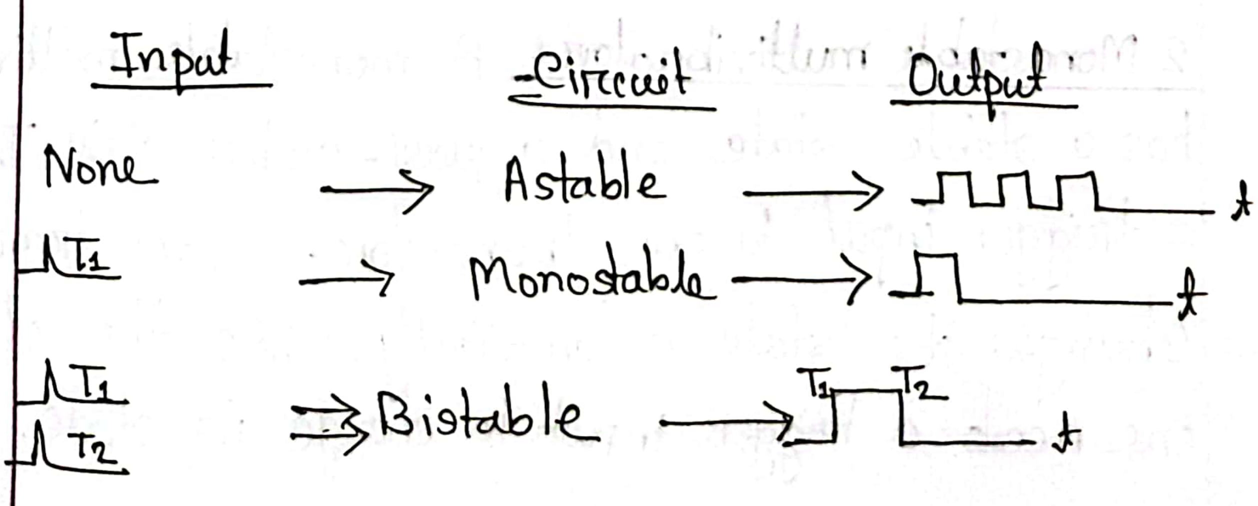
Multivibrators are classified into three types:

1. Astable multivibrator: An astable multivibrator is such a circuit that it automatically switches between the two states continuously without the application of any external pulse for its operation.

2. Monostable multivibrator: A monostable multivibrator has a stable state and a quasi-stable state. This has a trigger input to one transistor. So, one transistor changes its state automatically. while the other one needs a trigger input to change its state.

As this multivibrator produces a single output for each trigger pulse, this is known as One-shoot multivibrator. This muslltivibrator can not stay in quasi-stable state for a longer period while it stays in stable state untill trigger pulse is recieved.

<u>3. Bistable multivibrator:</u> A bistable multivibrator has both the two states stable. It requires two trigger pulses to be applied to change the states. Untill the trigger input is given, this multivibrator cannot change its state. It's also known as Flip-flop multivibrator.



Trigger: ON/OFF করার জন্যে বাইরে থেকে যে signal দেওয়া হয়।