LECTURE NOTES

ON

Linear & Digital IC Applications (20A04403T)

IV B. Tech I Semester (R20)

Prepared by

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JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY ANANTAPUR

B.Tech (EEE)– IV-I Sem

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(20A04403T) LINEAR& DIGITAL IC APPLICATIONS
(Professional Elective Course – V)

Course Objectives:

- To introduce the basic building blocks of linear integrated circuits.
- To teach the linear and non-linear applications of operational amplifiers.
- To introduce the theory and applications of PLL.
- To introduce the concepts of waveform generation and introduce some special function ICs.
- Exposure to digital IC's

Course Outcomes (CO):

- List out the characteristics of Linear and Digital ICs.
- Discuss the various applications of linear & Digital ICs.
- Solve the application-based problems related to linear and digital ICs.
- Analyze various applications based circuits of linear and digital ICs.
- Design the circuits using either linear ICs or Digital ICs from the given specifications.

UNIT – I ICs and OP- AMPS

INTEGRATED CIRCUITS AND OPERATIONAL AMPLIFIER: Introduction, Classification of IC's, IC chip size and circuit complexity, basic information of Op-Amp IC741 Op-Amp and its features, the ideal Operational amplifier, Op-Amp internal circuit, Op-Amp characteristics - DC and AC.

UNIT – II Applications of OP- AMP

LINEAR APPLICATIONS OF OP-AMP: Inverting and non-inverting amplifiers, adder, subtractor, Instrumentation amplifier, AC amplifier, V to I and I to V converters, Integrator and differentiator.

NON-LINEAR APPLICATIONS OF OP-AMP: Sample and Hold circuit, Log and Antilog amplifier, multiplier and divider, Comparators, Schmitt trigger, Multivibrators, Triangular and Square waveform generators, Oscillators

UNIT - III Active Filters and other ICs

ACTIVE FILTERS: Introduction, Butterworth filters – 1st order, 2nd order low pass and high pass filters, band pass, band reject and all pass filters.

TIMER AND PHASE LOCKED LOOPS: Introduction to IC 555 timer, description of functional diagram, monostable and astable operations and applications, Schmitt trigger, PLL - introduction, basic principle, phase detector/comparator, voltage controlled oscillator (IC 566), low pass filter, monolithic PLL and applications of PLL.

UNIT – IV Voltage Regulators and Converters

VOLTAGE REGULATOR: Introduction, Series Op-Amp regulator, IC Voltage Regulators, IC 723 general purpose regulators, Switching Regulator.

D to A AND A to D CONVERTERS: Introduction, basic DAC techniques - weighted resistor DAC, R-2R ladder DAC, inverted R-2R DAC, A to D converters - parallel comparator type ADC, counter type ADC, successive approximation ADC and dual slope ADC, DAC and ADC Specifications.

UNIT - V Digital ICs

CMOS LOGIC: CMOS logic levels, MOS transistors, Basic CMOS Inverter, NAND and NOR gates, CMOS AND-OR-INVERT and OR-AND-INVERT gates, implementation of any function using CMOS logic.

COMBINATIONAL CIRCUITS USING TTL 74XX ICS: Study of logic gates using 74XX ICs, Four-bit parallel adder (IC 7483), Comparator (IC 7485), Decoder (IC74138, IC 74154), BCD-to-7-segment decoder (IC 7447), Encoder (IC 74147), Multiplexer (IC 74151), Demultiplexer (IC74154).

SEQUNTIAL CIRCUITS USING TTL 74XX ICS: Flip Flops (IC 7474, IC 7473), Shift Registers, Universal Shift Register (IC 74194), 4- bit asynchronous binary counter (IC 7493).

Textbooks:

1. D. Roy Choudhury, Shail B. Jain, “Linear Integrated Circuit”, 4th edition (2012), New Age International Pvt.Ltd., New Delhi, India
2. Ramakant A. Gayakwad, “OP-AMP and Linear Integrated Circuits”, 4th edition (2012),Prentice Hall / Pearson Education, New Delhi.
3. Floyd, Jain, “Digital Fundamentals”, 8th edition (2009), Pearson Education, New Delhi.

References:

1. Sergio Franco (1997), Design with operational amplifiers and analog integrated circuits, McGraw Hill, New Delhi.
2. Gray, Meyer (1995), Analysis and Design of Analog Integrated Circuits,Wiley International, New Delhi.

Online Learning Resources:

1. https://nptel.ac.in/courses/108108111
2. https://nptel.ac.in/courses/108106069

(A). Introduction :-

1. Single stage Amplifier :- The transistor circuit which contains only single stage of amplification is known as single stage amplifier. This type of amplifier offers limited gain.

$V_o \rightarrow$ output voltage

$V_{in} \rightarrow$ input voltage

$A_V = \frac{V_o}{V_{in}}$ = voltage gain

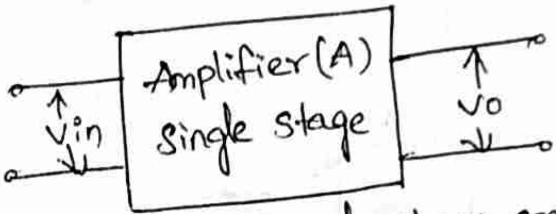


fig:- single stage amplifier

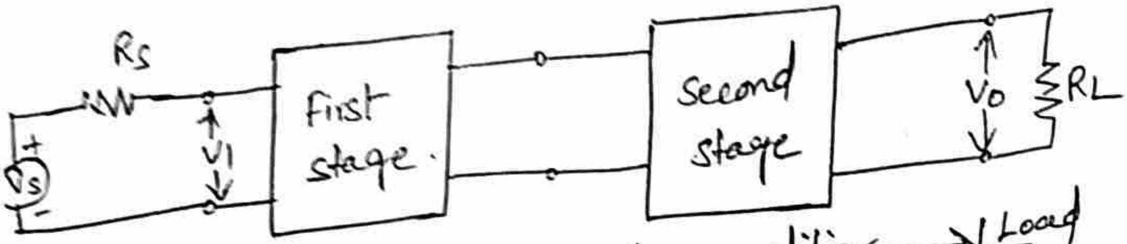
- The voltage (or) power gain obtained from a single stage small signal amplifier is not sufficient for a practical amplification.

For ex:- In some applications, the amplifier is must amplify the signal from weak sources such as Microphones then it must pass through loud speakers. The single stage is not suitable for such cases. This can be achieved by connecting number of amplifier stages to achieve necessary voltage (or) power gain.

Multistage amplifiers :-

- A transistor circuit which contains more than one stage for amplification is known as Multistage amplifier.
- In this the output of one stage is fed as the input to the next stage as shown below such

a connection is commonly referred as cascading amplifiers.



←Source→|← Two stage Cascade amplifier →|Load

Fig:- Multistage Amplifier.

In cascading Amplifiers, cascading is ~~also~~ done to achieve to correct input and output impedances for specific applications.

- Depending upon the type of amplifiers used in individual stages, Multistage amplifiers can be classified into several types.

- A Multistage amplifier using two (or) more single stage CE amplifiers is called cascaded amplifiers.

- A multistage amplifier with a common Emitter as the first stage and a common base as the second stage is called a cascode Amplifier. CE ↓ 1st CB ↓ 2nd

* Classification of Amplifiers :-

Amplifiers are classified based on many aspects. They are

i) According to frequency range
ii) According to coupling Mechanisms
iii) According to primary function performed
(iv) According to feedback technique.

(v) According to Bandwidth used.

(vi) According to operating point con Mode of operation.

(i) <u>According to frequency range</u>:-

a) Audio frequency amplifier (20HZ to 20KHZ)

b) Radio frequency amplifier (20KHZ to 30MHZ)

c) Very High frequency amplifier (30MHZ to 300MHZ)

d) Ultra High frequency amplifier (300MHZ – 3GHZ)

e) Micro frequency amplifier (>3GHZ).

(ii) <u>According to coupling mechanisms</u>!-

a) Direct coupled amplifier

b) RC- coupled amplifier

c) Inductive coupled amplifier (LC tuned circuits)

d) Transformer coupled amplifier.

(iii) <u>According to primary function</u>:-

a) Small Signal Amplifiers (Voltage amplifier)

b) Large Signal Amplifier.

→ Large signal Voltage Amplifier

→ Power Amplifier.

(iv) <u>According to feedback technique</u>:-

a) Positive feedback amplifier

b) Negative feedback amplifier

→ Voltage series feedback amplifier

→ Voltage shunt feedback amplifier

→ Current series feedback amplifier

→ Current shunt feedback amplifier.

) According to Bandwidth used :-

a) Narrow band Amplifier

b) wide band Amplifier.

Narrow band amplifiers are again classified into three types

- Single tuned amplifier
- Double tuned amplifier
- Stagger tuned amplifier.

According to operating point :-

a) Class-A Amplifier :- In class A Amplifier the operating point is in active region and output is distortionless.

b) Class-B amplifier :- In class B amplifier operating point is at cutoff region. So the amplification is done at only one half of the input cycle.

c) Class AB amplifier :- In Class AB amplifier, the operating point is below two extremeties defined for class A and Class B.

- The output signal exist for more than 180° and <360°.

D) Class-C amplifier :- In class C amplifier, the operating point is less than one half cycle of input.

Methods of Coupling :-

* when amplifiers are cascaded (coupled), it is necessary to use a coupling network between the output of first amplifier to the input of second amplifier.
- This type of coupling is called "Interstage coupling".

- The main purpose of coupling network is.
  - a) It transfers the ac output of one stage to the input of next stage.
  - b) It isolates the dc conditions of one stage to the next.

Multistage amplifiers are coupled by using four methods

1. Resistance- Capacitance (RC) Coupling.
2. Direct coupling
3. Transformer Coupling.
4. Tuned circuit Amplifiers.

1. Resistance- Capacitance (Rc) Coupling :-

In RC- coupling, the output of first stage is coupled to the next stage through Resistor (R_c) and Capacitor C_c.

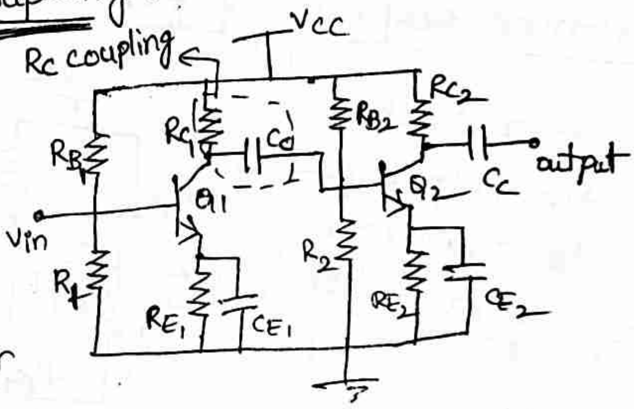


Fig:- Rc coupled amplifier

- where R_c is called as Collector Resistor.
- C_c is a coupling capacitor, which isolates the dc conditions from one stage to other stage.
- It is most commonly used and it is less expensive and has satisfactory frequency response.

2. Direct Coupling :-

- In direct coupled amplifier, the output of one stage is directly given to the input of next stage without any Reactive element (R, L, C).

This is widely preferred at Low frequencies.
The coupling devices such as capacitors and transformers
cannot be used at low frequencies because their
size becomes very large.

ecial dc voltage level
its are used to
ch the output dc levels.
ce this direct-coupled
plifiers are dc amplifiers.

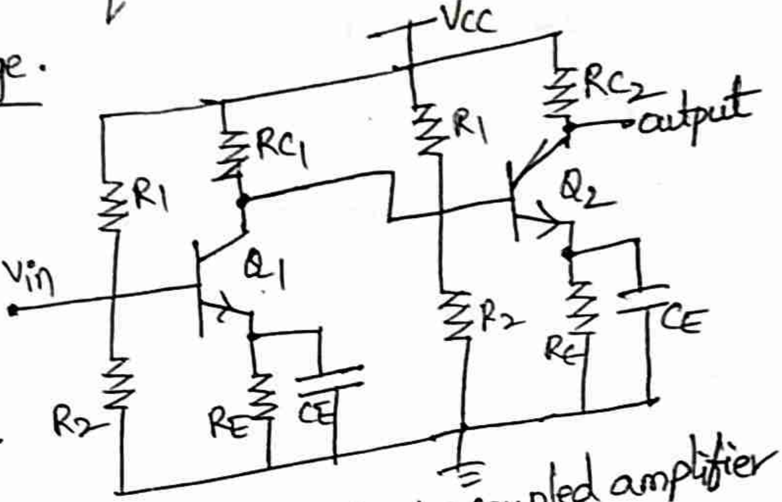
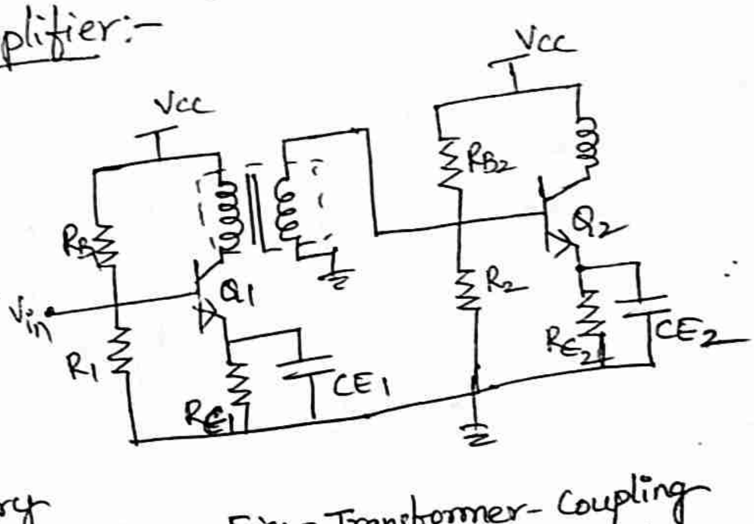


Fig:- Direct coupled amplifier

. Transformer coupled amplifier:-

, transformer coupled
plifier, the output of
mplifier is coupled to
ext stage through transformer.



n this method, the primary
inding of the transformer acts as a collector load and the secondary winding transfers the ac output signal directly to the base of the next stage.

Fig:- Transformer- Coupling Amplifier.

Due to transformer coupling overall circuit gain i.e Voltage (or) Current gain is increased.

- The impedance matching which is needed in power amplifiers can be achieved with the help of transformer coupling.
- It provides Maximum power transfer and efficiency.

- This method is less widely used because poor frequency response when compared to Rc- coupled amplifier. (4)
- More expensive.

(4). Tuned circuit Amplifiers:-

- In this type of amplifiers, an Lc tuned circuit is used which performs the impedance matching.

In tuned amplifiers the signal frequency is equal to resonant frequency f_0.

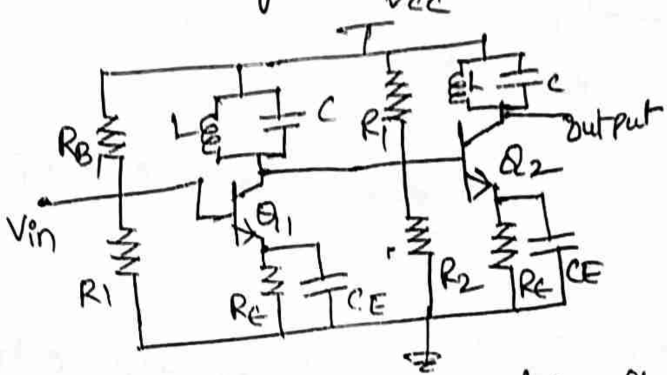


fig:- Lc tuned circuits

General Analysis of Cascading Amplifiers:-

- Cascade amplifier is formed by cascading several CE amplifier stages. The analysis of a general 'n' stage CE amplifier is shown below. fig (a).
- The biasing arrangements and coupling elements are omitted for simplicity.
- The expressions for quantities such as voltage gain, input impedance, current gain, power gain, output impedance of n-stage amplifier can be derived as follows.

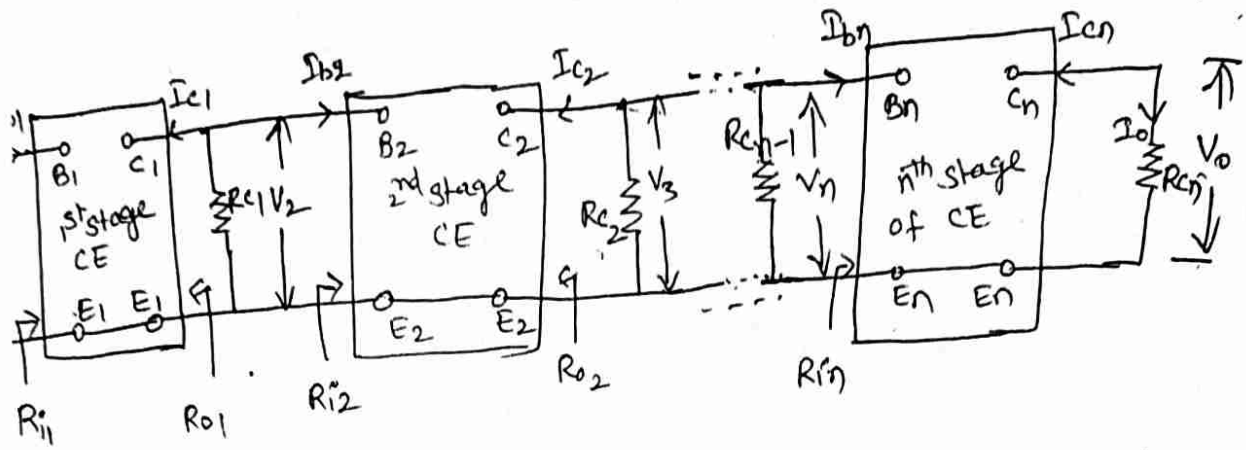


Fig: n-stage CE amplifier.

) Voltage gain :-

* In Multistage amplifier, the output voltage of first tage acts as the input voltage of second stage and so on.

The voltage gain of the complete cascade amplifier is equal to the product of voltage gains of individual stages.

proof :- The voltage gain of the first stage,

$$\bar{A}_{v_1} = \frac{\bar{V}_2}{\bar{V}_1} = \frac{\text{output voltage of first stage}}{\text{input voltage of first stage}}$$

$$= A_{v_1} \angle \theta_1$$

where A_{v_1} is the magnitude of voltage gain

θ_1 is the phase angle of output voltage relative to input voltage.

Similarly, $\overline{A_{V_2}} = \frac{\overline{V_3}}{\overline{V_2}} = \frac{\text{output voltage of the second stage}}{\text{input voltage of the second stage}}$

$= A_{V_2} \angle \theta_2$

- The expression for n-stage cascaded amplifier is given by

$$\overline{A_V} = \frac{\overline{V_o}}{\overline{V_1}} = \frac{\text{output voltage of the } n^{th} \text{ stage}}{\text{input voltage of first stage.}}$$

$\Rightarrow A_V \angle \theta$

But

$$\frac{\overline{V_o}}{\overline{V_1}} = \frac{\overline{V_2}}{\overline{V_1}} \times \frac{\overline{V_3}}{\overline{V_2}} \times \frac{\overline{V_4}}{\overline{V_3}} \times \cdots\cdots \times \frac{\overline{V_n}}{\overline{V_{n-1}}} \times \frac{\overline{V_o}}{\overline{V_n}}$$

- The above expression can be written as

$$\overline{A_V} = \overline{A_{V_1}} \cdot \overline{A_{V_2}} \cdot \overline{A_{V_3}} \cdots\cdots \overline{A_{V_n}} \longrightarrow (1)$$

$$= A_{V_1} \cdot A_{V_2} \cdot A_{V_3} \cdots\cdots A_{V_n} \cdots \angle\theta_1 + \angle\theta_2 + \cdots + \angle\theta_n$$

$$= A_V \cdot \angle\theta$$

Hence we can say that.

$$A_V = A_{V_1} \cdot A_{V_2} \cdot A_{V_3} \cdots\cdots A_{V_n} \longrightarrow (2)$$

$$\theta = \theta_1 + \theta_2 + \theta_3 \cdots\cdots + \theta_n \longrightarrow (3)$$

From equation (2) and (3) we can conclude that.

i) The magnitude of resultant voltage gain is the product of magnitudes of individual voltage gains.

ii) The phase shift of Resultant voltage gain is equal to the sum of phase shifts of individual stages.

Transistor configuration for cascading:-

For an amplifier circuit, the overall gain of the amplifier is an important consideration. To acheive maximum voltage gain, let us find the most suitable transistor configuration for cascading.

CC Amplifier.

Its voltage gain is less than unity
It is not suitable for Intermediate stages.

CB Amplifier

Its voltage gain is less than unity.
Hence not suitable for cascading.

CE Amplifier.

Its Voltage gain is greater than unity.
Voltage gain is further increased by cascading.
The characteristics of CE amplifier are such that, this configuration is very suitable for cascading in amplifier circuits. Hence most of the amplifier circuits use CE configuration.

~~It the~~

Two stage RC coupled amplifier :-

The two stage RC coupled amplifier is shown below.

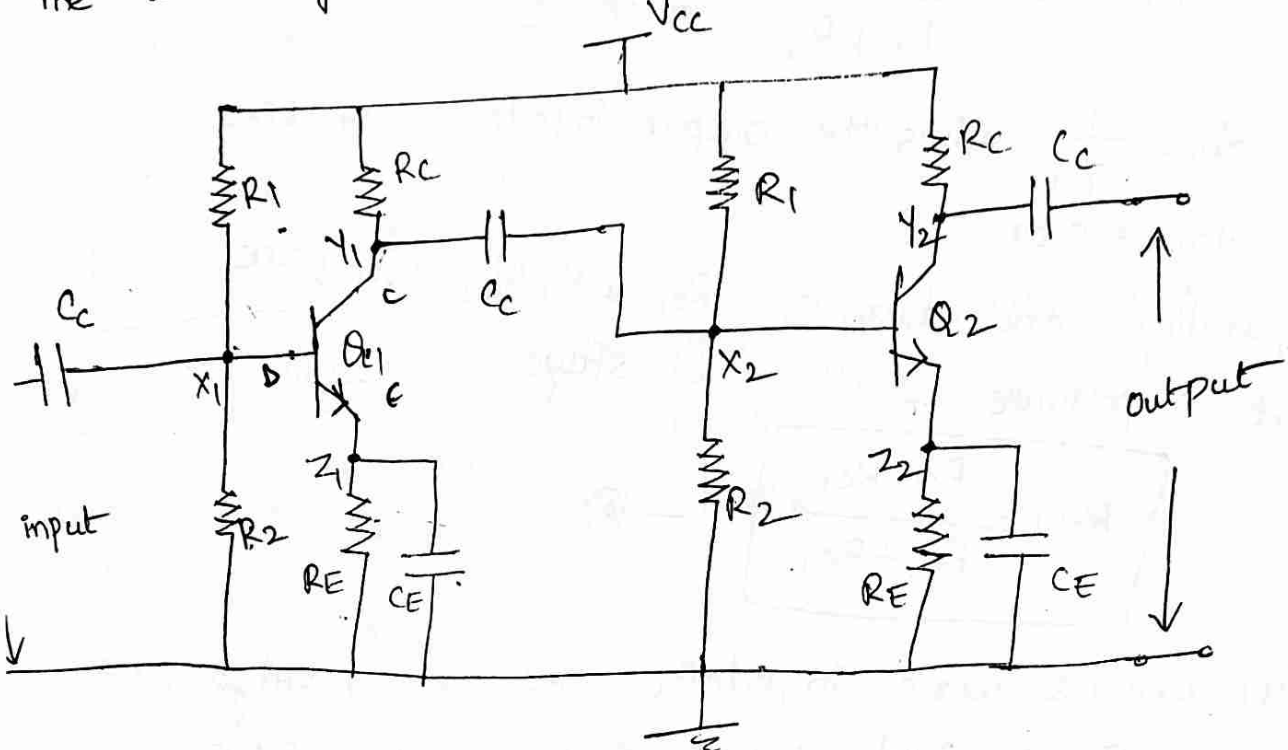


Fig:- Two Stage RC coupled Amplifier.

The two transistors are identical and a common power supply is used. R_C is the Collector (load) Resistor.

R_1, R_2 and R_E provides the required bias to the transistors

C_E is the bypass capacitor, prevents loss of amplification due to negative feedback.

The output of first stage is coupled to the second stage through coupling Capacitor C_c which is the blocking capacitor to keep the dc component of the output of first stage to second-stage and to pass to the ac components.

Operation:-

* when an ac input signal is applied at the base of the transistor Q_1, the signal gets amplified and its phase is reversed across the collector.
* The output of first stage is given to the base of Second stage transistor Q_2 through R_C and C_C.
* This signal at the base of Q_2 is further amplified and its phase is again reversed.
* Hence the output signal is twice amplified and the phase of output signal is inphase with the input.
* In mid band frequency range, the gain is constant because the coupling and bypass capacitors (C_C & C_E) acts as short circuits. $X_C = \frac{1}{2\pi f C} = \frac{1}{\infty} = 0$
* At high frequencies, the value of 'β' of the transistor decreases. Hence, the reactance of the capacitor C_c increases with the reduction in frequency of signal, the voltage gain of the amplifier reduces. $\beta\downarrow X_C\uparrow f\downarrow$
* At very low and very high frequencies, the gain of the amplifier reduces to almost zero.

Advantages of Rc coupling:-

i) It requires cheap components like resistors, Capacitors (Hence it is small size, light and inexpensive).

(ii) It gives uniform voltage amplification over a wide frequency range from few HZ to few MHZ. because sistor values are independent of frequency changes.

It has minimum Non linear distortion because of no transformers (or) coils are used.

Its overall amplification is higher than that of other couplings..

Disadvantages of RC coupling:-

①. Due to large drop across collector-load resistors, the collectors work at relatively small voltages unless high supply is used to overcome this voltage drop.

②. It is noisy in humidity weather.

③. The impedance matching is poor.

performance Difference between RC-coupled amplifier over single stage:-

①. Overall amplification is higher.

②. Its Non linear distortion is less

③. It has better fidelity over wide frequency range.

④. Its frequency response is much better over audio frequency range.

Applications:-

• Audio fidelity is excellent over a wide range of frequencies, RC coupled amplifier is used as voltage amplifier.

Ex:- It is used as ~~int~~ initial stages of public addressing systems.

(*). Analysis of two stage RC coupled amplifier:-

• The analysis of two stage RC-coupled amplifier can be done by replacing transistor Q_1 by high frequency hybrid π model.

The analysis is done at three frequency ranges

i) Middle frequency range (or) Mid band frequency

(ii) Low frequency range.

(iii) High frequency range.

ith the above simplifying assumptions the circuit educes to equivalent circuit as shown below.

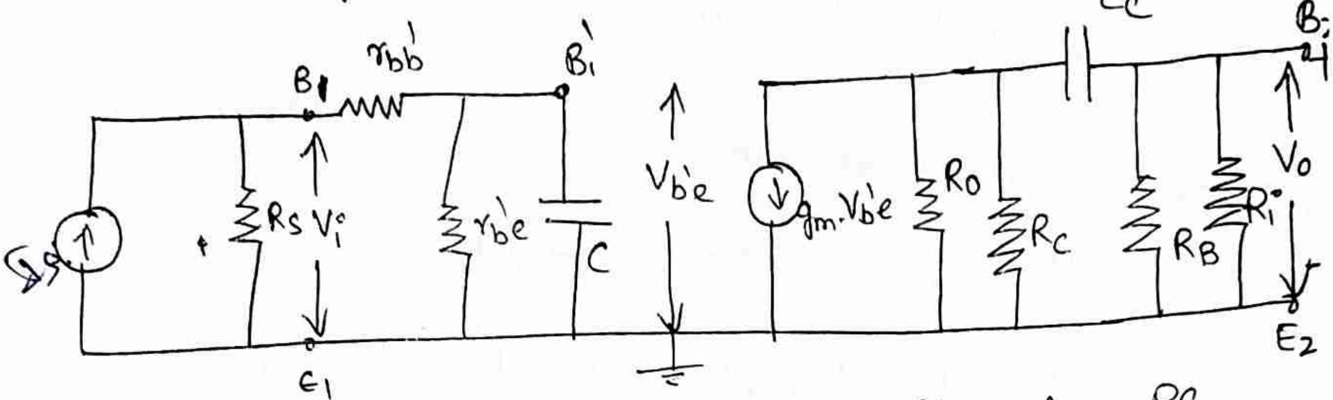


fig:- Simplified Equivalent circuit of an RC Coupled amplifier.

Let R_c' represents the parallel combination of R_o and R_c

$$\Rightarrow \quad R_c' = R_o \| R_c = \frac{R_o R_c}{R_o + R_c}$$

Let R_i' represents the parallel combination of R_B and R_i

$$R_i' = R_B \| R_i = \frac{R_B \cdot R_i}{R_B + R_i}$$

- From above assumptions the circuit reduces to

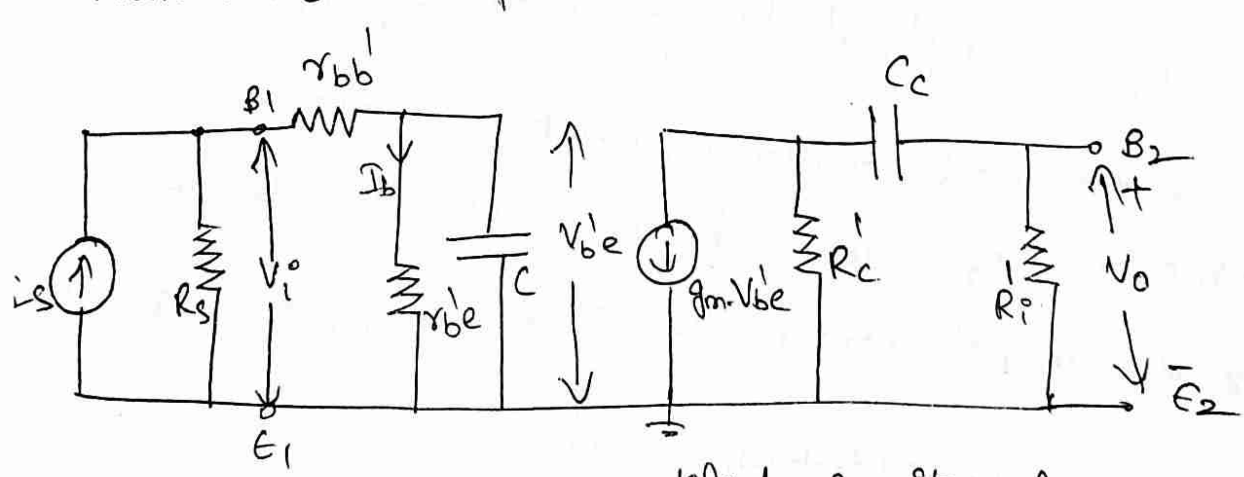


fig:- Further simplified circuit of Rc coupled amplifier.

In most cases $R_o >> R_c$, Hence $R_c' = R_c \| R_o \approx R_c$

Similarly $R_B >> R_i$; Hence $R_i' = R_i \| R_B \simeq R_i$.

$\Rightarrow$ R_c' and R_i' can be taken as R_c and R_i.

- The analysis of an RC coupled amplifier for three frequency ranges (Mid, Low & High) can be done using the simplified equivalent circuit which is shown below.

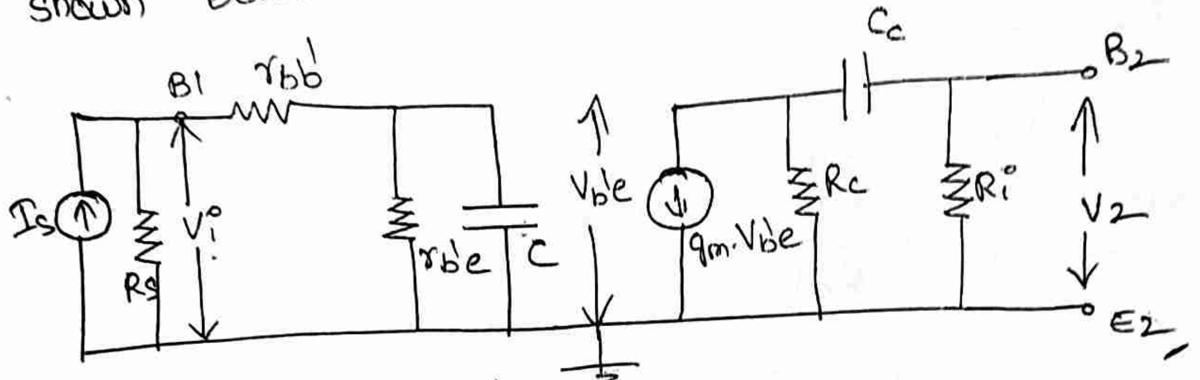


Fig:- Simplified circuit.

* i) Middle frequency range or Midband:-

- In the mid-frequency range, the reactance offered by C_c is small enough so it can be omitted.

- The frequency is further small enough to make the shunt capacitor (C) reactance $\left[X_c = \frac{1}{\omega c}\right]$ is extremely large Hence C can be omitted in the equivalent circuit.

- Let I_o be the current through the resistor R_i.

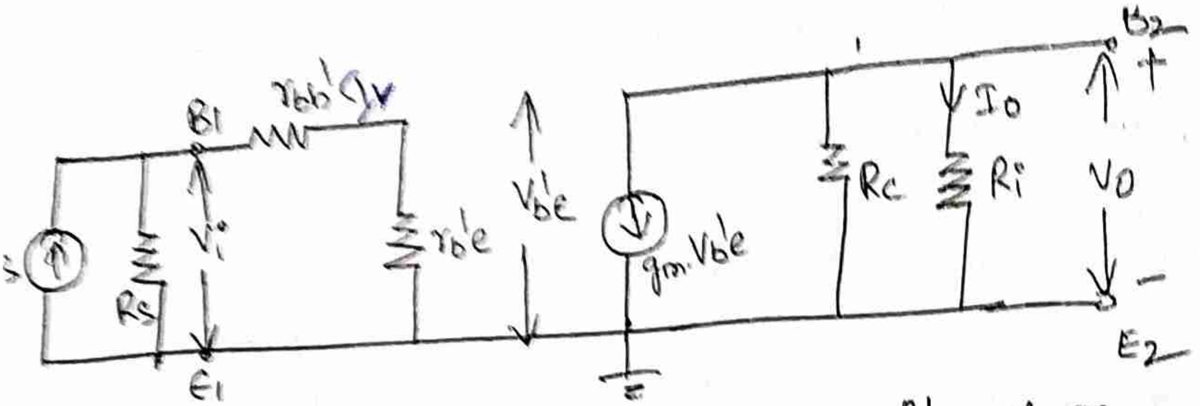


Fig:- Simplified equivalent circuit of an RC coupled amplifier for Mid-band range.

) Current gain A_{Im}:-

$$A_{Im} = \frac{I_o}{I_b}$$

$$\Rightarrow I_o = -g_m . V_{b'e} \cdot \frac{R_c}{R_c+R_i}$$

But $\quad V_{b'e} = I_b . r_{b'e}$

$$\Rightarrow I_o = -g_m . I_b . r_{b'e} \cdot \frac{R_c}{R_c+R_i}$$

Hence $\quad A_{Im} = \frac{I_o}{I_b} = \frac{-g_m . \cancel{I_b} . r_{b'e}}{\cancel{I_b}} \cdot \frac{R_c}{R_c+R_i}$

$$\Rightarrow A_{Im} = -g_m . r_{b'e} \cdot \frac{R_c}{R_c+R_i}$$

$$\Rightarrow \boxed{A_{Im} = -h_{fe} \cdot \frac{R_c}{R_c+R_i}} \qquad (\because h_{fe} = g_m . r_{b'e})$$

Hence, the current gain A_{Im} in the mid band is independent of frequency.

- Voltage gain (A_{vm}) :-

$$A_{vm} = \frac{V_o}{V_i}$$

$$V_o = -g_m \cdot V_{b'e} \cdot R_{ci} \qquad \left(\because R_{ci} = R_c \| R_i = \frac{R_c \cdot R_i}{R_c + R_i} \right)$$

$$\Rightarrow V_o = -g_m \cdot I_b \cdot r_{b'e} \cdot R_{ci} \qquad (V_{b'e} = I_b \cdot r_{b'e})$$

and $V_i = I_b(r_{bb'} + r_{b'e}) = I_b \cdot h_{ie}$ ($h_{ie} = r_{bb'} + r_{b'e}$)

Hence $A_{vm} = \frac{V_o}{V_i} = \frac{-g_m \cdot \cancel{I_b} \cdot r_{b'e} R_{ci}}{\cancel{I_b} \cdot h_{ie}}$

$$\Rightarrow \boxed{A_{vm} = \frac{-h_{fe} \cdot R_{ci}}{h_{ie}}} \qquad (\because h_{fe} = g_m \cdot r_{b'e})$$

*(iii) Low frequency range :- In the low frequency range, the capacitor 'C' is omitted which its reactance is large. However C_c is not neglected. The equivalent circuit is shown below.

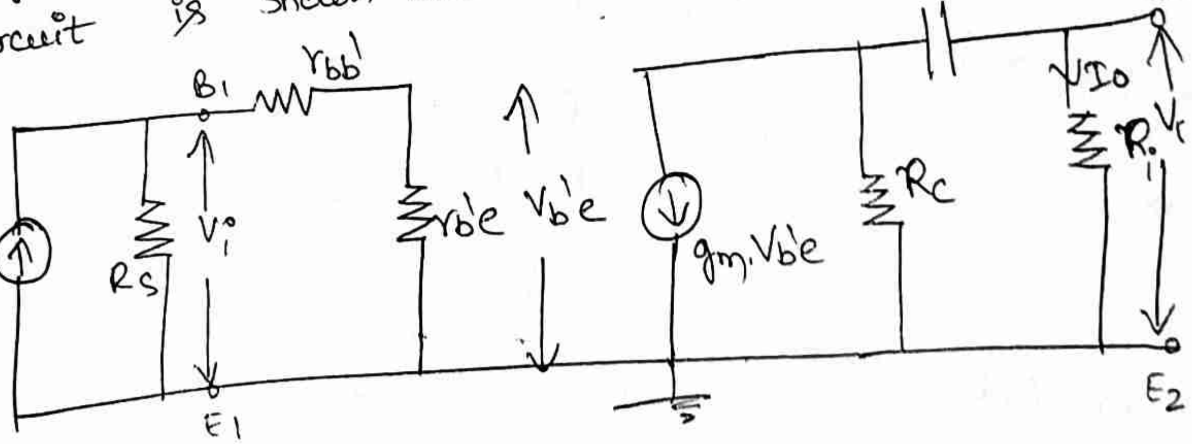


Fig:- Simplified equivalent circuit of an Rc coupled amplifier in low frequency range

Current gain (A_{Il}):-

$$A_{Il} = \frac{I_o}{I_b}$$

$$\Rightarrow I_o = -g_m \cdot V_{b'e} \cdot \frac{R_c}{R_c + (R_i - jX_{C_c})}$$

$$= -g_m \cdot V_{b'e} \cdot \frac{R_c}{R_c + \left(R_i + \frac{1}{j\omega C_c}\right)}$$

$$= -g_m \cdot I_b \cdot r_{b'e} \cdot \frac{R_c}{R_c + R_i + \frac{1}{j\omega C_c}} \quad (\because V_{b'e} = I_b \cdot r_{b'e}$$

tence the current gain

$$A_{Il} = \frac{I_o}{I_b} = \frac{-g_m \cdot \cancel{I_b} \cdot r_{b'e} \cdot \frac{R_c}{R_c + R_i + \frac{1}{j\omega C_c}}}{\cancel{I_b}}$$

$$A_{Il} = -h_{fe} \cdot \frac{R_c}{R_c + R_i + \frac{1}{j\omega C_c}} \quad (\because h_{fe} = g_m \cdot r_{b'e}$$

Multiply and divide $(R_c + R_i)$ in the above equation.

$$\Rightarrow A_{Il} = \frac{-h_{fe} \cdot R_c}{R_c + R_i} \cdot \frac{R_c + R_i}{R_c + R_i + \frac{1}{j\omega C_c}}$$

$$\Rightarrow A_{Il} = A_{Im} \cdot \frac{(R_c + R_i)}{(R_c + R_i)\left[1 + \frac{1}{j\omega C_c (R_c + R_i)}\right]}$$

$$\Rightarrow A_{Il} = A_{Im} \cdot \left[\frac{1}{1 - \frac{j}{\omega C_c (R_c + R_i)}}\right] \quad (\because \omega = 2\pi f)$$

$$\Rightarrow A_{Il} = \frac{A_{Im}}{\left(1 - j\frac{f_L}{f}\right)} \qquad \left[\because f_L = \frac{1}{2\pi C_c \cdot (R_c + R_i)}\right]$$

$$\Rightarrow |A_{Il}| = \frac{|A_{Im}|}{\sqrt{1 + \left(\frac{f_L}{f}\right)^2}}$$

- The phase angle of current gain at any frequency 'f' is given by

$$\phi_{Il} = \text{phase angle of } A_{Im} + \tan^{-1}\left(\frac{f_L}{f}\right)$$

$$= 180^\circ + \tan^{-1}\left(\frac{f_L}{f}\right)$$

$$= 180^\circ + \tan^{-1}\left(\frac{1}{2\pi f\, C_c (R_c + R_i)}\right)$$

- At $f = f_L \Rightarrow |A_{Il}| = \frac{|A_{Im}|}{\sqrt{2}} = 0.707 \cdot |A_{Im}|$

- where f_L forms the lower 3dB frequency for the current gain.

(ii) Voltage gain (A_{vl}):-

$$A_{vl} = \frac{V_o}{V_i}$$

$$\Rightarrow V_o = I_o \cdot R_i = -g_m \cdot I_b \cdot r_{b'e} \cdot \frac{R_c \cdot R_i}{R_c + R_i + \frac{1}{j\omega C_c}}$$

$$V_i = I_b (r_{bb'} + r_{b'e}) = I_b \cdot h_{ie}.$$

$$\Rightarrow A_{vl} = \frac{V_o}{V_i} = \frac{-g_m \cdot \cancel{I_b} \cdot r_{b'e} \cdot \frac{R_c R_i}{R_c + R_i + \frac{1}{j\omega C_c}}}{\cancel{I_b} \cdot h_{ie}}$$

$$\Rightarrow A_{vl} = \frac{-h_{fe}}{h_{ie}} \cdot \frac{R_c R_i}{R_c + R_i + \frac{1}{j\omega C_c}}$$

⇒ multiply and divide $R_c + R_i$ on bothe sides.

$$\Rightarrow A_{vl} = \frac{-h_{fe}}{h_{ie}} \cdot \frac{R_c R_i}{(R_c + R_i)} \cdot \frac{(R_c + R_i)}{R_c + R_i + \frac{1}{j\omega C_c}}$$

$$\Rightarrow A_{vl} = A_{vm} \cdot \frac{\cancel{(R_c + R_i)}}{\cancel{(R_c + R_i)}\left[1 + \frac{1}{j\omega C_c (R_c + R_i)}\right]}$$

$$\Rightarrow A_{vl} = A_{vm} \cdot \left[\frac{1}{1 - \frac{j}{\omega C_c (R_c + R_i)}}\right] \quad \left[\begin{array}{l} \omega = 2\pi f \\ f_L = \frac{1}{2\pi C_c (R_c + R_i)} \end{array}\right.$$

$$\Rightarrow A_{vl} = \frac{A_{vm}}{\left[1 - \frac{j f_L}{f}\right]}$$

$$\boxed{|A_{vl}| = \frac{|A_{vm}|}{\sqrt{1 + \left(\frac{f_L}{f}\right)^2}}}$$

- The phase angle of voltage gain A_{vl} is given by

$$\phi_{vl} = \text{phase angle of } A_{vm} + \tan^{-1}\left[\frac{f_L}{f}\right]$$

$$= 180° + \tan^{-1}\left[\frac{1}{2\pi f C_c (R_c + R_i)}\right]$$

- At $f = f_L$;

then $|A_{vl}| = \frac{|A_{vm}|}{\sqrt{2}} = 0.707\,|A_{vm}|$.

Thus f_L forms the lower 3dB frequency for voltage gain

- The lower 3dB frequencies are the same for current gain and voltage gain.

(iii) At High frequencies :-

- In this frequency range, coupling capacitance C_c can be omitted since its reactance is small and shunt capacitance C cannot be neglected and it is shown below.

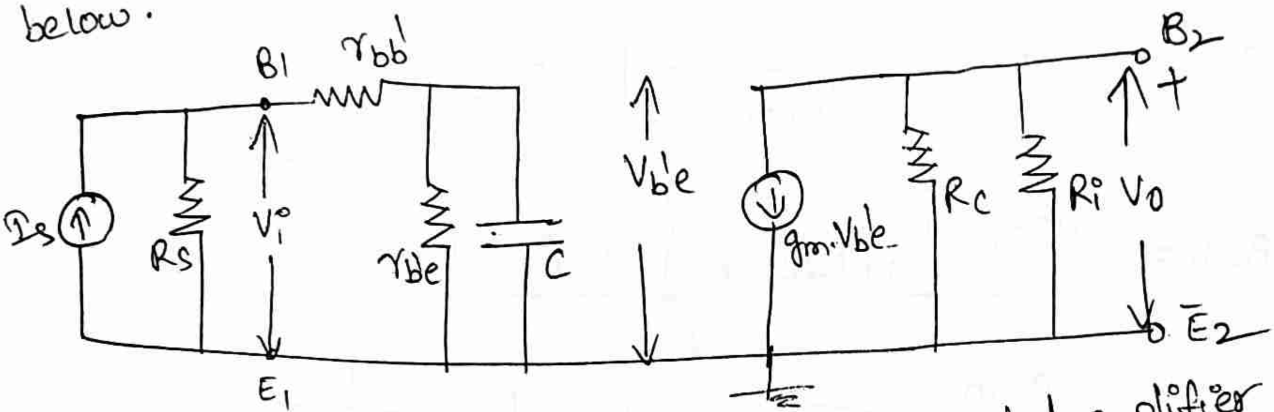


fig:- Equivalent circuit of an Rc coupled amplifier in high frequency range.

(i) Current gain (A_{Ih}):-

$$A_{Ih} = \frac{I_o}{I_b}.$$

$$\Rightarrow I_o = -g_m . V_{b'e} . \frac{R_C}{R_C + R_i}$$

where $V_{b'e} = \dfrac{I_b}{g_{b'e} + j\omega C} = \dfrac{I_b}{\frac{1}{r_{b'e}} + j\omega C}$

con

$r_{b'e} = I_b \times \left[\dfrac{r_{b'e} \times \frac{1}{j\omega C}}{r_{b'e} + \frac{1}{j\omega C}}\right]$

$$\Rightarrow V_{b'e} = \frac{I_b . r_{b'e}}{1 + j\omega C r_{b'e}}.$$

$$\Rightarrow I_o = -g_m \cdot \left[\frac{I_b \cdot r_{b'e}}{1 + j\omega C \cdot r_{b'e}}\right] \cdot \frac{R_C}{R_C + R_i}$$

Hence the current gain A_{Ih} is given by

$$A_{Ih} = \frac{I_o}{I_b} = \frac{-g_m \left[\frac{\cancel{I_b} \cdot r_{b'e}}{1 + j\omega C \cdot r_{b'e}}\right] \frac{R_C}{R_C + R_i}}{\cancel{I_b}}$$

$$\Rightarrow A_{Ih} = -g_m \cdot r_{b'e} \cdot \frac{R_C}{R_C + R_i} \cdot \left[\frac{1}{1 + j\omega C \cdot r_{b'e}}\right]$$

$$A_{Ih} = A_{Im} \cdot \left[\frac{1}{1 + j\omega C \cdot r_{b'e}}\right] \quad (\because \omega = 2\pi f$$

$$A_{Ih} = \frac{A_{Im}}{1 + j2\pi f C \cdot r_{b'e}} \quad (\because f_H = \frac{1}{2\pi C \cdot r_{b'e}}$$

$$\Rightarrow A_{Ih} = \frac{A_{Im}}{\left[1 + \frac{jf}{f_H}\right]}$$

$$\boxed{|A_{Ih}| = \frac{|A_{Im}|}{\sqrt{1 + \left(\frac{f}{f_H}\right)^2}}}$$

At $f = f_H \Rightarrow A_{Ih} = \frac{|A_{Im}|}{\sqrt{2}} = 0.707\,|A_{Im}|$

f_H forms the upper 3dB frequency.

Phase angle of the current gain at any frequency f is ϕ_{Ih} = phase angle of $A_{Im} - \tan^{-1}\left[\frac{f}{f_H}\right]$

$$\phi_{Ih} = 180^\circ - \tan^{-1}(2\pi f c\, r_{b'e})$$

(ii) Voltage gain A_{vh} :-

$$A_{vh} = \frac{V_o}{V_i} \qquad V_o = I_o \times R_i$$

$$\Rightarrow V_o = -g_m \cdot V_{b'e} \cdot R_{ci} \qquad (R_{ci} = R_c \| R_i)$$

$$V_o = -g_m \cdot \left[\frac{I_b \cdot r_{b'e}}{1 + j\omega c \cdot r_{b'e}}\right] \cdot R_{ci} \qquad \left(\because V_{b'e} = \frac{I_b \cdot r_{b'e}}{1 + j\omega c r_{b'e}} \right.$$

But $V_i = I_b \left[r_{bb'} + r_{b'e} \right] = I_b \cdot h_{ie}$.

$$\Rightarrow A_{vh} = \frac{V_o}{V_i} = \frac{-g_m \left[\frac{\cancel{I_b} \cdot r_{b'e}}{1 + j\omega c \cdot r_{b'e}}\right] \cdot R_{ci}}{\cancel{I_b} \cdot h_{ie}}$$

$$\Rightarrow A_{vh} = \frac{-h_{fe}}{h_{ie}} \cdot R_{ci} \cdot \frac{1}{1 + j\omega c r_{b'e}} = \frac{A_{vm}}{1 + j\omega c r_{b'e}}$$

let $\omega = 2\pi f$

$$f_H = \frac{1}{2\pi \cancel{f} c \cdot r_{b'e}}$$

$$\Rightarrow A_{vh} = \frac{A_{vm}}{\left(1 + j \frac{f}{f_H}\right)}$$

$$|A_{vh}| = \frac{|A_{vm}|}{\sqrt{1 + \left(\frac{f}{f_H}\right)^2}}$$

- At $f = f_H$; $|A_{vh}| = \frac{|A_{vm}|}{\sqrt{2}} = 0.707 |A_{vm}|$.

. Thus f_H forms the upper 3dB frequency.

phase angle of the voltage gain at any frequency 'f' is ϕ_{vh} = phase angle of $A_{vm} - \tan^{-1}\left[\frac{f}{f_H}\right]$

$$= 180° - \tan^{-1}(2\pi f\, C\, r_{b'e})$$

nce $f_H = \frac{1}{2\pi C\, r_{b'e}}$, in both cases, the upper 3dB frequen
cies of A_{Ih} and A_{vh} are same.

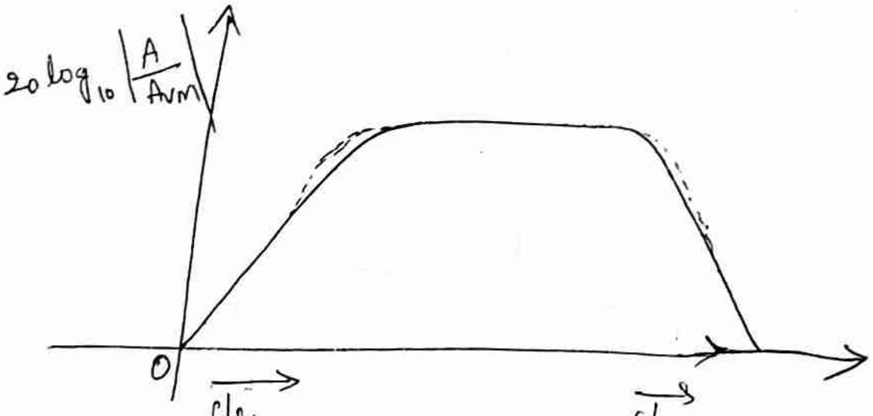


fig:- plot of gain vs frequency for an RC couple-d amplifier.

- Gain-Bandwidth product :- The gain bandwidth product for the current gain is given by

$$|A_{Im} \cdot f_H| = h_{fe} \cdot \frac{R_C}{R_C + R_i} \cdot \frac{1}{2\pi C \cdot r_{b'e}}$$

$$= \frac{g_m \cdot \cancel{r_{b'e}}}{2\pi C \cdot \cancel{r_{b'e}}} \cdot \frac{R_C}{R_C + R_i}$$

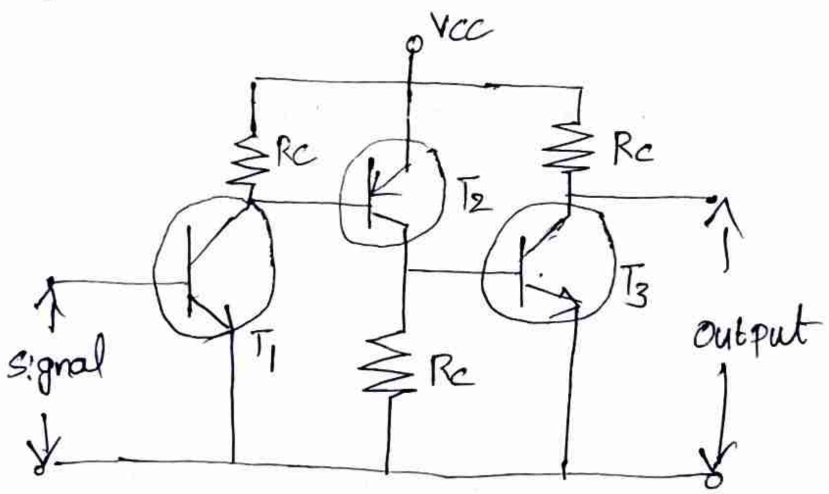
$$\Rightarrow \boxed{|A_{Im} \cdot f_H| = \frac{g_m}{2\pi C} \cdot \frac{R_C}{R_C + R_i}}$$

Direct coupled Amplifier:-

As no coupling devices are used, the coupling of the amplifier stages is done directly and hence called as Direct coupled amplifier.

Construction:-

The figure below indicates the three stage direct coupled transistor amplifier. The output of first stage transistor T_1 is connected to the input of second stage transistor T_2.



The transistor in the first stage will be an NPN Transistor, while the transistor in the next stage will be a PNP transistor and so on. This is because, the variations in one transistor tend to cancel the variations in the other. The rise in the collector current and the variation in β of one transistor gets cancelled by the ↓se in the other.

Operation:-

The input signal when applied at the base of transistor T_1, it gets amplified due to the transistor action and the amplified output appears at the collector resistor R_C of transistor T_1. This output is applied to the base of transistor T_2 which further amplifies the signal. In this way, a signal is amplified in a direct coupled amplifier circuit.

Advantages:-

-> The advantages of direct coupled amplifier are as follows

* the circuit arrangement is simple because of Minimum use of resistors.
* The circuit is of low cost because of the absence of expensive coupling devices.

Disadvantages:-

* It cannot be used for amplifying high frequencies.
* The operating point is shifted due to temperature variations.

Applications:-

* low frequency amplifications.
* low current amplifications.

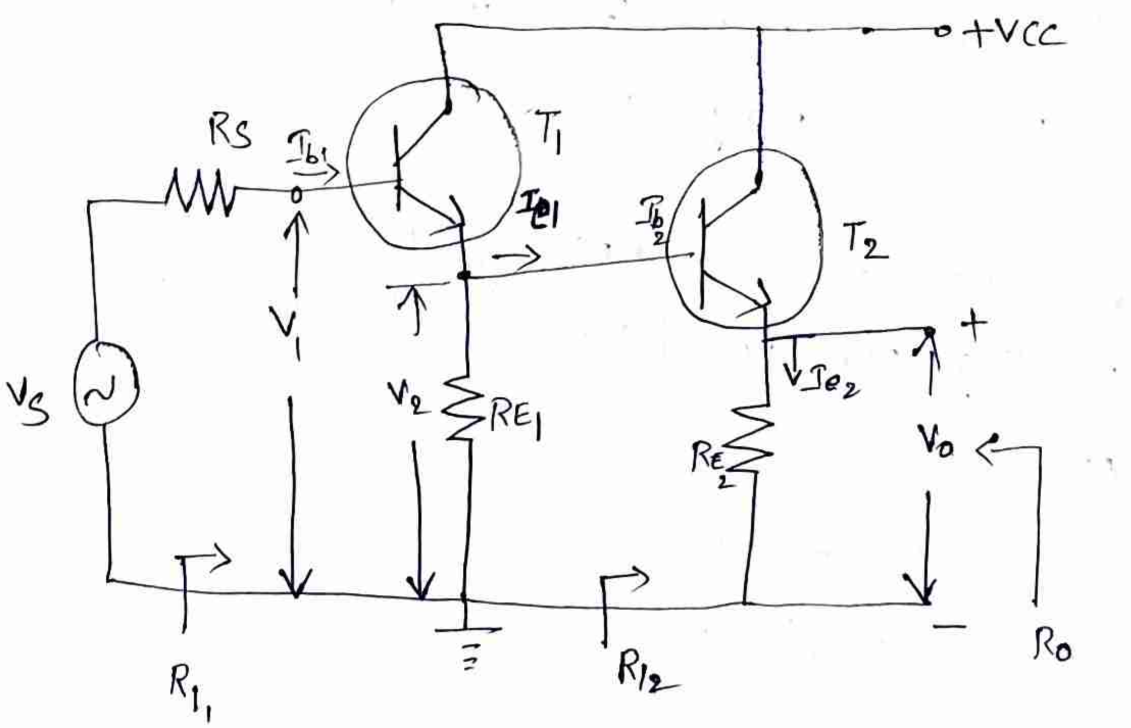
Darlington amplifier:-

out of three configurations CE, CB and CC, or emitter follower circuit has high i/p impedance. Typically it is 200KΩ to 300KΩ. However, the input Impedance considering biasing resistors is Significantly less. The input impedance of the circuit can be improved by direct coupling of two stages of emitter follower amplifier. The input impedance can be increased using two techniques

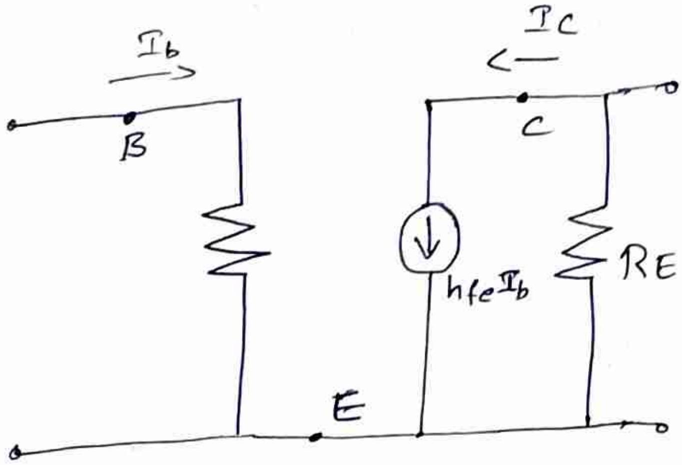
→ using direct coupling (Darlington connection)

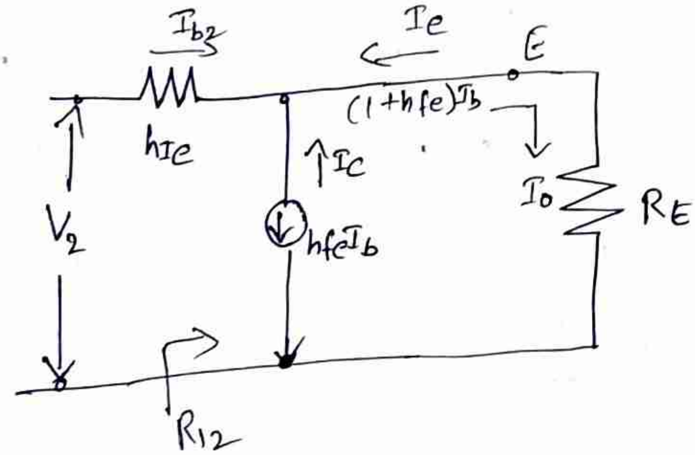
→ using Bootstrap technique.

Circuit diagram:-



Ac equivanlent:





Analysis of second stage:-

Current gain $A_{i2} = \frac{I_o}{I_b}$

$= \frac{-I_e}{I_b}$

$= \frac{I_b(1+h_{fe})}{I_b}$

$A_{i2} = 1 + h_{fe}$

Input Resistance $R_{i2} = \frac{V_2}{I_{b2}}$

Applying KVL to outer loop we get

$V_2 - I_{b2} h_{ie} - I_o R_E = 0$

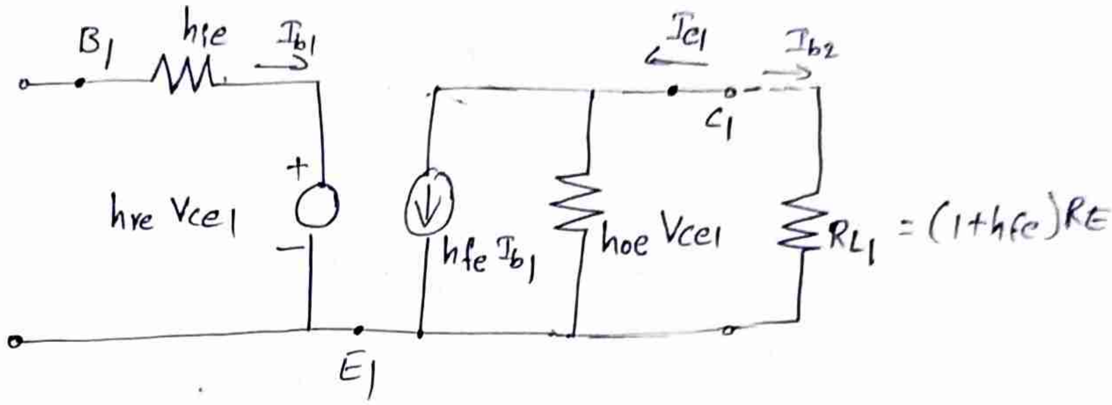
$$V_2 = I_{b2} h_{ie} + I_o R_E$$

$$\frac{V_2}{I_{b2}} = h_{ie} + \frac{I_o}{I_{b2}} R_E$$

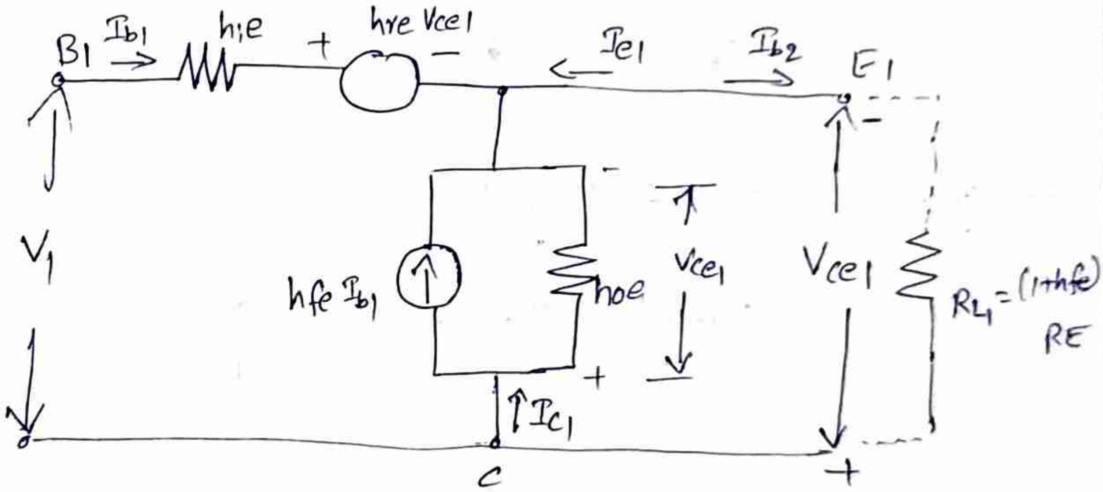
$$R_{i2} = h_{ie} + A_{i2} R_E$$

$$R_{i2} = h_{ie} + (1+h_{fe}) R_E$$

Analysis of first stage:-



The same circuit can be redrawn as



Current gain $A_{i1} = \frac{I_{b2}}{I_{b1}}$

$$= \frac{I_{e1}}{I_{b1}}$$

$$I_{e1} = -(I_{b1} + I_{c1})$$

$$I_{c1} = h_{fe} I_{b1} + h_{oe} V_{ce1}$$

$= h_{fe} I_{b1} + h_{oe} (-I_{b2} R_{L1})$

$= h_{fe} I_{b1} + h_{oe} (I_{e1} R_{L1})$

Sub value of I_{C1} in equation

$= -(I_{b1} + I_{C1})$ we get,

$$I_{e1} = -(I_{b1} + h_{fe} I_{b1} + h_{oe} (I_{e1} R_{L1}))$$

$$I_{e1} + h_{oe} (I_{e1} R_{L1}) = -I_{b1} (1+h_{fe})$$

$$-\frac{I_{e1}}{I_{b1}} = \frac{1+h_{fe}}{1+h_{oe}(1+h_{fe}) R_E}$$

$$A_{i1} = \frac{I_{e1}}{I_{b1}} = \frac{(1+h_{fe})}{1+h_{oe} h_{fe} R_E}, \quad h_{fe} >> 1$$

Input Resistance :-

$$R_{i1} = \frac{V_1}{I_{b1}}$$

Apply KVL to o/p loop we get

$$V_i - I_{b1} h_{ie} - h_{re} V_{ce1} + V_{ce1} = 0$$

$$V_i = I_{b1} h_{ie} + h_{re} V_{ce1} - V_{ce1}'$$

The terms $h_{re} V_{ce1}$ is negligable since h_{re} is in the order of 2.5×10^{-4}.

$$= I_{b1} h_{ie} - (-I_{b2} R_L)$$

$$= I_{b1} h_{ie} + I_{b2} R_L$$

$$R_{i1} = \frac{V_1}{I_{b1}} = h_{ie} + \frac{I_{b2}}{I_{b1}} R_{L1} = h_{ie} + A_{i1} R_{L1}$$

$$R_{i1} = h_{ie} + A_{i1} (1+h_{fe}) R_E$$

Substitute the value of A_{i1} we get

$$R_{i1} = \frac{V_1}{I_{b1}} = h_{ie} + \frac{(1+h_{fe})(1+h_{fe}) R_E}{1+h_{oe} h_{fe} R_E}$$

$$R_{i1} = h_{ie} + \frac{(1+h_{fe})^2 R_E}{1+h_{oe} h_{fe} R_E}$$

Overal Current gain (A_i),

$$A_i = A_{i1} \times A_{i2}$$

$$= \frac{(1+h_{fe})(1+h_{fe}) R_E}{1+h_{oe}(1+h_{fe}) R_E}$$

$$= \frac{(1+h_{fe})^2 R_E}{1+h_{oe}(1+h_{fe}) R_E}$$

Overal voltage gain (A_v),

$$A_v = A_i \frac{R_L}{R_i}$$

By subracting '1' on both sides we get

$$1 - A_v = 1 - A_i \frac{R_L}{R_i}$$

$$1 - A_v = \frac{R_i - A_i R_L}{R_i} = \frac{h_{ic} + h_{rc} A_i R_i - A_i R_L}{R_i}$$

$$= \frac{h_{ie}}{R_i}$$

$$A_v = 1 - \frac{h_{ie}}{R_i}$$

output Resistance (R_{o2}),

$\cancel{R_{o} = \frac{}{V_o}}$

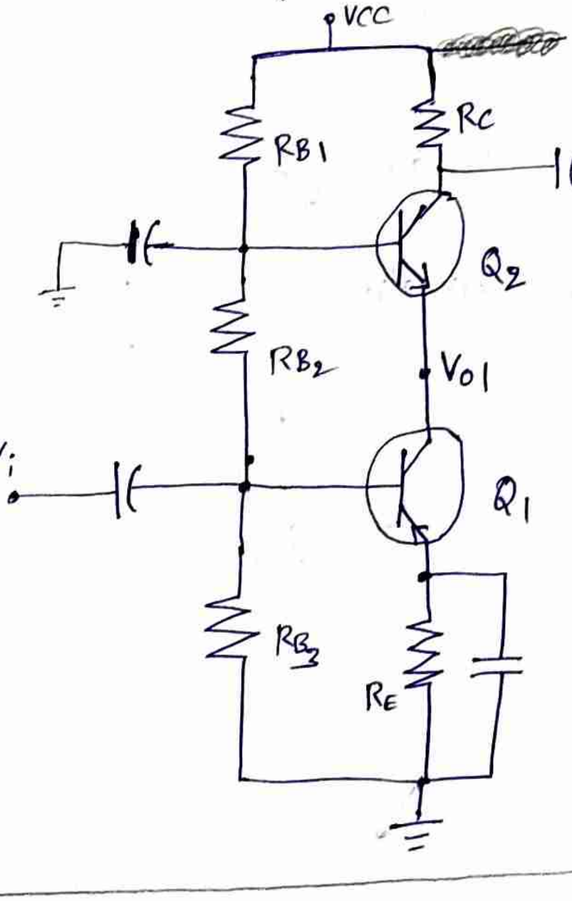
$$R_{o2} = \frac{R_s}{1+(h_{fe})^2} + \frac{2h_{ie2}}{1+h_{fe}}$$

Cascode Amplifier:-

Cascode amplifier is a Composite amplifier pair with a large bandwidth used for RF applications and as a video amplifier. It consists of a CE stage followed by a CB stage directly coupled to each other and combines some of the features of both the amplifiers.

For High frequency applications, CB configuration has the most desirable characteristics. However its suffers from low input impedance. The cascode configuration is designed to have the input impedance essentially that of CE amplifier. the current gain that of CE amplifier, the voltage gain that of CB amplifier and good isolation b/w the i/p & o/p.

The following fig. shows a cascode amplifier.



$1 + h_{oe} h_{fe} R_E$

Overall voltage gain

The voltage gain of the first stage CE amplifier is

$$A_{v_1} = \frac{V_{o1}}{V_i} = \frac{-R_{L1}}{r_{e1}}$$

Where $-R_{L1}$ is the load resistance as seen by $Q_1 = r_{e1} = h_{ib2}$ of Q_2, the i/p impedance of the second CB stage.

Hence,

$$A_{v_1} = \frac{V_{o1}}{V_i} = \frac{-r_{e2}}{r_{e1}}$$

consider identical transistors $r_{e1} = r_{e2}$

$$A_{v_1} = -1$$

The gain of the CE amplifier stage is maintained low to ensure that the i/p miller capacitance level is minimum for high frequency applications.

Voltage gain of the second CB stage is given by

$$A_{v_1} = \frac{R_{L2}}{r_{e2}} = \frac{R_C}{r_{e2}}$$

So that the overall voltage gain,

$$A_v = A_{v_1} A_{v_2} = \frac{-r_{e2}}{r_{e1}} \frac{R_C}{r_{e2}}$$

$$= \frac{-R_C}{r_{e1}}$$

$$= -g_{m1} R_C.$$

UNIT - 2

Feedback amplifiers

Introduction :

→ Feedback plays a very important role in electronic circuits.

→ Feedback is mostly used in amplifiers to improve its performance and to make it more ideal.

→ The process of feedback :

(i) the portion or part of the output signal is taken from the output of the amplifier and it is combined with the normal input signal.

(ii) Both the signals (i.e., input signal and part of the output signal) are inphase, the feedback is called positive feedback.

(iii) Both the signals (i.e., input signal and part of the output signal) are not inphase, the feedback is called negative feedback.

Classification of amplifiers (or) Feedback topology :-

1. Voltage amplifier $= \frac{V_o}{V_i}$ → voltage mixing voltage sampli[ng]

2. Current amplifier $= \frac{I_o}{I_i}$ → Current mixing current samplin[g]

3. Transconductance amplifier $= \frac{I_o}{V_i}$

→ voltage mixing current sampling

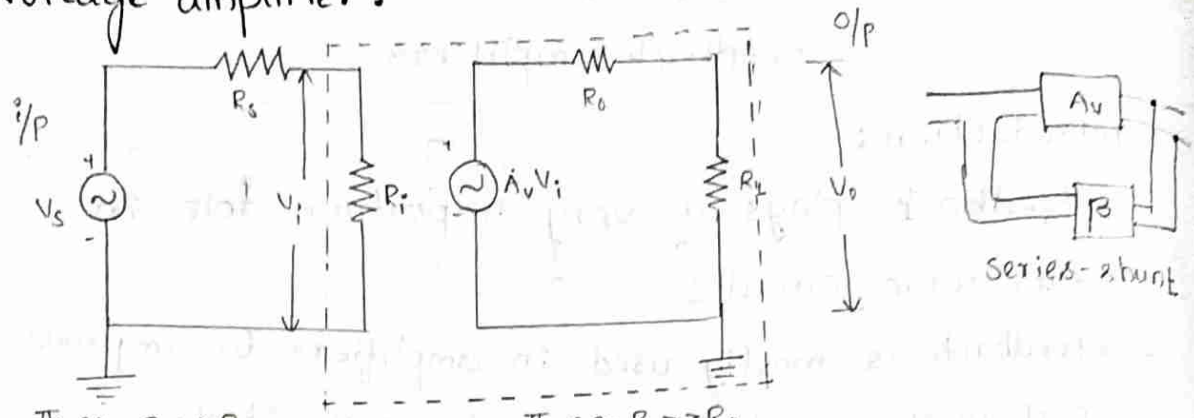
4. Trans resistance amplifier $= \frac{V_o}{I_i}$

→ Current mixing voltage sampling

* An amplifier is a circuit that has power gain > one.

$$\text{power gain} = \frac{o/p \text{ signal}}{i/p \text{ signal}}$$

1. Voltage amplifier :



→ If the amplifier i/p resistance (R_i) is large compared with the source resistance (R_s), then $V_i \simeq V_s$

→ If the external load resistance (R_L) is compared with the output resistance (R_0) ~~ext~~ of the amplifier $V_0 = A_v V_i$

→ Such amplifier circuit provides a voltage output proportional to the voltage input and the proportionality factor doesn't depend on the magnitudes of the source and load resistances.

→ Hence this amplifier is called voltage amplifier (voltage control voltage source).

→ An Ideal voltage amplifier must have infinite input resistance ($R_i = \infty$) and zero output resistance ($R_0 = 0$).

→ For practical voltage amplifier must have $R_i >> R_s$ and $R_0 << R_L$.

2 Current amplifier :

→ If amplifier o/p resistance (R_0) is infinite, then

$I_L = A_I \cdot I_i$

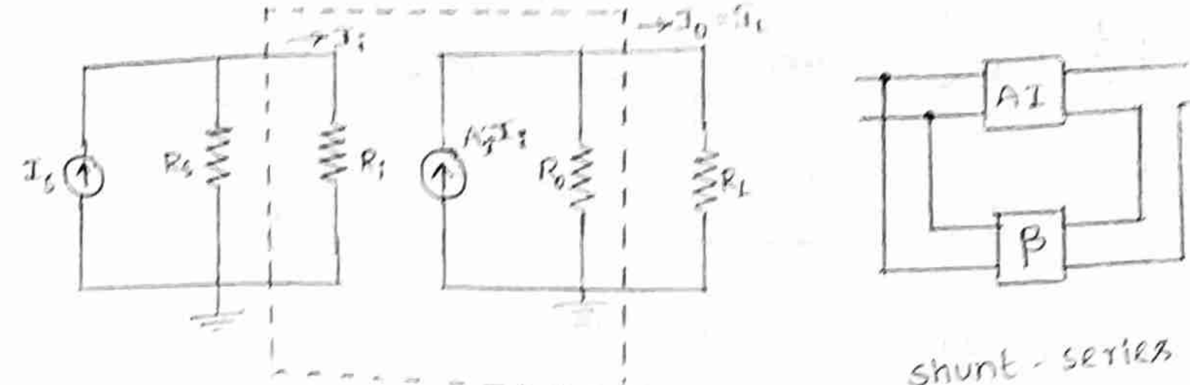
→ If amplifier i/p resistance (R_i) is zero, then $I_i \simeq I_s$

$$\therefore I_L = A_I \cdot I_S$$

→ such amplifier provides a current proportional to the signal input current and the proportionality factor is independent of source and load resistances.

→ Hence this amplifier is called current amplifier

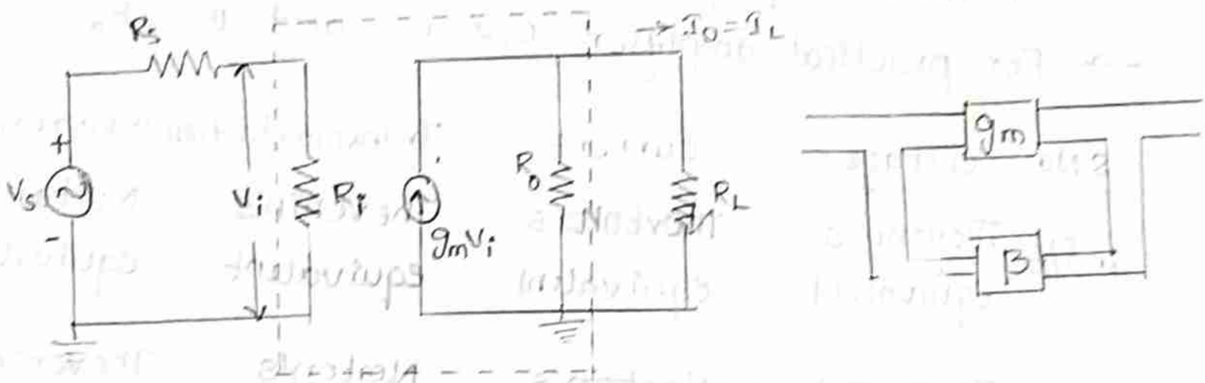
→ It is a current controlled current source



shunt - series

Norton's equivalent $R_i << R_s$ | Norton's equivalent $R_L << R_o$

3. Transconductance amplifier :



Thevenin's equivalent $R_i >> R_s$ | Norton's equivalent $R_L << R_o$

→ In this amplifier, an o/p current is proportional to the i/p signal voltage and proportionality factor is independent of the magnitudes of the source and resistances.

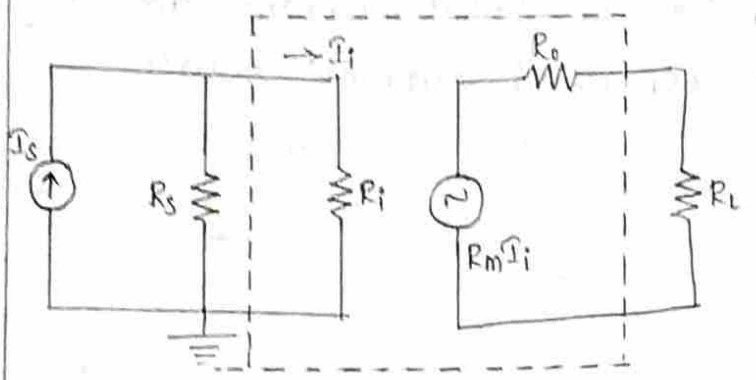
→ It is a current controlled voltage source.

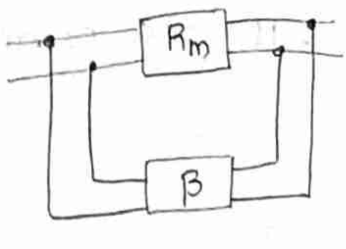
→ Ideally, the amplifier must have $R_i \to \infty$ and $R_o \to \infty$

→ For practical, transconductance amplifier must have $R_i >> R_s$ and $R_L << R_o$.

4. Transresistance amplifier :

→ In this amplifier, the o/p voltage is proportional to the i/p current and the proportionality factor is independent on the R_s & R_L of the amplifier.





Shunt - shunt

Norton's equivalent $R_i << R_s$

Thevenin's equivalent $R_L >> R_0$

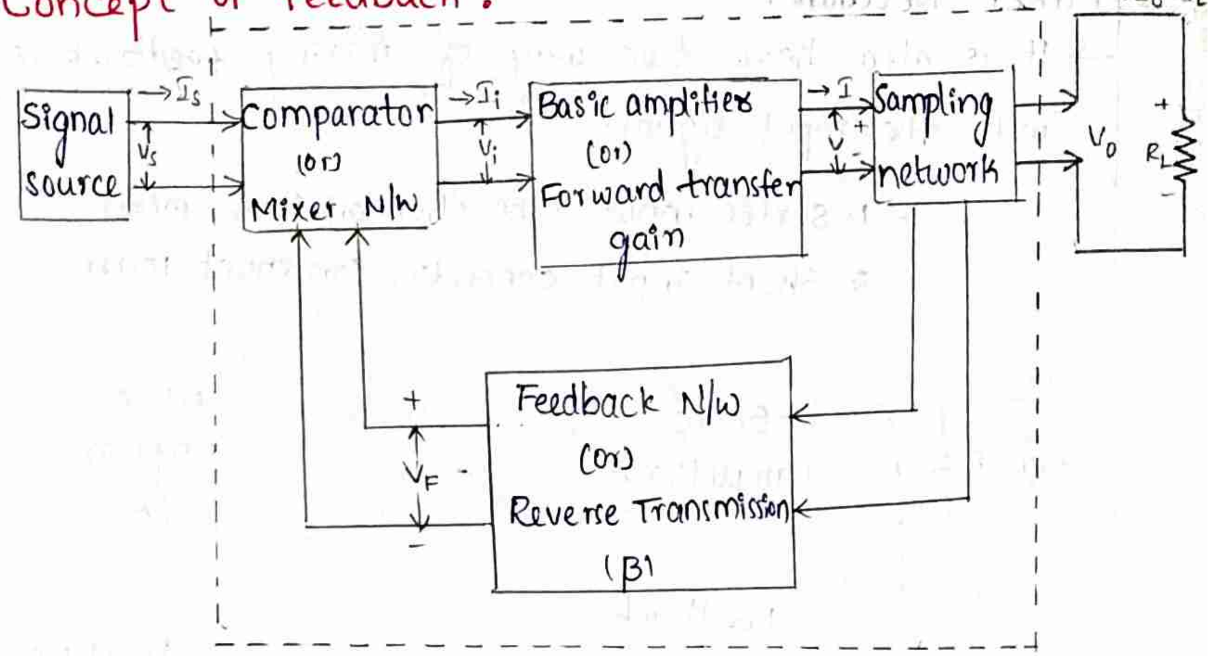
→ It is a voltage controlled current source.

→ In ideal amplifier $R_i \to 0$, $R_o \to 0$.

→ For practical amplifier $R_i << R_s$ and $R_L >> R_0$

S.NO	voltage	current	Transconductance	Trans resistance
1. i/p	Thevenin's equivalent	Norton's equivalent	Thevenin's equivalent	Norton's equivalent
2. o/p	Thevenin's equivalent	Norton's equivalent	Norton's equivalent	Thevenin's equivalent
3. Ideal i/p o/p	$R_i = \infty$ $R_0 = 0$	$R_i = 0$ $R_0 = \infty$	$R_i = \infty$ $R_0 = \infty$	$R_i = 0$ $R_0 = 0$
4. Prac. i/p o/p	$R_i >> R_s$ $R_0 << R_L$	$R_i << R_s$ $R_L << R_0$	$R_i >> R_s$ $R_L << R_0$	$R_i << R_s$ $R_L >> R_0$
5. P.F	A_V	A_I	g_m	R_m
6.	Independent of R_L, R_s	Independent of R_L, R_s	Independent of R_L, R_s	Independent of R_L, R_s

Concept of feedback :

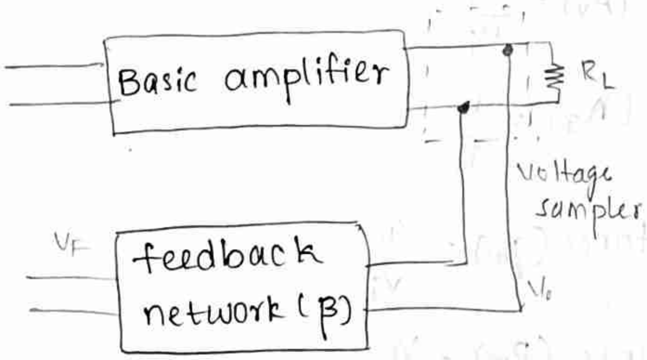


1. Sampling Network :

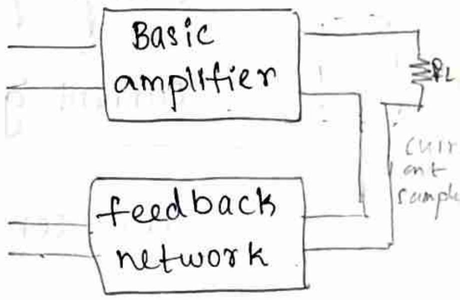
→ The o/p quantity voltage (or) current is sampled by a suitable sampler.

→ It is of two types.

1. Voltage sampler
2. Current sampler



Voltage (or) Node sampling



Current (or) Loop sampling

2. Feedback network :

→ It may consists of resistors, capacitors and inductors.

→ Most often it is simply a resistive configuration

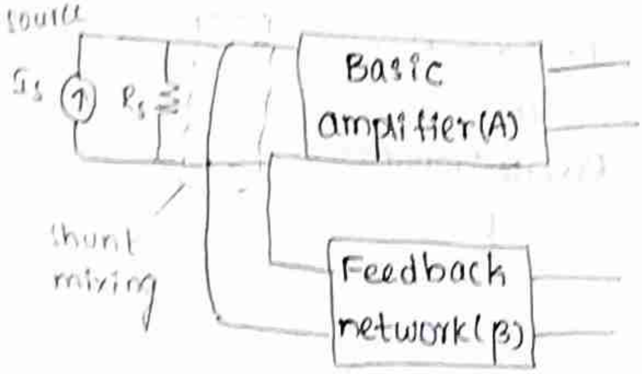
→ It provides reduced portion of the output as feedback signal to the input mixer network.

$$V_F = \beta V_0$$

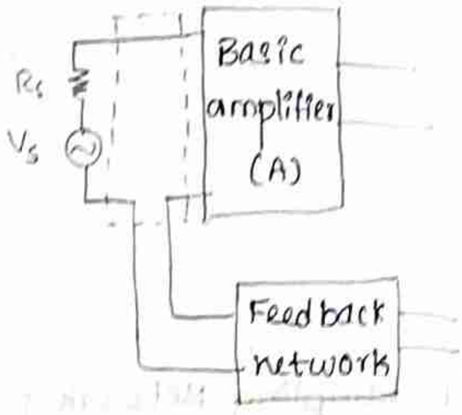
3. Mixer Network:

→ It is also have two ways of mixing feedback signal with the input signal.

1. Series input connection (or) series mixer
2. Shunt input connection (or) shunt mixer



Node mixing



Loop mixing

Transfer Ratio (or) gain:

→ The ratio of the output signal to the input signal of the basic amplifier is represented by the symbol (A)

Voltage gain $(A_V) = \frac{V_0}{V_i}$

Current gain $(A_I) = \frac{I_0}{I_i}$

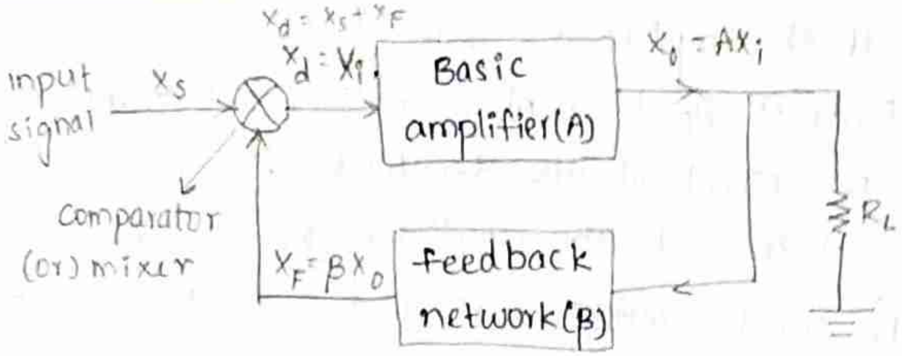
Trans conductance $(g_m) = \frac{I_0}{V_i}$

Trans resistance $(R_m) = \frac{V_0}{I_i}$

→ The four quantities A_V, A_I, g_m, R_m are referred as the transfer gain of the basic amplifier without feedback and use of symbol (A).

→ The transfer gain with feedback is represented by the symbol (A_F).

→ Here, the feedback signal is feedback to the input of the amplifer out of phase with input signal of the amplifier.



voltage gain with feedback $\frac{V_o}{V_s} = AV_F$

current gain with feedback $\frac{I_o}{I_s} = AI_F$

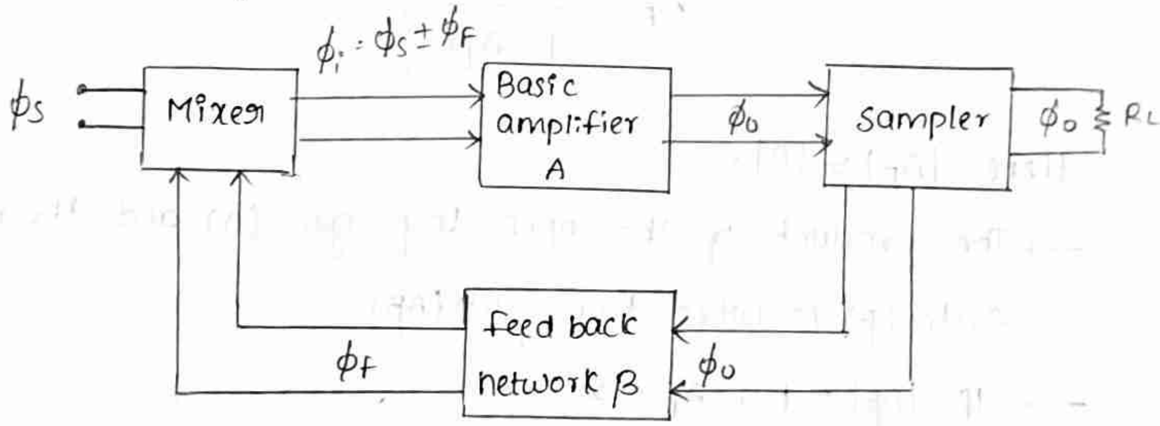
Transconductance with feedback $\frac{I_o}{V_s} = g_{mF}$

Trans resistance with feedback $\frac{V_o}{I_s} = R_{mF}$

Classification of Feedback amplifiers:

There are two types of feedback amplifiers. They are:

1. Positive feedback amplifier
2. Negative feedback amplifier



Here,

A = Gain of the basic amplifier $= \frac{\phi_o}{\phi_i}$

β = feedback ratio $= \frac{\phi_F}{\phi_o}$

A_F = gain of feedback amplifier $= \frac{\phi_o}{\phi_s}$

ϕ_s = ac signal in the i/p side (V or I)

ϕ_F = feedback signal (V or I)

Positive feedback amplifier:

→ If the feedback ϕ_F is inphase with input signal ϕ_S, then the net effect of the feedback will increase the input signal given to the amplifier $\boxed{\phi_i = \phi_S \pm \phi_F}$

→ Hence the input voltage applied to the basic amplifier is increased, thereby increasing ϕ_o exponentially.

→ This type of feedback is said to be positive or regenerative feedback.

→ In this positive feedback, amplifier accepts $\phi_i = \phi_S + \phi_F$.

$$\therefore A_F = \frac{\phi_o}{\phi_S} = \frac{\phi_o}{\phi_i - \phi_F}$$

$$= \frac{1}{\left(\frac{\phi_i}{\phi_o}\right) - \left(\frac{\phi_F}{\phi_o}\right)}$$

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

$$\boxed{A_F = \frac{A}{1 - A\beta}}$$

Here $|A_F| > |A|$.

→ The product of the open loop gain (A) and the feedback factor (β) is called loop gain ($A\beta$).

→ If $|A\beta| = 1$, $A_F = \infty$.

→ Hence the gain of the amplifier with positive feedback is infinite and the amplifier gives an ac output without ac input signal.

→ Thus the amplifier acts as an oscillator.

Disadvantages:

1. The +ve feedback increases the instability of an amplifier.
2. It reduces the bandwidth.
3. It increases the distortion and noise.

4. The property of the +ve feedback is utilized in oscillators.

Negative Feedback amplifiers:

→ If the feedback ϕ_F is not inphase with input signal ϕ_s, then the net effect of the feedback will decrease the input signal given to the amplifier.

→ Hence the input voltage applied to the basic ampr is decreased, thereby decreasing ϕ_o exponentially

→ This type of feedback is said to be negative feedback (or) degenerative feedback.

→ In this -ve feedback, amplifier accepts $\phi_i = \phi_s - \phi_F$

$$\therefore A_F = \frac{\phi_o}{\phi_s} = \frac{\phi_o}{\phi_i + \phi_F}$$

$$= \frac{1}{\frac{\phi_i}{\phi_o} + \frac{\phi_F}{\phi_o}}$$

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

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

Here $|A_F| < |A|$

→ The product of the node gain (A) and the f)

If $|A\beta| >> 1$, then $A_F = \frac{1}{\beta}$

→ Hence the gain depends less on the operating potentials and the characteristics of the transistor (or) vaccum tube.

→ The gain may be made to depend entirely on the feedback network.

→ If the feedback network contains only stable passive elements, the gain of the amplifier using -ve feedback is also stable.

Advantages:

1. -ve feedback is used to improve the performance of electronic device (amplifier).
2. It always helps to improve the bandwidth.
3. It reduces the distortion and noise
4. It modify input and output resistances as desired.

→ All above advantages are obtained at the expense of reduction in voltage gain.

General Characteristics of -ve feedback amplifiers:

→ The +ve feedback in amplifier circuits result in oscillator.

→ The -ve feedback in amplifier circuits results in decreased voltage gain, noise and distortion and increase in bandwidth.

1. Better stabilized voltage gain
2. Enhanced frequency response
3. Higher Input impedance
4. Lower output impedance
5. Reduction in noise
6. Increase in Linearity

1. Better stabilized voltage gain:

→ The gain of the amplifier with -ve feedback is

$$A_F = \frac{A}{1+A\beta} \longrightarrow (1)$$

Differentiating eqn(1) wrt 'A'

$$\frac{dA_F}{dA} = \frac{-A(0+\beta)+1(1+A\beta)}{(1+A\beta)^2} \qquad \frac{Vu'-uV'}{V^2}$$

$$= \frac{A\beta+1-A\beta}{(1+A\beta)^2}$$

$$= \frac{1}{(1+A\beta)^2}$$

$$\frac{1}{(1+A\beta)^2} = \frac{1}{1+A\beta} \cdot \frac{1}{1+A\beta}$$

from eqn (1) $= \frac{A_F}{A} = \frac{1}{1+A\beta}$

$$\therefore \frac{dA_F}{dA} = \frac{A_F}{A} \cdot \frac{1}{1+A\beta}$$

$$\frac{dA_F}{A_F} = \frac{dA}{A} \cdot \frac{1}{1+A\beta}$$

$$\frac{\left|\frac{dA_F}{A_F}\right|}{\left|\frac{dA}{A}\right|} = \frac{1}{1+A\beta} = S$$

where $\frac{dA_F}{A_F}$ represents the fractional change in amplifier voltage gain with feedback

$\frac{dA}{A}$ represents the fractional change in voltage gain without feedback.

here, $\frac{1}{1+A\beta}$ is called stability factor (or) it indicates the sensitivity of the amplifier.

→ The Reciprocal of the sensitivity is called desensitivity

2. ~~Enhanced Freque~~

2. Decreased distortion :

$$D_F = \frac{D}{1+A\beta}$$

3. Decreased Noise :

→ There are many sources of noise in an amplifier depending upon the active device used.

→ With using the -ve feedback with the feedback ratio(β) and the noise (N) can be reduced by a factor of $\frac{1}{1+A\beta}$.

$$N_F = \frac{N}{1+A\beta}.$$

4. Increase Of Bandwidth :

→ The bandwidth of an amplifier is the difference between the upper cut off frequency (f_2) and the lower cutoff frequency (f_1)

→ The product of voltage gain and bandwidth of an amplifier with feedback and without feedback are same.

$$\boxed{A_F \times BW_f = A \cdot BW}$$

→ As A_F reduces by the factor $\frac{1}{1+A\beta}$, its band width would be increased by $1+A\beta$.

$$\boxed{BW_f = (1+A\beta) BW} \quad \text{at mid band gain} \cdot A = 1$$

→ Due to -ve feedback in the amplifier, the upper 3db cut off frequency (f_2f) is increased by the factor $(1+A\beta)$ and the lower 3db cut off frequency (f_1f) is decreased by the factor $(1+A\beta)$.

$$f_2f = f_2(1+A\beta)$$

$$f_1f = \frac{f_1}{1+A\beta}.$$

5. Increased Input Impedance :

→ An amplifier should have high input impedance (resistance) so that it will not load the source, i.e., input voltage source.

→ Such desirable characteristic can be achieved with the help of -ve feedback.

$$\boxed{Z_{if} = Z_i(1+A\beta)}$$

6. Decreased output Impedance :

$$Z_{of} = \frac{Z_0}{1+A\beta}$$

	O/p	i/p
V	shunt	series
I	series	shunt

the output resistance of the amp...

Effect of Negative feedback on Amplifier Characteristics :

***.

SL No	Characteristic	Negative Feedback Amplifies.			
		Voltage-Series	Voltage-Shunt	Current-Series	Current-Shunt.
1	Voltage gain	Decreases	Decreases	Decreases	Decreases
2	Bandwidth	Improves or Increases	Increases	Increases	Increases.
3	Harmonic Distortion	Reduces or Decreases	Decreases	Decreases	Decreases
4	Noise	or Reduces Decreases	Decreases	Decreases	Decreases.
5	Input Resistance R_{if}	Increases $R_i(1+A\beta)$	Decreases $R_i/(1+A\beta)$	Increases $\frac{R_i}{(1+A\beta)}$	Decreases. $\frac{R_i}{1+A\beta}$.
6	Output Resistance R_{of}	Decreases $R_o/(1+A\beta)$	Decreases $\frac{R_o}{1+A\beta}$	Increases $R_o(1+A\beta)$	Increases. $R_o(1+A\beta)$.

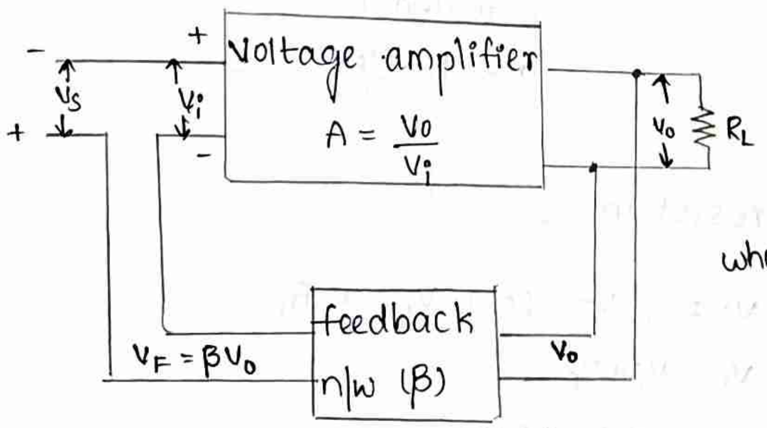
Types of negative-feedback amplifier :

1. voltage-series feedback amp'r se-sh
2. voltage-shunt feedback amp'r sh-sh
3. current-series feedback amp'r se-se
4. Current-shunt feedback amp'r sh-se

→ In the classification, the first term voltage refers to connecting o/p voltage as i/p to the feedback n/w & current refers to taking of o/p current as i/p to the feedback n/w.

→ The second terms, series refers to connecting the feedback signal in series to the i/p signal & shunt refers to connecting the feedback signal in shunt with an i/p signal.

1. voltage-series / series-shunt feedback :



where $A = A_v$

→ The gain of the amplifier without feedback $A = \frac{V_o}{V_i}$,

If the feedback is connected $V_s = V_i + V_F$

$$V_i = V_s - V_F$$

$$\beta = \frac{V_F}{V_o} \Rightarrow V_F = \beta V_o.$$

$$V_s = V_i + \beta V_o$$

$$V_s = V_i + \beta (AV_i)$$

$$\boxed{V_s = V_i (1 + A\beta)}$$

→ The gain of the amplifier with feedback,

$$A_{VF} = \frac{V_0}{V_S} = \frac{AV_i}{V_i(1+A\beta)}$$

$$\boxed{A_{VF} = \frac{A}{1+A\beta}}$$

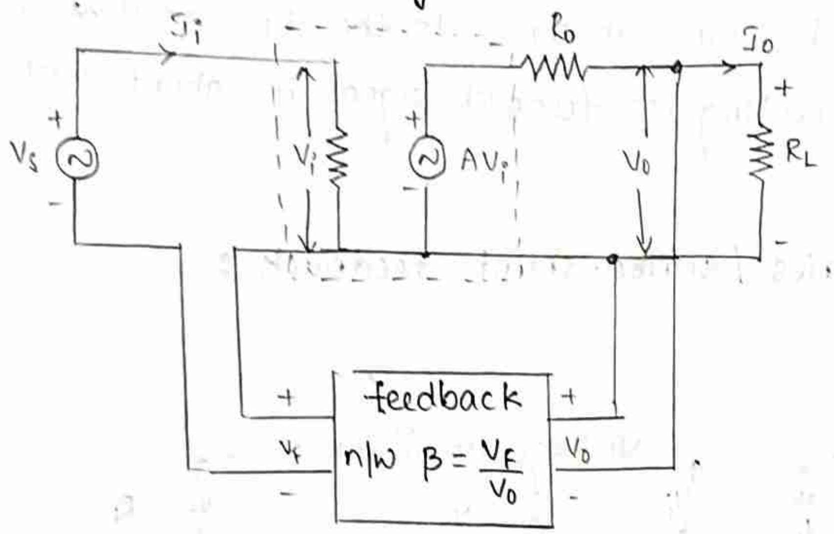
→ The shunt connection at the o/p reduces the o/p resistance

→ The series connection at the o/p reduces the o/p resistance

→ The series connection at the i/p increases the i/p resistance.

→ Here the basic amplifier is a true voltage amplifier.

Equivalent of the voltage-series feedback amplifier:



Input resistance:

$V_i = V_S - V_F$ (or) $V_i = I_i R_i$

$V_S = V_i + V_F$

$= I_i R_i + \beta V_0$ $(V_F = \beta V_0)$

$= I_i R_i + A\beta V_i$ $(V_0 = AV_i)$

$= I_i R_i + A\beta (I_i R_i)$

$V_S = I_i R_i (1+A\beta)$

$$R_{iF} = \frac{V_S}{I_i} = R_i(1+A\beta)$$

$$\boxed{R_{iF} = R_i(1+A\beta)}$$

Output resistance :

$$V_0 = I_0 R_0 + AV_i$$

$$V_i = V_S - V_F$$

($\because V_s$ is transferred to the o/p side hence $V_S = 0$)

$$V_i = -V_F$$

$$\therefore V_0 = I_0 R_0 - AV_F$$

$$V_0 = I_0 R_0 - A\beta V_0$$

$$(1+A\beta) V_0 = I_0 R_0$$

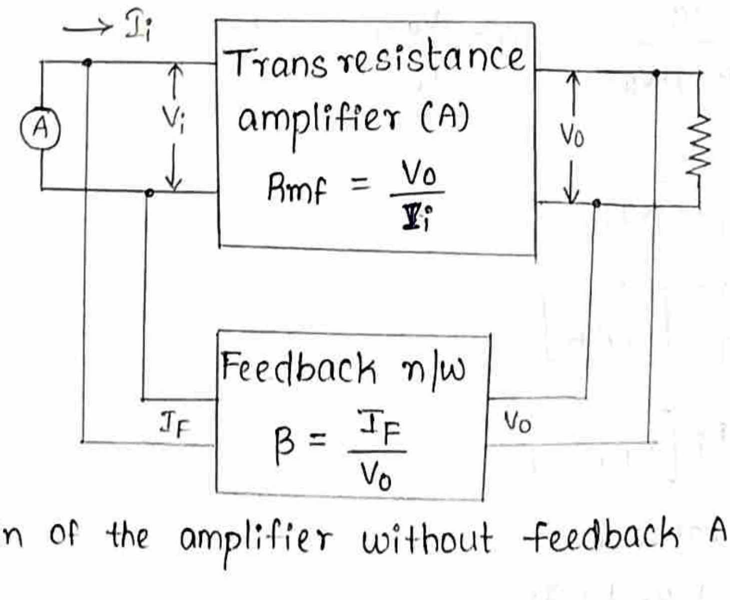
$$R_0 = \frac{(1+A\beta) V_0}{I_0}$$

$$R_0 = \frac{V_0}{I_0}(1+A\beta)$$

$$\boxed{R_{OF} = \frac{V_0}{I_0} = \frac{R_0}{1+A\beta}}$$

→ Hence the o/p resistance is reduced by a factor of $(1+A\beta)$ from the output impedance of the amplifier without feedback and the input impedance increased by a factor of $(1+A\beta)$.

2. voltage - shunt feedback amplifier (OR) shunt - shunt :



The gain of the amplifier without feedback $A = \frac{V_0}{I_i}$

$$V_0 = A I_i$$

$$I_S = I_i + I_F \quad \text{(or)} \quad I_i = I_S - I_F$$

$$= I_i + \beta V_0$$

$$= I_i + A\beta I_i$$

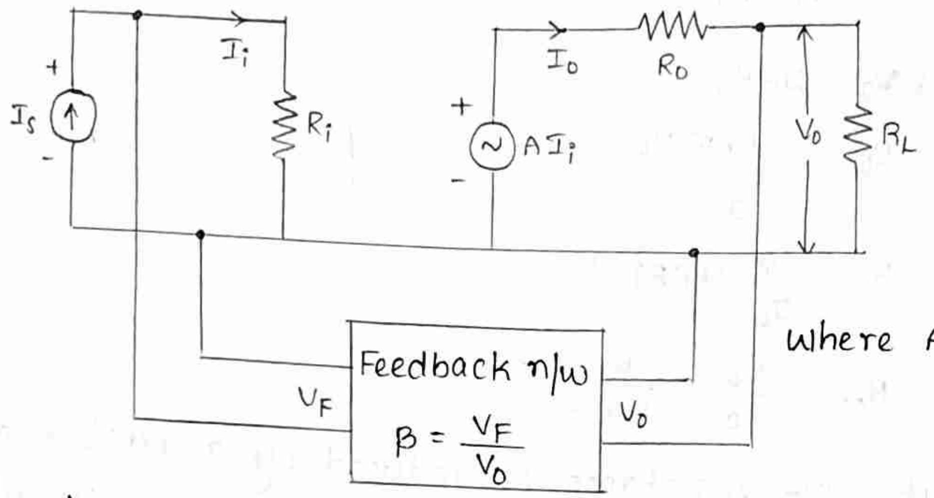
$$= (1+A\beta) I_i$$

$$A_F = \frac{V_O}{I_S}$$

$$A_F = \frac{AI_i}{(1+A\beta)I_i}$$

$$\boxed{A_F = \frac{A}{1+A\beta}}$$

Equivalent circuit for voltage-shunt feedback amplifier:



where $A = R_m$

Input resistance:

$$R_{iF} = \frac{V_i}{I_S}$$

$$= \frac{V_i}{I_i + I_F}$$

$$= \frac{V_i}{I_i + \beta V_O} \quad \left(\because A = \frac{V_O}{I_i}\right)$$

$$= \frac{V_i}{I_i + A\beta I_i}$$

$$= \frac{V_i}{I_i}\left[\frac{1}{1+A\beta}\right]$$

$$\boxed{R_{iF} = R_i\left[\frac{1}{1+A\beta}\right]}$$

Output resistance:

$$V_O = I_O R_O + A I_i$$

$$I_i = I_S - I_F$$

→ I_S is transferred to the output side, i.e., $I_S = 0$

$$I_i = -I_F$$

$$V_O = I_O R_O - A I_F$$

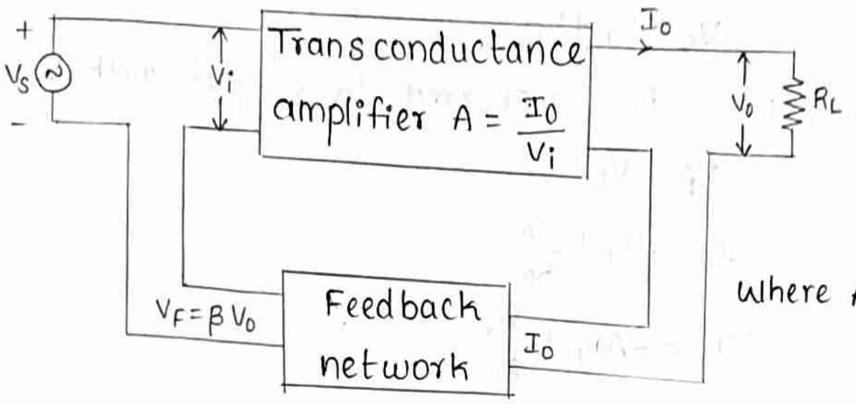
$$= I_O R_O - A\beta V_O \quad [\because I_F = \beta V_O]$$

$$V_0(1+A\beta) = I_0 R_0$$

$$\boxed{R_{OF} = \frac{V_0}{I_0} = \frac{R_0}{1+A\beta}}$$

→ Both the input resistance & output resistance is reduced by a factor of $(1+A\beta)$ from the input and output resistance of the amplifier without feedback.

3. Current-series feedback amplifier (or) Series-Series :



where $A = g_m$

The gain of the amplifier without feedback

$$A = \frac{I_0}{V_i}, \quad I_0 = AV_i$$

$$\text{Feedback ratio } (\beta) = \frac{V_F}{I_0}$$

$$V_F = \beta I_0$$

The gain of the amplifier with feedback

$$V_s = V_i + V_F$$

$$A_F = \frac{I_0}{V_s}$$

$$= \frac{I_0}{V_i + V_F}$$

$$= \frac{AV_i}{V_i + A\beta V_i}$$

$$= \frac{AV_i}{V_i(1+A\beta)}$$

$$\boxed{A_F = \frac{A}{1+A\beta}}$$

Input resistance :

$$V_s = V_i + V_F$$

$$= V_i + \beta I_0$$

$$V_s = V_i + A\beta V_i$$

$$V_s = V_i(1+A\beta)$$

$$V_s = I_i R_i (1+A\beta)$$

$$\frac{V_s}{I_i} = R_i(1+A\beta)$$

$$\boxed{R_{iF} = R_i(1+A\beta)}$$

Output resistance :

$$V_s = V_i + V_F$$

→ If $V_s = 0$, V_s is transferred to output with V_s shorted.

$$V_i = -V_F$$

$$I_0 = AV_i + \frac{V_0}{R_0}$$

$$I_0 = -AV_F + \frac{V_0}{R_0}$$

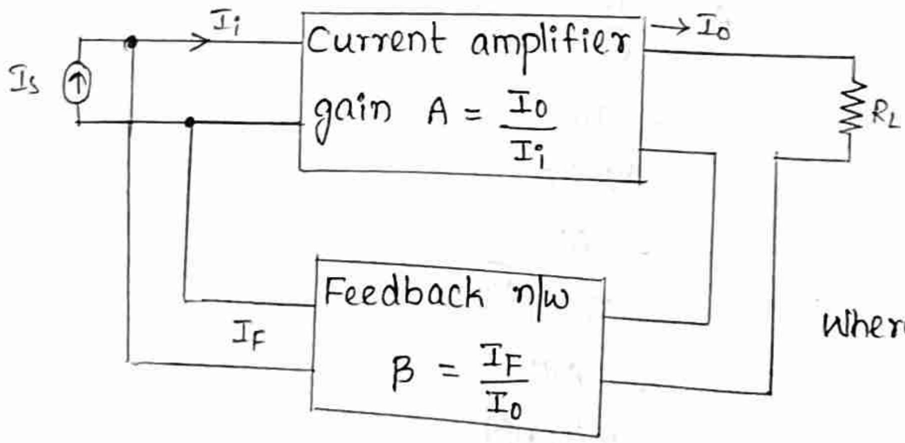
$$I_0 = -A\beta I_0 + \frac{V_0}{R_0}$$

$$(1+A\beta) I_0 = \frac{V_0}{R_0}$$

$$\frac{V_0}{I_0} = R_0(1+A\beta)$$

$$\boxed{R_{OF} = R_0(1+A\beta)}$$

4. Current shunt feedback amplifier (or) Shunt series :



Where $A = A_I$

The gain of the amplifier without feedback

$$A = \frac{I_0}{I_i} \Rightarrow I_0 = AI_i$$

Feedback ratio (β) $= \frac{I_F}{I_0} \Rightarrow I_F = \beta I_0$

$$I_S = I_i + I_F$$

The gain of the amplifier with feedback

$$A_F = \frac{I_0}{I_S}$$

$$= \frac{I_0}{I_i + I_F}$$

$$= \frac{A I_i}{I_i + \beta I_0}$$

$$= \frac{A I_i}{I_i(1+A\beta)}$$

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

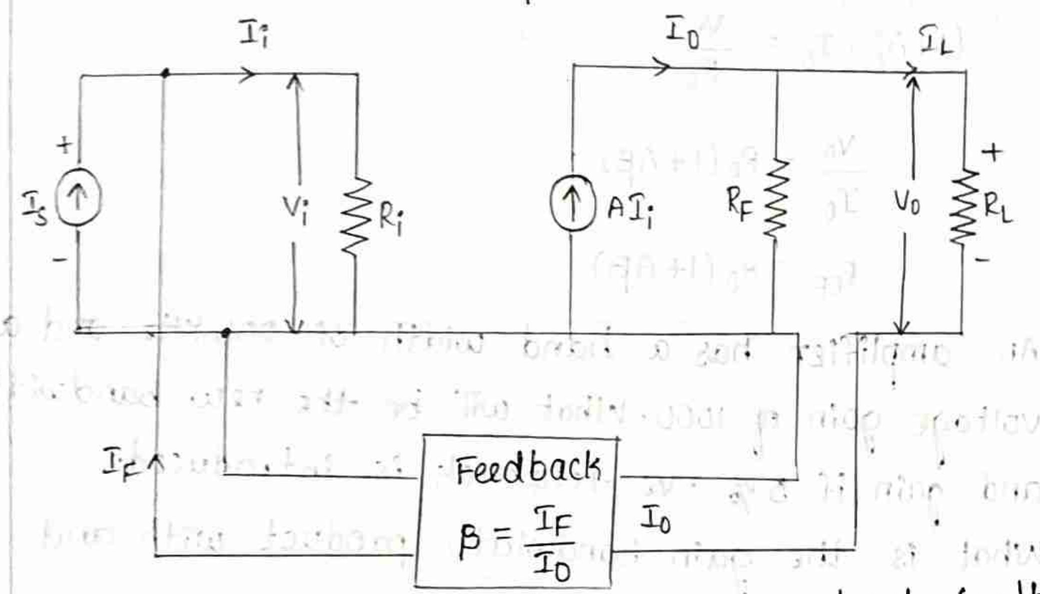


fig: Equivalent circuit of current shunt feedback.

Input resistance:

$$I_S = I_i + I_F$$

$$I_S = \frac{V_i}{R_i} + \beta I_0$$

$$I_S = \frac{V_i}{R_i} + A\beta I_i$$

$$I_S = \frac{V_i}{R_i} + A\beta \frac{V_i}{R_i}$$

$$I_S = \frac{V_i}{R_i}(1+A\beta)$$

$$R_{iF} = \frac{V_i}{I_S} = \frac{V_i}{\frac{V_i}{R_i}(1+A\beta)} = \frac{R_i}{(1+A\beta)}.$$

$$R_{iF} = \frac{R_i}{1+A\beta}$$

Output resistance:

$I_S = I_i + I_F$ (or) $I_i = I_S - I_F$

$\therefore I_S = 0$, the source is transfeored to output

$$I_i = -I_F$$

$$I_0 = AI_i + \frac{V_0}{R_0} \qquad \because I_F = \beta I_0$$

$$I_0 = \frac{V_0}{R_0} - AI_F$$

$$I_0 = \frac{V_0}{R_0} - A\beta I_0$$

$$(1+A\beta) I_0 = \frac{V_0}{R_0}$$

$$\frac{V_0}{I_0} = R_0(1+A\beta)$$

$$R_{0F} = R_0(1+A\beta)$$

1. (a) An amplifier has a band width of 200 KHz and a voltage gain of 1000. What will be the new bandwidth and gain, if 5% -ve feedback is introduced.

(b) What is the gain bandwidth product with and without feedback?

(c) What should be the amount of feedback if the bandwidth required is 1MHz.

Sol: Bandwidth without feedback (B.W) = 200 KHz

Voltage gain without feedback (A_V) = 1000

(a) $\beta = 5\% = 0.05$

The term $(1+A_V\beta) = 1+(1000 \times 0.05)$

$= 51$

Band width with feedback $(BW_F) = BW(1+A_V\beta)$

$= 10.2$ MHz

Voltage gain with feedback $(A_{VF}) = \frac{A_V}{1+A_V\beta}$

$= 19.6$

(b) Gain bandwidth product without feedback :

$$A_V \times BW = 1000 \times 200K$$

$$= 2 \times 10^8$$

Gain bandwidth product with feedback :

$$A_{VF} \times BW_F = 19.6 \times 10.2 \times 10^6$$

$$= 2 \times 10^8$$

2. An amplifier has an open loop gain of 1000. It's Lower and upper 3dB frequency are 50 Hz and 200 KHz respectively. It has a distortion of 5% without feedback. Determine the values of A_{VF}, Lower and upper 3dB frequencies and new distortion if a -ve feedback with $\beta = 0.01$ is applied.

Sol: Given,

$$A_V = 1000$$

$$\beta = 0.01$$

$$F_1 \text{ (or) } F_L = 50 \text{ Hz}$$

$$F_2 \text{ (or) } F_H = 200 \text{ KHz}$$

Distortion without feedback $= 5\%$

$= 0.05$

Voltage gain with feedback $(A_{VF}) = \dfrac{A_V}{1 + A_V\beta}$

$$= \frac{1000}{1 + (1000 \times 0.01)}$$

$$= \frac{1000}{11}$$

$$= 90.9$$

Upper 3dB frequency with feedback :

$$F_{2F} \text{ (or) } F_{HF} = F_2(1 + A_V\beta)$$

$$= 200\,[1 + (1000 \times 0.01)]$$

$$= 200\,[11]$$

$$= 2.2 \text{ MHz}$$

Lower 3dB frequency with feedback

$$F_{IF} \text{ (or) } F_{LF} = \frac{f_1}{(1+A_V\beta)}$$

$$= \frac{50}{[1+(1000\times0.01)]}$$

$$= \frac{50}{1+10}$$

$$= \frac{50}{11}$$

$$= 4.54 \text{ Hz}$$

Distortion with feedback $(D_F) = \dfrac{D}{1+A_V\beta}$

$$= \frac{0.05}{1+(1000\times0.01)}$$

$$= \frac{0.05}{11}$$

$$= 0.004$$

$$= 0.4\ \%$$

3. A current amplifier without feedback has the followin parameter values.

Short circuit current gain $(A_i) = -200$

Input resistance $(R_i) = 1\ k\Omega$

Output resistance $(R_o) = 40\ k\Omega$

Load resistance $(R_L) = 1\ k\Omega$

Band width $= 300\ \text{KHz}$.

Compute A_{iF}, R_{iF}, R_{oF} and BW_F, if 5% -ve current shunt feedback is used.

Sol: Given data is

$$\beta = 5\% = 0.05$$

Short circuit current gain $(A_i) = -200$

Input resistance $(R_i) = 1\ k\Omega$

Output resistance $(R_o) = 40\ k\Omega$

Load resistance $(R_L) = 1\ k\Omega$

Band width $(B.W) = 300\ KHz$

For -ve feedback $(1+A\beta)$ is +ve.

i.e., $(1+A\beta) >> 1$

So, we have to take $\beta = 0.05$, since A_I is -ve.

Factor Desensitivity $(1+A_i\beta)$

Input resistance with feedback for current shunt feedback

$$R_{if} = \frac{R_i}{1+A_I\beta}$$

$$= \frac{1K}{10.76}$$

$$= 92.94\ \Omega$$

Output resistance with feedback

$$R_{of} = R_o[1+A_I\beta]$$

$$= 40\ [10.76]$$

$$= 430.4\ k\Omega$$

If Load is consider $(R_o') = R_o \| R_L$

$$= 40K \| 1K$$

$$= \frac{40 \times 1}{41} K$$

$R_o' = 0.9756 \ K\Omega$

$R_o' = 975.6\Omega$

$1 + A_i\beta = 1 + (-200)(-0.05)$

$= 11$

$\boxed{\therefore \ 1 + A_I\beta = 10.76}$

$$R_{OF}' = \frac{R_o'(1 + A_i\beta)}{1 + A_I\beta}$$

$$= \frac{(0.976 K) \times 11}{10.76}$$

$$= \frac{10731.6}{10.76}$$

$= 997.7\Omega$

$R_{OF}' = 0.998 \ k\Omega$

$$A_{IF} = \frac{A_I}{1 + A_I\beta}$$

$$= \frac{-195.12}{10.76}$$

$A_{IF} = -18.13$

Bandwidth with feedback $(BW_F) = BW(1 + A_I\beta)$

$BW_F = 300K(10.76)$

$= 3.228 \ MHz$

4. An amplifier has voltage gain with feedback of 100. If the gain without feedback changes by 20 % and the gain with feedback should not vary more than 2%. Determine the value of open loop gain(A) and feedback ratio(β).

Ans: Given that,

$$A_F = 100$$

$$\frac{dA}{A} = 20\% = 0.2$$

$$\frac{dA_F}{A_F} = 2\% = 0.02$$

$$\text{sensitivity}(S) = \frac{\left(\frac{dA_F}{A_F}\right)}{\left(\frac{dA}{A}\right)} = \frac{0.02}{0.2} = 0.1$$

$$\frac{1}{1+A\beta} = 0.1$$

$$1+A\beta = 10$$

The gain with feedback $(A_F) = \frac{A}{1+A\beta}$

$$100 = \frac{A}{10}$$

$$\boxed{A = 1000}$$

$$1+A\beta = 10$$

$$A\beta = 9$$

$$\boxed{\beta = 0.9\%}$$

Oscillators

Introduction :

→ All electronic communication systems like TV, Radio, Computers and Industrial Instrumentation systems requires one or more of the different wave forms like sinusoidal, square, pulses or triangular wave of specified frequency and amplitude.

→ These signals are generated by electronic circuit known as oscillators or wave form generators.

→ It is basically an amplifier circuit with +ve feedback.

Oscillator :

→ It is a Circuit which is self generating some wave form without an ac input signal.

→ It is also known as converter. It converts power from dc supply into ac power.

Classification Of Oscillators :

→ Oscillators are classified in the following different ways.

⇒ 1. According to the wave form generated.

(a) sinusoidal (or) harmonic oscillator

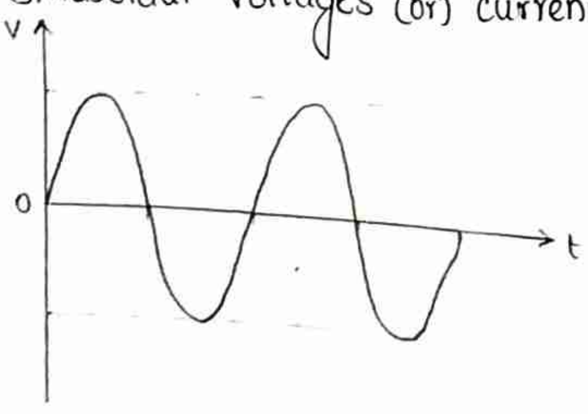
Ex: RC, LC

(b) Relaxation oscillator

Ex: UJT relaxation oscillator, multivibrators

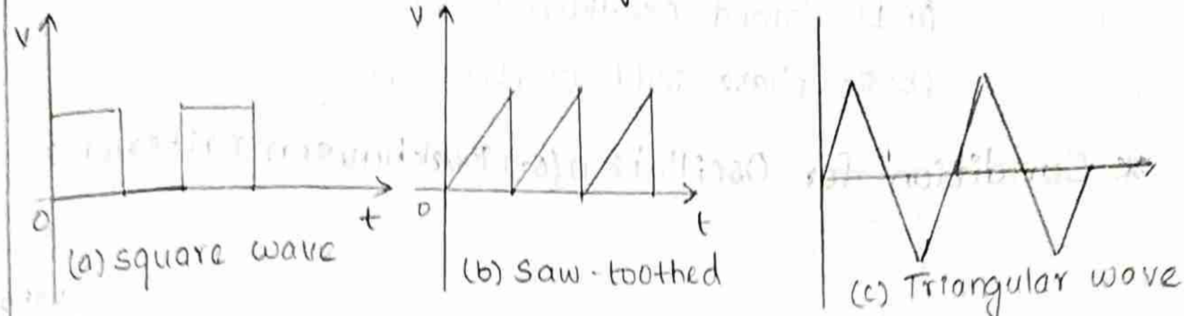
(a) **Sinusoidal Oscillator :**

→ It generates sinusoidal voltages (or) currents



(b) Relaxation Oscillator :

→ It generates voltage (or) currents which vary abruptly one (or) more times in a cycle of oscillations.



(a) square wave (b) Saw-toothed (c) Triangular wave

→ 2. According to the fundamental mechanisms involved.

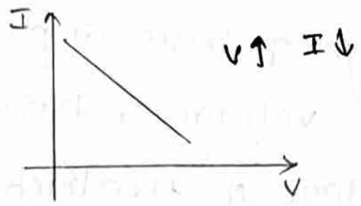
(a) –ve resistance oscillators / Two terminal oscillators

(b) Feedback oscillator | Four terminal oscillators

(a) –ve resistance oscillators :

→ It uses –ve resistance of the amplifying device to neutralize the +ve resistance of the oscillator.

Ex : Tunnel diode oscillator



(b) Feedback Oscillators :

→ It uses +ve feedback in the feedback amplifier to satisfy the "Barkhausen criterian".

Ex : RC oscillators, LC oscillators & Crystal oscillators

→ 3. According to the frequency generated

(a) Audio frequency oscillator : (20 Hz – 20 KHz)

(b) Radio frequency oscillator : 20 KHz – 30 MHz

(T.V, radio app) (c) Very High frequency Oscillator : 30 MHz – 300 MHz

(T.V. Broadcasting) (d) Ultra High frequency oscillator : 300 MHz – 3 GHz

(e) Microwave frequency oscillator : above 3 GHz

(Radar systems).

4. According to type of circuit used, sine wave oscillator may be classified as

(a) LC tuned oscillator (High frequency)

(b) RC phase shift oscillator (Low frequency)

* Condition for Oscillation (or) Barkhausen criterion :-

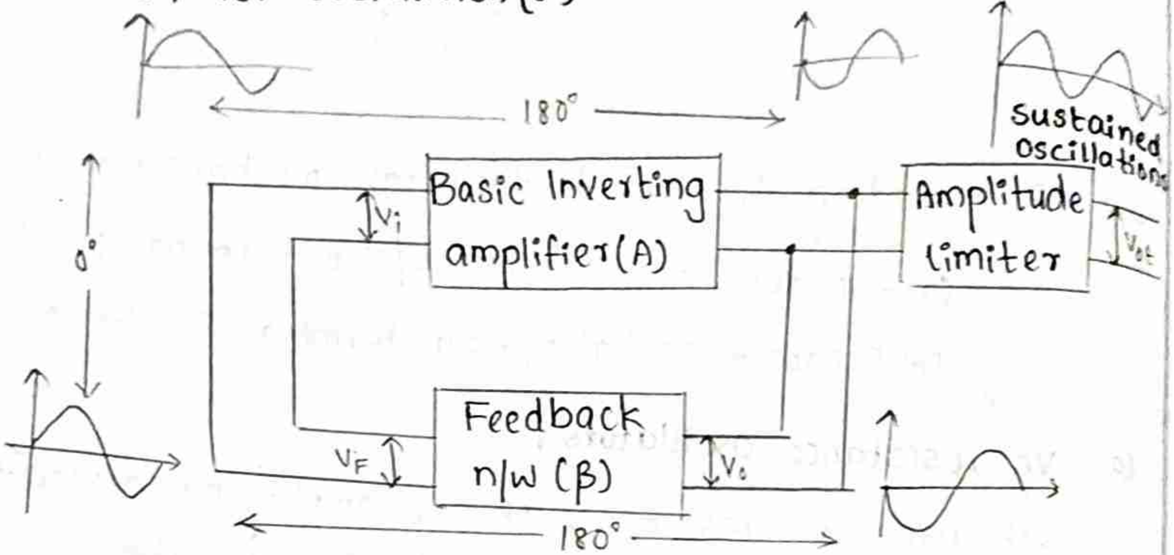


fig: Block diagram of Oscillator

Here, let us consider basic amplifier as a voltage amp'r.

and V_i = input voltage of basic amplifier

$V_0 = AV_i$ – output voltage of basic amplifier

V_F = output voltage of feedback network

$$\beta = \frac{V_F}{V_0} \qquad \boxed{\therefore V_F = \beta V_0}$$

→ To produce the oscillation, the feedback must be +ve i.e., feedback voltage should be inphase with input voltage (V_i).

→ Thus, feedback network needs to produce another shift of 180°.

→ This ensure the total phase shift with the loop is 360°, thus it produce the oscillation.

$$V_i = V_F$$
$$V_i = -\beta V_0$$

where –ve sign indicates that V_0 is 180° out of phase with V_F

$$V_i = -A\beta V_i$$

$$-A\beta = 1$$

$$\boxed{|A\beta| = 1}$$

→ The magnitude of the product of input open loop gain and feedback ratio is unity.

i.e., magnitude of $A\beta = 1$

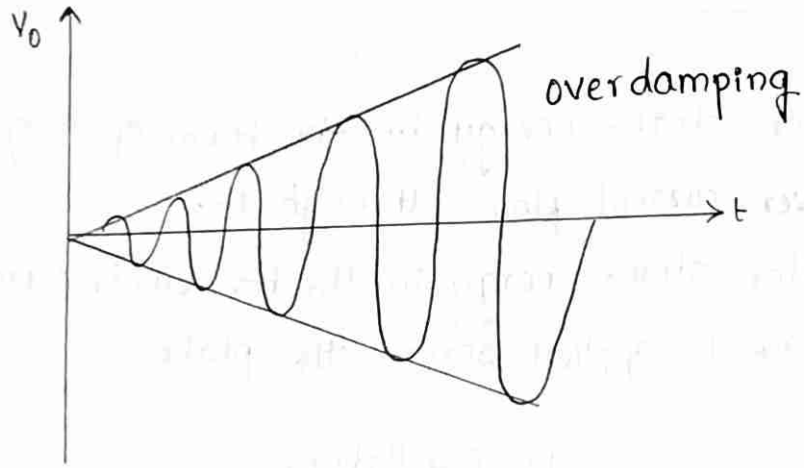
→ The <u>Barkhausen criterion defines</u> two basic requirements for oscillations.

1. The total phase shift in the closed loop is $0°$ or $360°$
2. ~~If thes~~ The magnitude of loop gain is unity. i.e., $|A\beta| = 1$

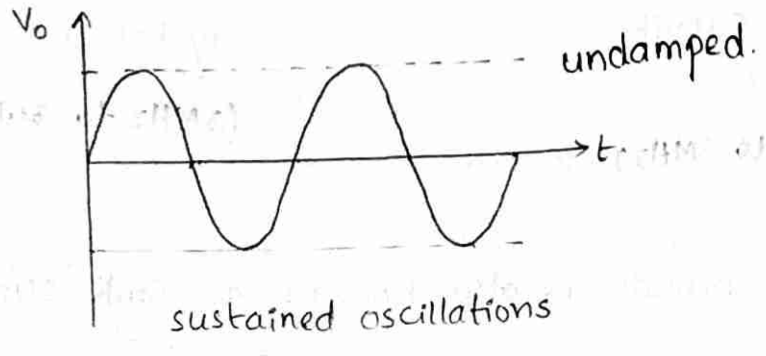
→ If these conditions are satisfied, the feedback amplifier will produce an oscillation, without applying any external input.

Case (i) : If $|A\beta| > 1$ & total phase shift is $0°$ or $360°$.

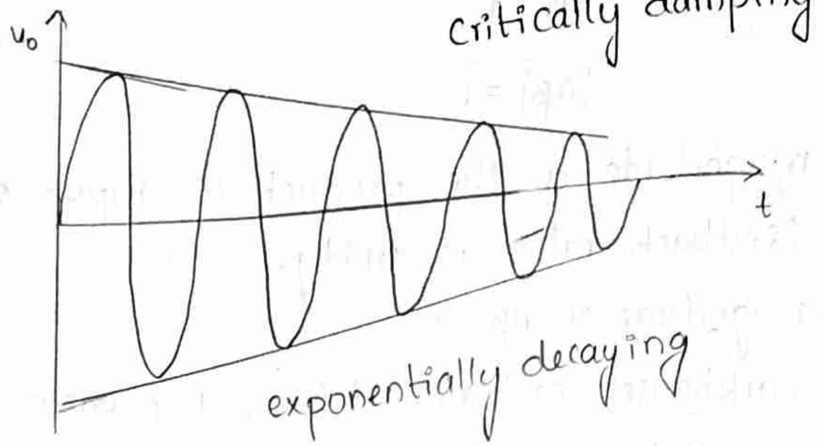
→ The oscillator which produces the signal which can be exponentially growing signal i.e., over damping.



Case (ii) : If $|A\beta| = 1$ & $\phi_{shift} = 0°$ or $360°$



Case (iii) : If $|A\beta| < 1$

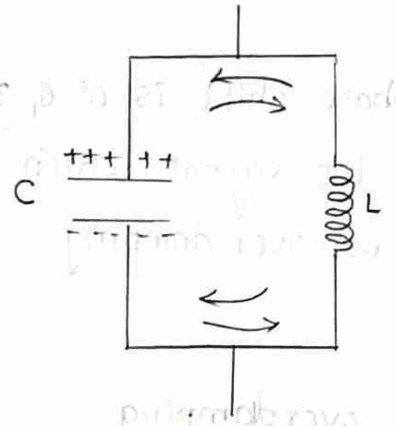


LC Oscillator : (Tank/Tuned/Resonant ckt)

→ An Oscillator circuit has two reactive elements inductance (L) and capacitance (C).

25/01/2024 → This LC circuit is known as tank circuit.

→ Both the elements are capable of storing electrical energy



L - inductor (Henries) M.F

C - capacitor (farads) E.F

→ Inductor stores energy in the form of magnetic field whenever current flows through it.

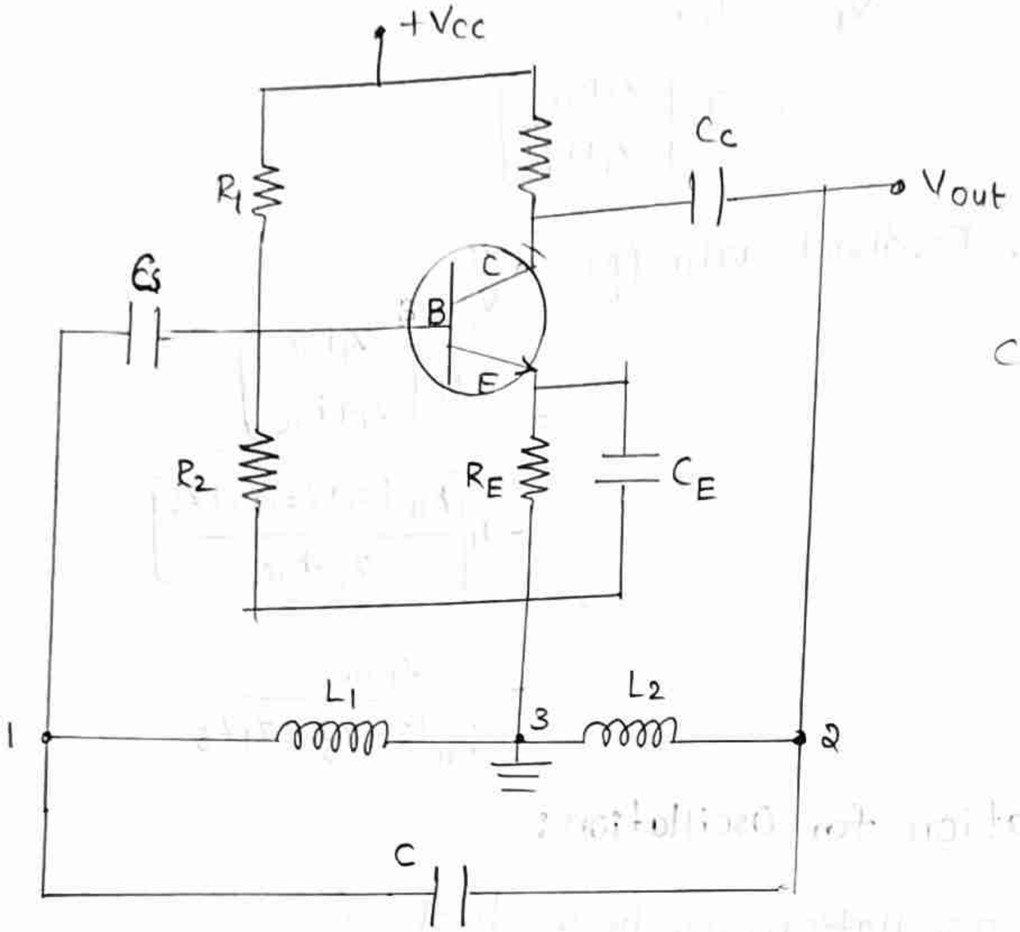
→ Capacitor stores energy in the its electric field, whenever a voltage is applied across the plates.

LC Oscillators

- Resonant circuit oscillator (20 KHz to 3MHz) – Hartley, Colpitts
- Crystal Oscillator (3MHz to 30MHz)

→ Resonant circuit is also knowns as Tank circuit.

Hartley Oscillator :



Colpitts

Working :

→ When the supply voltage plus Vcc is applied that means switch is ON,

→ A transient current is produced in the tank circuit consequently damped harmonic oscillations are setup in the circuit.

→ The oscillatory current in the tank circuit produces voltage across L_1 & L_2.

→ As terminal 3 is yeted it is at zero potential.

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

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

→ In CE mode the transistor produces phase shift of 180°.

→ Hence the total phase shift is 0° or 360° and the feedback is adjusted to loop gain ($A\beta$) and the circuit acts as an oscillator.

Analysis :

→ In the Hartley oscillator Z_1 & Z_3 are inductive reactance and Z_3 is capacitive reactance.

→ Suppose "M" is the inductance between the inductors, then

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

→ The general equation for LC Oscillation is

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

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

$$+ (j\omega L_1 + j\omega M)\left(\frac{-j}{\omega C}\right) = 0$$

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

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

$$\boxed{\therefore\; j\omega h_{ie}\left[L_1+L_2 \overset{+2M}{} + \cancel{\frac{-2M1}{\omega^2 C}}\right] - \omega^2 (L_1+M)(L_2+M)(1+h_{fe}) + \left(\frac{L_1+M}{C}\right) = 0}$$

Frequency of Oscillations :

To determine the frequency of oscillation, imaginary part is

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

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

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

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

But $\omega = 2\pi f$

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

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

If $M=0$, then $f = \frac{1}{2\pi\sqrt{C(L_1+L_2)}}$

$$f = \frac{1}{2\pi\sqrt{L_{eq}C}} \qquad \because L_1+L_2 = L_{eq}$$

Conditions for Oscillations :

To determine the oscillations condition, real part $= 0$

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

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

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

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

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

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

$$L_2+L_2h_{fe}+M+Mh_{fe} = L_1+L_2+2M$$

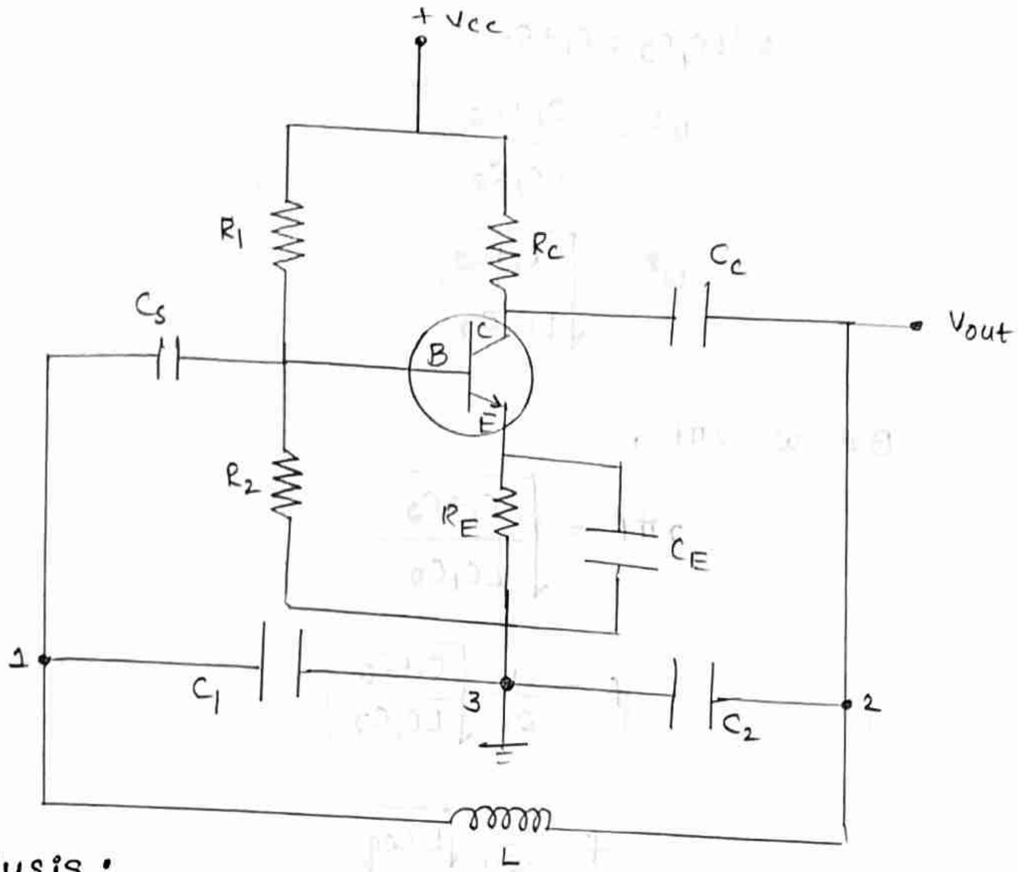
$$(1+h_{fe}) = \frac{(L_1+M)+(L_2+M)}{(L_2+M)}$$

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

$$\boxed{\beta \text{ (or) } h_{fe} = \frac{L_1+M}{L_2+M}}$$

If $M=0$, then h_{fe} (or) $\beta = \frac{L_1}{L_2}$.

Colpitts Oscillator:



Analysis :

In Colpitts Oscillator, $z_1 = \frac{1}{j\omega C_1} = \frac{-j}{\omega C_1}$

$$z_2 = \frac{1}{j\omega C_2} = \frac{-j}{\omega C_2}$$

$$z_3 = j\omega L$$

The general equation for LC oscillator is

$$h_{ie}(z_1+z_2+z_3) + z_1 z_2 (1+h_{fe}) + z_1 z_3 = 0$$

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

$$h_{ie}\left[\frac{-j\omega C_2 - j\omega C_1 + j\omega L(\omega^2 C_1 C_2)}{\omega^3 C_1 C_2}\right] - \frac{1+h_{fe}}{\omega^2 C_1 C_2} + \frac{L}{C_1} = 0$$

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

The frequency of oscillation, by equating the imp. part = 0

$$\boxed{h_{ie}\left[\omega^3 L C_1 C_2 - \omega(C_1+C_2)\right] = 0}$$

Frequency of Oscillations:

$$\omega\left[\omega^2 L C_1 C_2 - (C_1+C_2)\right] = 0$$

$$\omega^2 L C_1 C_2 = C_1 + C_2$$

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

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

But $\omega = 2\pi f$,

$$2\pi f = \sqrt{\frac{C_1+C_2}{L C_1 C_2}}$$

$$\boxed{f = \frac{1}{2\pi}\sqrt{\frac{C_1+C_2}{L C_1 C_2}}}$$

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

Condition for Oscillations:

To determine the oscillation condition, real part $= 0$

$$\frac{L}{C_1} - \frac{1+h_{fe}}{\omega^2 C_1 C_2} = 0$$

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

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

$$h_{fe} = 1 - \frac{C_1+C_2}{C_1 C_2}$$

$$h_{fe} =]$$

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

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

$$\cancel{L}\left(\frac{C_1+C_2}{\cancel{L} C_1 \cancel{C_2}}\right) = \frac{1+h_{fe}}{\cancel{C_2}}$$

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

$$h_{fe} = \frac{C_1+C_2}{C_1} - 1$$

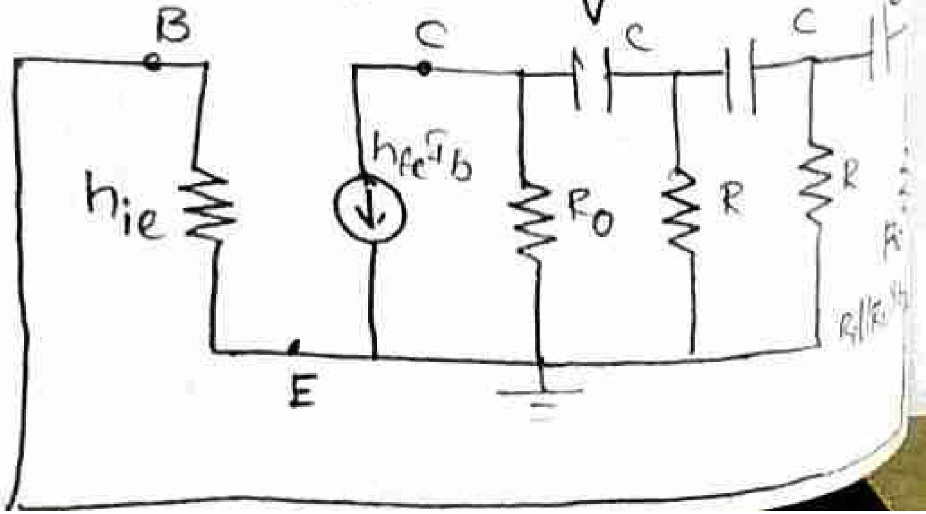
$$\boxed{h_{fe} = \frac{C_2}{C_1}}$$

RC phase shift Oscillator :

Analysis :

→ The approximate equivalent circuit of given network using h- parameter.

fig(2a):



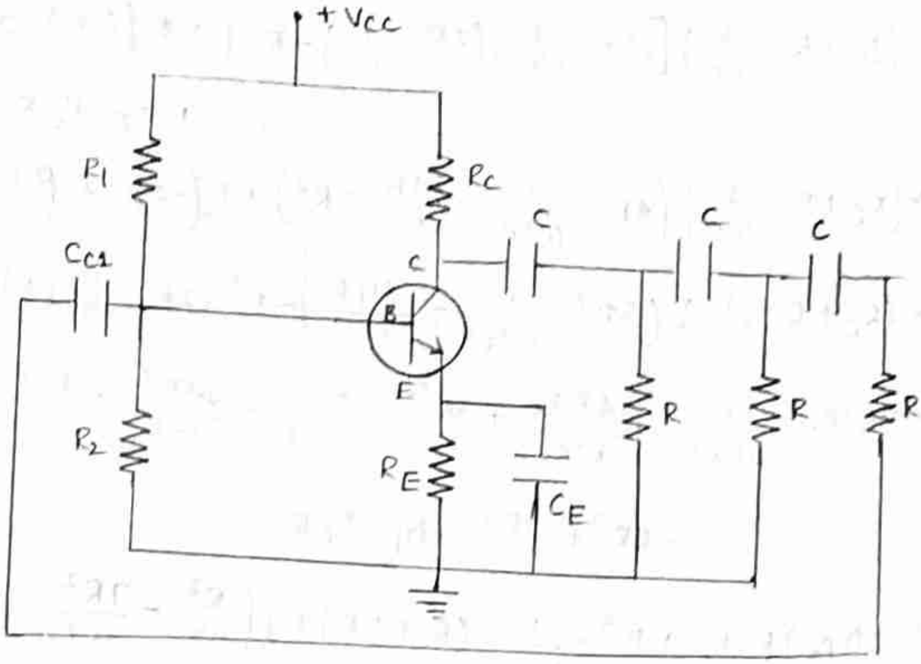


fig (1) :

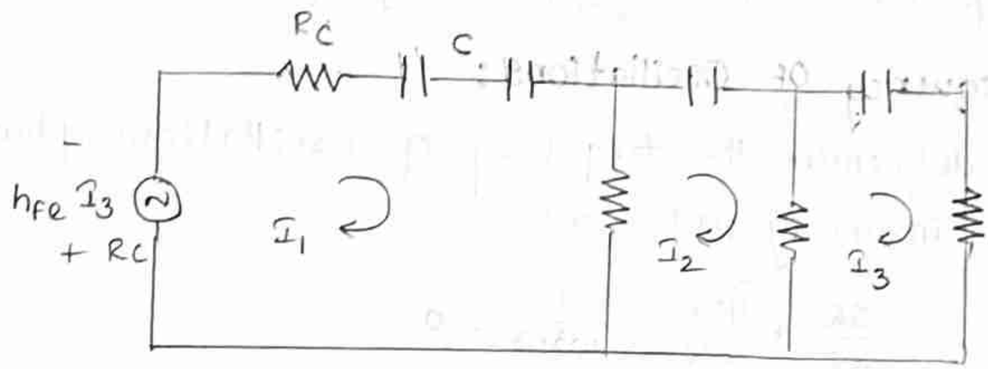


fig (2b) :

Let us apply KVL for 3 loops.

loop (1) $\Rightarrow$ $I_1 R_C + (I_1 - I_2)R + h_{fe} I_3 R_C + \frac{I_1}{j\omega C} = 0$

$$\left(R_C + R - \frac{j}{\omega C}\right) I_1 - R I_2 + h_{fe} I_3 R_C = 0 \longrightarrow (1)$$

loop(2) $\Rightarrow$ $(I_2 - I_1)R + \frac{I_2}{j\omega C} + (I_2 - I_3)R = 0$

$$-R(I_1) + \left(2R - \frac{j}{\omega C}\right) I_2 - R I_3 = 0 \longrightarrow (2)$$

loop (3) $\Rightarrow$ $(I_3 - I_2)R + \frac{I_3}{j\omega C} + R I_3 = 0$

$$-R I_2 + \left(2R - \frac{j}{\omega C}\right) I_3 = 0 \longrightarrow (3)$$

By writing in the matrix form, we have

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

$$\Rightarrow \left(R_C + R - \frac{j}{\omega C}\right)\left[\left(2R - \frac{j}{\omega C}\right)\left(2R - \frac{j}{\omega C}\right) - R^2\right] + R\left[(-R)\left(2R - \frac{j}{\omega C}\right)\right]$$

$$+ h_{fe} R_C R^2 = 0$$

$$\Rightarrow \left(R_C + R - \frac{j}{\omega C}\right)\left(4R^2 - \frac{1}{\omega^2 C^2} - \frac{j4R}{\omega C} - R^2\right) + R\left(-2R^2 + \frac{Rj}{\omega C}\right) + h_{fe} R_C R^2 = 0$$

$$\Rightarrow \left(R_C + R - \frac{j}{\omega C}\right)\left(3R^2 - \frac{1}{\omega^2 C^2} - \frac{j4R}{\omega C}\right) - R^2\left(2R - \frac{j}{\omega C}\right) + h_{fe} R_C R^2 = 0$$

$$\Rightarrow 3R^2 R_C - \frac{R_C}{\omega^2 C^2} - \frac{j4RR_C}{\omega C} + 3R^3 - \frac{R}{\omega^2 C^2} - \frac{j4R^2}{\omega C} - \frac{j3R^2}{\omega C} + j\frac{1}{\omega^3 C^3} - \frac{4R}{\omega^2 C^2}$$

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

$$\Rightarrow (3 + h_{fe}) R^2 R_C + R^3 - \frac{1}{\omega^2 C^2}(R_C + 5R) + j\left[\frac{R^2}{\omega C} - \frac{7R^2}{\omega C} - \frac{4RR_C}{\omega C} + \frac{1}{\omega^3 C^3}\right] = 0$$

$$\Rightarrow \left\{(3 + h_{fe})(R^2 R_C) + R^3 - \frac{1}{\omega^2 C^2}(R_C + 5R)\right\} - j\left[\frac{6R^2}{\omega C} + \frac{4RR_C}{\omega C} - \frac{1}{\omega^3 C^3}\right] = 0.$$

Frequency Of Oscillations:

To determine the frequency of oscillations, phase shift i.e., imaginary part $= 0$

$$\frac{6R^2}{\omega C} + \frac{4RR_C}{\omega C} - \frac{1}{\omega^3 C^3} = 0$$

$$6R^2 + 4RR_C = \frac{1}{\omega^2 C^2}$$

$$\omega^2 C^2 = \frac{1}{6R^2 + 4RR_C}$$

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

$$\omega = \frac{1}{C\sqrt{6R^2 + 4RR_C}}$$

$$\omega = \frac{1}{RC\sqrt{6 + \frac{4R_C}{R}}}$$

Let $\frac{R_C}{R} = K$, $\omega = 2\pi f$

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

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

If $\frac{R_c}{R} = 0$ (OR) $K = 0$

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

10/02/2020

Condition for Oscillations:

To determine the condition for oscillation, the real part is equal to zero.

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

substituted the value of $\frac{1}{\omega^2C^2} = 6R^2+4RR_c$

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

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

$$h_{fe}R^2R_c + R^3 = 23R^2R_c + 30R^2R + 4RR_c^2$$

$$h_{fe}R^2R_c = 23R^2R_c + 30R^2R + 4RR_c^2 - R^3$$

$$h_{fe} = \frac{23R^2R_c + 30R^2R + 4RR_c^2 - R^3}{R^2R_c}$$

$$= \frac{R(23RR_c + 30R^2 + 4R_c^2 - R^2)}{R^2R_c}$$

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

$$h_{fe} \text{ (or) } \beta = 23 + \frac{29}{K} + 4K, \text{ Let } K = \frac{R_c}{R}$$

$23 + \frac{29}{K} + 4k$, $\frac{R_c}{R}$

$$h_{fe} = 4K + 23 + \frac{29}{K}, \text{ if } R = R_c, K = 1$$

$$\boxed{h_{fe} = 56}$$

27
29
+
56

Min value of h_{fe}:

$$\frac{d}{dK}(h_{fe}) = 0$$

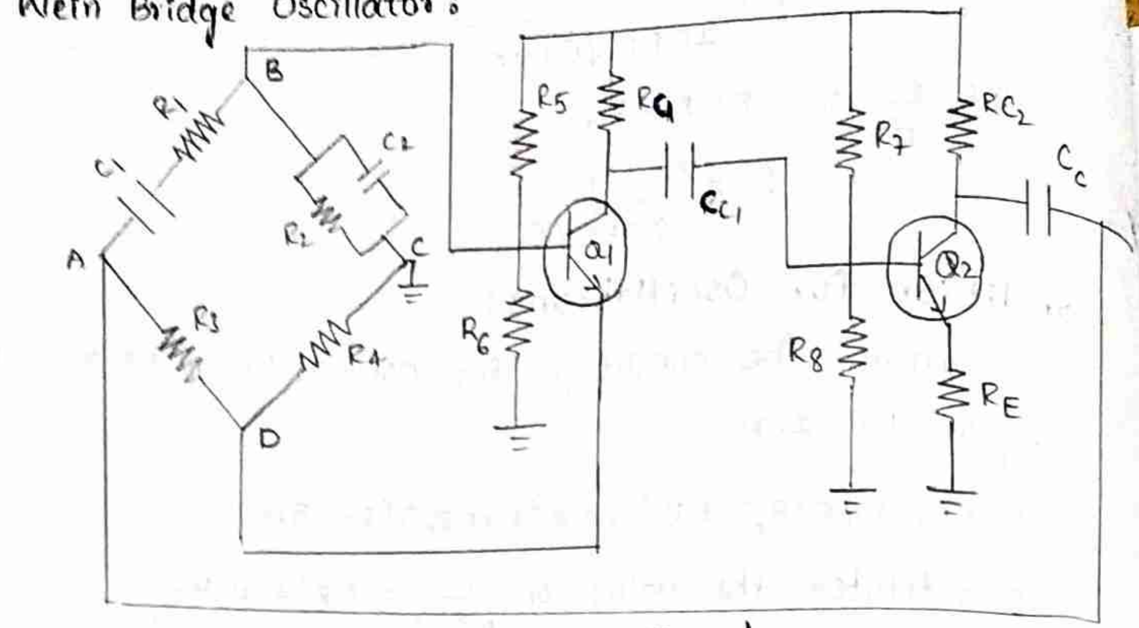
$$4 - \frac{29}{K^2} = 0$$

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

$$\boxed{K = 2.6925}$$

11/03/2019

Wein Bridge Oscillator:

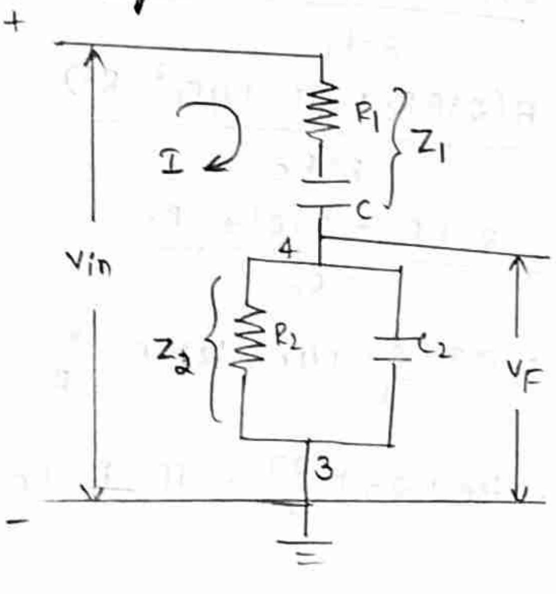


When bridge is balanced $\dfrac{R_3}{R_4} = \dfrac{R_1 + \frac{1}{j\omega C_1}}{\left(R_2 \parallel \frac{1}{j\omega C_2}\right)}$

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

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

Lead Lag network:



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

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

$$Z_2 = R_2 \parallel \left(\frac{1}{j\omega C_2}\right)$$

$$= \frac{R_2 / j\omega C_2}{R_2 + \frac{1}{j\omega C_2}}$$

$$= \frac{R_2}{j\omega R_2 C_2 + 1}$$

Instead of "$j\omega$" we replace 's' for simple.

$$Z_1 = \frac{1 + sR_1C_1}{sC_1} \longrightarrow (1)$$

$$Z_2 = \frac{R_2}{1 + sR_2C_2} \longrightarrow (2)$$

Current $I = \dfrac{V_{in}}{Z_1 + Z_2}$

$$\boxed{V_F = I Z_2}$$

Feedback ratio $\beta = \dfrac{V_F}{V_{in}}$

$$\boxed{\beta = \frac{Z_2}{Z_1 + Z_2}}$$

$$\beta = \frac{\left(\dfrac{R_2}{1 + sR_2C_2}\right)}{\left(\dfrac{1 + sR_1C_1}{sC_1} + \dfrac{R_2}{1 + sR_2C_2}\right)}$$

$$\beta = \frac{sR_2C_1}{1 + s\left[R_1C_1 + R_2C_1 + R_2C_2\right] + s^2(R_1C_1R_2C_2)}$$

put $j\omega = s \Rightarrow s^2 = -\omega^2$

$$\beta = \frac{j\omega R_2C_1}{1 - \omega^2(R_1R_2C_1C_2) + j\omega(R_1C_1 + R_2C_2 + R_2C_1)}$$

By rationalization, we have

$$\beta = \frac{j\omega R_2C_1\left\{\left[1 - \omega^2(R_1R_2C_1C_2)\right] - j\omega(R_1C_1 + R_2C_2 + R_2C_1)\right\}}{(1 - \omega^2R_1R_2C_1C_2)^2 + \omega^2(R_1C_1 + R_2C_2 + R_2C_1)^2}$$

$$\beta = \frac{j\left\{\omega R_2C_1\left[1 - \omega^2(R_1R_2C_1C_2)\right]\right\} + \omega^2R_2C_1(R_1C_1 + R_2C_2 + R_2C_1)}{(1 - \omega^2R_1R_2C_1C_2)^2 + \omega^2(R_1C_1 + R_2C_2 + R_2C_1)^2}$$

To determine frequency of oscillations, img part $= 0$

i.e., $\omega^2(R_1R_2C_1C_2) = 1$

$$\omega^2 = \frac{1}{R_1R_2C_1C_2}$$

$$\omega = \frac{1}{\sqrt{R_1R_2C_1C_2}} \qquad \because \omega = 2\pi f$$

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

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

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

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

Condition for Oscillations:

To determine the condition for oscillation, real part must be equated to zero.

i.e., $\omega^2 R_2 C_1 (R_1C_1 + R_2C_2 + R_2C_1) = 0$

and substitute $R_1 = R_2 = R$ and $C_1 = C_2 = C$, we have

$$\omega^2 RC\,(3RC) = 0$$

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

substitute $\omega = \frac{1}{RC}$, we have,

$$\beta = \frac{3+j(1-1)}{(1-1)^2+9}$$

$$\beta = \frac{3}{9}$$

$$\boxed{\beta = 1/3}$$

$$\frac{V_0}{V_i} = 1$$

$$\frac{A R_2 C_1 \omega}{\omega(R_1C_1 + R_2C_2 + R_2C_1)} = 1$$

$$R_1C_1 + R_2C_2 + R_2C_1 = AR_2C_1$$

$$\frac{R_1}{R_2} + \frac{C_2}{C_1} + 1 = A$$

If $R_1 = R_2 = R$, $C_1 = C_2 = C$ then $\boxed{A=3}$

$$A\beta = 1$$

$$\boxed{\beta = 1/3}$$

loop gain $|A\beta| \geq 1$

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

$$|A| \geq 3$$

where A is open loop gain.

∴ The Oscillator is used in Commercial audio signal generator

17/02/2020 Frequency Stability of an Oscillator :

1. In a transistorized Hartley Oscillator, the two inductances are 2mH and 20μH while the frequency is to be changed from 950 KHz to 2050 KHz. Calculate the range over which the capacitor is to be varied.

Ans: For Hartley Oscillator,

$L_1 = 2mH = 2\times10^{-3}$ H

$L_2 = 20\mu H = 20\times10^{-6}$ H

$F_1 = 950$ KHz $= 950\times10^{3}$ Hz

$f_2 = 2050$ KHz $= 2050\times10^{3}$ Hz

we know that,

$$f_0 = \frac{1}{2\pi\sqrt{(L_1+L_2)C}}$$

$$950\times10^{3} = \frac{1}{2\pi\sqrt{(2\times10^{-9}\times20C}}$$

$$C = \frac{1}{20\times4\pi^2(2\times10^{-9})(950\times10^{3})^2}$$

$$C = 1.389\times10^{-11}$$

$$= 13.89\ PF$$

$$C = \frac{1}{4\pi^2(L_1+L_2)f_2^2}$$

$$= 2.98\ PF$$

2. Determine the frequency of oscillator when a RC phase shift oscillator has $R = 10K\Omega$, $C = 0.01\ \mu F$ and $R_C = 2.2\ K\Omega$ and also find the minimum current gain needed for this purpose

Sol: Given that,

$R = 10\ K\Omega$

$C = 0.01\mu F$

$R_c = 2.2\ K\Omega$

$$f_0 = \frac{1}{2\pi\sqrt{6+4k}\,RC} \quad \text{where } k = \frac{R_C}{R}$$

$$f_0 = \frac{1}{2\pi\sqrt{6+4\times 0.22}\times 10\times 0.01\times 10^{-6}} \quad k = 0.22$$

$$f_0 = 607\ Hz$$

The minimum value of the current gain (or) h_{fe}

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

$$= 23 + \frac{29}{0.22} + 4(0.22)$$

$$\boxed{h_{fe} = 155.7}$$

3. Find the value of 'C' in RC phase shift oscillator using BJT. Design for a frequency of 1 KHz having value of $R = 10\ k\Omega$

Ans: Given that $f_0 = 1\ KHz$

$$R = 10\ k\Omega$$

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

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

$$\boxed{C = 6.4\ nF}$$

4. In a Wein bridge Oscillator, if the value of R is $100\ k\Omega$ and capacitor 159 pF, find frequency.

Ans: Given that $R = 100\ k\Omega$

$$C = 159\ pF$$

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

$$= \frac{1}{2\pi \times 100\times 10^{3}\times 159\times 10^{-12}}$$

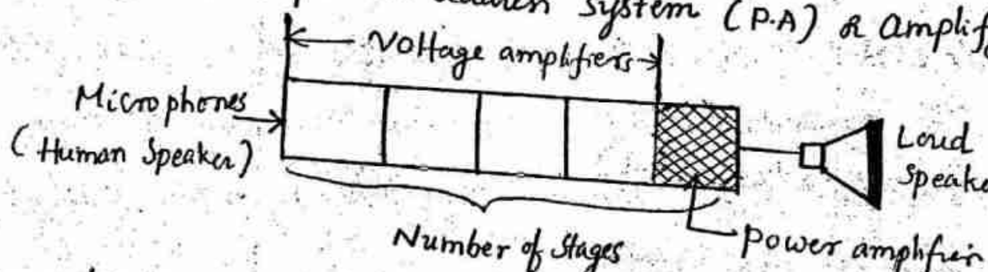
$$= 10\ KHz$$

Large Signal Amplifiers.

Syllabus: Class-A power amplifier, Maximum value of Efficiency of Class-A amplifier, transformer coupled amplifier-Push-pull amplifier, complementary Symmetry circuits (Transformer less Class B power amplifier). phase Inverters, transistor Power Dissipation, thermal runaway, Heat sinks.

Introduction:

Consider a public address system (P.A) & amplifying system.



The system consists of many stages connected in cascade. (Multistage amplifier)
The input is sound signal of a human speaker and output is given to the Loud speaker which is an amplified input signal.
The intermediate stages are small signal amplifiers. (Voltage amplifiers)
But the last stage must be capable of delivering an appreciable amount of a.c. power to the load like loudspeaker, servomotor, handling the large signals is called "Large signal amplifiers" & "Power amplifiers".

Applications:

Power amplifiers find their applications in the

1. Public address systems,
2. Radio Receivers,
3. driving servomotor in Industrial control systems,
4. Tape players, T.V. Receivers
5. Cathode Ray Tubes etc.

Features of Power Amplifiers:

The various features of power amplifiers are

1. The output of power amplifier has large current and voltage swings.
2. h-parameters analysis is applicable to the small signal amplifier but power amplifiers is carried out graphically by drawing a load line on the output characteristics of the transistor.
3. The power amplifiers must have Low output impedance. Hence CC a Emitter follower ckt is very common in power amplifiers.
4. The transistors used in the power amplifiers are of large size, having large power dissipation rating, called power transistors.
5. The analysis of signal distortion in case of power amplifiers is important.
6. The input signal level & amplitude of a power amplifier is large of the order of few Volts.
7. Power amplifiers are also called audio amplifiers a audio frequency (AF) power amplifiers.

Classification of Large signal Amplifiers:

For an amplifier, a quiescent operating point (Q-point) is fixed by selecting the proper d.c. biasing to the transistors used. The Q-point is shown on the load line which is plotted on the output characteristics of the transistor.

The position of the Q-point on the load line decides the class of operation of the power amplifiers. They are.

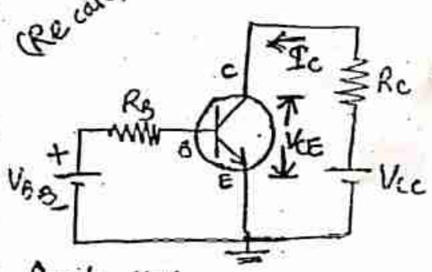
1. Class A
2. Class B
3. Class AB
4. Class C
5. Class D
6. Class S

} Power amplifiers.

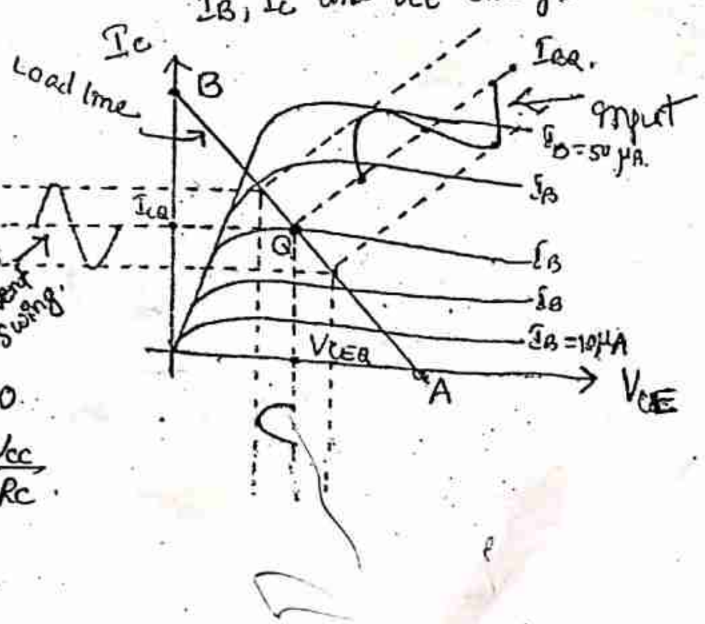
Comparison of Small-signal and Large signal Amplifiers: ②

S.No	Small signal Amplifiers	Large signal Amplifiers
1	Voltage is amplified	→ Power & current is amplified.
2	The h-parameter analysis is applicable	→ The graphical analysis is required as h-parameters can not be used.
3	Harmonics are not present for sinusoidal signals.	→ Harmonics are present.
4	The normal transistors are sufficient	→ The power transistors are required.
5	The heat sinks are not required as heat dissipation is not the problem.	→ The heat sinks are essential so as to dissipate large heat produced.
6	The size is small.	→ The size is large and bulky.
7	Distortion is not present.	→ Due to the harmonics, signal is likely to be distorted.
8	The power handling capacity is small.	→ The power handling capacity is large.
9.	The output current and voltage swings are small.	→ There are large output current and voltage swings.
10	The operating point is always on the linear portion of transfer characteristics.	→ The operating point can be anywhere on the transfer characteristics including non linear region.
11.	Used as a voltage amplifier	→ Used as a large stage in Public address system and other audio circuits.

* Consider Common Emitter circuit (Recall).



Graphical representation of I_B, I_C and V_{CE} swings.



Apply KVL $V_{CC} - I_C R_C - V_{CE} = 0$

$V_{CE} = V_{CC} - I_C R_C$.

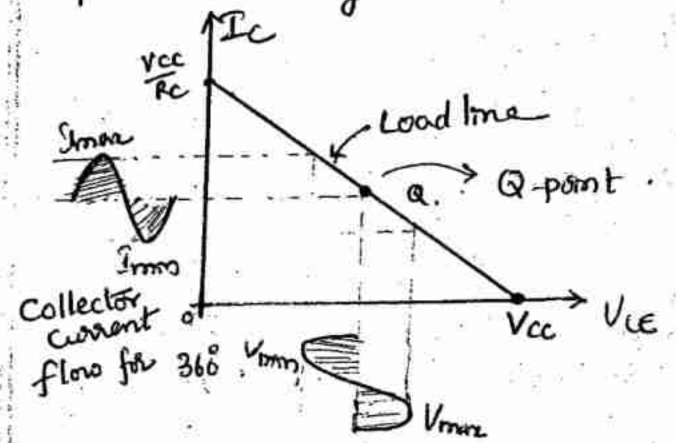
$\therefore A(V_{CC}, 0)$ when $V_{CE} = V_{CC}$, $I_C = 0$

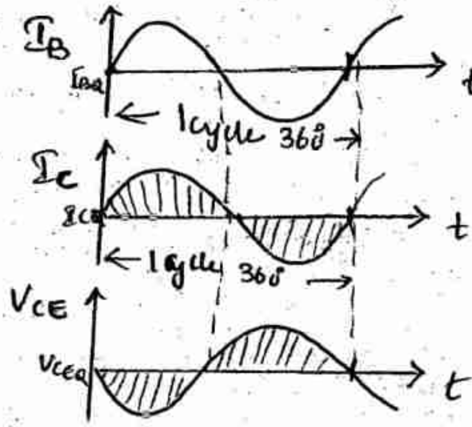
$B\left(0, \frac{V_{CC}}{R_C}\right)$ when $V_{CE} = 0$, $I_C = \frac{V_{CC}}{R_C}$.

Class A Power amplifiers:

The power amplifier is said to be Class A amplifier if the Q-point and the input signal are selected such that the output signal is obtained for a full input cycle.

For Class A position of the Q-point is approximately at the midpoint of the load line. Here signal is faithfully reproduced at the output, without any distortion. This is an important feature of a class-A operation. The efficiency of Class A operation is very small.



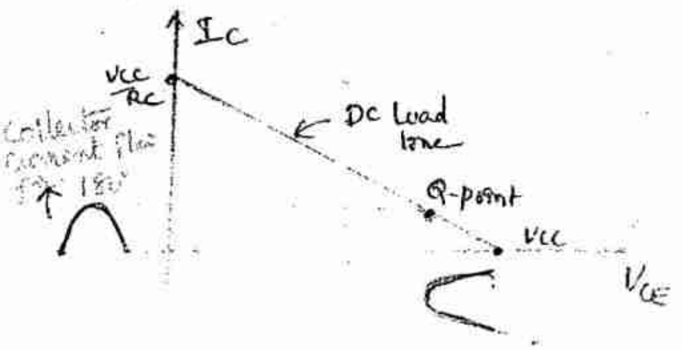


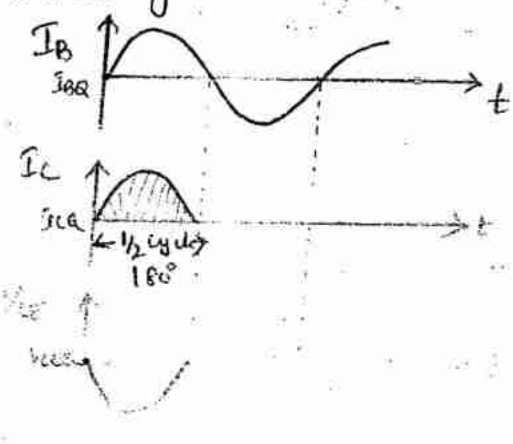
Class-B Power amplifiers:

The power amplifier is said to be class B amplifier if the Q-point and the input signal are selected, such that the output signal is obtained only for one half cycle for a full input cycle.

For class-B operation the Q point is shifted on X-axis so transistor is biased to cut-off.

The output signal is distorted in this mode of operation. To eliminate this distortion, practically two transistors are used in the alternate half cycles of the input signal. The efficiency of class B is much higher than the Class A operation.





Class-C power Amplefiers :- ③

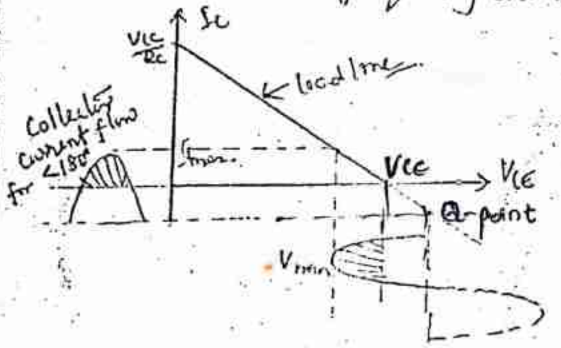
The power amplifier is said to be class-C amplifier, if the Q-point and the input signal are selected such that the output signal is obtained for less than a half cycle, for a full input cycle.

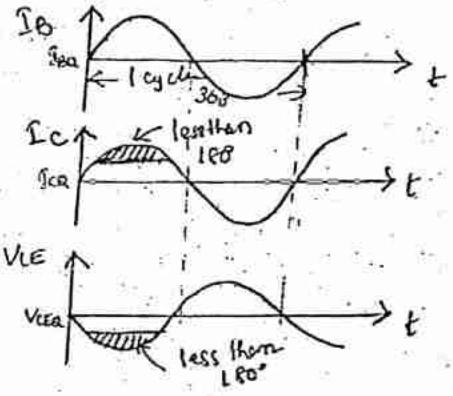
For Class-C operation, the Q-point is to be shifted below X-axis.

In class-C operation the transistor is biased well beyond cut off. As the collector current flows for less than 180°, the output is much more distorted and hence the class C mode is never used for A.F power amplifiers.

But the efficiency of class C operation is much higher and can reach very close to 100%.

The class C-amplifiers are used in tuned circuits, used in communication areas, in radio frequency (RF) with tuned RLC loads.



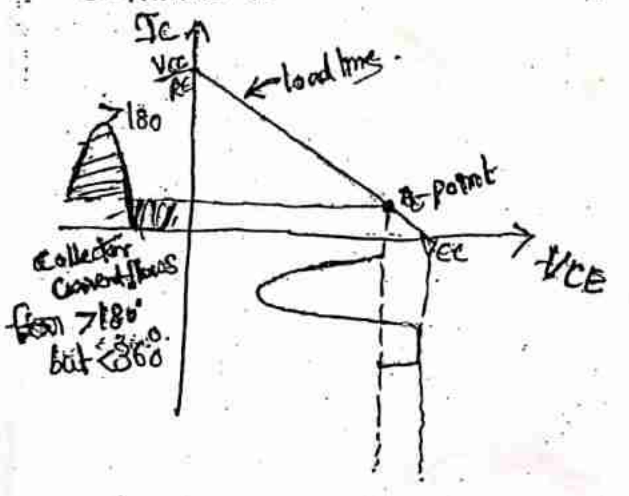


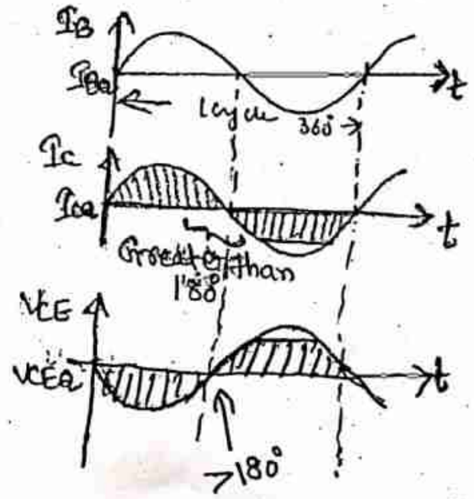
Class-AB Power Amplifiers :

The power amplifier is said to be class AB amplifier, if the Q-point and the input signal are selected such that the output signal is obtained for more than 180° but less than 360° for a full input cycle.

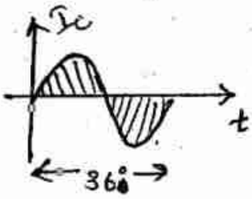
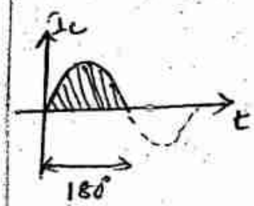
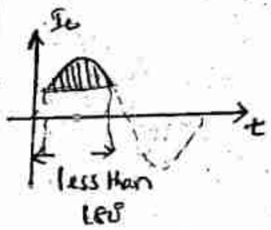
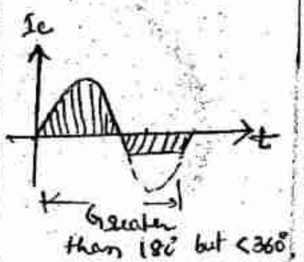
The Q-point position is above X-axis but below the midpoint of a load line.

The output signal is distorted in class-AB operation. The efficiency is more than class A but less than class B operation. The class AB operation is important to eliminate cross over distortion.





Comparision of Power Amplifiers :

SL No	Class → Feature ↓	Class A	Class B	Class C	Class AB
1	Operating cycle	360°	180°	Less that 180°	180° to 360°.
2.	Position of Q-point	Centre of load line	On x-axis	Below x-axis	Above x-axis but below the centre of load line.
3.	Efficiency	Poor. 25 % to 50%	Better 78.5%	High	Higher than A but less than B, 50% to 78.5%.
4	Distortion	Absent No distortion	Present More than Class A	Highest	Present.
5	Power Dissipation in transistors	Very high	Low	Very low	Moderate.
6.	Nature of output current waveform				

Analysis of Class-A Power Amplifiers:

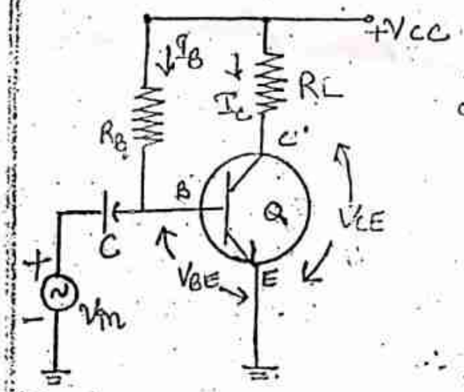
The power amplifier is said to be Class A amplifier, if the Q-point and the input signal are selected such that the output signal is obtained for a full input cycle (360°). The position of the Q-point approximately at the midpoint of the load line.

The class A amplifiers are classified as two types.

1. Direct coupled & Series fed class A Amplifier. : Here the load is directly connected in the collector ckt.
2. Transformed Coupled Class A amplifier : Here the load is coupled to the collector using a transformer called an output transformer.

Series fed. Directly coupled Class A Amplifier :— ④

~~Consider A simple fixed bias ckt can be used as a large signal~~ class A amplifier.



Here the load is a loudspeaker, the impedance of which varies from 3 to 4 to 16 Ω. β is < 100.

Apply KVL to the o/p loop.

$V_{CC} = I_C R_L + V_{CE}$

$I_C R_L = -V_{CE} + V_{CC}$

$\therefore I_C = \left(-\frac{1}{R_L}\right) V_{CE} + \frac{V_{CC}}{R_L}.$

when $I_C = 0$ $V_{CE} = V_{CC}$

where $V_{CE} = 0$, $I_C = \frac{V_{CC}}{R_C}$.

D.C operation :

$I_{BQ} = \frac{V_{CC} - V_{BE}}{R_B}$ if $V_{BE} = 0.7$

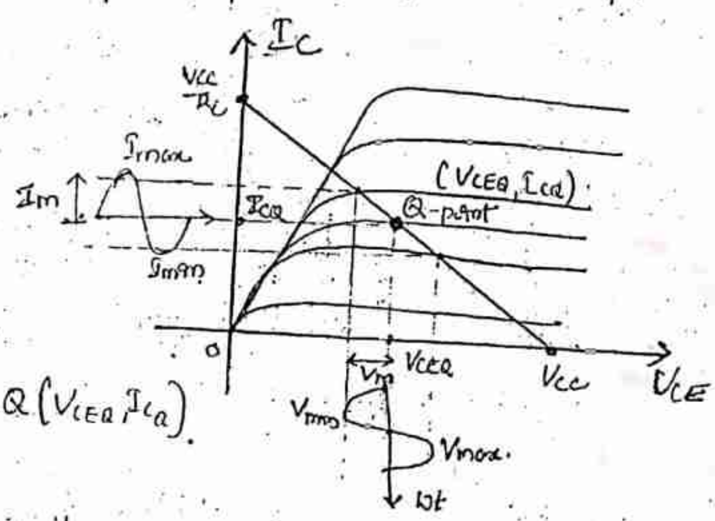
Base current $\boxed{I_{BQ} = \frac{V_{CC} - 0.7}{R_B}}$

Collector Current $\boxed{I_{CQ} = \beta I_{BQ}}$

$\boxed{V_{CEQ} = V_{CC} - I_{CQ} R_L}$

Hence the Q-point can be defined as $Q(V_{CEQ}, I_{CQ})$.

Graphical representation of class A Amplifier :



Efficiency : The efficiency of an amplifier represents the amount of a.c power delivered & transferred to the load, from the d.c source to accepting the d.c power input.

$\therefore \boxed{\% \eta = \frac{P_{ac}}{P_{dc}} \times 100.}$

DC power input : The d.c power input is provided by the supply with no input signal, the d.c. current flows is the collector bias current I_{CQ}.

Hence d.c power input $\boxed{P_{dc} = V_{CC} \cdot I_{CQ}.}$

AC power input : The a.c power delivered by the amplifier to the load can be expressed by using rms values maximum.

[PTO]

$$\therefore P_{ac} = V_{rms} \cdot I_{rms} \text{ or } I_{rms}^2 \cdot R_L \text{ or } \frac{V_{rms}^2}{R_L}$$

where $V_{rms} = \frac{V_m}{\sqrt{2}}$, $I_{rms} = \frac{I_m}{\sqrt{2}}$

where $V_m = \frac{V_{max} - V_{min}}{2}$, where $I_m = \frac{I_{max} - I_{min}}{2}$

$$\therefore P_{ac} = \frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}} = \frac{V_m \cdot I_m}{2}$$

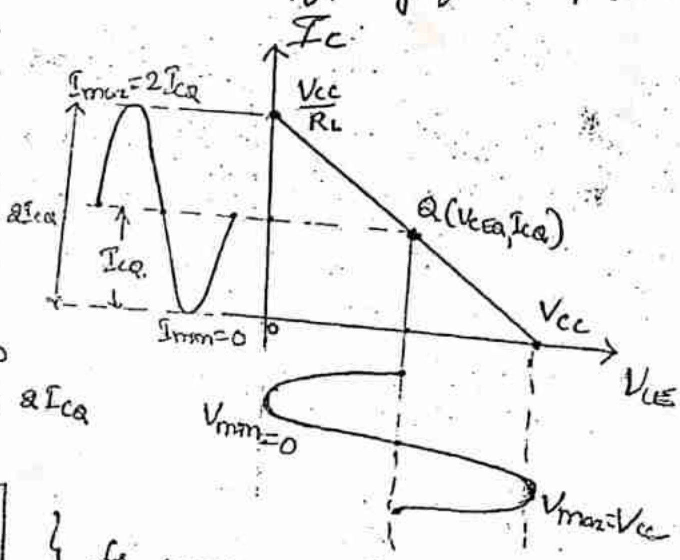
$$= \left[\left(\frac{V_{max} - V_{min}}{2}\right) \times \left(\frac{I_{max} - I_{min}}{2}\right) \right] \times \frac{1}{2}$$

$$P_{ac} = \frac{(V_{max} - V_{min}) \times (I_{max} - I_{min})}{8}$$

$$\therefore \text{Efficiency } \eta = \frac{P_{ac}}{P_{dc}} \Rightarrow \boxed{\% \eta = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8 \cdot V_{cc} \cdot I_{CQ}} \times 100}$$

The efficiency is also called Conversion efficiency of an amplifier.

Maximum Efficiency :



From Fig.

The minimum voltage possible is Zero and maximum voltage possible is V_{CC} for a maximum swing.

lly the minimum current is zero
The maximum current possible is $2I_{CQ}$ for a maximum swing.

ie

$$\boxed{\begin{matrix} V_{max} = V_{CC} \text{ and } V_{min} = 0 \\ I_{max} = 2I_{CQ} \text{ and } I_{min} = 0 \end{matrix}} \Bigg\} \text{ for maximum swing.}$$

$$\therefore \text{Efficiency } \% \eta_{max} = \frac{(V_{CC} - 0)(2I_{CQ} - 0)}{8 \cdot V_{CC} \cdot I_{CQ}} \times 100 = \frac{V_{CC} \cdot 2I_{CQ}}{8 \cdot V_{CC} \cdot I_{CQ}} \times 100$$

$$\boxed{\therefore \% \eta_{max} = 25\%}$$

Hence the maximum efficiency possible in case of directly coupled series fed Class A amplifier is just 25%. (This is an ideal value).
For practical ckt it is much less than 25% of the order of 10 to 15%.

Power Dissipation (P_D) :

The amount of power that must be dissipated by the transistor is the difference between the d.c power input P_{dc} and the a.c power delivered to the Load P_{ac}.

$$\boxed{P_D = P_{dc} - P_{ac}.}$$

The power dissipation in large signal amplifier is also large.

∴ The max. power dissipation occurs when there is zero ac input signal. But transistor operates at quiescent condition, drawing d.c input power from the supply equal to $V_{cc} \cdot I_{cq}$. This entire power gets dissipated in the form of heat. ∴ $\boxed{P_{D(max)} = V_{cc} \cdot I_{cq}.}$ ($\because P_{ac} = 0$)

Advantages of Class-A amplifier :

The advantages of directly coupled class A amplifiers are

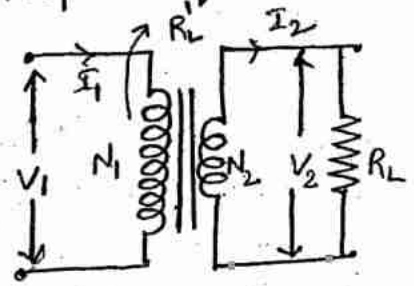
1. The circuit is simple to design and to implement.
2. The load is connected directly in the collector ckt hence the output transformer is not necessary. This makes the circuit cheaper.
3. Less number of components required as load is directly coupled.

Disadvantages of Class-A amplifier :

1. The load resistance is directly connected in collector and carries the quiescent collector current. This causes considerable wastage of power.
2. Power dissipation is more. Hence power dissipation arrangements like heat sink are essential.
3. The output impedance is high hence circuit cannot be used for low impedance loads such as loud speakers.
4. The efficiency is very poor, due to large power dissipations. This is the biggest disadvantage of class A amplifier.

Transformer Coupled Class A amplifier :

Properties of Transformer :



Trans ratio : $\eta = \frac{N_2}{N_1}$

where N_1 - no. of turns on primary.
N_2 - no of turns on secondary.

Voltage transformation : $\frac{V_2}{V_1} = \frac{N_2}{N_1} = n$.

Current transformation : $\frac{I_2}{I_1} = \frac{N_1}{N_2} = \frac{1}{n}$.

Impedance transformation :

$$R_L = \frac{V_2}{I_2} \text{ and } R_L' = \frac{V_1}{I_1}, \quad V_1 = \frac{N_1}{N_2} \cdot V_2 \text{ and } I_1 = \frac{N_2}{N_1} \cdot I_2$$

$$\therefore R_L' = \frac{N_1/N_2 \cdot V_2}{N_2/N_1 \cdot I_2} = \left(\frac{N_1}{N_2}\right)^2 \times \frac{V_2}{I_2} \Rightarrow \boxed{\left(\frac{1}{n}\right)^2 \times R_L = R_L'} \text{ (or) } \boxed{R_L' = \left(\frac{N_1}{N_2}\right)^2 \cdot R_L}$$

where R_L' is called reflected impedance.

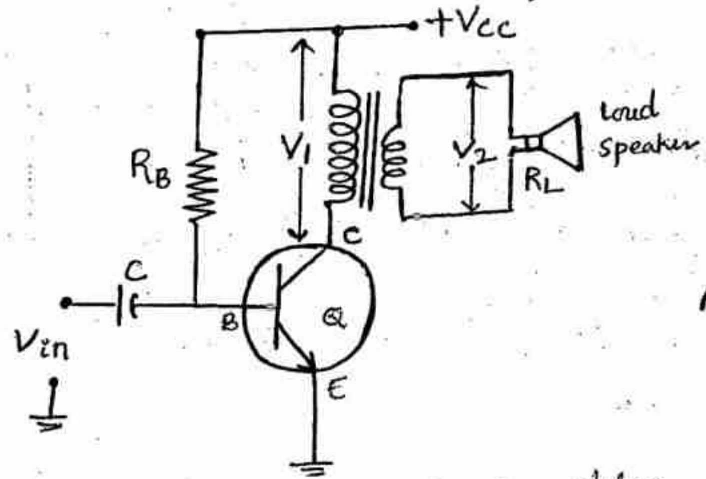


Fig: Transformer coupled class A amplifier.

The transformer used as a step down transformer with trans ratio is $\boxed{n = \frac{N_2}{N_1}}$.

Assume winding resistances are Zero Ω.

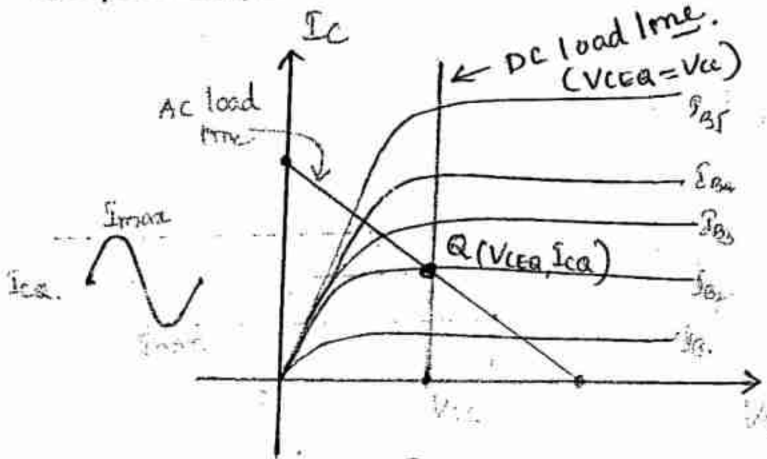
Apply KVL to the collector ckt.

$V_{CC} - V_{CE} = 0$.

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

$\therefore \boxed{V_{CEQ} = V_{CC}}$

Graphical representation ↓



Here slope of the d.c load line is ideally infinite ie vertically straight line.

& Here the output voltage varies sinusoidally around its quiescent value V_{CEQ} which is V_{CC}.

Efficiency: $\% \eta = \frac{P_{ac}}{P_{dc}} \times 100$

Here P_{dc} = D.C power input $= V_{cc} \cdot I_{CQ}$ $\therefore \boxed{P_{dc} = V_{cc} \cdot I_{CQ}}$

The ac power delivered & developed on the primary is

$$P_{ac} = V_{1\,rms} \cdot I_{1\,rms} \text{ \& } I_{1\,rms}^2 R_L' \text{ or } \frac{V_{1\,rms}^2}{R_L'}$$

where $V_{1\,rms} = \frac{V_{1m}}{\sqrt{2}}$, $I_{1\,rms} = \frac{I_{1m}}{\sqrt{2}}$

$\therefore P_{ac} = \frac{V_{1m} \cdot I_{1m}}{2}$. ||ly $P_{ac} = \frac{V_{2m} \cdot I_{2m}}{2}$

$\therefore P_{ac} = \frac{V_m \cdot I_m}{2}$. where $V_m = \frac{(V_{max} - V_{min})}{2}$ & $I_m = \frac{(I_{max} - I_{min})}{2}$.

$$\therefore P_{ac} = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8}.$$

$\therefore$ Efficiency $= \frac{P_{ac}}{P_{dc}} \Rightarrow \boxed{\eta = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8 \cdot V_{cc} \cdot I_{CQ}}}$

Maximum Efficiency:

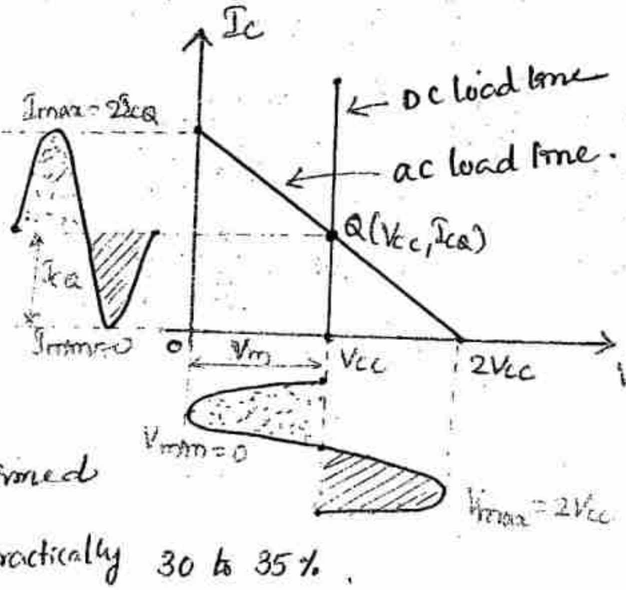
Assume the Q-point is exactly at the centre of the load line for max. swing.

$$\therefore \left.\boxed{\begin{matrix} V_{min} = 0 \text{ and } V_{max} = 2V_{cc} \\ I_{min} = 0 \text{ and } I_{max} = 2I_{CQ} \end{matrix}}\right\} \text{ for maximum swing.}$$

$$\% \eta_{max} = \frac{(2V_{cc} - 0)(2I_{CQ} - 0)}{8 \cdot V_{cc} I_{CQ}} \times 100$$

$$= \frac{4 \times V_{cc} \times I_{CQ}}{8 \times V_{cc} \times I_{CQ}} \times 100$$

$= 50\%$ $\therefore \boxed{\% \eta_{max} = 50\%}$



Hence the efficiency in case of transformer coupled class-A amplifier is 50%. practically 30 to 35%.

$V_{1m} = V_{cc}$ for maximum output power.

$I_{1m} = I_{CQ}$.

$R_L' = \frac{V_{1m}}{I_{1m}} = \frac{V_{cc}}{I_{CQ}}$ $\therefore (P_{ac})_{max} = \frac{1}{2} \cdot \frac{V_{cc}^2}{R_L'}$.

this is applicable only in case of maximum power transfer condition.

Power Dissipation (P_D):

The power dissipation by the transistor is the difference between the a.c power output and the d.c power input. The power dissipated by the transformer is very small due to negligible (d.c) winding resistance & can be neglected.

$$\boxed{P_D = P_{dc} - P_{ac}.}$$

When the input signal is larger, more power is delivered to the load and less is the power dissipation.

But when there is no input signal, the entire d.c input power gets dissipated in the form of heat, which is max. power dissipation.

$$\therefore \boxed{P_{d(max)} = V_{cc} I_{CQ}}$$

Advantages of Class-A amplifier:

The advantages of transformer coupled class-A amplifiers are.

1. The efficiency of the operation is higher than directly coupled class-A amplifier.
2. The impedance matching required for max. power transfer is possible.
3. The d.c bias current that flows through the load in case of directly amplifier is stopped in case of transformer coupled amplifier.

Disadvantages of Class-A Amplifier:

The disadvantages of transformer coupled class A amplifiers are

1. Due to the transformer, the circuit becomes bulkier, heavier and costlier compared to directly coupled amplifier.
2. The circuit is complicated to design and implement compared to directly coupled circuit.
3. The frequency response of the circuit is poor.

Class-B Power Amplifier :

For class-B operation, the Q-point is located on the x-axis itself. Due to this collector current flows only for a half cycle for a full cycle of the input signal. Hence output signal is distorted.

To get a full cycle across the load, a pair of transistors are used in the class-B operation.

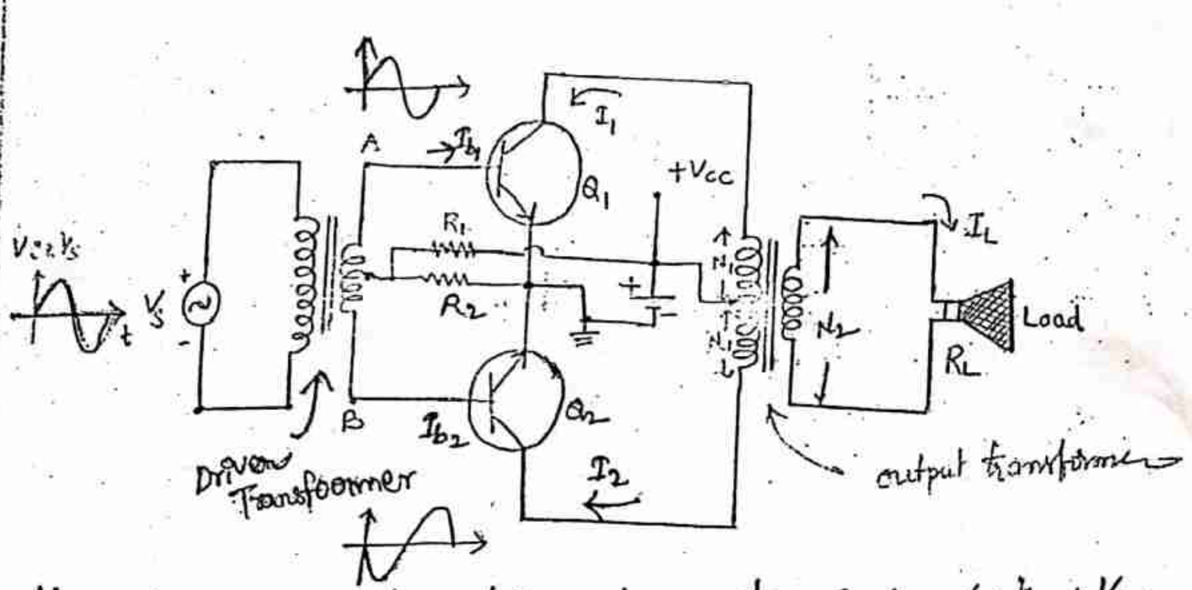
Types of class-B amplifiers are

(1). When both the transistors are of same type ie either npn & pnp then the ckt is called Pushpull class B A.F power amplifier circuit.

(2). when the two transistors form a complementary pair ie one n-p-n and other p-n-p then the ckt is called Complementary symmetry class-B A.F amplifier ckt.

Push pull Class-B Amplifier :

The push pull ckt requires two transistors, one as input transformer called driver transformer and the other to connect the load called output transformer. Both the transformers are centre tapped transformers.



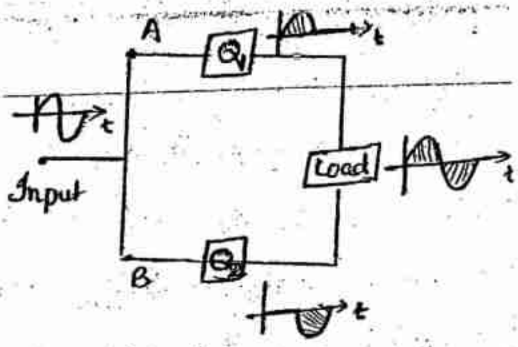
Here both Q_1 & Q_2 transistors are of npn type & supply is $+V_{cc}$.

If transistors are of pnp type the supply is $-V_{cc}$ remains same.

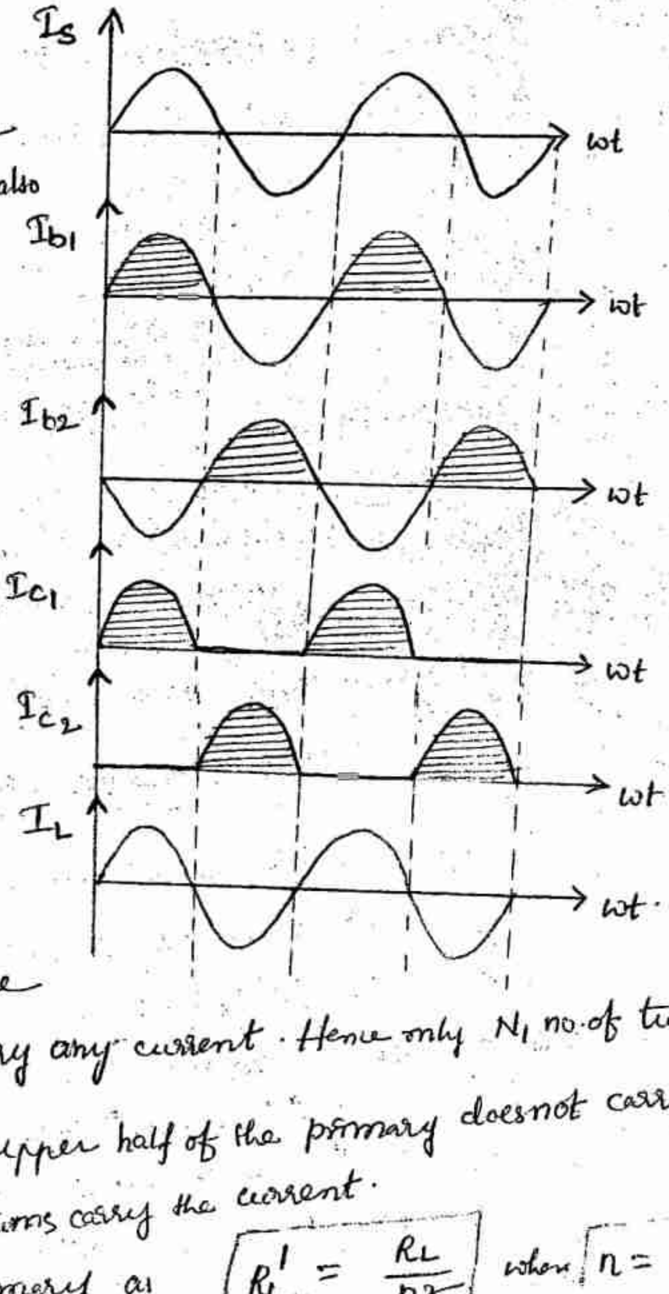
Both the transistors are the Common emitter configuration.

When point A is positive, the transistor Q_1 gets driven into an active region while the transistor Q_2 is in cut-off region.

When point A is negative, the point B is positive hence the transistor Q_2 gets driven into an active region while the transistor Q_1 is in cut-off region.



The waveforms of the input current I_S, base currents I_{b1}, I_{b2} and collector currents I_{C1}, I_{C2} also also the load current I_L are shown.



Analysis:

DC operation: The d.c biasing point ie Q point is adjusted on the X-axis such that $V_{CEQ} = V_{CC}$ and I_{CQ} is zero.

$\therefore$ Q-point - $Q(V_{CC}, 0)$.

There is no d.c bias (base bias) voltage.

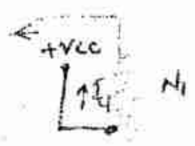
A.C Operation:

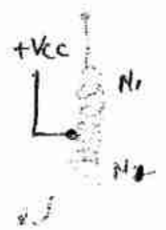
When the a.c signal is applied

For +ve half cycle Q_1 conducts, & Lower half of the primary of the output transformer does not carry any current. Hence only N_1 no. of turns carry the current.

For -Ve half cycle Q_2 conducts. Upper half of the primary does not carry any current. again only N_1 no of turns carry the current.

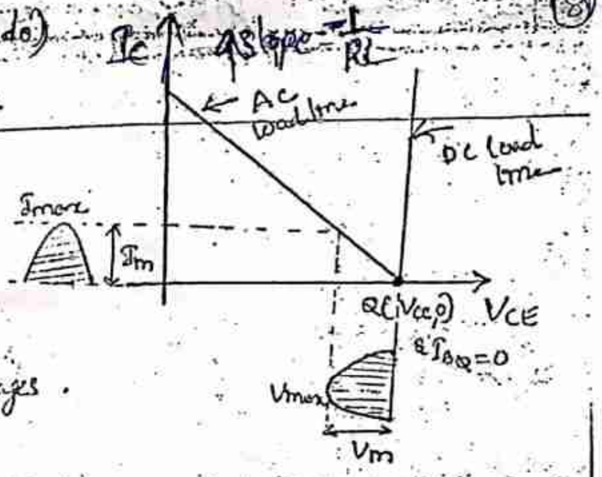
$\therefore$ Reflected load on the primary as $\boxed{R_L' = \frac{R_L}{n^2}}$ where $\boxed{n = \frac{N_2}{N_1}}$.





The slope of the ac load line (magnitude)

can be represented in terms of V_m & I_m :



$$\therefore \frac{1}{R_L'} = \frac{I_m}{V_m}$$

$$\therefore R_L' = \frac{V_m}{I_m}.$$

where V_m & I_m are peak values of the output current & voltages.

Efficiency : The efficiency of the class B amplifier as

$$\% \eta = \frac{P_{ac}}{P_{dc}} \times 100 .$$

D.C power input : Each transistor output is in the form of half rectified wave form. So, the d.c average value is $\frac{I_m}{\pi}$. where I_m - peak value of output current

The two currents drawn by the two transistors, from the d.c supply are in the same direction. $\therefore I_{dc} = \frac{I_m}{\pi} + \frac{I_m}{\pi} = \frac{2I_m}{\pi}.$

$\therefore$ The total d.c power is $P_{dc} = V_{CC} \times I_{dc}$

$$\therefore \boxed{P_{dc} = \frac{2I_m}{\pi} . V_{CC}}$$

A.C power output : $P_{ac} = V_{rms} \cdot I_{rms}$ where $V_{rms} = \frac{V_m}{\sqrt{2}}$

(or)

$I_{rms}^2 \cdot R_L'$ (or) $\quad I_{rms} = I_m/\sqrt{2}$.

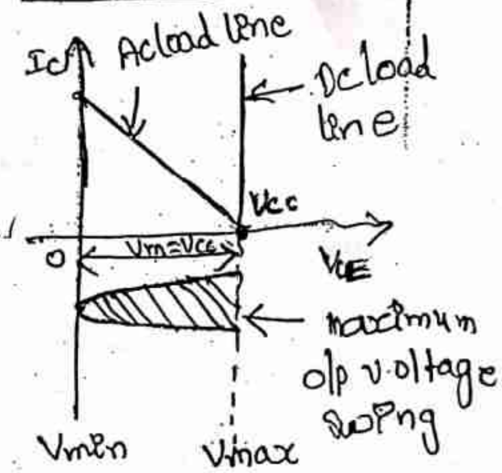
V_{rms}^2 / R_L'

$$\therefore \boxed{P_{ac} = \frac{V_m \cdot I_m}{2}} \quad \text{or} \quad P_{ac} = \frac{I_m^2 R_L'}{2} \quad \& \quad P_{ac} = \frac{V_m^2}{2R_L'} .$$

$$\therefore \text{Efficiency } \% \eta = \frac{\left(\frac{V_m \cdot I_m}{2}\right)}{\left(\frac{2 I_m}{\pi}\right) V_{CC}} \times 100 \Rightarrow \boxed{\% \eta = \frac{\pi}{4} \cdot \frac{V_m}{V_{CC}} \times 100}$$

Maximum Efficiency :

For max. efficiency $V_m = V_{CC}$



$$\therefore \% \eta = \frac{\pi}{4} \times 100 = 78.5\%$$

$$\% \eta_{max} = 78.5\% \text{ Ideal.}$$

for

Practical ckt efficiency is upto 65 to 70 %.

Power Dissipation: The power dissipation by both the transistors is the difference between a.c power output and dc power input.

$$P_D = P_{dc} - P_{ac} = \frac{2}{\pi} V_{cc} I_m - \frac{V_m I_m}{2}$$ → Instead of I_m we have substituting $\frac{V_m}{R_L'}$

$$\therefore P_D = \frac{2}{\pi} V_{cc} \cdot \frac{V_m}{R_L'} - \frac{V_m^2}{2R_L'} \rightarrow (1) \qquad \left(\because R_L' = \frac{V_m}{I_m}\right) \Rightarrow I_m = \frac{V_m}{R_L'}$$

In Class-A amplifier, it is max., when no input signal.

But in class B, when input signal is zero, $V_m = 0$ hence the power dissipation is zero & not the maximum.

Max. Power dissipation: $\frac{\partial P_D}{\partial V_m} = 0 \Rightarrow \frac{\partial}{\partial V_m}\left(\frac{2}{\pi} V_{cc} \cdot \frac{V_m}{R_L'} - \frac{V_m^2}{2R_L'}\right) = 0$

$$\frac{2}{\pi} \frac{V_{cc}}{R_L'} \cdot \frac{\partial}{\partial V_m}(V_m) - \frac{1}{2R_L'} \frac{\partial}{\partial V_m}(V_m^2) = 0 \Rightarrow \frac{2V_{cc}}{\pi} \cdot \frac{1}{R_L'}(1) - \frac{2V_m}{2R_L'} = 0 \quad (\because \text{From } (1))$$

$$\Rightarrow \frac{2V_{cc}}{\pi R_L'} = \frac{V_m}{R_L'}$$

$$\therefore \boxed{V_m = \frac{2}{\pi} V_{cc}}$$

This is the condition for max. power dissipation.

$$\therefore P_D(max) = \frac{2}{\pi} V_{cc} \times \frac{2V_{cc}}{\pi R_L'} - \frac{4}{\pi^2} \times \frac{V_{cc}^2}{2R_L'} = \frac{4}{\pi^2} \frac{V_{cc}^2}{R_L'} - \frac{2}{\pi^2} \frac{V_{cc}^2}{R_L'}$$

$$\therefore \boxed{P_D(max) = \frac{2}{\pi^2} \cdot \frac{V_{cc}^2}{R_L'}}$$

Advantages of Pushpull class-B Amplifier:

1. The efficiency is much higher than the class-A operation.
2. When there is no input signal, the power dissipation is zero.
3. Due to the transformer, impedance matching is possible.
4. Ripple present in supply voltage also get eliminated.
5. The even harmonics get cancelled. This reduces the harmonic distortion.
6. As the d.c current components flow in opposite direction through the primary winding, there is no possibility of dc saturation of the core.

Disadvantages of Pushpull class-B Amplifier:

1. Two centre-tap transformers are necessary.
2. The transformers make the ckt bulky and hence costlier.
3. Frequency response is poor.

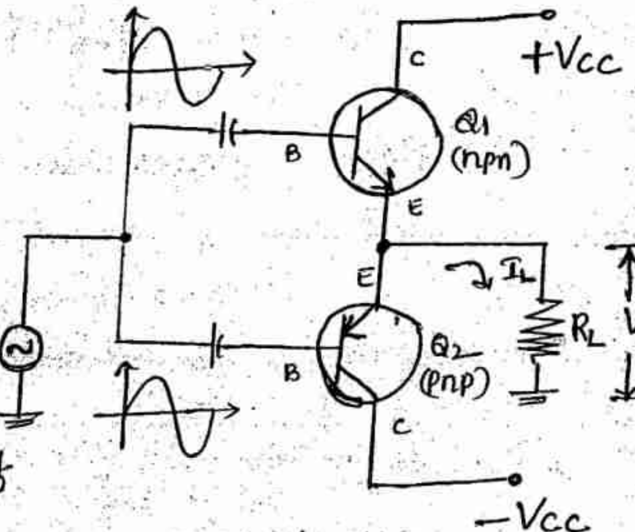
Complementary Symmetry Class B Amplifier (a):

Transformer less Class-B Amplifier

Here one transistor is n-p-n type and other is p-n-p type is used. But with common emitter configuration, it becomes difficult to match the output impedance for max power transfer without an output transformer. Hence the matched pair of complementary transistors are used in common collector (Emitter follower) configuration.

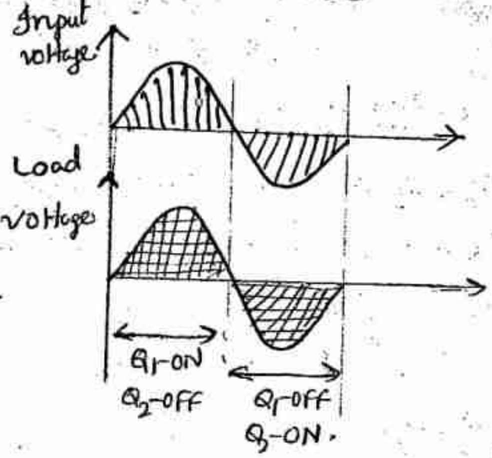
So, lowest output impedance & impedance matching is possible.

Operation:



The circuit is driven from a dual supply of $\pm V_{cc}$.

* During the positive half cycle of the input signal
  Transistor Q_1 - ON - & Conducting
  Q_2 - OFF - not conducting.
* During the negative half cycle of the input signal.
  Transistor Q_2 - ON - conducting
  Q_1 - OFF - not conducting.



Analysis: All the results derived for pushpull transformer coupled class B amplifier are applicable to the complementary class B amplifier. The only change is that as the output transformer is not present so, $R_L' = R_L$.

Advantages:

1. As the ckt is transformerless, its weight, size & cost are less.
2. Due to common collector configuration, impedance matching is possible.
3. The frequency response improves due to transformerless class-B amplifier.

Disadvantages:

1. The circuit needs two seperate voltage supplies. ($\pm V_{cc}$).
2. The output is distorted to cross over distortion.

*Comparison of Series Fed and Transformer Coupled Class A Amplifiers:

SL No	Series Fed Class A	Transformer Coupled Class A
1	Load is directly connected in collector so transformer not required.	→ Output transformer is used to connect the load.
2	Simple to design and implement.	→ Complecated to design.
3.	The output impedance is high hence can not be used for low impedance.	→ Low impedance matching is possible due to transformer.
4	Considerable wastage of power.	→ Power wastage is small.
5	Less no-of components are required.	→ More no-of components required.
6.	The circuit is not heavier bulkier and costlier.	→ The transformer makes the ckt heavier, bulkier and costlier.
7.	The max. efficiency is 25%	→ The max. efficiency is 50%
8	The frequency response is better.	→ The frequency response is poor.

*Comparison of Push pull and Complementary Symmetry Class-B Amplifiers:

SL NO	Pushpull Class B	Complementary Symmetry Class B
1.	Both the transistors are similar either p-n-p or n-p-n	→ Transistors are complementary type ie one n-p-n other p-n-p.
2.	The transformer is used to connect the load as well as input.	→ The Circuit is transformer less.
3.	The impedance matching is possible due to the output transformer.	→ The impedance matching is possible due to the common collector ckt.
4	Frequency response is poor.	→ Frequency response is improved.
5	Due to transformers, the ckt is bulky costly and heavier.	→ As transformerless, the ckt is not bulky and costly.
6	Dual power supply is not required	→ Dual power supply is required.
7.	Efficiency is higher than class A	→ The efficiency is higher than the pushpull amplifier.

complementary symmetry push pull amplifiers (or) Transformerless

Power Relations: class-B Amplifier:

DC Input power (P_{dc}):

$$P_{dc} = P_{dc}(Q_1\ ON) + P_{dc}(Q_2\ OFF)$$

$$= \frac{1}{2} V_{cc} I_1 + \frac{1}{2} V_{cc} I_2$$

$$= \frac{V_{cc}}{2}(I_1 + I_2)$$

Let $I_1 = I_2 = \frac{I_m}{\pi}$ because the current flows only half cycle period.

$$P_{dc} = \frac{V_{cc}}{2}\left(\frac{I_m}{\pi} + \frac{I_m}{\pi}\right) = \frac{V_{cc} I_m}{\pi} \longrightarrow (1)$$

output AC power:

$$P_{ac} = V_{rms} \cdot I_{rms}\ (Q_1\ ON) + V_{rms} \cdot I_{rms}\ (Q_2\ ON)$$

$$P_{ac} = I_{1rms}^2 R_L + I_{2rms}^2 R_L \longrightarrow (2)$$

we know

$$I_{1rms} = \frac{I_m}{\sqrt{2}} = I_{2rms}$$

The rms value of half wave is

$$I_{rms}^2 = \left(\frac{I_m}{\sqrt{2}}\right)^2 \Big/ 2 = \frac{I_m^2}{2} \times \frac{1}{2} = \left(\frac{I_m}{2}\right)^2$$

$$I_{rms} = \frac{I_m}{2}$$

$$I_{1rms} = I_{2rms} = I_{rms} = \frac{I_m}{2}$$

$\therefore$ equation (2) becomes

$$P_{ac} = \left(\frac{I_m}{2}\right)^2 R_L + \left(\frac{I_m}{2}\right)^2 R_L$$

$$= \frac{I_m^2 R_L}{4} + \frac{I_m^2 R_L}{4}$$

$$\left[\because I_m = \frac{V_m}{R_L} = \frac{V_{CC}-0}{2} \Big/ R_L = \frac{V_{CC}}{2R_L} \right]$$

$$\therefore I_m = \frac{V_{CC}}{2R_L}$$

$$= \frac{I_m^2 R_L}{2}$$

$$= \frac{V_{CC}^2 \cancel{R_L}}{4R_L^{\cancel{2}} \times 2}$$

$$P_{ac} = \frac{V_{CC}^2}{8 \cdot R_L} \longrightarrow (3)$$

(or)

$$\left\{ I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{V_{CC}}{2\sqrt{2}\, R_L} \right.$$

$$\left. \therefore P_{ac} = I_{rms}^2 \cdot R_L = \frac{V_{CC}^2}{8 \cdot R_L} \right\}$$

Efficiency $\eta = \frac{P_{ac}}{P_{dc}} = \frac{V_{CC}^2}{8 \cdot R_L} \Big/ \frac{V_m I_m}{\pi}$

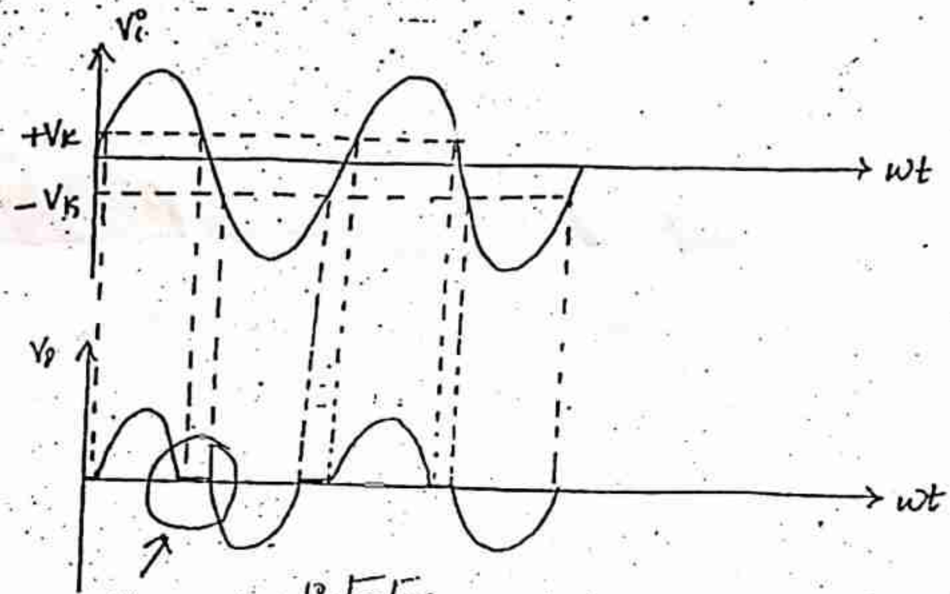
$$= \frac{V_{CC}^2}{8 \cdot R_L} \Big/ \frac{V_m \times V_{CC}}{2 \cdot R_L \cdot \pi}$$

$$= \frac{V_{CC}^{\cancel{2}}}{\cancel{8}_4 \cancel{R_L}} \times \frac{\cancel{2}\cancel{R_L}\pi}{\cancel{V_m} \times \cancel{V_{CC}}} \qquad [\because V_m = V_{CC}]$$

$$\eta = \frac{\cancel{V_{CC}}}{4} \times \frac{\pi}{\cancel{V_{CC}}} = \frac{\pi}{4}$$

$$\boxed{\therefore \eta = 78.5\%}$$

Cross-over distortion :-



Crossover distortion
(both transistors OFF)

→ For a transistor to be in active region the base emitter-junction must be forward biased.

→ The junction is cannot be forward biased till the voltage applied becomes greater than cut-in vtg (V_K) of the junction, which is generally 0.7V for silicon & 0.2 V for Ge.

→ Thus when i/p is less than 0.7V, the base - emitter junction is reverse biased, the collector current remain zero & transistor remains in cut-off region.

→ Hence there is a period b/n the crossing of the half cycles of the i/p signal, for which none of the transistors is active & the o/p is zero.

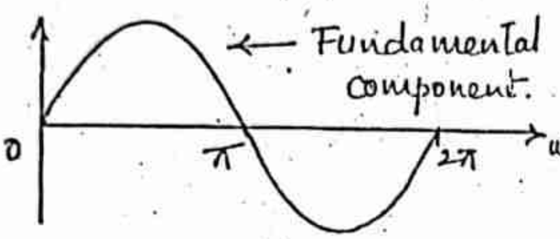
→ Hence the o/p signal gets distorted.

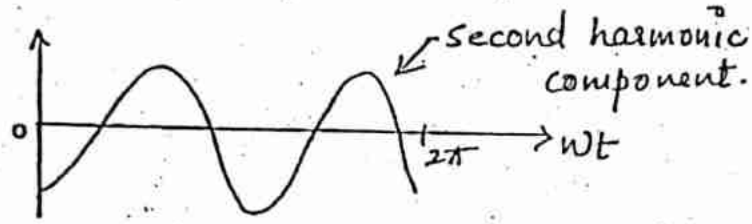
→ Such distortion in the o/p signal is called cross-over distortion.

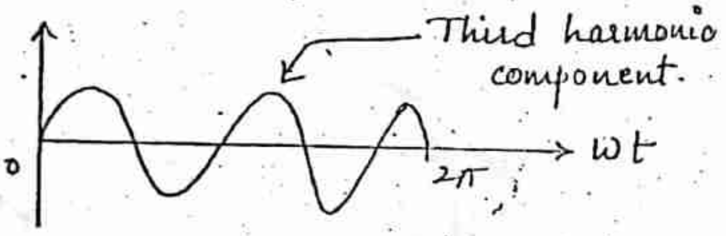
→ Due to cross-over distortion each transistor conducts for less than a half cycle rather than the complete half cycle.

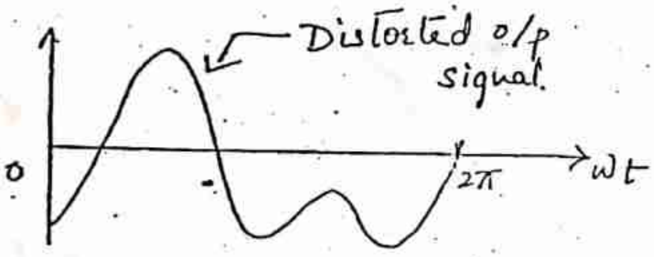
Harmonic distortion

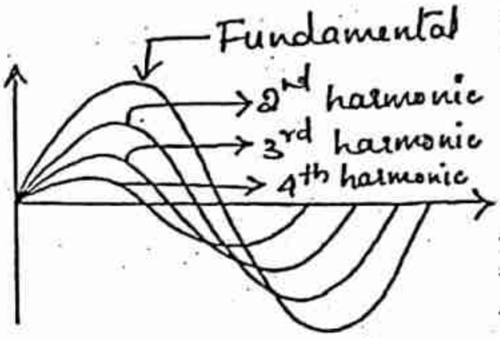
Harmonic distortion :-











→ The presence of frequency components in the o/p waveform which are not present in the i/p signal is called as harmonic distortion.

→ The component with frequency same as i/p signal is called fundamental frequency.

→ Additional frequency components which are integer multiples of fundamental frequency are called harmonics.

→ The fourier analysis of the o/p signal reveals that as the order of the harmonic increases, its amplitude decreases & frequency increases.

Expression for % harmonic distortion :-

→ In general.

% n^{th} harmonic distortion is given by

$$\% D_n = \frac{\text{Magnitude of } n^{th} \text{ harmonic component}}{\text{Magnitude of fundamental.}} \times 100$$

$$D_n = \frac{|B_n|}{|B_1|} \times 100 \%$$

where $B_1 \rightarrow$ amplitude of the fundamental frequency component

$B_n \rightarrow$ amplitude of the n^{th} frequency component.

Eg → % second harmonic distortion is given by

$$D_2 = \frac{|B_2|}{|B_1|} \times 100 \%$$

→ Total harmonic distortion

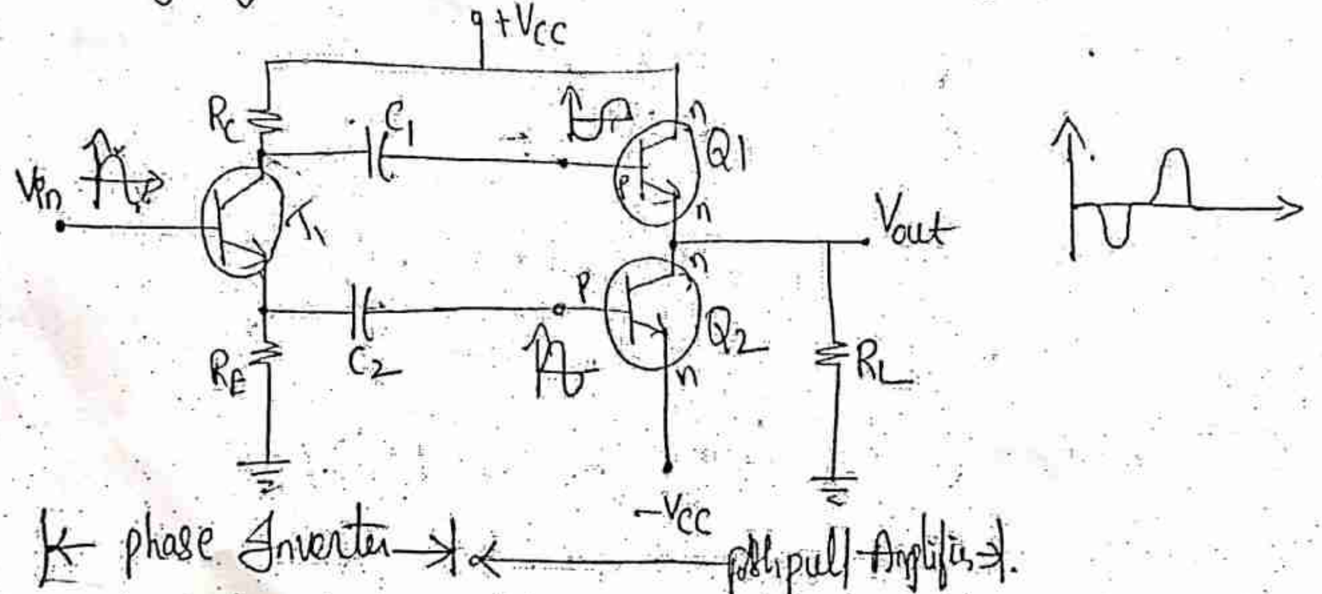
$$THD = \sqrt{D_2^2 + D_3^2 + \dots D_n^2} \times 100 \%$$

Phase Inverter (Transformer less Class B pushpull Amplifier)

The pushpull Configuration using transformer has two major drawbacks namely (i) It requires a bulky and expensive transformer.

(ii) It uses i/p resistance transformer to produce the i/p signal 180° out of phase with each other.

Following figure (A) shows phase Inverter arrangement,



Fig(A) : phase Inverter.

phase Inverter removes both above mentioned drawbacks. But retains the advantages of pushpull Configuration.

Write a note on Transistor Power Dissipation

Power dissipation of a transistor can be defined as the product of voltage drop across the collector to Emitter junction and the collector current; i.e $\boxed{P_D = V_{CE} \times I_C}$

Where,

P_D = Power dissipation

V_{CE} = Voltage drop across collector to Emitter junction.

I_C = collector current.

Hence, maximum power dissipation of a transistor can be evaluated from the collector current and collector to Emitter voltage.

If a transistor operating in its linear region dissipates low power, a heat sink should be used to increase its power dissipation capability. Maximum power dissipation capacity of transistor depends on,

atmospheric temperature

* The ambient temperature.
* Maximum junction temperature.

Thermal runaway :—

The Expression for the collector current of common Emitter circuit is given as,

$$I_C = \beta I_B + (1+\beta) I_{CBO} \longrightarrow (1)$$

When the temperature increases, the parameters 'β', I_{CBO} & I_B in Eq (1) are also increases. specially the reverse saturation current I_{CBO} increases greatly with rise in temperature i.e, for every 10° raise in temperature, I_{CBO} gets doubled. Initially the collector base junction temperature is increased by collector current 'I_C' which in turn increase I_{CBO}. This increases the collector current 'I_C' from Equation (1), which will further increase the collector-~~basen~~ base junction temperature. This process will become cumulative and leads to "thermal runaway". The transistor may destroy by itself as the rating of the transistor are Exceeded.

Thermal Resistance :—

Thermal resistance can be defined as the property of a device to resist the flow of heat per unit power dissipated.

Thermal resistance is denoted by 'θ' and can be Expressed as,

$$\boxed{\theta = (T_J - T_A)/P_D}$$

Where,

T_j = Collector base junction temperature.

T_A = Ambient temperature.

P_D = powed dissipated.

Generally for high power transistor, its value is $0.2^\circ C/W$

$$T_J - T_A = \theta P_D$$

$$\Rightarrow (T_J - T_A) \propto P_D$$

Hence, thermal resistance value depends on difference b/w junction temperature and ambient temperature. If this difference is high then thermal resistance becomes high.

Heat Sinks :-

Heat sink is basically a large metallic heat conducting device, Which When placed near a transistor cools it by increasing its effective surface area.

Requirement and types of heat sinks for power dissipation in large signal amplifiers.

For transistors operating at high power levels, the heat sink must be designed to remove heat by metallic conduction (or) forced air cooling.

The purpose of heat sinks is to keep the operating temperature of the transistor prevent thermal breakdown. Due to increase in temperature I_{CO} increases and due to increase in I_{CO}, I_C increases which results in the increase in power dissipation and thereby temperature increases. This is a cummulative process. Due to this, transistor fail or breakdown occurs. In order to prevent this, heat sinks are used which maintain low temperatures and to dissipates power.

If heat sinks are used, the heat is transferred from die to the surface of package and from package to heat sink and ~~from~~ heat sink to the ambient. Heat sink fastens the power dissipation and prevents breakdown of the device.

Types of Heat sinks :-

Heat sinks are broadly classified as ;

1. Low power transistor type.
2. High power transistor type.

1. **Low Power Transistor Type:**

*. Low power transistors can be mounted directly on the metal chasis to increase the heat dissipation capability.

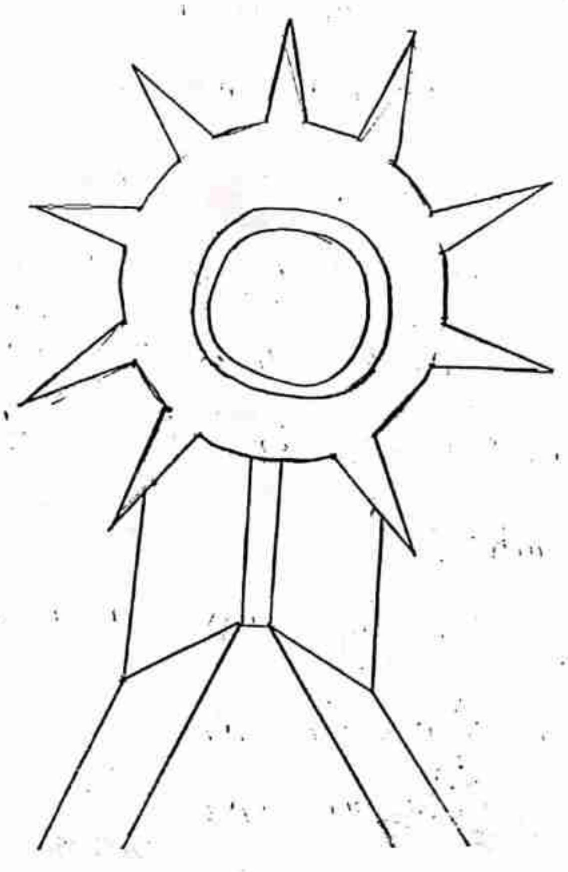
*. The casing of the transistor must be insulated from the metal chasis to prevent short circuit.

Beryllium oxide and zinc oxide are good example for this type:

*. In Beryllium oxide, insulating washers are used for insulating casing from the chasis which passes good thermal conductivity.

*. zinc oxide film, silicon compound between water and chasis improves the heat transfer from semiconductor device to case to the chasis.

A Low power transistor heat sink is shown in figure below:



8. High Power Transistor Type:-

TO-3, TO-66 are the two types of high power transistors.

These transistors are of diamond shape and dissipates power in the order of 100W.

The transistor heat sinks shown in figure below Perform cooling by conduction, convection and radiation methods.

The figure represents high power transistor heat sink.

The thermal resistance of the heat sinks will be typically $3^\circ C/W$.

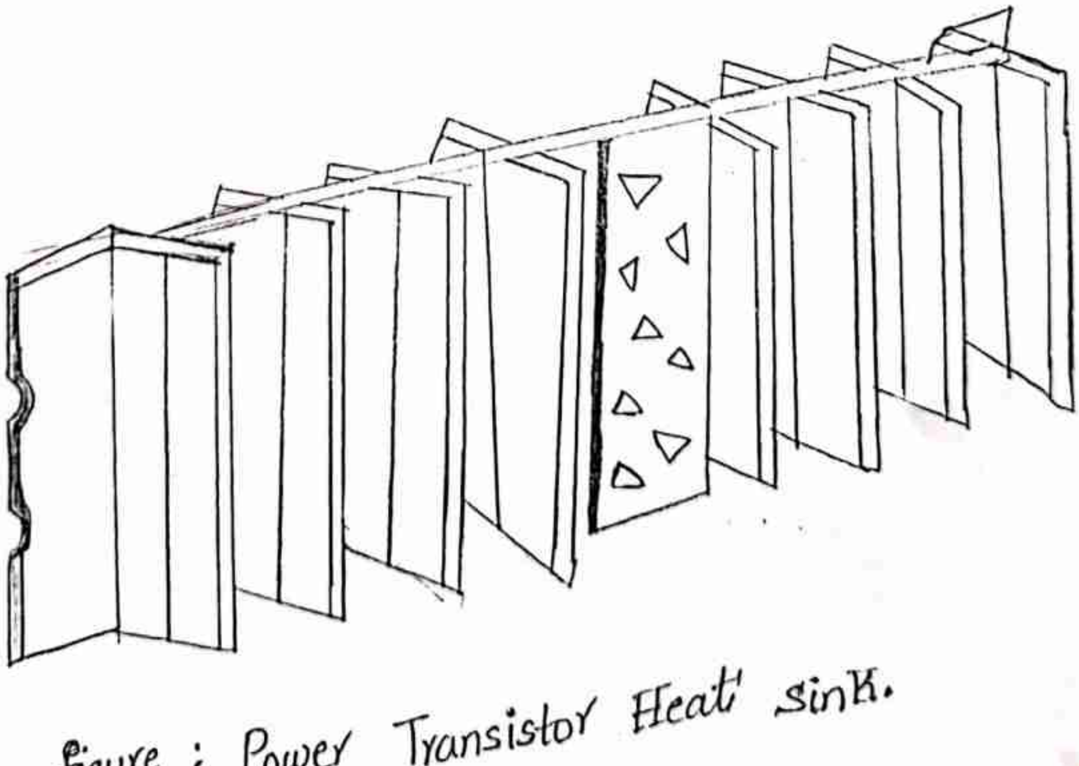
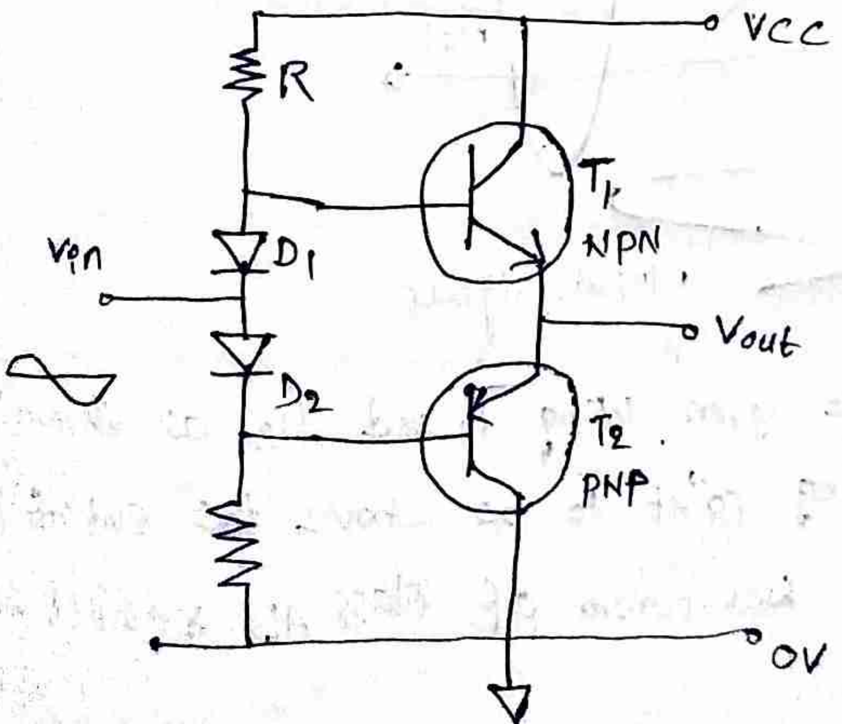


figure : Power Transistor Heat sink.

Class AB power Amplifier:-

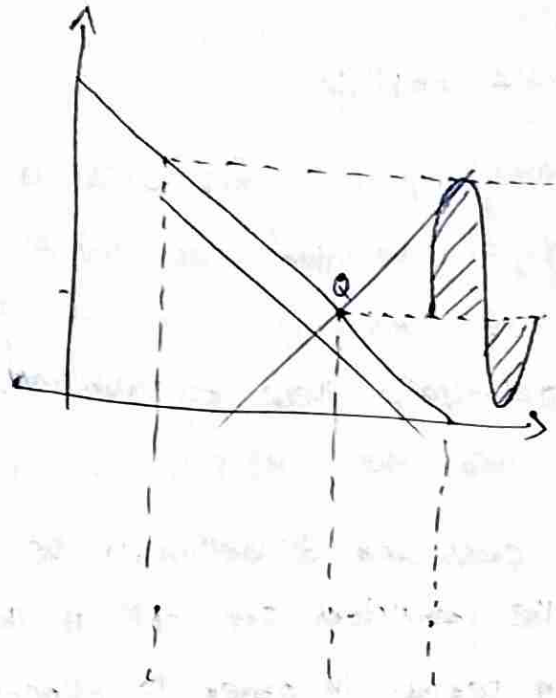
As the name implies, Class AB is a combination of class A and class B type of amplifiers. As class A has the problem of low efficiency and class B has distortion problem, this class AB is emerged to eliminate these two problems, by utilizing the advantages of both the classes.

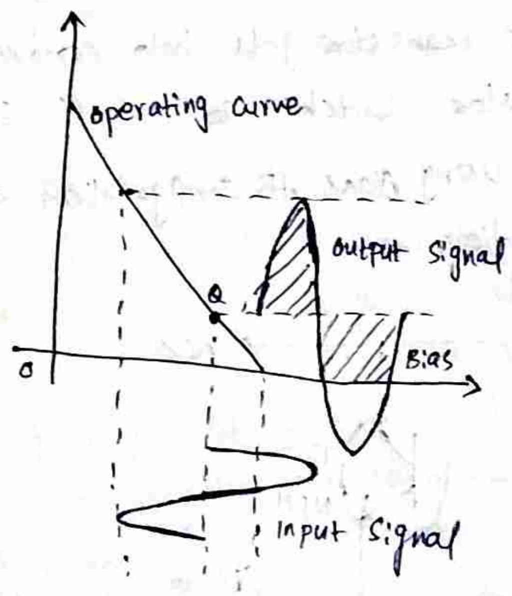
The cross over distortion is the problem that occurs when both the transistors are OFF at the same instant, during the transition period. In order to eliminate this, the condition has to be chosen for more than one half cycle, Hence, the other transistor gets into conduction, before the operating transistor switches to cut off state. This is acheived only by using class AB configuration, as shown in the following circuit diagram.



Therefore, in Class AB Amplifier design, each of the push-Pull transistors is conducting for slightly more than the half cycle of conduction in class B, but much less than the full cycle of conduction of class A.

The conduction angle of Class AB amplifier is somewhere between 180° to 360° depending upon the operating point selected. This is understood with the help of below fig.





The small bias voltage given using D_1 and D_2 as shown in above fig, helps the operating point to be above the cutoff point. Hence the output waveform of class AB results as seen in the above fig.

the cross over distortion created by class B is overcome by this Class AB, as well as the inefficiencies of class A and B don't affect the circuit.

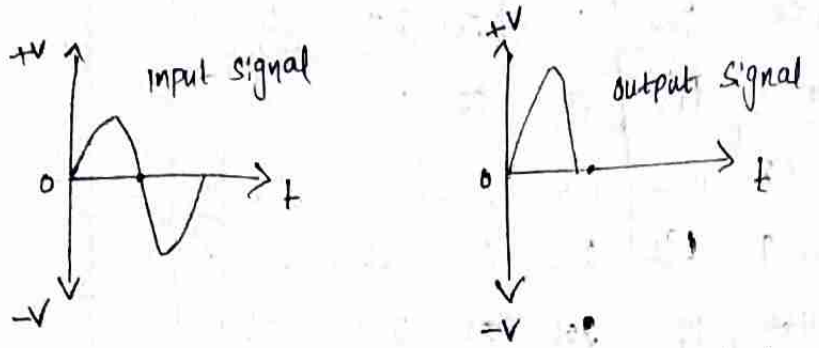
So, the class AB is a good compromise between class A and class B in terms of efficiency and linearity having the efficiency reaching about 50% to 60%. The class A, B and AB amplifiers are called as " linear amplifiers' because the output signal amplitude and phase are linearly related to the input signal amplitude and phase.

Class C power Amplifier:-

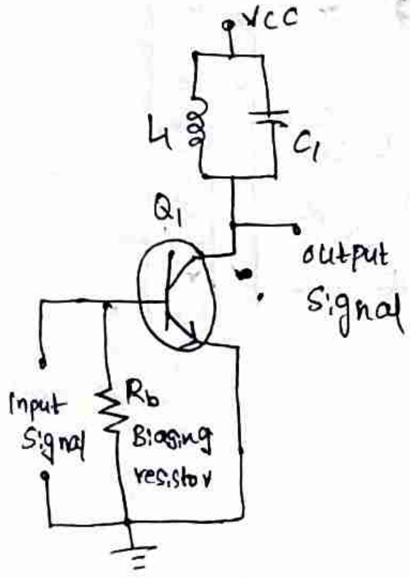
Class C power amplifier is a type of amplifier where the transistor conduct for less than one half cycle of the input signal. Les than one half cycle means the conduction angle is less than 180° and its typical value is 80° to 120°. The reduced conduction angle improves the efficiency to a great extend but causes a lot of distorti theoretical maximum efficiency of a class C amplifier is around 90%.

Due to the huge amounts of distortion, the class C configurations are not used in audio applicati The most common application of the class C amplifie is the RF circuits where there are additional tuned circuits for retrieving the original input signal from the pulsed output of the class C amplifier and so the distortion caused by the amplifier has little effect on the final output.

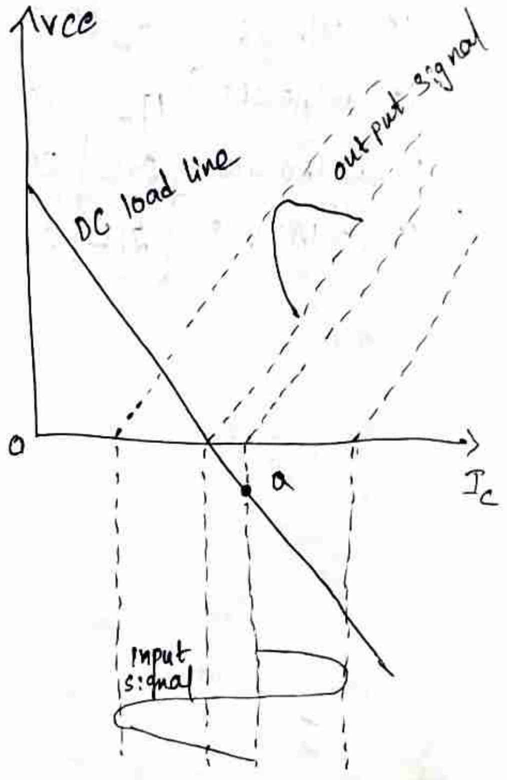
input and output waveforms of a typical class c power amplifier is shown in the below fig.



From the above figure, it is clear that more than half of the input signal is missing in the o/p and output is in the form of some sort of a pulse.



Class c power amplifier



output characteristics of class c power Amplifier.

In the above figure, the operating point is placed some way below the cut-off point in the DC load-line and so only a fraction of the input waveform is available at the output.

Biasing resistor Rb pulls the base of Q_1 further downwards and the Q-point will be set some way below the cut-off point in the DC load line. As a result the transistor will start conducting only after the input signal amplitude has risen above the base emitter voltage ($V_{be} \sim 0.7V$) plus the downward bias voltage caused by R_b. That is the reason why the major portion of the input signal is absent in the output signal.

Inductor L_1 and capacitor C_1 forms a tank circuit which aids in the extraction of the required signal from the pulsed o/p of the transistor. Here transistor is to produce a series of current pulses according to the input and make it flow through the resonant circuit. Values of L_1 & C_1 are so selected that the resonat circuit oscillates in the frequency of the input signal. Since the resonat circuit oscillates in one frequency all other frequencies are attenuated and the required frequency can be squeezed out using a suitably tuned load. Harmonics or noise present in the output signal can be eliminated using additional filters. A coupling transformer can be used for transferring the power to the load.

Advantages:-

-> High Efficiency.

-> Excellent in RF applications.

-> Lowest physical size for a given power output.

Disadvantages:-

-> Lowest linearity

-> Not suitable in audio applications.

-> creates a lot of RF interference.

-> It is difficult to obtain ideal Inductors and coupling transformers.

-> Reduced Dynamic range.

Applications:-

-> RF oscillators

-> RF amplifier

-> FM transmitters

-> Booster Amplifiers.

-> High frequency repeaters.

-> Tuned Amplifiers.

Problems :-

1 series fed class-A amplifier ~~amplifies~~ uses a supply voltage of 10V and load resistance of 20Ω. The input voltage results in a base current of 4 mA. Calculate,

(i) DC input power

(ii) A.C output power

(iii) % efficiency.

Given that,

For a series fed class-A amplifier,

supply voltage, $V_{CC} = 10V$

Load resistance, $R_L = 20\Omega$

Base current, $I_b = 4 mA$

To find,

(i) DC input power, $P_{D.C} = ?$

(ii) A.C. output power, $P_{A.C} = ?$

(iii) percentage efficiency, $\eta = ?$

Assuming,

$\beta = 50$ and

$R_B = 1 k\Omega$

(i) The D.C input power for a series fed class-A amplifier is obtained as,

$$P_{D.C} = V_{cc} \times I_{CQ}$$

where $I_{CQ} = \beta \cdot I_{BQ}$

$$I_{BQ} = \frac{V_{CC} - V_{BE}}{1 \times 10^3} = \frac{10 - 0.7}{10^3} = 9.3 \times 10^{-3}$$

$$\therefore I_{BQ} = 9.3 mA$$

$$I_{CQ} = 50 \times 9.3 \times 10^{-3} \quad \therefore \boxed{I_{CQ} = \beta \cdot I_{BQ}}$$

$$I_{CQ} = 465 mA$$

$$\therefore \boxed{P_{DC} = 4.65 W}$$

(ii) we have

$$I_C = \beta \cdot I_b$$

$$= 50 \times 4 \times 10^{-3} \quad [\because \text{Given } I_b = 4 mA]$$

$$\therefore I_C = 200 mA$$

$$I_{C(rms)} = \frac{I_C}{\sqrt{2}} = \frac{200 \times 10^{-3}}{\sqrt{2}}$$

$$\therefore I_C(rms) = 141.42 mA = I_{rms}$$

Then, the A.C. output power for a series fed class-A power amplifier is obtained as.

$$\therefore P_{A.C} = I^2_{r.m.s} \cdot R_L$$

$$= (141.42 \times 10^{-3})^2 \cdot 20 = 0.4 W$$

$$\boxed{\therefore P_{A.C} = 0.4 W}$$

(iii) Efficiency of a series fed class A power amplifier is obtained as,

$$\% \eta = \frac{P_{A.C}}{P_{D.C}} \times 100 = \frac{0.4}{4.65} \times 100 = 8.6$$

$$\boxed{\therefore \% \eta = 8.6}$$

(2) A transistor in a transformer coupled (class-A) power amplifier has to deliver a maximum of 5 watts to a load of 4Ω. The quiescent point is adjusted for symmetrical swing and the collector supply voltage is $V_{cc} = 20$ volts.

Assume $V_{min} = 0$ volts.

(i) what is the transformer turns ratio?

(ii) what is the peak collector current?

To find,

For a transformer coupled (class-A) power amplifier, power delivered to the load, $p = 5W$

supply voltage, $V_{cc} = 20V$

Load resistance, $R_L = 4\Omega$

$V_{min} = 0V$

(i) Transformer turns ratio, $n = ?$

(ii) peak collector current, $I_m = ?$

(i) The expression for turns ratio of a transformer is given as,

$$n^2 = \frac{R_L}{R_L'}$$

$$n = \sqrt{\frac{R_L}{R_L'}} \longrightarrow (1)$$

solving for R_L'

The expression for power developed or delivered to the load is given by,

$$p = \frac{1}{2}\frac{V_m^2}{R_L'}$$

As $V_{min} = 0V$,

$V_m = V_{cc}$

$$\Rightarrow p = \frac{1}{2}\frac{V_{cc}^2}{R_L'}$$

$$\Rightarrow R_L' = \frac{V_{cc}^2}{2p} = \frac{(20)^2}{2\times5}$$

$$R_L' = \frac{400}{10} = 40\Omega$$

On substituting corresponding values in equation (1), we get,

$$n = \sqrt{\frac{R_L}{R_L'}} = \sqrt{\frac{4}{40}} = \frac{1}{\sqrt{10}} = 0.316$$

(ii) The expression for power delivered to the load can also be written as,

$$P = \frac{1}{2} I_m^2 R_L'$$

$$\Rightarrow I_m^2 = \frac{2P}{R_L'}$$

$$I_m = \sqrt{\frac{2P}{R_L'}}$$

$$= \sqrt{\frac{2 \times 5}{40}} = 0.5$$

$$\boxed{\therefore I_m = 0.5A}$$

~~9652192554~~

10M

class-A power amplifiers two types

1. Direct coupled or series fed class-A power amplifier.
2. Transformer coupled class-A power amplifier.

class-B power amplifiers are also two types:-

1. push pull class-B amplifier

   Here Both the transistors are same type. (Either NPN or PNP)

2. Complementary symmetry class-B AF amplifiers.

   Here two transistors form a Complementary symmetry class-B power amplifier.

   i.e. one npn transistor
   one pnp transistor.

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2m

1. All difference tables
2. power dissipation
3. Thermal run away
4. phase inverter
5. Heat sinks
   - Types
     - Low power Transistor type
     - High power transistor type
6. problems.

INTRODUCTION ABOUT
LINEAR INTEGRATED CIRCUITS

Introduction :

Here we will discuss about linear Integrated Circuits.

* What is circuit means ?

Circuit is made of lot of electronic components like transistor, inductor, capacitor, diodes and resistors. They are connected through wires and these circuit is used for specific applications.

suppose if an application demand lot of electronic components for example 1000's of electronic components and if we design as a circuit in a PCB (or) breadboard, the size of PCB (or) breadboard that we use become large and we use that PCB for certain application, then the entire becomes enlarge.

So, here there is a technique developed in which these discrete components can be fabricated on a single chip. The size of the chip is very small and in the chip all these components are fabricated and the inter-connections are made. So, they specify specific application.

The technology in which it is done is called as Linear Integrated circuits. The discrete components are integrated in a single stone (or) single chip. Hence we call it as Integrated circuit (IC).

Linearity means there it exhibits linear characteristics. Linearity means if voltage increases the current also increases. That is called as linear characteristics. In other words, if voltage dropdowns then current also dropdowns.

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If opposite thing happens, the circuits is showing non-linearity characteristics.

FOR EXAMPLE :-

PCB - In this PCB lot of electronic components are placed. Discrete eletronic components. Discrete means unique/individual: Electronic components are placed, connected by using wires around 100's of components. (few 100's of electronic components). These PCB's is converted to a small Integrated circuits based on area, density of components.

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Integrated Circuit :-

Integrated Circuit (or) IC is a miniature low cost electronic circuit consisting of active and passive components fabricated on a single crystal chip of silicon. Most of the components used in IC's are not similar to conventional components in appearence although they perform similar electrical functions.

Advantages of IC's :-

1. Miniaturization and hence increased equipment density.
2. Cost reduction
3. Improved functional performance
4. Increased operating speeds
5. Reduction in power consumption
6. Increased system reliability.

Classification :-

Integrated circuits offer a wide range of applications and could be broadly classified as

1. Linear IC's
2. Digital IC's

Based upon the requirements, two different technologies were developed.

Integrated Circuits
- Monolithic Circuits
  - Bipolar
    - P-n junction isolation
    - Dielectric isolation
  - Unipolar
    - MOSFET
    - JFET
- Hybrid Circuits

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IC chip size and circuit complexity :-

In the first generation of electronic world, Vaccum tubes were used. But the size of Vaccum tube is very large when compared to that of a transistor. The transistor is discovered by William, Brattain and John Bardeen at Bell Laboratories. The first IC was Introduced by Texas instruments and fairchaild Semiconductors. Since that time, the size and complexity of IC's have increased rapidly as shown.

1. Invention of transistor (Ge)	1947
2. Development of 'Si' transistor (using silicon planar technology)	
3. First IC (SSI)	3-30 gates 100 transistors per chip [Logic gates ; flip flops]
4. MSF	30-300 gates / chip 100-1000 transistors per chip [counters, multiplexers, Adders]
5. LSI	300-3000 gates/chip 1000-20,000 transistors/chip [8 bit μp, RAM-ROM]
6. VLSI	> 3000 gates / chip 20000 - 1 Lakh transistors/chip [16 & 32 bit μp]
7. ULSI	10^6-10^7 transistors / chip (special processors)
8. GSI	$>10^7$ transistors / chip
9. NSI	$>10^7$ transistors / chip

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Operational Amplifier [Op-amp] :-

The operational amplifier is a multi-terminal device which internally is a quite complex. Why the name given to IC, which performs mathematical operations like arithmetic and logical operations for the input and amplifies the output (or) result.

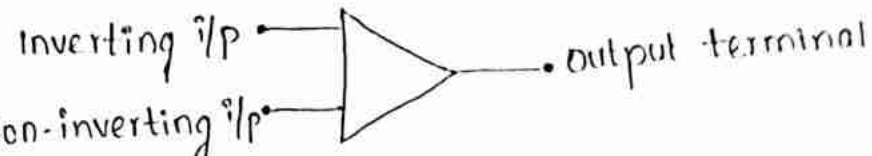

fig : Circuit symbol of op-amp

The shape of the op-amp is a triangle. It has two input terminals and one output terminal.

The terminal with a -ve sign is called inverting i/p terminal and the terminal with a +ve sign is called Non-inverting i/p terminal.

The op-amp's are designed for analog components to perform mathematical operations like integration, differentiation, Averaging, Summation, Inversion and so on.

The Linear IC's are used in no. of electronic applications like audio or video or radio communications, medical electronics and instrumentation control etc.

Definition Of Operational Amplifier :

→ An Operational amplifier is a direct coupled high gain amplifier consisting of one or more differential amplifiers, followed by a level translator and an output stage.

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→ It is a versatile device that can be used to amplify ac as well as dc input signals and designed for computing mathematical functions such as addition, subtraction, multiplication, integration & differentiation.

Basic Circuit Symbol and terminals for IC's :

→ An Op-amp is a triangle as shown in fig. It has 2 input terminals and one output terminal. The terminal with -ve sign is inverting i/p terminal and +ve sign is non-inverting i/p terminal.

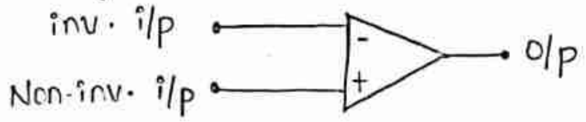
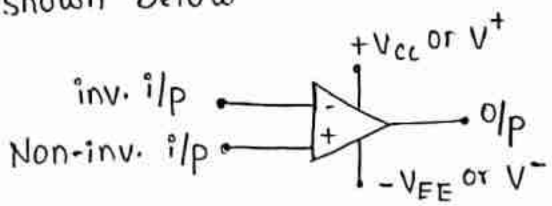


fig: circuit Symbol

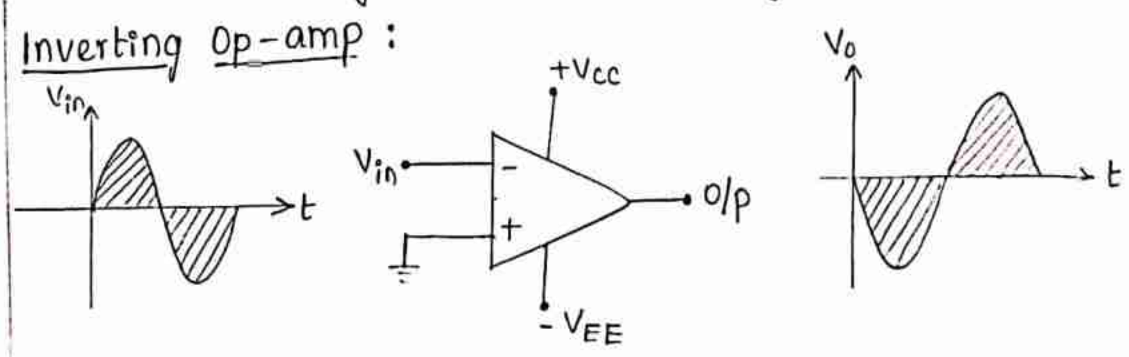
→ The symbol for an op-amp along with its various terminals is shown below.



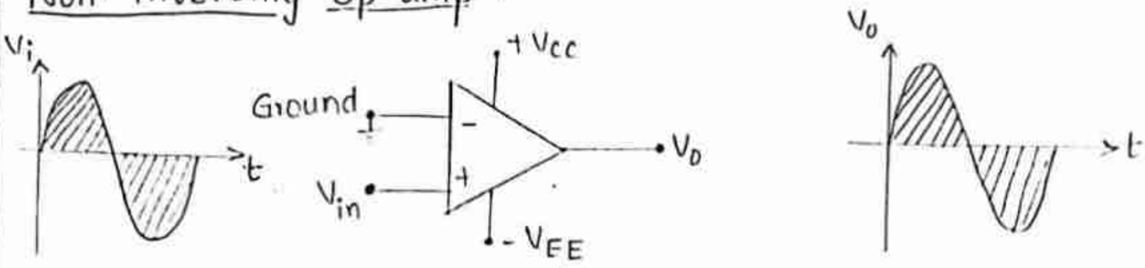
→ All the Op-amp's have atleast following 5 terminals.

- +ve power supply voltage terminal (V_{cc} or V^+)
- -ve power supply voltage terminal (V_{EE} or V^-)
- o/p terminal
- inverting i/p terminal (-ve sign)
- Non-Inverting i/p terminal (+ve sign).

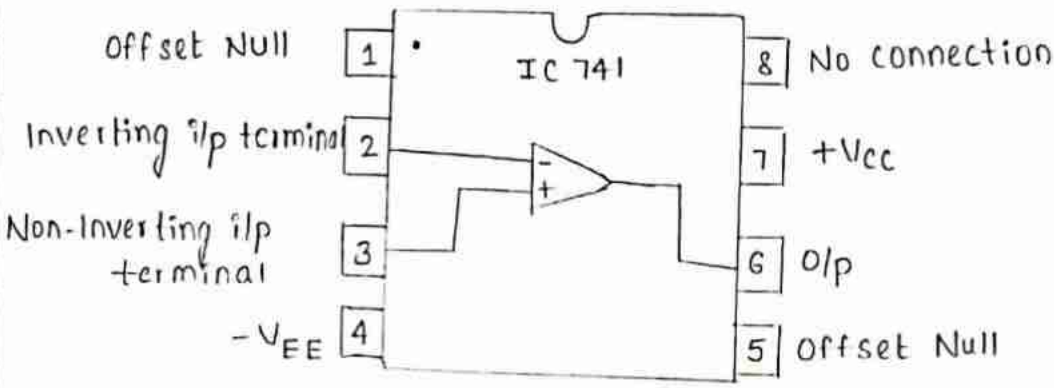
Inverting Op-amp :



Non-Inverting Op-amp :



* 741 Op-amp and its features :



→ The 741 op-amp is high performance monolithic op-amp IC. It is available in 8 pin, 10 pin, 14 pin configuration.

→ If output is produced without any i/p it is Offset value. Offset value is cancelled by using Offset null.

Features :

1. Short circuit protection is provided
2. No. frequency compensation required
3. Offset voltage null Capability
4. Large Common mode & differential voltage range
5. No latch up.

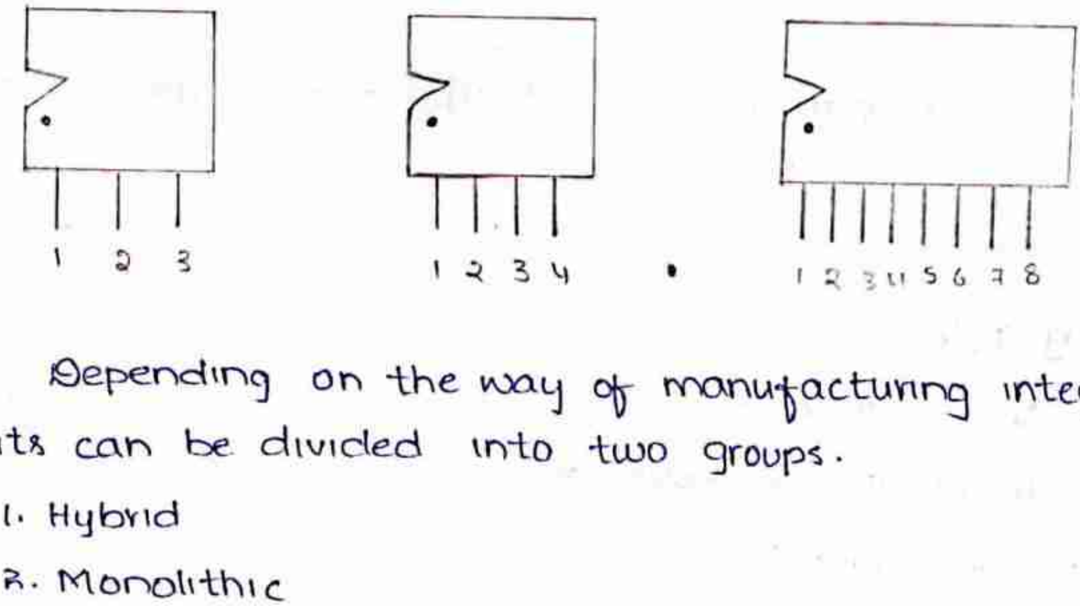
Introduction :-

Integrated Circuits (IC) play a very important part in Electronics.

Most of the IC's specially made for a specific task and contains upto thousands of Transistors, Diodes & Resistors.

Special purpose IC's such as Audio amplifiers, FM radios, logic blocks, regulators and even a whole micro computer in the form of a micro controller can be fitted inside a tiny package.

Some of simple integrated circuits are shown in below figures.



Depending on the way of manufacturing integrated circuits can be divided into two groups.

1. Hybrid
2. Monolithic

Hybrid :

Hybrid contains more than one layer.

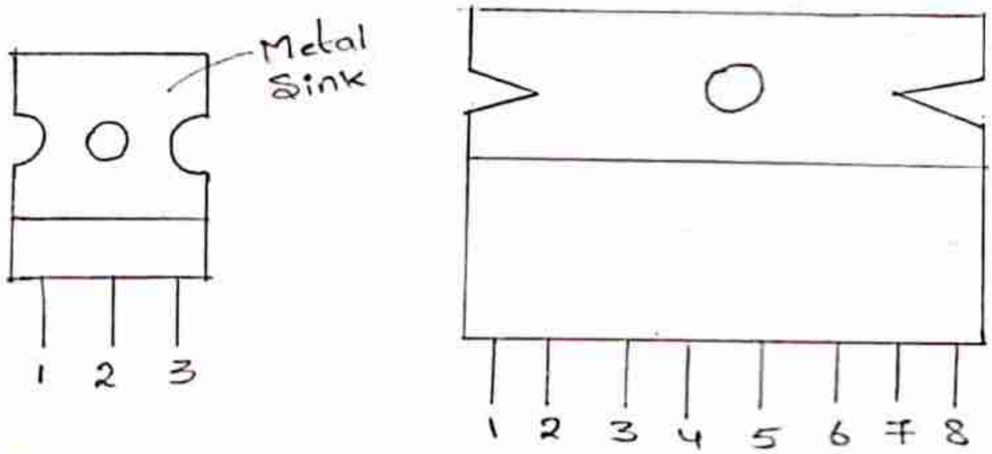
Monolithic :

It contains only one layer.

Most of the integrated circuits are in DIL (Dual in line) package. This means that there are two rows of pins.

The device is view from the top and the pins are numbered in an anticlockwise direction.

High power IC's can generate more heat and they have metal tag that can be connected to a heat sink to dissipate the heat.



IC's can be divided into two further groups.

1. Analog
2. Digital

Analog IC's :

Analog IC's is refered to as a output voltage of a linear circuit is continous and follows changes any input.

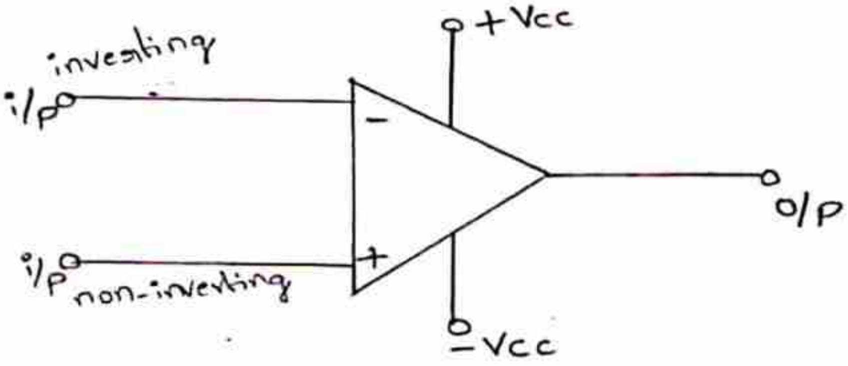
Ex: Audio Amplifier

When signal from a microphone is connected to the input, the output will vary in the same way as the voltage from microphone.

Digital IC's :

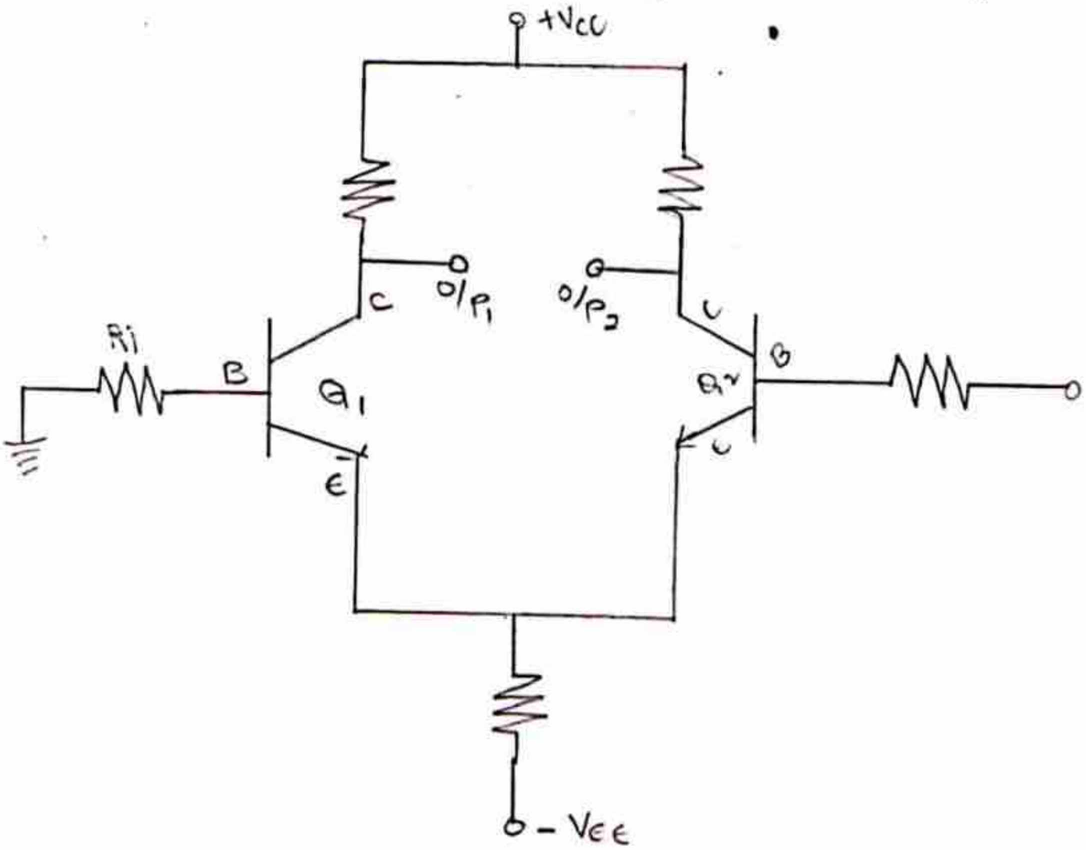
It is refered to as a output voltage is not continous. It is either low or high. and it changed from one state to other very quickly.

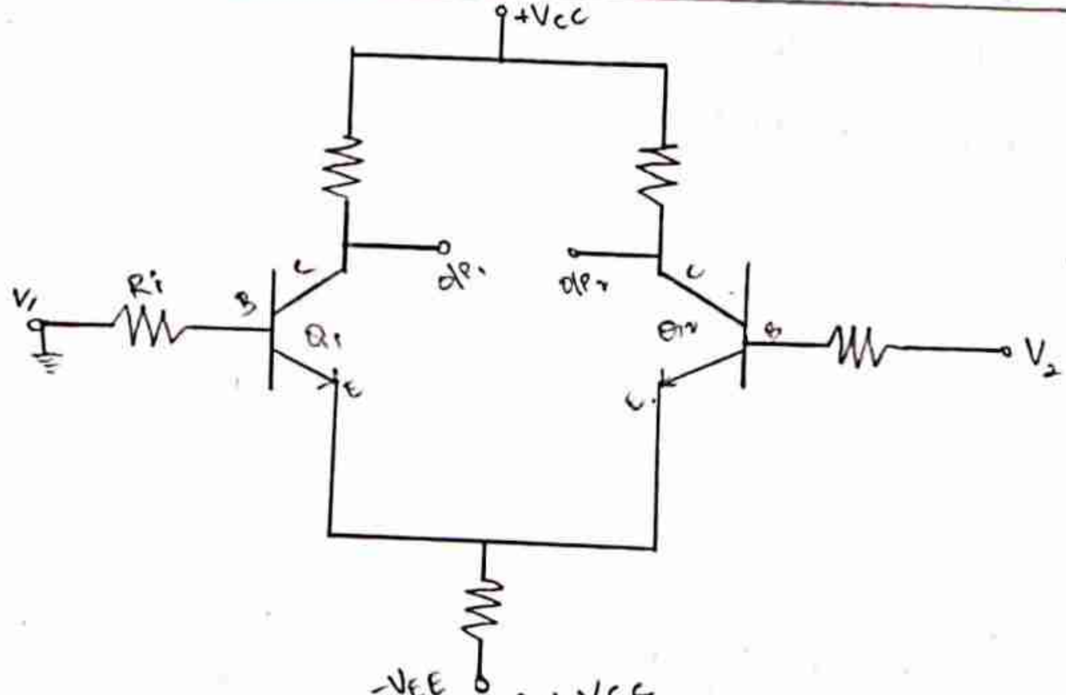
The symbol of an IC is commonly used as a amplifier (or) Operational amplifier.



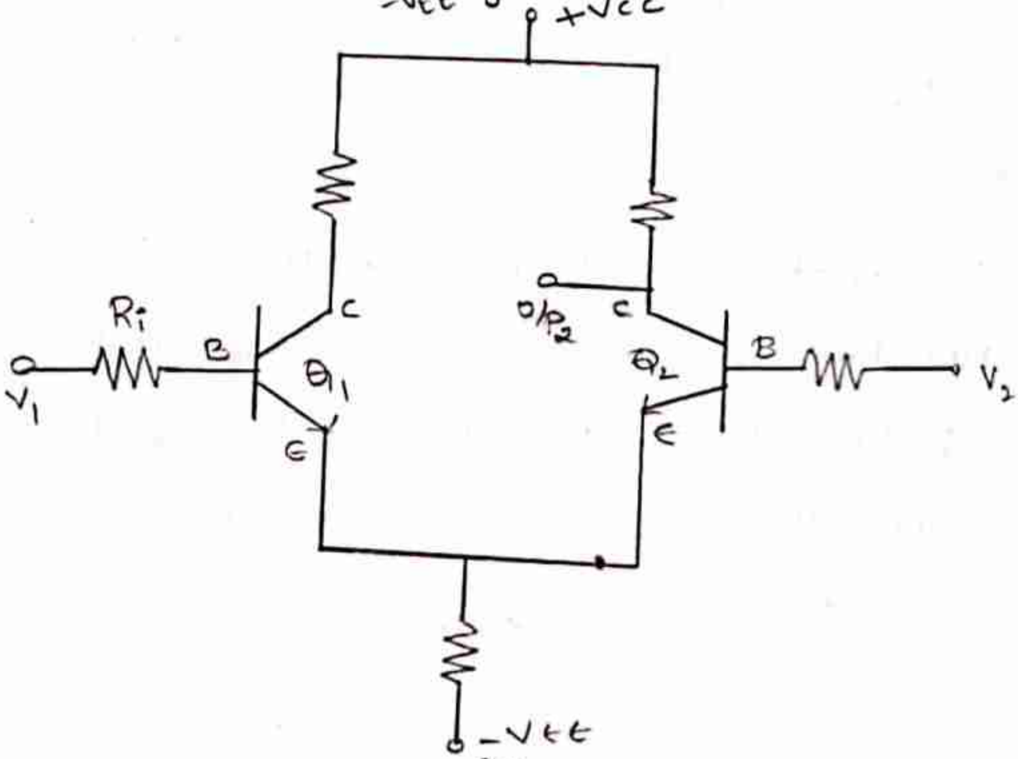
Differential amplifier is an device which is used to amplifies the difference of two input signals. It has 4 configurations.

1. Dual i/p, balanced o/p Differential Amplifier
2. Dual i/p, unbalanced o/p Differential Amplifier
3. Single i/p, balanced o/p Differential Amplifier
4. Single i/p, unbalanced o/p Differential Amplifier

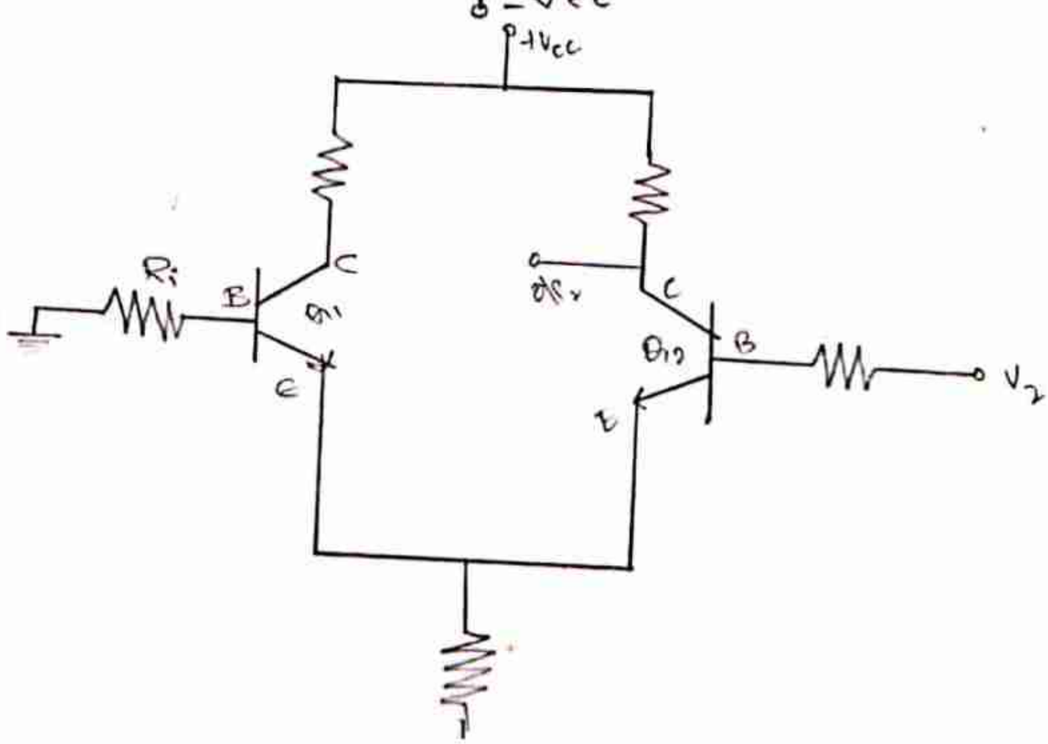




+Vcc
o/p1
o/p2
Ri
V1
B
C
E
Q1
Q2
V2
-VEE



+Vcc
Ri
V1
B
C
E
Q1
o/p2
Q2
V2
-VEE



+Vcc
Ri
B
C
E
Q1
o/p2
Q2
V2

* Basic Information of Op-Amp :-

Op-Amp is a operational Amplifier. Op-Amp is an integrated circuit that operates as a voltage amplifier. An Op-amp has a differential input. The symbol for an op-amp along with its various terminals is shown in below fig.

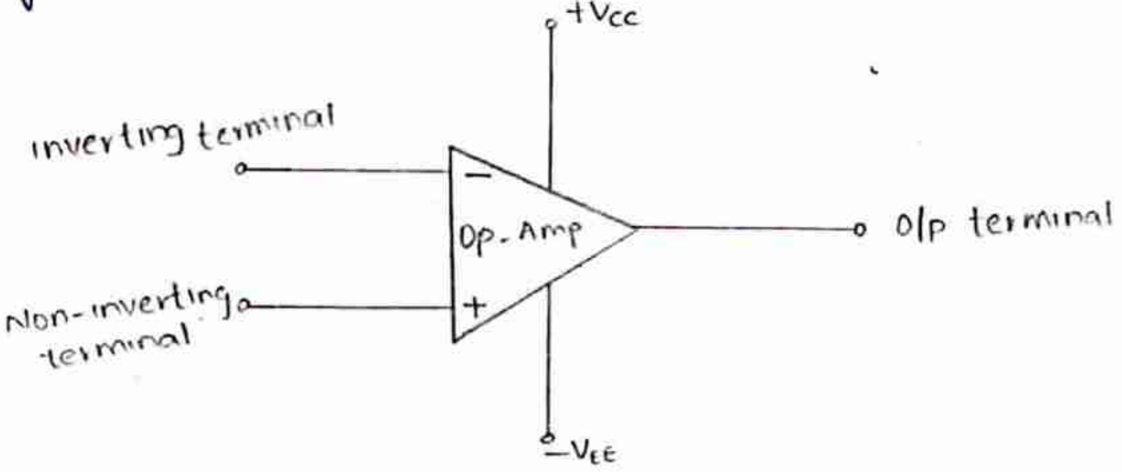


fig :- Symbol of an Op-Amp

The op-amp is indicated by a triangle with points in the direction of the signal flow.

→ Op-amp has 2 inputs of opposite polarities and it has single o/p and has 2 power supplies.

→ These amplifiers are called Operation Amplifiers because they were initially designed as an effective device for performing arithmetic operations (+, -, x, %) in an analog circuit.

→ Almost all the op-amp have atleast 5 terminals

a. The positive supply voltage terminal $+V_{cc}$

b. Negative supply voltage terminal $-V_{EE}$

c. Output terminal

d. Inverting input terminal (-)

e. Non-inverting input terminal (+).

→ The i/p at inverting terminal is positive voltages the o/p is -ve voltage and vice versa.

→ While the i/p at non-inverting terminal results is the same polarity output signal at the o/p terminal. This is shown in below fig.

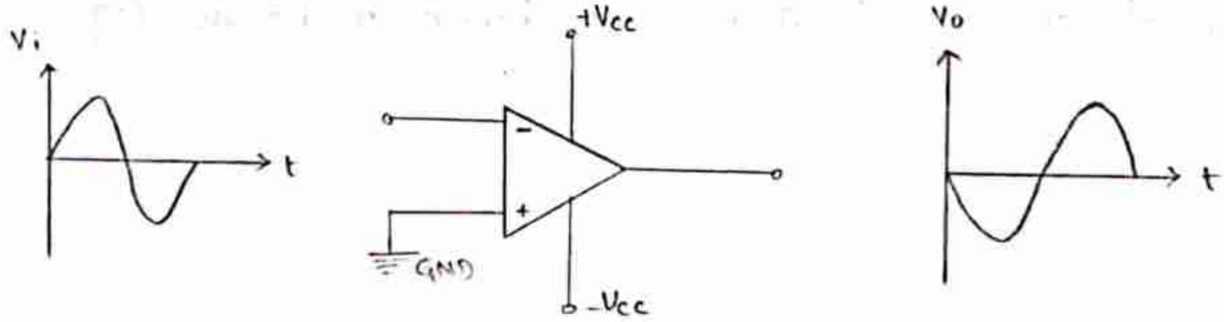


fig: input is applied to the inverting terminal

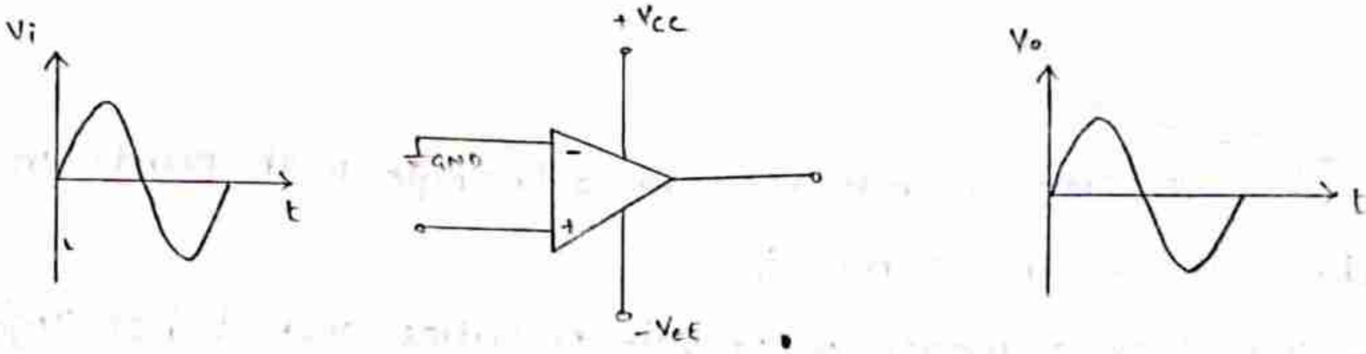


fig: input is applied to the Non-inverting terminal

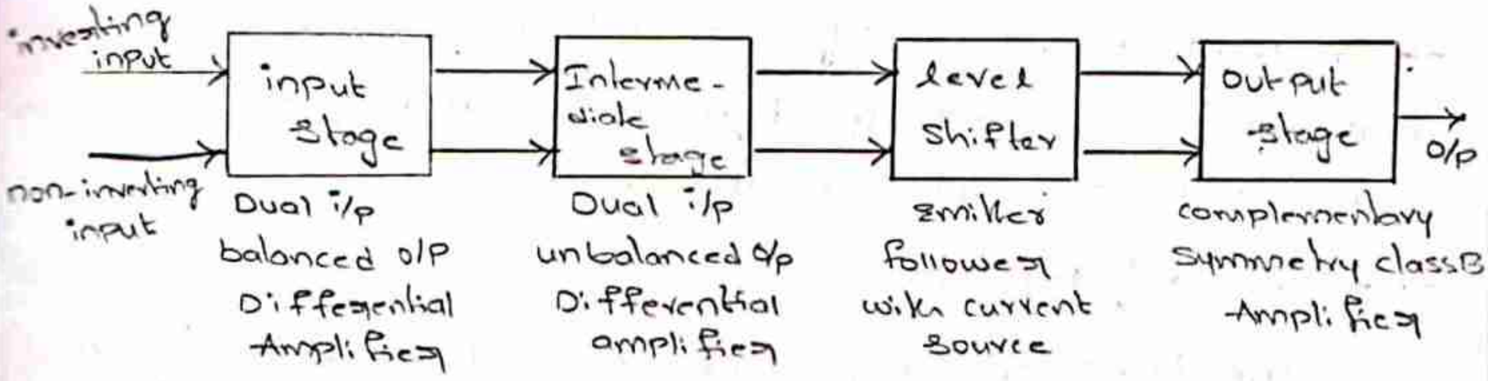
→ The Op-amp works on dual power supply.

→ The dual power supply is generally balanced i.e., the voltage of the +ve supply $+V_{CC}$ and -ve supply $-V_{EE}$ are same magnitude. The typically used power supply voltag are ±15V.

→ But if the 2 voltage magnitudes are not equal in a dual supply it is called as unbalanced power supply.

→ But almost we use the balanced dual power supply for Op-amp in practically.

* Block Diagram of Op-Amp :-



The fig. shows the block diagram of Op-amp. It consists of 4 cascaded blocks.

a. Input stage
b. Intermediate stage
c. Level shifter
d. Output stage

1. Input stage :-

The ~~output~~ input stage requires high i/p impedence to avoid loading on the sources. It requires 2 i/p terminals & also it requires low o/p impedence.

→ All such requirements are achieved by using dual i/p balanced o/p differential amplifier at the i/p stage.

→ This stage provides most of the voltage gain of the amplifier & also establishes the i/p resistance of the amplifier.

2. Intermediate Stage :-

The o/p of the i/p stage drives the next stage which is an intermediate stage. This is another differential amplifier with dual i/p unbalanced o/p i.e., single ended o/p.

→ The overall gain of requirement of the op-amp is very high.

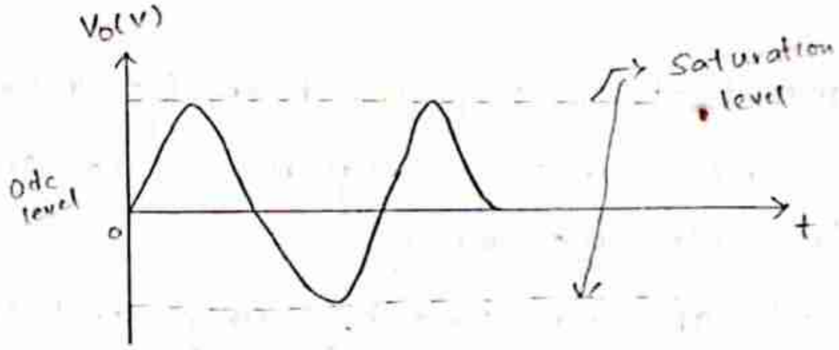
→ In most of the amplifier an intermediate stage is a dual i/p unbalanced o/p differential amplifier. This stage increases voltage gain of the amplifier.

3. Level shifting stage :-

The level shifting stage is used after the intermediate stage to shift the dc level at the o/p of the intermediate stage downward to zero volts wrt ground.

→ Here coupling capacitors are not used to couple the amplifiers in the intermediate state. Dc biasing voltage level propagates through the amplifier. Due to this a significant dc level appears at the o/p along with ac o/p.

→ Due to this effect o/p gets distorted & limits the maximum o/p voltage. This is shown in below fig.



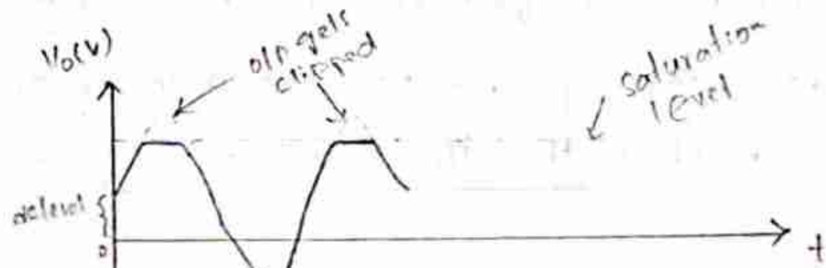
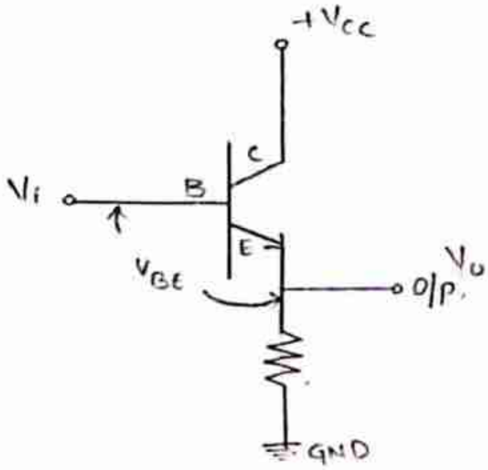


fig: Distorted o/p due to Additional level.

→ So the main purpose of the level shifting stage is to shift the o/p 'Q' point dc level towards the ground with minimum change in the ac signal.

→ This also satisfies that the o/p should have equal voltage level of 0V for '0' i/p signal.

Eg :- 1. How to vary o/p vtg by giving i/p



Applying KVL to the i/p side

$$V_i - V_{GS} - V_o = 0$$

$$\boxed{V_o = V_i - V_{GS}}$$

By varying i/p vtg, the o/p is decreasing.

Proof :- Let us assume that

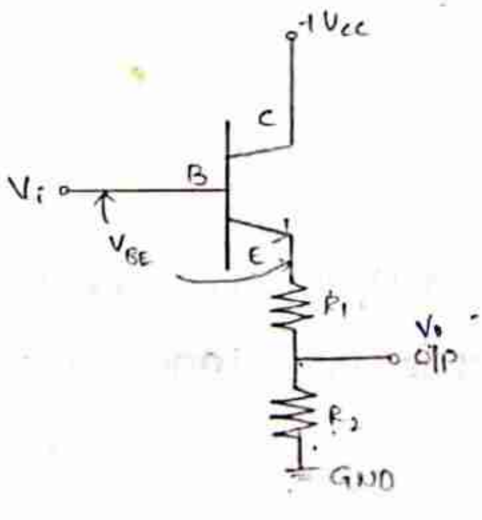
$V_i = 5V$, $V_{GS} = V_{BE} = 0.7V$

$$V_o = V_i - V_{GS}$$

$$= 5 - 0.7$$

$$\boxed{V_o = 4.3V}$$

Eg : 2



Applying KVL to the circuit

$$V_i - V_{BE} - I(R_1 + R_2)$$

$$I(R_1 + R_2) = V_i - V_{BE}$$

$$I = \frac{V_i - V_{BE}}{R_1 + R_2}$$

$$\frac{V_o}{R_2} = \frac{V_i - V_{BE}}{R_1 + R_2}$$

$$V_o = \frac{V_i - V_{BE}}{R_1 + R_2} \times R_2$$

proof :- let us assume

$$V_o = \frac{5 - 0.7}{10 + 4} \times 4$$

$$= \frac{4.3 \times 4}{14}$$

$$= \frac{17.2}{14}$$

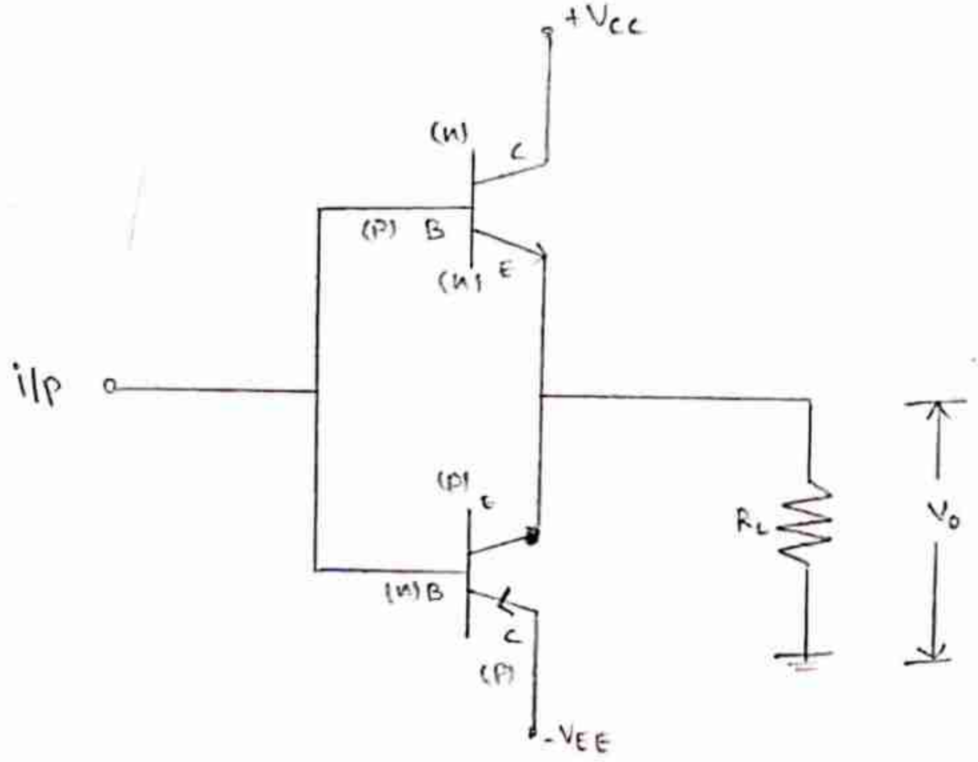
$$V_o = 1.22 \quad V_o \downarrow$$

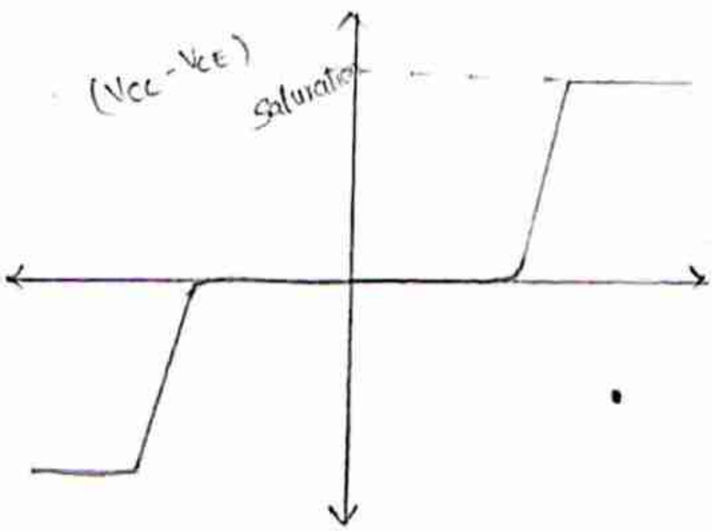
4. Output Stage :-

The last stage is a complimentary class B pushpull amplifier. The basic requirements of an o/p stage are low o/p impedence.

1. large o/p voltage
2. large o/p current
3. low o/p impedence
4. low power dissipation
5. Short circuit protection.

A pushpull amplifier satisfies the above requirements & hence commonly used in the o/p stage of an Op-amp.





* Packages and Pinouts :-

The op-amp is fabricated on a very small silicon chip and is package in a suitable case.

The Op-amp is generally available in 2 packages.

1. Metal can
2. DIP (Dual in line package)

→ Metal can's are available with 8, 10 or 12 pins.

→ DIP packages are having 8 (or) 14 pins.

→ DIP package is most widely used.

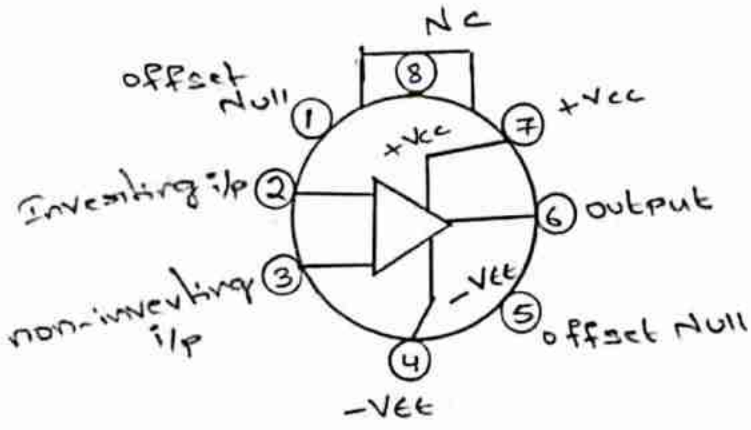


fig: Metal Can Package

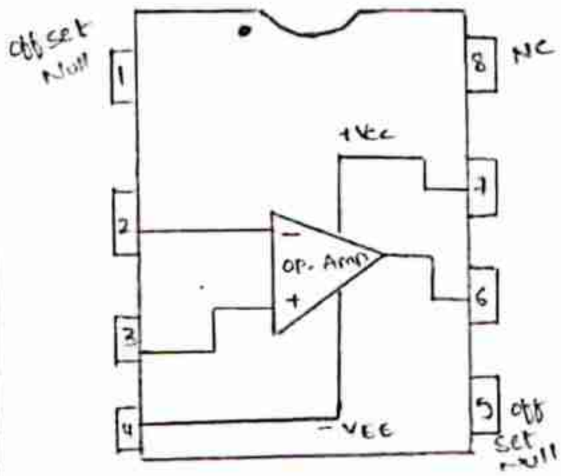


fig: 8-pin DIP package

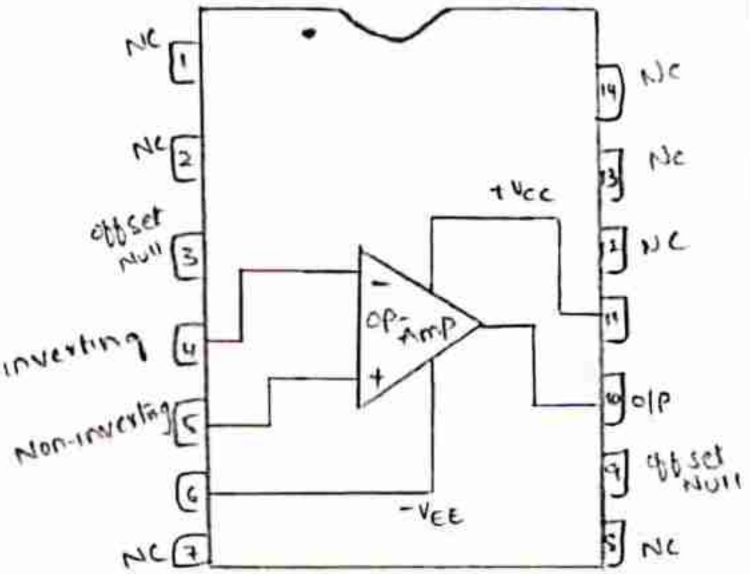
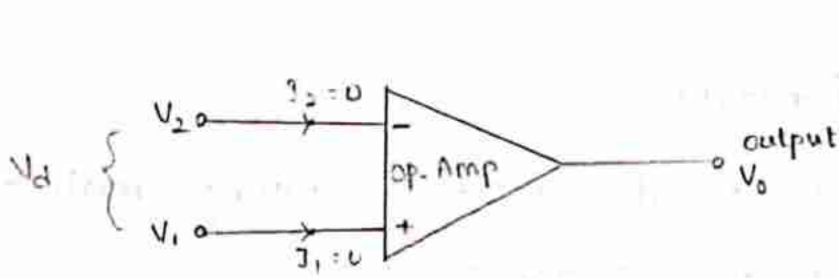


fig: 14-pin DIP package

* Ideal Op-Amp :-



The above fig. shows an ideal op-amp. It has two i/p signals V_1 & V_2 applied to non-inverting and inverting terminals respectively.

The op-amp amplifies the difference b/w the voltages applied at the non-inverting i/p & inverting i/p.

→ V_1 is the voltage applied at the non-inverting terminal and V_2 is the voltage applied at the inverting terminal. The difference between the 2 voltages $(V_1 - V_2)$ can be acts as an input to the op-amp. It is denoted by V_d.

$$\boxed{V_d = V_1 - V_2}$$

→ If the gain of the op-amp is 'A', then

$$A = \frac{V_{out}}{-V_d}$$

$$\boxed{V_{out} = A \times V_d}$$

→ The above expression says that the o/p voltage is directly proportional to the algebric difference b/w the 2 i/p voltages.

→ Hence the op-amp amplifies the difference b/w the 2 i/p voltages.

→ An ideal op-amp draws no current at the i/p terminals i.e., $I_1 = I_2 = 0$. Hence its i/p impedence is infinity $(Z_i = \infty)$. This means that any source can drive it & there is no loading effect on the drivers stage.

→ The gain of an ideal op-amp is infinity, hence the differential i/p $V_d = V_1 - V_2$ is essentially zero for the finding o/p voltage V_{out}.

→ The o/p voltage V_{out} is independent of current drawn from the o/p terminals thus its o/p impedence is zero.

→ Hence output can drive an infinite of other circuits.

* Characteristics of an Ideal Op-Amp :-

1. Infinite input Resistance :

It is denoted by R_i and it is infinite for an ideal op-amp. This ensures that no current can flow into an ideal op-amp.

2. Infinite Voltage Gain :

It is denoted by A_{OL} (or) A. It is infinite for an idea op-amp.

3. Zero o/p impedence :

It is denoted by R_o. It is infinite for an ideal op-amp.

4. Zero offset Voltage :

The presence of the small o/p voltage $V_1 = V_2 = 0$ is called as an offset voltage. It is zero for an ideal op-amp.

5. Infinite Band width :

The band width of an ideal op-amp is infinite. This means that the operating frequency range is from 0 to ∞. This ensures that the gain of the op-amp remains constant over the frequency range from dc to infinite frequency. Theref an op-amp can amplify dc as well as ac signals.

6. Infinite CMRR :

It is defined as the ratio of differential gain and common mode gain. It is infinite for an ideal op-amp.

$$\boxed{CMRR = \frac{A_D}{A_C}}$$

7. Slew Rate :

It is defined as the maximum rate of change of o/p voltage with respect to time. It is infinite for an ideal op-am

It is denoted by 's'.

$$\boxed{s = \frac{dV_o}{dt}}$$

* Practical Op-Amp :-

The characteristics of an ideal op-amp can be approximated closely enough, for many practical op-amp characteristics are little bit different than the ideal op-amp characteristics.

1. Input Resistance :

It is denoted by R_i. It has large value in practical op-amp. The typical value of op-amp is $2M\Omega$.

2. Open Loop Gain :

It is the voltage gain of an op-amp when no feedback is applied, practically it is large.

3. output Impedence :

It is denoted by R_o. It has very small value. The typical value of o/p resistance is few ohms i.e., 1Ω or 2Ω etc.

4. Band Width :

The band width of a practical op-amp is very small but if we apply -ve feedback it can be increased to a desired value.

* Virtual Ground :-

It is the situation in which the inverting input of an op-amp is at ground potential even though it is not connected directly to ground.

Assuming that the op-amp is ideal and it is producing some finite o/p. Then the open loop gain will be finite.

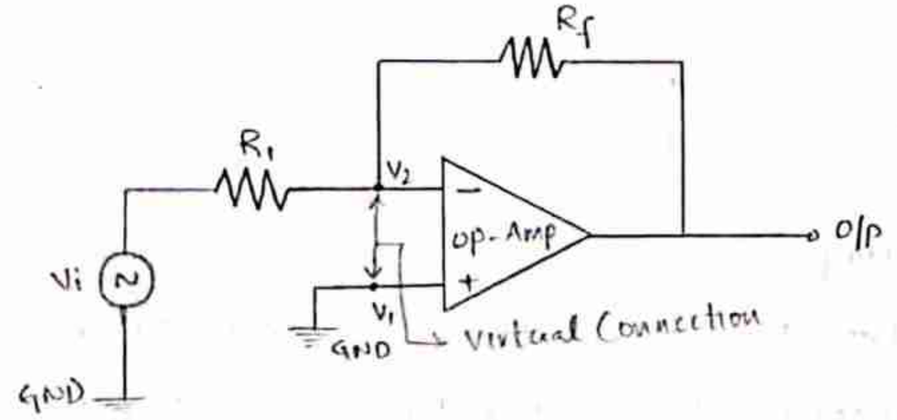


fig:- Practical Inverting Op-Amp.

For an op-amp, we know that

$$A = \frac{V_{out}}{V_d}$$

$$V_d = V_1 - V_2$$

$$A = \frac{V_{out}}{V_1 - V_2}$$

$$V_1 - V_2 = \frac{V_{out}}{A}$$

$$V_1 - V_2 = \frac{V_{out}}{\infty} = 0$$

$$V_1 - V_2 = 0$$

$$\boxed{V_1 = V_2}$$

→ From above eqn it is observes that the ~~practical~~ potential difference b/w 2 terminals is zero. We can say that virtual short circuit exists b/w the 2 i/p terminals.

→ Here, the word virtual is used to clear that actually we are not shorting the i/p terminals.

→ A virtual short circuit means that what ever voltage is at non-inverting terminal, it will automatically appear at the inverting terminal.

DC characteristics of an op-amp (or) properties of practical op-amp :-

An ideal op-amp draws no current from the source and its response is also independent of temperature.

However, ~~a~~ real op-amp, the current is taken from the source into op-amp ~~the current is taken~~ and also the two inputs responds differently to the current & voltage due to mismatch in transistors.

This Non-ideal DC characteristics that had some error components to the DC o/p voltage are.

(i) Input bias current
(ii) Input offset current
(iii) Input offset voltage
(iv) Thermal drift.

(i) Input bias current :- The base currents entering into the inverting and non-inverting terminals are I_{B1} & I_{B2} respectively.

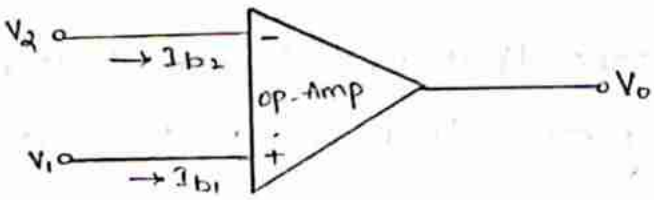


fig: input bias currents

Mathematically, it is expressed as

$$\boxed{I_B = \frac{I_{b1} + I_{b2}}{2}}$$

→ Ideally it should be zero, practically it should be $I_B = 200n$

→ Consider basic inverting amplifier as shown in fig. ②

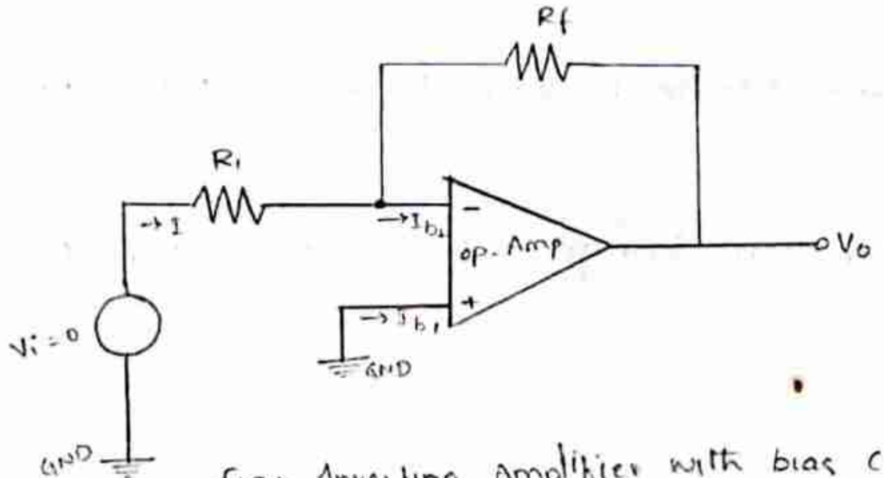


fig:- Inverting Amplifier with bias currents

→ If i/p voltage V_i is said to zero volts, the o/p voltage V_o should also be zero volt.

→ o/p voltage V_o is given that $\boxed{V_o = I_b R_f}$

for a op-amp have 1 MΩ feedback resistor

$$V_o = 200\,nA \times 1\,M\Omega$$

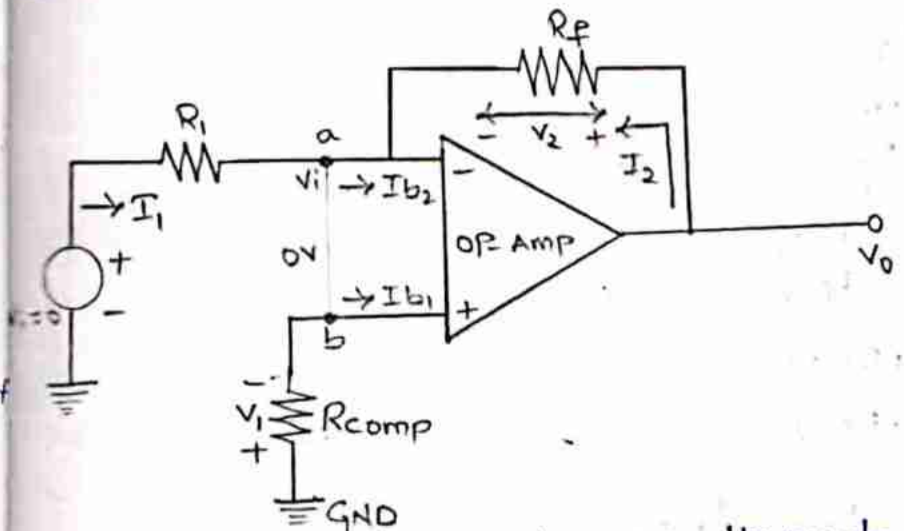
$$\boxed{V_o = 200\,mV}$$

→ The o/p is driven to 200mV with zero i/p because of t

bias currents.

→ In applications where signal levels are measured in mV, this is totally ac unacceptable.

→ This effect can be compensated by a compensation resistor [Rcomp] has been added between the non-inverting terminal and ground. It is shown in below fig.



→ Where current I_{b1} flowing through the compensating resistor [Rcomp] and V_1 voltage drop across it.

Applying KVL, we get

$$-V_1 + 0V + V_2 - V_0 = 0$$

$$V_0 = V_2 - V_1 \quad \rightarrow (1)$$

$$V_2 = V_1$$

→ By selecting proper value of Rcomp, V_2 can be cancelled with V_1 & o/p will be zero

→ The value of Rcomp is derived as

$$I_{b1} = \frac{V_1}{R_{comp}} \quad \rightarrow (2)$$

[droping vtg across Rcomp $V_1 = I_{b1} R_{comp}$]

→ The node 'a' is the voltage V_1 because the voltage at non-inverting terminal is V_1. so we get

$$I_1 = \frac{V_1}{R_1} \quad \rightarrow (3)$$

$$I_2 = \frac{V_2}{R_f}$$

from eq(1)

$V_1 = V_2$, so we get

$$I_2 = \frac{V_1}{R_f}$$

Applying KCL at node 'a' gives

$$I_{b2} = I_1 + I_2$$

$$= \frac{V_1}{R_1} + \frac{V_1}{R_f}$$

$$= V_1 \left[\frac{1}{R_1} + \frac{1}{R_f}\right]$$

$$= V_1 \left[\frac{R_f + R_1}{R_1 R_f}\right]$$

let us consider $I_{b1} = I_{b2}$

$$\Rightarrow \frac{\cancel{V_1}}{R_{comp}} = \cancel{V_1} \left[\frac{R_1 + R_f}{R_1 R_f}\right]$$

$$\boxed{R_{comp} = \frac{R_1 R_f}{R_1 + R_f}} \qquad \left(\because R_{comp} = R_1 \| R_f\right)$$

i.e., to compensate for bias currents, the compensation resistor R_{comp} should be equal to the parallel combination of resistor tied to the inverting i/p terminal.

2. Input offset Current :

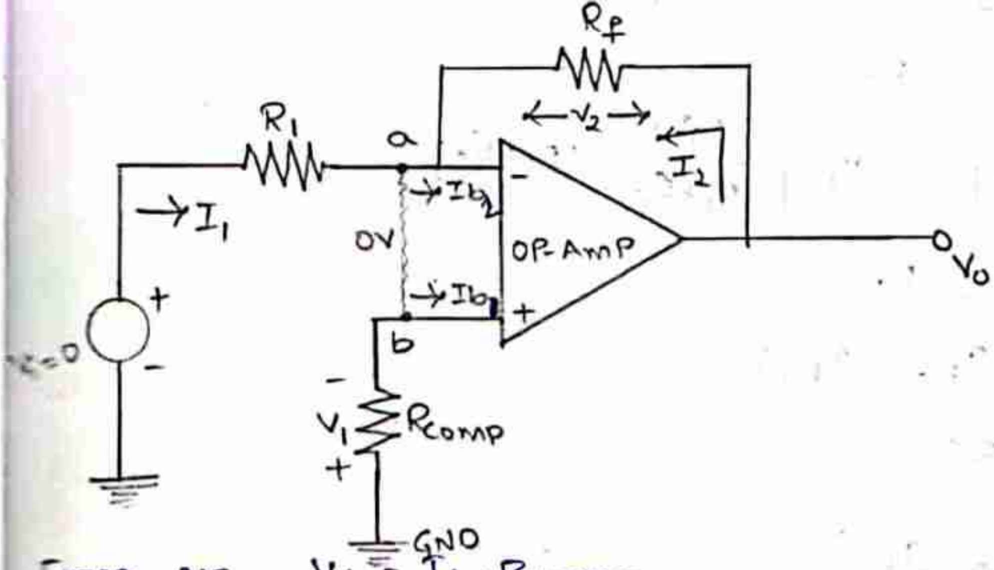
It is defined as the algebric difference between the currents flowing into the 2 i/p terminals of the op-amp. It is denoted by I_{ios}.

Mathematically it is given by

$$I_{ios} = I_{b1} - I_{b2}$$

Effect of i/p offset current on o/p voltage :

Let us consider the op-amp used in the closed loop configuration with R_{comp} as shown in below fig.



From fig. $V_1 = I_{b1} R_{comp}$

$$I_{b1} = \frac{V_1}{R_{comp}}$$

But $I_1 = \frac{V_1}{R_1}$

$$= \frac{I_{b1} R_{comp}}{R_1}$$

Now, $I_{b2} = I_1 + I_2$

$$I_2 = I_{b2} - I_1$$

So we get $I_2 = I_{b2} - \frac{I_{b1} R_{comp}}{R_1}$

we know that, $V_o = V_2 - V_1$

from fig. $V_2 = I_2 R_f$

So, $V_o = I_2 R_f - I_{b1} R_{comp}$

$$= \left[I_{b2} - \frac{I_{b1} R_{comp}}{R_1} \right] R_f - I_{b1} R_{comp}$$

$$= \frac{\left[I_{b2} R_1 - I_{b1} R_{comp} \right] R_f}{R_1} - I_{b1} R_{comp}$$

$$= \frac{I_{b2} R_1 R_f - I_{b1} R_{comp} R_f - I_{b1} R_1 R_{comp}}{R_1}$$

$$= \frac{I_{b2} R_1 R_f - I_{b1} R_{comp} (R_1 + R_f)}{R_1}$$

$$= \frac{I_{b2} R_1 R_f - I_{b1} \left[\frac{R_1 R_f}{\cancel{R_1 + R_f}} \right] (\cancel{R_1 + R_f})}{R_1}$$

$$= \frac{\cancel{R_1} R_f (I_{b2} - I_{b1})}{\cancel{R_1}}$$

$$= R_f (I_{b2} - I_{b1})$$

$$\boxed{V_o = R_f I_{ios}}$$

→ The o/p voltage exists by the i/p offset current.

3. Input offset Voltage:

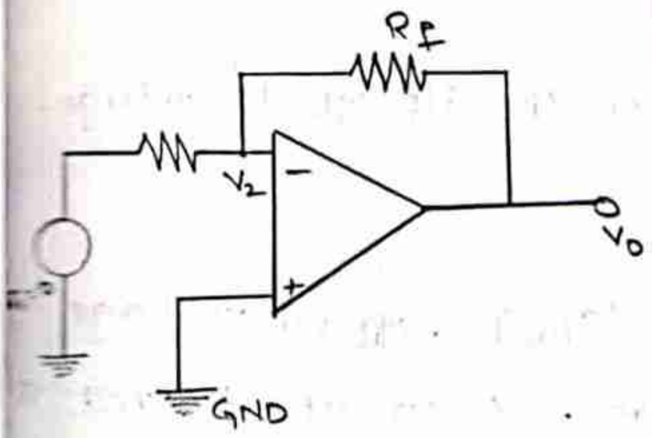
The differential voltage must be applied b/w the 2 i/p terminals of an op-amp, to make the o/p voltage zero. is called as input offset voltage. It is denoted by Vios.

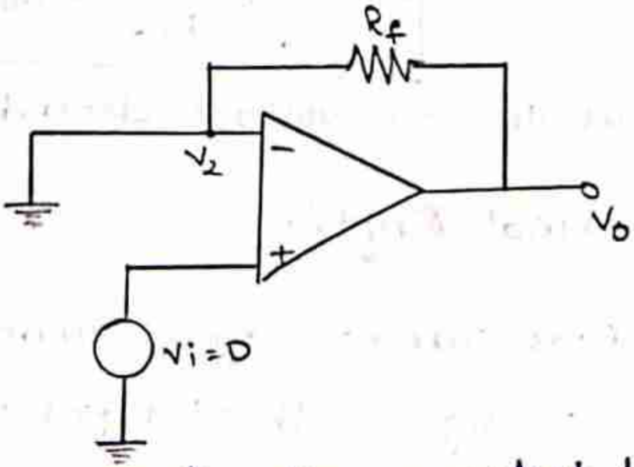
→ Whenever both the i/p terminals of the op-amp are grounded ideally the o/p voltage should be zero. However, in this condition the practical op-amp shows a small non-zero o/p voltage. This is due to mis-matching present in the internal circuit of an op-amp. Such a voltage can cause error in the practical applications, for which op-amp is used.

→ To make such a voltage to zero, it is necessary to apply small difference voltage b/w the 2 i/p terminals of an op-amp. This voltage is called i/p offset voltage.

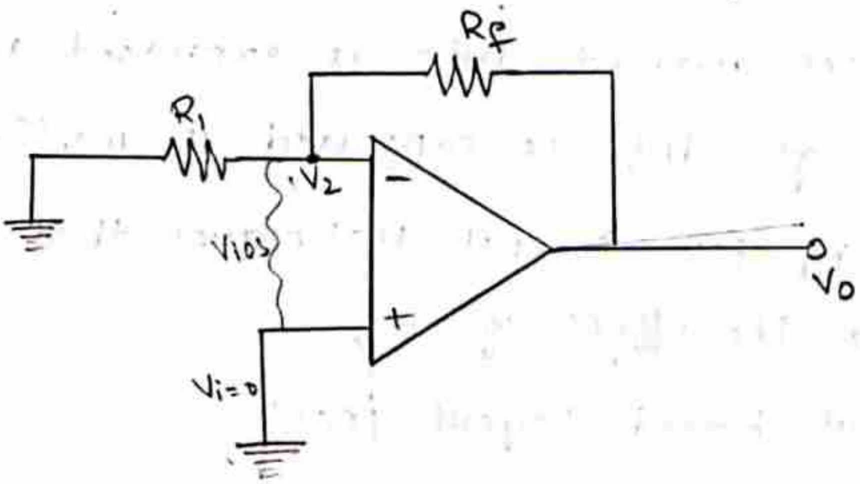
→ For an IC op-amp i/p offset voltage is 6mV.

→ Let us see the effect of Vios on the o/p of non-inverting & inverting op-amp amplifiers shown in below figures.





→ The $V_i = 0$ for both the terminals, the equivalent becomes same as shown in below fig.



→ The voltage V_2 at the inverting i/p terminal is given by according to potential divider theorem.

$$V_2 = \frac{V_o R_1}{R_1 + R_f}$$

$$V_o = \frac{R_1 + R_f}{R_1} \times V_2$$

$$V_o = 1 + \frac{R_f}{R_1} \times V_2$$

Since $V_{ios} = V_i - V_2$

But $V_i = 0$

$V_{ios} = V_2$

we get,

$$V_o = \left[1 + \frac{R_f}{R_1}\right] \times V_{ios}$$

→ Thus the o/p voltage depends on the i/p offset voltage.

4. Thermal Drift :

Bias current, offset current (I_{ios}), off set voltage (V_{ios}) change with temperature. A circuit designed 25°c may not remain so when temperature raises to 35°c. This is called drift.

→ Op-amp offset current drift is expressed nA/°C. and offset voltage drift is expressed in mv/°c.

→ There are very few circuit techniques that can be used to minimize the effect of drift.

1. printed Circuit board layout (PCB)
2. Forced air cooling.

1. PCB Layout :

It can be used to keep op-amp away from source of heat.

2. Forced air Cooling :

It may be used to stablize the temperature.

Modes of Operation :

Op-Amp will performs the two modes operation.

1. Open loop mode of Operation
2. Closed Loop Mode of Operation.

1. Open Loop Mode of Operation :

It says that no feedback terminal in b/w input and output but op-amp will performs the three basic operation in open loop mode of operation.

1. Inverting Amplifier
2. Non-inverting Amplifier
3. Differential Amplifier

(a) Inverting Amplifier :

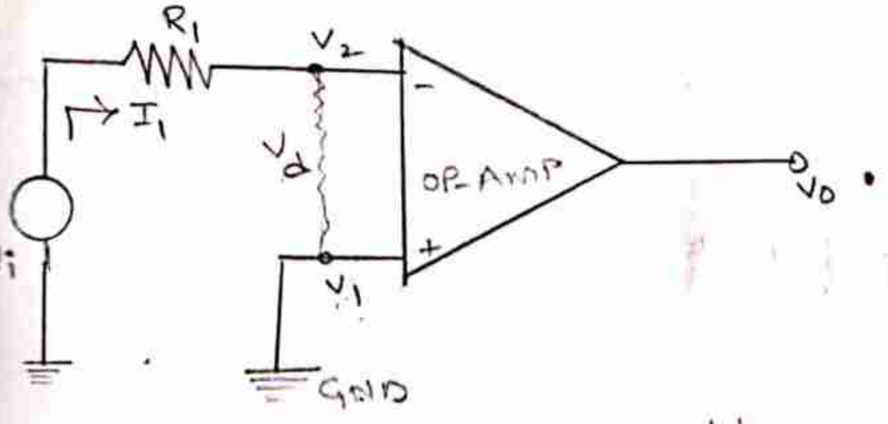


fig : Inverting Amplifier

→ In this the input is applied at inverting terminal and the non-inverting terminal is grounded.

→ In this the output is out of phase (180° phase shift) with the input.

→ We know that, open loop gain,

$$A = \frac{V_o}{V_d}$$

where, $V_d = V_1 - V_2$

So, $A = \frac{V_o}{V_1 - V_2}$

$$V_o = A(V_1 - V_2)$$

If source resistance R_i is very small, then it is neglected

$$\therefore V_2 = V_i$$

$$V_o = A(V_1 - V_i)$$

from fig. $V_1 = 0$ ($\because$ it is connected to ground)

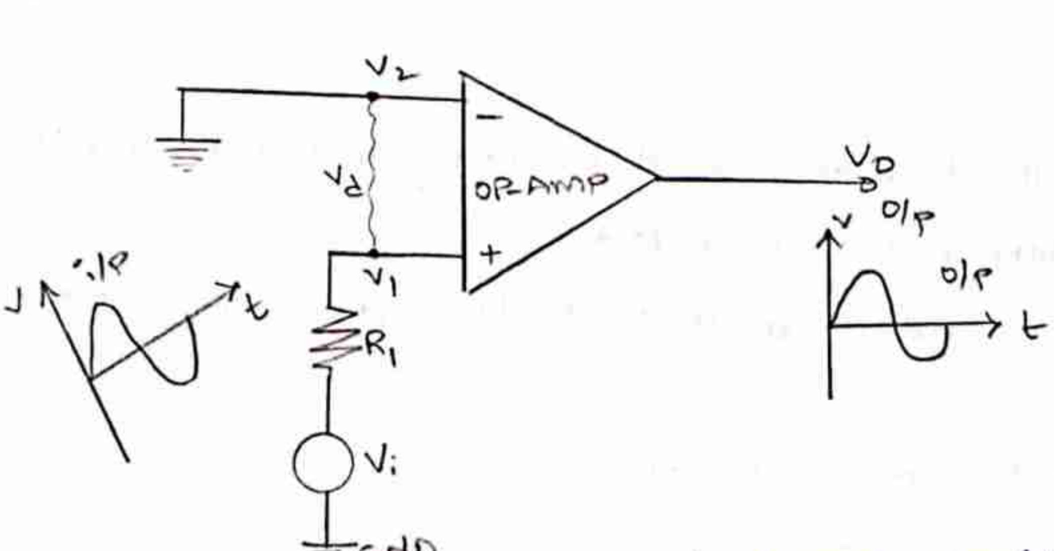
$$V_o = A(0 - V_i)$$

$$\boxed{V_o = -AV_i}$$

where, -ve sign indicates that phase shift provided in b/w input & output.

The above eqn says that the o/p voltage 'A' times larger (or) increased then the input.

(b) Non-inverting Amplifier:



→ In this the i/p is applied at non-inverting terminal and the inverting terminal is grounded.

→ In this the output is in phase (0° (or) 360°) with the i/p.

→ we know that open loop gain,

$$A = \frac{V_0}{V_d}$$

where, $V_d = V_1 - V_2$

so, $$A = \frac{V_0}{V_1 - V_2}$$

$$V_0 = A(V_1 - V_2)$$

→ If source resistance Ri is very small, then it is neglected.

$$\therefore V_1 = V_i$$

$$V_0 = A(V_i - V_2)$$

from fig. $V_2 = 0$ ($\because$ it is grounded)

$$V_0 = A(V_i - 0)$$

$$\boxed{V_0 = AV_1}$$

where, +ve sign indicates that phase shift is zero provided in input and output.

(c) Differential Amplifier: *

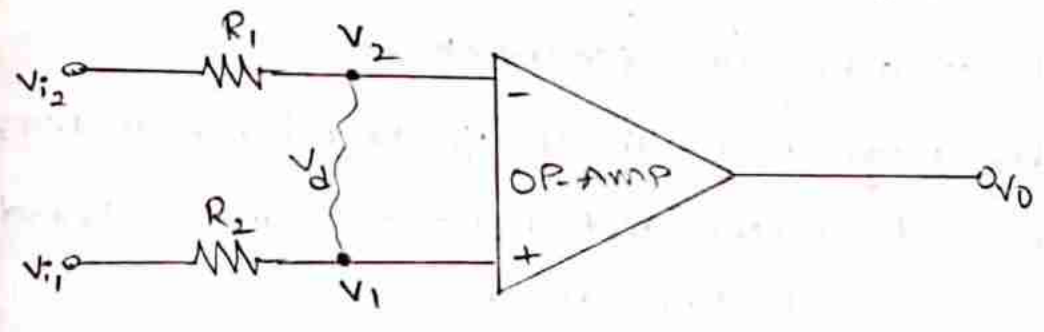


fig: Differential - Amplifier

→ In these inputs are applied at both the inverting and non-inverting terminals. Since the difference b/w two input signals is amplifies which is called Differential Amplifier.

→ We know that open loop gain,

$$A = \frac{V_o}{V_d}$$

Where, $V_d = V_1 - V_2$

so, $A = V_o/V_d$

$$A = \frac{V_o}{V_1 - V_2}$$

$$V_o = A(V_1 - V_2)$$

→ If source resistance R_i is very small, then it is neglecte

$$V_{i_1} = V_1 \quad ; \quad V_{i_2} = V_2$$

So, $V_o = A(V_1 - V_2)$

$$\boxed{V_o = A(V_{i_1} - V_{i_2})}$$

2. Closed Loop Mode of Operation:

In this feedback exist, in b/w input & output. These feedback is a negative feedback.

→ Due to this negative feedback i/p resistance increases output resistance decreases and noise is reduced, band width is increases and gain is decreases.

→ But op-amp will performs three basic operation in closed loop mode of operation.

1. Inverting Amplifier
2. Non-inverting Amplifier
3. Differential Amplifier.

(a) Inverting Amplifier :

In this inverting i/p is applied at the inverting terminal and non-inverting terminal is grounded.

→ In this o/p signal is out of phase with the input signal

→ The o/p voltage V_o is fed back to the inverting input terminals through $R_f - R_1$ network.

where, R_f = feedback resistor

→ The inverting amplifier circuit shown in below figure.

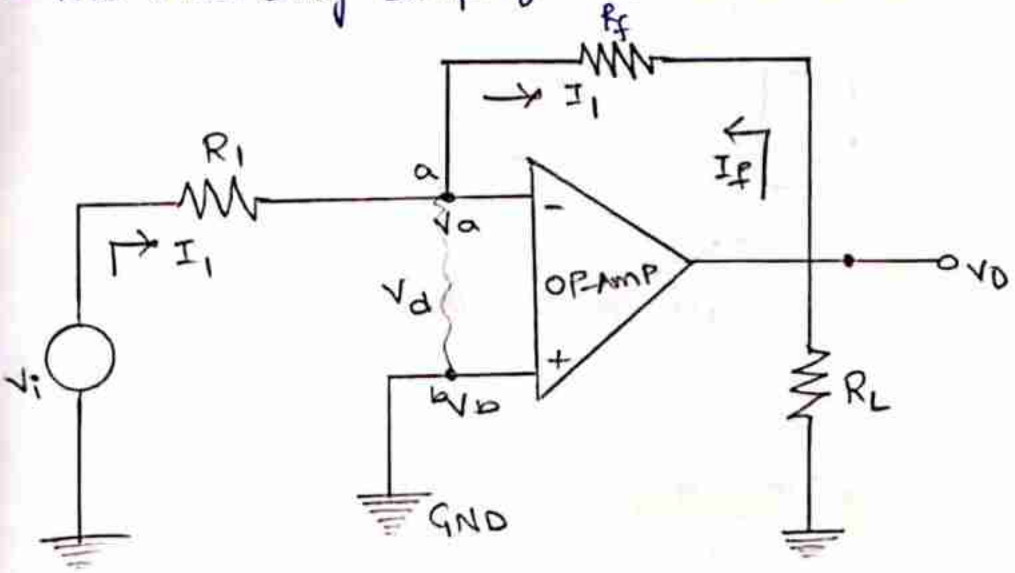


fig -

Analysis :

→ Let us assume an ideal op-amp $V_d = 0$. and node A is at ground potential (virtual ground potential) then and I_1 current flows through R_1 resistor.

$$\text{so,} \quad I_1 = \frac{V_A}{R_1} \quad \longrightarrow (1)$$

→ Since op-amp draws no current, all the current flowing with R_1 must flow through R_f resistors. The o/p voltage V_o is given by

$$V_o = -I_1 R_f \rightarrow (2)$$

since on sub. eq(1) & (2), we get

$$V_o = -\frac{V_i}{R_1} \times R_f$$

$$\boxed{\frac{V_o}{V_i} = \frac{-R_f}{R_1}}$$

Hence the closed loop gain of the inverting amplifier is given by A_{CL}

$$A_{CL} = V_o/V_i$$

so, $$\boxed{A_{CL} = \frac{-R_f}{R_L}}$$

Method - II :

According to nodal eq^n at node A,

$$I_1 = I$$

so, $$\frac{V_i - V_a}{R_1} = \frac{V_a - V_o}{R_f}$$

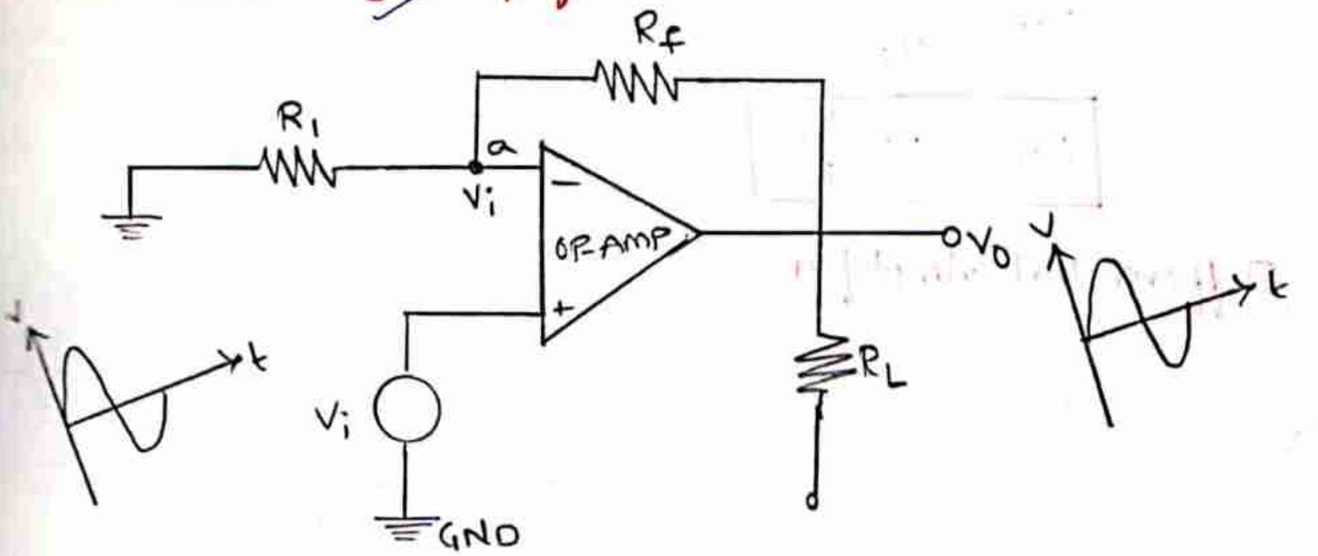
But $V_a = 0$; (because V_a is virtually grounded)

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

$$\boxed{\frac{V_o}{V_i} = \frac{-R_f}{R_1}}$$

where, -ve sign indicates that the 180° phase shift provided in b/w input & output.

(c) Non-Inverting Amplifier :



→ If a signal is applied to the non-inverting input terminal then it is called as non-inverting amplifier.

→ If a signal is applied to the non-inverting terminal and feedback is connected from output to input as shown in above figure.

→ It may be noted that it is also a -ve feedback system as output is being fed back to the inverting input terminal.

→ As a differential voltage V_d at the input terminal of op-amp is zero, the voltage at node 'A' is V_i, same as the input voltage applied to non-inverting input terminal.

→ In circuit R_f and R_1 forms a potential divider. Hence, according to potential divider theorem,

$$V_i = \frac{R_1 V_o}{R_1 + R_f}$$

$$V_o = \frac{R_1 + R_f}{R_1} \times V_i$$

$$V_o = 1 + \frac{R_f}{R_1} \times V_i$$

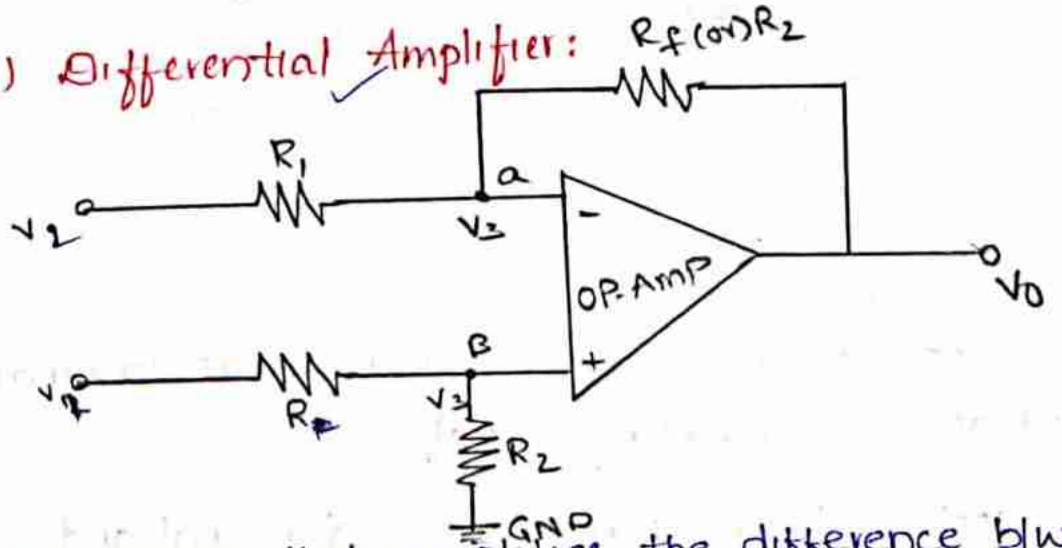
$$\frac{V_o}{V_i} = 1 + \frac{R_f}{R_1}$$

we know that,

$$A_{CL} = \frac{V_0}{V_i}$$

$$\boxed{A_{CL} = 1 + \frac{R_f}{R_1}}$$

(c) Differential Amplifier:



→ A circuit that amplifies the difference b/w two input signals is called as difference amplifier (or) Differential amplifier.

→ The differential amplifier circuit is shown in above figure

→ Since the differential voltage at the input terminal of the op-amp is zero.

→ Node A and Node B are at the same potential i.e., V_3

→ The nodal eqn at node A is,

$$\frac{V_2 - V_3}{R_1} = \frac{V_3 - V_0}{R_2}$$

$$\frac{V_3 - V_2}{R_1} + \frac{V_3 - V_0}{R_2} = 0$$

$$V_3\left[\frac{1}{R_1} + \frac{1}{R_2}\right] - \frac{V_2}{R_1} - \frac{V_0}{R_2} = 0 \longrightarrow (1)$$

The nodal eqn at node B is.

$$\frac{V_1 - V_3}{R_1} = \frac{V_3}{R_2}$$

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$$\frac{V_3 - V_1}{R_1} + \frac{V_3}{R_2} = 0$$

$$V_3\left[\frac{1}{R_1} + \frac{1}{R_2}\right] - \frac{V_1}{R_1} = 0 \quad \rightarrow (2)$$

subtracting the above two equations, we get

$$\cancel{V_3\left[\frac{1}{R_1} + \frac{1}{R_2}\right]} - \frac{V_2}{R_1} - \frac{V_0}{R_2} - \cancel{V_3\left[\frac{1}{R_1} + \frac{1}{R_2}\right]} + \frac{V_1}{R_1} = 0$$

$$\frac{V_1}{R_1} - \frac{V_2}{R_1} - \frac{V_0}{R_2} = 0$$

$$1/R_1\,[V_1 - V_2] = V_0/R_2$$

$$\frac{V_0}{V_1 - V_2} = \frac{R_2}{R_1}$$

$$\boxed{V_0 = \frac{R_2}{R_1}(V_1 - V_2)}$$

Differential Mode Gain :

We know that,

$$V_0 = \cancel{V} A_d (V_1 - V_2)$$

$$V_0 = A_d \times V_d$$

where, A_d is the differential gain.

→ The differential gain is the gain in which differential amplifier amplifies the difference b/w two input signals. Hence it is called as differential gain of the differential amplifier.

→ The difference b/w the two inputs $(V_1 - V_2)$ is generally is called as difference voltage that is represented by V_d.

so, $V_0 = A_d \times V_d$

$$A_d = \frac{V_o}{V_d}$$

→ The gain is represented by decibals and it is given b 20 log A_d.

Common Mode Gain :

→ The gain in which it amplifies the common mode signal (to same signals) to produce the output is called as Comm mode gain of the differential amplifier. It is denoted by

→ If we apply two input voltages which are applied (or) equal in all the respects to the differential amplifier then ideally output voltage must be zero.

i.e., $V_o = V_1 - V_2$

If we know that, $V_1 = V_2$

we get, $\boxed{V_o = 0}$.

→ But the o/p voltage of the practical differential amplifier not only depends on the difference voltage but also depen on the average common level of the two inputs.

→ Such an average level of two input signals is called common mode signal, it is denoted as V_c.

i.e., $V_c = \frac{V_1 + V_2}{2}$

→ The o/p voltage is given by, when common input signa is consider.

$$\boxed{V_o = A_c \times V_c}$$

→ Thus there exists some finite o/p. so the total o/p o any differential amplifier can be expressed as

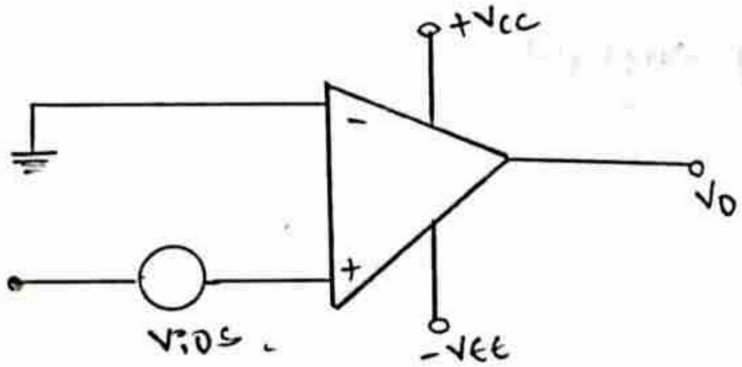
$$\boxed{V_o = V_d A_d + A_c V_c}$$

Note :

→ In op-amp differential mode gain is infinity and common mode gain is zero.

PSRR :

It is defined as the change in i/p offset voltage due to change in any one power supply, remaining power supply must be constant is called as "Power Supply Rejection Ratio". It is also called as power supply sensitivity (PSS).



→ if V_{EE} = constant & due to certain change in V_{cc}, there is change in i/p offset voltage, then

$$PSRR = \left.\frac{\Delta V_{ios}}{\Delta V_{cc}}\right|_{V_{EE} = \text{constant}}$$

→ If V_{cc} = constant & due to certain change in V_{EE}, there is change in i/p offset voltage, then

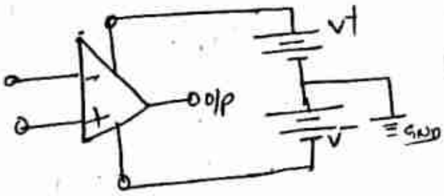
$$PSRR = \left.\frac{\Delta V_{ios}}{\Delta V_{EE}}\right|_{\Delta V_{cc} = \text{constant}}$$

* Power Supply:-

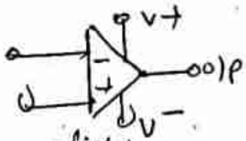
The op-amp works on a dual supply, a dual supply consist of two supply voltages both are dc whose middle point is generally the ground terminal. The dual supply is basically Balanced. i.e., the voltages of the +ve supply $+V_{CC}$ & that of -ve supply $-V_{EE}$ are same in magnitude.

If the two voltages are not same in dual supply it is called as unbalanced dual supply. The typical supply voltage used is ±15V but in general the supply voltage may range from ±15V to ±25V. The positive pin is connected to +ve terminal of one source & the -ve pin is connected to -ve terminal of another source as illustrated in fig. & common reference points are grounded.

The equivalent representation of fig(a) is shown in fig (b)



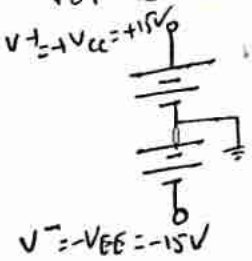
fig(a)



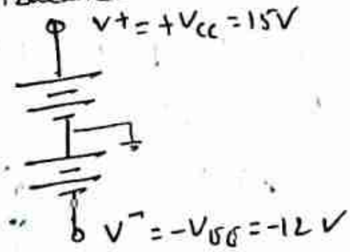
fig(b)

-> Balanced & Unbalanced types of dual supply:-

For Balanced



For unbalanced



-> obtain dual supply from single supply:-

The Common point of two power supplies must be grounded otherwise the supply voltage will get applied to the op-amp may damage.

To avoid a use of two separate power supplies, the dual power supply is derived from a single supply.

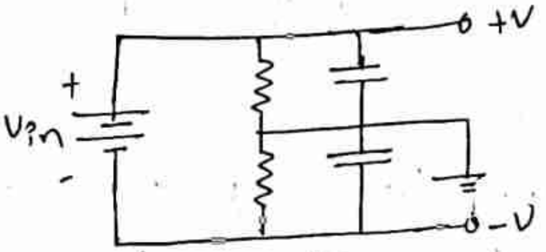
There are various methods of obtaining such dual supply from the single power supply.

a) Balanced on resistive potential divider Network:- (3)

The fig(1) shows a single power supply of voltage vin using -ve potential divider N/w & a ground. It is converted to a dual supply.

Each +ve & -ve supply obtained has a magnitude equal to half of the single supply voltage i.e., $\frac{V_{in}}{2}$

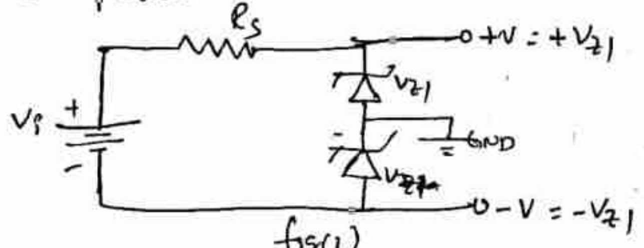
The two capacitors provide decoupling of the power supply. The ~~current~~ Resistor R should not draw high current from supply. Hence their values are more than 10kΩ & capacitors are in the range 0.01 to 10 μF



fig(1)

(b) Using zener diodes:-

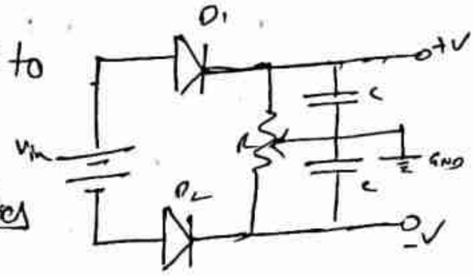
If the voltages required more than $\frac{V_{in}}{2}$ then zener diode give symmetric supply voltages. The value of R_s is chousen such that, the it supply sufficient current for diodes to operate in avalanch mode It is shown in fig(2)



fig(2)

c) Using potentiometer:-

In fig(3) Potentiometer is used to get the equal values of V^+ & V^- & to avoid the changes due to reversal of polarities connected to IC.



Here the diodes D_1 & D_2 are used for protect the IC.

The transfer function of an op-amp with 3 break frequencies can be assumed as,

$$A = \frac{A_{OL}}{1+j\left(\frac{f}{f_0}\right)} \quad \left(\because \text{for single capacitor (or) for 1 break frequency} \right)$$

$$A = \frac{A_{OL}}{\left[1+j\left(\frac{f}{f_1}\right)\right]\left[1+j\left(\frac{f}{f_2}\right)\right]\left[1+j\frac{f}{f_3}\right]}$$

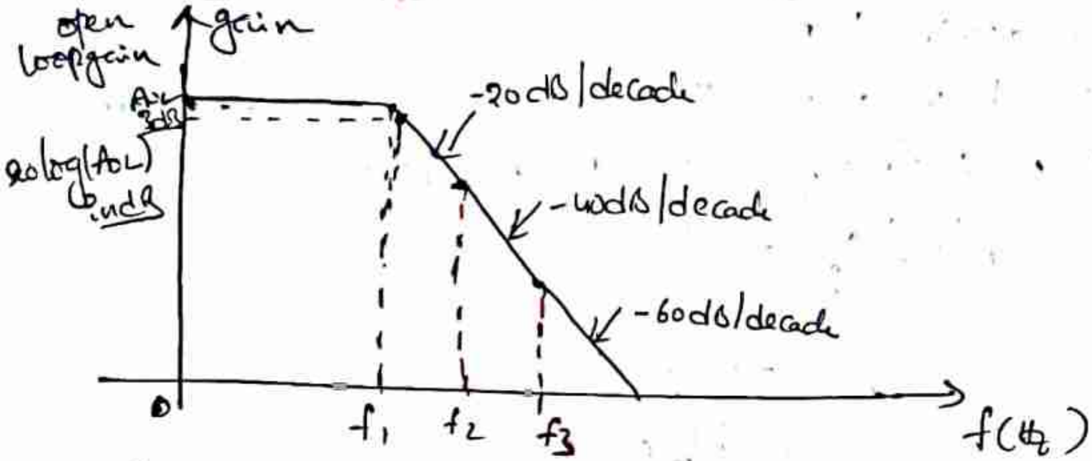


fig: The graph b/w openloop gain Vs frequency

* <u>Frequency Compensation</u>:- If bandwidth increases, gain decreases.

In some applications, we have to desires large Bandwidth & lower closed loop gain. For this there are some suitable compensation techniques. There are 2 types of compensation techniques

1) External compensation Technique
2) Internal "

1) <u>External Compensation Technique</u>:-

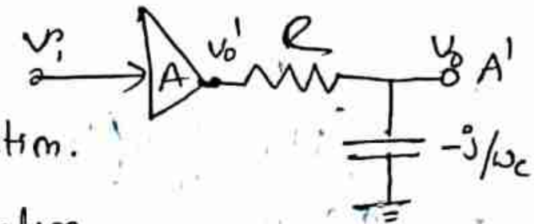
We have to connect a circuit at the External of an op-amp for reducing the gain & improves the B.W. There are 2 Methods for compensation

(i) Dominant - pole compensation
(ii) pole - zero compensation.

(i) Dominant - pole compensation :-

The circuit for dominant pole compensation is shown in fig.

Let 'A' is the Uncompensated transfer function of an op-amp in open loop condition.



In dominant pole compensation, RC Network is added inseries with op-amp. therefore Compensated transfer function (A') becomes,

$$A' = \frac{v_0}{v_i} = \frac{v_0}{v_0'} \cdot \frac{v_0'}{v_i}$$

$$= A \cdot \frac{-j/\omega c}{R - j/\omega c}$$

$$= A \cdot \frac{\frac{1}{j\omega c}}{R + \frac{1}{j\omega c}} = \frac{\frac{A}{\cancel{j\omega c}}}{\frac{j\omega RC + 1}{\cancel{j\omega C}}}$$

$$A' = \frac{A}{1 + j\omega RC}$$

$$A' = \frac{A}{1 + j\,2\pi f RC}$$

$$A' = A\left[\frac{1}{1 + j\left(\frac{f}{f_d}\right)}\right] \quad \left(\because \text{where } f_d = \frac{1}{2\pi RC}\right)$$

$\therefore$ we know that 'A' value for 3 break frequencies is

$$A = \frac{A_{OL}}{\left(1 + j\frac{f}{f_1}\right)\cdot\left(1 + j\frac{f}{f_2}\right)\cdot\left(1 + j\left(\frac{f}{f_3}\right)\right)}$$

Sub 'A' value in A', then,

$$A' = \frac{A_{OL}}{\left(1 + j\frac{f}{f_d}\right)\left(1 + j\frac{f}{f_1}\right)\left(1 + j\frac{f}{f_2}\right)\left(1 + j\frac{f}{f_3}\right)}$$

→ Magnitude of $A_{OL}(f)$ is

$$|A_{OL}(f)| = \frac{|A_{OL}|}{\sqrt{1+\left(\frac{f}{f_0}\right)^2}}$$

→ phase angle is,

$$\phi(f) = -\tan^{-1}\left(\frac{(f/f_0)}{1}\right)$$

$$\Rightarrow \boxed{\phi(f) = -\tan^{-1}\left(\frac{f}{f_0}\right)}$$

→ As frequency increases, till 'f_0' the gain is almost constant but after f_0, the gain reduces with a rate of -20dB per decay.

→ The maximum possible phase shift is $-90°$ by observing frequency response of an op-amp ~~is shown~~.

→ By observing frequency response the magnitude characteristics are

(i) for frequency $f \ll f_0$, the magnitude of the gain is $20 \log A_{OL}$ in dB

(ii) At frequency $f = f_0$ the gain is 3dB down from the DC value of A_{OL} in dB. This frequency (f_0) is called "Corner frequency"

(iii) for $f \gg f_0$ the gain roll off at the rate of -20dB per decay (or) -6dB per octave (ie -6dB/octave)

→ Similarly, the phase characteristics,

(i) the phase angle is zero at frequency $f = 0$

(ii) At corner frequency f_0, the phase angle is $-45°$ (lagging)

(iii) At infinite frequency phase angle is $-90°$.

→ A practical op-amp, however has no. of stages & each stage produces a capacitive component.

frequency in Hz	$A_{OL} = 199900$ $\lvert A_{OL}(f) \rvert = 20 \log \frac{A_{OL}}{\sqrt{1+(f/f_0)^2}}$	$\phi(f) = -\tan^{-1}(f/f_0)$ $f_0 = 5Hz$
0	106 016	0
5	103.005	$-45°$
10	99 026	-63.43
100	7998	-87.13
1k	$59.99 \cong 60$	-89.71
10k	$39.99 \cong 40$	-89.97
1M	0.0	-89.999

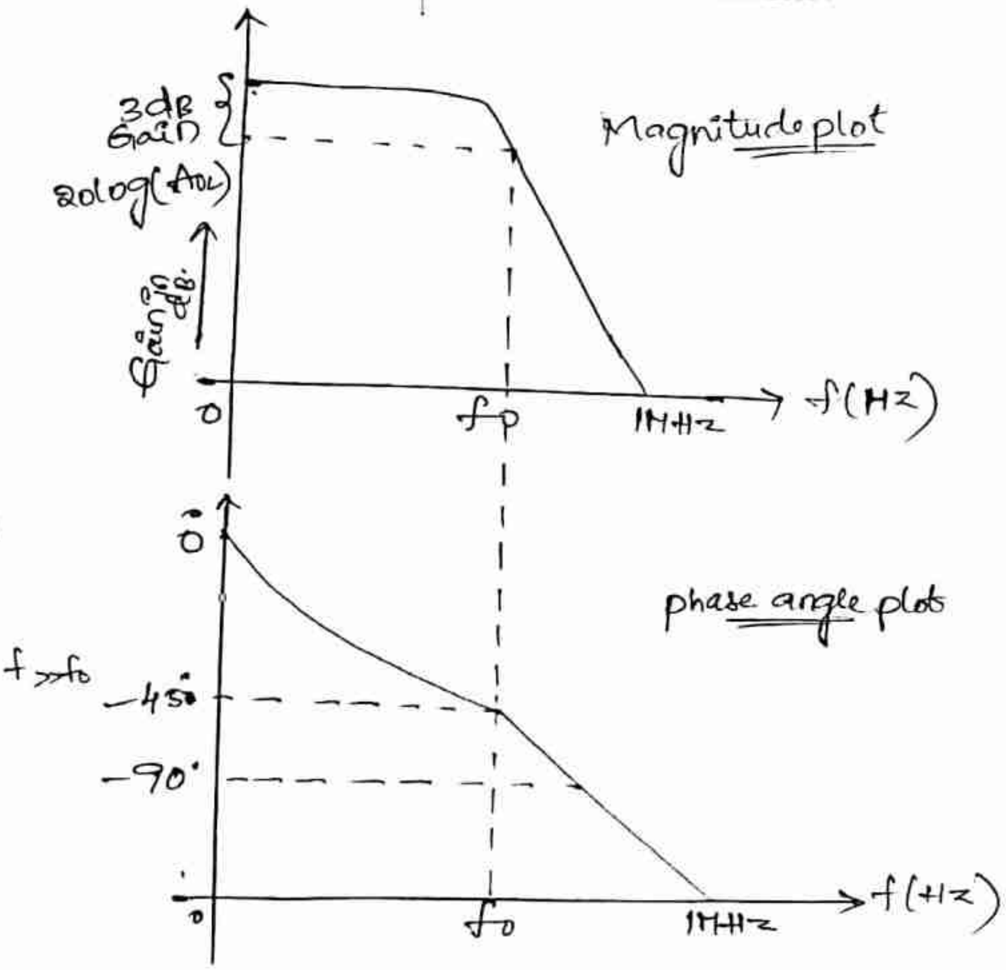
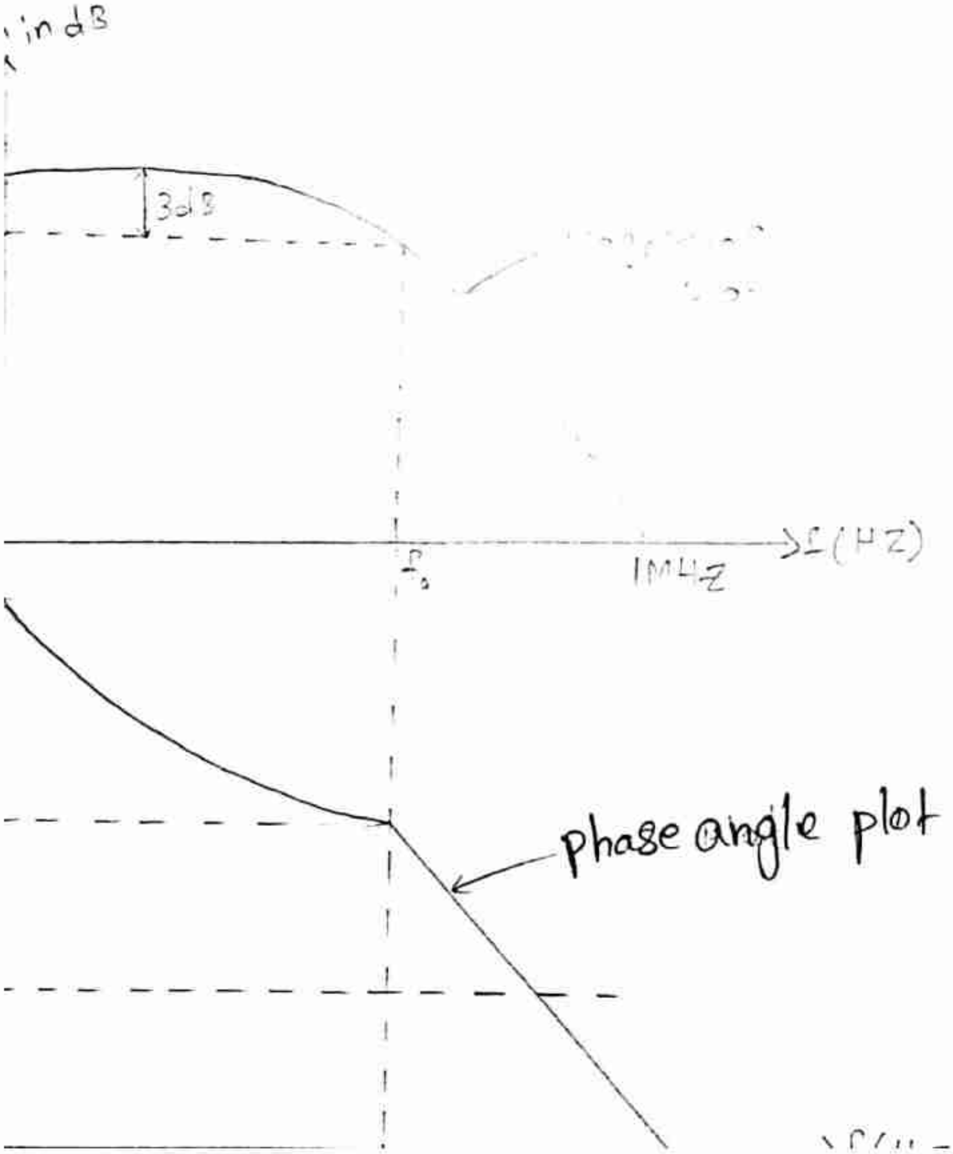


fig: frequency response of an Op-amp.

(8(a)

$A_{OL} = 1999000$ $\lvert A_{OL}(f)\rvert = 20\log\left(\frac{A_{OL}}{\sqrt{1+(f/f_o)^2}}\right)$	$\phi(f) = -\tan^{-1}(f/f_o)$ $f_o = 5\,KHZ$
106.016	0
103.005	$-45°$
99.026	$-63.43°$
79.98	$-87.13°$
$59.99 \simeq 60$	$-89.71°$
$39.99 \simeq 40$	$-89.97°$
0	$-89.99°$



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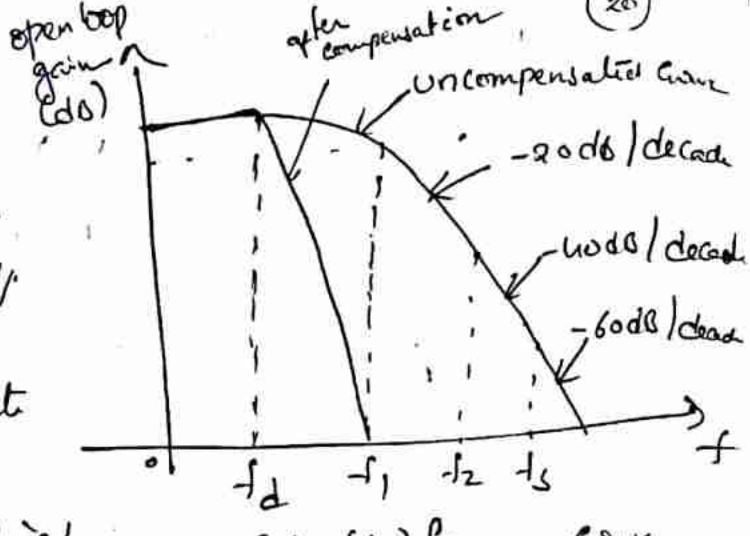
The capacitance 'c' is choosen so that the modified loop gain drops to 0dB with a slop of -20dB / decade at a freq. where the pole of compensated transfer function 'A' contribute negligeble phase shift.



gain (vs) frequency curve.

The value of capacitor 'c' can be calculated by,

$$\boxed{f_d = \frac{1}{2\pi R C}}$$

→ Advantages:-

* Corner frequencies get degreases.
* phase angle will be less than -180°
* Noise immunity of the system is improved.

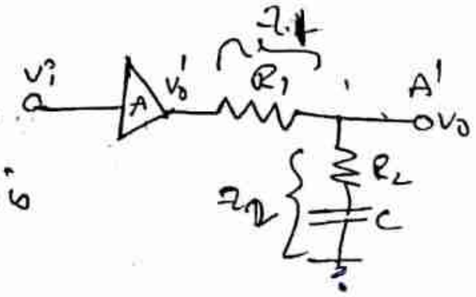
→ Disadvantages:-

* Bandwidth get's decreases.

(ii) Pole - zero Compensation Technique :-

For pole-zero compensation, we will connect compensation Network as shown in fig.

Let 'A' be the uncompensated transfer function. The transfer function of the compensated n/w is given by



$$A' = A \cdot A_1 \quad \text{——} \quad (1)$$

where uncompensated transfer function

$$A = \frac{A_{OL}}{\left(1+j\frac{f}{f_0}\right)\left(1+j\frac{f}{f_1}\right)\left(1+j\frac{f}{f_2}\right)} \quad \text{——} \quad (2)$$

The transfer function of Compensating N/W

$$A_1 = \frac{V_0}{V_0'} = \frac{\cancel{R_2 + jX_C}}{\cancel{R_1 + R_2 + jX_C}} = \frac{Z_2}{Z_1 + Z_2} \quad \text{—— (3)}$$

$$A_1 = \frac{R_2 - j\frac{1}{2\pi f C_2}}{R_1 + R_2 - \frac{j}{2\pi f C_2}} \qquad \left(\because X_C = \frac{1}{2\pi f C}\right)$$

$$A_1 = \frac{R_2 + \frac{1}{j2\pi f C_2}}{R_1 + R_2 + \frac{1}{j2\pi f C_2}} = \frac{R_2(j2\pi f C_2) + 1}{(R_1 + R_2)(j2\pi f C_2) + 1}$$

$$A_1 = \frac{1 + j2\pi f R_2 C}{1 + j2\pi f (R_1 + R_2) C} \quad \text{—— (4)}$$

$Z_1 = R_1$

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

$$A_1 = \frac{1 + j\left(\frac{f}{f_1}\right)}{1 + j\left(\frac{f}{f_3}\right)}, \quad \text{where } f_1 = \frac{1}{2\pi R_2 C_2}.$$

$$f_0 = f_3 = \frac{1}{2\pi (R_1 + R_2) C_2}$$

The overall transfer function of the Circuit

$$A' = A A_1$$

$$A' = \frac{A_{OL}}{\left(1 + j\frac{f}{f_0}\right)\cancel{\left(1 + j\frac{f}{f_1}\right)}\left(1 + j\frac{f}{f_2}\right)} \times \frac{\cancel{\left(1 + j\frac{f}{f_1}\right)}}{\left(1 + j\frac{f}{f_3}\right)}$$

$$A' = \frac{A_{OL}}{\left(1 + j\frac{f}{f_0}\right)\left(1 + j\frac{f}{f_2}\right)\left(1 + j\frac{f}{f_3}\right)}$$

here, $0 < f_0 < f_1 < f_2 < f_3$

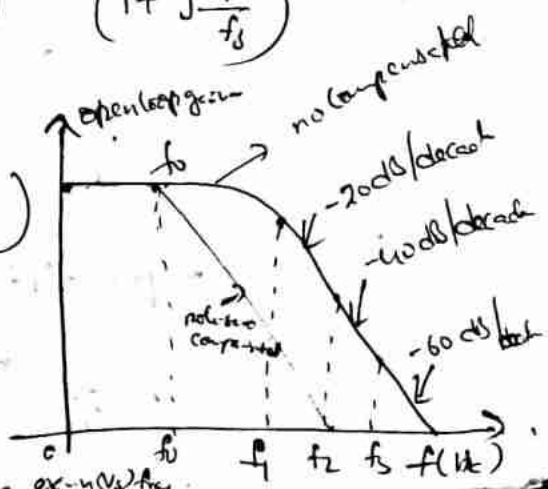


fig gain (Vs) freq

Advantages:-

* Bandwidth is improved

*

⟹ A compensation of dominant pole & pole-zero compensation technique is shown below,

The dominant pole is selected, so that the compensated transfer function goes through 0 dB at first pole f_1 of the uncompensated system.

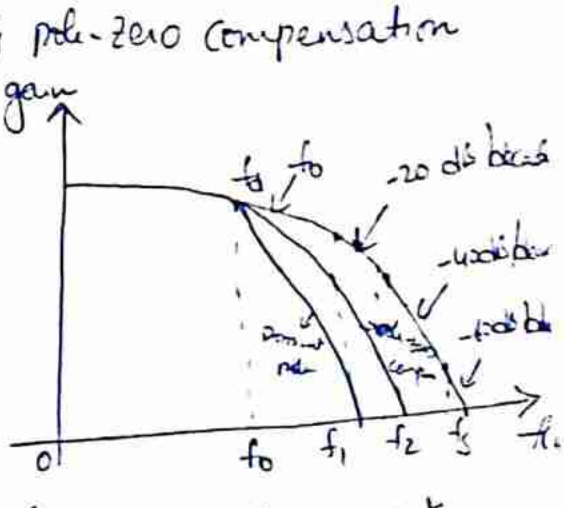
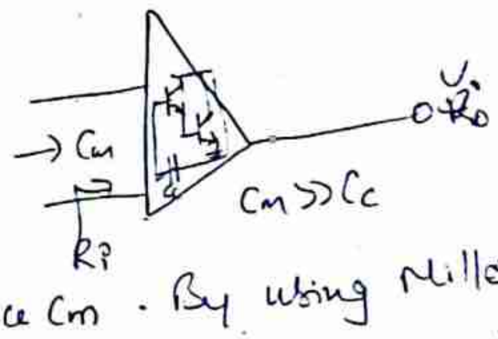


fig. 3dB B.W improvement

2) Internal Compensation Technique:-

The internal compensation technique is also called as "Miller effect Compensation Technique."

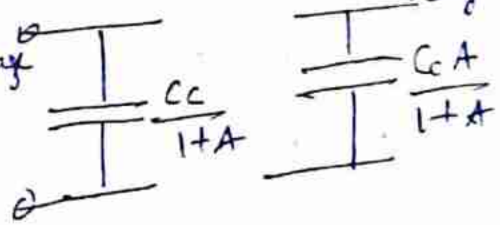
Let us take 741 IC has one capacitor which is built inbetween the two transistors present inside of an op-amp. The internal ckt of μA741 op-amp is shown in fig:



The gain of darlington stage is

$$A = -G_m R_o$$

Looking to the i/p terminals, C_c appears as the miller's capacitance C_m. By using Miller's effect capacitance values are



The i/p Miller capacitance,

$$Z_{cm} = \frac{Z_{cc}}{1+A}$$

$$\frac{1}{j\omega C_m} = \frac{1}{j\omega C_c(1+A)}$$

$$\frac{1}{C_m} = \frac{1}{C_c(1+A)} \Rightarrow \boxed{C_m = C_c(1+A)}$$

The frequency of an op-amp is, $f_d = \frac{1}{2\pi R C_m}$ by using this circuit, we can improve the stability of op-amp.

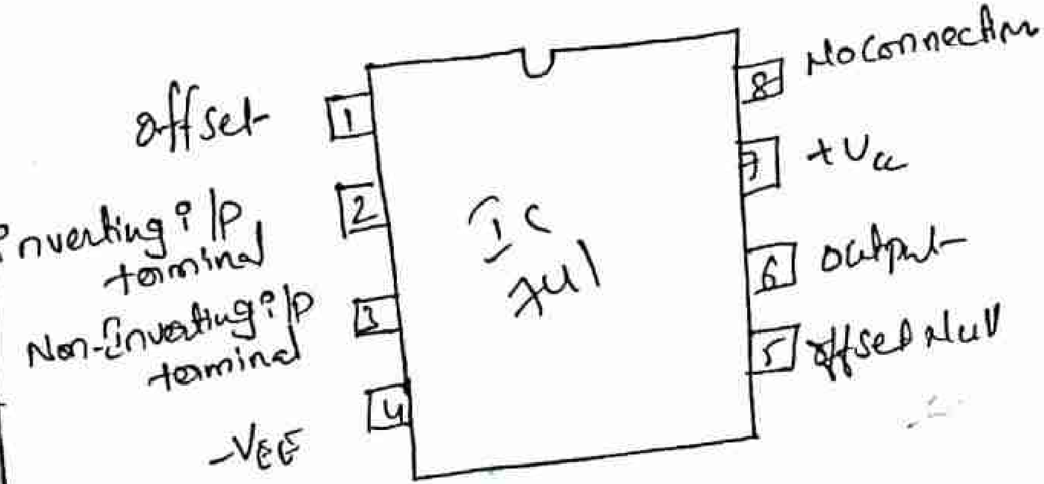
This internal compensation techniques is mainly used in instrumentational applications, because for instrumentation applications bandwidth is limited.

* 741 op-amp & its features:-

The IC 741 is high performance monolithic op-amp IC. It is available in 8, 10, 14 pin configuration. The 8 pin configuration of 741 op-amp as shown in fig:

→ **Features:-**

1) Short ckt-protection is provided.
2) No frequency compensation required.
3) Offset voltage null capability
4) Large common mode & differential voltage range.
5) No latch up.



UNIT -5

Applications of Linear Integrated Circuits.

Basic circuit symbol and terminals for IC's:-

An op-amp is a triangle as shown in fig. It has 2 input terminals and one output terminal. The terminal with -ve sign is Inverting i/p terminal and +ve sign is non-inverting i/p terminal.

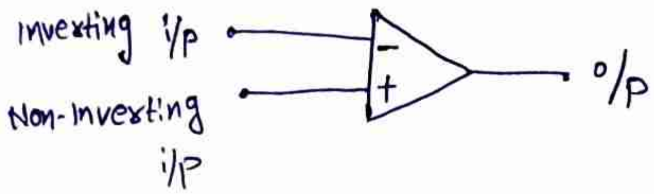
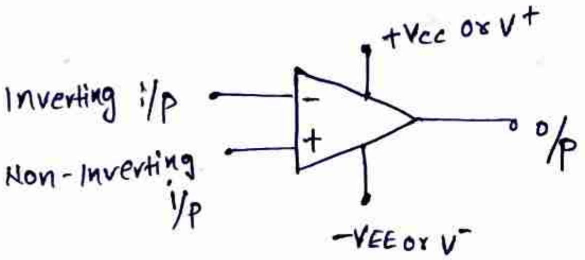


fig:- circuit symbol.

The symbol for an op-amp along with its various terminals is shown below.



All the op-amp's have atleast following 5 terminals.

-> +ve power supply voltage terminal (V_{cc} or V^+)

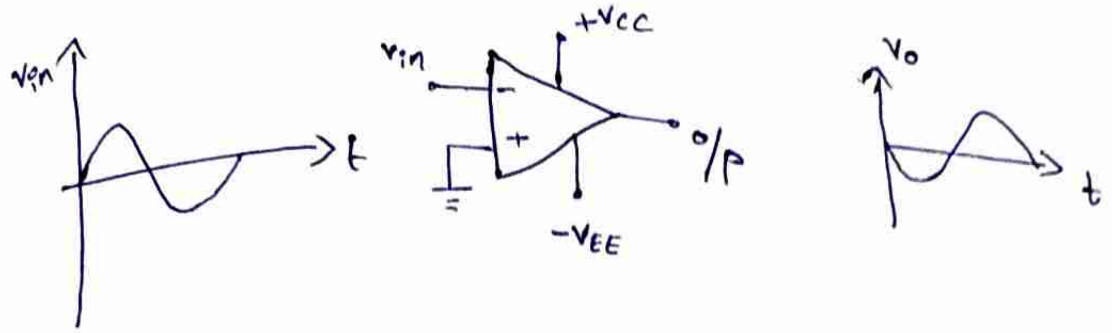
-> -ve power supply voltage terminal (V_{EE} or V^-)

-> o/p terminal

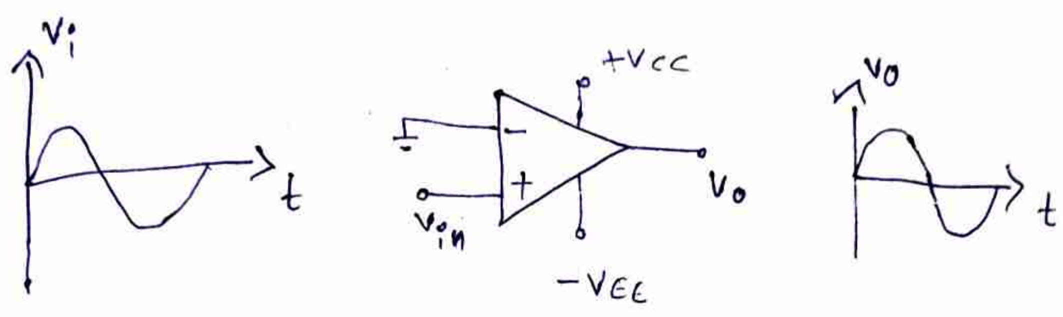
-> inverting i/p terminal (-ve sign)

-> Non-Inverting i/p terminal (+ve sign)

Inverting op-amp:-



Non-inverting op-amp:-



Basic Applications of op-Amp:-

A op-amp is a basic building block of linear & non-linear analog systems. In linear circuits (such as adder, subracter, differentiator, integrator, voltage to current, I-V converter, Instrumentation amplifier etc.,) the o/p signal varies directly or linearly with the i/p signal.

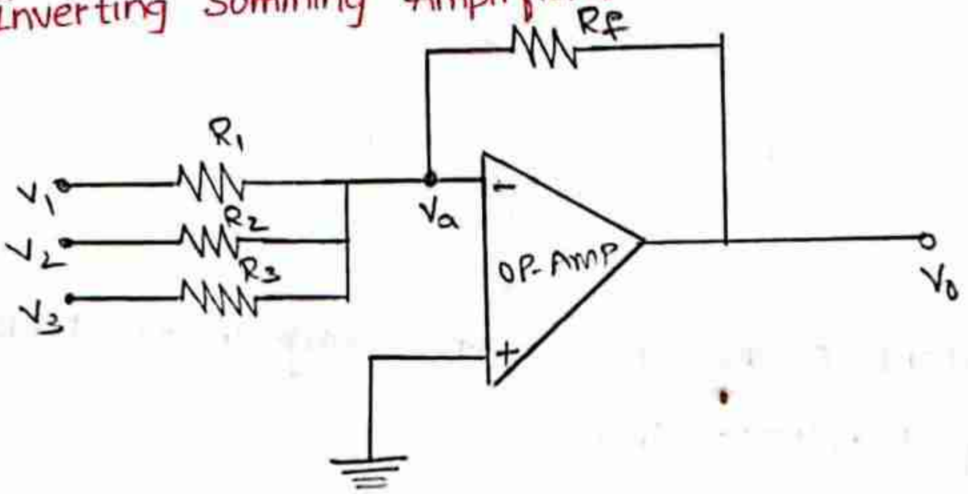
Summing Amplifier :

Op-amp may be used to design the circuit whose o/p the sum of several i/p signals. such a circuit is called Summing Amplifier (or) summer.

→ The summing amplifier are classified into two types.

1. Inverting summing amplifier
2. Non-inverting summing amplifier.

1. Inverting Summing Amplifier :



→ A typical summing amplifier with 3 i/p voltages V_1, V_2, V_3 & three i/p resistors R_1, R_2, R_3 & one feedback resistor R_f sha in above fig.

→ The voltage at node 'a' is zero ($V_a = 0$) because the non-inverting terminal is grounded.

The nodal equ at node 'a' is given by

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

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

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

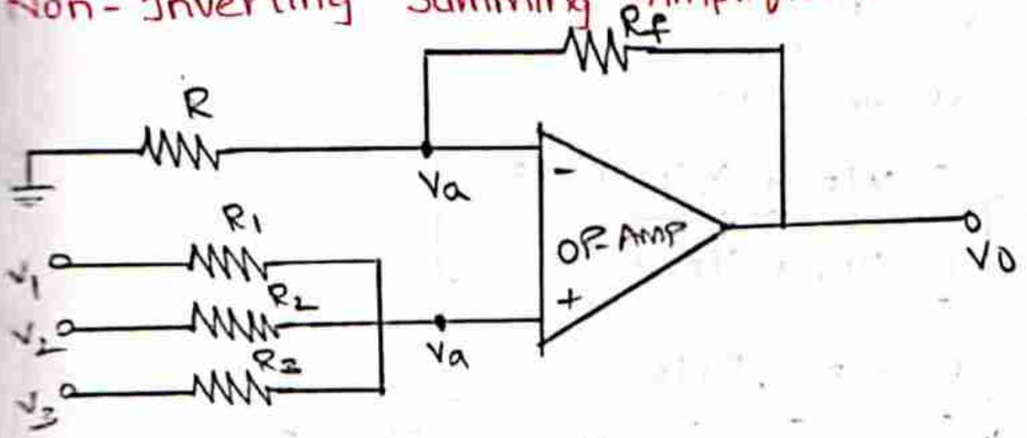
$$V_o = -\left[V_1 \frac{R_f}{R_1} + V_2 \frac{R_f}{R_2} + V_3 \frac{R_f}{R_3}\right]$$

Let $R_1 = R_2 = R_3 = R_f$

$$V_o = -\left[V_1 + V_2 + V_3\right]$$

where "-ve" sign indicates that phase difference b/w i/p & o/p. So it is called as inverting summing amplifier.

Non-Inverting Summing Amplifier :



- The non-inverting summing amplifier shown in above fig.
- The i/p voltages V_1, V_2, V_3 is fed to the non-inverting terminal. The voltage at non-inverting i/p terminal is V_a.
- The voltage at the inverting i/p terminal will also be V_a, because they are virtually grounded.

i.e., the voltage across the inverting terminal is same as that of the non-inverting terminal.

The nodal eq^n at node 'a' is given by

$$\frac{V_1 - V_a}{R_1} + \frac{V_2 - V_a}{R_2} + \frac{V_3 - V_a}{R_3} = 0$$

$$\frac{V_1}{R_1} - \frac{V_a}{R_1} + \frac{V_2}{R_2} - \frac{V_a}{R_2} + \frac{V_3}{R_3} - \frac{V_a}{R_3} = 0$$

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = V_a\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]$$

$$V_a = \frac{V_1/R_1 + V_2/R_2 + V_3/R_3}{1/R_1 + 1/R_2 + 1/R_3}$$

W.K.T gain of non-inverting amplifier is

$$A = \frac{V_o}{V_d} = 1 + \frac{R_f}{R_1}$$

But Here $V_d = V_a$

$$V_o = \left[1 + \frac{R_f}{R}\right] V_a$$

sub. V_a in above eqn

$$V_o = \left[1 + \frac{R_f}{R}\right]\left[\frac{V_1/R_1 + V_2/R_2 + V_3/R_3}{1/R_1 + 1/R_2 + 1/R_3}\right]$$

Let $R_1 = R_2 = R_3 = R = R_f/2$

$$V_o = \left[1 + \frac{R_f}{R_f/2}\right]\left[\frac{2V_1/R_f + 2V_2/R_f + 2V_3/R_f}{2/R_f + 2/R_f + 2/R_f}\right]$$

$$= \cancel{3} \times \frac{\cancel{2}(V_1 + V_2 + V_3)}{\cancel{6}\ \cancel{3}}$$

$$\boxed{V_o = V_1 + V_2 + V_3}$$

→ Here the o/p voltage is in phase with sum of the i/p voltages. So it is called as non-inverting summing amplifier.

Instrumentation Amplifier :

Many industrial systems, consumer systems & process control systems require a measurement of the physical quantities like temperature, humidity, weight etc.

→ The measurement of the physical quantities is generally carr out with the help of a device called "Transducer."

→ A transducer is a device which converts one form of energy into another form of energy. Eg: microphone.

→ But most of the transducer o/p are generally very low leve signals. such low level signals are not sufficient to drive the next stage of the op-amp. Hence, before the next stage it is necessary to amplify the level of such signal, rejecting th noise & interference.

→ However, a general amplifier like CE amplifier is not suita to amplify such signals.

→ For rejection of noise, such amplifiers must have high CMRR. But CE amplifier has low CMRR. So it is not useful Therefore a special amplifier is used to amplify such signals

→ A special amplifier which is used for such a low level amplification with high CMRR, high i/p impedence, low o/p impedence, low power consumption is known as instrumentation amplifier. It is also called as Data Amplifier.

→ The requirements of an good instrumentation amplifier given by :

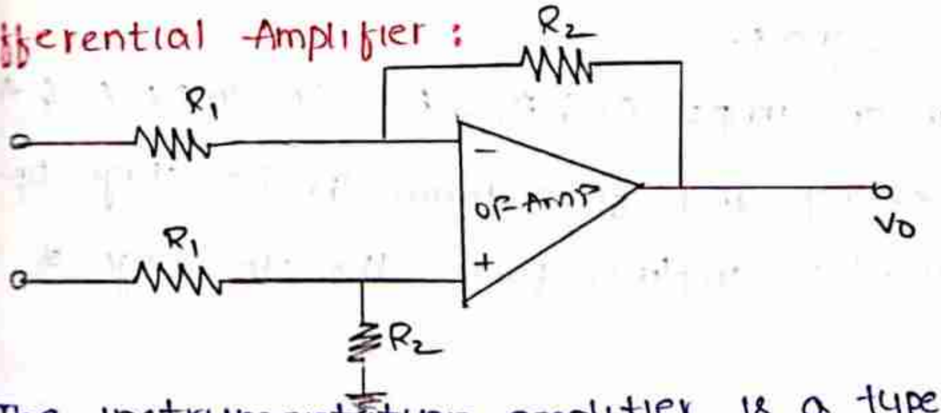
(a) High i/p impedence

(b) low o/p impedence

(c) High CMRR

- Low power consumption
- Easier gain adjustment
- High slew rate.
- Gain is high (or) finite stable gain.

Differential Amplifier :



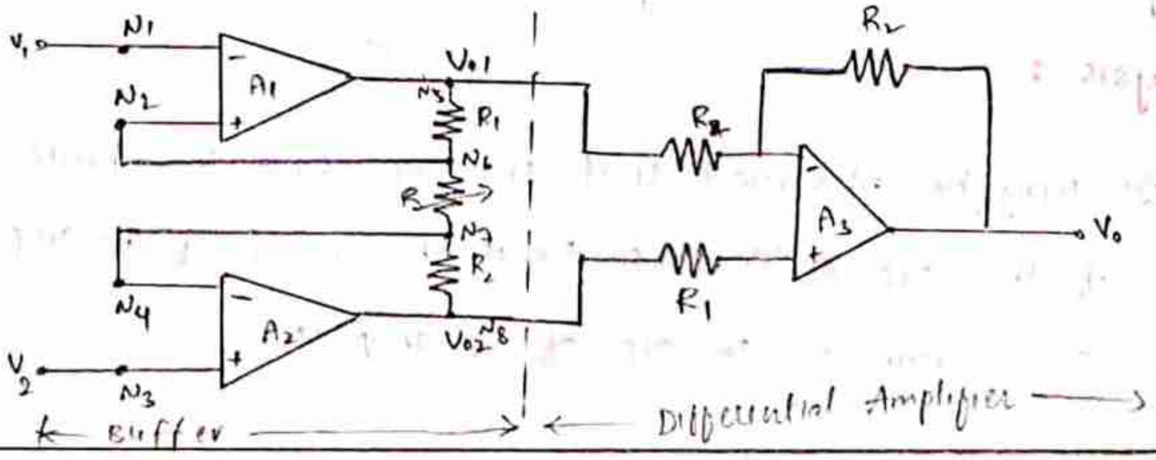
→ The instrumentation amplifier is a type of differential amplifier. Hence differential amplifier is shown in above fig.

From fig.

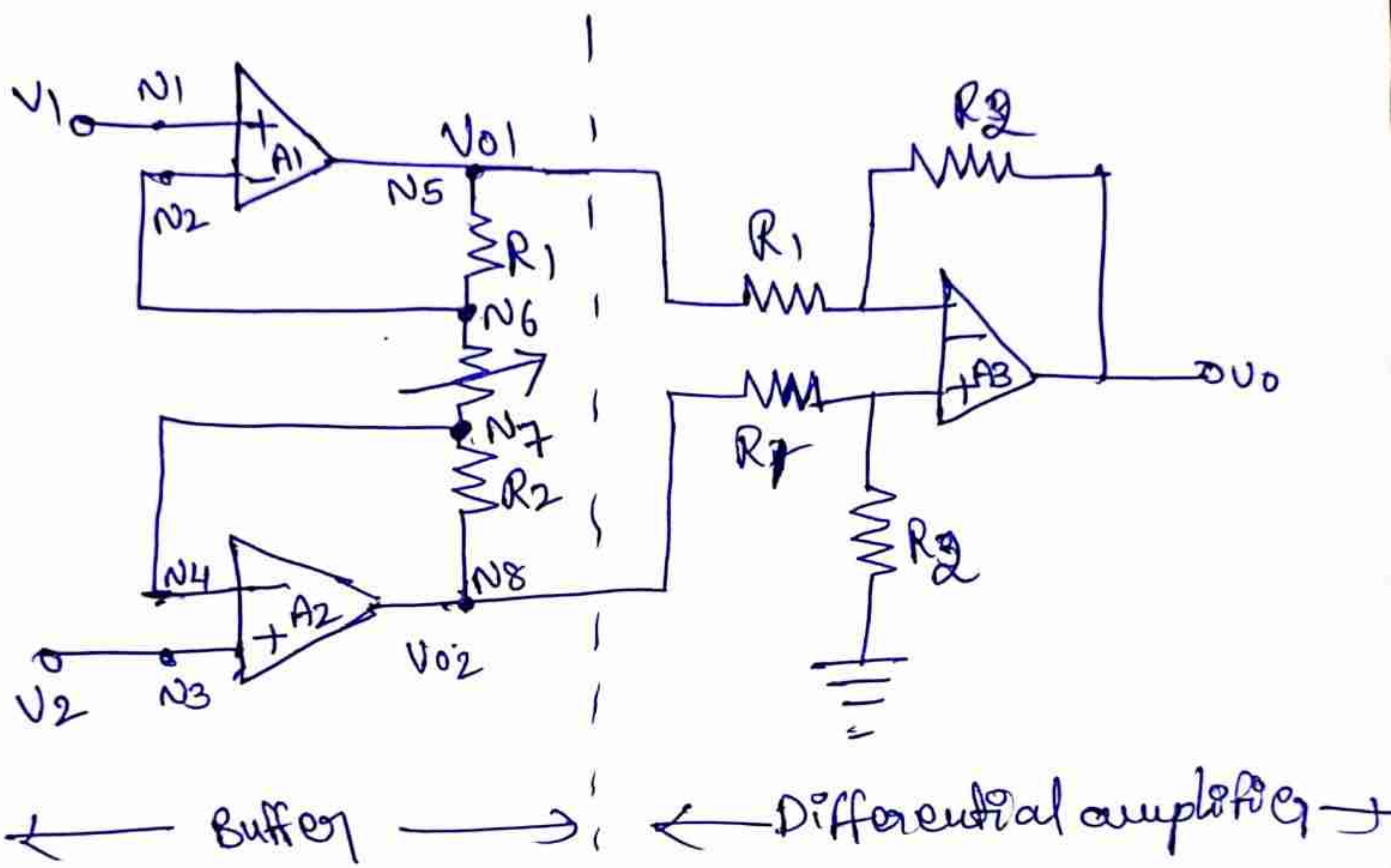
$$\boxed{V_O = \frac{R_2}{R_1}(V_2 - V_1)}$$

→ The instrumentation amplifier is a type of D.A i.e, the D.A using op-amp can be used as instrumentation amplifier. But the main problem in using it as an instrumentation amplifier is its i/p impedence.

→ The i/p impedence of D.A is low while the I.A needs very high i/p impedence. To get very high i/p impedence, the D.A can be modified by using Buffer (or) voltage follower circuits at the i/p. It is shown in below fig.



Instrumentational amplifier



→ The gain of the voltage follower circuit is unity. While its i/p impedence is very high. Hence the circuit provides same voltage gain as provided by the op-amp differential amplifier.

→ The above ckt provides high i/p impedence for accurate measurement of signals.

→ It consists of op-amps A_1 & A_2 & A_3. Op-amps A_1 & A_2 are the non-inverting amplifiers forms the i/p stage. Op-amp A_3 is the differential amplifier forms the o/p stage of the amplifier.

→ One variable resistor R_1 is inserted b/w the o/p's of A_1 & A_2 op-amp's with the help of this resistor gain can be varied.

→ Gain depends on the external resistances & hence can be adjusted accurately.

→ The i/p impedence depends on the i/p impedence of the non-inverting amplifier which is very high.

→ The o/p impedence is the o/p impedence of the op-amp A_3 which is very low.

→ The CMRR of the op-Amp A_3 is very high. Thus the circuit satisfies the all the requirements of a good instrumentation amplifier & hence commonly used in practical applications.

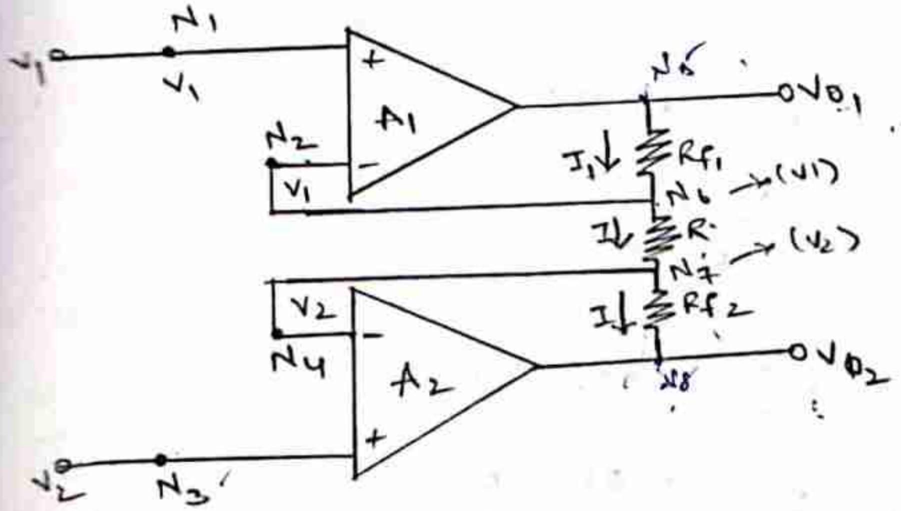
Analysis :

It may be observed that the o/p stage is a basic D.A. Hence if the o/p of op-amp A_1 is V_{o1} & o/p of op-amp A_2 is V_{o2}. So we can write o/p of op-amp is

$$\boxed{V_o = \frac{R_2}{R_1}(V_{o2} - V_{o1})} \rightarrow (1)$$

→ Let us find out the expression for V_{o2} & V_{o1} in terms of V_1, V_2, R_{f1}, R_{f2}, R.

→ Let us consider the first stage of an I.A shown in fig.



→ The node N_1 voltage of op-amp A_1 is V_1. So that will be appeared at the node N_2 by virtual connection. so the voltage at node N_6 is V_1.

→ The node N_3 voltage of op-amp A_2 is V_2. So that will be appeared at the node N_4 by virtual connection. so the voltage at node N_7 is V_2.

→ The i/p current of op-amp A_1 & A_2 both are zero. Hence current I remains same through R_{f1}, R, R_{f2}.

→ Applying ohms law b/w the nodes N_5 & N_8, we get

$$I = \frac{V_{o1} - V_{o2}}{R_{f1} + R + R_{f2}}$$

let, $R_{f1} = R_{f2} = R_f$

So $$\boxed{I = \frac{V_{o1} - V_{o2}}{2R_f + R}} \rightarrow (2)$$

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Now at the nodes N_6 & N_7

$$\boxed{I = \frac{V_1 - V_2}{R}} \longrightarrow (3)$$

Equate eq(2) & eq(3), we get

$$\frac{V_{O1} - V_{O2}}{2R_f + R} = \frac{V_1 - V_2}{R}$$

multiply '-' on b/s, we get

$$\frac{V_{O2} - V_{O1}}{2R_f + R} = \frac{V_2 - V_1}{R}$$

$$V_{O2} - V_{O1} = \frac{V_2 - V_1}{R}(2R_f + R)$$

$$= V_2 - V_1 \left(\frac{2R_f}{R} + \frac{R}{R} \right)$$

$$\boxed{V_{O2} - V_{O1} = V_2 - V_1 \left(1 + \frac{2R_f}{R} \right)} \longrightarrow (4)$$

sub. eq(4) in eq(1), we get

$$\boxed{V_O = \frac{R_2}{R_1} \left(1 + \frac{2R_f}{R} \right) (V_2 - V_1)}$$

This is the overall voltage gain of the I.A.

where R is the variable resistor.

∴ The gain is depends on the R.

Applications :

1. Temperature controller
2. Light intensity meter
3. Analog weight scale
4. Measure the pressure, weight & humidity.

Voltage - Current Convertor :

→ In V-I convertor the o/p load current is proportional to the i/p voltage.

→ According to connection of load there are 2 types

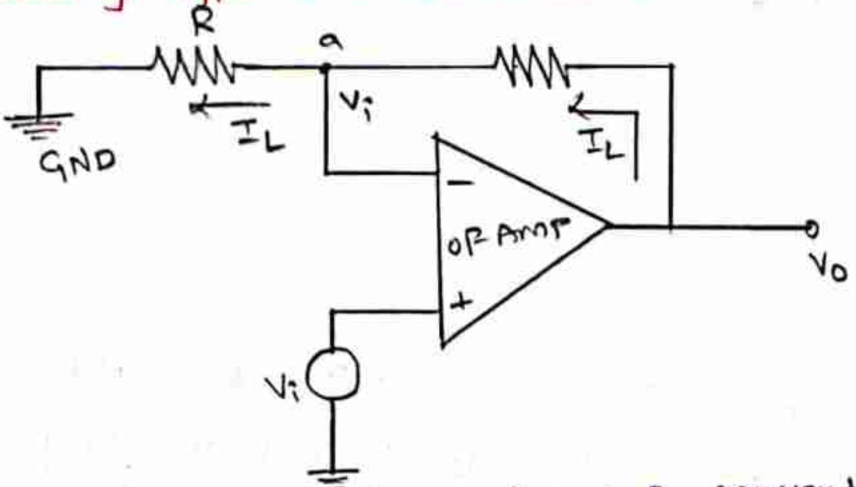
1. Floating type V-I convertor
2. Grounded type V-I convertor.

→ In floating type V-I convertor, the load resistor R_L is not connected to the ground.

→ In grounded type V-I convertor, the load resistor R_L is directly connected to the ground.

→ This circuit is also called as voltage controlled current source (VCCS) because here the i/p voltage controls the o/p current (or) o/p current is controlled by the input voltage.

1. Floating Type V-I convertor :



→ The above fig. shows the V-I convertor. Here the load resistor R_L is not connected to the ground.

Since the voltage at node 'a' is $\boxed{V_i = I_L R}$

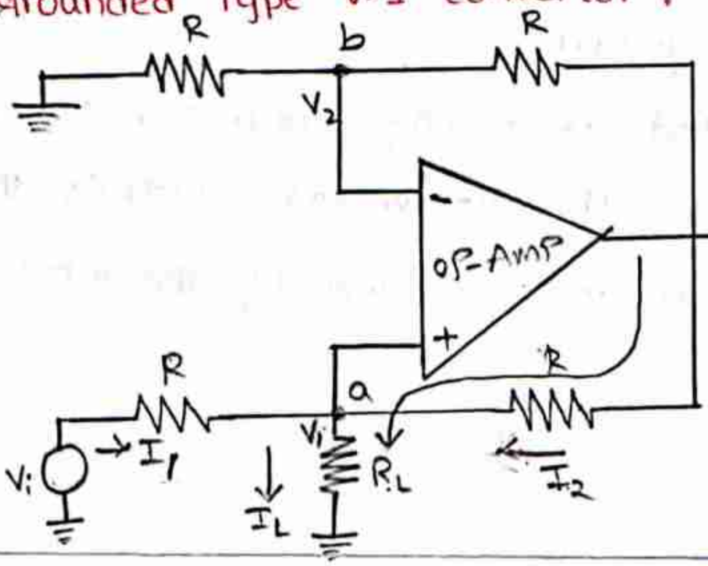
$$\boxed{\therefore I_L = \frac{V_i}{R}}$$

→ Thus the load current is directly proportional to the i/p voltage and it is given by

$$\boxed{I_L \propto V_i}$$

i.e., the i/p voltage Vi is converted into an o/p current I_L. Here we observed that the proportionally constant is generally $1/R_1$. Therefore this circuit is called Transconductance amplifier.

2. Grounded Type V-I convertor :



- A V-I convertor with grounded load is shown in above fig.
- Let V_1 be the voltage at node 'a'. applying KCL at node 'a' we get

$$\boxed{I_1 + I_2 = I_L} \rightarrow (1)$$

from fig. $I_1 = \frac{V_i - V_1}{R} \rightarrow (2)$

$$I_2 = \frac{V_0 - V_1}{R} \rightarrow (3)$$

sub. eq(2) & eq(3) in eq(1)

$$\frac{V_i - V_1}{R} + \frac{V_0 - V_1}{R} = I_L$$

$$V_i - V_1 + V_0 - V_1 = I_L R$$

$$V_i - 2V_1 + V_0 = I_L R$$

$$\boxed{V_1 = \frac{V_i + V_0 - I_L R}{2}} \rightarrow (4)$$

W.K.T, $A = \frac{V_0}{V_1} = 1 + \frac{R_f}{R}$

But Here we have $R_f = R$

$$\frac{V_0}{V_1} = 1 + \frac{R}{R}$$

$$= 2$$

$$\boxed{V_0 = 2V_1} \rightarrow (5)$$

sub. eq(4) in eq(5)

$$V_0 = \frac{\cancel{2}(V_i + V_0 - I_L R)}{\cancel{2}}$$

$$\cancel{V_0} = V_i + \cancel{V_0} - I_L R$$

$$V_i = I_L R$$

$$\therefore I_L = \frac{V_i}{R}$$

→ From the above expression, we can say that the load curr I_L depends on the i/p voltage V_i.

$$\boxed{\therefore I_L \propto V_i}$$

Applications :

1. Low voltage to dc voltage convertor
2. Diode tester
3. Zener Diode tester.

Current - Voltage Convertor :

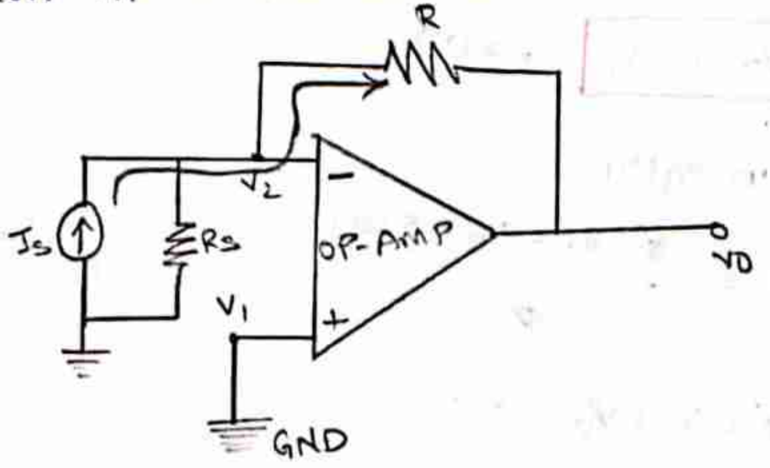
→ In I-V convertor the o/p voltage is directly proportiona to the i/p current.

$$\boxed{V_o \propto I_s}$$

where, V_o = o/p voltage

I_s = i/p current

→ This circuit is also called as current controlled voltage source (CCVS) because the o/p voltage controlled by i/p current (or) i/p current controlls the o/p voltage.



→ The above fig. shows the current to voltage convertor because of virtual ground the voltage $V_2 = 0$.

Applying KCL at node 'a'.

$$I_S = \frac{V_2 - V_0}{R}$$

$$V_2 = 0$$

$$I_S = \frac{-V_0}{R}$$

$$\boxed{V_0 = -I_S R}$$

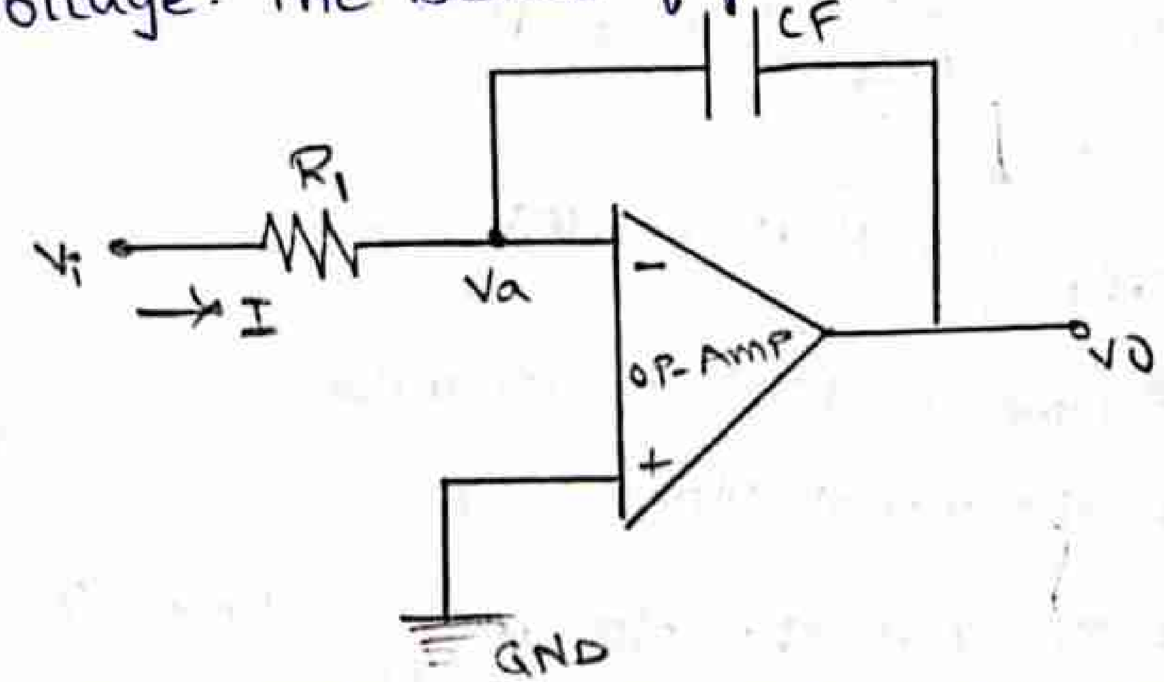
→ Thus the o/p voltage is proportional to the i/p current so the circuit works as current to voltage convertor. It is also called as Trans resistance amplifier.

Applications :

1. Photo diode detectors
2. Photo Fet detector.

Integrator :

Integrator is a circuit in which o/p voltage is integral of i/p voltage. The below fig. shows the ideal integrator circuit.



→ The i/p voltage Vi is applied to the inverting i/p terminal through

R_1 resistor.

→ The capacitor current I is given by $I = C_F \frac{dv}{dt}$.

→ Since o/p current of Op-amp is zero, the entire current flowing through R_1 & C_F.

Applying KCL at node 'a'

For i/p side $I = \frac{V_i - V_a}{R_1}$

where $V_a = 0\,V$; because virtual connection

$$\boxed{I = \frac{V_i}{R_1}} \rightarrow (1)$$

At o/p side; $I = C_F \frac{d(V_a - V_o)}{dt}$

$$\boxed{I = -C_F \frac{dV_o}{dt}} \rightarrow (2)$$

equating eq(1) & eq(2)

$$\frac{V_i}{R_1} = -C_F \frac{dV_o}{dt}$$

$$dV_o = -\frac{V_i\,dt}{R_1 C_F}$$

integrating on b.s, we get

$$\int_0^t dV_o = -\frac{1}{R_1 C_F} \int_0^t V_i\,dt$$

$$V_o(t) - V_o(0) = \frac{-1}{R_1 C_F} \int_0^t V_i(t)\,dt$$

$$V_o(t) = \frac{-1}{R_1 C_F} \int_0^t V_i(t)\,dt + V_o(0)$$

Where, $R_1 C_F = \tau$ = Time constant of integrator

$V_o(0)$ is the initial o/p voltage

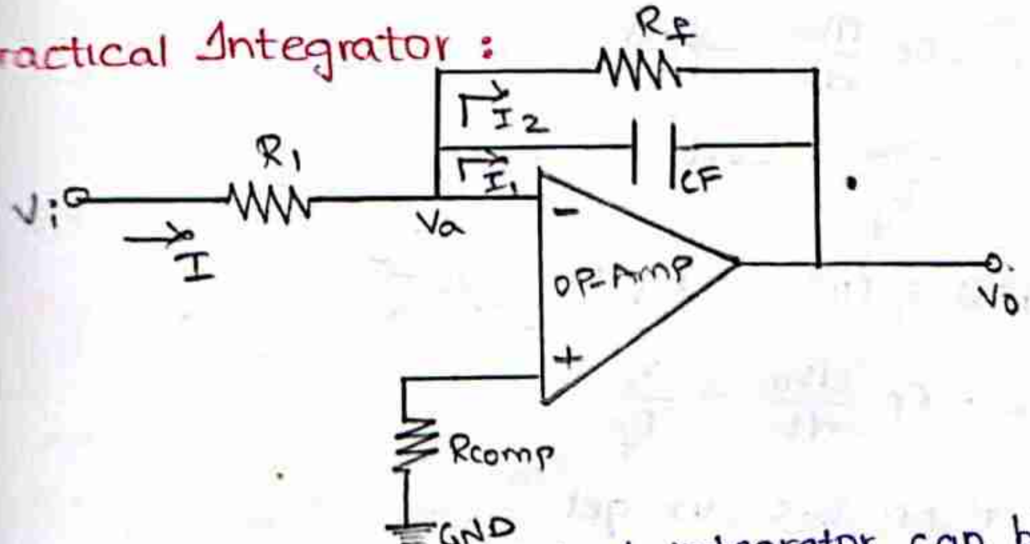
→ The above eqn shows that the o/p is $\frac{-1}{R_1 C_F}$ times the integral of i/p.

Drawbacks :

- Without giving any i/p , we get some voltage at the o/p so we can treat that as error signal.
- Capacitor gets charging & discharging due to bias currents & add its effects on o/p error voltage. After sometime o/p of op-amp may achieve its saturation level.
- Band width is very small for ideal integrator. Hence ideal integrator can be used for very small frequency range of i/p's only.

→ Because of all the above drawbacks the ideal integrator is not used in practically. Some additional components are used along with basic integrator circuit to reduce the effect of an error voltage in practically such an integrator is called as practical integrator circuit.

Practical Integrator :



→ The drawbacks of an ideal integrator can be minimised in the practical integrator circuit, which consists of resistance R_F in parallel with the capacitance C_F.

→ The practical integrator circuit shown in above fig.

→ The resistance Rcomp is used to overcome the errors due to the bias currents.

→ The resistance R_f reduces the low frequency gain of the op-amp.

→ The parallel combination of R_f & C_f behaves like a practical capacitor which dissipates power unlike an ideal capacitor. For this reason this circuit is also called as "Lossy integrator."

→ Since i/p current of op-amp is zero, from the concept virtual ground $V_a = 0$.

Applying KCL at node 'a',

$$I = I_1 + I_2 \quad \rightarrow (1)$$

But $$I = \frac{V_i - V_a}{R_1}$$

$$I = \frac{V_i}{R_1} \quad \rightarrow (2)$$

$$I_1 = -C_F \frac{dV_o}{dt} \quad \rightarrow (3)$$

$$I_2 = \frac{-V_o}{R_f} \quad \rightarrow (4)$$

sub. eq(2), (3) & (4) in eq(1)

$$\frac{V_i}{R_1} = -C_F \frac{dV_o}{dt} - \frac{V_o}{R_f}$$

Apply L.T on b.s, we get

$$\frac{V_i(s)}{R_1} = -sC_F V_o(s) - \frac{V_o(s)}{R_f}$$

$$\frac{V_i(s)}{R_1} = -V_o(s)\left[sC_F + \frac{1}{R_f}\right]$$

$$V_o(s) = \frac{-V_i(s)}{R_1\left[sC_F + 1/R_f\right]}$$

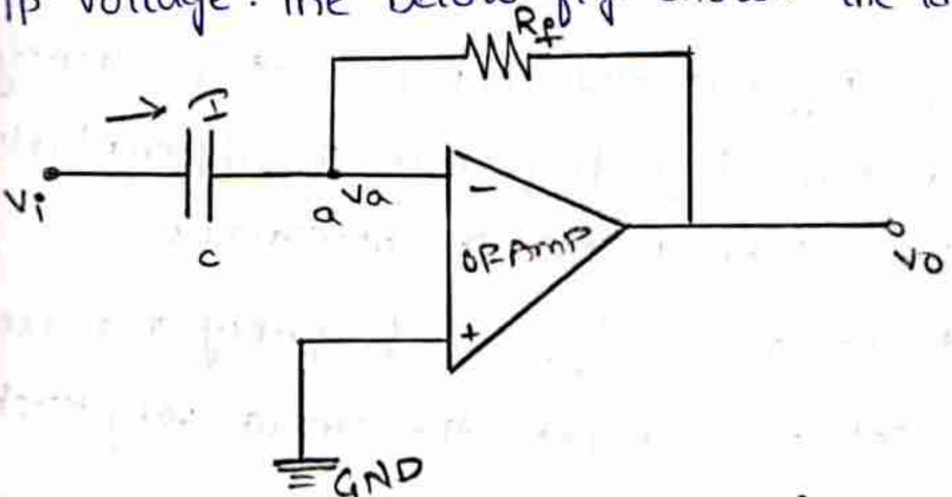
$$\boxed{V_o(s) = \frac{-V_i(s)}{sCR_1 + R_1/R_f}}$$

Applications :-

- It is used in Analog computers
- It is used in analog to digital convertors
- It is used in solving differential equations
- It is used in wave shapping circuits.

Differentiator :-

Differentiator is a circuit in which o/p voltage is differentiate of i/p voltage. The below fig. shows the ideal differentiator.



The node 'a' is at virtual ground potential i.e., $V_a = 0$.

→ The current I flowing through the capacitor is

$$I = C\frac{dv}{dt}$$

→ Apply KCL at node 'a'

$$I = C\frac{d(V_i - V_a)}{dt}$$

Due to virtual connection $V_a = 0$

$$I = C\frac{dV_i}{dt} \rightarrow (1)$$

Similarly at the o/p side

$$I = \frac{V_a - V_o}{R_f}$$

$$I = \frac{-V_o}{R_f} \rightarrow (2)$$

Equating above 2 eqns

$$C \frac{dV_i}{dt} = \frac{-V_o}{R_f}$$

$$\boxed{V_o = -R_f C \frac{dV_i}{dt}}$$

where, $R_f \cdot C$ = Time constant.

→ Thus the o/p voltage V_o is constant $(-R_f \cdot C)$ times the derivative of the i/p voltage.

Drawbacks :-

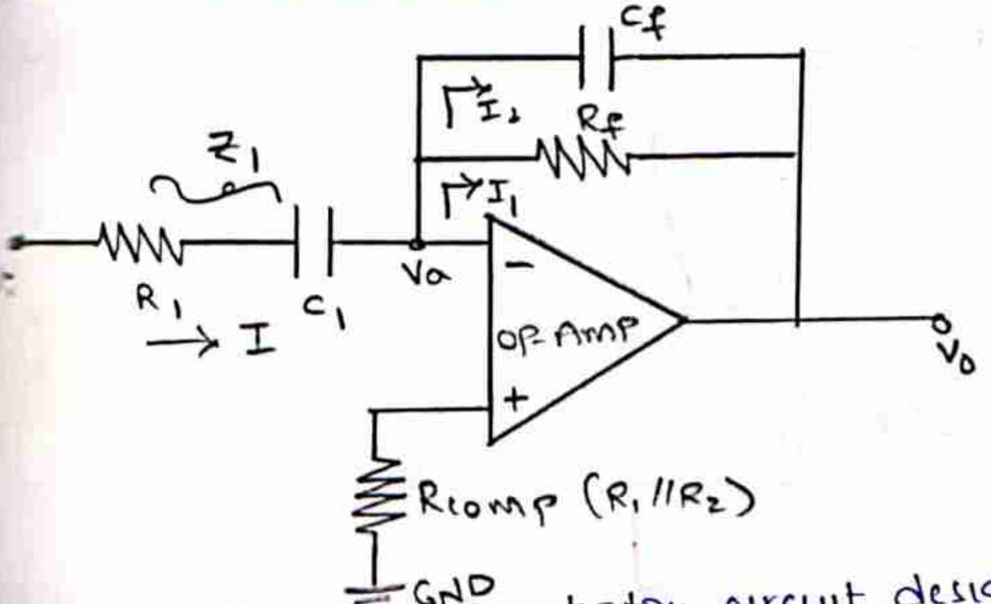
1. The gain of the differentiator increases as frequency increases. Thus at some high frequency the differentiator may become unstable & break into the oscillations.
2. The i/p impedence $X_{C1} = \frac{1}{2\pi f C}$, if frequency increases impedence decreases. This makes the circuit very much senstive to the noise.
3. This noise may completely overwrite the o/p of the differentiator.

Hence the differentiator circuit ~~satisfies~~ suffers from the stability & noise problem at high frequencies.

→ These problems can be overcome by adding additional components.

Practical Differentiator :

→ The differentiator circuit suffers from the stability & noise problems at high frequencies. These problems can be eliminated by practical differentiator.



- The practical differentiator circuit designed by using resistance R_1 is in series with C_1 & capacitor C_f is in parallel with resistance R_f.
- The resistance Rcomp is used for bias compensations.

Analysis :

- The current I flowing through the R_1 & C_1 components. But the series combination of R_1 & C_1 is denoted by impedence Z_1.

So, $I = \frac{V_i}{Z_1}$

According to L.T

$$I = \frac{V_i(s)}{Z_1} \longrightarrow (1)$$

W.K.T, $Z_1 = R_1 + \frac{1}{j\omega C_1}$

$$= R_1 + \frac{1}{sC_1}$$

$$\boxed{Z_1 = \frac{R_1 sC_1 + 1}{sC_1}}$$

Sub. Z_1 in eq(1)

$$I = \frac{V_i(s)\, sC_1}{1 + R_1 sC_1}$$

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Similarly $I_1 = \frac{-V_o}{R_f}$

$$\boxed{I_1 = \frac{-V_o(s)}{R_f}}$$

$$I_2 = -C_F \frac{dV_o}{dt}$$

$$\boxed{I_2 = -SC_F V_o(s)}$$

Apply KCL at node 'a'

$$I = I_1 + I_2$$

$$\frac{V_i(s) SC_1}{1 + R_1 SC_1} = \frac{-V_o(s)}{R_f} - SC_f V_o(s)$$

$$= \cancel{\frac{-V_o(s)}{R_f}} \cdot -V_o(s)\left[\frac{1}{R_f} + SC_f\right]$$

$$= -V_o(s)\left[\frac{1 + SC_f R_f}{R_f}\right]$$

$$\boxed{V_o(s) = -\frac{V_i(s) SC_1 R_f}{(1 + SC_1 R_1)(1 + SC_f R_f)}}$$

Let us assume $R_f C_f = R_1 C_1$

$$V_o(s) = -\frac{V_i(s) SC_1 R_f}{(1 + SC_f R_f)^2}$$

If $R_f C_1 > C_f R_f$, then the denominator can be neglected

$$\boxed{\therefore V_o(s) = -V_i(s) SC_1 R_f}$$

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By applying inverse L.T to the above eqn, we get

$$\boxed{\therefore V_o(t) = -R_f C_1 \frac{dV_i(t)}{dt}}$$

Applications :

- It is used in wave shaping circuits
- It is used in convertors i.e., analog to digital.

ACTIVE FILTERS & OSCILLATORS

Introduction :

→ Filter is a frequency selective device. It is a circuit which is used for selecting a particular band of frequency.

→ Filter can be designed which passive and as well as the active components.

→ Passive elements are resistance, capacitor & inductor.

→ If the circuit designed with RLC which is called Passive filter.

→ Active elements are transistors, OP-amps. If the circuit is designed with op-amp which is called as active filter.

→ In active filter resistors and capacitors are also be used to desire circuit.

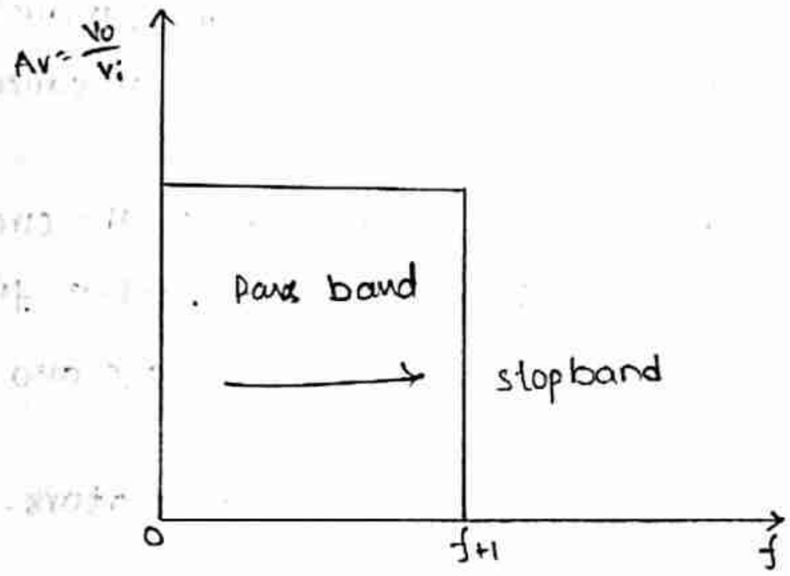
→ RC filters are used for low frequency oscillators. LC filters are used for high frequency oscillators.

Advantages of Active (or) Passive filters :

1. Gain and frequency adjustment flexibility.
2. No loading effect.
3. It is cheap (It is the cost is very low)
4. The most commonly used filters are
   - (a) Low pass filter (LPF)
   - (b) High pass filter (HPF)
   - (c) Band pass filter (BPF)
   - (d) Band Reject filter (BRF)
   - (e) All Pass filter

Low Pass Filter :

In ideal low pass filter, the input signal frequency at the lower range of the band are allowed to pass and its completely stops after designed cutoff frequency (f_H).



→ The low pass filter allows frequency for lower range of frequency upto f_H. and beyond f_H which is the cutoff frequencies, a higher cutoff frequency is totally stopped.

→ If we plot the gain vs frequency of an ideal low pass filter we should get such type of characteristics.

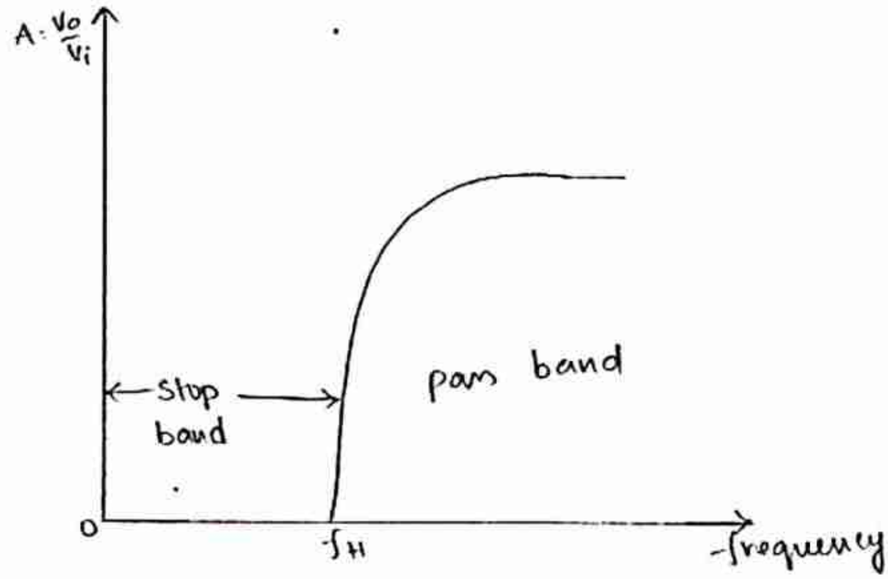
→ The region or over the frequency band in which the signal is allow to pass i.e., called pass band.

→ The frequencies beyond f_H is called stop band.

High Pass filter :

In high pass filter the higher band of frequency will be allowed and lower band of frequencies will not be allowed.

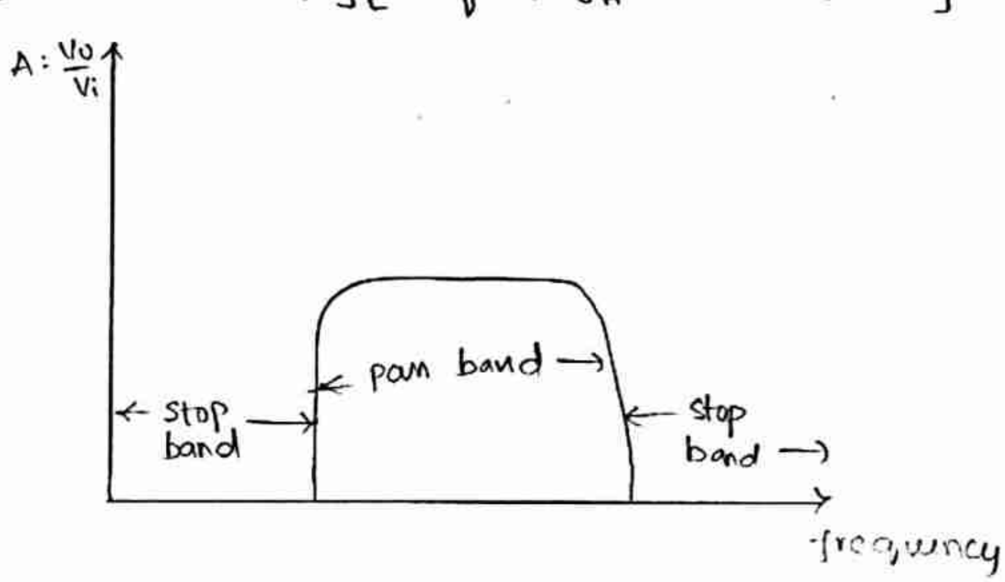
→ If we plot the gain v_s frequencies.



Band Pass Filter :

The signal is passed with in a particular band which is called pass band.

→ Here between f_L and f_H band of frequencies is allowed but below f_L after f_H it is totally stoped.

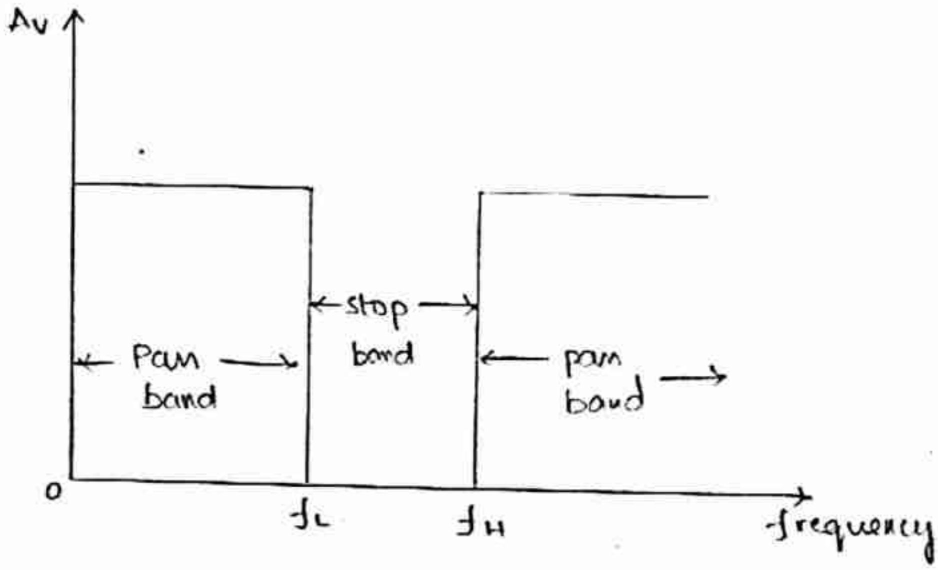


→ Basically band pass filter is a combination of high pass and low pass filters.

Band Reject Filter :

In band reject filter below the frequency band f_L is allow and above f_L and below f_H and frequency band is stopped.

→ Frequency band above f_H is allowed



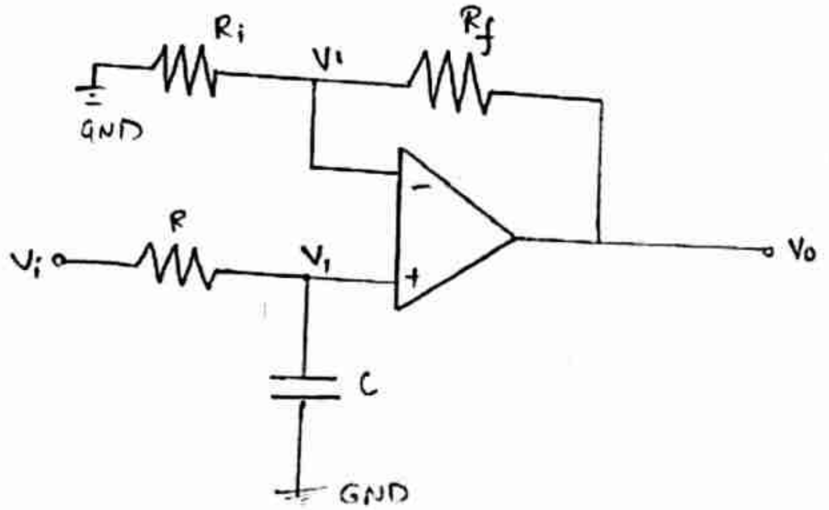
All pass Filter :

It will be allowing all frequencies to pass through it.

First Order LPF :

→ First order filter consists of a single RC network connected to the non-inverting input terminal of op-amp.

→ First order LPF shown in below figure.



→ Resistors R_f & R_i determines the gain of the filter.

→ The resistor R & capacitance c determines the cut off frequencies of the filter.

→ Since the op-amp is used in the non-inverting configuration, so the closed loop gain of the filter is given by

$$\boxed{A_{VF} = 1 + \frac{R_f}{R_i}}$$

Analysis :

→ We have to obtain the expression for ~~at~~ V_1 which is the voltage across the capacitor c.

→ The resistor R & capacitor c forms a voltage divider network across the i/p voltage Vi.

→ Therefore voltage V_1 at non-inverting terminal is given by according to potential divider theorem,

$$V_1 = \frac{V_i \cdot \frac{1}{j\omega C}}{R + \frac{1}{j\omega C}}$$

$$= \frac{V_i \cdot \frac{1}{\cancel{j\omega C}}}{\frac{j\omega RC + 1}{\cancel{j\omega C}}}$$

$$\boxed{V_1 = \frac{V_i}{1 + j\omega RC}}$$

We know that, $A_{VF} = 1 + \frac{R_f}{R_i}$

$$\frac{V_o}{V_i} = 1 + \frac{R_f}{R_i}$$

$$V_o = \left(1 + \frac{R_f}{R_i}\right) V_i$$

$$= \left(1 + \frac{R_f}{R_i}\right) \frac{V_i}{1 + j\omega RC}$$

$$\frac{V_o}{V_i} = \left(1 + \frac{R_f}{R_i}\right) \frac{1}{1 + j\omega RC}$$

$$= A_{VF} \cdot \frac{1}{1 + j\omega RC}$$

But $\omega = 2\pi f$

$$\frac{V_o}{V_i} = A_{VF} \frac{1}{1 + j2\pi fRC}$$

$$= A_{VF} \frac{1}{1 + j\, f/\frac{1}{2\pi RC}}$$

$$\left[\because f_c = \frac{1}{2\pi RC}\right]$$

$$= A_{VF} \frac{1}{1 + j\,(f/f_h)}$$

$$\boxed{\left|\frac{V_o}{V_i}\right| = \frac{A_{VF}}{\sqrt{1+(f/f_H)^2}}}$$

The first order LPF can be verified from the above eqn as under 3 conditions.

1. At very low frequencies i.e., $f \ll f_h$

$$\left|\frac{V_o}{V_i}\right| \simeq A_{VF}$$

Thus at very Low frequencies, the filter gain is constant.

2. At $f = f_h$.

$$\left|\frac{V_o}{V_i}\right| = \frac{A_{VF}}{\sqrt{1+(1)^2}}$$

$$= \frac{A_{VF}}{\sqrt{2}}$$

$$\left|\frac{V_o}{V_i}\right| = 0.707\, A_{VF}$$

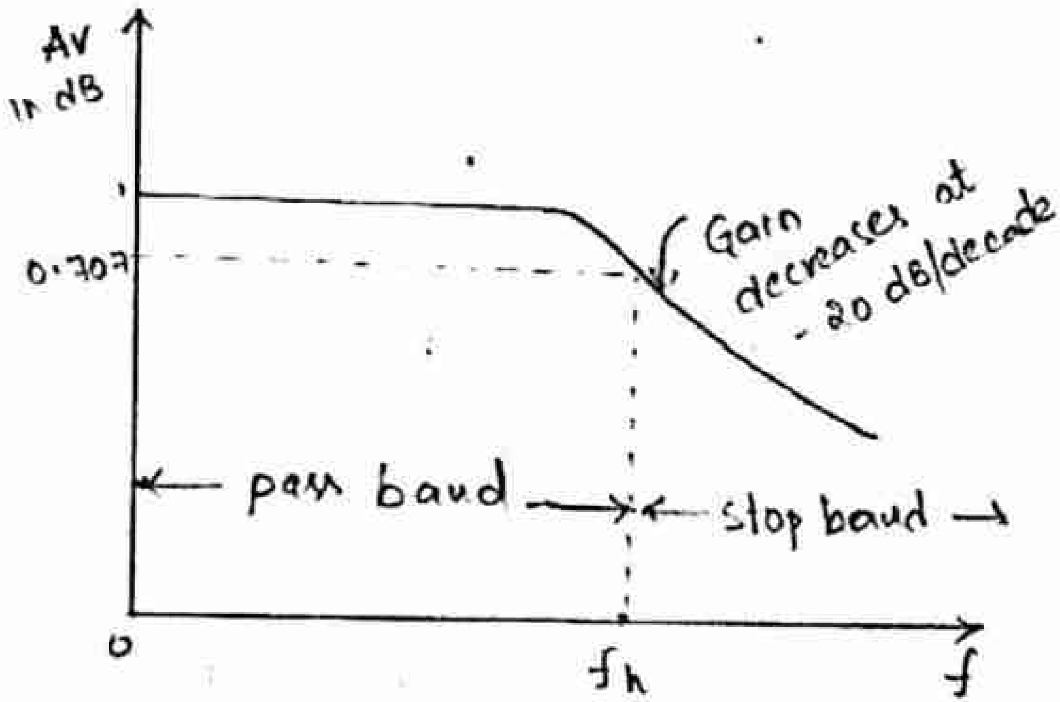
Thus at $f = f_h$, the filter gain reduces by 3 dB, as the dB value of 0.707.

3. At very high frequencies i.e., $f \gg f_h$.

$$\left|\frac{V_o}{V_i}\right| < A_{VF}$$

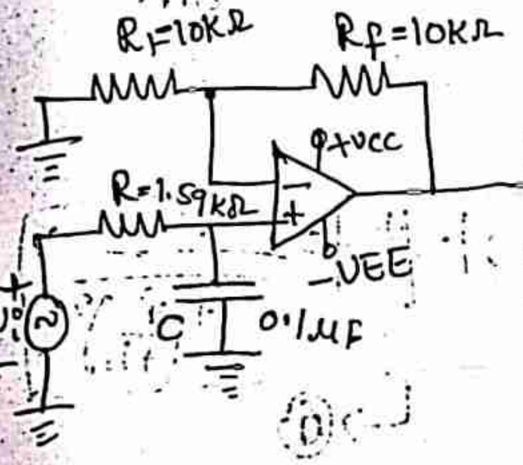
Thus the filter gain will keep decreasing with increasing frequency. This decreases takes place at a constant rate of -20 dB/decade. Here "decade" means 10 times & the gain is expressed in dB. & -ve sign indicates that gain is decreasing.

→ ~~Hence~~, frequency response of first order LPF is shown in below fig.



1. choose a value of high cut off frequency f_h.
2. select the value of 'C' is less than or equal to 1µF.
3. calculate the value of 'R' by using $R = \frac{1}{2\pi f_h C}$
4. select value of R_1 and R_F depending on the desired pass band gain A_0, by using $A_0 = 1 + \frac{R_F}{R_1}$

(1) Design a LPF when a cut off frequency of 1KHZ with a pass band gain of 2.



Given data:-

$f_h = 1KHZ$

$A_0 = 2$

$A_0 = 1 + \frac{R_F}{R_1} = 2$

$1 + \frac{R_F}{R_1} = 2$

$\frac{R_F}{R_1} = 2 - 1$

$\frac{R_F}{R_1} = 1$

$R_F = R_1$

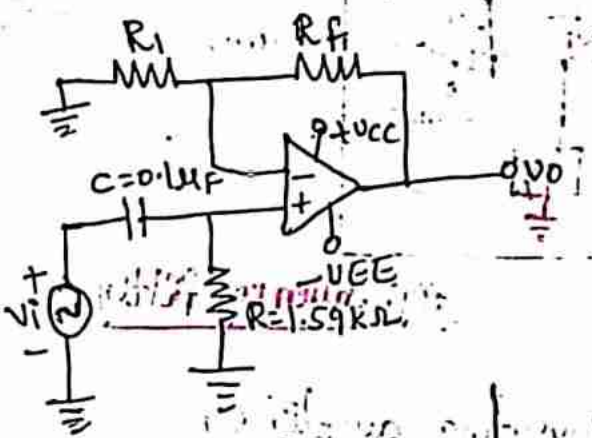
Assume $R_F = 10K\Omega$ so $R_1 = 10K\Omega$

consider $C = 0.1\mu F$

$$R = \frac{1}{2\pi f_h C} = \frac{1}{2\pi \times 10^3 \times 0.1 \times 10^{-6}}$$

$\therefore \boxed{R = 1.59K\Omega}$

(2) Design a HPF when a cut-off frequency of 1KHz with a pass band gain '2'.



Given data:

It is HPF so here cut-off frequency as

$f_L = 1KHz$

$A_0 = 2$

So assume $R_F = 10K\Omega$

$R_F = R_1 = 10K\Omega$

Let $C = 0.1\mu F$

$$\boxed{R = \frac{1}{2\pi f_L C}}$$

$$R = \frac{1}{2\pi \times 10^3 \times 0.1 \times 10^{-6}}$$

$$R = 1.59\,K\Omega$$

$$A_0 = 1 + \frac{R_F}{R_1} = 2$$

$$\frac{R_F}{R_1} = 2 - 1$$

$$\frac{R_F}{R_1} = 1$$

$$R_F = R_1$$

Second order active filter (Sallen Key filter):

→ An improved filter response can be obtained by using second order active filter.

→ The second order active filter consists of two RC networks and roll off rate is −40dB/decade

→ A general second order filter is shown in figure.

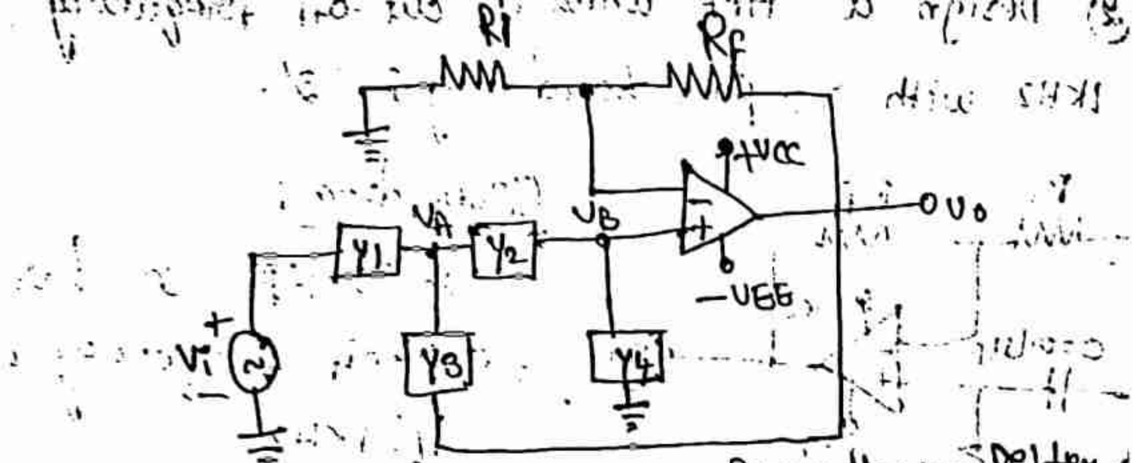


fig: sallen key filter

$$\frac{V_o}{V_B} = 1 + \frac{R_F}{R_1}$$

since it is non-inverting amplifier

$$\frac{V_o}{V_B} = A_0 \qquad A_0 = \left[1 + \frac{R_F}{R_1}\right]$$

$$\boxed{V_B = \frac{V_o}{A_0}}$$

Apply KCL at node A.

$$I = \frac{V}{R} = V \cdot Y = V \cdot \frac{1}{R}$$

$$I = V \cdot \frac{1}{R}$$

$$(V_i - V_A) Y_1 = [V_A - V_B] Y_2 + [V_A - V_o] Y_3$$

$$V_i Y_1 - V_A Y_1 = V_A Y_2 - V_B Y_2 + V_A Y_3 - V_o Y_3$$

$$V_i Y_1 = V_A Y_2 + V_A Y_1 - V_B Y_2 + V_A Y_3 - V_o Y_3$$

$$V_i Y_1 = V_A [Y_1 + Y_2 + Y_3] - V_o Y_3 - V_B Y_2$$

$$V_B = \frac{V_o}{A_0}$$

$$V_i Y_1 = V_A [Y_1 + Y_2 + Y_3] - V_o Y_3 - \frac{V_o}{A_0} Y_2$$

$$V_i Y_1 = V_A [Y_1 + Y_2 + Y_3] - V_o \left[Y_3 + \frac{Y_2}{A_0}\right] \rightarrow (1)$$

Apply KCL at node B

$$[V_A - V_B]\,Y_2 = (V_B)\,Y_4$$

$$V_A Y_2 = V_B\,[Y_4 + Y_2]$$

$$V_A = V_B\,[Y_4 + Y_2]$$

$$V_A = \frac{V_o}{A_o Y_2}\,[Y_2 + Y_4] \longrightarrow (2)$$

substitute V_A in eq (1)

$$V_i Y_1 = \frac{V_o}{A_o Y_2}\,[Y_2 + Y_4]\,[Y_1 + Y_2 + Y_3] - V_o\left[Y_3 + \frac{Y_2}{A_o}\right]$$

$$V_i Y_1 = \frac{V_o}{A_o Y_2}\left[Y_2 Y_1 + Y_2^2 + Y_2 Y_3 + Y_4 Y_1 + Y_4 Y_2 + Y_4 Y_3\right] - \frac{V_o}{A_o Y_2}\left[A_o Y_2 Y_3 + Y_2^2\right]$$

$$V_i Y_1 = \frac{V_o}{A_o Y_2}\left[Y_2 Y_1 + \cancel{Y_2^2} + Y_2 Y_3 + Y_4 Y_1 + Y_4 Y_2 + Y_4 Y_3 - A_o Y_2 Y_3 - \cancel{Y_2^2}\right]$$

$$V_i Y_1 = \frac{V_o}{A_o Y_2}\left[Y_4\,[Y_1 + Y_2 + Y_3] + Y_2 Y_1 + Y_2 Y_3\,[1 - A_o]\right]$$

$$\boxed{H(s) = \frac{V_o}{V_p} = \frac{A_o Y_1 Y_2}{Y_2 Y_1 + Y_2 Y_3\,[1 - A_o] + Y_4\,[Y_1 + Y_2 + Y_3]}}$$

This is the general transfer function of second order active filter.

Second order active low pass filter:-

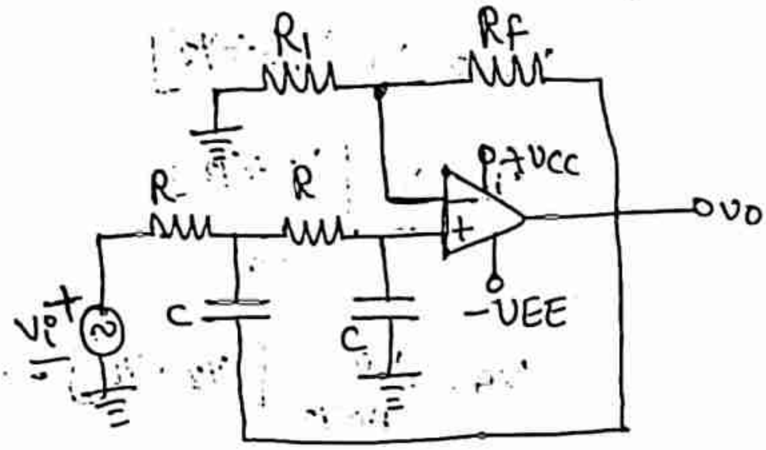


fig:- second order LPF

To make low pass filter $Y_1 = Y_2 = \frac{1}{R}$ and $Y_3 = Y_4 = SC$.

The T/F H(s) of second order low pass filter is

$$H(s) = \frac{V_0}{V_i} = \frac{A_0\left(\frac{1}{R}\right)\left(\frac{1}{R}\right)}{\left(\frac{1}{R}\right)\left(\frac{1}{R}\right) + \left(\frac{1}{R}\right)(SC)(1-A_0) + SC\left[\frac{1}{R}+\frac{1}{R}+SC\right]}$$

$$= \frac{A_0\left(\frac{1}{R^2}\right)}{\frac{1}{R^2} + \frac{SC}{R}(1-A_0) + SC\left[\frac{1}{R}+\frac{1}{R}+SC\right]}$$

$$= \frac{A_0/\cancel{R^2}}{\frac{1+SCR(1-A_0)+(SCR)(2+RSC)}{\cancel{R^2}}}$$

$$= \frac{A_0}{1+SCR(1-A_0)+(SCR)(2+RSC)}$$

$$= \frac{A_0}{1+SCR-SCRA_0+2SCR+R^2S^2C^2}$$

$$\boxed{\frac{V_0}{V_i} = \frac{A_0}{S^2C^2R^2+SCR(3-A_0)+1}}$$

Let, $RC = \frac{1}{\omega_h}$, $f_h = \frac{1}{2\pi RC}$ $(\omega = 2\pi f)$ $RC = \frac{1}{2\pi f_h} = \frac{1}{\omega_h}$

$$\frac{V_0}{V_i} = \frac{A_0}{s^2\left(\frac{1}{\omega_h}\right)^2 + s\left(\frac{1}{\omega_h}\right)\cdot(3-A_0)+1}$$

$$= \frac{A_0}{\frac{s^2}{\omega^2 h^2} + \frac{s}{\omega h}(3-A_0)+1}$$

$$\boxed{\frac{V_0}{V_i} = \frac{A_0\omega_h^2}{s^2+s\omega_h(3-A_0)+\omega_h^2}}$$

This is the transfer function of second order LPF

Where A_0 = gain,

α = damping coefficient $=(3-A_0)$

$$\boxed{H(s) = \frac{A_0\omega_h^2}{s^2+s\omega_h(\alpha)+\omega_h^2}}$$

The value of damping coefficient 'α' for low pass RC active filter can be determined by the value of A_0

put $s=j\omega$.

$$\frac{V_0}{V_i} = \frac{A_0}{\frac{s^2}{\omega_h^2} + \frac{s}{\omega_h}(3-A_0)+1}$$

$$H(j\omega) = \frac{V_0}{V_i} = \frac{A_0}{\frac{(j\omega)^2}{\omega_h^2} + \frac{j\omega}{\omega_h}(3-A_0)+1}$$

The normalized expression for LPF is $H(j\omega) = \frac{A_0}{S_n^2+S_n\alpha+1}$

Where, $S_n = \frac{j\omega}{\omega_h}$; S_n = normalising frequency

$$H(j\omega) = \frac{A_0}{\frac{-\omega^2}{\omega_h^2} + \frac{j\omega}{\omega_h}(3-A_0)+1} = \frac{A_0}{1-\frac{\omega^2}{\omega_h^2} + j\frac{\omega}{\omega_h}\alpha}$$

$$\boxed{|H(j\omega)| = \frac{A_0}{\sqrt{\left(1-\frac{\omega^2}{\omega_h^2}\right)^2 + \left(\frac{\omega}{\omega_h}\alpha\right)^2}}}$$

Butterworth filter :-

* The flatest pass band occurs for a damping coefficient (α) of 1.414. This is called butterworth filter

$$|H(j\omega)| = \frac{A_0}{\sqrt{\left(1-\frac{\omega^2}{\omega_h^2}\right)^2 + \left(\frac{\omega}{\omega_h}\alpha\right)^2}}$$

$\alpha = 1.414 = \sqrt{2}$

$$|H(j\omega)| = \frac{A_0}{\sqrt{\left(1-\frac{\omega^2}{\omega_h^2}\right)^2 + \left(\frac{\omega}{\omega_h}(1.414)\right)^2}}$$

$$= \frac{A_0}{\sqrt{\left(1-\frac{\omega^2}{\omega_h^2}\right)^2 + \left(\frac{\omega}{\omega_h}\sqrt{2}\right)^2}}$$

$$= \frac{A_0}{\sqrt{1+\frac{\omega^4}{\omega_h^4} \cancel{-\frac{2\omega^2}{\omega_h^2}} \cancel{+\frac{2\omega^2}{\omega_h^2}}}}$$

$$= \frac{A_0}{\sqrt{1+\left(\frac{2\pi f}{2\pi f_h}\right)^4}} \quad (\omega = 2\pi f)$$

$$\boxed{\left|\frac{V_0}{V_i}\right| = \frac{A_0}{\sqrt{1+\left(\frac{f}{f_h}\right)^4}}}$$

case (i) : $f > f_h \Rightarrow |H(j\omega)| = 0$

case (ii) : $f = f_h \Rightarrow |H(j\omega)| = \frac{A_0}{\sqrt{2}}$

case (iii) : $f < f_h \Rightarrow |H(j\omega)| = A_0$

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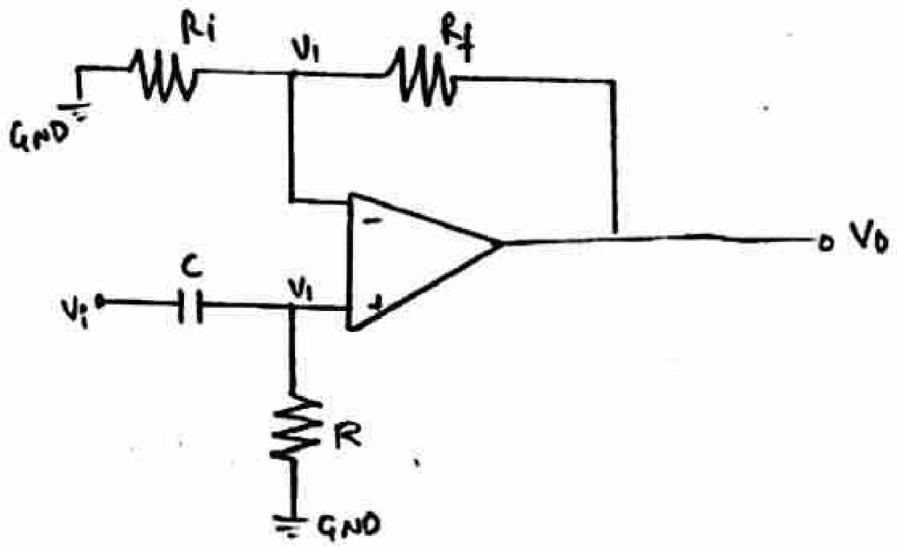
First Order HPF :



Analysis :

→ We obtain voltage across resistor R. i.e., V_1.

→ According to potential divider rule,

$$V_1 = V_i \cdot \frac{R}{R + \frac{1}{j\omega C}}$$

$$V_1 = V_i \frac{j\omega RC}{1 + j\omega RC}$$

W.K.T $\quad A_{VF} = 1 + \frac{R_f}{R_i}$

$$\frac{V_o}{V_1} = 1 + \frac{R_f}{R_i}$$

$$V_o = \left(1 + \frac{R_f}{R_i}\right) V_1$$

$$= \left(1 + \frac{R_f}{R_i}\right) \times V_i \frac{j\omega RC}{1 + j\omega RC}$$

$$\frac{V_o}{V_i} = \left(1 + \frac{R_f}{R_i}\right) \times \frac{j\omega RC}{1 + j\omega RC}$$

But $\omega = 2\pi f$

$$= \left(1 + \frac{R_f}{R_i}\right) \times \frac{j 2\pi f RC}{1 + j 2\pi f RC}$$

$$= \left(1 + \frac{R_f}{R_i}\right) \times \frac{j\, f/\tfrac{1}{2\pi RC}}{1 + j\, f/\tfrac{1}{2\pi RC}}$$

$$\frac{V_o}{V_i} = A_{VF} \times \frac{j\, f/f_L}{1 + j\, f/f_L}$$

$$\left|\frac{V_o}{V_i}\right| = \frac{A_{VF} \times (f/f_L)}{\sqrt{1 + (f/f_L)^2}}$$

$$= \frac{A_{VF}}{\sqrt{\frac{1 + (f/f_L)^2}{(f/f_L)^2}}}$$

$$\boxed{\left|\frac{V_o}{V_i}\right| = \frac{A_{VF}}{\sqrt{1 + (f/f_L)^2}}}$$

→ The first order HPF can be verified from the above eqn. under 3 conditions.

1. At very low frequencies i.e $f << f_L$

$$\left|\frac{V_o}{V_i}\right| < A_{VF}$$

Thus at very low frequencies, gain is Low, with increase in ~~2. At f = fL~~ frequency, gain also increases.

2. At $f = f_L$

$$\left|\frac{V_o}{V_i}\right| = \frac{A_{VF}}{\sqrt{2}}$$

$$= 0.707\, A_{VF}$$

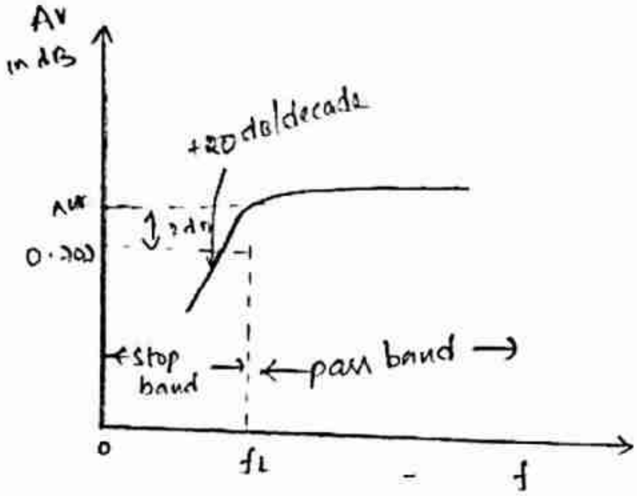
Thus at $f = f_L$ the filter gain increases by 3 dB.

3. At very high frequencies i.e., $f >> f_L$.

$$\left|\frac{V_o}{V_i}\right| \simeq A_{VF}$$

→ Thus at very high frequencies the filter gain is constant.

→ Hence the frequency response of first order HPF shown in below figure.



Second order Active High pass filter:-

High pass filter is the complement of LPF, and can be obtained simply by interchanging R and C in low pass configuration.

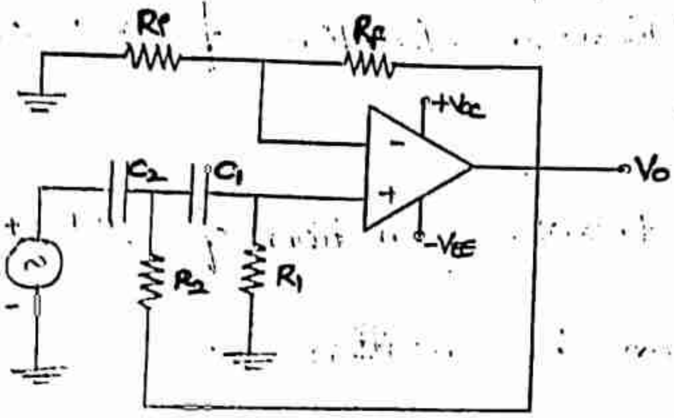


fig: Second order HPF

The transfer function is given below as

$$\frac{V_o}{V_i} = \frac{A Y_1 Y_2}{Y_1 Y_2 + Y_2 Y_3 [1-A_o] + Y_4 [Y_1+Y_2+Y_4]} \longrightarrow (1)$$

put $Y_1 = Y_2 = SC$; $Y_3 = Y_4 = 1/R$

$$\frac{V_o}{V_i} = \frac{AS^2 c^2}{s^2c^2 + \frac{sc}{R}(1-A_o) + \frac{1}{R}(sc+sc+1/R)}$$

$$= \frac{A_o S^2 c^2}{s^2c^2 + \frac{sc}{R}(1-A_o) + 1/R^2(2scR+1)}$$

$$\frac{V_o}{V_i} = \frac{A_o s^2c^2 R^2}{s^2c^2 R^2 + scR(3-A_o)+1}$$

Put $RC = 1/\omega_c$

$$V_o/V_i = \frac{A_o S^2/\omega_L^2}{S^2/\omega_L^2 + S/\omega_L\,[3-A_o]+1}$$

$$V_o/V_i = \frac{A_o S^2}{S^2 + S\omega_L\,[3-A_o] + \omega_L^2} \longrightarrow ②$$

eq ② indicates
Transfer function of 2nd order high pass filter.

The transfer function of 2nd order High pass filter can be written as

$$\frac{V_o}{V_i} = \frac{A_o}{1+\frac{\omega_L}{s}[3-A_o]+\left[\frac{\omega_L}{s}\right]^2}$$

$$\therefore H(s) = \frac{V_o}{V_i} = \frac{A_o}{1+\frac{\omega_L}{s}(\alpha)+\left(\frac{\omega_L}{s}\right)^2}$$

put $S = j\omega$ in the above equation

then

$$H(j\omega) = \frac{V_o}{V_i} = \frac{A_o}{1+\frac{\omega_L}{j\omega}(\alpha)+\left(\frac{\omega_L}{j\omega}\right)^2}$$

Let $\alpha = 1.414$

$$H(j\omega) = \frac{V_o}{V_i} = \frac{A_o}{1+(\omega_L/j\omega)(1.414)+(\omega_L/j\omega)^2}$$

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The voltage gain magnitude equation for 2^{nd} order butterworth HPF can be obtained as

$$\boxed{H(s) = \frac{V_o}{V_i} = \frac{A_o}{1+(\omega_L/s)\alpha + (\omega_L/s)^2}} \quad \left(\because \frac{1}{j} = -j\right)$$

By substituting $s = j\omega$

$$\frac{V_o}{V_i} = \frac{A_o}{1 - j\omega_L/\omega\alpha - (\omega_L/\omega)^2}$$

$\omega = 2\pi f$

$$\frac{V_o}{V_i} = \frac{A_o}{1 - j\left[\frac{2\pi f_L}{2\pi f}\right]\alpha - \left[\frac{2\pi f_L}{2\pi f}\right]^2}$$

$$= \frac{A_o}{1 - j(f_L/f)\alpha - (f_L/f)^2}$$

$$|H(j\omega)| = \frac{A_o}{\sqrt{(1 - f_L/f)^2 + (f_L/f)^2 (\sqrt{2})^2}} \quad (\sqrt{2})^2$$

$$\boxed{|H(j\omega)| = \frac{A_o}{\sqrt{1 + (f_L/f)^4}}}$$

for n^{th} order butterworth HPF, $\boxed{|H(j\omega)| = \frac{A_o}{\sqrt{1+\left(\frac{f_L}{f}\right)^{2n}}}}$

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order	LPF	HPF
1st	$\dfrac{A_0}{\sqrt{1+\left(\frac{f}{f_H}\right)^2}}$	$\dfrac{A_0}{\sqrt{1+\left(\frac{f_L}{f}\right)^2}}$
2nd	$\dfrac{A_0}{\sqrt{1+\left(f/f_H\right)^4}}$	$\dfrac{A_0}{\sqrt{1+\left(f_L/f\right)^4}}$
3rd	$\dfrac{A_0}{\sqrt{1+\left(f/f_H\right)^6}}$	$\dfrac{A_0}{\sqrt{1+\left(\frac{f_L}{f}\right)^6}}$

Band Pass Filter :

→ A band pass filter has a pass band b/w two cut-off frequencies f_H & f_L. i.e., it is passes the frequencies f_H & f_L. Outside of this pass band will stopped the frequencies.

There are two types of band pass filter. which are classified as per the quality factor.

(a) Wide band pass filter

(b) Narrow band

→ If the quality factor is less than 10 ($Q < 10$) then the filter is called as wide band pass filter.

→ If the quality factor is greater than 10 ($Q > 10$) then the filter is called as Narrow band pass filter.

Quality factor:

→ Quality factor Q is the measure of selectivity of filter. The value of Q is given by

$$Q = \frac{f_c}{f_H - f_L}$$

where, $f_H - f_L$ = Band width, so

$$Q = \frac{f_c}{B.W}$$

where $f_c = \sqrt{f_H f_L}$

f_H = upper cut-off frequency

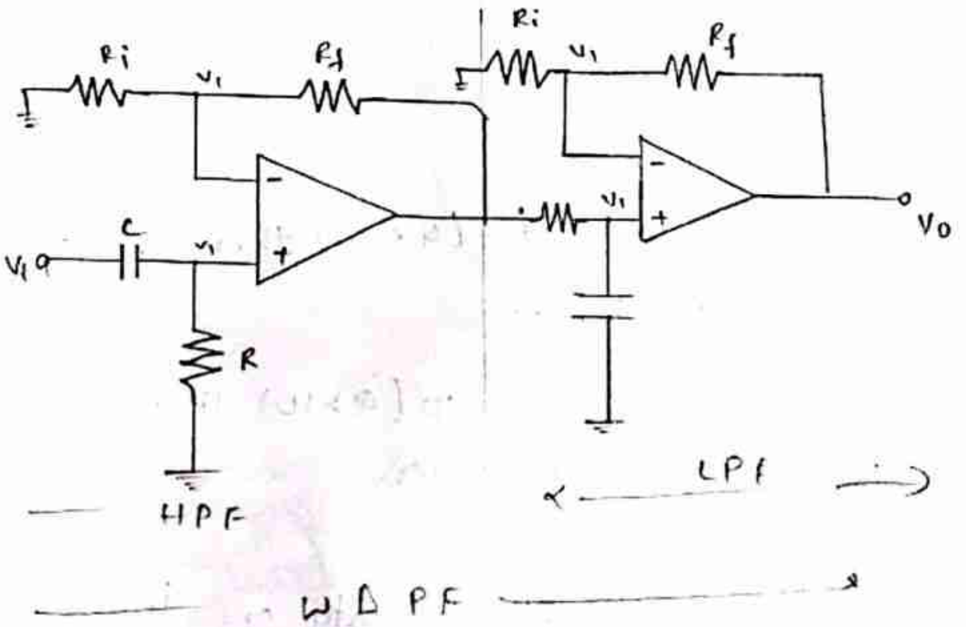
f_L = Lower cut-off frequency

(a) Wide Band pass Filter:

→ A wide band pass filter is implemented by Cascading a first order HPF & first order LPF.

→ It has more band width b/w the two frequencies.

→ The circuit diagram of wide band pass filter shown in below figure.



→ Let us consider individual voltage gains of HPF & LPF is A_{VF_1} & A_{VF_2}.

→ The overall voltage gain of the wide band pass filter is A_{VF}.

→ Then A_{VF} is the product of individual voltage gains.

i.e., $\boxed{A_{VF} = A_{VF_1} \times A_{VF_2}}$

→ The magnitude voltage gain of first order HPF is given by

$$\left|\frac{V_0}{V_i}\right| = \frac{A_{VF_1}}{\sqrt{1+(f_L/f)^2}}$$

→ The magnitude voltage gain of first order LPF is given by

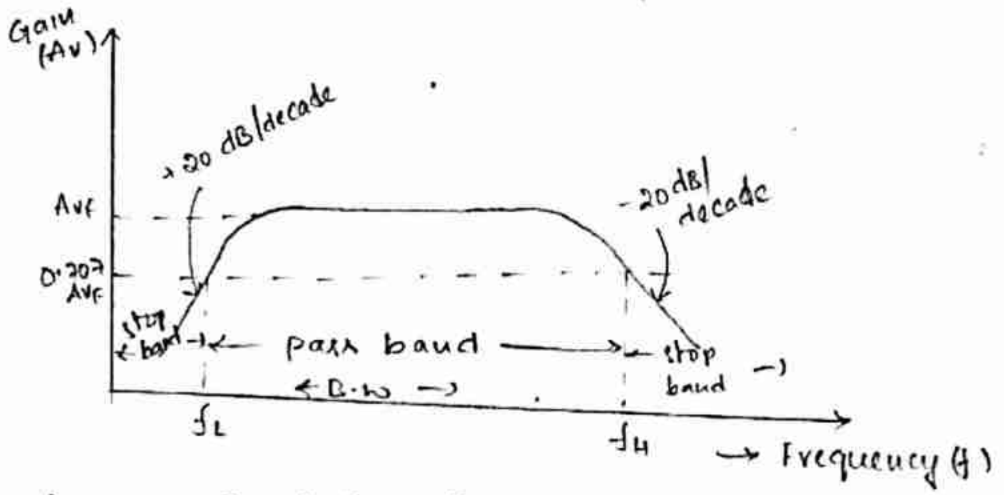
$$\left|\frac{V_0}{V_i}\right| = \frac{A_{VF_2}}{\sqrt{1+(f/f_H)^2}}$$

→ Now, the magnitude voltage gain of wide band pass filter is the product of first order HPF & LPF.

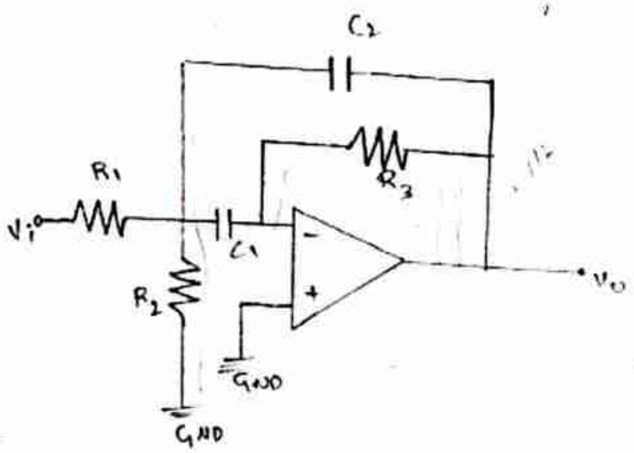
$$\left|\frac{V_0}{V_i}\right| = \frac{A_{VF}}{\left[\sqrt{1+(f_L/f)^2}\right]\left[\sqrt{1+(f/f_H)^2}\right]}$$

where, $\boxed{A_{VF} = A_{VF_1} \times A_{VF_2}}$

→ The frequency response of wide band pass filter is shown in below fig.

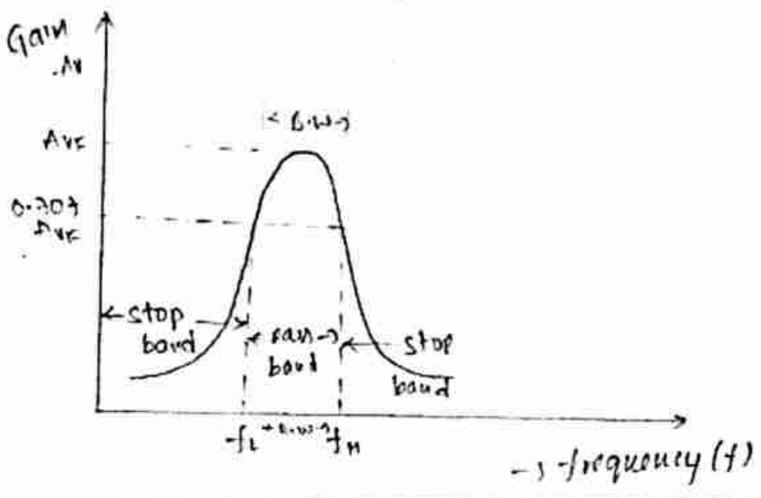


(b) Narrow Band Pass Filter :



→ The narrow band pass filter shown in below fig.

→ The narrow band pass filter is a band pass filter with a small band width shown in below fig.



→ The frequency response of narrow band pass filter is sharper than that of a wide band pass filter.

→ The quality factor of this filter is high than that of wide band pass filter.

→ The main features of this filter is

(a) It has only one op-amp

(b) It has two f/b paths. Hence it is called as multipath f/b filter.

(c) Here the op-amp is inverting mode.

(d) Here the Band width is small compared to WBPF.

Band Reject Filter :

→ Band reject filter is a filter in which stop the frequencies in stop band & passes all the frequencies outside the stop band.

→ It is also called as Band stop filter (or) Band elimination filter.

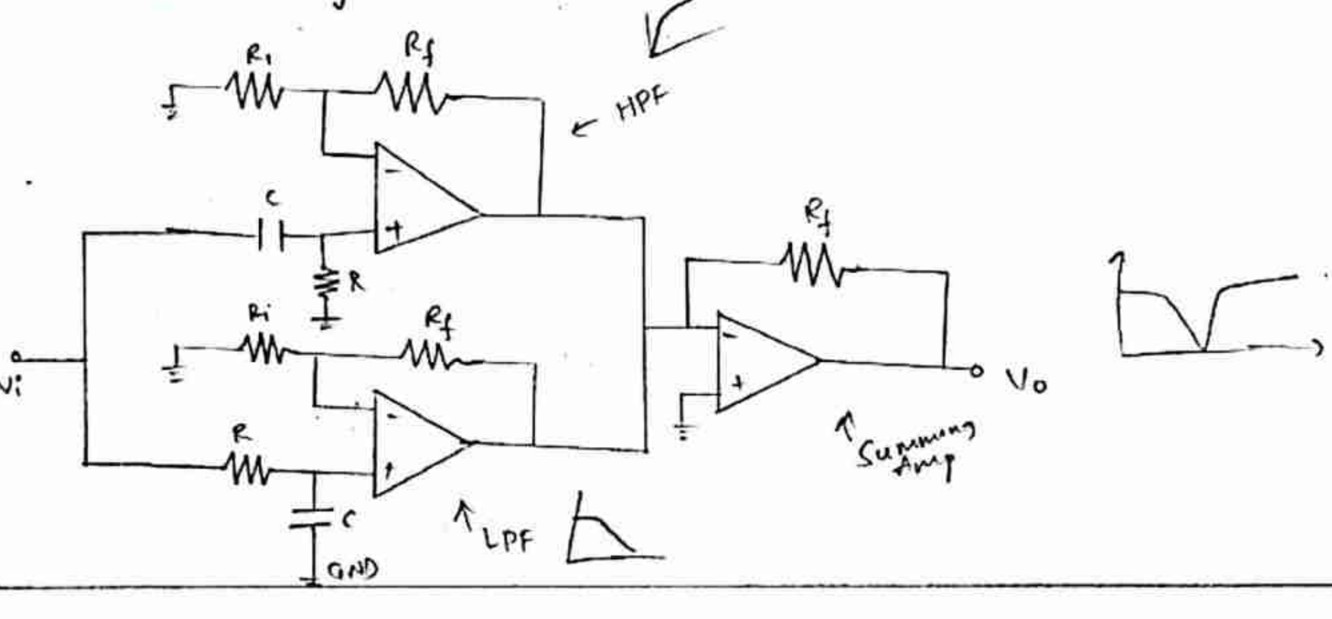
→ The band reject filter operation is exactly opposite to the band pass filter.

→ Band reject filter are classified into 2 types.

(a) Wide band reject filter

(b) Narrow band reject filter

Wide Band Reject Filter :



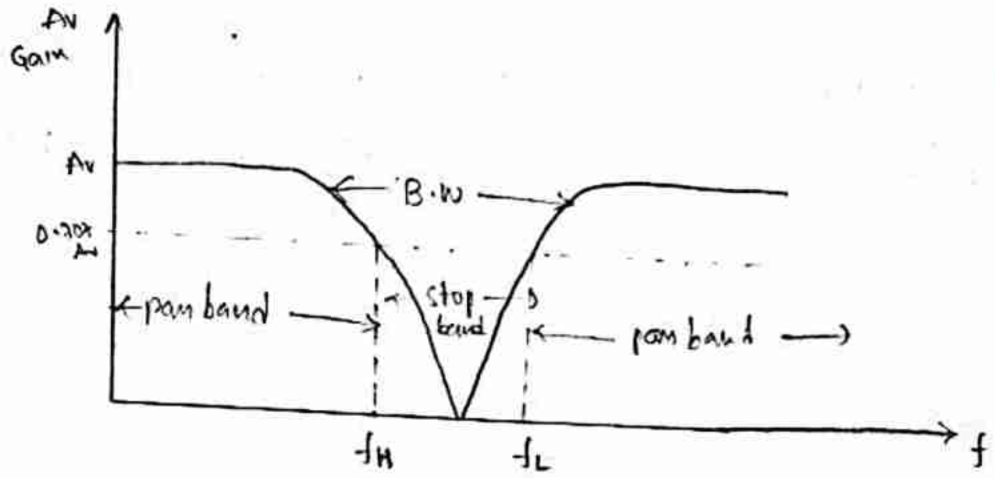
→ Like WBPF, this filter also consists of a first order HPF & LPF sections. Additionally it consists of a summing amplifier.

→ Here stops the all frequencies b/w f_H & f_L.

→ The lower cut-off frequency f_L must be greater than the higher cut-off frequency f_H. It is shown in frequency response of the filter. shown in below fig.

→ The pass band gain of both high pass & low pass sections must be equal.

→ Hence the frequency response of the filter is shown in below fig.



Narrow Band Reject Filter :

→ Narrow band reject filter is also called as the notch filter. The quality factor Q of such filters is higher than that of the WBRF.

→ Narrow band reject filter have a ~~fre~~ very sharp frequency response characteristics.

→ These are used for rejecting a single frequency such as 50 Hz power line frequency hum.

→ Notch filter is the Twin-T n/w shown in below fig.

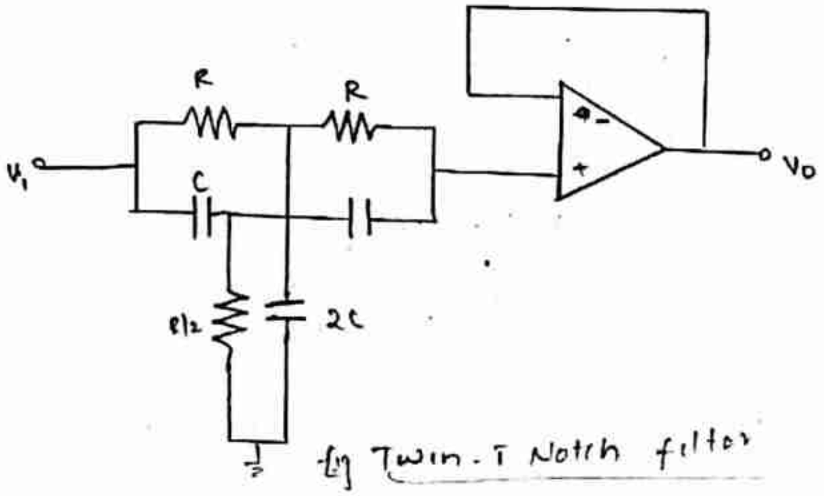
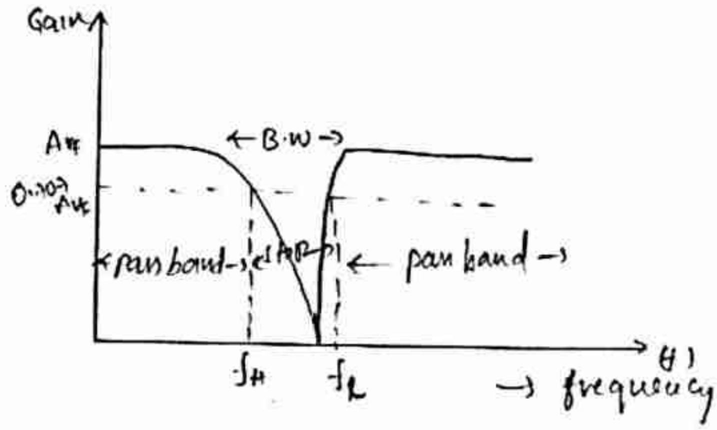


fig Twin - T Notch filter

→ The ckt consists of two T - networks. One consist of 2 resistors & a capacitor while other consist of 2 capacitor & a resistor.

→ To design a Notch filter to reject the particular frequency.

→ The frequency responce of the Notch filter shown in below fig.



Applications :-

1. Communication circuits
2. Biomedical instruments in order to eliminate the particular frequency.

Bark Hausen Criterion :

It states that

1. The total phase shift around a loop should be 0° or 360°.

2. The magnitude of the product of open loop gain of the op-amp and feedback factor(β) is unity.

i.e., $|A\beta| = 1$

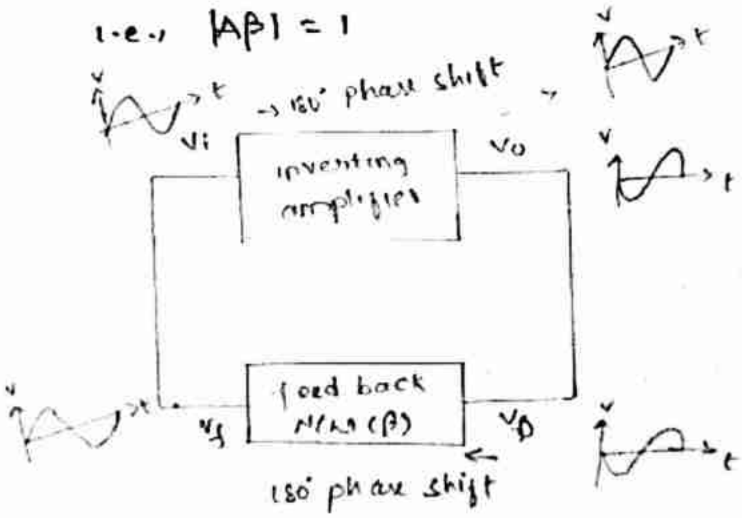


fig: Block Diagram of oscillator circuit

→ The f/b n/w i/p is Vo, then the feedback n/w produces 180° phase shift.

→ This feedback signal is given to the i/p of the inverting amplifier then again 180° phase shift is provided by the inverting amplifier. so total phase shift around a loop is 0° (or) 360°.

→ Let input voltage of the feedback n/w is Vo i.e o/p voltage of the inverting amplifier. It is given by

$$V_o = A \cdot V_i \qquad \left[\because A = \frac{V_o}{V_i}\right]$$

→ The feedback n/w β provides 180° phase shift i.e., given by

$$V_f = -\beta V_o \qquad \beta = V_f / V_o$$

$$V_f = \beta V_o$$

where, -ve sign indicates that 180° phase shift provided by the f/b network.

→ For the oscillator, V_f must acts as an i/p voltage V_i. So

$$V_i = -\beta V_0$$

we know that, $V_0 = AV_i$

$$\cancel{V_i} = -\beta A \cancel{V_i}$$

$$-\beta A = 1$$

let us take magnitude on b.s

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

→ The above condition is called as Bark Hausen criterion.

→ The phase of V_f must be as i/p voltage V_i i.e., feedback n/w introduces 180° phase shift. In addition to 180° phase shift introduced by the amplifier. so total phase shift around a loop is 360°. In this condition feed back voltage V_f drives the circuit without external i/p. so the circuit acts as an oscillator.

→ Similarly the magnitude of product of open loop gain & feedback factor is unity. It is also called as Bark Hausen Criterion.

→ The above 2 conditions are required to satisfy the circuit works as an oscillator producing sustained oscillations of constant frequency & amplitude.

→ Let us see the effect of magnitude of product of gain & f/b factor [$|A\beta|$] on the nature of the oscillations.

(1) $|A\beta| > 1$:

when the total phase shift around a loop is 0° or 360° and $|A\beta| > 1$ then the oscillations are growing type i.e., the amplitude of the oscillations goes on increasing. It is shown in fig.

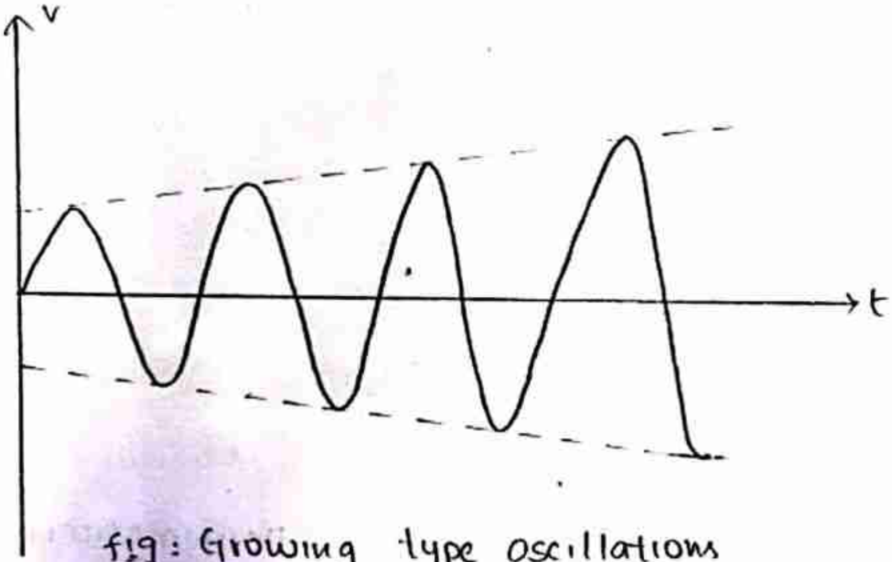


fig: Growing type oscillations

(ii) $|A\beta| = 1$:

When the total phase shift around a loop is $0°$ or $360°$ & $|A\beta| = 1$, then the oscillations are with constant frequency & amplitude, it is called as sustained oscillations. It is shown in below fig.

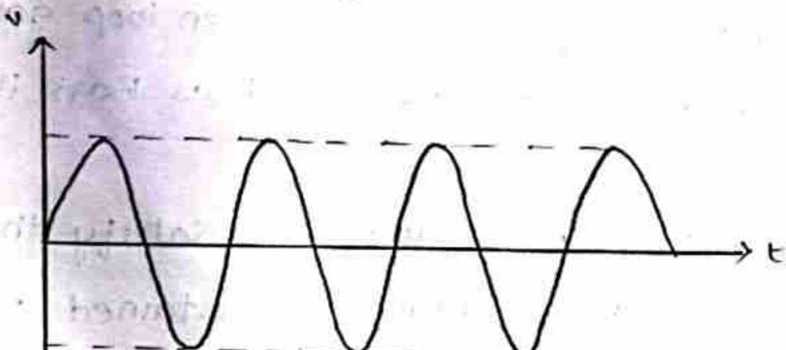


fig: sustained oscillations

(iii) $|A\beta| < 1$:

When the total phase shift around a loop is $0°$ (or) $360°$ & $|A\beta| < 1$ then the oscillations are decaying type i.e., the amplitude of the oscillations decreases exponentially. It is shown in below fig.

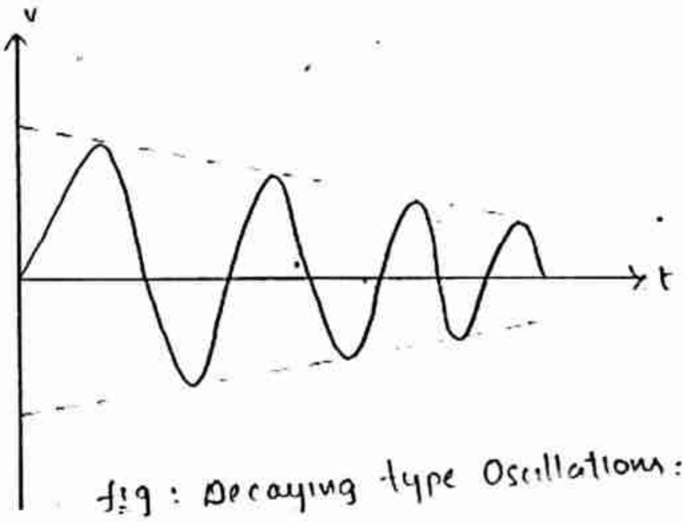


fig : Decaying type Oscillations:

Classification of Oscillations :

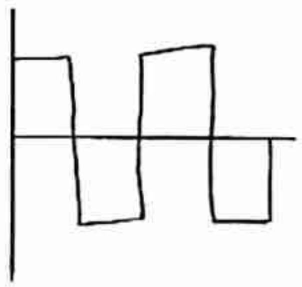
Oscillators are classified into different ways

(1) According to waveform
(2) According to frequency range
(3) According to RLC components.

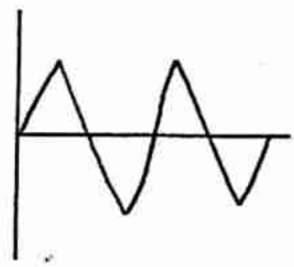
(1) According to waveform : According to waveform the oscillator can be classified into 2 types.

(a) Sinusoidal oscillator : A sinusoidal oscillator generates the sinusoidal signals only.

(b) Non-sinusoidal oscillator : It generates the non-sinusoidal signals like square, triangular & sawtooth.



Square waveform



Triangular waveform

Sawtooth waveform

(2) According to frequency range : According to frequency range the oscillator can also be classified into different types.

(a) Audio frequency oscillator :- 20 HZ - 20 KHZ

(b) Radio frequency oscillator :- > 20 KHZ

(c) Very high frequency oscillator :- 30 MHZ - 300 MHZ

(d) Micro wave frequency oscillator :- > 300 MHZ

(3) According to RLC components : According to RLC components the oscillator can be classified into different ways.

(a) RC oscillators: The oscillator using the components R & C are called as RC oscillators. It can be used to generate the low frequency signals in audio range.

(b) LC oscillators : The oscillator using the components L & C are called as LC oscillators. It can be used to generate the high frequency signals.

(c) Crystal Oscillators : The oscillator using the crystal is called as crystal oscillator. It can be used to generate the very high frequency signals.

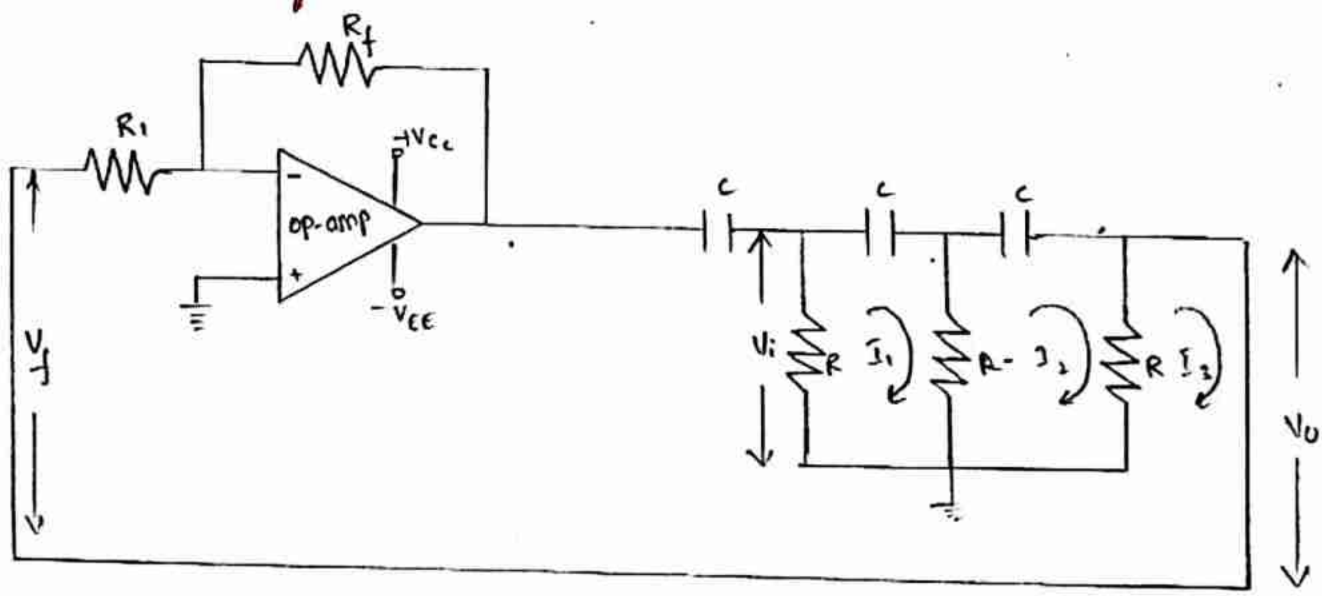
RC oscillator :

RC oscillator is a one type of oscillator which generates oscillations in the low frequency range (audio frequency range).

→ RC oscillators can be classified into 2 types.

1. RC phase shift oscillator
2. Wein bridge oscillator

RC Phase Shift Oscillator :



→ It consists of CE amplifier followed by a 3 sections of RC phase shift network. In the RC phase shift n/w RC oscillator can be used as a feedback path.

→ In oscillator, amplifier produces 180° phase shift & feedback must introduced 180° phase shift to obtain a total phase shift around a loop is 360°.

→ One RC network produces phase shift of $\phi = 60°$.

→ Here 3 RC networks are available to produce phase shift is 180° (60°+60°+60°). The feedback network is also called as ladder network.

→ In this network all the resistances & capacitances values are same. so that for a particular frequency each section of RC produces a phase shift is 60°. The o/p of RC phase shift n/w is connected to the input of CE amplifier through RC feedback network.

→ To make 3 RC sections are identical (similar), R_3 should be choosen as

$$R_i' = R_i + R_3$$

$$R_i = R_i' - R_3$$

$$R_3 = R_i' - R_i$$

→ The phase shift ϕ produced by the RC section is

$$\phi = \tan^{-1}\left[\frac{1}{\omega RC}\right]$$

$$= \tan^{-1}\left[\frac{1}{2\pi f RC}\right]$$

Let us assume $R = 1K\Omega$, $C = 0.1\mu F$, $F = 1KHz$

$$\phi = \tan^{-1}\left[\frac{1}{2\times\pi\times 1\times 10^3\times 1\times 10^3\times 0.1\times 10^{-6}}\right]$$

$$\phi = 57.85 \simeq 60^\circ$$

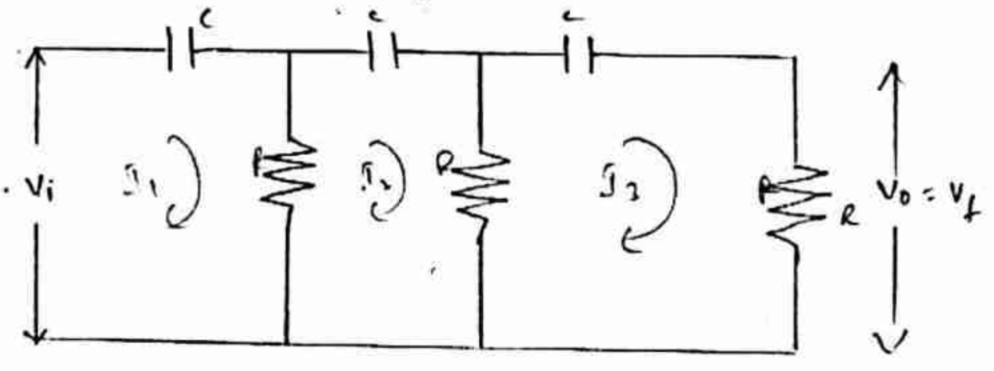
→ If all the resistors & Capacitors are same in 3 sections then each section can produce a phase shift of 60°. So, the ladder network produce 180° phase shift in between o/p & i/p voltages.

→ The total phase shift from the base of the op-amp around the circuit will be exactly 360°. so there by satisfying Bark-Hausen Criterion for Oscillations.

→ The frequency generated by the RC phase shift oscillator is

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

Derivation for frequency of Oscillations :



Apply KVL for 1st, 2nd and 3rd loop

loop (1) :- $V_i = I_1\left(\frac{1}{j\omega C}\right) + R(I_1 - I_2)$

$$= I_1\left[\frac{1}{j\omega C} + R\right] - R I_2 \rightarrow (1)$$

loop(2) : $0 = I_2\left(\frac{1}{j\omega C}\right) + R\,(I_2 - I_1) + R\,(I_2 - I_3)$

$$= I_2\left(\frac{1}{j\omega C} + 2R\right) - RI_1 - RI_3$$

$$0 = -RI_1 + I_2\left(\frac{1}{j\omega C} + 2R\right) - RI_3 \rightarrow (2)$$

loop (3) : $V_o = I_3\left(\frac{1}{j\omega C}\right) + R\,(I_3 - I_2) + RI_3$

$$= I_3\left(\frac{1}{j\omega C} + 2R\right) - RI_2$$

$$V_o = -RI_2 + I_3\left(\frac{1}{j\omega C} + 2R\right) \rightarrow (3)$$

By solving the 3 eqns, we get

$$I_3 = \frac{V_i}{R}\left[\frac{1}{(1-5\alpha^2) + j\alpha(\alpha^2-6)}\right]$$

$$\alpha = \frac{1}{\omega RC} \quad \text{(or)} \quad \alpha = \frac{1}{2\pi f RC}$$

W.K.T ; $V_o = I_3 R$

$$V_o = V_i\left[\frac{1}{(1-5\alpha^2) + j\alpha(\alpha^2-6)}\right]$$

for determining the frequency of an oscillator the imaginary part must be equal to zero

i.e., $\alpha(\alpha^2-6) = 0$

$$\alpha^2 - 6 = 0$$

$$\alpha^2 = 6$$

$$\alpha = \pm\sqrt{6}$$

W.K.T, $\alpha = \frac{1}{\omega RC}$

$$\frac{1}{\omega RC} = \sqrt{6}$$

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

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

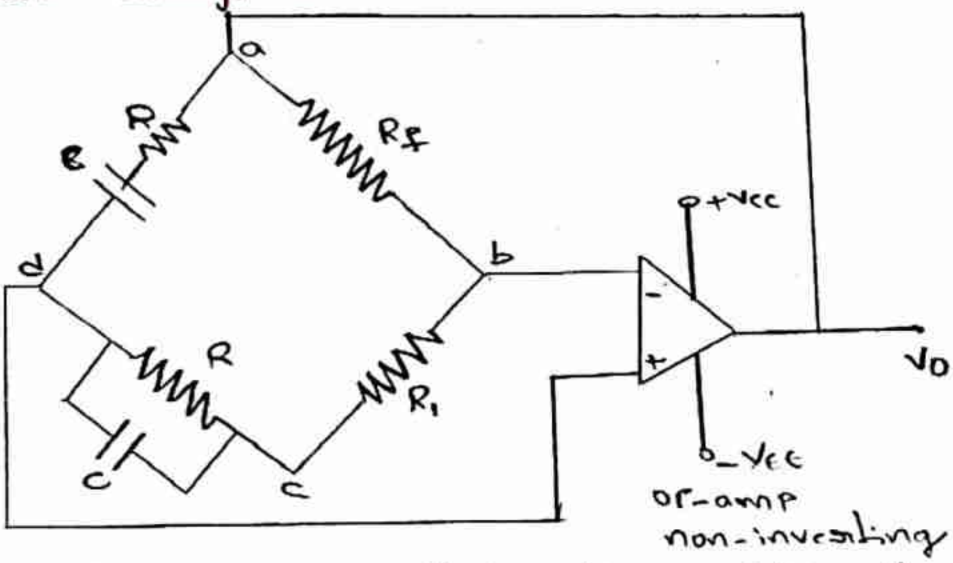
Advantages :

1. The circuit is simple to design.
2. It is suitable to produce o/p waveform for audio frequencies only.
3. It produces sinusoidal o/p voltages.
4. It is able to generate the low frequency signals.

Disadvantages :

1. By changing the values of R & C, the frequency of oscillator can be changed.
2. It is unable to generate the high frequency signals.

(2) Wein Bridge Oscillator :



→ Generally in an oscillator the amplifier stages introduces 180° phase shift and feed back network introduces another 180° phase shift. To obtain a phase shift of 360° around a loop.

→ But wein-bridge oscillator consist of non-inverting amplifier & hence does not provide any phase shift during amplifier stage.

→ As the total phase shift required is 360° in wein bridge, because no phase shift is necessary.

→ The o/p of amplifier is connected b/w terminals a & c which is i/p.

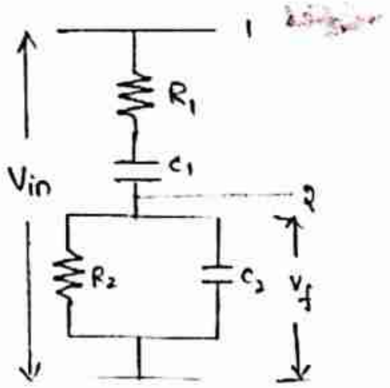
→ While the amplifier i/p is connected b/w terminals b & d which is o/p.

→ The bridge n/w consists of 2 arms namely R_1C_1 in series & R_2C_2 in parallel. These arms are called frequency sensitive arms which decides the frequency.

→ The frequency of wein bridge oscillator

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

→ This is also called as lead lag n/w because at low frequency signals the voltage leads current.



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

$$= \frac{j\omega R_1C_1 + 1}{j\omega C_1}$$

$$Z_2 = \frac{R_2 \times {}^1/_{j\omega C_2}}{R_2 + \frac{1}{j\omega C_2}}$$

$$= \frac{R_2/j\omega C_2}{\frac{j\omega C_2R_2+1}{j\omega C_2}}$$

$$= \frac{R_2}{1+j\omega C_2R_2}$$

$$Z_1 = \frac{1+SR_1C_1}{SC_1}\ ;\ Z_2 = \frac{R_2}{1+SC_2R_2}$$

From fig. $I = \frac{V_{in}}{Z_1+Z_2}$ i.e., $V_f = I \times Z_2$

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

We know that, $\beta = \frac{V_f}{V_{in}}$

$$= \frac{\dfrac{V_{in} \times Z_2}{Z_1 + Z_2}}{V_{in}}$$

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

$$\beta = \frac{SC_1R_2}{1 + SC_1R_1(1 + SC_2R_2) + SC_1R_2}$$

$$= \frac{SC_1R_2}{1 + SC_2R_2 + SC_1R_1 + S^2C_1R_1C_2R_2 + SC_1R_2}$$

$$= \frac{SC_1R_2}{1 + S(C_2R_2 + C_1R_1 + C_1R_2) + S^2C_1C_2R_1R_2}$$

$$= \frac{j\omega C_1R_2}{1 + j\omega(C_2R_2 + C_1R_1 + C_1R_2) - \omega^2C_1C_2R_1R_2}$$

$$= \frac{R_2 / \cancel{SC_2R_2} + 1}{\dfrac{(1 + SC_1R_1)(1 + SR_2C_2) + R_2SC_1}{SC_1(1 + \cancel{SC_2R_2})}}$$

$$= \frac{R_2SC_1}{(1 + SC_1R_1)(1 + SR_2C_2) + R_2SC_1}$$

$$= \frac{SR_2C_1}{1 + S(R_1C_1 + R_2C_2) + S^2R_1R_2C_1C_2 + SC_1R_2}$$

$$\beta = \frac{j\omega C_1R_2}{1 + j\omega(R_1C_1 + R_2C_2) - \omega^2R_1R_2C_1C_2 + j\omega C_1R_2}$$

$$= \frac{j\omega C_1R_2}{j\omega(R_1C_1 + R_2C_2 + C_1R_2) - (\omega^2R_1R_2C_1C_2 - 1)}$$

Rationalising with expression

Then

$$\beta = \frac{\omega^2 C_1 R_2 \left(R_1C_1 + R_2C_2 + C_1R_2\right) + j\omega C_1 R_2 \left(1-\omega^2 R_1 R_2 C_1 C_2\right)}{(1-\omega^2 R_1 R_2 C_1 C_2) + \omega^2 (R_1C_1 + R_2C_2 + R_2C_1)}$$

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

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

let $R_1 = R_2 = R$

$C_1 = C_2 = C$

$$\omega^2 = \frac{1}{RC}$$

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

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

Here $\beta = 1/3$

$|A| \times 1/3 \geq 1$

$|A| \geq 3$

Without any phase shift, gain of amplifier

Advantages :

1. Different frequency ranges can be obtained by varying the 2 capacitor values.
2. Perfect sine wave is possible.
3. It is useful for audio frequency range.

Disadvantages :

1. Poor frequency stability

* Square Wave Generator [Astable multivibrator]

The astable multivibrator is also called a free running oscillator,

The principle of generation of square wave o/p is to force an op-amp to operate in the saturation region. The simple square wave generator as shown in fig.

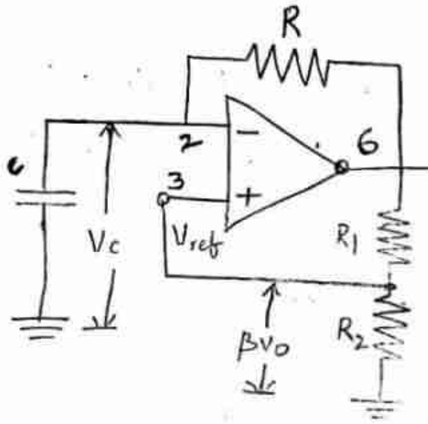


fig: Square wave generator
Astable multivibrator

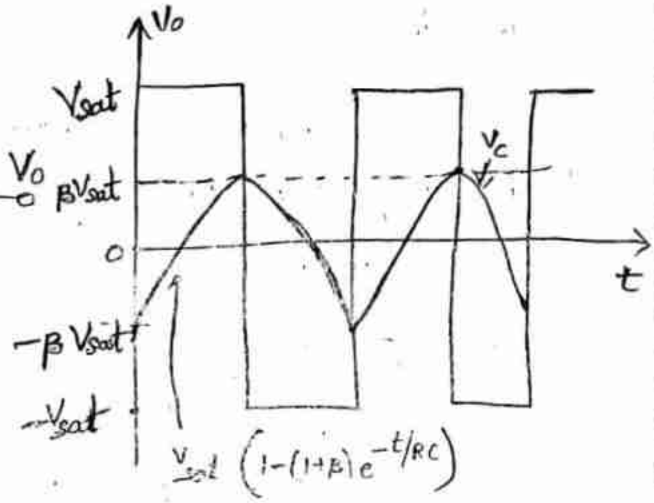


Fig: i/p - o/p waveforms

In fig. the reference voltage is obtained by using of divider at o/p and fedback to (+) i/p terminal (i.e).,

$$V_{ref} = \frac{R_2}{R_1+R_2} V_o \longrightarrow (1)$$

i.e $V_{ref} = \beta V_o$ —— (2) where, $\beta = \frac{R_2}{R_1+R_2}$

The o/p is also fedback to the (-) i/p terminal after integrating by means of a low-pass RC Combination. In astable multivibrator, both the states one quasistable states only. Whenever i/p at the (-) input terminal exceeds V_{ref}, switching takes place resulting in a square wave o/p.

Let us consider the o/p is at $+V_{sat}$, the capacitor states changing towards $+V_{sat}$ through resistor R. The voltage at (+) i/p terminal is held at $+\beta V_{sat}$.

The o/p is still $+V_{sat}$ untill the capacitor rises exceeds $+\beta V_{sat}$ (V_{ref}) if the voltage of (-) i/p terminal greater than V_{ref} then the o/p driven to $-V_{sat}$ and the capacitor this states discharges from $+\beta V_{sat}$ through resistor R towards $-V_{sat}$. The o/p is $-V_{sat}$ untill. whenever the capacitor exceeds $-\beta V_{sat}$ after that o/p switches back $+V_{sat}$. This cycle is repeats it self.

The frequency is determined by the time it takes the capacitor to change from $-\beta V_{sat}$ to $+\beta V_{sat}$ & vice versa.

→. The voltage across the capacitor as a function of time is given by

$$V_c(t) = V_f + (V_i - V_f)e^{-t/RC} \longrightarrow (3)$$

Where,

$$V_f = +V_{sat} \text{ (Final value)} \longrightarrow (4)$$

$$V_i = -\beta V_{sat} \text{ (Initial value)} \longrightarrow (5)$$

Sub (4) & (5) and (3)

$$\therefore V_c(t) = V_{sat} + (-\beta V_{sat} - V_{sat})e^{-t/RC}$$

$$V_o(t) = V_{sat} - V_{sat}(1+\beta)e^{-t/RC} \longrightarrow (6)$$

At $t = T_1$, Voltage across the capacitor is $+\beta V_{sat}$

$$\therefore V_c(T_1) = +\beta V_{sat}$$

$$= V_{sat} - V_{sat}(1+\beta)e^{-T_1/RC} \longrightarrow (7)$$

[∵ from Eq (6) by sub $t = T_1$]

$$\beta \cancel{V_{sat}} = \cancel{V_{sat}} \left[1 - (1+\beta) e^{-T_1/RC} \right]$$

$$\beta = 1 - (1+\beta) e^{-T_1/RC}$$

$$(1+\beta) e^{-T_1/RC} = 1-\beta$$

$$e^{-T_1/RC} = \frac{1-\beta}{1+\beta}$$

Apply logarithm on both sides then

$$\frac{-T_1}{RC} = \ln\left(\frac{1-\beta}{1+\beta}\right)$$

$$T_1 = -RC \ln\left(\frac{1-\beta}{1+\beta}\right)$$

$$= RC \ln\left(\frac{1-\beta}{1+\beta}\right)^{-1}$$

$$\therefore \boxed{T_1 = RC \ln\left(\frac{1+\beta}{1-\beta}\right)}$$

This is only one half of the period. The total time period is twice that of half period.

i.e $T = 2T_1$

$$= 2RC \ln\left(\frac{1+\beta}{1-\beta}\right)$$

The o/p waveforms are symmetrical if $R_1 = R_2$ then $\beta = 0.5$ by substituting

$$T = 2RC \ln\left(\frac{1+0.5}{1-0.5}\right) = 2RC \ln(3)$$

$$\boxed{T = 1.1\,RC}$$

frequency $f = 1/T$

$$\boxed{f = \frac{1}{1.1\,RC}}$$

Introduction :

555 Timer :

→ 555 timer is a timing circuit that can produce accurate & high stable time delays (or) oscillations.

→ 555 timer is available in 8 pin DIP & 14 pin DIP packages.

→ It can be used with supply voltages range in b/w +5v to +18v.

→ The below fig. shows the pin diagram of 8 pin DIP package.

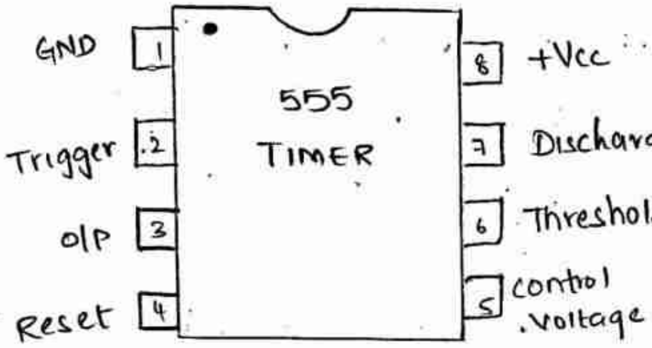


fig: 555 Timer

Features :

1. It can be used with supply voltages over a range in b/w +5V to +18V.
2. It is easy to use.
3. It can drive the load upto 200 mA.
4. It is compatable with TTL (Transistor transistor logic) & CMOS (complimentary metal oxide semiconductor).
5. It is used in various applications such as square wave generator, ramp & pulse wave generator, astable & monostable multivibrators.

Functional Diagram :

→ It consists of 2 comparators namely upper comparator & lower comparator that can drive set (S) & reset (R) terminals of a flip flop.

→ These flipflops can control the ON & OFF cycles of the discharge transistor Q1.

→ It has 3, 5KΩ resistors which acts as potential divider, providing biasing voltages of $2/3\ V_{cc}$ to the upper comparator & $1/3\ V_{cc}$ to the lower comparator where V_{cc} = supply voltage.

→ These voltages are called as reference voltages. These are required to control the timing.

→ The timing can be controlled by externally applying voltage to the control voltage terminal.

→ If no such control voltage is required then the control voltage terminal can be bypassed by a capacitor to ground.

→ Typically the capacitor value is choosen of about 0.1 μF.

Operation :

→ In the stand by state (stable state), the o/p $\bar{Q}$ of the control flipflop is high ($\bar{Q}=1$; $Q=0$). This makes o/p low because of power amplifier can be acts as a invertor.

→ A -ve triggering pulse passes through $\frac{V_{cc}}{3}$, the o/p of the lower comparator goes high & sets the flipflop ($Q=1$; $\bar{Q}=0$)

→ When the threshold voltage at pin 6 passes through $2/3\ V_{cc}$ the o/p of upper comparator goes high & resets the flipflop ($Q=0$; $\bar{Q}=1$)

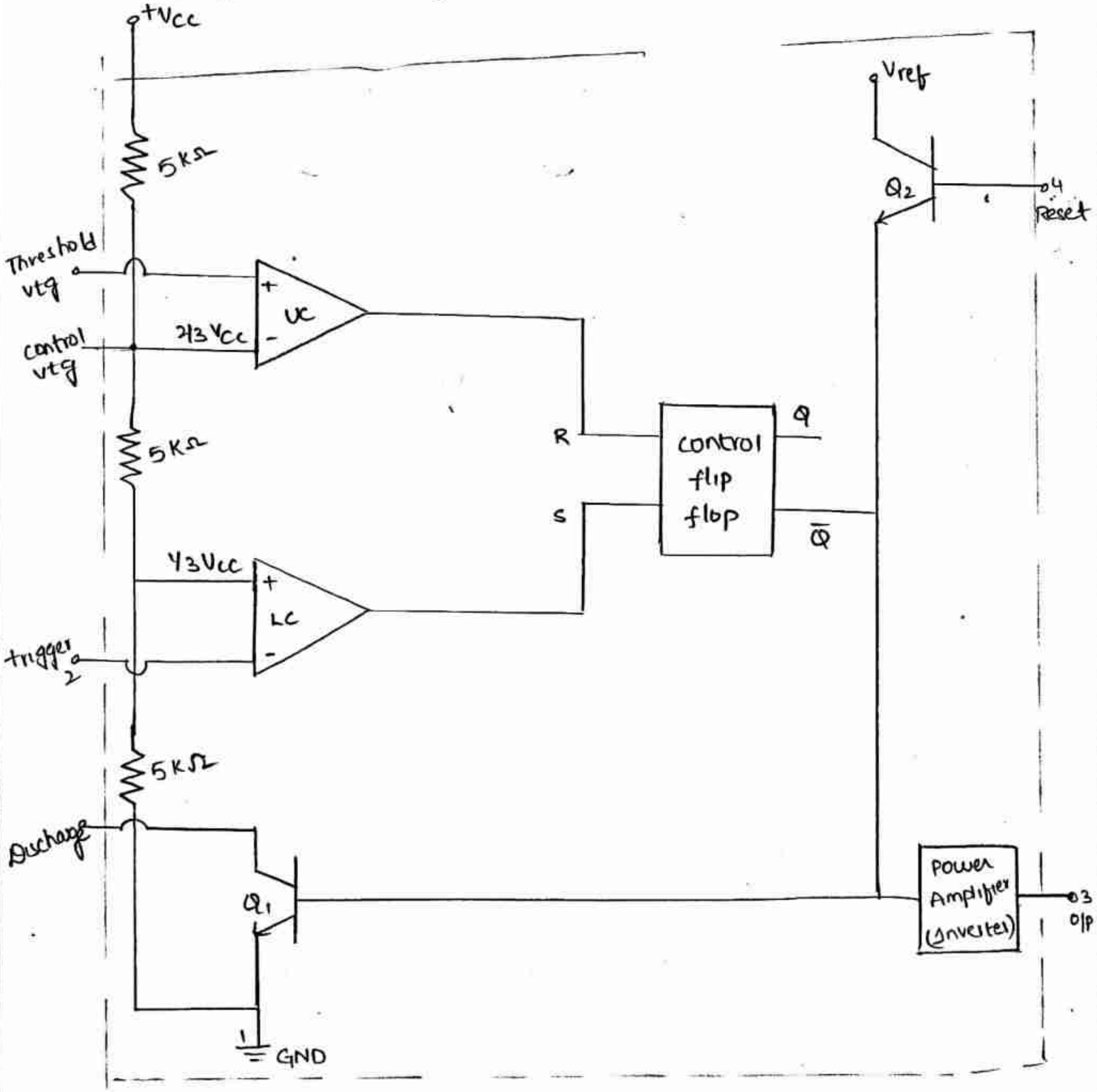
→ A separate reset terminal is produced to reset the flipflop externally.

→ Normally the reset terminal is not used, if we need it should be connected to +ve supply voltage Vcc.

→ The transistor Q_2 acts as buffer to isolate the reset i/p from the flipflop & the transistor Q1.

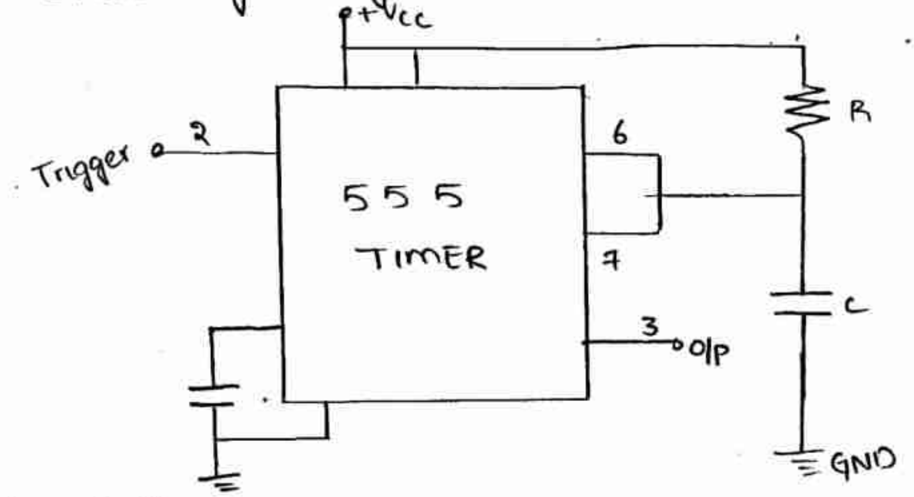
→ The transistor Q_2 is driven by an internal ~~resista~~ reference voltage V_{ref} obtained from supply voltage V_{cc}.

→ If $\bar{Q}$ is high, the transistor Q_1 is ON due to this it become s/c in b/w discharge pin to ground. Similarly $\bar{Q}$ is low, the transistor Q_1 is OFF & it becomes open circuit in b/w discharge pin to ground.

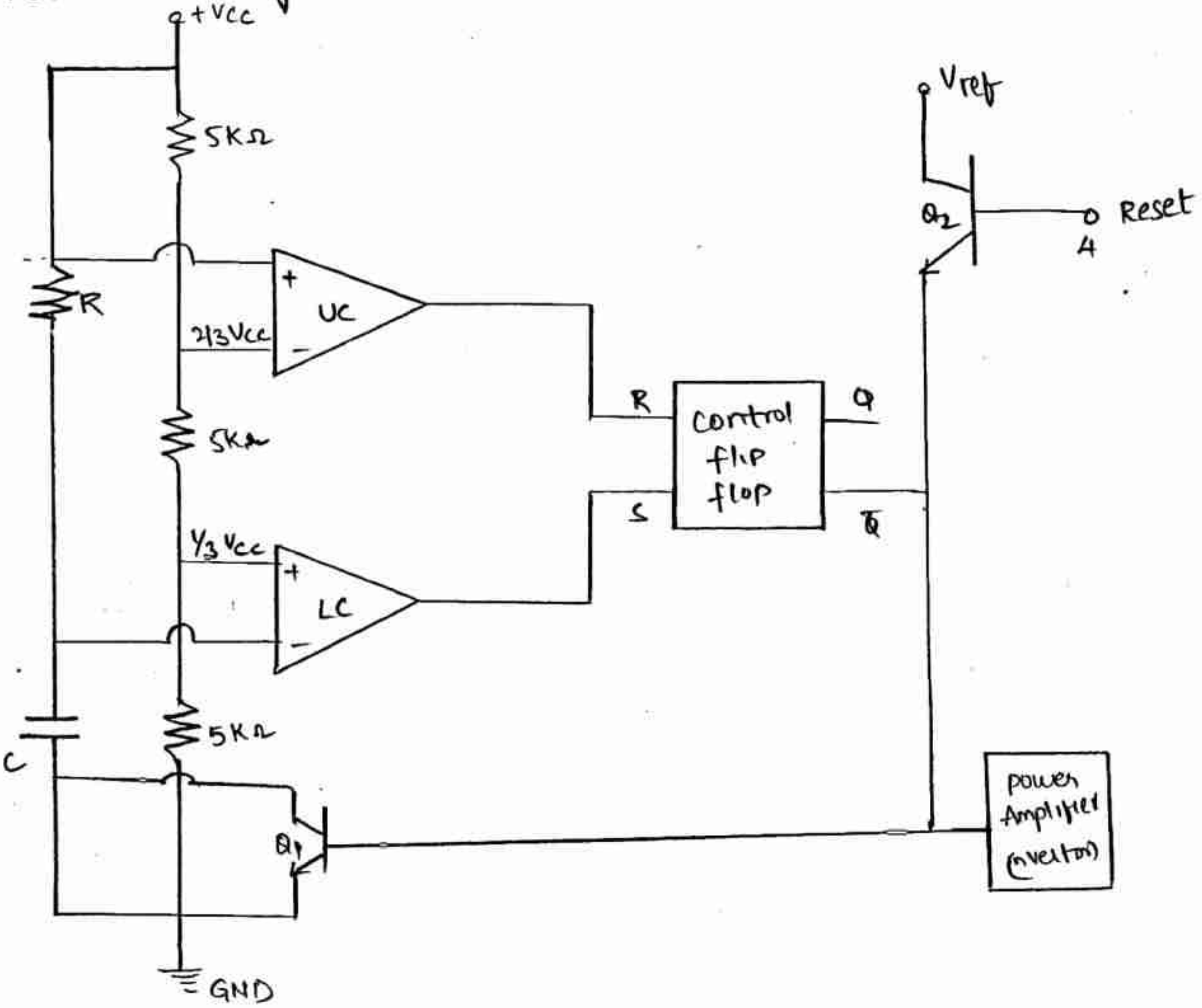


Monostable Multivibrator :-

Monostable multivibrator is a circuit which generates the non- sinusoidal signals. It has one stable state and one quasi stable state. The below fig. shows the monostable multivibrator by using 555 timer.



Functional Diagram :-



The above fig. shows the functional block diagram of monostable multivibrator.

1. In the stand by state [stable state] $Q = 0$; $\bar{Q} = 1$. So o/p is low. Under this condition transistor is ON i.e., it becomes short circuit through capacitor. 'C' to the ground.

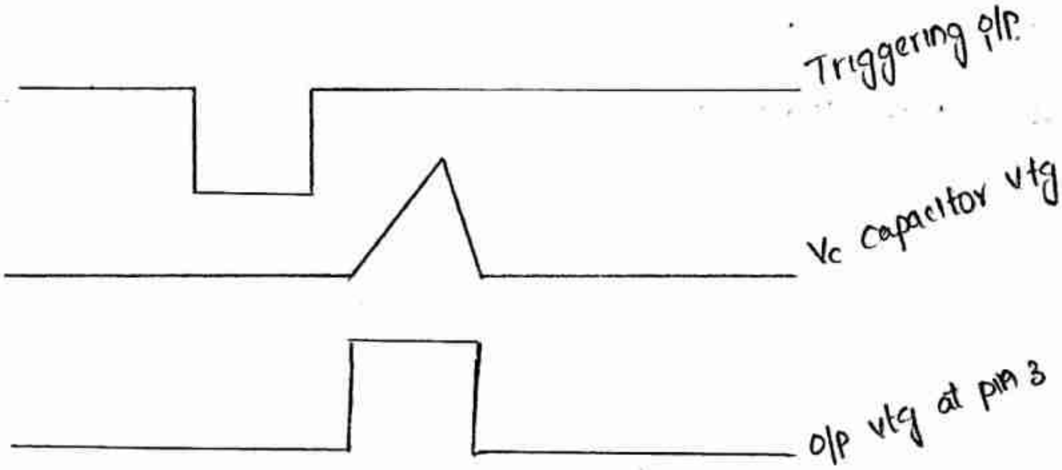
2. Now the triggering passes through $V_{cc}/3$ at 2^{nd} pin, due to this lower comparator o/p is high. So $Q = 1$, $\bar{Q} = 0$. This makes transistor Q_1 OFF & it becomes a open circuit across the capacitor. so o/p is high.

3. Now, the capacitor takes charging by V_{cc}.

4. After a time period T, the capacitor voltage is just greater than 2/3 Vcc and upper comparator o/p is high. so $Q = 0$; $\bar{Q} = 1$.

5. Under this condition, o/p is low & transistor Q_1 goes on there by discharging capacitor 'c' rapidly to ground.

6. The corresponding o/p waveforms of monostable multivibrator is shown in fig.



Analysis of Time Constant :

The capacitor voltage across the capacitor is given by

$$V_c = V_{cc}\left(1 - e^{-t/RC}\right) \rightarrow (1)$$

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At $t = T$, the capacitor charges by $V_c = 2/3\, V_{cc} \rightarrow (2)$

sub. eq(2) in eq(1)

$$2/3\, V_{cc} = V_{cc} - V_{cc}\, e^{-t/RC}$$

$$2/3\, V_{cc} + V_{cc}\, e^{-T/RC} = V_{cc}$$

$$e^{-T/RC} = \frac{V_{cc} - 2/3\, V_{cc}}{V_{cc}}$$

Apply log on b.s

$$\ln[a/b] = -\ln[b/a]$$

$$\ln\left[e^{-T/RC}\right] = \ln\left[\frac{V_{cc} - 2/3\, V_{cc}}{V_{cc}}\right]$$

$$\cancel{-}\frac{T}{RC} = \cancel{-}\ln\left[\frac{V_{cc}}{V_{cc} - 2/3\, V_{cc}}\right]$$

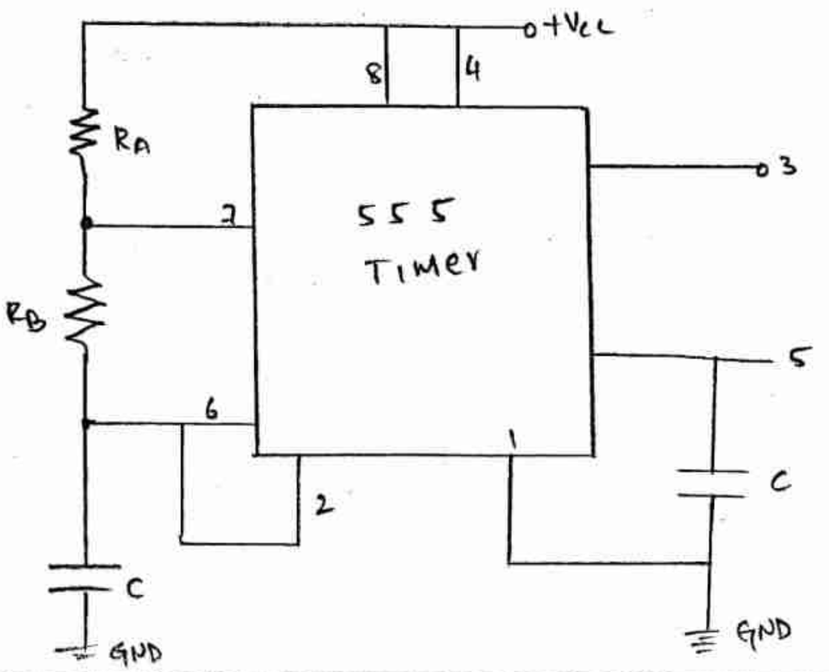
$$T = \ln RC(3)$$

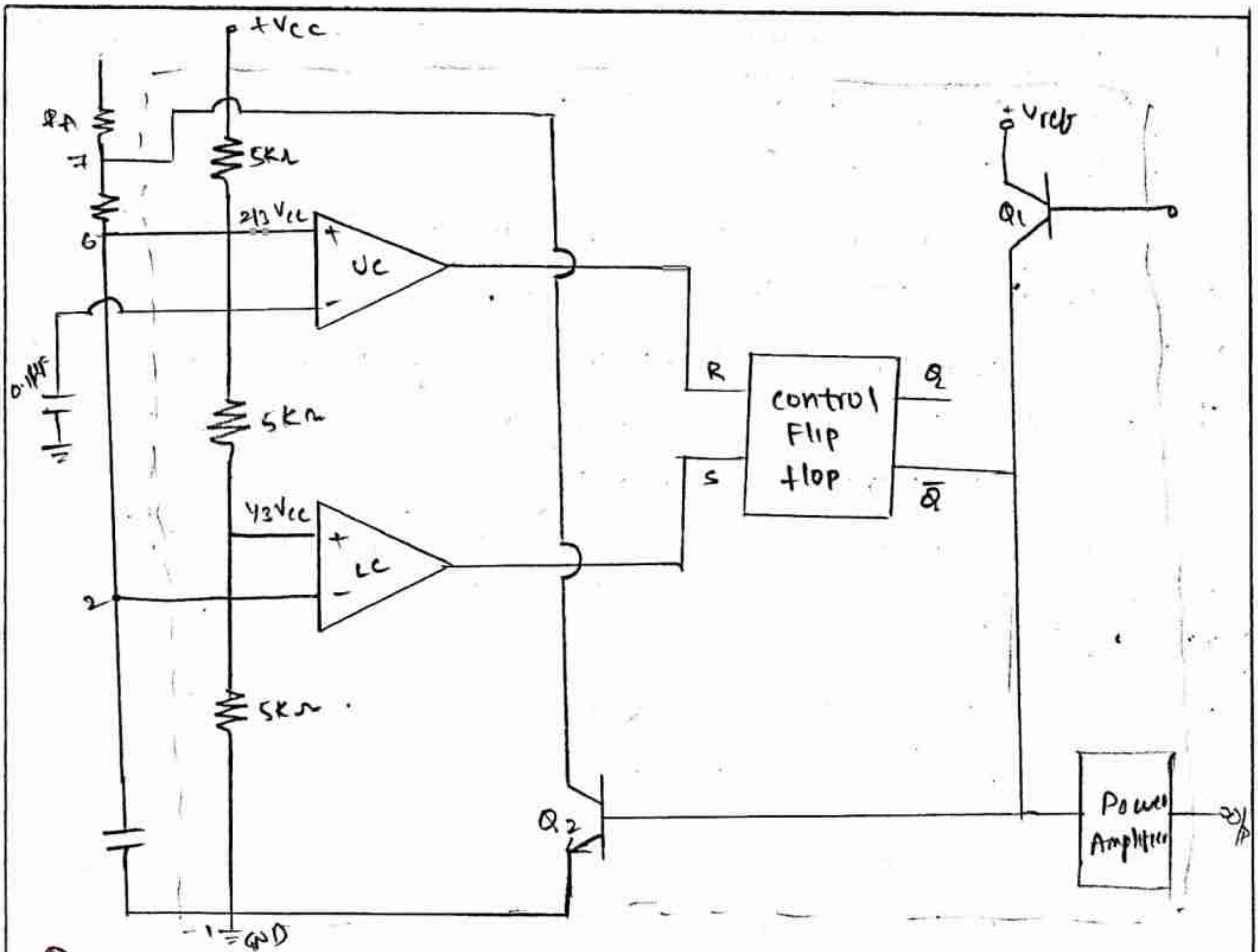
$$\boxed{\therefore T = 1.1\, RC}$$

Applications :

1. Pulse width generator
2. Water level control.

Asstable Multivibrator :





Operation :

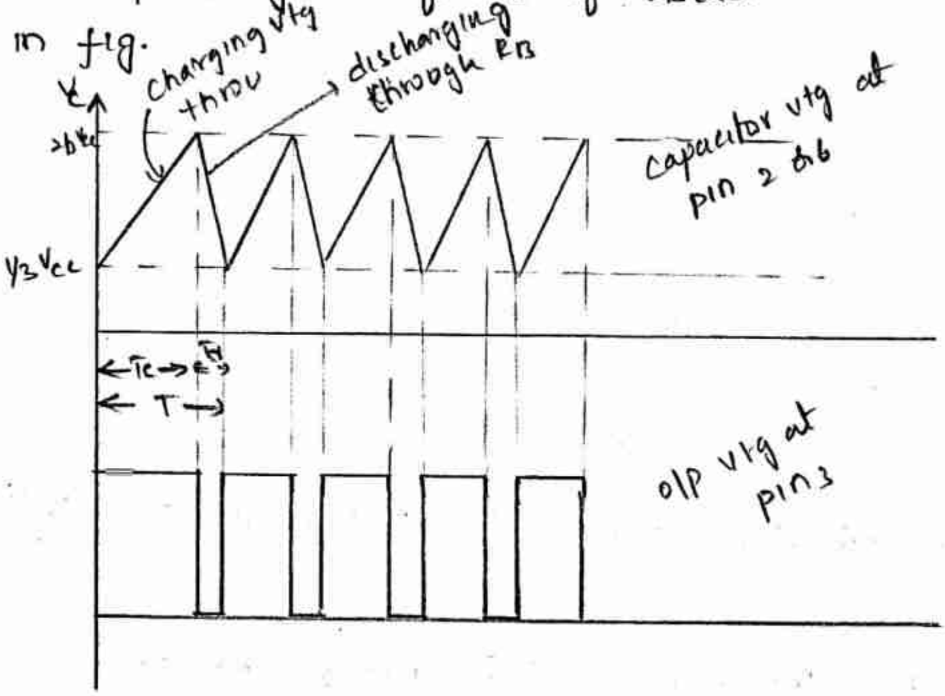
1. Asstable multivibrator has no stable states. It has 2 quasi stable states.
2. The astable multivibrator circuit by using 555 timer is shown in above fig.
3. Comparing with monostable multivibrator, the timing resistor is now split into 2 sections i.e., R_A & R_B.
4. The discharging transistor Q_1 is connected in b/w R_A & R_B.
5. When supply voltage is connected, the external capacitor gets charging through R_A & R_B resistors.
6. When the charging voltage reaches the 1/3 Vcc voltage then lower comparator goes high. Due to this $R=0$; $S=1$; $\bar{Q}=0$; $Q=1$ and therefore o/p is high.

7. Similarly when charging voltage reaches $2/3\ V_{cc}$ then upper comparator o/p goes high. Due to this $R=1$; $S=0$; $\bar{Q}=1$; $Q=0$ and the o/p becomes low.

8. When $\bar{Q}=1$, the discharging transistor Q_2 is ON & it makes short circuited across the capacitor.

9. So the capacitor gets discharging through R_B resistor towards the ground. The capacitor discharging voltage reaches $1/3\ V_{cc}$ & again lower comparator o/p goes high.

10. The corresponding waveforms of Astable multivibrator is shown in fig.



Analysis of time constant :-

$$V_c = V_{cc}(1-e^{-t/RC}) \rightarrow (1)$$

at $t=t_1$, $V_c = 1/3\ V_{cc}$

$$1/3\ V_{cc} = V_{cc} - V_{cc}\, e^{-t_1/RC}$$

$$V_{cc}\, e^{-t_1/RC} = V_{cc} - 1/3\ V_{cc}$$

$$e^{-t_1/RC} = \frac{V_{cc} - 1/3\ V_{cc}}{V_{cc}}$$

Taking log on b/s

$$-\frac{t_1}{RC} = \ln\left[\frac{V_{CC} - 1/3 V_{CC}}{V_{CC}}\right]$$

$$-\frac{t_1}{RC} = -\ln\left[\frac{V_{CC}}{V_{CC} - 1/3 V_{CC}}\right]$$

$$t_1 = RC \ln\left[\frac{1}{1-1/3}\right]$$

$$t_1 = RC \ln(1.5)$$

$$\boxed{\therefore t_1 = 0.405\, RC}$$

→ When the capacitor charges from $1/3\, V_{CC}$ to $2/3 V_{CC}$.

at $t = t_2$; $V_{CO} = 2/3 V_{CC}$

$$2/3\, V_{CC} = V_{CC} - V_{CC}\, e^{-t_2/RC}$$

$$V_{CC}\, e^{-t_2/RC} = V_{CC} - 2/3 V_{CC}$$

$$e^{-t_2/RC} = \frac{V_{CC} - 2/3 V_{CC}}{V_{CC}}$$

Taking log on b/s

$$-t_2/RC = \ln\left[\frac{V_{CC} - 2/3\, V_{CC}}{V_{CC}}\right]$$

$$t_2 = \ln RC\left[\frac{V_{CC}}{V_{CC} - 2/3 V_{CC}}\right]$$

$$t_2 = RC \ln(3)$$

$$\boxed{\therefore t_2 = 1.1\, RC}$$

$$T_C = t_2 - t_1$$

$$= 1.1 - 0.405$$

$$= 0.695\, RC$$

$$\boxed{\therefore T_C = 0.695\,(R_A + R_B)\, C}$$

→ The capacitor takes discharging from 2/3 Vcc to 1/3 Vcc

$$\frac{1}{3} V_{cc} = \frac{2}{3} V_{cc}\, e^{-t/RC}$$

$$e^{-t/RC} = \frac{\frac{1}{\cancel{3}} V_{cc}}{\frac{2}{\cancel{3}} V_{cc}}$$

$$e^{-t/RC} = \frac{1}{2}$$

$$-t/RC = \ln(1/2)$$

$$t/RC = \ln(2)$$

$$t = RC\ln(2)$$

$$\boxed{\therefore T_d = 0.69 R_B C}$$

→ Total time constant $T = T_C + T_D$

$$= 0.69(R_A + R_B)C + 0.69 R_B C$$

$$= 0.69 R_A C + 0.69 R_B C + 0.69 R_B C$$

$$\boxed{\therefore T = 0.69\,(R_A + 2R_B)\,C}$$

$$f = 1/T$$

$$= \frac{1}{0.69(R_A + 2R_B)C}$$

$$\boxed{\therefore f = \frac{1.449}{(R_A + 2R_B)C}}$$

Applications :-

1. Frequency Shift Key (FSK)
2. Pulse position modulator

Voltage Controlled oscillator (VCO) :-

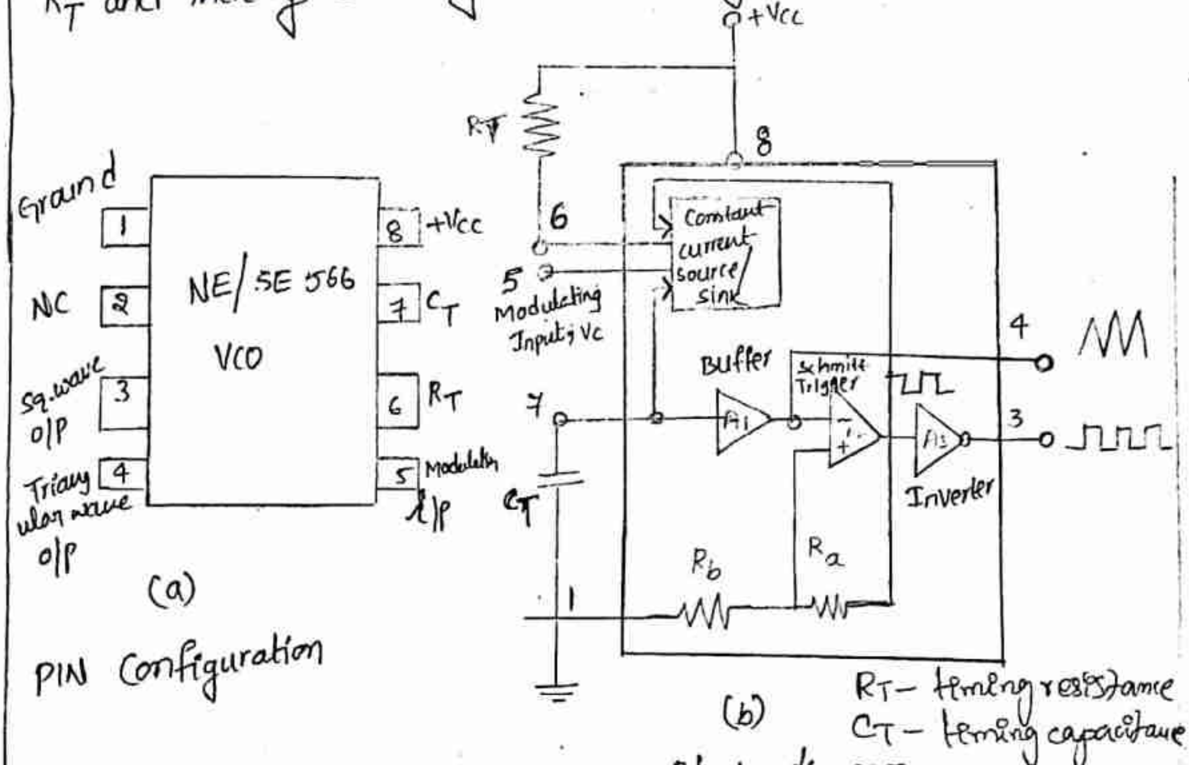
A common type of VCO available in IC form is Signetics NE/SE566. The pin configuration and basic block diagram of 566 VCO are shown in fig. (a).

Referring to fig (b) a timing capacitor C_T is linearly charged (or) discharged by a constant current source / sink.

The amount of current can be controlled by changing the voltage V_C applied at the modulating input (pin 5) or by changing the timing resistor R_T external to IC chip.

The voltage at pin 6 is held at the same voltage as pin 5.

Thus, if the modulating voltage at pin 5 is increased, the voltage at pin 6 also increases, resulting in less voltage across R_T and there by decreasing the charging current.



(a)

PIN Configuration

(b)

Block diagram

R_T – timing resistance

C_T – timing capacitance

→ A small capacitor of 0.01 μF should be connected b/w pin 5 and 6 to eliminate possible oscillations.

→ A VCO is commonly used for low frequency signals such as EEGs, EKG into an audio frequency range.

→ These audio signals can be transmitted over telephone lines or a two way radio communication system for diagnostic purposes (or) can be recorded on a magnetic tape for further reference.

→ The voltage across the capacitor C_T is applied to the inverting input terminal of schmitt trigger A_2 via buffer amplifier A_1.

→ The output voltage swing of the schmitt trigger is designed to V_{cc} and $0.5V_{cc}$. If $R_a = R_b$ in the +ve feedback loop, the voltage at the non-inverting input terminal of A_2 swings from $0.5V_{cc}$ to $0.25\ V_{cc}$. fig(b).

→ When the voltage on the capacitor C_T Exceeds $0.5\ V_{cc}$ during capacitor charging, the output of the schmitt Trigger goes low ($0.5\ V_{cc}$).

→ The capacitor now discharges and when it is at $0.25\ V_{cc}$, the o/p of the schmitt trigger goes HIGH (V_{cc}).

→ since the source and sink currents are Equal, capacitor charges and discharges for the same amount of time.

→ This gives a triangular voltage waveform across C_T which is also available at pin 4.

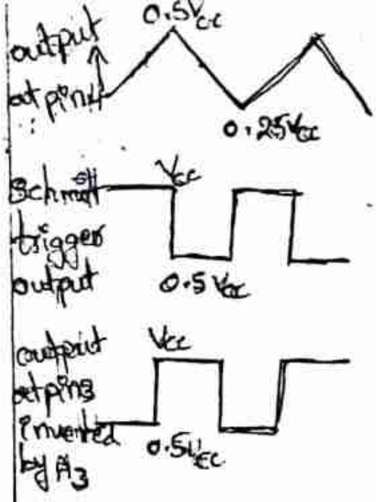
→ The square wave o/p of the schmitt trigger is inverted by inverter A_3 and is available at pin 3. The inverter A_3 is basically a current amplifier used to drive the load.

→ The o/p waveforms are fig(c). The output frequency of the VCO can be calculated as follows:

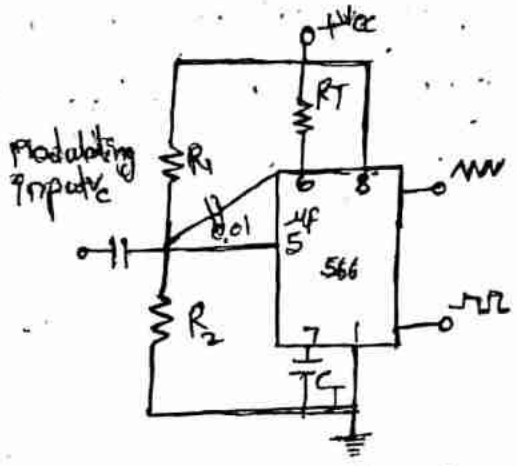
→ VCO is commonly used in converting low frequency components such as EEG's, EKG into audio frequency range

→ The audio frequency range is 20-2000 KHz

→ The voltage across CT is controlled by constant current source.



(c) output waveform



(d) Typical connection diagram

The total voltage on the capacitor changes from 0.25 Vcc to 0.5 Vcc. Thus $\Delta V = 0.25\,V_{cc}$. The capacitor charges with a constant current sources. The amount of current at C_T is controlled by R_T.

So $\quad \dfrac{\Delta V}{\Delta T} = \dfrac{i}{C_T}$ $\qquad V \propto \frac{1}{C}\int i\,dt.$

or, $\quad \dfrac{0.25\,V_{CC}}{\Delta t} = \dfrac{i}{C_T}$

or, $\quad \Delta t = \dfrac{0.25\,V_{CC}\,C_T}{i}$

The time period T of the triangular waveform $= 2\Delta t$. The frequency of oscillator f_o is,

$$f_o = \frac{1}{T} = \frac{1}{2\Delta t} = \frac{i}{0.5\,V_{CC}\,C_T}$$

But, $\quad i = \dfrac{V_{CC} - V_C}{R_T} \implies i = \dfrac{V_{CC} - V_C}{0.5\,R_T C_T \cdot V_{CC}}$

where, V_c is the voltage at pin 5. Therefore,

$$f_o = \frac{2\,(V_{CC} - V_c)}{C_T R_T V_{CC}}$$

The output frequency of the VCO can be changed either by (i) R_T, (ii) C_T or (iii) the voltage V_c at the modulating input terminal pin 5. The voltage V_c can be varied by connecting a $R_1 R_2$ circuit as shown in Fig 9.7 (d). The components R_T and C_T are first selected so that VCO output frequency lies in the centre of the operating frequency range. Now the modulating input voltage is usually varied from 0.75 Vcc to Vcc which can produce a

Phase Locked Loop :-

Introduction :

1. PLL is a phase locked loop. It is a closed loop circuit & its o/p frequency & o/p phase (ϕ) to be locked.

2. The PLL is an important building block of linear systems.

3. The PLL was used in 1930. At the time PLL has many features. so PLL circuits was very costly.

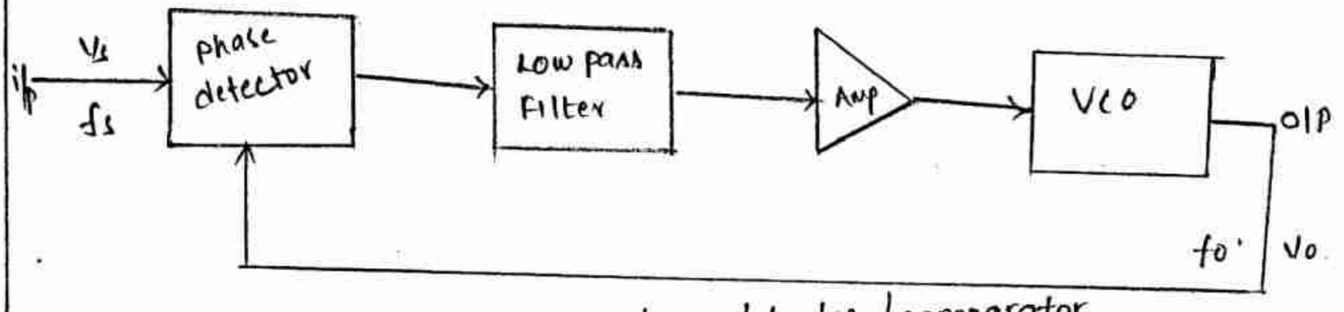
4. However, after the development of integrated technology, the cost of PLL has reduced.

5. Hence we observed that PLL has become one of the fundamental building block in electronic technology.

6. The PLL principle is used in FM demodulation, FSK de-modulation, motor speed control, frequency multiplication & division etc.

7. The PLL is available in single package. The example of PLL is 565 IC.

Block Diagram of PLL :



It consists of 4 blocks ; 1. phase detector / comparator
2. Low pass filter
3. Amplifier
4. VCO (voltage controlled oscillator)

1. Phase Detector/comparator :

1. When i/p signal V_s at frequency f_s is applied to the phase detector & it compares the phase or frequency of incoming signal to that of the o/p of VCO.

2. The phase detector compares the 2 i/p signals & produce an voltage.

3. Phase detector basically acts as an multiplier, so it produces the sum $(f_s + f_o)$ & difference $(f_s - f_o)$ components at its o/p.

2. Low pass Filter :

The low pass filter used to remove high frequency signals i.e., coming from phase detector. It passes only low frequency signals i.e., the difference of two i/p signal $(f_s - f_o)$.

3. Amplifier :

The amplifier is used to amplifies the difference of frequency signal & the amplified signal is given to the voltage controlled oscillator.

4. Voltage Controlled Oscillator :

1. VCO is a frequency running multivibrator and operates at a set frequency f_o called free running frequency.

2. This frequency is determined by an external timing capacitor and an external resistor.

3. It can be shifted to either side by applying a dc control voltage V_c.

4. The frequency derivation is directly proportional to the dc current control voltage and it is called VCO.

5. The VCO frequency f_o is compared with the i/p frequency f_i by the phase detector and it is adjusted continuosly until it is equal to the i/p frequency f_s.

$$\boxed{f_o = f_s}$$

6. The signal V_c shifts the VCO frequency in a direction to reduce the frequency difference b/w f_s and f_o.
7. Once this action starts, we say that the signal is in the capture range.
8. The circuit is then said to be locked. Once locked, the o/p frequency f_o of VCO is identical (same) to f_s except for a finite phase ϕ. Thus, a PLL goes through 3 stages.

1. Free Running state :

In this state, there is no control on VCO o/p frequency f_o.

2. Lock Range :

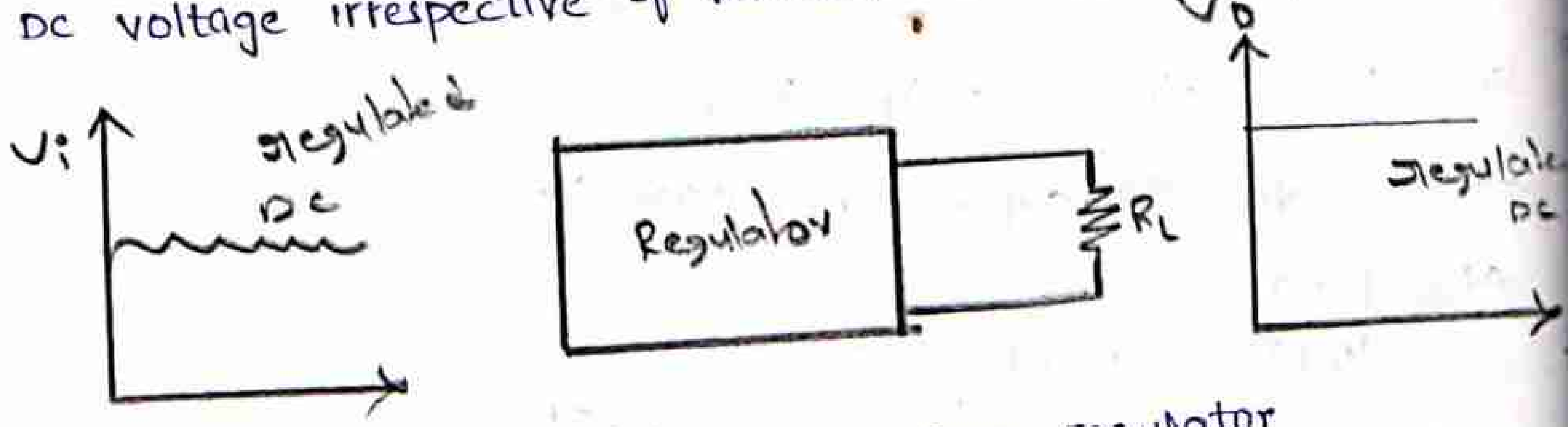
In this state when f_o is exactly equal to f_i, the PLL is said to be phase locked. once locked $f_o = f_i$ except for a finite ϕ.

3. Capture Range :

In this State, the comparision of f_o and f_i begins. The control voltage V_c starts adjusting f_o to bring it closer to f_i. The LPF controls the capture range.

Voltage Regulators :

→ Voltage regulator is an electronic circuit that gives const o/p DC voltage irrespective of variation in i/p voltage & load.



These are of 3 types :- 1. Series voltage regulator
2. Switching voltage regulator
3. Shunt voltage regulator

Series Voltage Regulator :

1. In series regulator, we use power transistor (control element) connected in series in b/w i/p & load.

2. The o/p voltage is controlled by the continous voltage drop

taking place across the series pass transistor.

- Since the transistor conducts in the active (or) linear region these regulators are also called as linear regulators.
- Series regulators (or) linear regulators may have fixed & variable voltage regulators & it should be +ve (or) -ve voltages.

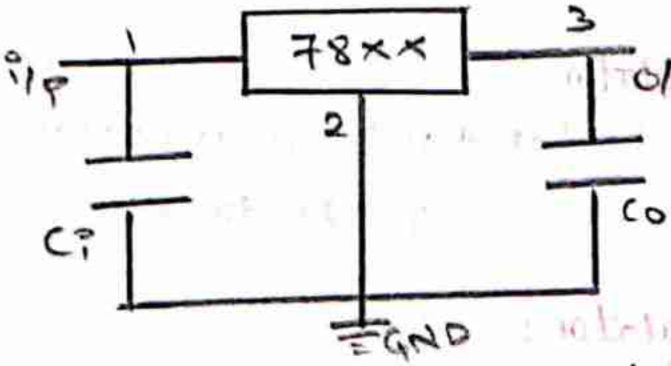
Fixed Voltage Regulators :

- It provides a fixed constant o/p voltage as designed by the manufacturer. These are classified as 2 types.

a) +ve fixed voltage regulator
b) -ve fixed voltage regulator

a) +ve fixed voltage regulator :

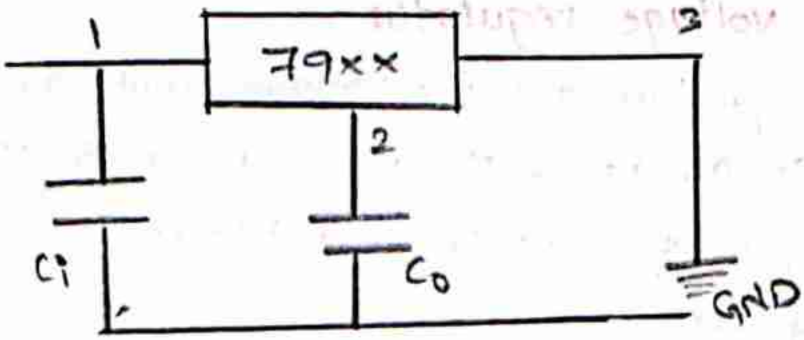
- 78XX series regulators are +ve voltage regulators. It has 3 terminals 1st terminal acts as i/p & 2nd as grounded & 3rd as o/p terminal.
- The last 2 digits of 78XX series indicates the o/p voltage of regulator. For eg : 7805
- It indicates +ve 5 volts produced by the circuit.
- The 78XX has different o/p voltage options they are 5V, 7V, 9V, 12V, 15V, 18V, 24V.
- The standard representation of 78XX series is shown in below fig.



- Here pin 1 is the i/p pin, pin 2 is grounded, pin 3 is the o/p.
- The i/p capacitor Ci is used to remove the fluctuation in given i/p signal & o/p capacitor Co is used to impove transient response.

(b) -ve fixed voltage regulator:

1. 79xx series is a -ve voltage regulators. It is a 3 terminal device. 1st pin acts as i/p, 2nd pin acts as o/p, 3rd pin acts as grounded terminal.
2. The last 2 digits of 79xx series indicates the -ve o/p voltage of regulator. for eg: 7905
   it indicates -ve 5 volts produced by circuit.
3. 79xx has different o/p voltage options. They are -5V, -9V, -12V, -15V, -18V, -24V.
4. The standard representation of 79 series is shown below.



Variable Voltage Regulator:

1. It is a kind of regulator whose regulated o/p voltage can be varied over the range.
2. It has 2 types. (a) +ve variable regulator
   (b) -ve variable regulator.

(a) +ve variable regulator:

LM317 is a +ve adjustable voltage regulator whose o/p voltage can be varied over a range of 1.2V to 57V.

(b) -ve variable regulator:

LM337 is a -ve adjustable regulator whose o/p voltage can be varied over a range of -1.2V to -57V.