2/9/22

UNIT-1:

- GENERAL AMPLIFIER CHARACTERISTICS
- Concept of Amplifiers
- Voltage gain
- Current gain
- Power gain
- Input and output resistances
- Conversion Efficiency
- Frequency Responce
- Band width
- Distortion
- BJT AMPLIFIERS
- Small signal low frequency model of the transistor
- Analysis of common Emitter, Common Base, Common collector amplifiers
- Approximate model analysis
- Effects of coupling and bipass capacitors on low frequency response
- Hybrid-π model at high frequencies
- Calculation of High frequency parameters in terms of low frequency parameters
- CE short circuit gain
- CE current gain with resistive low

UNIT-2:
- FET AMPLIFIERS
- Small signal model
- Analysis of common source
- Common Drain and Common gate amplifiers.
- Comparision of performance of 3 configurations
- High frequency FET circuits
- common source amplifier at high frequencies
- common drain amplifier at high frequencies

- MULTI STAGE AMPLIFIERS
- Types of coupling
- Choice of amplifier configuration
- Overall voltage gain
- Bandwidth of n^{th} stage amplifier
- Darlington Bootstrap circuits

UNIT- 3:. FEED BACK AMPLIFIERS
- Feed back concept
- Classification
- Affects of -ve feedback on gain
- Stability, Noise
- Distortion, Bandwidth
- Input resistance & output resistance

- OSCILLATORS: - generators signal without input
- Review of basic concept
- Barkhausen criterion
- RC oscillators (Phase shift, wien Bridge etc)
- LC oscillators (Hartley, Colpitt, clapp)
- CRYSTAL

UNIT-4: POWER AMPLIFIERS
- Series FET class-A power amplifiers
- Transformer coupled class-A power amplifiers
- Harmonic Distortion
- Pushpull amplifiers
- class-B amplifiers
- Class-AB operation
- complementary, symmetry, pushpull class-B power amplifiers
- cross over distortion

UNIT-5:

- DIFFERENTIAL AMPLIFIER:
- Basic structure and principle of operation
- Calculation of differential gain
- Common mode gain
- CMRR
- Circuit to improve CMRR
- Transfer characteristics
- OPERATIONAL AMPLIFIER:
- Ideal Opamp characteristics
- Opamp internal circuit
- Examples of IC Opamps
- DC and AC characteristics
- Inverting & Non-inverting modes of operation
- Voltage Follower

TEXT BOOKS:

→ "Integrated circuits" by milliman & Halkias - Mc Grawhill
→ "Electronic devices & circuits" by Motter shed - PHI
→ "Micro electronics" by J.Milliman & A. Grabel - Mc Graw hill 2nd edition
→ "Electronic devices & circuits" by Salivahanan - TMH
→ "Electronic devices & circuits" by David E bell - PHI
→ "Linear Integrated Circuits" by Ray chowdary and Shail Bala Jain - New age International publishers

29/9/22

UNIT-1

* Classification of Amplifiers:

- Based on the transistor configuration:
  - * CB Amplifier
  - * CE Amplifier
  - * CC Amplifier

- configuration
- Mode
- stage
- Input
- coupling
- Output
- characteristics
- Band width
- Active devices

- Based on mode of operation:
  - * class - A Amplifier
  - * class - B Amplifier
  - * class - AB Amplifier
  - * class - C Amplifier

- Based on number of stages:
  - * Single - stage Amplifier
  - * Multi - stage Amplifier

- Based on active devices:
  - * BJT Amplifiers
  - * FET Amplifiers

- Based on input
  - * Small signal Amplifier
  - * Large signal Amplifier

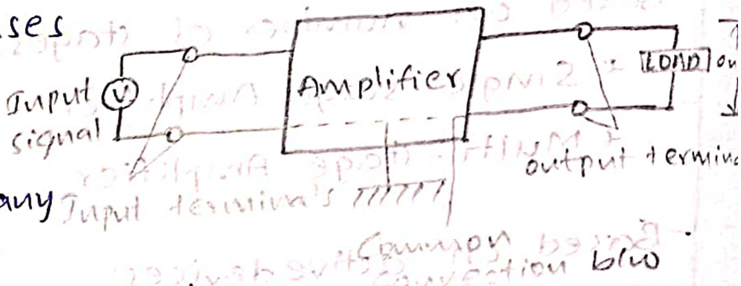
- Based on output
  - * voltage Amplifier
  - * Power Amplifier

- Based on frequency capabilities
  - * Audio frequency Amplifier
  - * Radio frequency Amplifier
  - * Intermediate frequency Amplifer
  - * UHF and
  - * Microwave Frequency Amplifier

- Based on manner of coupling:
  - * RC coupled Amplifier
  - * Transformer coupled Amplifier
  - * Direct coupled Amplifier

- Based on bandwidth:
  - * Narrow band Amplifier
  - * wide band Amplifier

* CONCEPT OF AMPLIFIER:

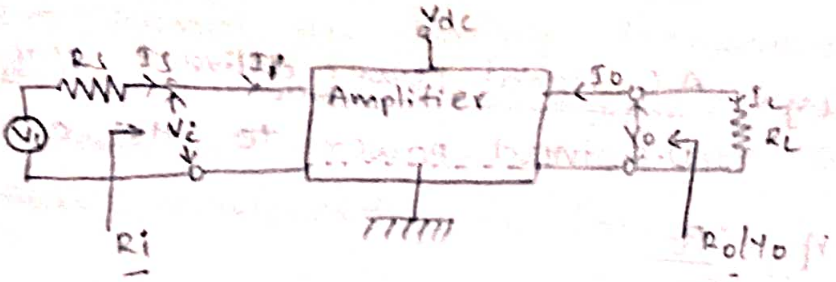


- A circuit that increases the amplitude of the given input signal is an "amplifier" (without any change in frequency).
- The amplifier two port network having 2 input terminals for the signal that is to be amplified and 2 output terminals for the connection of loads.
- One of the input and output terminal are made generally common which was shown in figure.

- The amplifier contains atleast one active device (BJT/FET) for their operation as an amplifier it requires a source of energy this make it provided by a battery (or) DC source.

NOTE: The process of raising strength of weak signal without any change in it's general shape & frequency is known as "Amplification".

AMPLIFIER NOTATIONS:



V_s - Input source

R_s - Internal resistance of source

I_i - Input current to amplifier

V_i - Actual input to amplifier

V_o - Voltage across load resistance R_L

I_o - Output current

I_L - Load current $[I_o = -I_L]$

R_L - Load resistance

R_i - Input resistance of amplifier

R_o - Output resistance of amplifier $[Y_o = \frac{1}{R_o}]$

V_{dc} - DC voltage (To be in active region)

- Current gain is defined as the ratio of output current to input current. (A_i)

$$\boxed{A_i = \frac{I_o}{I_i}}$$

- Voltage gain is defined as the ratio of output voltage to input voltage. (A_v) $\boxed{A_v = \frac{V_o}{V_i}}$

- Ratio of output power to input power is power gain (A_p)

$$A_p = \frac{P_o}{P_i} = \frac{V_o I_o}{V_i I_i} = A_v \cdot A_i$$

- Input resistance, $\boxed{R_i = \frac{V_i}{I_i}}$

- Output resistance, $R_o = \frac{V_o}{I_o} \Big|_{(V_s = 0)}$

- CONVERSION EFFICIENCY:

A measure of the ability of an active device to convert the DC power of the supply into the A.C power delivered to the load is called the conversion efficiency (or) Theoritical efficiency, also called the collector circuit efficiency for a transistor.

$$\text{Efficiency} = \frac{\text{A.C signal power deliverd across load}}{\text{D.C input power to the active load}}$$

$$\eta = \frac{P_o}{P_{dc}}$$

$$\boxed{\eta = \frac{V_o I_o}{V_{dc} I_{dc}}}$$

$$\% \eta = \frac{P_o}{P_{dc}} \times 100$$

** DISTORTION:

The application of sinusodial signal to the input of an amplifier will result in a sinusodial output. Generally the output is not replica of the input because of various types of distortions may arise either from non-linearity characteristics of Active devices. (BJT/FET) (or) from the influence of the associated circuit.

- The various types of distortions are:
  * Non-linear / Amplitude / Harmonic distortion
  * Intermodulation distortion
  * Frequency distortion
  * Phase shift distortion

- Non-linear Distortion:

This type of distortion results from the production of new frequencies in the output, which are not present in the input signal. These new frequencies (are) Harmonics are generated, when the transistor operates in the Non-linear region of it's characteristics. The component with frequency same as input signal is called as "Fundamental frequency component".

-The additional frequency components present in the output signal are having frequency components which are integer multiples of fundamental frequency components. The components are called Harmonics/ Harmonic components.

INTER MODULATION DISTORTION:

For a system analysis, we prefer sinusoidal as it has only one frequency component.

It occurs when input signal consists more than one frequency component. (speech, music etc.,). It is also a type of non-linear distortion, which generates frequency components not harmonically related to the signal frequencies i.e., if an input signal contains two frequencies f_1, f_2 the output signal will contain their harmonics $2f_1, 3f_1, \ldots$ and $2f_2, 3f_2, \ldots$. In addition there would be components f_1+f_2 & f_1-f_2 and also the sum & difference of the harmonics. These sum & difference frequencies are called "Intermodulation frequencies". The distortion due to these frequencies is called "Intermodulation distortion."

FREQUENCY DISTORTION:

It occurs even when the device is working in linear region. It is basically due to change in amplifier gain with frequency. i.e., the different input signal frequencies are amplified by different frequencies. But an amplifier should provide same amplification for all frequencies. Generally at lower & higher frequencies there is a loss & gain, which is usually due to the capacitive components associated with the circuit (or) active device itself.

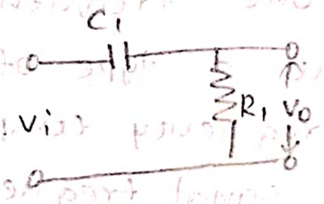
In the case of audio signals the frequency distortion leads to a change in the quality of signal.

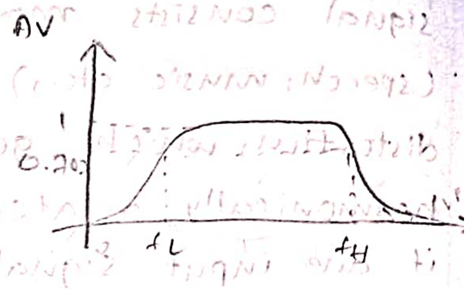
PHASE SHIFT DISTORTION:

This distortion results from unequal phase of signals of different frequencies. The unequal shift is due to frequency dependent components C, L etc., associated with the circuit and the active device of the amplifier.

FREQUENCY RESPONSE:

HPF:





$$V_0 = V_i \frac{R_1}{R_1 - jX_C}$$

$$\frac{V_0}{V_i} = A_V = \frac{R_1}{R_1 - jX_C}$$

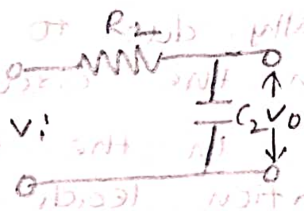
$$= \frac{1}{1 - \frac{jX_{C_1}}{R_1}}$$

$$A_V = \frac{1}{1 - \frac{j}{2\pi f C_1 R_1}}$$

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

at, $f_L = f$, $|A_V| = \frac{1}{\sqrt{2}} = 0.707$

LPF:



$$V_0 = V_i \cdot \frac{-jX_{C_2}}{R_2 - jX_{C_2}}$$

$$\frac{V_0}{V_i} = \frac{-jX_{C_2}}{R_2 - jX_{C_2}} = \frac{-1}{\frac{R_2}{jX_{C_2}} - 1} = \frac{-1}{\frac{R_2}{j2\pi f C_2} - 1} = \frac{1}{1 - \frac{R_2}{j2\pi f C_2}} = \frac{1}{1 + \frac{jR_2}{2\pi f C_2}}$$

$$A_V = \frac{1}{1 + \frac{jR_2}{2\pi f C_2}}$$

$\boxed{BW = f_H - f_L}$

below midband = HPF
above midband = LPF

1 bel = 10 dB

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

Gain in dB:-

The gain of an amplifier can be expressed as a number, but it is of great practical importance to assaign it a unit. The Assigned unit is "bel (or) dB".

- 1 bel = 10 dB

- The common logarithm of power gain is known as "bell power gain".

- power gain = $\log_{10} \frac{P_{out}}{P_{in}}$ bel

- power gain = $10 \log_{10} \frac{P_o}{P_i}$ dB

- As power is directly proportional to V^2 & $i^2 \Rightarrow P \propto V^2 ; P \propto i^2$

Therefore, voltage gain & current gain are expressed in dB.

$\therefore$ Voltage gain = $20 \log_{10} \frac{V_o}{V_i}$ dB

$\therefore$ Current gain = $20 \log_{10} \frac{I_o}{I_i}$ dB

- The unit dB is a logarithmic unit. Our ear response is also logarithmic i.e., loudness of sound ~~created~~ heard by ear is not according to the intensity of sound, but according to the log of intensity of sound.

- In multi-stage amplifiers it permits to add individual gains of stages to calculate overall gain (logarithm changes multiplication to addition).

- It allows us to denote both very small as well as very large quantities of linear scale by considerably small figures.

Ex:- 0.0000001 and 100000
= -140 dB 100 dB.

$\alpha : 0.95 \rightarrow 0.9$
$\beta : 50 \rightarrow 400$

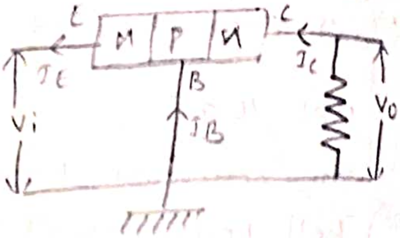
Band width:- The range of frequencies over which the voltage gain is equal to (or) greater than 70.7 % 6U0 of the maximum gain is known as "Band width".

The human ear is not a very sensitive hearing device, it has been found that if the gain falls to 70.7 % of maximum gain, the ear cannot detect the change. However, if the gain falls below 70.7 % of the maximum gain the ear will hear clear distortion.

* C.B:
Let, $R_i = 20\Omega$

$V_i = 200\,mV$

$R_L = 5\,k\Omega$



$\therefore I_C = \alpha I_E + I_{CBO}$

$I_E = \dfrac{200 \times m}{20} = 10\,mA$

$I_C = \alpha I_E = I_E$

$\therefore I_C = 10\,mA$

$\therefore \boxed{V_o = I_C \times R_L}$

$= 10 \times 5 \times 10^3 \times 10^{-3}$

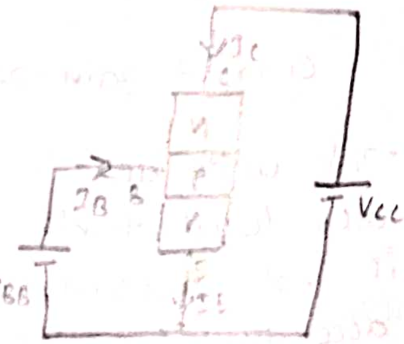
$\boxed{V_o = 50V}$

$A_V = \dfrac{V_o}{V_i} = \dfrac{50 \times 10^3}{200} = 250$ used for

$A_i = \dfrac{I_o}{I_i} = \dfrac{10 \times 10^{-3}}{10 \times 10^{-3}} = \alpha = 1$

$A_i < 1$

* C.E:



$I_E = I_C + I_B$

$I_C = \alpha I_E + I_{CBO}$

$I_C = \alpha(I_C + I_B) + I_{CBO}$

$I_C(1-\alpha) = \alpha I_B + I_{CBO}$

$I_C = \dfrac{\alpha}{1-\alpha} I_B + \dfrac{1}{1-\alpha} I_{CBO}$

"used for A_i"

$I_C = \beta I_B + (\beta+1) I_{CBO}$

$\boxed{I_C = \beta I_B + I_{CEO}}$

$I_C = \beta I_B$

$\therefore \beta = \dfrac{\alpha}{1-\alpha}$.

i) $\alpha = 0.95$

$\beta = \dfrac{0.95}{0.05} = 19$

ii) $\alpha = 0.98$

$\beta = \dfrac{0.98}{0.02} = 49$

Let $I_B = 1mA$ & $\beta = 100$

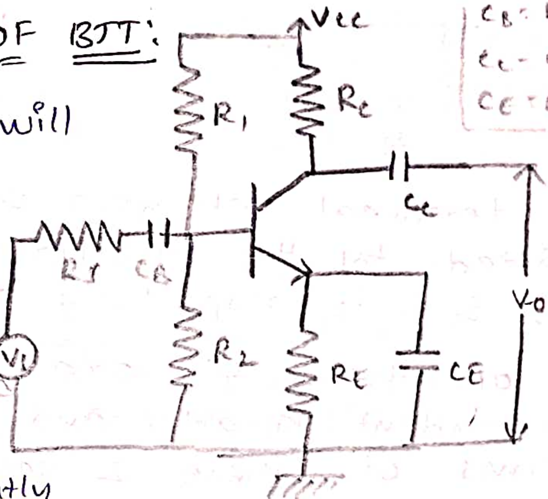
$\therefore I_C = \beta I_B = 100 mA$ //

- The voltage gain of CC amplifier is approximately equal to unity. i.e., $A_V = 1$ & $A_i = \beta$

- $\boxed{\gamma = \beta + 1 = \frac{1}{1-\alpha}}$

SMALL SIGNAL ANALYSIS OF BJT:

C_B: Blocking capacitor
C_C - Coupling Capacitor
C_E - Bypass Capacitor



- In the AC analysis, we will come across small and large signal analysis.

- Large signal amplifiers are called "power amplifiers".

- Small signal is the signal having magnitude sufficiently small to keep the transistor in active region.

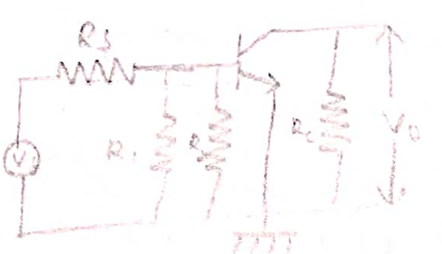
- For AC response,
  (i) AC equivalent circuit
  (ii) Replace transistor with equivalent model / equivalent circuit

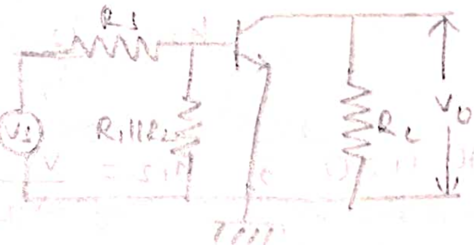
- For AC equivalent circuit,

Step-1 :- Short circuit all the DC sources.

Step-2 :- Short all the capacitors

Step-3 :- Redraw the network removing all the elements which are shortcircuited in step-1 & step-2.





EQUIVALENT MODEL:

An equivalent model is a combination of circuit elements (R, L, C) properly choosen to best represent the actual behaviour of device under specific operating point.

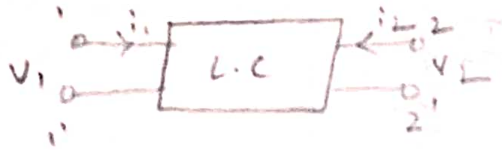
Transistor

Hybrid Model
re Model
Hybrid π Model

HYBRID PARAMETERS:

Every linear circuit having input & Output termi can be analysed by four parameters (1 in ohm, 1 in m 2 are dimension less) called "Hybrid / h-parametrs."

NOTE: Hybrid means mixed. Since these parameters have mixed dimensions, they are called "hybrid parameter



where, i_1 = Input Current
i_2 = Output current
v_1 = Input Voltage

- The terminal behaviour of any two port network, can specified by the two-port voltages, terminal currents v_1, v_2 & i_1, i_2 respectively as shown in figure.

- Out of these '4' variables, two can be selected as independent variables and remaining '2' can be expres interms of these 2 variables.

- If the current i_1, Voltage v_2 as independent, then we can write, i_2 as function of (i_1, v_2) and v_1 a function of (i_1, v_2)

$$v_1 = h_{11} i_1 + h_{12} v_2$$

$$i_2 = h_{21} i_1 + h_{22} v_2$$

- The four hybrid parameters $h_{11}, h_{12}, h_{21}, h_{22}$ are differ as follows:

At $v_2 = 0$, $h_{11} = \frac{i_1}{v_1}$ [input impedance]

$h_{21} = \frac{i_2}{i_1}$ [forward current gain]

At $i_1 = 0$; $h_{12} = \frac{v_1}{v_2}$ [Reverse voltage gain/transfer]

$h_{22} = \frac{i_2}{v_2}$ [output admittance]

- Dimensions of h-parameters are as follows:

h_{11} : Ω

h_{22} : $\mho$

h_{12}, h_{21}: dimension less.

The alternative subscript notations recommended by IEEE is:

11 = i : Input

22 = o : Output

21 = f : Forward Transfer

12 = r : Reverse Transfer.

* $V_1 = h_{11} i_1 + h_{12} V_2$ — ①

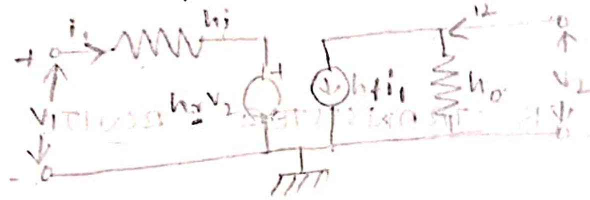
$i_2 = h_{21} i_1 + h_{22} V_2$

①&② can be rewritten as using notations recommended by IEEE are:

$V_1 = h_i i_1 + h_r V_2$

$i_2 = h_f i_1 + h_o V_2$

- By using h-parameters, the mathematical model for 2 port network known as "Hybrid model or h-parameter model" can be developed which is shown in figure



Hybrid Model

NOTATIONS USED IN TRANSISTOR CIRCUITS:

S.NO	h-parameter	Notation in CB	Notation in CE	Notation in CC
1.	h_{11}	h_{ib}	h_{ie}	h_{ic}
2.	h_{12}	h_{rb}	h_{re}	h_{rc}
3.	h_{21}	h_{fb}	h_{fe}	h_{fc}
4.	h_{22}	h_{ob}	h_{oe}	h_{oc}

The use of h-parameters to analyse a transistor have the following advantages:

i, h-parameters are real numbers upto radio frequencies.

ii, They are easy to measure

iii, They can be determined from the transistor, static characteristic curves.

iv, They are convinient to use in circuit analysis and design.

v, Easily convertable from one configuration to other.

v_i, Readily supplied by manufacturers.

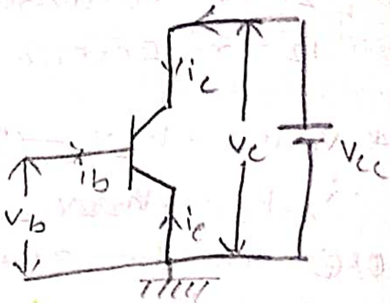
HYBRID MODEL FOR CE TRANSISTOR CIRCUIT:

Here, $i_1 = i_b$

$i_2 = i_c$

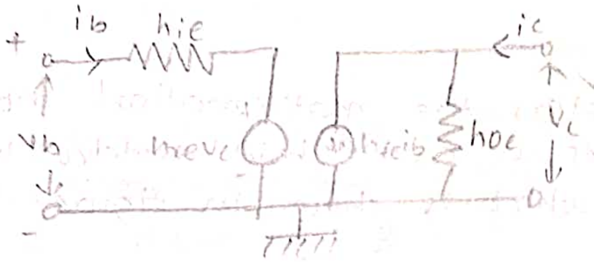
$V_1 = V_b$

$V_2 = V_c$



$\therefore$ $V_b = h_{ie} i_b + h_{re} V_c$

$i_c = h_{fe} i_b + h_{oe} V_c$



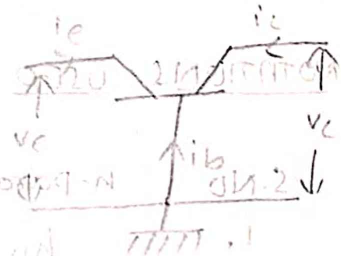
HYBRID MODEL FOR CB TRANSISTOR CIRCUIT:

Here, $i_1 = i_e$

$i_2 = i_c$

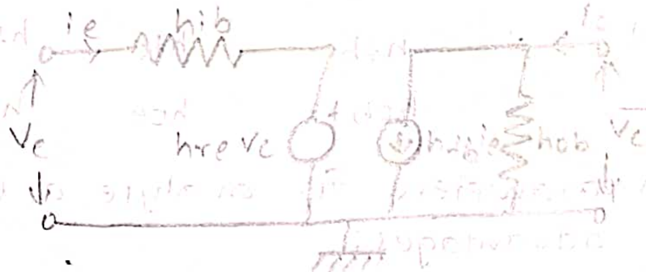
$V_1 = V_e$

$V_2 = V_c$



$\therefore$ $V_e = h_{ib} i_e + h_{rb} V_c$

$i_c = h_{fb} i_e + h_{ob} V_c$



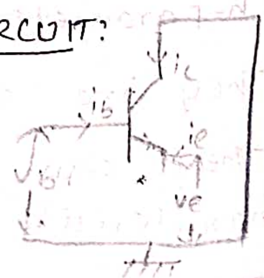
HYBRID MODEL FOR CC TRANSISTOR CIRCUIT:

Here, $i_1 = i_b$

$i_2 = i_e$

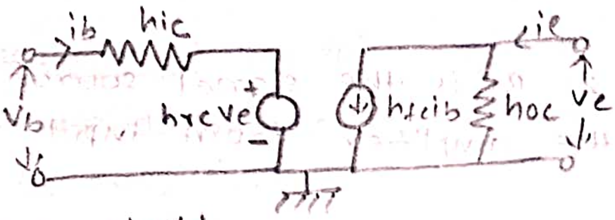
$V_1 = V_b$

$V_2 = V_e$



$\therefore$ $V_b = h_{ic} i_b + h_{rc} V_e$

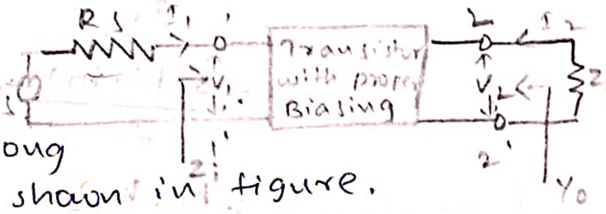
$i_e = h_{fc} i_b + h_{oc} V_e$



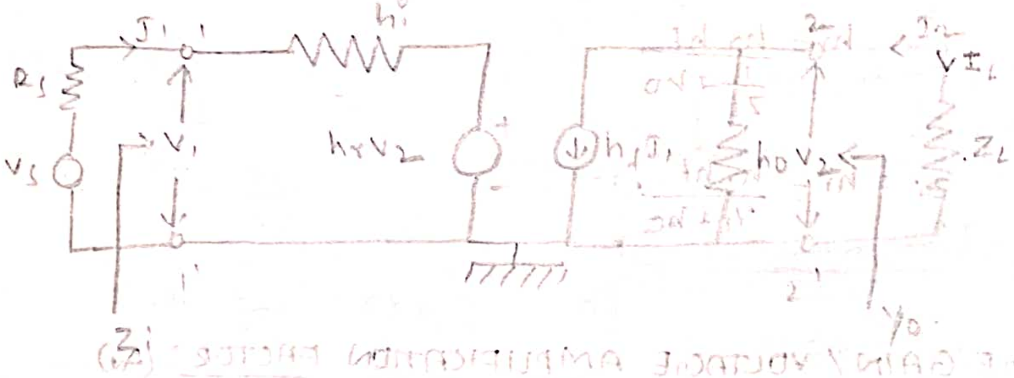
Exact analysis

ANALYSIS OF A TRANSISTOR AMPLIFIER USING h-PARAMETERS:-

A Transistor amplifier can be constructed by connecting an external load & signal source along with proper biasing, which was shown in figure.



-Replace the transistor in any one of it's configuration. The hybrid equivalent circuit is valid for any type of load, whether it is impedance/Resistance/Another transistor. It is assumed that h-parameters remain constant over the operating range and the input is sinusoidal.



$1,1' \to$ I/P terminals

$2,2' \to$ O/P terminals

* Current gain factor:-

$$A_I = \frac{I_L}{I_1} = \frac{-I_2}{I_1}$$

$$I_2 = h_f I_1 + h_o V_2$$

$$I_2 = h_f I_1 - h_o I_2 Z_L$$

$$I_2(1+h_o Z_L) = h_f I_1$$

$$\frac{I_2}{I_1} = \frac{h_f}{1+h_o Z_L}$$

$$\therefore \quad \boxed{A_I = -\frac{h_f}{1+h_o Z_L}}$$

INPUT IMPEDANCE (Z_i):

Input impedance Z_i. R_s is the signal source resistan
Z_i is looking into the amplifier from input terimanls
is given by,

$$Z_i = \frac{V_1}{I_1}$$

$$V_1 = I_1 h_i + h_r V_2$$

$$V_2 = -I_2 Z_L$$

$$= \frac{I_1 h_i + h_r V_2}{I_1}$$

$$= h_i + h_r \frac{V_2}{I_1}$$

$$A_i = \frac{I_2}{I_1} \Rightarrow I_2 = A_i I_1$$

$$= h_i + h_r \cdot \frac{-I_2 Z_L}{I_1}$$

$$= h_i + h_r \cdot A_I \cdot Z_L$$

$$= h_i + h_r \cdot \left[\frac{-h_f}{1 + h_o Z_L} \right] Z_L$$

$$= h_i - \frac{h_r h_f}{\frac{1}{Z_L} + h_o}$$

$$\boxed{Z_i = h_i - \frac{h_r h_f}{Y_L + h_o}}$$

VOLTAGE GAIN / VOLTAGE AMPLIFICATION FACTOR: (A_v)

$$A_v = \frac{\text{o/p voltage}}{\text{i/p voltage}}$$

$$= \frac{V_2}{V_1}$$

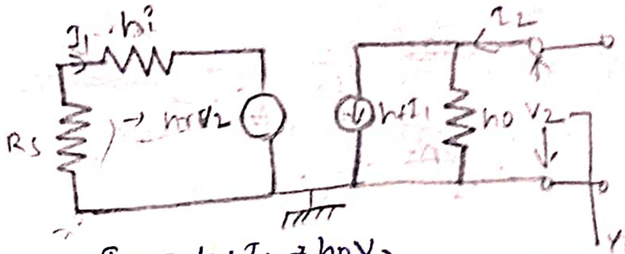
$$= \frac{-I_2 Z_L}{V_1}$$

$$= A_i \frac{I_1}{V_1} Z_L$$

$$\boxed{A_v = \frac{A_i Z_L}{Z_i}}$$

OUTPUT ADMITANCE: (Z_o/Y_o)

By the definition, Y_o is obtained by setting V_s to 0 and Z_L to infinity.



$$Y_o = \frac{I_2}{V_2}$$

$$= \frac{h_f I_1 + h_o V_2}{V_2}$$

$$= \frac{h_f}{V_2} I_1 + h_o$$

$I_2 = h_f I_1 + h_o V_2$

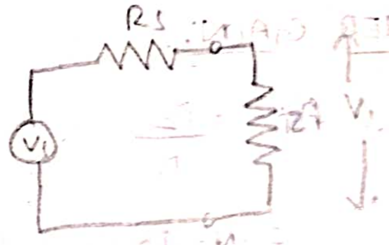
KVL $\Rightarrow R_s I_1 + h_i I_1 + h_r V_2 = 0$

$\Rightarrow I_1 = \frac{-h_r V_2}{R_s + h_i}$

$$\boxed{Y_o = h_o - \frac{h_r h_f}{R_s + h_i}}$$

$$Z_o = \frac{1}{Y_o}$$

VOLTAGE GAIN INCLUDING SOURCE (OVERALL VOLTAGE GAIN):



$$A_{vs} = \frac{V_2}{V_s}$$

$$= \frac{V_2}{V_1} \cdot \frac{V_1}{V_s}$$

$$= A_v \cdot \frac{V_1}{V_s} = A_v \cdot \frac{V_s \cdot Z_i}{(Z_s + R_i) V_s}$$

$V_1 = V_s \cdot \frac{Z_i}{R_s + Z_i}$

$$\boxed{A_{vs} = A_v \cdot \frac{Z_i}{R_s + Z_i}}$$

$A_v = A_I \frac{Z_L}{Z_i}$

$$= A_I \frac{Z_L}{Z_i} \cdot \frac{Z_i}{R_s + Z_i}$$

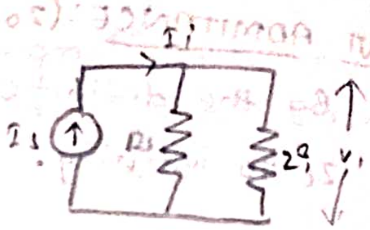
$$\boxed{A_{vs} = A_I \frac{Z_L}{R_s + Z_i}}$$

- If $R_s = 0$, then $A_{vs} = A_I \cdot \frac{Z_L}{Z_i}$

$$\boxed{A_{vs} = A_v}$$

Then, A_v is the voltage gain with an ideal voltage source

OVERALL CURRENT GAIN:



$$A_{Is} = \frac{I_L}{I_s}$$

$$= \frac{I_L}{I_1} \cdot \frac{I_1}{I_s}$$

$$= A_I \cdot \frac{I_1}{I_s}$$

$$I_1 = I_s \cdot \frac{R_s}{R_s + Z_i}$$

$$\boxed{A_{Is} = A_I \cdot \frac{R_s}{R_s + Z_i}}$$

$$A_{Vs} = A_I \cdot \frac{Z_L}{R_s + Z_i}$$

$$\therefore \boxed{\frac{A_{Vs}}{A_{Is}} = \frac{Z_L}{R_s}}$$

POWER GAIN:

$$A_p = + \frac{P_2}{P_1}$$

$$= \frac{-V_2 I_2}{V_1 I_1}$$

$$\boxed{A_p = A_V A_I}$$

$$= A_I \cdot \frac{Z_L}{Z_i} \cdot A_I$$

$$\boxed{A_p = A_I^2 \cdot \frac{Z_L}{Z_i}}$$

SMALL SIGNAL ANALYSIS OF A TRANSISTOR AMPLIFIER:

* $A_I = \frac{-h_f}{1 + h_o Z_L}$

* $A_V = A_I \cdot \frac{Z_L}{Z_i}$

* $Z_i = h_i + h_r A_I Z_L = h_i - \frac{h_f h_r}{Y_L + h_o}$, $Y_o = h_o - \frac{h_r h_f}{h_o + R_s}$

  $\downarrow$
  R_i

$R_i = h_{ie} + h_{re} A_I R_L$

* $A_{Vs} = A_V \cdot \frac{Z_i}{R_s+Z_i} = A_I \frac{Z_L}{R_s+Z_i} = A_{Is} \cdot \frac{Z_L}{R_s}$

* $A_{Is} = A_I \cdot \frac{R_s}{R_s+Z_i} = A_{Vs} \cdot \frac{R_s}{Z_L}$

* $A_p = A_V A_I = A_I^2 \cdot \frac{Z_L}{Z_i}$

- The above formulas are valid for all the 3 configurations

Conversion Formulas For Hybrid Parameters:

CC	CB
$h_{ic} = h_{ie}$	$h_{ib} = \frac{h_{ie}}{1+h_{fe}}$
$h_{rc} = 1$	$h_{rb} = \frac{h_{ie} h_{oe}}{1+h_{fe}} - h_{re}$
$h_{fc} = -(1+h_{fe})$	$h_{fb} = \frac{-h_{fe}}{1+h_{fe}}$
$h_{oc} = h_{oe}$	$h_{ob} = \frac{h_{oe}}{1+h_{fe}}$

Typical h-parameter values for a Transistor:

Parameter	CE	CC	CB
h_{ie}	1100Ω	1100Ω	22Ω
h_{re}	2.5×10^{-4}	1	3×10^{-4}
h_{fe}	50	-51	-0.98
h_{oe}	24 µA/V	25 µA/V	0.49 µA/V
$\frac{1}{h_o}$	40k	40k	2.04 M

COMPARISION OF TRANSISTOR AMPLIFIER CONFIGURATION

The values of A_I, A_V, R_i, R_o and A_p are calculated for typical transistor using h-parameters which the values of R_L & R_s are $3k\Omega$.

PARAMETER	CB	CC	CE
A_I	0.98	47.5	-46.5
A_V	131	0.989	-131
R_i	22.6Ω	144 kΩ	1065Ω
R_o	1.72 MΩ	80.5 Ω	45.5kΩ
A_P	128.38	46.98	6091.5

- FOR CC, phase is 180°, Hen[ce] A_I is -ve.

- FOR oscillator phase shift: 3[60°] ↓ Generating sig[nal]

* **Characteristics of CB Amplifier:**

- Current gain is less than unity and it's magnitude decreases with the increase of Load resistance 'R_L'.
- Voltage gain 'A_V' is high for normal values of 'R_L'.
- The input Resistance 'R_i' is the lowest of all the '3' configurations.
- The output resistance 'R_o' is the highest of all the 3 configurations.

Applications:

- This is not commonly used for amplification purpose, but is used for

i, Matching a very low impedance source

ii, As a non-inverting amplifier with voltage gain exceeding unity.

iii, For driving a high impedance load.

iv, As a constant current source.

* **Characteristics of CC Amplifier:**

- For low values of 'R_L', the current gain A_I is high and almost equal to that of a CE amplifier.
- The voltage gain is less than unity.
- The Input resistance is the highest of all the 3 configur[ations]
- The output resistance is the lowest of all 3 configuratio[ns]

Applications:

1. The CC amplifier is widely used as a buffer stage b/w a high impedance source and a low impedance load.

2. CC amplifier is called the emitter follower.

* Characteristics of CE Amplifier:

1. The current gain A_I is high for low values of R_L (<10 kΩ)

2. The voltage gain is high for normal values of R_L.

3. The Input resistance R_i is medium.

4. The output resistance R_o is moderately high.

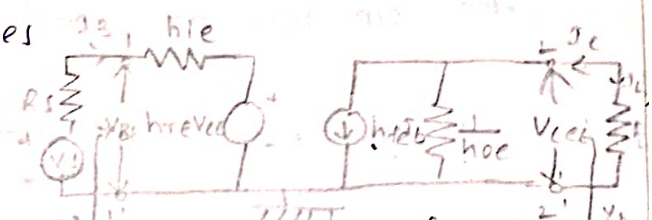
Applications:

1. CE amplifier provides both voltage gain and current gain

2. The input resistance R_I & Output resistance R_o are moderately high. Hence, CE amplifier is widely used for amplification purpose.

APPROXIMATE MODEL ANALYSIS / SIMPLIFIED HYBRID MODEL:

As the h-parameters themselves vary widely for the same type of transistor.



∴ It is better to make approximations and simplify ~~for~~ the expression for A_I, A_V, R_I, R_o & A_P

- In the above hybrid model $\frac{1}{h_{oe}}$ is parallel with R_L, the parallel combination of two unequal impedances i.e., $\frac{1}{h_{oe}}$ & R_L is approximately equal to the lower value i.e. R_L.

- If $\frac{1}{h_{oe}} >> R_L \Rightarrow h_{oe} R_L << 1$, the term h_{oe} may be neglected. If h_{oe} is omitted the collector current "$I_C = h_{fe} \cdot I_b$"

- Under this condition the magnitude of voltage generator is, $h_{re} V_{ce} = h_{re} \cdot I_C R_L$

$$= h_{re} \cdot h_{fe} I_b R_L$$

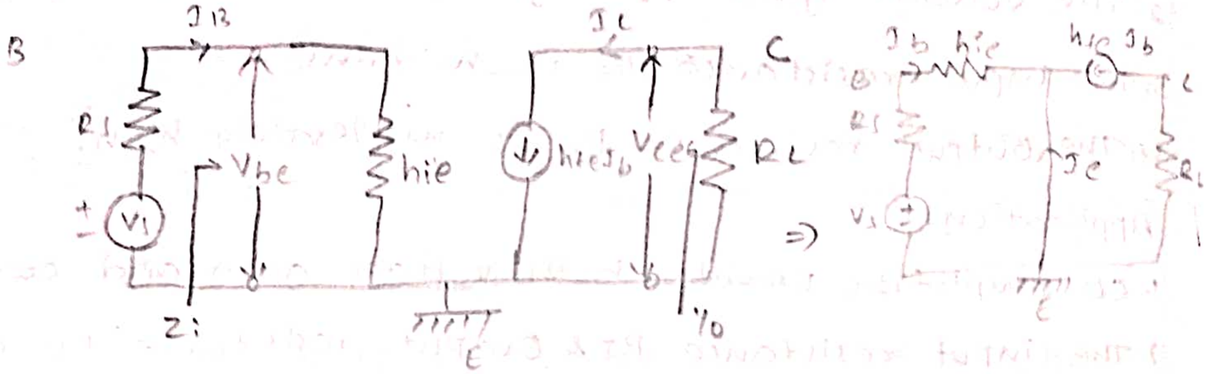
- Since $h_{re} \cdot h_{fe} = 0.01$, this voltage may be neglected in comparision with voltage drop across h_{ie} i.e., $h_{ie} \cdot i_b$

provided that 'Ri' is not too large.

NOTE:

- If $h_{oe} \cdot R_L \leq 0.1$, using approximate model we can show the error deviation is $< 10\%$.

- If the load resistance 'Ri' is small, it is possible to neglect the parameters h_{re} & h_{oe} then the approximate equivalent circuit is



- The simplified hybrid circuit that can be used for any configuration by simply grounding the appropriate terminal which is shown in fig (a). The signal is connected b/w the i/p terminal & Ground and the load is placed b/w the o/p terminal and ground.

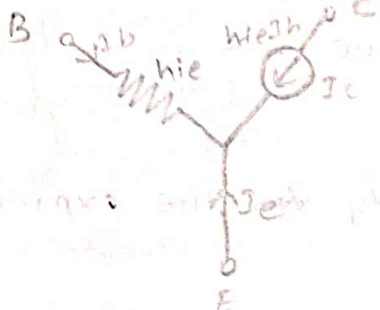


Fig (a)

- The approximate hybrid model used for all the 3 configurations is shown in fig(a).

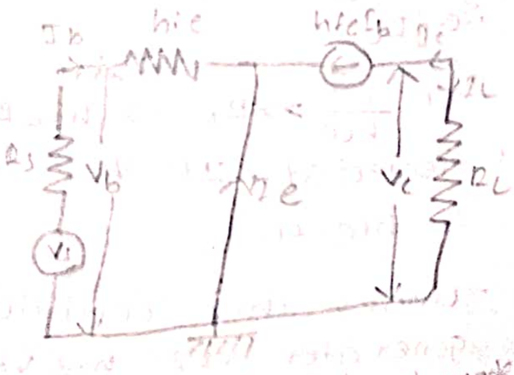
→ $A_I = \dfrac{-h_{fe}}{1+h_{oe}R_L}$

$\boxed{A_I = -h_{fe}}$ $\quad (h_{oe}R_L \leq 0.1)$

→ $A_I = \dfrac{I_L}{I_b} = \dfrac{-I_c}{I_b}$

$= \dfrac{-h_{fe}I_b}{I_b}$

$\boxed{A_I = -h_{fe}}$



Simplified hybrid model.

* $R_i = h_{ie} + h_{re} A_I R_L$

$= h_{ie}\left[1 + \frac{h_{re}}{h_{ie}} \cdot A_I R_L\right]$

$= h_{ie}\left[1 + \frac{h_{re} \cdot h_{fe}}{h_{ie} \cdot h_{oe}} \cdot \frac{A_I R_L \cdot h_{oe}}{h_{fe}}\right]$ $[R_L \cdot h_{oe} \sim 0.1]$

~ 0.5 $[A_I = -h_{fe}]$

$= h_{ie}[1 - 0.5]$

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

(or)

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

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

* $A_V = A_I \cdot \frac{R_L}{R_i}$

$\boxed{A_V = \frac{-h_{fe}}{h_{ie}} \cdot R_L}$

* $1/R_o : Y_o = h_{oe} - \frac{h_{re} h_{fe}}{R_s + h_{ie}}$ (or) * $R_o = \frac{V_c}{I_c} = \frac{V_c}{0} = \alpha$ $[\because V_s = 0]$

$= 0 - 0$ (h_{oe} & h_{fe} are neglected)

$Y_o = 0$ (or)

$\boxed{R_o = \alpha}$ * $\Rightarrow R_o = R_s + h_{ie} + \alpha$

$\boxed{R_o = \alpha}$

* Voltage gain along with source,

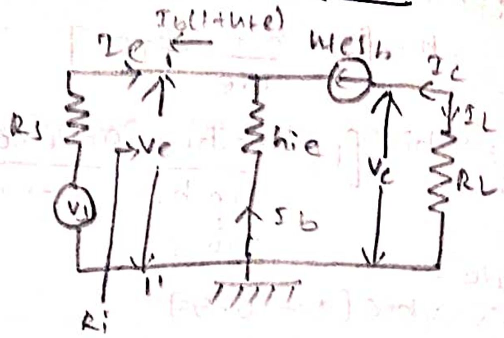
$A_{vs} = A_V \frac{R_i}{R_i + R_s}$

$\boxed{A_{vs} = A_V \cdot \frac{h_{ie}}{h_{ie} + R_s}}$

$\boxed{A_{Is} = A_I \frac{R_s}{R_s + R_i}}$

APPROXIMATE HYBRID MODEL FOR COMMON BASE:

① Current gain,



$$A_I = \frac{I_L}{I_e} = -\frac{I_c}{I_e}$$

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

$\rightarrow I_e = -(I_c + I_b)$

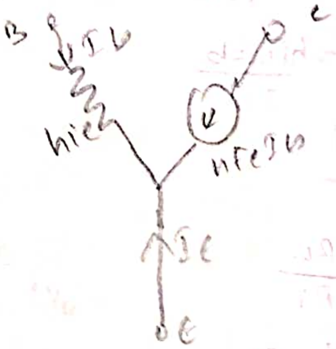
$I_e = -I_b(1+h_{fe})$

$$\therefore A_I = \frac{-h_{fe} \cancel{I_b}}{-\cancel{I_b}(1+h_{fe})}$$

$$\boxed{A_I = \frac{h_{fe}}{1+h_{fe}}}$$

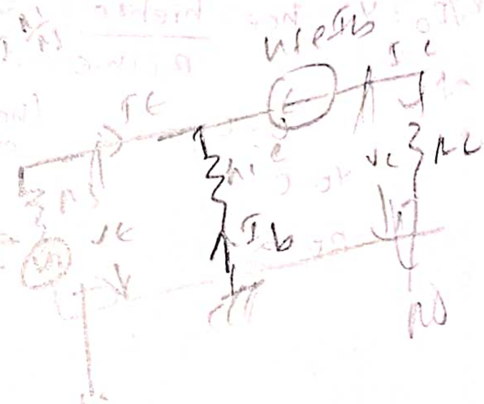
$\rightarrow h_{fb} = -\left(\frac{h_{fe}}{1+h_{fe}}\right)$

$\boxed{A_I = h_{fb}}$



② $$R_I = \frac{V_e}{I_e} = \frac{-\cancel{I_b}h_{ie}}{-\cancel{I_b}(1+h_{fe})}$$

$$\boxed{R_I = \frac{h_{ie}}{1+h_{fe}}} \; = h_{ib}$$



③ $$A_V = A_I \cdot \frac{R_L}{R_i}$$

$$= \frac{h_{fe}}{1+h_{fe}} \cdot \frac{R_L}{\frac{h_{ie}}{1+h_{fe}}}$$

$$\boxed{A_V = \frac{h_{fe}}{h_{ie}} R_L}$$

$A_V = h_{fb} R_L / h_{ib} = \frac{h_{fe}/(1+h_{fe})}{h_{ie}/(1+h_{fe})} R_L = \frac{h_{fe}}{h_{ie}} R_L$

④ $$R_o = \left.\frac{V_c}{I_c}\right|_{V_s=0}$$

$$= \frac{V_c}{0}$$

$\boxed{R_o = \infty}$

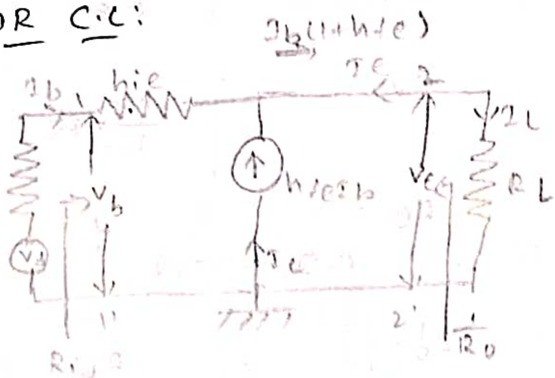
$R_o' = \infty \,||\, R_L$

$\boxed{R_o' = R_L}$

⑤ $A_{vs} = A_v \cdot \frac{R_i}{R_i + R_s}$

⑥ $A_{Is} = A_I \cdot \frac{R_s}{R_s + R_i}$

APPROXIMATE HYBRID MODEL FOR C.C:



① $A_I = \frac{I_L}{I_b} = \frac{-I_e}{I_b} = \frac{I_b(1+h_{fe})}{I_b}$

$\boxed{A_I = 1 + h_{fe}}$

② $R_I = \frac{V_b}{I_b}$

$\rightarrow V_b = h_{ie} I_b + I_L R_L$

$= h_{ie} I_b + I_b(1+h_{fe}) R_L$

$\therefore R_I = \frac{h_{ie} I_b + I_b(1+h_{fe}) R_L}{I_b}$

$\boxed{R_I = h_{ie} + (1+h_{fe}) R_L}$

③ $A_V = A_I \cdot \frac{R_L}{R_I}$

$A_V = \frac{(1+h_{fe})}{h_{ie} + (1+h_{fe}) R_L} \cdot R_L$

$R_L(1+h_{fe}) >> h_{ie}$

$\therefore A_V = \frac{(1+h_{fe}) R_L}{(1+h_{fe}) R_L}$

$\boxed{A_V \simeq 1}$

④ $R_O = \frac{V_e}{I_e} = \frac{-I_b(R_s + h_{ie})}{-I_b(1+h_{fe})}$

$\boxed{R_O = \frac{R_s + h_{ie}}{1 + h_{fe}}}$

⑤ $A_{vs} = A_v \cdot \frac{R_i}{R_i + R_s}$

⑥ $A_{Is} = A_I \cdot \frac{R_s}{R_s + R_i}$

Summary of approximate equations of all configurations with the condition "$h_{oe} \cdot R_L \leq 0.1$":

Parameter	CE	CC	CB
A_I	$-h_{fe}$	$1+h_{fe}$	$\frac{h_{fe}}{1+h_{fe}}$
R_i	h_{ie}	$h_{ie}+(1+h_{fe})R_L$	$\frac{h_{ie}}{1+h_{fe}}$
A_V	$\frac{-h_{fe}}{h_{ie}} R_L$	$\frac{(1+h_{fe})R_L}{h_{ie}+R_L(1+h_{fe})}$	$\frac{h_{fe}}{h_{ie}} R_L$
R_o	∞	$\frac{R_s+h_{ie}}{1+h_{fe}}$	∞
R_o'	R_L	$R_o \parallel R_L$	R_L

Q: A common emitter amplifier is driven by a voltage source of internal resistance $R_s = 800\,\Omega$, and the load impedance is a resistance $R_L = 1000\,\Omega$. The h-parameters are $h_{ie} = 1\,k\Omega$; $h_{re} = 2\times10^{-4}$; $h_{fe} = 50$; $h_{oe} = 25\,\mu A/V$. Compute the current gain A_I, Input resistance R_i, A_V, R_o using exact analysis and using approximate analysis.

Sol: ① EXACT ANALYSIS:

* $A_I = \frac{-h_{fe}}{1+h_{oe}R_L}$

$= \frac{-50}{1+0.025}$

$= \frac{-50}{1.025}$

$\boxed{A_I = -48.78}$

* $R_i = h_{ie} + h_{re} \cdot A_I \cdot R_L$

$= 1k\Omega + 2\times10^{-4} \times -50\times10^{3}$

$= 1k\Omega + 100\times10^{-1}$

$\boxed{R_i = 1k\Omega - 10} = 990.20$

* $A_V = A_I \cdot \frac{R_L}{R_i}$

$= -48.78 \times \frac{10^3}{990.20}$

$\boxed{A_V = +49.[illegible]}$

② APPROXIMATE ANALYSIS:

* $A_I = -h_{fe}$

$A_I = -50$

$h_{oe}R_L = 25\times10^{-6} \times 1000$

$h_{oe}R_L = 0.025$

* $R_i = h_{ie}$

$\boxed{R_i = 1k\Omega}$

* $A_V = \frac{-h_{fe}}{h_{ie}} R_L$

$= \frac{-50}{1k\Omega} \times 10^3$

* $R_O = \frac{1}{Y_O}$ * $R_O = \alpha$

$$= \frac{1}{h_{oe} - \frac{h_{re}h_{fe}}{R_s + h_{ie}}} = \frac{1}{25\times10^{-6} - \frac{10^{-2}}{800+10^3}}$$

$\boxed{R_O = 51.42 k\Omega}$

* $R_O' = R_L$ * $R_O' = R_L$

(5) A voltage source of internal resistance, $R_s = 900\Omega$, dries a CC amplifier using Load resistance, $R_L = 2000\Omega$. The CE h-parameters are $h_{ie} = 1200\Omega$, $h_{re} = 2\times10^{-4}$, $h_{fe} = 60$, $h_{oe} = 25\,\mu A/V$. compute A_I, R_i, A_V, R_O using Exact & Approximate analysis. $h_{ic}: h_{ie} = 1200\Omega$, $h_{fc} = -(1+h_{fe}) = -61$, $h_{rc} = 1$, $h_{oc} = h_{oe} = 25\,\mu A/V$

Sol:- EXACT ANALYSIS

(1) $A_I = \frac{-h_{fc}}{1+h_{oe}R_L}$

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

$= \frac{1+60}{1+25\times10^{-6}\times2\times10^3}$

$= \frac{61}{1+5\times10^{-2}}$

$= \frac{61}{1+0.05}$

$\boxed{A_I = 58.095}$

(2) $R_i = h_{ic} + h_{rc}\cdot A_I\cdot R_L$

$= 1200 + 1\times58.095\times2\times10^3$

$= 1200 + 116190$

$= 117390$

$\boxed{R_i = 117.39 k\Omega}$

(3) $A_V = A_I\cdot\frac{R_L}{R_i}$

$= 58.095\times\frac{2\times10^3}{117.39\times10^3}$

$= 58.095\times0.017$

$\boxed{A_V = 0.987}$

APPROXIMATE ANALYSIS

(1) $A_I = 1 + h_{fe}$

$= 1 + 60$

$\boxed{A_I = 61}$

(2) $R_i = h_{ie} + (1+h_{fe})R_L$

$= 1200 + (1+60)\,2\times10^3$

$= 1200 + 122\times10^3$

$= 123200$

$\boxed{R_i = 123.2 k\Omega}$

(3) $A_V = \frac{(1+h_{fe})R_L}{h_{ie} + (1+h_{fe})R_L}$

$= \frac{61\times2\times10^3}{123.2\times10^3}$

$\boxed{A_V = 0.9902}$

(4) $R_O = \frac{R_s + h_{ie}}{1+h_{fe}}$

$= \frac{900+1200}{1+60}$

$R_O = \frac{2100}{61}$

$\boxed{R_O = 34.42}$

④ $R_O = \frac{1}{Y_O}$

$= \frac{1}{h_{oc} - \frac{h_{rc} h_{fc}}{R_s + h_{ic}}} = \frac{1}{25\times10^{-6} - \frac{1, -61}{900+1200}} = \frac{1}{25\times10^{-6} + 0.0290476} = \frac{1}{0.029}$

$\boxed{R_O = 3.442}$

③ For a CB transistor amplifier driven by a voltage source of internal resistance, $R_s = 1200\Omega$, $R_L = 1000\Omega$, the h-parameters are $h_{ib} = 22\Omega$, $h_{rb} = 3\times10^{-4}$, $h_{fb} = -0.98$, $h_{ob} = 0.5\mu A/V$. Compute $A_I, R_i, A_V, R_O, A_{VS}, A_{IS}, A_P$, using exact and approximate analysis.

Sol: Given, $R_s = 1200\Omega$
$R_L = 1000\Omega$

$h_{ib} = 22\Omega$, $h_{ib} : \frac{h_{ie}}{1+h_{fe}}$

$h_{rb} = 3\times10^{-4}$, $h_{rb} : \frac{h_{ie}.h_{oe}}{1+h_{fe}} - h_{re}$

$h_{fb} = -0.98$, $h_{fb} : -h_{fe}/1+h_{fe}$

$h_{ob} = 0.5\mu A/V$, $h_{ob} : h_{oe}/1+h_{fe}$.

EXACT ANALYSIS:

① $A_I = \frac{-h_{fb}}{1+h_{ob}R_L} = \frac{+0.98}{1+0.5\times10^{-6}\times10^{3}}$

$= \frac{0.98}{1+0.0005}$

$\boxed{A_I = 0.979}$

0.98

→ $A_I = \frac{-h_{fb}}{1+h_{ob}R_L}$

→ $R_i = h_{ib} + h_{rb} A_I R_L$

→ $A_V = A_I \cdot \frac{R_L}{R_i}$

→ $R_O = \frac{1}{Y_O} - \frac{h_r h_f}{R_s + h_{ie}} + h_o$

→ $A_{VS} = A_V \cdot \frac{R_i}{R_s + R_i}$

→ $A_{IS} = A_I \cdot \frac{R_s}{R_s + R_i}$

② $R_i = h_{ib} + h_{rb} \cdot A_I \cdot R_L$

$= 22 + (3\times10^{-4} \times 0.979\times10^{3})$

$= 22 + 2.937\times10^{-1}$

$\boxed{R_i = 22.2937\Omega}$

③ $A_V = A_I \cdot \frac{R_L}{R_i}$

$= \frac{0.979\times10^{3}}{22.2937}$

$= 0.043913\times10^{3}$

$\boxed{A_V = 43.913}$

④ $R_O = \frac{1}{0.5\times10^{-6} + \frac{3\times10^{-4}.0.98}{1200+22}}$

$= \frac{1}{0.5\times10^{-6} + 2.94\times10^{-4}} = \frac{1}{0.5\times10^{-6} + 2.4059\times10^{-7}}$

$R_O =$

$$= \frac{10^6}{0.7405}$$

$$\boxed{R_O = 1.35 \times 10^6}$$

$\Rightarrow y_0 = 0.7405 \times 10^6$

(5) $A_{VS} = A_V \cdot \frac{R_i}{R_s + R_i}$

$$= 43.913 \cdot \frac{22.293}{1222.29}$$

$$= \frac{978.952}{1222.29}$$

$$\boxed{A_{VS} = 0.8009}$$

(6) $A_{IS} = A_I \cdot \frac{R_S}{R_s + R_i}$

$$= 0.979 \times \frac{1200}{1222.29}$$

$$= \frac{1174.8}{1222.29}$$

$$\boxed{A_{IS} = 0.9611}$$

(7) $A_P = A_V \cdot A_I$

$$= 0.979 \times 43.913$$

$$\boxed{A_P = 42.99}$$

Approximate analysis

$A_I = -h_{fb} = +0.98$

$R_i = +h_{ib} = 22\,\Omega$

$A_V = \frac{-h_{fb}}{h_{ib}} R_L = \frac{0.98}{22} \times 1000 = \frac{980}{22} = 44.54$

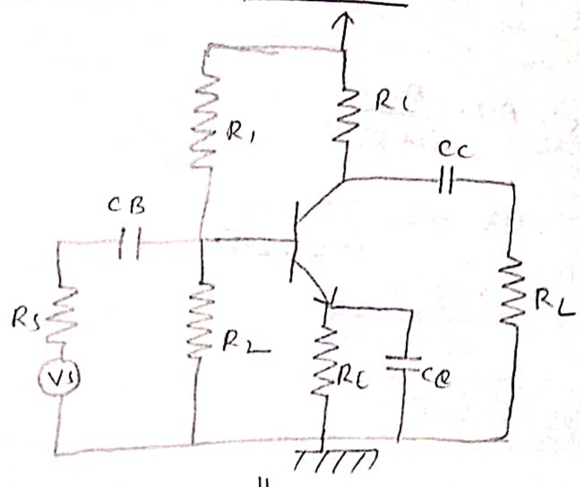
$R_O = \alpha$

$A_P = A_V \cdot A_I = 0.98 \times 44.54 = 43.64$

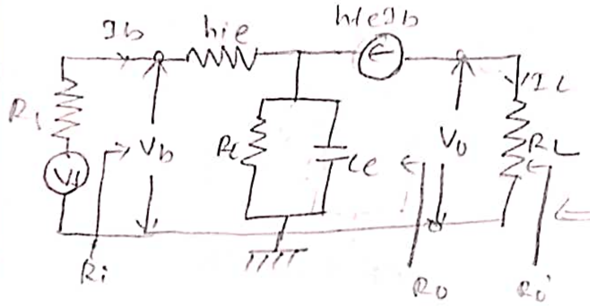
$A_{VS} = A_V \cdot \frac{R_i}{R_s + R_i} = \cancel{0.98} \times \frac{22}{22+1200} = \cancel{0.98}\ 44.54 \times \frac{22}{1222} = 0.798$

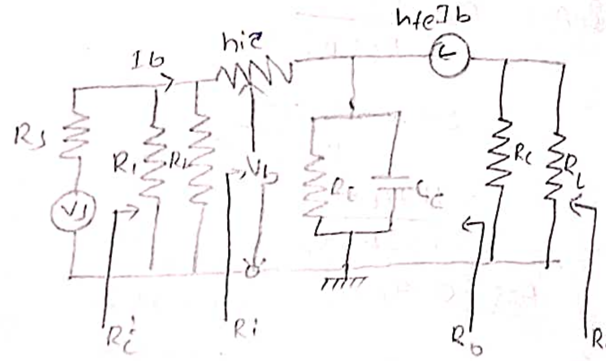
$A_{IS} = A_I \cdot \frac{R_s}{R_s + R_i} = 0.98 \times \frac{1200}{1222} = 0.958$

EFFECT OF BIPASS CAPACITOR and BLOCKING, COUPLING CAPACITOR ON LOW FREQUENCY RESPONSE.



⇓





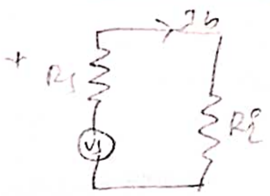
- The equations which we have obtained for current and voltage gain for a small signal amplifier are applicable in the midband frequency region. where, it is assumed that reactance of coupling & bipass capacitors are negligable in this region.

Assume that in the low frequency region, the capacitors C_B & C_C are sufficiently large, so that it's reactance is small it doesn't have any effect on the response. Further it is assumed $R_1 \| R_2$ is much larger than R_L.

$$* A_V = \frac{V_O}{V_S}$$

$$\rightarrow V_O = I_L R_L$$

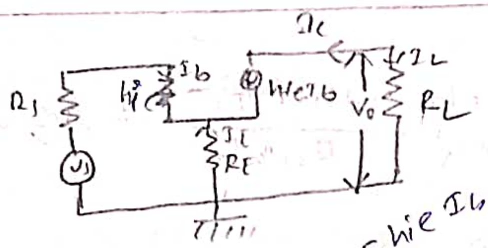
$$\boxed{V_O = -h_{fe} I_b R_L}$$

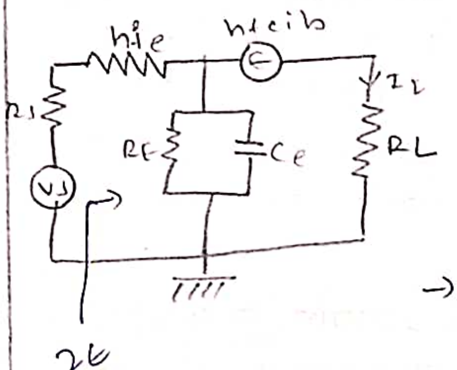


$$I_b = \frac{V_s}{R_s + R_i}$$

$$\rightarrow R_i = \frac{V_b}{I_b}$$

$$V_b = I_b h_{ie} + (1+h_{fe}) I_b \cdot R_E$$





$V_b = h_{ie} I_b + I_E R_E$

$= h_{ie} I_b + (I_b + h_{fe} I_b) R_E$

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

$$R_i = \frac{V_b}{I_b} = h_{ie} + (1+h_{fe}) R_E$$

$$R_i = h_{ie} + (1+h_{fe}) Z_E$$

$$\rightarrow Z_E = R_E \parallel \frac{1}{j\omega C_e}$$

$$= \frac{R_E \parallel j\omega C_e}{R_E + \frac{1}{j\omega C_e}}$$

$$Z_E = \frac{R_E}{1 + R_E j\omega C_e}$$

$$\therefore R_i = h_{ie} + (1+h_{fe}) \cdot \frac{R_E}{1 + R_E j\omega C_e}$$

$$\therefore I_b = \frac{V_s}{R_s + h_{ie} + \frac{(1+h_{fe}) R_E}{1 + R_E j\omega C_e}}$$

$$\frac{V_o}{V_s} = \frac{-h_{fe} I_b R_L}{I_b \cdots}$$

$$\therefore \boxed{A_{V(LF)} = \frac{V_o}{V_s} = \frac{-h_{fe} R_L}{R_s + h_{ie} + \frac{(1+h_{fe}) R_E}{1 + R_E j\omega C_e}}}$$

At midband frequency, ω is high. Therefore, $\frac{(1+h_{fe}) R_E}{1 + R_E j\omega C_e}$ is neglected comparing with $R_s + h_{ie}$.

$$\therefore \boxed{A_{V(MF)} = \frac{-h_{fe} R_L}{R_s + h_{ie}}}$$

$$\cancel{A_{V(HF)} = \frac{-h_{fe}}{1 + h_{oe} R_L}}$$

$$\therefore \frac{A_{V(LF)}}{A_{V(MF)}} = \frac{R_s + h_{ie}}{R_s + h_{ie} + \frac{(1+h_{fe}) R_E}{1 + R_E j\omega C_e}}$$

$$= \frac{1}{1 + \frac{(1+h_{fe}) R_E}{1 + R_E j\omega C_e} \cdot \frac{1}{R_s + h_{ie}}}$$

$$= \frac{1}{1 + \frac{(1+h_{fe}) R_E}{R_s + h_{ie}} \cdot \frac{1}{1 + R_E j\omega C_e}}$$

let, $b = \frac{(1+h_{fe})R_E}{R_s+h_{ie}}$ & $c = \omega R_E C_e$

$$\therefore \frac{A_{V(LF)}}{A_{V(MF)}} = \frac{1}{1+\frac{b}{1+jc}} = \frac{1}{1+\frac{b(1-jc)}{1+c^2}}$$

$$= \frac{1}{1+\frac{b-jbc}{c^2}} \quad \because [c^2 >> 1]$$

$$= \frac{1}{1+\frac{b}{c^2}-\frac{jbc}{c^2}}$$

$$\boxed{\frac{A_{V(LF)}}{A_{V(MF)}} = \frac{1}{1-\frac{jb}{c}}} \quad \because \left[\frac{b}{c^2} << 1\right]$$

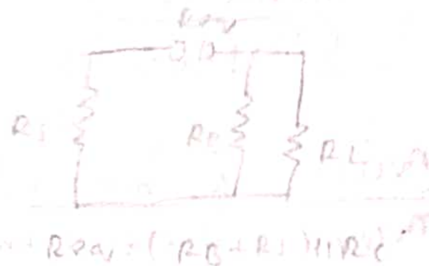
$$* \; A_{V(LF)} = \frac{1}{1-j\left(\frac{f_L}{f}\right)}$$

$$\therefore \frac{f_L}{\cancel{f}} = \frac{b}{c} = \frac{(1+h_{fe})\cancel{R_E}}{R_s+h_{ie}} \cdot \frac{1}{2\pi \cancel{f} \cancel{R_E} C_e}$$

$$\boxed{f_L = \frac{(1+h_{fe})}{(R_s+h_{ie})2\pi C_e}}$$

$$\therefore \boxed{C_e = \frac{(1+h_{fe})}{(R_s+h_{ie})2\pi f_L}}$$

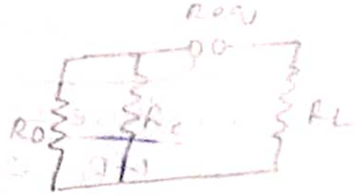
$$* \; f_L = \frac{1}{2\pi R_{eq} C_B}$$



$$\boxed{f_L = \frac{1}{2\pi[(R_s+R_B)||R_L]C_B}}$$

$R_{eq} = (R_B+R_s)||R_L$

$$* \; f_L = \frac{1}{2\pi R_{eq} C_c}$$



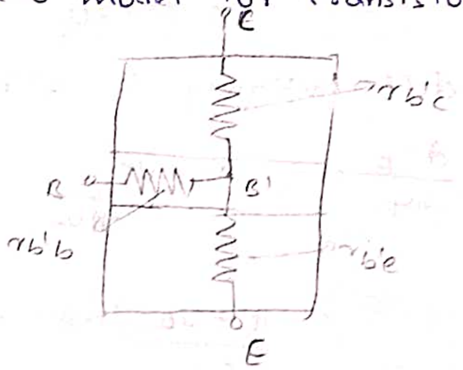
$$\boxed{f_L = \frac{1}{2\pi[R_o||(R_c+R_L)]C_c}}$$

$R_{eq} = R_o||(R_c+R_L)$

* HYBRID π MODEL/TRANS CONDUCTANCE MODEL:

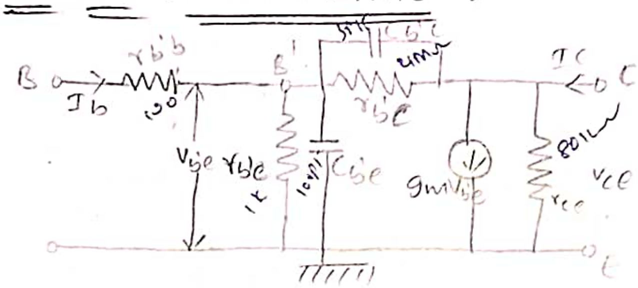
At high frequencies the capacitive effects of transistor junction and the delay in the response of the transistor caused by the process of diffusion carriers taken into account in determining the high frequency model of a transistor.

- A high frequency π model/ Giacoleto model for transistor is shown in figure.



B': virtual base

* HYBRID π MODEL FOR A TRANSISTOR IN CE CONFIGURATION:



- $r_{bb'}$:- is a base spreading resistance b/w actual Base 'b' & virtual base 'b''. It's Typical value is 100Ω.

- $r_{b'e}$:- Resistance b/w virtual base B' and emitter terminal 'E'. Typical value is 1KΩ

- $r_{b'c}$: Resistance b/w virtual base B' and collector terminal 'c'. It has a large value, which is 4MΩ.

- $C_{b'e}$ (C_d): Diffusion capacitance of the normally forward biased BE junction. Typical value is 100 PF.

- $C_{b'c}$ (C_t): Transition capacitance of the normally reverse biased CB junction. Typical value is 3PF.

- $g_m V_{b'e}$: Output current generator where 'g_m' is the trans conductance of the transistor.

- r_{ce} : Output resistance with a typical value of 80KΩ.

Hybrid π Conductance In Terms of Low Frequency h-parametrs:

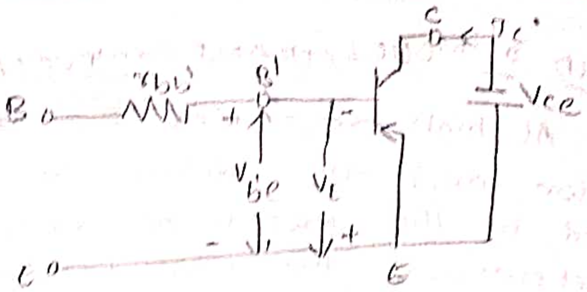
→ $\boxed{I_C = I_0 - \alpha I_E}$

⇒ $\alpha = \dfrac{I_0 - I_C}{I_E}$

$\boxed{I_C = -\alpha I_E}$

⇒ $I_C = -\alpha I_E$

⇒ $I = I_0(e^{V/\eta V_T} - 1)$



$I_E = I_0(e^{V_E/\eta V_T} - 1)$

$I_E = I_0 e^{V_E/\eta V_T} - I_0$

⇒ $\boxed{I_0 e^{V_E/\eta V_T} = I_E + I_0}$

- differentiating 'I_E' w.r.to 'V_E',

$$\frac{\partial I_E}{\partial V_E} = I_0 \cdot e^{V_E/\eta V_T} \cdot \frac{1}{\eta V_T}$$

$$= \frac{I_E + I_0}{\eta V_T}$$

$$\boxed{\frac{\partial I_E}{\partial V_E} = \frac{I_E}{\eta V_T}}$$

⇒ Trans conductance, $g_m = \frac{\partial I_C}{\partial V_{b'e}}$

$$= \frac{-\alpha \partial I_E}{\partial V_{b'e}}$$

$$= \alpha \cdot \frac{\partial I_E}{\partial V_E}$$

$$= \alpha \cdot \frac{I_E}{\eta V_T}$$

$$= \alpha \cdot \frac{I_C}{-\alpha \cdot \eta V_T}$$

$$g_m = \frac{-I_C}{\eta V_T}$$

[∵ $\eta = 1$, Ge
$\eta = 2$, Si]

$$\boxed{g_m = \frac{|I_C|}{V_T}}$$

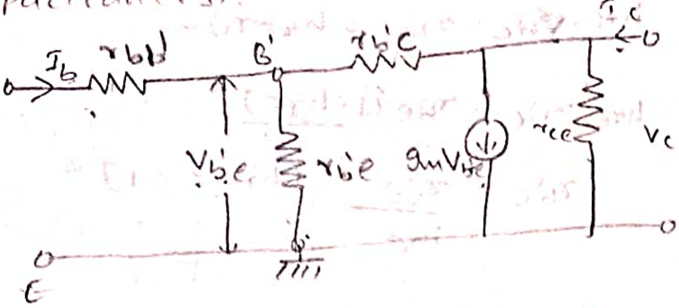
, $V_T = \frac{T}{11600}$

- For either type of transistor, g_m is +ve, where $g_m \propto I$ & $g_m \propto \frac{1}{T}$.

Hybrid π Model at Low Frequency:

(Neglecting all capacitances)

* Input Conductance ($g_{b'e}$):



$$\boxed{V_{b'e} = I_b r_{b'e}}$$

$$I_c = g_m V_{b'e}$$

$$V_{b'e} = \frac{I_c}{g_m}$$

$g_{b'e}$
$r_{bb'}$
$g_{b'c}$
g_{ce}

- $r_{b'c}$ is very high ⇒ I_b doesn't flow
- I_c also will not flow through $r_{b'c}$

$$\Rightarrow V_{b'e} = I_b r_{b'e}$$

$$\frac{I_c}{g_m} = I_b r_{b'e}$$

$$\frac{I_c}{I_b} = g_m r_{b'e}$$

$$h_{fe} = g_m r_{b'e} \quad \Rightarrow r_{b'e} = \frac{h_{fe}}{g_m}$$

$$\boxed{g_{b'e} = \frac{g_m}{h_{fe}}}$$

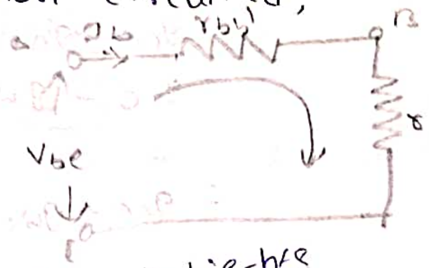
$r_{b'e} = \frac{h_{fe}}{g_m}$

$\boxed{g_{b'e} = \frac{g_m}{h_{fe}}}$

$V_{b'e} = I_b r_{b'e}$
$I_c = g_m V_{b'e}$
$V_{b'e} = \frac{I_c}{g_m}$
$\frac{I_c}{I_b} = g_m r_{b'e}$
$\frac{h_{fe}}{g_m} = r_{b'e}$
$\boxed{g_{b'e} = \frac{g_m}{h_{fe}}}$

* Base spreading resistance ($r_{bb'}$):

- Input resistance with the output is short circuited,



$$V_{be} = I_b(r_{bb'} + r_{b'e})$$

$$\frac{V_{be}}{I_b} = r_{bb'} + r_{b'e}$$

$$h_{ie} = r_{bb'} + r_{b'e} \quad (\because I_b = h_{ie})$$

$$r_{bb'} = h_{ie} - r_{b'e}$$

$r_{bb'} = h_{ie} - \frac{h_{fe}}{g_m}$

$$\boxed{r_{bb'} = h_{ie} - \frac{h_{fe}}{g_m}}$$

* Feedback Conductance: ($g_{b'c}$)

$$\rightarrow V_{b'e} = V_{cc'} \cdot \frac{r_{b'e}}{r_{b'e} + r_{b'c}}$$

$$\frac{V_{b'e}}{V_{cc'}} = \frac{r_{b'e}}{r_{b'e} + r_{b'c}}$$

$$h_{re} = \frac{r_{b'e}}{r_{b'e} + r_{b'c}}$$

$h_{re} \cdot V_{b'c} = r_{b'e} - h_{re} r_{b'e}$

$h_{re} \cdot r_{b'c} = r_{b'e}(1 - h_{re})$

$r_{b'c} = \dfrac{r_{b'e}}{h_{re}}$ [$h_{re} << 1$]

$g_{b'c} = h_{re} \cdot g_{b'e}$

$$\boxed{g_{b'c} = h_{re} \cdot \frac{g_m}{h_{fe}}}$$

$$\boxed{\begin{array}{l} g_{b'c} = h_{re} \cdot g_{b'e} \\ g_{b'c} = h_{re} \cdot \dfrac{g_m}{h_{fe}} \end{array}}$$

* Output conductance (g_{ce}):

$h_{re} = \dfrac{V_{b'e}}{V_{ce}}$

* $I_c = \dfrac{V_{ce}}{r_{ce}} + g_m V_{b'e} + \dfrac{V_{ce}}{r_{b'e} + r_{b'c}}$

$\dfrac{I_c}{V_{ce}} = \dfrac{1}{r_{ce}} + \dfrac{g_m \cdot V_{ce} \cdot h_{re}}{V_{ce}} + \dfrac{1}{r_{b'c}}$ [$r_{b'c} >> r_{b'e}$]

$h_{oe} = \dfrac{1}{r_{ce}} + g_m h_{re} + \dfrac{1}{r_{b'c}}$

$= g_{ce} + g_m h_{re} + g_{b'c}$ [$\because \dfrac{g_m}{h_{fe}} = g_{b'e}$]

$= g_{ce} + g_{b'c} + \cancel{g_{b'e}} \cdot h_{fe} \cdot \dfrac{g_{b'c}}{\cancel{g_{b'e}}}$ [$\because h_{re} = \dfrac{g_{b'c}}{g_{b'e}}$]

$= g_{ce} + g_{b'c}(1 + h_{fe})$

$h_{oe} = g_{ce} + g_{b'c} \cdot h_{fe}$ ($h_{fe} >> 1$)

$g_{ce} = h_{oe} - g_{b'c} \cdot h_{fe}$

$\boxed{g_{ce} = h_{oe} - h_{re} \cdot g_m}$

$g_{ce} = h_{oe} - h_{re} g_m$

$\Rightarrow g_{b'e} = \dfrac{g_m}{h_{fe}}$

$\Rightarrow r_{bb'} = h_{ie} - \dfrac{h_{fe}}{g_m}$

$\Rightarrow g_{b'c} = \dfrac{h_{re}\, g_m}{h_{fe}}$

$\Rightarrow g_{ce} = h_{oe} - h_{re} g_m$

$\therefore$ * $g_{b'e} = \dfrac{g_m}{h_{fe}}$

* $r_{bb'} = h_{ie} - \dfrac{h_{fe}}{g_m}$

* $g_{b'c} = h_{re} \cdot \dfrac{g_m}{h_{fe}}$

* $g_{ce} = h_{oe} - h_{re} \cdot g_m$

CE short-circuit current gain:

* $I_1 = \frac{V_1 - V_2}{R}$

$= V_1 \left[\frac{1 - \frac{V_2}{V_1}}{R}\right]$

$\frac{I_1}{V_1} = \frac{1-A}{R}$

$\therefore R_1 = \frac{R}{1-A}$

$\frac{I_1}{V_1} = \frac{r_{b'c}}{(1-A)}$

$\boxed{R_1 = \frac{r_{b'c}}{1-A}}$

* $I_2 = \frac{V_2 - V_1}{R}$

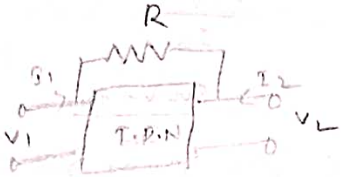
$= V_2 \left(\frac{1 - \frac{V_1}{V_2}}{R}\right)$

$\frac{I_2}{V_2} = \frac{1 - \frac{1}{A}}{R}$

$R_2 = \frac{R}{1 - 1/A}$

$R_2 = \frac{RA}{A-1}$

$\boxed{R_2 = \frac{RA}{A-1}}$



* $-jX_{cm} = \frac{-jX_{cc}}{1-A}$

$\frac{1}{2\pi C_m \cdot f} = \frac{1}{2\pi f X_c (1 + g_m R_L)}$

$\therefore [A_V = \frac{V_{cc}}{V_{b'e}}, V_{cc} = I_L R_L = -I_c R_L = -g_m V_{b'e} . R_L]$

$[A_V = \frac{-g_m [V_{b'e}] . R_L}{V_{b'e}}]$

$\boxed{A_V = -g_m . R_L}$

$\frac{1}{C_m} = \frac{1}{C_c (1 + g_m R_L)}$

$\boxed{C_m = C_c (1 + g_m R_L)}$

* $X_{cm} = \frac{X_{cc}}{1 - \frac{1}{A}}$

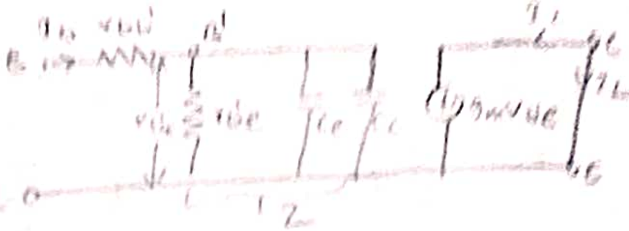
$= \frac{X_{cc}}{\left[1 - \left(\frac{-1}{g_m R_L}\right)\right]}$

$= \frac{X_{cc}(g_m R_L)}{g_m R_L + 1} = \frac{X_{cc}(g_m R_L)}{g_m R_L + 1}$

$\frac{1}{\omega . C_m} = \frac{g_m R_L}{\omega . C_c (g_m R_L + 1)} = \frac{g_m R_L}{\omega (g_m R_L + 1)}$

$C_m = \frac{C_c (g_m R_L + 1)}{g_m R_L} \Rightarrow \boxed{C_m = \frac{C_c (g_m R_L + 1)}{g_m R_L}}$

The transistor high frequency capability can be known by expressing the CE shortcircuit current gain as a function of frequency.



* $A_I = \frac{I_L}{I_b}$

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

$= -\frac{g_m V_{b'e}}{I_b}$

$= -g_m \cdot \frac{I_b Z}{I_b}$

$= -g_m \cdot \frac{r_{b'e}}{r_{b'e} \cdot j\omega(C_e + C_c) + 1}$

$= -\frac{g_m \cdot r_{b'e}}{r_{b'e} j\omega(C_e + C_c) + 1}$

$V_{b'e} = I_b Z$

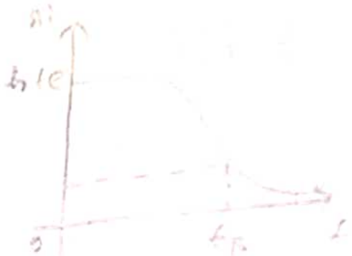
$Z = r_{b'e} \parallel -j\frac{1}{\omega(C_e+C_c)}$

$= \frac{r_{b'e} \cdot \frac{1}{j\omega(C_e+C_c)}}{r_{b'e} + \frac{1}{j\omega(C_e+C_c)}}$

$Z = \frac{r_{b'e}}{r_{b'e}[j\omega(C_e+C_c)]+1}$

$A_i = \frac{-h_{fe}}{1 + j\left(\frac{f}{f_B}\right)}$ $\left[f_B = \frac{1}{2\pi(C_e+C_c)r_{b'e}}\right]$

$$\boxed{|A_i| = \frac{h_{fe}}{\sqrt{1 + \left(\frac{f}{f_B}\right)^2}}}$$



when, $f = f_B$

$$\boxed{|A_i| = \frac{h_{fe}}{\sqrt{2}}}$$

- The frequency range upto 'f_B' is referred to as the Bandwidth of the circuit.
- The value of 'A_i' at $\omega = 0$ is '$-h_{fe}$'.

→ $-h_{fe}$ is the low frequency short circuit CE current gain.

⇒ 'f_B' is the frequency at which a transistor CE short circuit currentgaindrops 3 dB ($\frac{1}{\sqrt{2}}$) times h_{fe}. From its value at lower mid frequencies.

⇒ f_B is also called as "B-cutoff frequency".

α cutoff frequency: A CB amplifier has a much higher 3DB frequency than a CE amplifier with o/p short circuited

$$A_i = \frac{I_L}{I_b}$$

$$\boxed{A_i = \frac{-h_{fb}}{1+j\left(\frac{f}{f_\alpha}\right)}}$$

$$h_{fb} = \frac{-h_{fe}}{1+h_{fe}}$$

$$f_\alpha = \frac{1}{2\pi r_{b'e}(1+h_{fb})C_{b'e}} \approx \frac{h_{fe}}{2\pi r_{b'e} . C_{b'e}}$$

$$f_\alpha = \frac{h_{fe} . f_\beta (C_{b'e}+C_{b'c})}{C_{b'e}}$$

→ 'f_α' is the 'α' cutoff frequency at which the CB short-circuit current gain drops 3DB from it's value at low frequencies.

Parameter (f_T):-

Which is defined as the frequency at which s.c CE current gain attains unit magnitude.

$$A_i = \frac{-h_{fe}}{1+\frac{f}{f_\beta}}$$

$$|A_i| = 1$$

$$1 = \frac{h_{fe}}{\sqrt{1+\left(\frac{f_T}{f_\beta}\right)^2}} \qquad \left(\frac{f_T}{f_\beta}\right)^2 >> 1$$

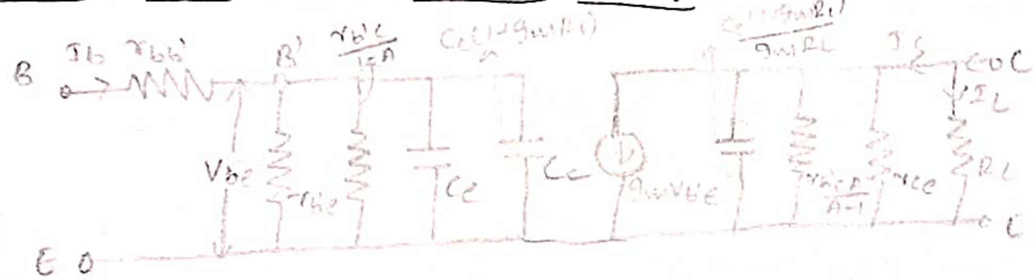
$$\therefore \frac{f_T}{f_\beta} = h_{fe}$$

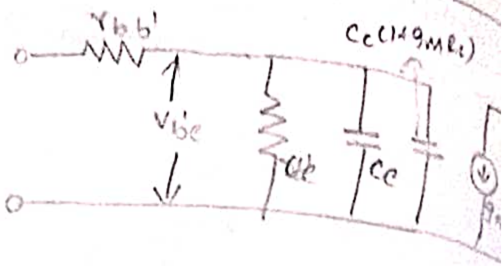
$$\boxed{f_T = h_{fe} . f_\beta}$$

→ 'f_T' is gain, Band width product.

- In the case of CB, $\boxed{f_T = h_{fb} . f_\alpha}$

CE Current gain with resistive load:-





$$\boxed{A_i = \frac{-h_{fe}}{1+j\left(\frac{f}{f_2}\right)}}$$

where, $f_2 = \dfrac{1}{2\pi \cdot r_{b'e}(C_e + C_c(1+g_mR_L))}$

24/11/2020

2. FET AMPLIFIERS

* Impedance Mismatch
↓
Loading Effect

CS →
CD → $A_V < 1 \approx 1$ → B.A ($V_0 = V_i$)

Field Effect Transistor

FET Amplifiers provide an excellent voltage gain with the added feature of high input impedance. They have low power consumption with a good frequency range, minimal size & weight. Therefore, FETs are preferable than BJTs. Both JFET & DEPLETION MOSFET Devices can be used to design amplifiers having similar voltage gain. The depletion MOSFET circuit has much higher input impedance than a similar JFET configuration.

The Common source configuration is the most popular one providing inverted and amplified signal. However, the CD [source follower] circuit provides unity gain with no inversion and CG circuit provides gain with no inversion.

Due to very high i/p impedance, the i/p current is generally assumed to be negligible, and it is of the order of few micro amps (μA) and the current gain is an undefined quantity.

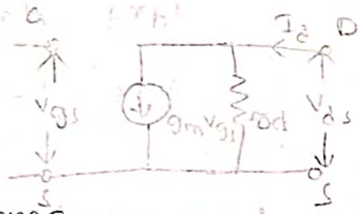
SMALL SIGNAL MODEL OF FET AMPLIFIER:

From the drain and Transfer characteristics of the FET, the drain current is a function of drain-source voltage (V_{DS}) & ~~gate~~ gate-source voltage (V_{GS}). The small signal model of FET can be drawn analogous to BJT.

$$\boxed{i_D = f(V_{GS}, V_{DS})}$$

The change in drain current is given approximately By first 2 terms in the Taylor's series expansion of above equation is,

$$\Delta i_D = \frac{\partial i_D}{\partial V_{GS}}\bigg|_{V_{DS}} \Delta V_{GS} + \frac{\partial i_D}{\partial V_{DS}}\bigg|_{V_{GS}} \Delta V_{DS}$$



For small signal model, notations become, SSM FET in CS (a)

$$\Delta i_d = i_d \; ; \; \Delta V_{GS} = V_{gs} \; ; \; \Delta V_{DS} = V_{ds}$$

$$i_d = \frac{\partial i_D}{\partial V_{GS}}\bigg|_{V_{DS}} \cdot V_{gs} + \frac{\partial i_D}{\partial V_{DS}}\bigg|_{V_{GS}} V_{ds}$$

$g_m V_{gs}$
V_{ds}

$$\Rightarrow \frac{\partial i_D}{\partial V_{GS}}\bigg|_{V_{DS}} = \frac{\Delta i_D}{\Delta V_{GS}}\bigg|_{V_{DS}} = \underline{g_m}$$

$\because V \propto I$
$V = IR$
$I = \frac{V}{R}$
$\frac{1}{R} = \frac{I}{V}$

$$\Rightarrow \frac{\partial i_D}{\partial V_{DS}}\bigg|_{V_{GS}} = \frac{\Delta i_D}{\Delta V_{DS}}\bigg|_{V_{GS}} = \frac{1}{r_d}$$

$$\therefore \boxed{i_d = g_m V_{gs} + \frac{1}{r_d} \cdot V_{ds}}$$

A small signal model for FET in common source configuration is shown in figure-ⓐ, it has Norton's output circuit with a dependent current generator, whose magnitude is proportional to the Gate-Source Voltage.

→ The proportionality factors trans conductance 'g_m'

→ r_d is the internal drain resistance

→ The i/p resistance b/w gate & source is infinite, since it is assumed that the reverse biased gate draws no current.

→ The small signal model for CS FET can be used for analysing the 3 basic FET amplifier configurations.

① Common Source

② Common Drain / Source Follower

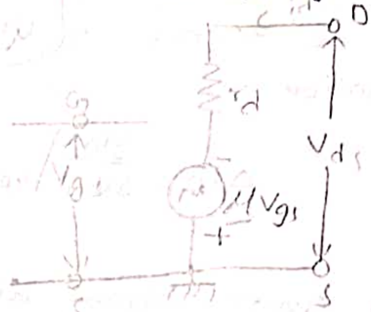
③ Common Gate

- The CS amplifier provides good voltage amplification
- The CD amplifier with high input impedance and near unity voltage gain is used as a Buffer amplifier
- The CG amplifier is used as high frequency amplifier
- The small signal current source model for the FET in CS configuration shown is figure ⓐ is redrawn with the voltage source model (Thevenin's Equivalent) is shown in Figure ⓑ

$$i_d r_d = g_m r_d v_{gs} + V_{ds}$$

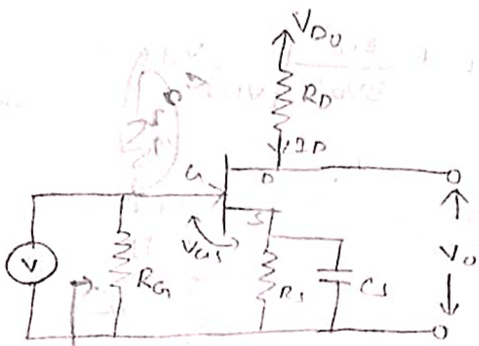
$$\boxed{V_{ds} = i_d r_d - \mu V_{gs}}$$

$$\boxed{\mu = g_m r_d}$$



ⓑ

COMMON SOURCE AMPLIFIER:



A simple CS amplifier is shown in figure and associated SCE circuit using voltage source model of FET is shown in figure.

* Voltage gain:

It is the ratio of o/p voltage to i/p voltage.

$$A_v = \frac{o/p}{i/p} = \frac{V_{ds}}{V_{gs}}$$

$$\rightarrow V_{ds} = -\mu v_{gs} \cdot \frac{R_D}{r_d + R_D}$$

$$\frac{V_{ds}}{V_{gs}} = -\mu \cdot \frac{R_D}{r_d + R_D}$$

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

* Input impedance:

$$Z_i = R_G$$

with voltage divider bias,

$$\boxed{Z_i = R_1 \parallel R_2}$$

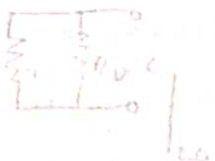
* Output impedance:

Output impedance is the impedance measured at the o/p terminals with i/p voltage $V_i = 0$.

when, $V_i = 0 \Rightarrow V_{gs} = 0$

$\therefore \mu v_{gs} = 0$

$$\boxed{Z_0 = r_d \parallel R_D}$$



① In the CS amplifier as shown in figure $R_D = 5\,k\Omega$, $R_G = 10\,M\Omega$, $\mu = (50)$ & $r_d = 35\,k\Omega$. Evaluate A_v, Z_i, Z_0.

sol Given, $R_D = 5\,k\Omega$

$R_G = 10\,M\Omega$

$\mu = (50)$

$r_d = 35\,k\Omega$

$$\therefore A_v = \frac{-\mu \cdot R_D}{r_d + R_D}$$

$$A_v = -\frac{(50) \cdot 5}{35+5} = \frac{-250}{40} = -6.25$$

* $Z_i = R_G = 10\,M\Omega$

$* \; Z_o = R_d \parallel r_d$

$= 5k\Omega \parallel 35k\Omega$

$\boxed{Z_o = 5k\Omega}$

(1) A FET amplifier in CS configuration uses a load resistance 500 kΩ. The AC drain resistance of the device is 100 kΩ. Trans conductance is 0.8 mA/V. Calculate 'Av' of amplifier.

sol. Given, $R_L = 500k\Omega \; (R_D)$

$r_d = 100k\Omega$

$g_m = 0.8$

$\mu = g_m r_d$

$\mu = 0.8 \times 100k$

$\boxed{\mu = 80k}$

$$A_V = -80\times10^3 \times \frac{500\times10^3}{500\times10^3 + 100\times10^3}$$

$$= \frac{-4\times10^6}{600} = -\frac{4}{6}\times10^4$$

$$= -0.66\times10^4$$

$$\boxed{A_V = -6\times10^3}$$

$=$

$$= \frac{-80\times500\times10^6}{(500+100)10^3}$$

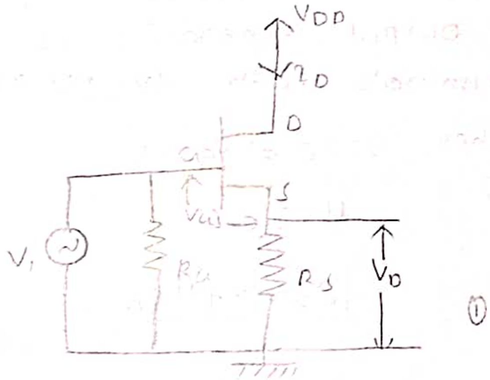
$$= -\frac{4\times10^3\times10^6}{600\times10^3}$$

$$= -\frac{4}{6}\times10^4$$

$$= -0.667\times10^4$$

$$= -6.67\times10^3$$

* COMMON DRAIN AMPLIFIER:



$i_d R_S + (i_d - g_m V_{gs}) r_d = 0$

$i_d R_S + i_d r_d - g_m V_{gs} r_d = 0$

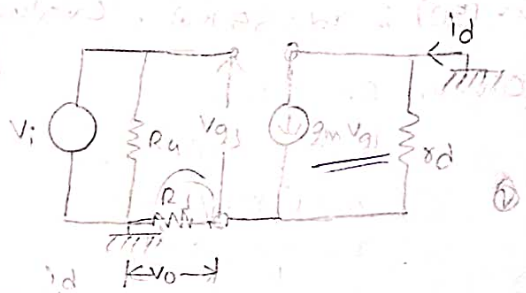
$i_d R_S + i_d r_d - g_m (v_i - i_d R_S) r_d = 0$

$i_d R_S + i_d r_d - g_m v_i \cdot r_d + g_m i_d R_S r_d = 0$

$i_d [R_S + r_d + \mu R_S] = \mu \cdot v_i$

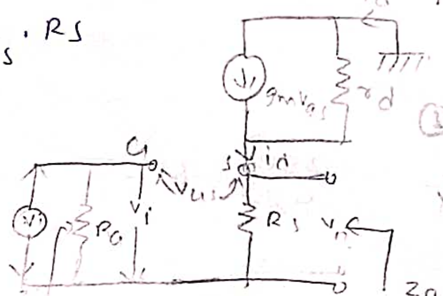
$+ g_m r_d = \mu$

$$\therefore \boxed{i_d = \frac{\mu v_i}{r_d + (\mu+1) R_S}}$$



$\rightarrow V_o = i_d R_S$

$$V_o = \frac{\mu v_i}{r_d + (\mu+1)R_S} \cdot R_S$$



$\boxed{V_{gs} = V_i - i_d R_S}$

$$\frac{V_o}{V_i} = A_v = \frac{\mu \cdot R_s}{r_d + (\mu+1)R_s} = \frac{g_m r_d R_s}{r_d + (\mu+1)R_s}$$

$$= \frac{g_m \cdot \left(\frac{r_d}{\mu+1}\right) R_s}{R_s + \left(\frac{r_d}{\mu+1}\right)}$$

$$\left[R_s >> \frac{r_d}{\mu+1}\right]$$

$$= \frac{g_m \cdot r_d \cdot \frac{R_s}{\mu+1}}{R_s} = \frac{g_m r_d}{\mu+1}$$

$$\boxed{A_v = \frac{\mu}{\mu+1}}$$

$$[\mu >> 1]$$

$$A_v = \frac{\mu}{\mu}$$

$$\boxed{A_v = 1}$$

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

$$\boxed{V_o = V_i}$$

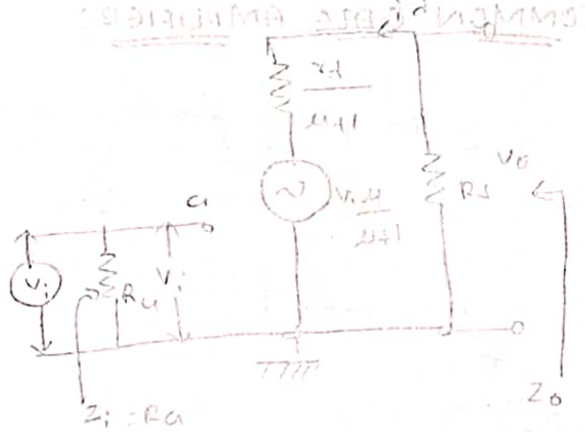
* Output impedance:

$$V_o = i_d R_s$$

$$i_d = \frac{V_o}{R_s} = \frac{A_v \cdot V_i}{R_s}$$

$$= \frac{\frac{\mu}{\mu+1} \cdot V_i \cdot \cancel{R_s}}{\left(R_s + \frac{r_d}{\mu+1}\right)\cancel{R_s}}$$

$$i_d = \frac{V_i \cdot \frac{\mu}{\mu+1}}{R_s + \frac{r_d}{\mu+1}}$$



$$\therefore Z_o = R_s \parallel \frac{r_d}{\mu+1} \quad [V_i = 0]$$

$$\boxed{Z_o = R_s \parallel \frac{1}{g_m}} \quad [\mu >> 1]$$

$$V_o = \frac{V_i \cdot \frac{\mu}{\mu+1} R_s}{R_s + \frac{r_d}{\mu+1}}$$

* $\boxed{Z_i = R_G}$

① The CD amplifier as shown in figure, $\mu = 50$, $r_d = 35$ [cut off], $R_S = 4k\Omega$, $R_G = 10M\Omega$. Evaluate voltage gain, input impedance & o/p impedance

Sol: Given, $\mu = 50$

$r_d = 35k\Omega$

$R_S = 4k\Omega$

$R_G = 10M\Omega$

$$A_V = \boxed{\frac{\mu R_S}{r_d + (\mu+1)R_S}}$$

$$\frac{50 \times 4 \times 10^3}{35\times10^3 + (51)\cdot 4\times10^3} = \frac{200}{239} = 0.836$$

① Voltage gain $= \dfrac{\mu}{\mu+1}$

$$= \frac{50}{51}$$

$$\boxed{A_V = 0.98}$$

0.8

$\mu = g_m \cdot r_d$

$g_m = \dfrac{\mu}{r_d} = \dfrac{50}{35\times}$ [cut off]

$= \dfrac{10\times10^{-3}}{7}$

$= \dfrac{10^{-2}}{7}$

$g_m = 1.42\times$ [cut off]

② Input impedance, $Z_i = R_G$

$$\boxed{Z_i = 10M\Omega}$$

③ Output impedance, $Z_o = R_S \parallel \dfrac{1}{g_m}$

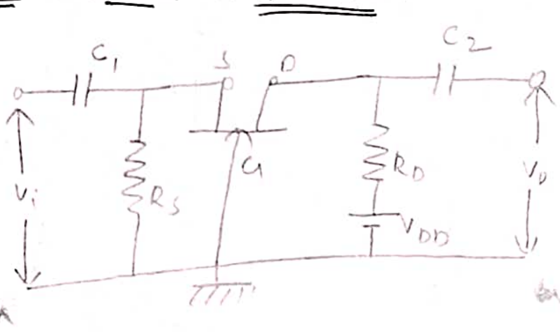
600Ω

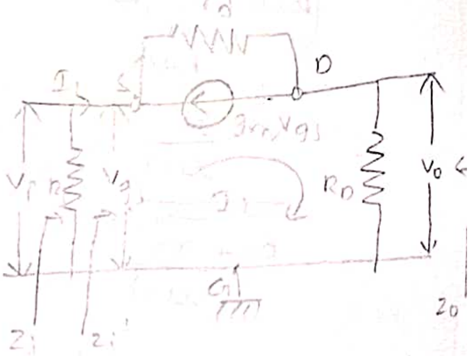
$$= 4k\Omega \parallel \frac{1}{1.42\times10^3} = 4k\Omega \parallel 0.704k\Omega$$

$$= \frac{2.816\times10^6}{4.704\times10^3} = 0.598\times10^3$$

$= 598 \Omega$ //

* **COMMON GATE AMPLIFIER:**





→ $V_i = V_s$

$V_{gs} = V_g - V_s$

$= 0 - V_s$

$V_{gs} = -V_s$

$$\boxed{V_{gs} = -V_i}$$

$$I_1 + g_m V_{gs} = I_{rd}$$

$$I_1 = I_{rd} - g_m V_{gs}$$

$$* \quad I_{rd} = \frac{V_s - V_o}{r_d}$$

$$I_{rd} = \frac{V_s - I_1 R_D}{r_d}$$

$$I_1 = \frac{V_s - I_1 R_D}{r_d} + g_m V_i$$

$$[V_i = V_s]$$

$$I_1\left(1 + \frac{R_D}{r_d}\right) = V_s\left[\frac{1}{r_d} + g_m\right]$$

$$\frac{V_s}{I_1} = \frac{1 + \frac{R_D}{r_d}}{\frac{1}{r_d} + g_m}$$

$$\boxed{Z_i' = \frac{r_d + R_D}{1 + g_m r_d}}$$

$$* \quad Z_i = Z_i'' \parallel R_s$$

$$\boxed{Z_i = R_s \parallel \frac{r_d + R_D}{1 + g_m r_d}}$$

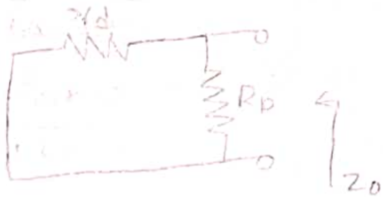
$$= R_s \parallel \frac{r_d}{g_m r_d} \qquad \left[\begin{array}{l} r_d >> R_D \\ g_m r_d >> 1 \end{array}\right]$$

$$\boxed{Z_i = R_s \parallel \frac{1}{g_m}}$$

input voltage

* Z_o is output impedance looking from output terminals with input short circuited.

$$\therefore \quad V_i = 0$$



$$\boxed{Z_o = r_d \parallel R_D}$$

$$\boxed{Z_o = R_D} \qquad (\text{if } r_d >> R_D)$$

→ Voltage gain:

$$V_o = r_d\,(i_d - g_m V_{gs}) + V_i$$

$$\left[V_o = i_d R_D \Rightarrow i_d = -\frac{V_o}{R_D}\right]$$

$$V_o = r_d\left(-\frac{V_o}{R_D} - g_m \underset{(V_i)}{V_{gs}}\right) + V_i$$

$$V_o\left[1 + \frac{r_d}{R_D}\right] = V_i\left[1 + g_m r_d\right]$$

$$\frac{V_o}{V_i} = A_V = \frac{1 + g_m r_d}{1 + \frac{r_d}{R_D}}$$

$$\boxed{A_V = \frac{R_D(1 + g_m r_d)}{r_d + R_D}}$$

① Common Gate amplifier as shown in figure $R_D = 2k\Omega$ $R_S = 1k\Omega$, $g_m = 1.43\times10^{-3}$ and $r_d = 35k\Omega$. Evaluate A_v, Z_o, Z_i

sol: Given, $R_D = 2k\Omega$

$R_S = 1k\Omega$

$g_m = 1.43\times10^{-3}$

$r_d = 35k\Omega$

① $$\boxed{A_v = \frac{R_D(1+g_m r_d)}{R_D + r_d}}$$

$$= \frac{2\times10^3[1+1.43\times10^{-3}\times35\times10^3]}{2\times10^3+35\times10^3}$$

$$= \frac{2[1+1.43\times35]}{37} \quad (2.75)$$

$$\boxed{A_v = 2.759}$$

② $$\boxed{Z_i = \frac{r_d + R_D}{1+g_m r_d} \parallel R_S}$$

$$= \frac{35\times10^3 + 2\times10^3}{1+1.43\times10^{-3}\times35\times10^3} \parallel 1\times10^3$$

$$= \frac{37\times10^3}{1+1.43\times35} \parallel 1k\Omega$$

$0.41k\Omega$

$$= \frac{37\times10^3}{51.05} \parallel 1k\Omega$$

$$= 0.724 \parallel 1k\Omega$$

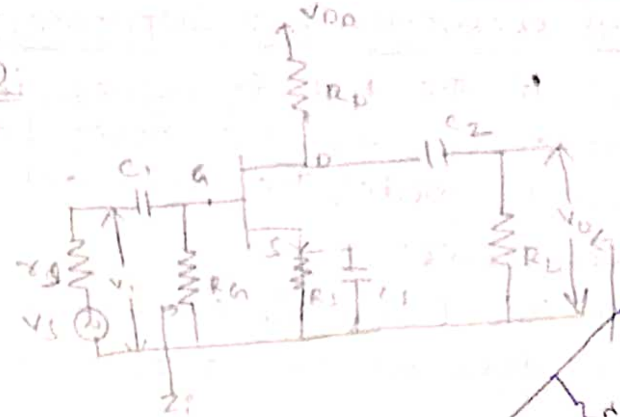
③ $\boxed{Z_o = r_d \parallel R_D}$

$= 35k\Omega \parallel 2k\Omega$

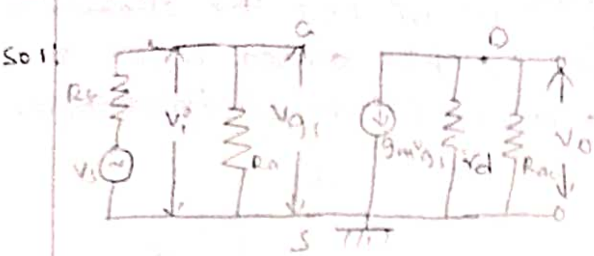
$\boxed{Z_o = 2k\Omega}$

② Calculate, A_v, A_{vs}, Z_i, Z_o.

Q:



Sol:



① $v_o = -g_m V_{gs}(r_d \parallel R_D)$

$V_o = -g_m . v_i \left[\frac{r_d . R_D}{R_D + r_d}\right]$

$\frac{V_o}{V_i} = -g_m \left[\frac{r_d R_D}{R_D + r_d}\right]$

$$\boxed{A_v = -g_m \left[\frac{r_d R_D}{R_D + r_d}\right]}$$

② $V_{gs} = V_s \left\{\frac{R_G}{R_s + R_G}\right]$

$V_s = V_{gs}\left(\frac{R_s + R_G}{R_G}\right)$

$\therefore \quad A_{vs} = \frac{V_o}{V_s} = \frac{-g_m \cancel{V_{gs}}[r_d \parallel R_D]}{\cancel{V_{gs}}\left[\frac{R_s + R_G}{R_G}\right]}$

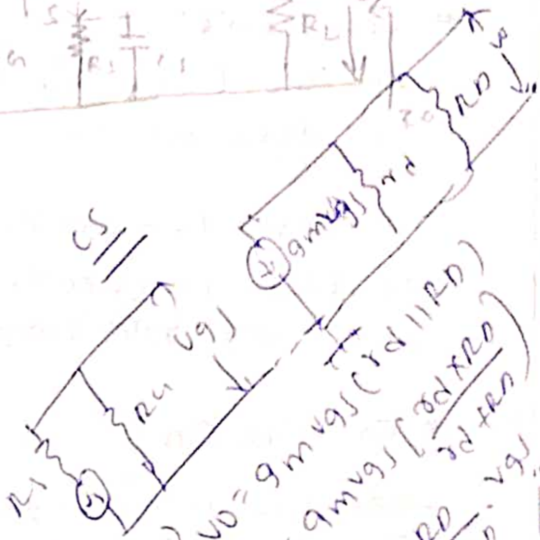
$$\boxed{A_{vs} = -g_m \left[\frac{\frac{r_d R_D}{r_d + R_D}}{\frac{R_s + R_G}{R_G}}\right]}$$

③ $Z_i = R_G$

④ $Z_o = R_D \parallel r_d$

$Z_o = R_D \parallel r_d$

CS



$\rightarrow V_o = g_m V_{gs}(r_d \parallel R_D)$

$= g_m V_{gs}\left[\frac{r_d \times R_D}{r_d + R_D}\right]$

$V_o = \frac{\mu R_D}{r_d + R_D} . V_{gs}$

$\frac{V_o}{V_{gs}} = \frac{\mu R_D}{R_D + r_d}$

$\rightarrow V_{gs} = \frac{V_s . R_G}{R_s + R_G}$

$A_v = \frac{V_o}{V_s} = \frac{-g_m V_{gs}(r_d \parallel R_D)}{\frac{V_{gs}(R_s + R_G)}{R_G}}$

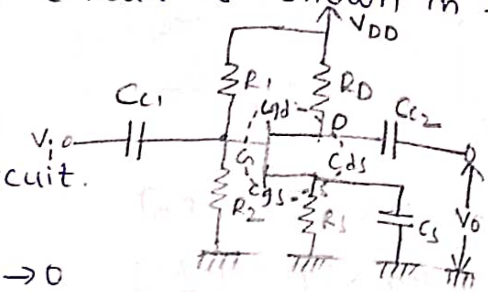
$A_{vs} = -g_m . \frac{\frac{r_d R_D}{r_d + R_D}}{\frac{R_s + R_G}{R_G}}$

$\rightarrow Z_i = R_G$

$\rightarrow Z_o = r_d \parallel R_D$ //

HIGH FREQUENCY FET AMPLIFIERS:-

In the high frequency of model of FET, the characteristic capacitances b/w the nodes have to be added in the low frequency model, the resultant circuit is shown in figure.



* C_{C1}, C_{C2}, C_S:

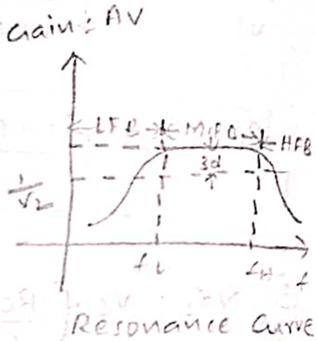
→ At low Frequency: $f \to 0$ & $X_C \to \infty$

- Capacitors act like a open circuit.

→ At high Frequencies: $f \to \infty$ & $X_C \to 0$

- At high Frequencies, the capacitors. $C_{C1}, C_{C2}, \& C_S$ will not play any role, simply acts like a short circuit.

* C_{gs}, C_{gd}, C_{ds}:



→ At low Frequency: $f \to 0$ & $X_C \to \infty$

- Capacitors act like a open circuit.

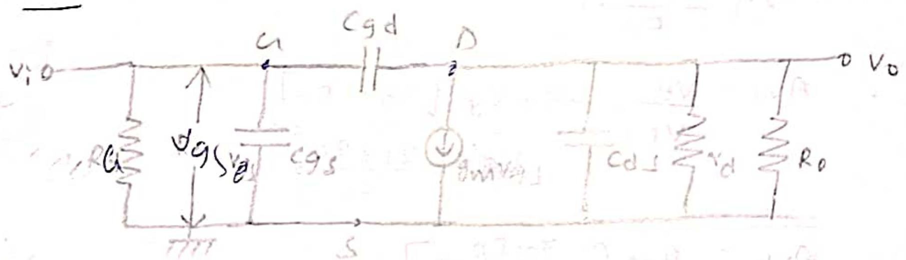
→ At high Frequency: $f \to \infty$ & $X_C \to 0$

- Capacitors act like a short circuit.

Resonance Curve

$BW = f_H - f_L$

→ Equivalent Circuit:



→ $C_{eq} = C_{gd} + C_{mi}$

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

$$f_{Hi} = \frac{1}{2\pi R\, C_{eq}}$$

$$f_{Ho} = \frac{1}{2\pi R' C_{eq}}$$

$\boxed{C_{mi} = C_{gd}(1 - A_V)}$

$\boxed{C_{mo} = C_{gd}\left(1 - \frac{1}{A_V}\right)}$

∴ $f_H = \min[f_{Hi} + f_{Ho}]$ Vi

→ 'C_{gs}' represents the barrier capacitance b/w G & S

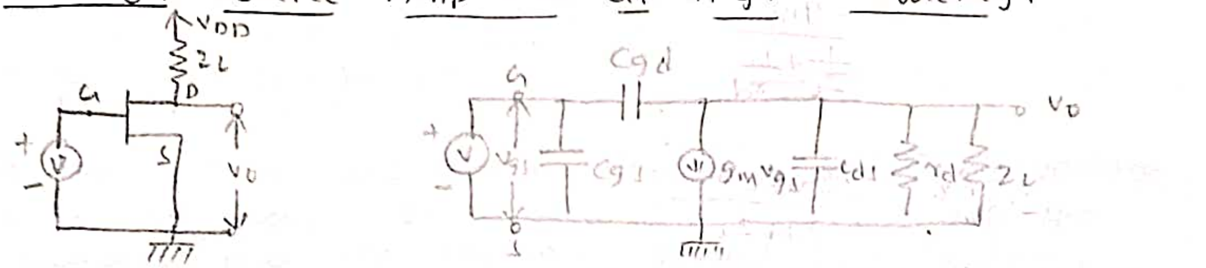
→ 'C_{gd}' represents the barrier capacitance b/w gate and drain.

→ Cds is the source capacitance of the channel. [feedback from o/p]* These internal capacitances lead to feedback from o/p to i/p and the voltage amplification decreases at high frequencies.

The parameters of FET are shown in the table:

Parameter	g_m	r_d	C_{ds}	C_{gs} C_{gd}	r_{gs}	r_{gd}
Range	0.1–10 $\frac{mA}{V}$	0.1–1 MΩ	0.1–1 PF	1–10 PF	$>10^8 \Omega$	$>10^8 \Omega$

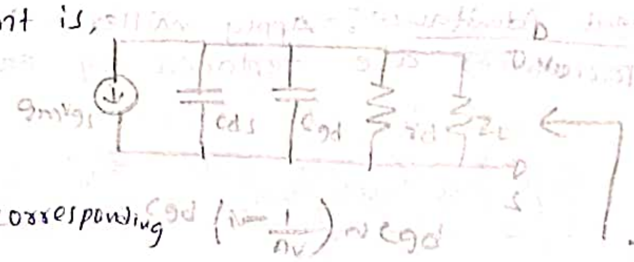
* Common Source Amplifier at high Frequency:



Small signal Equivalent circuit of CS amplifier at high frequencies

→ Admitance at o/p point is,

$$Y = \frac{1}{Z} = Y_L + g_d + Y_{gd} + Y_{ds}$$

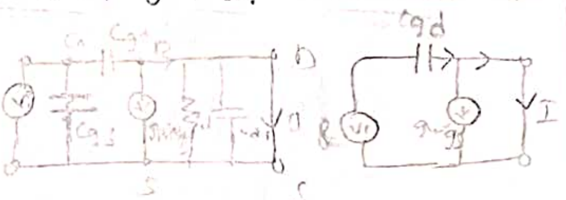


where,

- $Y_L = \frac{1}{Z_L}$ is admittance corresponding to Z_L
- $g_d = \frac{1}{r_d}$ is conductance corresponding to r_d.
- $Y_{ds} = j\omega C_{ds}$ is admitance corresponding to C_{ds}.
- $Y_{gd} = j\omega C_{gd}$ is admitance corresponding to C_{gd}.

→ The equivalent circuit to find the short circuit current from drain to source is shown in figure:

$$I = -g_m V_{gs} + \frac{V_i}{1/j\omega C_{gd}}$$



$$= j\omega C_{gd} V_i - g_m V_i$$

$$\boxed{I = V_i (j\omega C_{gd} - g_m)}$$

$$X_{cgd} = \frac{1}{j2\pi f C_{gd}}$$

$$\therefore A_V = \frac{V_O}{V_I} = \frac{IZ}{V_i} = \frac{I}{V_i Y}$$

$$\therefore \quad A_V = \frac{j\omega C_{gd} - g_m}{Y_L + g_d + Y_{ds} + Y_{gd}}$$

$$\boxed{A_V = \frac{Y_{gd} - g_m}{Y_L + g_d + Y_{ds} + Y_{gd}}}$$

- At low frequencies, FET internal capacitances can be neglected and hence, $Y_{ds} = Y_{gd} = 0$

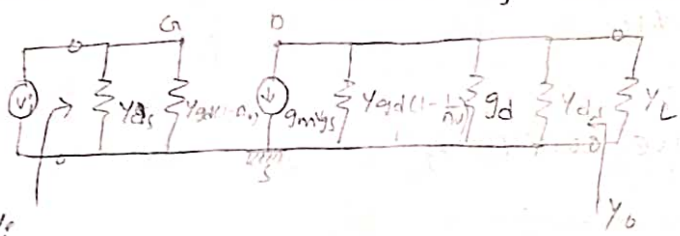
$$A_V = \frac{-g_m}{Y_L + g_d}$$

$$= \frac{-g_m}{\frac{1}{Z_L} + \frac{1}{r_d}}$$

$$\boxed{A_V = \frac{-g_m Z_L r_d}{r_d + Z_L}}$$

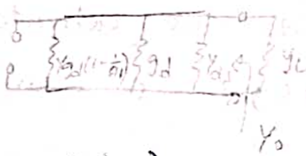
$$A_V = -g_m Z_L' \qquad [Z_L' = Z_L \parallel r_d]$$

Input Admitance :- Apply millers theorem, to the circuit, where capacitances are replaced by equivalent admitances. Therefore



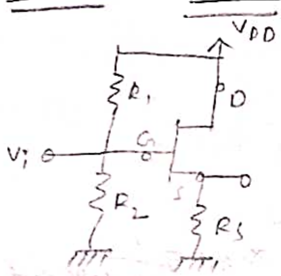
$\Rightarrow \quad Y_i = Y_{ds} + Y_{gd}(1 - A_V)$

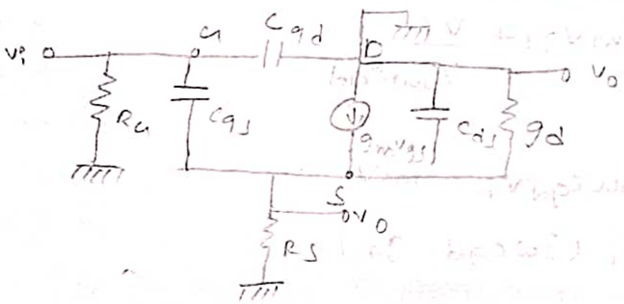
$\Rightarrow \quad Y_o = Y_{ds} + g_d + Y_{gd}\left(1 - \frac{1}{A_V}\right), \; V_i = 0$



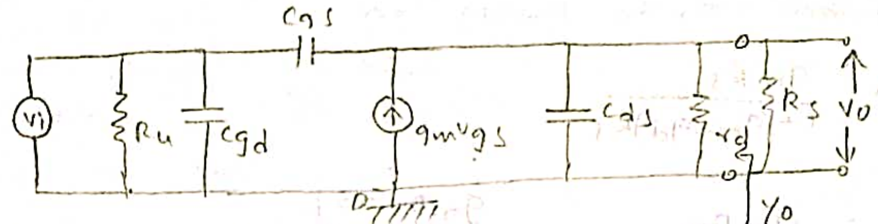
$\Rightarrow \quad Y_i = Y_{ds} + Y_{gd}(1 - A_V) + \frac{1}{r_g}, \; (r_g = r_1 \parallel r_2)$

* COMMON DRAIN AMPLIFIER AT HIGH FREQUENCIES :

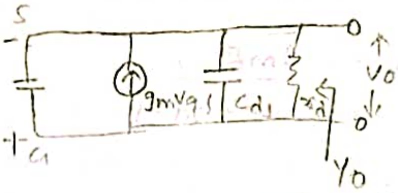




Common Drain Circuit from C.S. circuit.



→ The o/p admitance with i/p voltage set to zero is



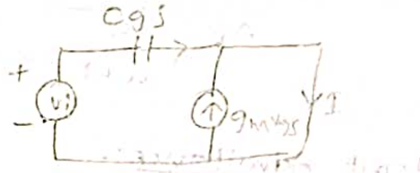
$$\rightarrow I_1 = \frac{V_1}{r_d} + \frac{V_1}{1/j\omega C_{ds}} - g_m V_{gs} - \frac{V_{gs}}{1/j\omega C_{gs}}$$

$$I_1 = \frac{V_1}{r_d} + V_1(j\omega C_{ds}) + g_m V_i + V_1 Y_{gs}$$

$$\frac{I_1}{V_1} = g_d + Y_{ds} + g_m + Y_{gs}$$

$$\therefore \boxed{Y_o = g_d + Y_{ds} + g_m + Y_{gs}}$$

→ To calculate V_o, use Norton's theorem, i.e., the o/p voltage 'V_o' is the product of short circuit current and the impedance b/w the terminals source and ground.

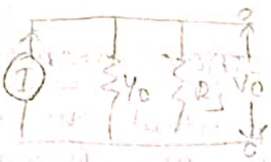


$$\rightarrow I = g_m V_{gs} + \frac{V_i}{1/j\omega C_{gs}}$$

$$I = g_m V_{gs} + V_i Y_{gs}$$
$$= V_i Y_{gs} + g_m V_i \qquad [V_{gs} = V_i]$$

$$\boxed{I = V_i(Y_{gs} + g_m)}$$

$$\rightarrow V_o = \frac{I}{Y_o + \frac{1}{R_s}}$$



$$V_o = \frac{V_i(Y_{gs} + g_m)}{Y_o + \frac{1}{R_s}}$$

$$\frac{V_o}{V_i} = \frac{Y_{gs} + g_m}{Y_o + \frac{1}{R_s}}$$

$$A_V = \frac{Y_{gs} + g_m}{\frac{1}{R_s} + g_d + Y_{ds} + g_m + Y_{gs}}$$

$$\boxed{A_V = \frac{R_s(Y_{gs} + g_m)}{1 + R_s(g_d + Y_{sd} + g_m + Y_{gs})}}$$

At low frequencies, $Y_{gs} = Y_{ds} = 0$

$$\therefore \quad A_V = \frac{g_m R_s}{1+(g_m+g_d)R_s}$$

$$= \frac{g_m R_s}{(g_m+g_d)R_s} \qquad [g_m R_s >> 1]$$

$$A_V = \frac{g_m R_s}{g_m R_s + g_d R_s}$$

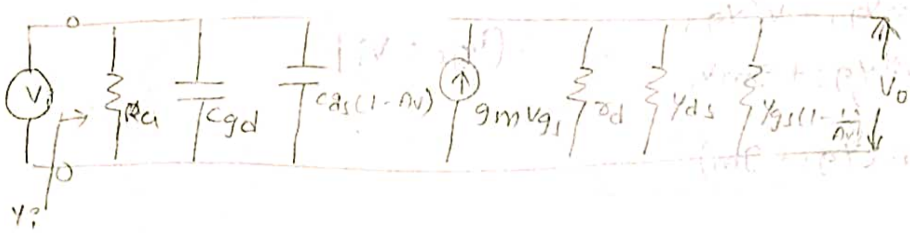
$$\boxed{A_V = \frac{g_m}{g_m+g_d}}$$

$$= \frac{g_m}{g_m + \frac{1}{r_d}}$$

$$= \frac{g_m r_d}{g_m r_d + 1}$$

$$\boxed{A_V = \frac{\mu}{\mu+1}}$$

<u>Input Admitance</u>:-



$$\rightarrow Y_i = \frac{1}{R_a} + Y_{gd} + Y_{gs}(1-A_V)$$

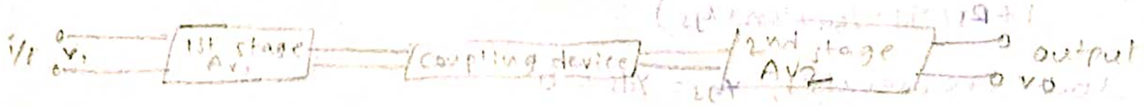
* MULTI STAGE AMPLIFIER:

In practical the o/p of a single state amplifier is insufficient though they are power and voltage amplifier. Hence they are replaced by multi stage amplifiers.

In multi stage amplifiers, the o/p of first stage amplifier connected to i/p of next stage using a coupling device. This coupling device can be a capacitor (or) a transformer.

"This process of joining two amplifiers using a coupling device can be called as cascading".

- The following figure shows the two-stage amplifier connected in cascade.



The overall gain is the product of the voltage gain of the individual stages.

$$\boxed{A_V = A_{V_1} \times A_{V_2} = \frac{V_2}{V_1} \times \frac{V_o}{V_2} = \frac{V_o}{V_1}}$$

where, A_V = Overall gain

A_{V_1} = Voltage gain of 1st stage

A_{V_2} = voltage gain of 2nd stage

The purpose of a coupling device are:

- To tranfer the AC from output of one stage to the i/p of next stage.
- To block the DC to pass from o/p, which means to isolate the DC conditions.

Types of coupling: There are 3 basic methods of coupling,

① Resistance-capacitance coupling:-
This is the mostly used method of coupling, formed using simple resistor - capacitor combination. The capacitor which allows AC and blocks DC is the main coupling element used here. The coupling capacitor connects the AC o/p of one stage to i/p of nxt stage. while blocking the DC components from DC bias voltages.

② TRANSFORMER COUPLING: The coupling method that uses a transformer as coupling device is called as "Transformer coupling."

- There is no capacitor used in this method of coupling bcz transformer itself conveys AC component directly to the base of second stage. The secondary winding of the transformer provides a base return path and hence there is no need of base resistance. This coupling is famous for it's efficiency and high impedance matching & is mostly used.

③ Direct coupling: If the previous amplifier stage is connected to the nxt stage directly, is called as "direct coupling". The individual stage bias conditions are so designed that the stages can be directly connected with DC isulation.

- The direct method is mostly used when the load is connected in series, with the o/p terminal of the active circuit element. Ex: Head phones, loud speakers etc.

→ Role of capacitors in Amplifiers: other than coupling purpose, there are other purposes for which few capacitors are especially employed in amplifiers

→ Input capacitor Cin: It is present at the initial stage of amplifier, couples AC signal to the base of the transistor. If it is not present, the signal source is directly ~~attac~~parallel to resistor R_2 and the bias voltage of transistor will be changed.

→ Cin allows AC to flow into i/p circuit, without affecting biasing conditions-

-> Emitter By-pass capacitor Ce: It is connected in parallel with emitter resistor. It offers a low reactance path to amplifier AC signal. In the abscence of this capacitor, the voltage developed across RE will feedback to input thus decreasing the o/p voltage

-> Coupling capacitor Cc: It connects the two stages and prevents DC interface b/w two stages and controls operating point from shifting. In the absences of coupling capacitor Rc will come in parallel with resistance R1 of next stage and changing biasing condition.

*Amplifier Consideration!

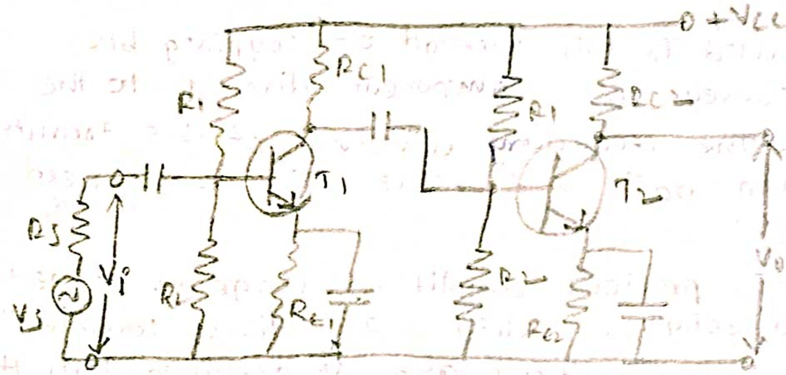
-> CC Amplifier: -It has unity voltage gain.
-Not suitable for intermediate gases.

-> CB Amplifier: Its voltage gain is less than unity.
-Hence not suitable for cascading.

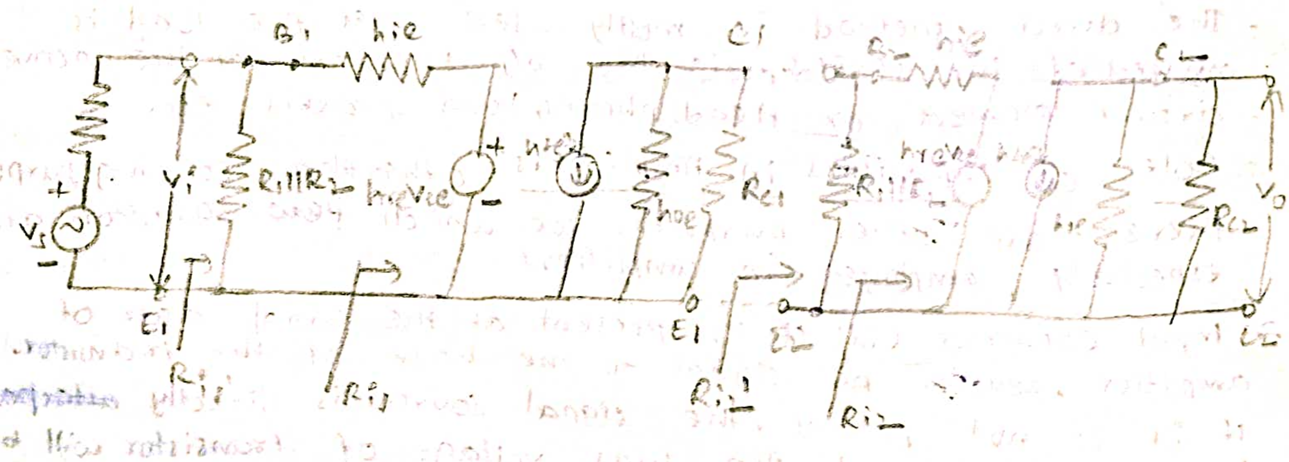
-> CE Amplifier: -Its voltage gain is greater than unity.
- Voltage is further increased by cascading.

- The characteristics of CE amplifier is such that, this configuration is very suitable for cascading in amplifier circuits. Hence most of the amplifier circuits use CE configuration.

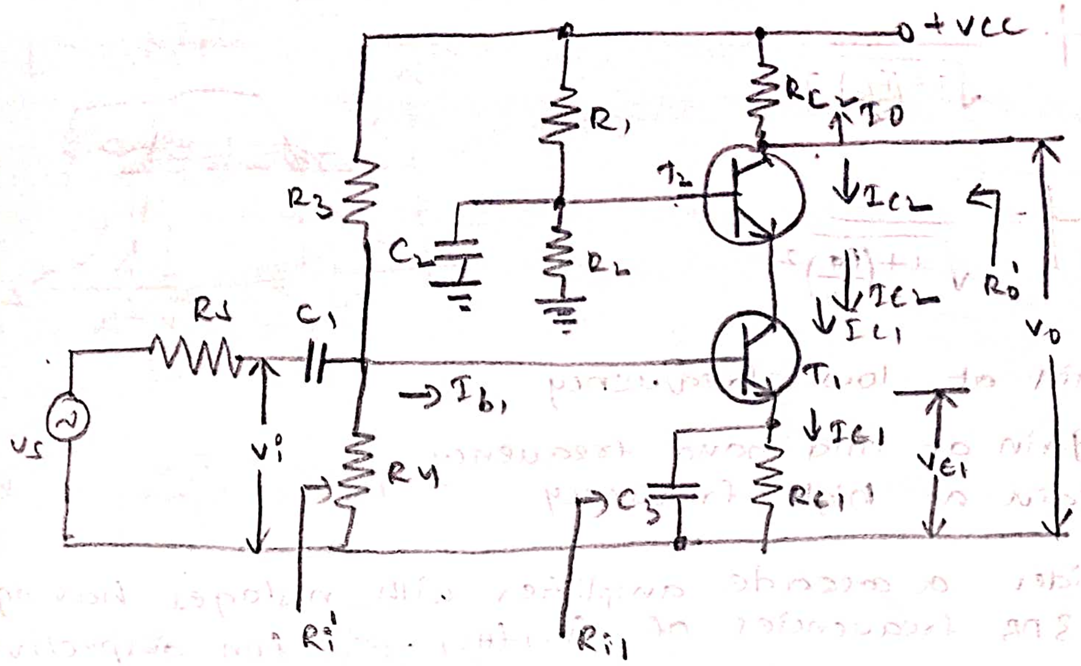
=> Two stage CE-CE Cascade Amplifier:



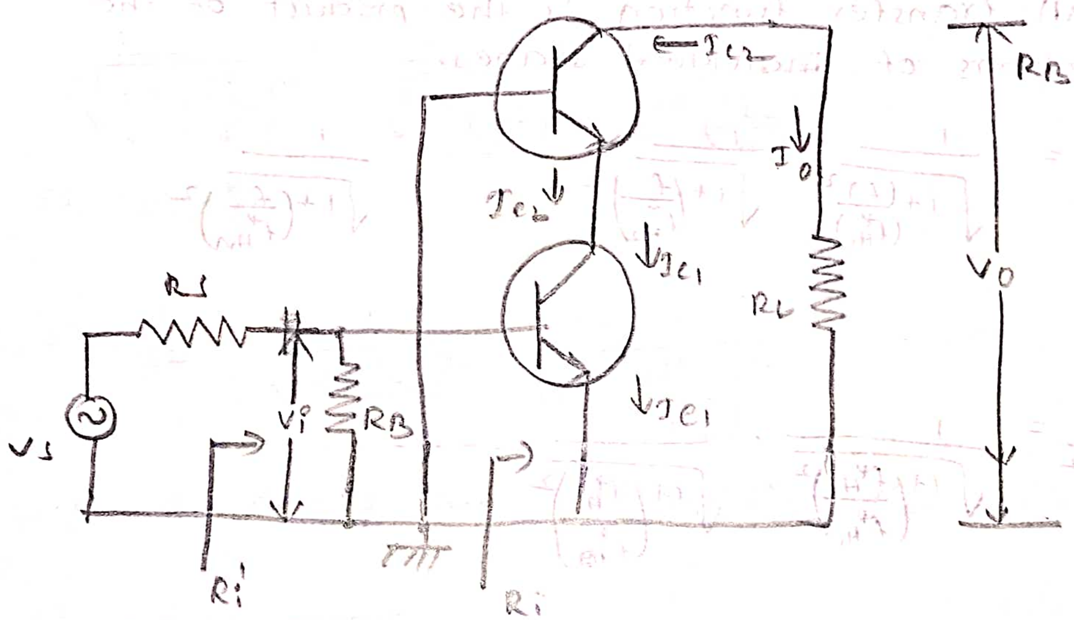
-> h-parameter equivalent circuit



→ CASCODE AMPLIFIER:

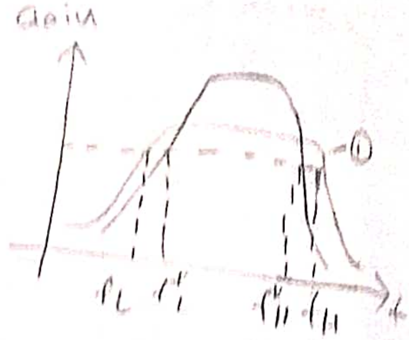


AC Equivalent circuit:



Bandwidth of N-stage Amplifier:-

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



$\Rightarrow \left|\frac{A_H}{A_{mid}}\right| = \frac{1}{\sqrt{1+\left(\frac{f_H}{f_H}\right)^2}}$

- A_L : gain at low frequency
- A_{mid} : gain at mid band frequency
- A_H : gain at high frequency

Consider a cascade amplifier with n-stages having higher 3DB frequencies of $f_{H_1}, f_{H_2}, \ldots f_{H_n}$ respective

- Let f_H^* be the higher 3DB frequency of the cascade Multi-stage amplifier.

- The overall transfer function is the product of the transfer functions of individual stages.

$$\frac{1}{\sqrt{1+\left(\frac{f}{f_H^*}\right)^2}} = \frac{1}{\sqrt{1+\frac{(f)^2}{(f_{H_1}^*)^2}}} \cdot \frac{1}{\sqrt{1+\left(\frac{f}{f_{H_2}^*}\right)^2}} \cdots\cdots \frac{1}{\sqrt{1+\left(\frac{f}{f_{H_n}^*}\right)^2}}$$

At $f = f_H^*$

$$\frac{1}{\sqrt{1+\left(\frac{f_H^*}{f_H^*}\right)^2}} = \frac{1}{\sqrt{1+\left(\frac{f_H^*}{f_{H_1}^*}\right)^2}} \cdot \frac{1}{\sqrt{1+\left(\frac{f_H^*}{f_{H_2}^*}\right)^2}} \cdots\cdots$$

$$\frac{1}{\sqrt{1+1}} = \frac{1}{\sqrt{1+\left(\frac{f_H^*}{f_{H_1}^*}\right)^2}} \cdot \frac{1}{\sqrt{1+\left(\frac{f_H^*}{f_{H_2}^*}\right)^2}} \cdots\cdots$$

$$\frac{1}{\sqrt{2}} = \frac{1}{\sqrt{1+\left(\frac{f_H^*}{f_{H_1}^*}\right)^2}} \cdot \frac{1}{\sqrt{1+\left(\frac{f_H^*}{f_{H_2}^*}\right)^2}} \cdots\cdots$$

- If all stages are equal;

$f_{H_1}^* = f_{H_2}^* = \cdots\cdots = f_H$

$$\therefore \left[\frac{1}{\sqrt{1+\left(\frac{f_H^*}{f_H^*}\right)^2}}\right]^n = \frac{1}{\sqrt{2}}$$

$$\rightarrow \left[\sqrt{1+\left(\frac{f^*_H}{f_H}\right)^2}\right]^n = \sqrt{2}$$

$$\rightarrow \sqrt{1+\left(\frac{f^*_H}{f_H}\right)^2} = (\sqrt{2})^{1/n}$$

$$\rightarrow 1+\left(\frac{f^*_H}{f_H}\right)^2 = 2^{1/n}$$

$$\rightarrow \left(\frac{f^*_H}{f_H}\right)^2 = 2^{1/n}-1$$

$$\boxed{f^*_H = f_H\sqrt{(2^{1/n}-1)}}$$

→ similarly,

$$\frac{1}{\sqrt{1+\left(\frac{f^*_L}{f}\right)^2}} = \frac{1}{\sqrt{1+\left(\frac{f^*_{L1}}{f}\right)^2}} \cdot \frac{1}{\sqrt{1+\left(\frac{f^*_{L2}}{f}\right)^2}} \cdots$$

At $f = f^*_L$

$$\Rightarrow \frac{1}{\sqrt{2}} = \frac{1}{\sqrt{1+\left(\frac{f^*_{L1}}{f^*_L}\right)^2}} \cdot \frac{1}{\sqrt{1+\left(\frac{f^*_{L2}}{f^*_L}\right)^2}} \cdots$$

- If all stages are similar, $f^*_{L1} = f^*_{L2} \cdots = f_L$

$$\Rightarrow \frac{1}{\sqrt{2}} = \frac{1}{\left[\sqrt{1+\left(\frac{f_L}{f^*_L}\right)^2}\right]^n}$$

$$\rightarrow \sqrt{2} = \left[\sqrt{1+\left(\frac{f_L}{f^*_L}\right)^2}\right]^n$$

$$\rightarrow 1+\left(\frac{f_L}{f^*_L}\right)^2 = (2)^{1/n}$$

$$\therefore \frac{f_L}{f^*_L} = \sqrt{2^{1/n}-1}$$

$$\boxed{f^*_L = f_L/\sqrt{2^{1/n}-1}}$$

$\rightarrow \quad A_V = A_{V1} \cdot A_{V2} \cdot \cdots A_{Vn}$

$$\rightarrow \sqrt{\frac{1}{1+\left(\frac{f_L^*}{f}\right)^2}} = \frac{1}{\sqrt{1+\left(\frac{f_{L1}}{f}\right)^2}} \cdot \frac{1}{\sqrt{1+\left(\frac{f_{L2}}{f}\right)^2}} \cdots$$

$$\rightarrow \sqrt{1+\left(\frac{f_L^*}{f}\right)^2} = \sqrt{1+\left(\frac{f_{L1}}{f}\right)^2} \cdot \sqrt{1+\left(\frac{f_{L2}}{f}\right)^2} \cdots$$

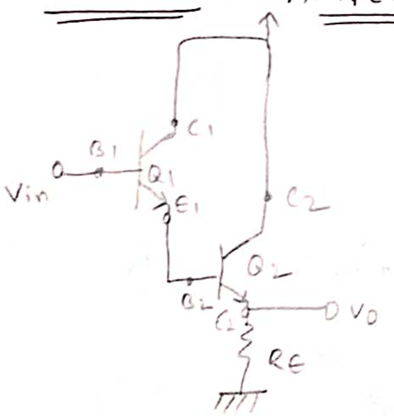
$$\rightarrow 1+\left(\frac{f_L^*}{f}\right)^2 = \left[1+\left(\frac{f_{L1}}{f}\right)^2\right]\left[1+\left(\frac{f_{L2}}{f}\right)^2\right] \cdots$$

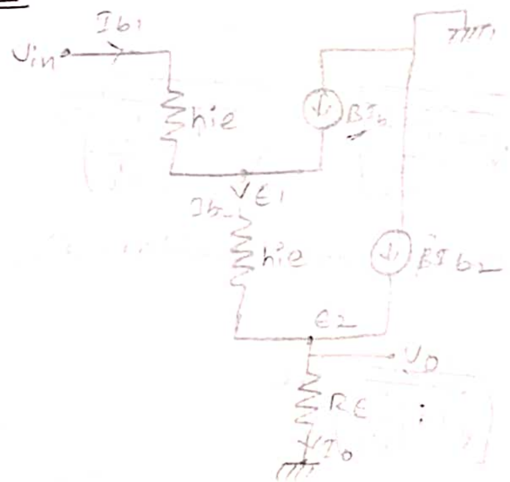
$$1+\left(\frac{f_L^*}{f}\right)^2 = 1+\left(\frac{f_{L1}}{f}\right)^2+\left(\frac{f_{L2}}{f}\right)^2+\left[\frac{f_{L1}\cdot f_{L2}}{f^2}\right]^2+\cdots$$

$$\boxed{f_L^* = \sqrt{(f_{L1})^2+(f_{L2})^2+\cdots}}$$

lly, $$\boxed{f_H^* = \sqrt{\frac{1}{f_{H_1}^2}+\frac{1}{f_{H_2}^2}+\cdots}}$$

DARLINGTON AMPLIFIER:





Equivalent circuit using Approximate analysis of trans

(1)

$\rightarrow$ Current Gain, $A_I = \frac{I_o}{I_{in}}$

- $I_{in} = I_{b1}$

$\rightarrow I_o = I_{b2} + \beta I_{b2} = I_{b2}(1+\beta)$

where, $I_{b2} = I_{b1}(1+\beta)$

$\therefore \quad I_o = I_{b1}(1+\beta)^2$

$$A_I = \frac{I_o}{I_{b1}} = (1+\beta)^2 \approx \beta^2$$

② $R_{in} = \frac{V_{in}}{I_{in}}$

$\rightarrow I_{in} = I_{b1}$

$\rightarrow V_{in} = h_{ie} I_{b1} + h_{ie} \underline{I_{b2}} + I_O R_E$

$V_{in} = h_{ie} I_{b1} + h_{ie} \cdot I_{b1}(1+\beta) + \underline{I_{b1}(1+\beta)^2} R_E$

$\frac{V_{in}}{I_{b1}} = h_{ie} + (1+\beta) h_{ie} + (1+\beta)^2 R_E$

$\therefore \boxed{R_{in} = h_{ie} + (1+\beta) h_{ie} + (1+\beta)^2 R_E}$

which gives exact value of current gain.

and $\boxed{R_{in} = \beta^2 R_E}$ [$\because$ hie is very very low]

③ voltage gain, $A_V = \frac{V_O}{V_{in}}$

$\rightarrow V_O = I_O R_E = I_{b1}(1+\beta)^2 R_E$

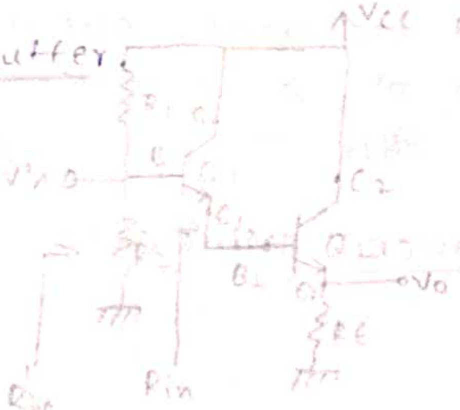
$\rightarrow A_V = \frac{V_O}{V_{in}}$

$= \frac{I_{b1}(1+\beta)^2 R_E}{I_{b1}[h_{ie} + \underbrace{(1+\beta) h_{ie}}_{\text{neglected}} + (1+\beta)^2 R_E]}$

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

$\boxed{A_V = 1}$

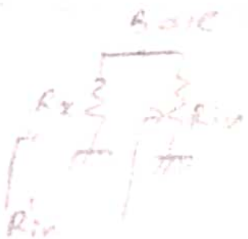
- This amplifier is having very high input impedance.
- Unity voltage gain, very high current gain [super β - amplifier].
- It is used as a voltage buffer.



$\rightarrow$ $R_{in} = \beta^2 R_E$

$R_x = R_1 \parallel R_2$

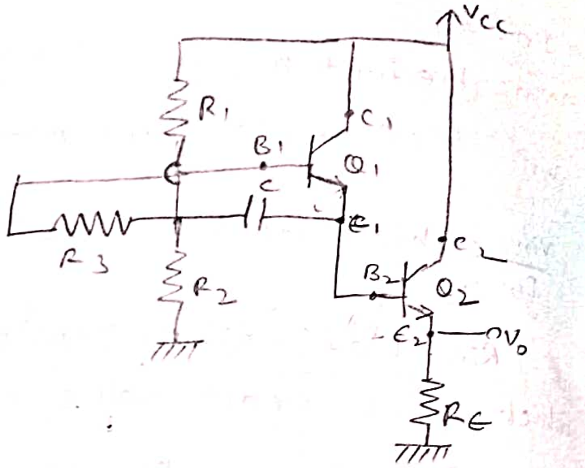
$\therefore R_{in}' = R_x \parallel R_{in}$



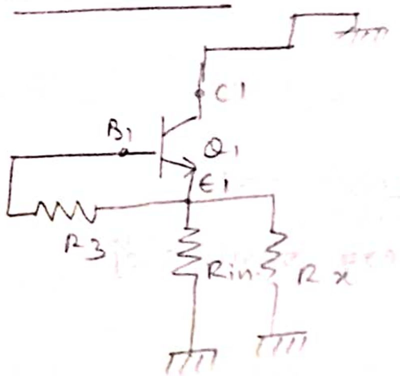
$\boxed{R_{in}' = R_x}$ [$\because$ Rin vv high]

The biasing resistance Reduce the i/p resistance of amplifier.

→ **BOOT STRAP BIASING:**

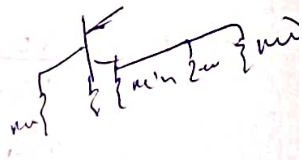


AC ANALYSIS



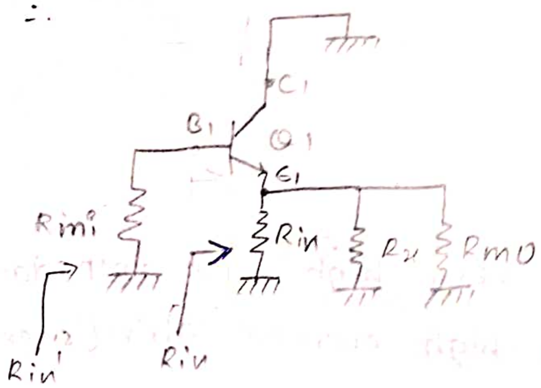
– By miller's theorem,

$$R_{mi} = \frac{R_3}{1 - A_V} = \frac{R_3}{1-1} = \frac{R_3}{0} = \alpha$$



$$R_{mo} = \frac{R_3}{1 - \frac{1}{A_V}}$$

∴

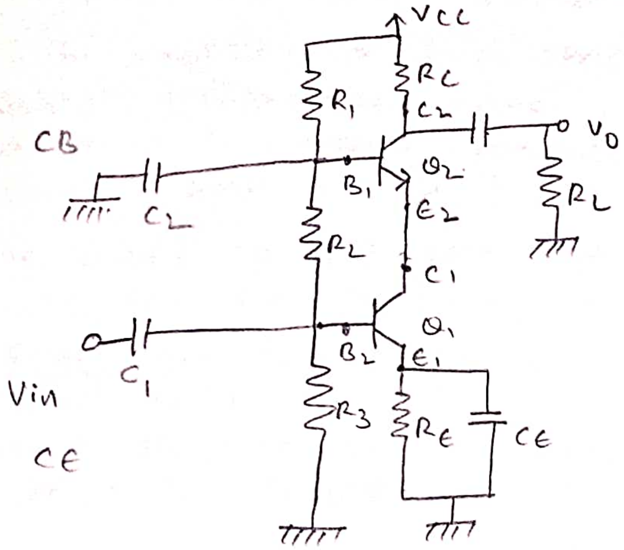


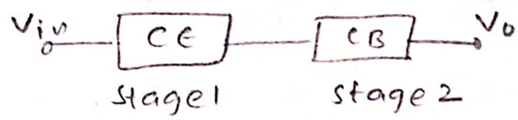
$R_{in}' = R_{in} \parallel R_{mi}$

$\boxed{R_{in}' = R_{in}}$ $[\because R_{mi} = \alpha]$

– A Boot stramp circuit is one, where the part of the o/p of an amplifier stage is applied to the i/p so as to alter the i/p impedance of the amplifier.

→ CASCODE AMPLIFIER:





video frequency transmission

- Transistors in CASCODE amplifiers are linked in parallel. The transistors of CASCADE amplifiers are linked in chain. which the o/p of 1st transistor serving as i/p of 2nd transistor.
- The transistors in CASCODE amplifier are stopped one on top of the other.
- It has large bandwidth, known as "wide amplifier".
- It is also known CE-CB amplifier.
- It is used as video frequency amplifier. i/p resistance is small, current gain is '-β' and voltage gain is

$$\boxed{A_v = \frac{-\beta R_L}{h_{ie}}}$$

- Overall transconductance of CASCODE amplifier is 'gm'.

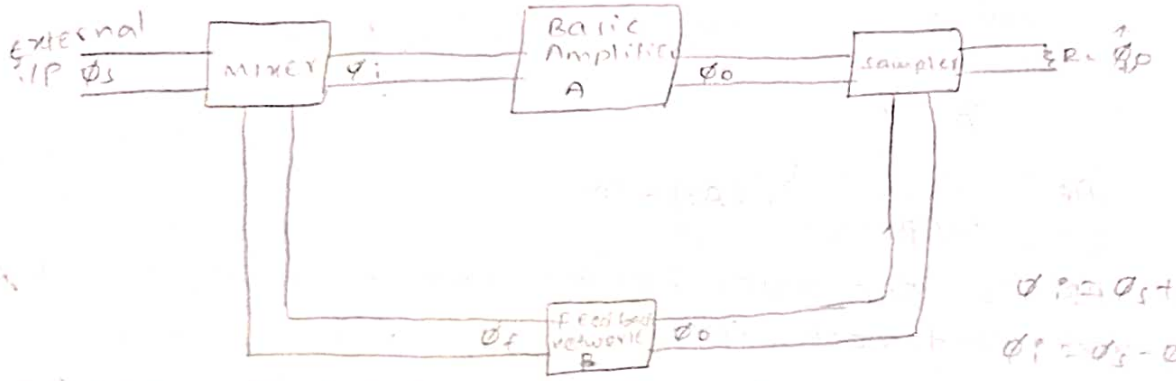
05/01/23

3. FEED BACK AMPLIFIERS

In amplifiers, a hum may be introduced due to several temparature changes, due to non-linearity characteristics and parameter variation. we will not get faithful amplification in the mid band frequency range.

- In order to overcome the above drawbacks, we will go for the feed back amplifiers.

Feed Back: The process of injecting a fraction of o/p signal back to the i/p is known as feedback. A block diagram of an amplifier with feed back is shown in figure:



$\phi_i = \phi_s + \phi_f \rightarrow +ve$

$\phi_i = \phi_s - \phi_f \rightarrow -ve$

- A = open lood gain of amplifier $= \frac{\phi_o}{\phi_i}$
- B = Feed back factor $= \frac{\phi_f}{\phi_o}$
- Af = Gain of feed back amplifier $= \frac{\phi_o}{\phi_s}$

- The o/p quantity (V/I) is sampled by a suitable sampler, which is of two types. Namely voltage sampler and current sampler, and fed to the feedback network. The o/p of feedback network which has a fraction of o/p signal is combined with external source signal 'ϕ_s' through a mixer and fed to basic amplifier. Mixer is also known as 'comparator' is of two types Namely, series mixer and shunt mixer.

- There are two types of feedback. One is +ve feedback and -ve feed back:

→ **Positive Feed Back:**

- If ϕ_f is in phase with signal (ϕ_s) is 0° i.e, '$\phi_i = \phi_f + \phi_s$', The net affect of the feedback will increase the i/p signal given to amplifier hence o/p increases. This type of feedback is called +ve feedback (or) regenerative feedback.

Gain of the Amplifier with +ve feed back.

$$A_f = \frac{\phi_o}{\phi_s}$$

$$= \frac{\phi_o}{\phi_i - \phi_f}$$

$$= \frac{1}{\frac{\phi_i}{\phi_o} - \frac{\phi_f}{\phi_o}}$$

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

$$\boxed{A_f = \frac{A}{1 - A\beta}}, \quad |A_f| > |A|$$

where $A\beta$ is loop gain, i.e., the product of the open l[oop] gain and feed back factor.

- If $|A\beta| = 1$, then $A_f = \alpha$
- The gain of the amplifier with +ve feedback is infi[nite] and the amplifier gives an AC output without AC i/[p] signal. Thus, the amplifier acts an oscillator. (Gain will not depend on i/p)
- The +ve feedback increases gain, in-stability, distorti[on] and with noise. Decreases the 'Band width.'

-) <u>Negative</u> <u>Feed back</u>: If the feedback signal 'ϕ_f' is out phase with the i/p signal ϕ_s, then $\boxed{\phi_i = \phi_s - \phi_f}$. So th[e] i/p voltage apply to the basic amplifier is decrease[d] and correspondingly the o/p is decreased. Therefore the voltage gain is reduced. This type of feedback is know[n] as -ve feedback (or) degenerative feed back.

Gain of the amplifier with -ve feed back:

$$A_f = \frac{\phi_o}{\phi_s}$$

$$= \frac{\phi_o}{\phi_i + \phi_f}$$

$$= \frac{\phi_o}{\phi_i + \phi_f}$$

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

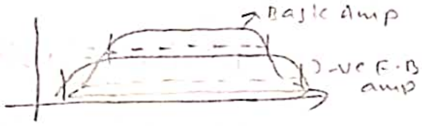
$$= \frac{1}{\frac{1}{A} + \beta}$$

$$\boxed{A_f = \frac{A}{1+A\beta}} \quad , |A_f| < |A|$$

- If $|A\beta| >> 1$, then $A_f = \frac{1}{\beta}$.

where 'β' is feedback ratio/feedback factor that gain depends less on the characteristics of the transistor. That gain may be made to depend entirely on the feedback network. If the feed back network contains only stable passive element, the gain of the amplifier using -ve feedback is stable.

Advantages of -ve feedback:



- Increases the stability.
- Increases the Bandwidth, less amplitude and less harmonic distortion.
- less frequency and phase distortion.
- less noise
- I/p and o/p resistances can be modified as per requirement.

Disadvantage

- Voltage gain decreases.

→ Band width of -ve Feedback amplifier:-

w.k.A. $A_f = \frac{A}{1+A\beta}$

$$A_{f\,LOW} = \frac{A_{LOW}}{1+A_{LOW}\beta}$$

$$A_{f\,Mid} = \frac{A_{mid}}{1+A_{mid}\beta}$$

$$A_{f\,High} = \frac{A_{high}}{1+A_{high}\beta}$$

and $A_{Low} = \dfrac{A_{mid}}{1 - j\left(\frac{f_L}{f}\right)}$

$\therefore$ $A_{fLow} = \dfrac{A_{Low}}{1 + A_{Low}\beta}$

$= \dfrac{(A_{mid})/1 - j\left(\frac{f_L}{f}\right)}{1 + \left[\frac{A_{mid}}{1 - j\left(\frac{f_L}{f}\right)}\right]\beta}$

$= \dfrac{A_{mid}}{1 - j\left(\frac{f_L}{f}\right) + A_{mid}\cdot\beta}$

$= \dfrac{A_{mid}}{1 + A_{mid}\beta - j\left(\frac{f_L}{f}\right)}$

Divide = with $1 + A_{mid}\beta$

$= \dfrac{A_{mid}/1 + A_{mid}\beta}{1 - j\frac{f_L}{f}\cdot\frac{1}{1 + A_{mid}\beta}}$

$$\boxed{A_{fLow} = \frac{A_{fmid}}{1 - j\frac{f_{Lf}}{f}}}$$

$$\boxed{f_{Lf} = \frac{f_L}{1 + A_{mid}\beta}}$$

similarly,

$A_{fHigh} = \dfrac{A_{mid}}{1 + j\left(\frac{f}{f_H}\right)}$

$\therefore$ $A_{fHigh} = \dfrac{A_{High}}{1 + A_{High}\cdot\beta}$

$= \dfrac{A_{mid}}{1 + j\left(\frac{f}{f_H}\right) + A_{mid}\cdot\beta}$

$$= \frac{A_{mid} / 1 + A_{mid} \cdot \beta}{1 + j \frac{f}{f_H} \cdot \frac{1}{A_{mid}(\beta) + 1}}$$

$$= \frac{A_{fmid}}{1 + j \frac{f}{f_H (1 + A_{mid} \beta)}}$$

$\boxed{f_{Hf} > f_H}$

$$A_{fHigh} = \frac{A_{fmid}}{1 + j \frac{f}{f_{Hf}}} , \quad \boxed{f_{Hf} = f_H (1 + A_{mid} \beta)}$$

→ Lower cut off frequency with feed back, $\boxed{f_{Lf} = \frac{f_L}{1 + A_{mid} \cdot \beta}}$

∴ Lower cut off frequency with feed back is less than Lower cut off frequency without feed back by a factor $[1 + A_{mid} \cdot \beta]$.

→ Upper cut off frequency with feed back is, $\boxed{f_{Hf} = f_H (1 + A_{mid} \cdot \beta)}$

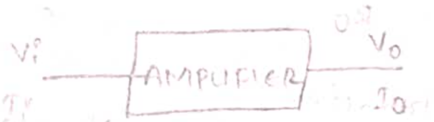
- From the above equation it is clear that the upper cut off frequency with feed back is greater than upper cut off frequency without feedback by a factor $[1 + A_{mid} \cdot \beta]$

∴ By introducing negative feedback, the band width of the amplifier is $BW = A_{Hf} - f_{Lf}$

$$\boxed{BW = f_{Hf} - f_{Lf}}$$

→ Classification of -ve feedback amplifiers:

classification is based on i/p, o/p parameters:



① I/p = V_i ; O/p = V_o ⇒ Gain $A_v = \frac{V_o}{V_i}$

→ Voltage Amplifier

② If i/p is current (I_i) and output is current (I_o), then the amplifier is known as current amplifier.

Gain, $A_I = \frac{I_o}{I_i}$

③ If i/p is voltage (v_i) and output is current (I_o), then the amplifier is called as "Trans conductance" amplifier.

gain, $G_m = \frac{I_o}{V_i}$

④ If i/p is current (I_i) and o/p is voltage (v_o), then the amplifier is called as 'Trans resistance amplifier'

gain, $R_m = \frac{V_o}{I_i}$

* VOLTAGE AMPLIFIER:

→ $v_i = V_s \cdot \frac{R_i}{R_s + R_i}$

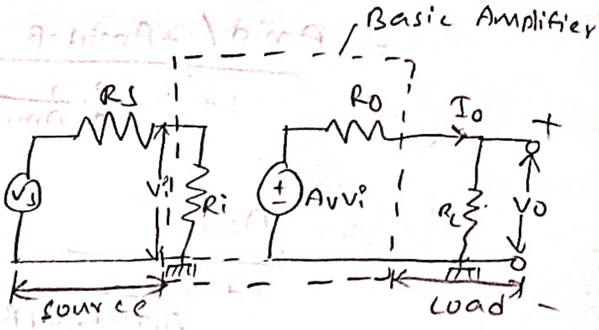
① Ideal case,

$v_i = V_s$ [∵ $R_s = 0$]

Practical case,

$R_s << R_i$

∴ $\boxed{v_i \simeq V_s}$



THEVENIN'S EQUIVALENT CIRCUIT OF VOLTAGE AMPLIFIER.

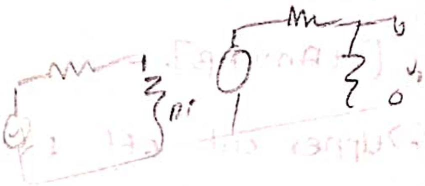
Ri

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

→ $V_o = A_V V_i \cdot \frac{R_L}{R_o + R_L}$

① Ideal case,

$V_o = A_V V_i$ [∵ $R_L = \alpha$]



② practical case,

$\boxed{V_o \simeq A_V V_i}$ [∵ $R_L >> R_o$]

$\boxed{V_o \simeq A_V V_s}$

* Ideal Amplifier Characteristics:

parameter	V.Amp	I.Amp	TC.Amp	TR.Amp
Ri	α	0	α	0
Ro	0	α	α	0
Transfer characteristic	$V_o = A_V V_s$	$I_o = A_I I_s$	$I_L = G_m V_s$	$V_o = R_m I_s$

* CURRENT AMPLIFIER:

→ → Ideal case:

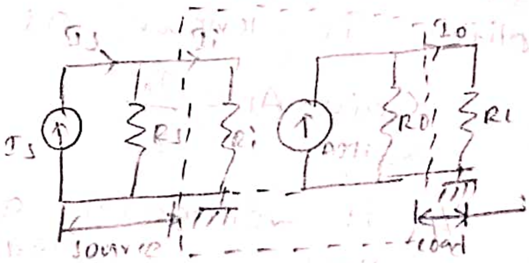
$I_i = \frac{I_s R_s}{R_s + R_i}$

$R_i = 0$

$R_o = \alpha$

⇒ $I_i = I_s$

and $I_o = A_I I_i$



Norton's Equivalent circuit for i/p & o/p of current amplifier

→ Practical case:

① $R_s >> R_i$

$R_o >> R_L$

$\rightarrow$ $I_i = I_s \cdot \frac{R_s}{R_s + R_i}$

$= I_s \cdot \frac{R_s}{R_s}$

$\boxed{I_i \simeq I_s}$

$I_o = A_i I_i \cdot \frac{R_o}{R_o + R_L}$

$= A_i I_i \cdot \frac{R_o}{R_o}$

$I_o \approx A_I I_i$

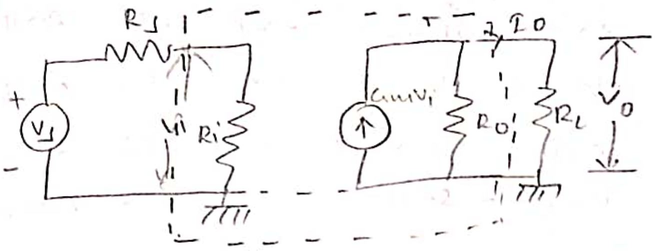
$\boxed{I_o \sim A_I I_s}$

* TRANS CONDUCTANCE AMPLIFIER:

$\rightarrow$ Ideal, $R_i = \alpha$

$R_o = \alpha$

$\therefore$ $\boxed{V_i \sim V_s}$; $\boxed{I_o = G_m V_i}$



$\rightarrow$ practical,

$R_i >> R_s$

$R_o >> R_L$

$\therefore$ $V_i = V_s \cdot \frac{R_i}{R_i + R_s}$

$V_i = V_s \cdot \frac{R_i}{R_i}$

$\boxed{V_i \simeq V_s}$

$I_o = G_m V_i \cdot \frac{R_o}{R_o + R_L}$

$= G_m V_i \cdot \frac{R_o}{R_o}$

$I_o \simeq G_m V_i$

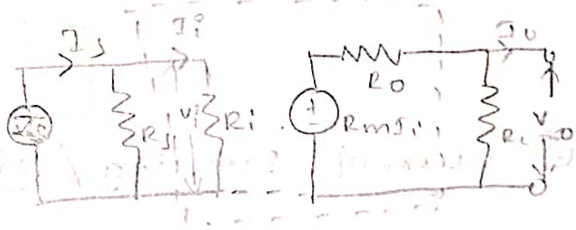
$\boxed{I_o \sim G_m V_s}$

* TRANS RESISTANCE AMPLIFIER:

$\rightarrow$ Ideal, $R_i = 0$; $R_o = 0$

$\Rightarrow$ $V_o = R_m I_i$

$\rightarrow$ $I_i = I_s$



$\rightarrow$ Practical case

$\rightarrow$ $R_s >> R_i$

$\rightarrow$ $R_L >> R_o$

$\therefore$ $I_i = I_s \cdot \frac{R_s}{R_s + R_i}$

$= I_s \cdot \frac{R_s}{R_s}$

$\boxed{I_i \simeq I_s}$

$V_o = R_m I_i \cdot \frac{R_L}{R_o + R_L}$

$= R_m I_i \cdot \frac{R_L}{R_L}$

$= R_m I_i$

$\boxed{V_o \sim R_m I_s}$

TOPOLOGIES FOR -VE FEEDBACK AMPLIFIER:

→ Sampler, Mixer

① Voltage-Series -ve F.B Amplifier
② Voltage-shunt -ve FB Amplifier
③ Current-series -ve FB Amplifier
④ current-shunt -ve FB Amplifier.

① Vol ser
② Curre shunt
③ Volta shunt
④ current series

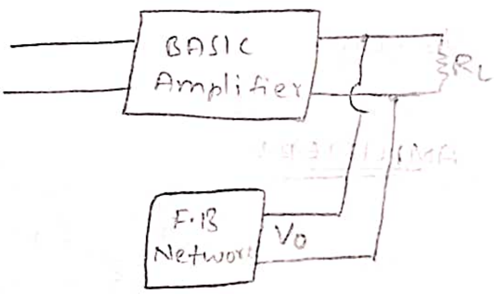
→ Mixer, Sampler

ⓐ series-shunt -ve FB Amplifier
ⓑ shunt-shunt -ve FB Amplifier
ⓒ series-series -ve FB Amplifier
ⓓ shunt-series -ve FB Amplifier

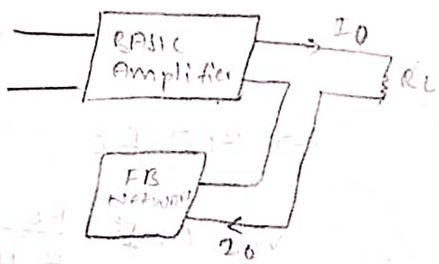
→ Based on i/p & o/p parameters

i) voltage-voltage -ve FB Amplifier
ii) current-voltage -ve FB Amplifier
iii) voltage-Current -ve FB Amplifier
iv) current-current -ve FB Amplifier

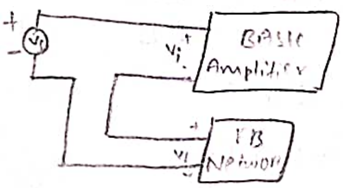
① Voltage shunt Sampling / shunt Circuit:



② Current Sampling / series Circuit:

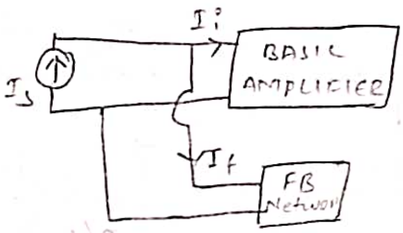


③ Voltage Mixing / series Mixing



$V_s = V_i + V_f$

④ Current Mixing / shunt Mixing:

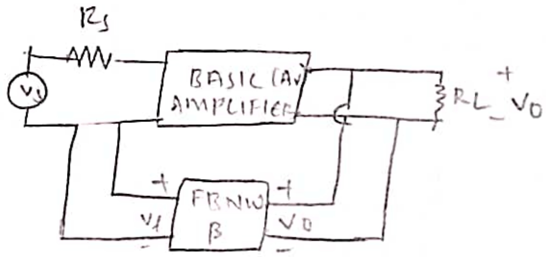


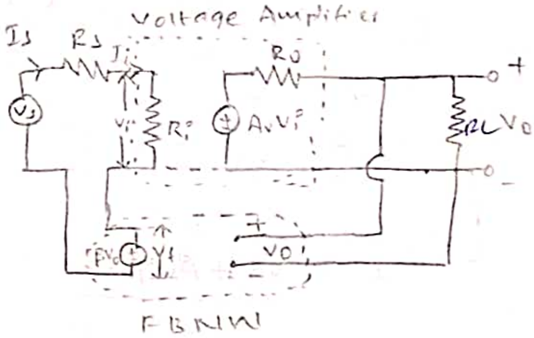
$$\boxed{I_s = I_i + I_f}$$

① * Voltage-Series -ve Feed Back Amplifier:

BLOCK DIAGRAM

Sampler - Voltage - shunt
Mixer - Voltage - Series





→ $A_v = \frac{V_o}{V_i}$; $\beta = \frac{V_f}{V_o}$

→ Voltage gain with FB:

→ $A_v = \frac{V_o}{V_i}$

→ $A_{vf} = \frac{V_o}{V_s}$, $V_s = V_i + V_f$

$= V_i + \beta V_o$

$= V_i + \beta A_v V_i$

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

$= \frac{V_o}{V_i(1+\beta A_v)}$

$A_{vf} = \frac{A_v}{1+\beta A_v}$ [Gain with FB]

$$\boxed{A_{vf} = \frac{A_v}{1+A_v\beta}}$$

→ Input Impedance with FB:

→ Input resistance without FB, $R_i = \frac{V_i}{I_i}$

→ Input resistance with FB, $\Rightarrow \boxed{V_i = R_i I_i}$

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

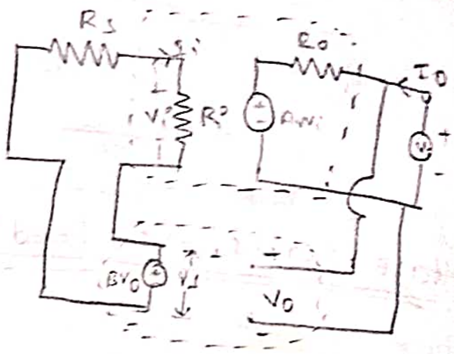
→ $V_s = V_i[1+A_v\beta]$

$V_s = I_i R_i[1+A_v\beta]$

$$\boxed{R_{if} = \frac{V_s}{I_i} = R_i[1+A_v\beta]}$$

→ Output impedance with FB:-

→ $R_{of} = \frac{V_o}{I_o}$



* $I_o = \frac{V_o - A_v V_i}{R_o}$

and $V_i = V_s - V_f$

$V_i + V_f = V_s$

$V_i + V_f = 0$ $\because [V_s = 0]$

$V_i = -V_f$

$\boxed{V_i = -\beta V_o}$

$\therefore I_o = \frac{V_o + A_v . \beta V_o}{R_o}$

$\boxed{I_o = \frac{V_o [1 + A_v\beta]}{R_o}}$

$\Rightarrow R_{of} = \frac{V_o}{I_o} = \frac{V_o}{\frac{V_o(1+A_v\beta)}{R_o}}$

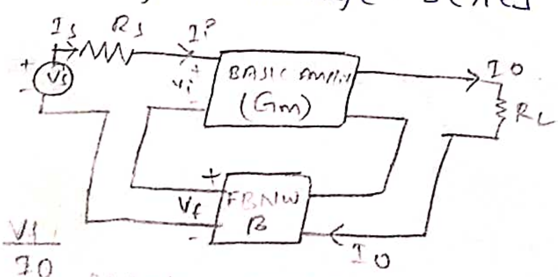
$\boxed{R_{of} = \frac{R_o}{1 + A_v\beta}}$

Parameter	w/o FB	W. F.B
Gain	A_v	$\frac{A_v}{1+A_v\beta}$
I/p impedance	R_i	$R_i(1+A_v\beta)$
O/p impedance	R_o	$\frac{R_o}{1+A_v\beta}$

* CURRENT SERIES -VE FEED BACK AMPLIFIER:

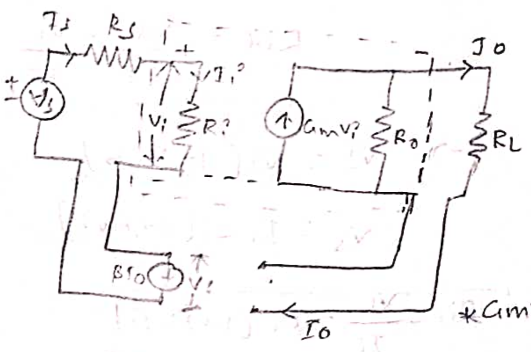
→ Sampling - Current - series

→ Mixing - Voltage - series



$* \beta : \frac{V_f}{I_o}$

BLOCK DIAGRAM



CIRCUIT DIAGRAM

$* G_m =$

* Gain with Feed Back:

* $G_{mf} = \frac{I_o}{V_s}$

→ $V_s = V_i + V_f$

$= V_i + \beta I_o$

$= V_i + \beta G_m V_i$

$\boxed{V_s = V_i[1+\beta G_m]}$

∴ $G_{mf} = \frac{I_o}{V_i[1+\beta G_m]}$

$\boxed{G_{mf} = \frac{G_m}{1+\beta G_m}}$

* Input Resistance:

* $R_i = \frac{V_i}{I_i}$ ⇒ $V_i = I_i R_i$

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

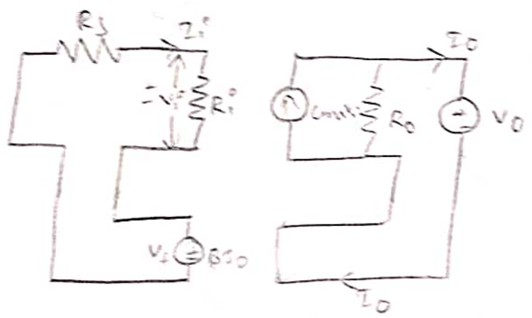
$V_s = V_i[1+G_m\beta]$

$\boxed{V_s = I_i R_i[1+G_m\beta]}$

∴ $R_{if} = \frac{I_i R_i[1+G_m\beta]}{I_i}$

$\boxed{R_{if} = R_i[1+G_m\beta]}$

* Output Resistance:



→ $R_{of} = \frac{V_o}{I_o}$

→ $I_o = G_m V_i + \frac{V_o}{R_o}$

$I_o = -G_m \beta I_o + \frac{V_o}{R_o}$

$\boxed{V_o = I_o R_o[1+G_m\beta]}$

∴ $R_{of} = \frac{V_o}{I_o}$

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

* $V_s = V_i + V_f$

$V_i = -V_f$ ∵ $[V_s = 0]$

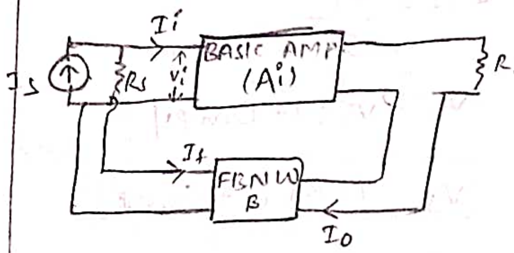
$V_i = -\beta I_o$

*

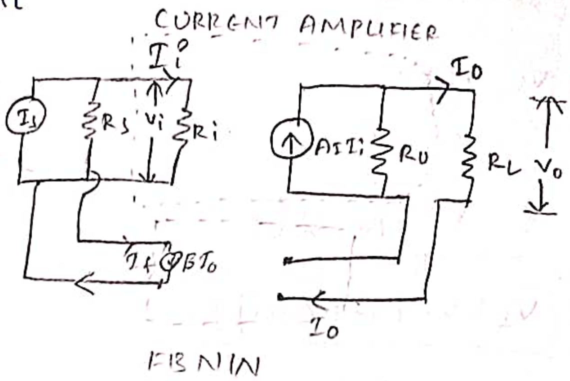
Parameter	w/o FB	w FB
Gain	G_m	$(G_m)/1+G_m\beta$
I/p resistance	R_i	$R_i(1+G_m\beta)$
O/p resistance	R_o	$R_o(1+G_m\beta)$

* CURRENT SHUNT -VE FEEDBACK AMPLIFIER:

* Sampler - Current - ~~Shunt~~ Series
* Mixer - Current - Shunt



BLOCK DIAGRAM



CIRCUIT DIAGRAM

* $A_I = \frac{I_o}{I_i}$; $\beta = \frac{I_f}{I_o}$

* Gain with FeedBack:

$\rightarrow A_I = \frac{I_o}{I_i}$

$\rightarrow A_{If} = \frac{I_o}{I_s}$

$I_s = I_i + I_f$

$= I_i + \beta I_o$

$= I_i + \beta A_I I_i$

$\boxed{I_s = I_i[1 + A_I \beta]}$

$\therefore A_{If} = \frac{I_o}{I_i[1 + A_I \beta]}$

$\boxed{A_{If} = \frac{A_I}{1 + A_I \beta}}$

* Input impedance with FeedBack:

$\rightarrow R_i = \frac{V_i}{I_i}$

$\rightarrow R_{if} = \frac{V_i}{I_s}$

$I_s = I_i[1 + A_I \beta]$

$\boxed{I_s = \frac{V_i}{R_i}[1 + A_I \beta]}$

$\therefore R_{if} = \frac{V_i}{\frac{V_i}{R_i}[1 + A_I \beta]}$

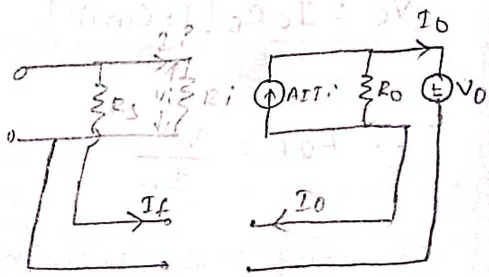
$\boxed{R_{if} = \frac{R_i}{1 + A_I \beta}}$

* Output impedance with FeedBack:

$\rightarrow R_o = \frac{V_o}{I_o}$

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

1. $I_s = 0$ (O.C)
2. R_L (O.C)
3. V_o, I_o
4. $\frac{V_o}{I_o}$



$\rightarrow I_o = A_I I_i + \frac{V_o}{R_o}$

$I_o = -A_I \beta I_o + \frac{V_o}{R_o}$

$I_o[1 + A_I \beta] = \frac{V_o}{R_o}$

$\boxed{I_o = \frac{V_o}{R_o(1 + A_I \beta)}}$

$I_s = I_i + I_f$

$I_i = -I_f$

$\boxed{I_i = -\beta I_o}$

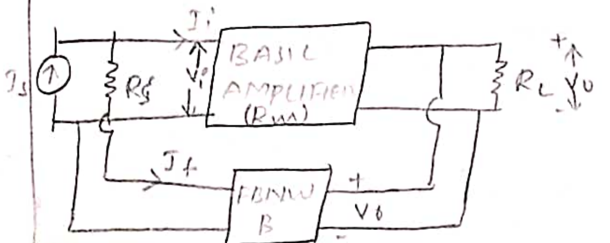
$\therefore \boxed{R_{of} = R_o(1 + A_I \beta)}$

Parameter	w/o FB	W FB
Gain	A_I	$A_I/(1+A_I\beta)$
input resistance	R_i	$R_i/(1+A_I\beta)$
Output resistance	R_o	$R_o(1+A_I\beta)$

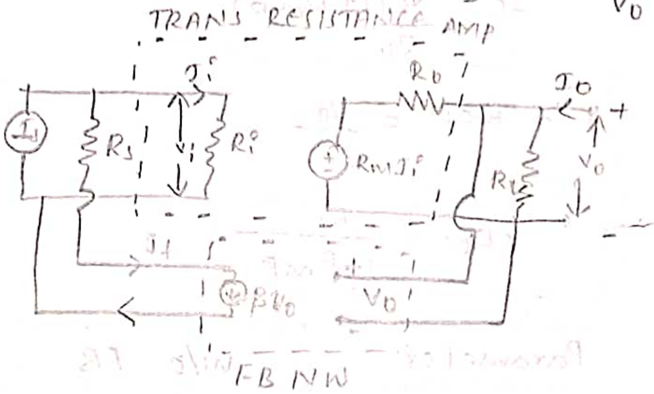
* VOLTAGE SHUNT -VE FB AMPLIFIER:

Sampler - Voltage - shunt
Mixer - current - shunt
o/p - V ; I/p - I

$R_m = \frac{V}{I}$; $\beta = \frac{I_f}{V_o}$



BLOCK DIAGRAM



CIRCUIT DIAGRAM

→ Gain with FeedBack:

→ $R_m = \frac{V_o}{I_i}$

→ $R_{mf} = \frac{V_o}{I_s}$

$I_s = I_i + I_f$

$= I_i + \beta V_o$

$= I_i + \beta \cdot R_m I_i$

$= \frac{V_o}{I_i(1+R_m\beta)}$ $\boxed{I_s = I_i(1+R_m\beta)}$

$$\boxed{R_{mf} = \frac{R_m}{1+R_m\beta}}$$

→ Input Resistance with FeedBack:

$R_i = \frac{V_i}{I_i}$

→ $R_{if} = \frac{V_i}{I_s}$

$I_s = I_i(1+R_m\beta)$

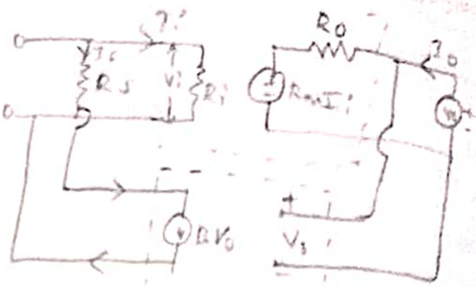
$\boxed{I_s = \frac{V_i}{R_i}(1+R_m\beta)}$

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

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

→ Output resistance with FeedBack:

→ $I_o = \frac{V_o - R_m I_i}{R_o}$



→ $I_s = I_i + I_f$

$I_i + I_f = 0$

$I_i = -\beta V_o$

$\therefore I_o = \frac{V_o + R_m \beta V_o}{R_o}$

$$\boxed{I_o = \frac{V_o(1+R_m\beta)}{R_o}}$$

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

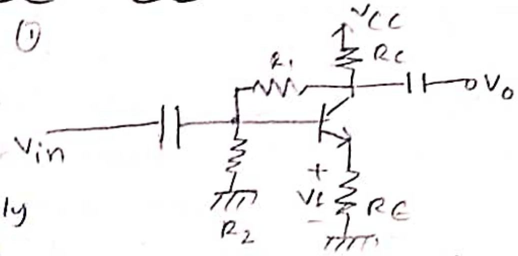
$$\boxed{R_{of} = \frac{R_o}{1+R_m\beta}}$$

Parameter	w/o FB	W. FB
Gain	R_m	$R_m/(1+R_m\beta)$
I/p resistance	R_i	$R_i/(1+R_m\beta)$
O/p resistance	R_o	$R_o/(1+R_m\beta)$

	SHUNT-SHUNT	SERIES-SHUNT	SHUNT-SERIES	SERIES-SERIE
MIXER	SHUNT	SERIES	SHUNT	SERIES
SAMPLER	SHUNT	SHUNT	SERIES	SERIES
I/p signal	I	V	I	V
O/p signal	V	V	I	I
AMPLIFIER	TRANS RESISTANCE	VOLTAGE	CURRENT	TRANS CONDUCTA
GAIN	$R_{mf} = \frac{R_m}{1+R_m\beta}$	$A_{vf} = \frac{A_v}{1+A_v\beta}$	$A_{If} = \frac{A_I}{1+A_I\beta}$	$G_{mf} = \frac{G_m}{1+G_m\beta}$
R_{if}	$R_i/(1+R_m\beta)$	$R_i(1+A_v\beta)$	$R_i/(1+A_I\beta)$	$R_i(1+G_m\beta)$
R_{of}	$R_o/(1+R_m\beta)$	$R_o/(1+A_v\beta)$	$R_o(1+A_I\beta)$	$R_o(1+G_m\beta)$
Other name	Voltage-shunt (or) Voltage-current	Voltage-series Voltage-Voltage	Current-shunt Current-current	Current-seri Current-Volt

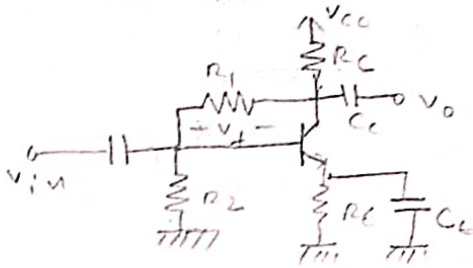
Procedure to identify type of Feed Back:

(1)



- Identify feed back element from given circuit.
- If feed back element is directly connected to output node, then it indicates voltage sampling otherwise it indicates current sampling.
- If feed back element is directly connected to input node, then it is shunt mixing otherwise it is series mixing.

(2)



(1) I/p NODE : BASE

o/p Node : COLLECTOR

f/b E : RE

-> current sampling

-> series mixing

∴ current - series -ve FB amplifier

(2) I/p Node : BASE

o/p Node : COLLECTOR

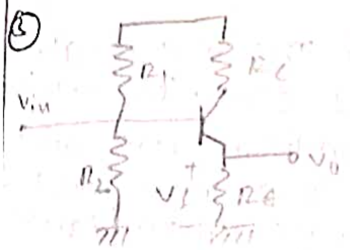
f/b E : R1

-> Voltage sampling

-> shunt mixing

∴ Voltage - shunt -ve FB Amp.

(3)



i/p : series

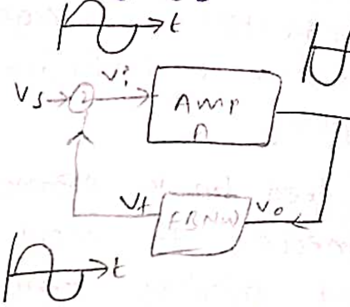
o/p : shunt

∴ voltage - series -ve FB Amp

OSCILLATORS

Any circuit which is used to generate AC voltage without AC input is called an "oscillator". To generate AC voltage the circuit is supplied energy from a DC source. Oscillator generates sinusoidal and non-sinusoidal signals with constant desired frequency. Oscillators uses the +ve F...

– There are 3 types of Oscillator:- i) UD ii) Sustained (Bark Hause...) iii) OD

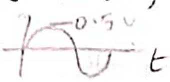


$A = \frac{V_o}{V_i}$

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

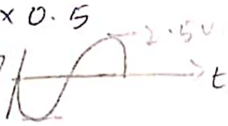
i) $|A\beta| < 1$:

→ $A = 5$; $\beta = 0.1$; $V_s = 0.5V$,
$\phi = 180°$ $\phi = 180°$



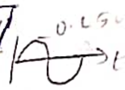
→ $V_o = AV_i = 5 \times 0.5$

$\boxed{V_o = 2.5V}$

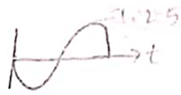


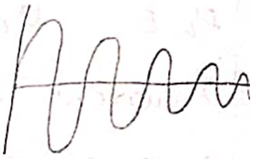
* The oscillators, in which system oscillates at a frequency marginally different than undamped oscillator and the amplitude of signal gradually decreases to zero is called 'UDO'.

→ $V_f = \beta V_o$
$= 0.1 \times 2.5$
$\boxed{V_f = 0.25V}$



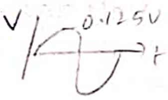
⇒ $V_o = AV_i$
$= 5 \times 0.25$
$\boxed{V_o = 1.25V}$



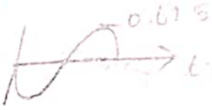


Under Damping Oscillations

→ $V_f = \beta V_o$
$= 0.1 \times 1.25$
$V_f = 0.125V$



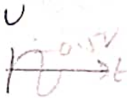
⇒ $V_o = AV_i$
$= 5 \times 0.125$
$\boxed{V_o = 0.625V}$



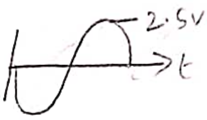
ii) $|A\beta| = 1$:

Criteria: The circuit gives sustained oscillations only when two conditions are satisfied
i) The loop gain must be greater than/equal to unity.
ii) Feed back signal must be phase shifted by 360°

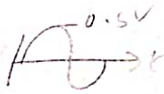
- $A = 5$; $\beta = 0.2$; $V_s = 0.5V$
$\phi = 180°$ $\phi = 180°$



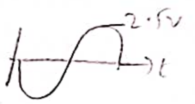
→ $V_o = AV_i$
$= 5 \times 0.5$
$V_o = 2.5V$



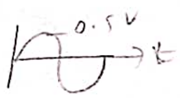
⇒ $V_f = \beta V_o$
$= 2.5 \times 0.2$
$V_f = 0.5V$

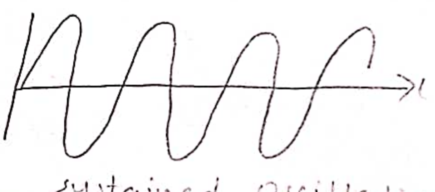


→ $V_o = AV_i$
$= 5 \times 0.5$
$V_o = 2.5V$



$V_f = \beta V_o$
$= 2.5 \times 0.2$
$V_f = 0.5V$

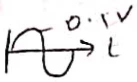




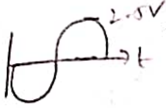
BARKHAUSEN CRITERIA

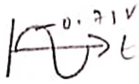
sustained oscillations

(iii) (AB>1)

A = 5; B = 0.3; V_s = 0.5 

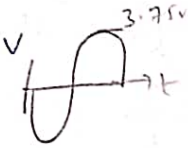
→ $V_o = AV_i$ ⇒ $V_f = BV_o$

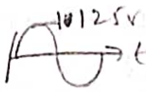
V_o = 2.5V 

V_f = 0.75V 

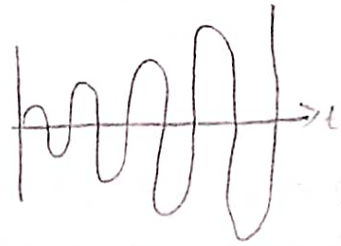
→ $V_o = AV_i$ ⇒ $V_f = BV_o$

= 5 × 0.75 V_f = 0.3 × 3.75

V_o = 3.75 V 

V_f = 1.125 V 

*when damping ~~frequency~~ (force) is greater than critical damping force, over damped oscillations are obtained.



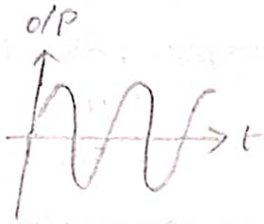
Over Damping Oscillations

∴ To get sustained oscillations AB = 1 $\phi = 0^\circ$ (or) 360° Barkhausen criteria.

→ Barkhausen Criteria:

$A\beta = 1$, $\angle A\beta = 0^\circ$

sustain Oscillations (to)



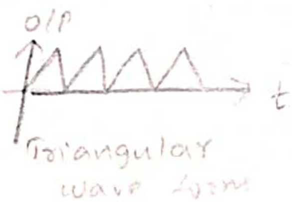
Types of Oscillators:-

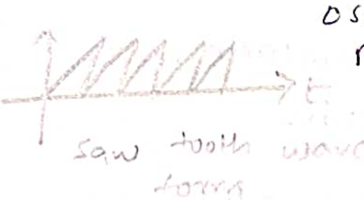
- Depending on the nature of the o/p: i/p → oscillator → o/p

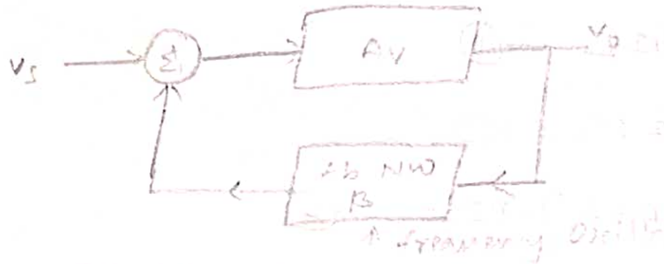
1. Harmonic Oscillator:
 - Sinusoidal Oscillator → o/p 

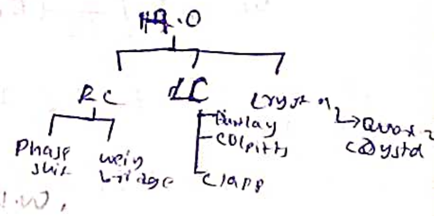
2. Relaxation Oscillator
 - Non sinusoidal Oscillator

→ It is a nonlinear electronic oscillator circuit that produces non-sinusoidal, repetitive o/p signal such as triangular / square / sawtooth wave

o/p 



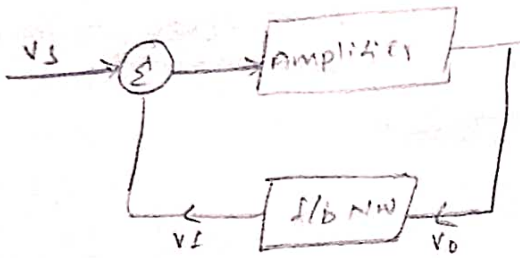
⇒ 



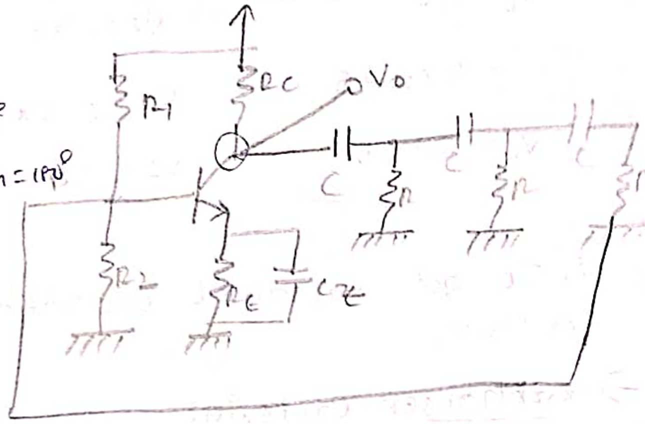
Frequency is selected by using R, L, C & crystal elements.

RC	LC	Crystal
(a) phase shift	(a) Hartley Oscillator	(a) Quartz crystal oscillator
(b) wien bridge	(b) Colpitts Oscillator	
→Audio frequency signal	(c) clapp oscillator	

① RC phase shift Oscillator using BJT:



→ A phase-shift oscillator is a linear electronic circuit that produces a sine wave.
→ It consists of an inverting amplifier element with its o/p fed back to i/p through a phase-shift n/w consisting of R & C in ladder n/w.



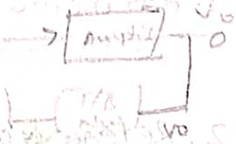
① - Audio frequency Oscillator
② - Amplifier - CE configuration : 180°
③ Feed back N.W - R, C, combination = 180°
Total phase = 360°

④ - $A\beta = 1$
A = real
β = real (imaginary = 0)

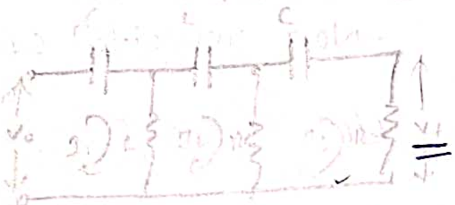
⑤ -) Advantages: . No inductor used, hence small size.
. It is well suited for frequency below 10 KHZ
. Fixed frequency oscillator, $f_0 = \frac{1}{2\pi RC\sqrt{6}}$

⑥ -) Disadvantages: . . small o/p due to small feed back
. Frequency stability is poor due to temparature, aging.
. Require high gain, practically not possible.

→ Mathematical Analysis of RC phase shift Oscillator:



$A\beta = 1$, A is always real number
∴ β also must be real number.



Feed Back Network

X_C = Capacitive reactance (Ω)

→ $X_C = \frac{1}{sC}$; $s = j\omega$

$V_0 = \frac{I_1}{sC} + R_1(I_1 - I_2)$

$V_0 = I_1\left[\frac{1}{sC} + R_1\right] - R_1 I_2$ —①

→ $\frac{1}{sC} I_2 + R(I_2 - I_1) + R(I_2 - I_3) = 0$

$-RI_1 + I_2\left[2R + \frac{1}{sC}\right] - RI_3 = 0$ —②

→ $I_3 \cdot \frac{1}{sC} + RI_3 + R(I_3 - I_2) = 0$

$0 I_1 - I_2 R + I_3\left[2R + \frac{1}{sC}\right] = 0$ —③

-) using cramer's rule:

$$\begin{bmatrix} R+\frac{1}{sC} & -R & 0 \\ -R & 2R+\frac{1}{sC} & -R \\ 0 & -R & 2R+\frac{1}{sC} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} V_0 \\ 0 \\ 0 \end{bmatrix}$$

$\rightarrow$ Find I_3, $\therefore V_f = I_3 R$.

Find determinant of matrix, $D = \begin{vmatrix} R+\frac{1}{sC} & -R & 0 \\ -R & 2R+\frac{1}{sC} & -R \\ 0 & -R & 2R+\frac{1}{sC} \end{vmatrix}$

$$|D| = \left[R+\frac{1}{sC}\right]\left[\left(2R+\frac{1}{sC}\right)^2 - R^2\right] + R\left[-R\left(2R+\frac{1}{sC}\right)\right]$$

$I_3 = \frac{D_3}{\Delta}$

$$= \left(\frac{1+sCR}{sC}\right)\left[4R^2 + \frac{1}{s^2C^2} + \frac{4R}{sC} - R^2\right] - 2R^3 - \frac{R^2}{sC}$$

$$= \left(\frac{1+sCR}{sC}\right)\left[\frac{4R^2s^2C^2 + 1 + 4RsC - R^2s^2C^2}{s^2C^2}\right] - \left(\frac{2R^3sC + R^2}{sC}\right)$$

$$= \frac{1 + 4R^2s^2C^2 + 4RCs - R^2s^2C^2 + sCR + 4R^3s^3C^3 + 4R^2s^2C^2 - R^3s^3C^3 - 2R^3s^3C^3 - R^2s^2C^2}{s^3C^3}$$

$$\boxed{|D| = \frac{1 + 6R^2s^2C^2 + R^3s^3C^3 + 5RCs}{s^3C^3}}$$

To find I_3, find D_3 of matrix.

$$[D_3] = \begin{bmatrix} \frac{1+RCs}{sC} & -R & V_0 \\ -R & 2R+\frac{1}{sC} & 0 \\ 0 & -R & 0 \end{bmatrix}$$

$$|D_3| = V_0\left(+R^2\right)$$

$$\boxed{|D_3| = V_0R^2}$$

$$\therefore I_3 = \frac{|D_3|}{|D|} = \frac{V_0R^2s^3C^3}{1 + 6R^2s^2C^2 + R^3s^3C^3 + 5RCs}$$

$(s = j\omega)$

$$V_f = I_3 R$$

$$\beta = \frac{V_f}{V_0} = \frac{R^3s^3C^3}{1 + 5RCs + 6R^2s^2C^2 + R^3s^3C^3}$$

$(s = j\omega)$, $j^2 = -1$

$j^3 = -j$

$j^4 = 1$

$$= \frac{-j\omega^3R^3C^3}{1 + 5RCj - 6R^2\omega^2C^2 - jR^3\omega^3C^3}$$

Dividing numerator & denominator by $-j\omega^3R^3C^3$.

$$\therefore \quad \beta = \cfrac{1}{\cfrac{-1}{j\omega^3R^3C^3} + j\cfrac{5\omega RC}{-j\omega^3R^3C^3} - 6\cfrac{\omega^2R^2C^2}{-j\omega^3R^3C^3} - \cfrac{j\omega^3\cancel{R^3}C^3}{-j\omega^3R^3C^3}}$$

$$= \cfrac{1}{1 - \cfrac{5}{\omega^2R^2C^2} + \cfrac{(6j)}{\omega RC} - \cfrac{j}{\omega^3R^3C^3}}$$

Let, $\alpha = \frac{1}{\omega CR}$

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

$\alpha^3 = \frac{1}{\omega^3C^3R^3}$

$$\beta = \frac{1}{1 - 5\alpha^2 + (6j\alpha) + j\alpha^3}$$

As 'A' is real, 'B' must be real,

$$\therefore \quad -6\alpha + \alpha^3 = 0$$

$$\alpha(\alpha^2 - 6) = 0$$

$$\alpha^2 = 6$$

$$\boxed{\alpha = \sqrt{6}}$$

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

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

$$\therefore \quad f = \frac{\omega}{2\pi}$$

capacitive, $\omega = 2\pi f$

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

which is the frequency of oscillator.

At this frequency, $\beta = \frac{1}{1 - 5\alpha^2}$

$$= \frac{1}{1 - 5(6)}$$

$$\beta = \frac{1}{-29}$$

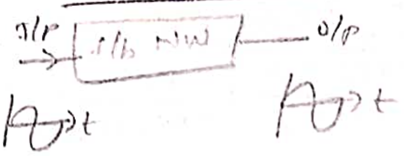
-ve sign indicates phase of $180°$.

$$\therefore \quad |B| = \frac{1}{29} \; ; \quad |AB| \geq 1 \;/\; |AB| = 1$$

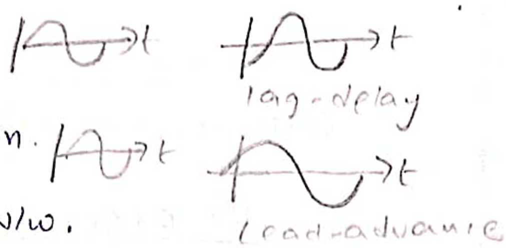
$$\therefore \quad |A| \geq 29$$

-) **WIEN BRIDGE OSCILLATOR:** electronic ckt produces sine waves. It is based on a bridge circuit originally developed for the measurement of impedances. It consists of 4 resistors & 2 capacitors.

- Audio frequency oscillator.
- Lead-lag N/w is used as f/b N/w
- at f_0 - No phase introduces.

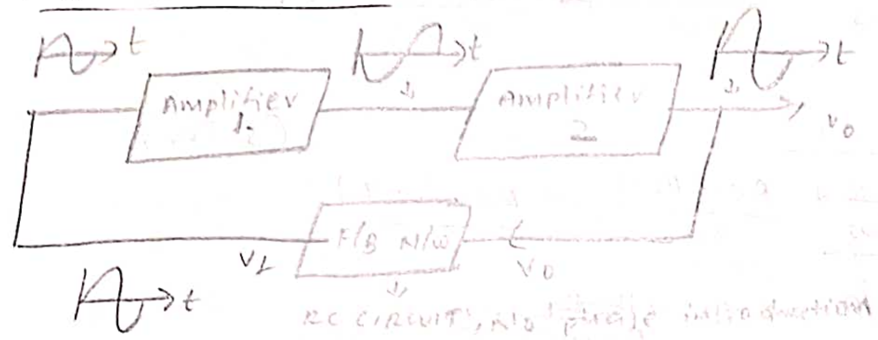


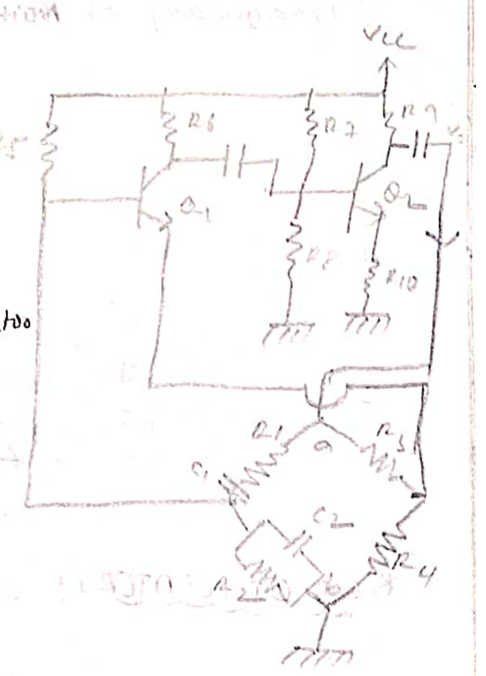
- at $f > f_0$ phase lag introduction.
- at $f < f_0$ phase lead introduction.



- R, C elements are used in f/b N/w.
- overall gain is high (2 Amplifiers)
- provide variable frequency range.
- complex circuit, need to balance bridge.

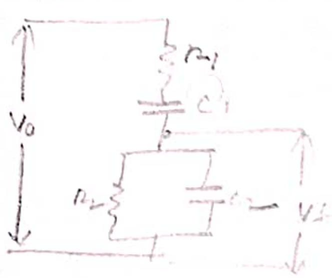
Circuit and Block Diagram:





-> R_3 & R_4 for voltage divider Bias.
- Bridge is balanced means, keep the ammeter between a & b, if $I = 0$, the Bridge is balanced, then we will get sustained oscillations.

-> Mathematical analysis of wein Bridge oscillator

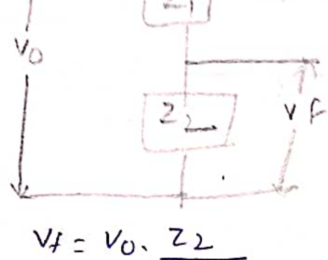


$R_1 = \Omega$

$X_{C1} = \frac{1}{C_1 s} - \Omega$

$X_{C2} = \frac{1}{C_2 s} - \Omega$

$R_2 - \Omega$



$$Z_1 = R_1 + \frac{1}{C_1 s} = \frac{1 + R_1 C_1 s}{C_1 s}$$

$$Z_2 = \frac{R_2 \times \frac{1}{C_2 s}}{R_2 + \frac{1}{C_2 s}} = \frac{R_2}{R_2 C_2 s + 1}$$

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

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

$$= \frac{R_2/1+R_2C_2s}{\frac{1+R_1C_1s}{C_1s} + \frac{R_2}{1+R_2C_2s}}$$

$$= \frac{R_2C_1s}{(1+R_1C_1s)(1+R_2C_2s)+R_2C_1s}$$

$$= \frac{R_2C_1s}{1+(R_1C_1+R_2C_2)s+R_1R_2C_1C_2s^2+R_2C_1s}$$

$$= \frac{1}{\frac{1}{R_2C_1s} + \frac{R_1C_1+R_2C_2}{R_2C_1} + \frac{R_1\cancel{R_2}\cancel{C_1}C_2s^{\cancel{2}}}{\cancel{R_2}\cancel{C_1}\cancel{s}} + 1}$$

$$\beta = \frac{1}{\frac{1}{R_2C_1jw} + \frac{R_1C_1+R_2C_2}{R_2C_1} + R_1C_2jw+1)} \qquad (s=jw]$$

Imaginary of β, $wR_1C_2 - \frac{\cancel{R_2C_1}}{R_2wC_1} = 0$

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

$$w = \frac{1}{\sqrt{R_1R_2C_1C_2}}$$

$$f = \frac{w}{2\pi}$$

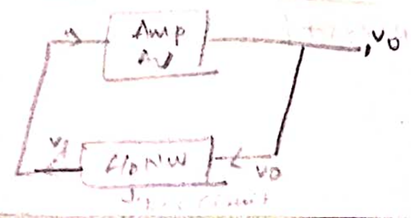
$$\therefore \quad f = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}$$

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

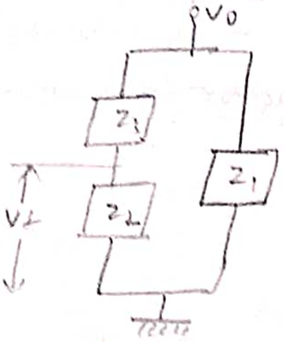
* **LC OSCILLATORS:**
  - Hartlay Oscillator
  - Colpitts oscillator
  - Clapp oscillator

- used for high frequency sustained oscillator.
- L, C elements are used in f/b NW.

Block Diagram:



Feed back N/w:



if $Z_1 =$ —||—

$Z_2, Z_3 \rightarrow$ —ooo—

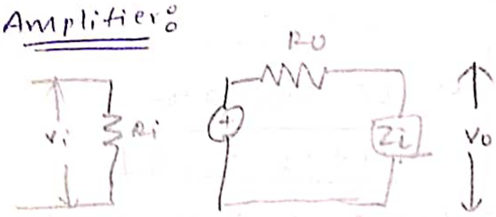
$\Rightarrow$ Hartley oscillator

& if $Z_1 \rightarrow$ —ooo—

$Z_2, Z_3 \rightarrow$ —||—

$\Rightarrow$ Colpitts Oscillator

Amplifier:



$$V_0 = V_i \cdot \frac{Z_L}{Z_L + R_0}$$

Gain, $A_V = \frac{V_0}{V_i} = \frac{Z_L}{Z_L + R_0}$

$$\therefore V_f = \frac{Z_2}{Z_2 + Z_3} \cdot V_0$$

$$\beta = \frac{V_f}{V_0} = \frac{Z_2}{Z_2 + Z_3}$$

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

concept $A\beta = 1$, real

$$\frac{\left[A_V \cdot \frac{(Z_2+Z_3)Z_1}{Z_1+Z_2+Z_3}\right]\left[\frac{Z_2}{Z_2+Z_3}\right]}{\frac{(Z_2+Z_3)Z_1}{(Z_1+Z_2+Z_3)} + R_0} = 1 \text{ (or) real}$$

$$\rightarrow \frac{A_V Z_1 Z_2 + A_V Z_1 Z_3}{(Z_2+Z_3)Z_1 + R_0(Z_1+Z_2+Z_3)} \cdot \frac{Z_2}{(Z_2+Z_3)} = \text{real}$$

$$\rightarrow \frac{A_V \cdot Z_1 Z_2}{Z_1 Z_2 + Z_1 Z_3 + R_0(Z_1+Z_2+Z_3)} = \text{real.}$$

$Z_1 = j X_1$

$Z_2 = j X_2$

$Z_3 = j X_3$

$$\rightarrow \frac{-A_V X_1 X_2}{-X_1 X_2 - X_1 X_3 + R_0 j(X_1+X_2+X_3)} = \text{real}$$

$$\rightarrow R_0(X_1 + X_2 + X_3) = 0$$

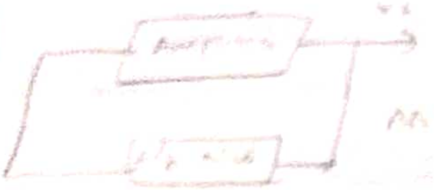
$R_0 \neq 0$; $\boxed{X_1 + X_2 + X_3 = 0.}$

→ HARTLAY OSCILLATOR:

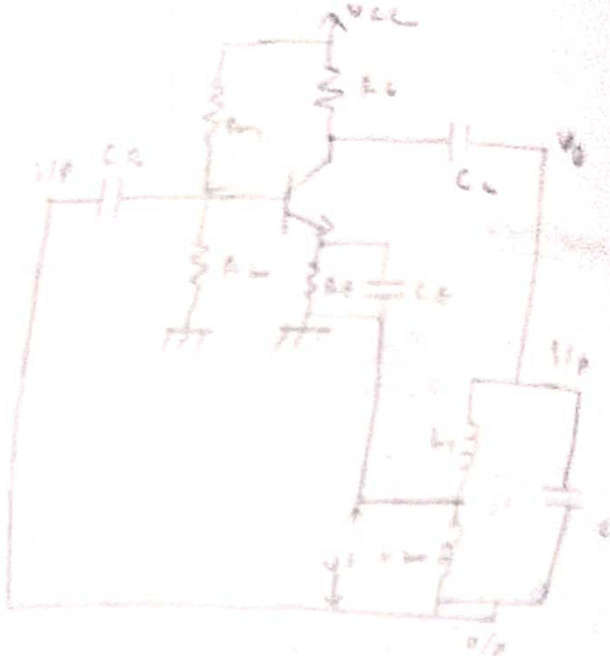
- an LC oscillator
- FB N/w → 2 ind. + cap.

- Radio frequency oscillator
- uses 2 inductors and one capacitor in fb N/w.

BLOCK DIAGRAM:



$A\beta = 1$



For LC oscillator

$$\boxed{X_1 + X_2 + X_3 = 0}$$

$L_1 - X_1$ (inductive reactance)

$= L_1 s = jwL_1$

$L_2 - X_2 = L_2 s = jwL_2$

$C - X_3 = \frac{1}{Cs} = \frac{1}{jwC}$ $(s = jw)$

$X_1 + X_2 + X_3 = 0$

$\Rightarrow jw(L_1 + L_2) + \frac{1}{jwC} = 0$

$jw(L_1 + L_2) - \frac{j}{wC} = 0$

$w(L_1 + L_2) = \frac{1}{wC}$

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

$\Rightarrow w = \frac{1}{\sqrt{(L_1+L_2)C}}$

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

$\because w = 2\pi f$

$f = \frac{w}{2\pi}$

Advantages:

- Radio frequency o/p
- Adjustable frequency from capac
- Use of Auto transformer (single

Disadvantages:

- Size is very large (2 inductors)
- High cost
- Cannot generate low frequency
- Poor frequency stability.

→ COLPITTS OSCILLATOR:

$\rightarrow X_1, C_1 \rightarrow = \frac{1}{C_1 s} = \frac{1}{jwC_1}$ (X_1)

$X_2, C_2 \rightarrow = \frac{1}{C_2 s} = \frac{1}{jwC_2}$ (X_2)

$X_3, L \rightarrow = Ls = jwL$ (X_3)

$X_1 + X_2 + X_3 = 0$

$\frac{1}{jwC_1} + \frac{1}{jwC_2} + jwL = 0$

$$\frac{-j}{\omega C_1} - \frac{j}{\omega C_2} + j\omega L = 0$$

$$\cancel{j}\omega L = \cancel{j}\left[\frac{1}{\omega C_1} + \frac{1}{\omega C_2}\right]$$

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

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

$$\omega^2 = \frac{1}{L \cdot \left(\frac{C_1 C_2}{C_1 + C_2}\right)}$$

$$\omega = \sqrt{\frac{1}{L \cdot \left(\frac{C_1 C_2}{C_1 + C_2}\right)}}$$

$$\therefore \boxed{f = \frac{1}{2\pi\sqrt{L\left(\frac{C_1 C_2}{C_1 + C_2}\right)}}} \quad \text{(or)} \quad \omega^2 = \frac{1}{L}\left(\frac{1}{C_1} + \frac{1}{C_2}\right)$$

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

→ **Advantages:**

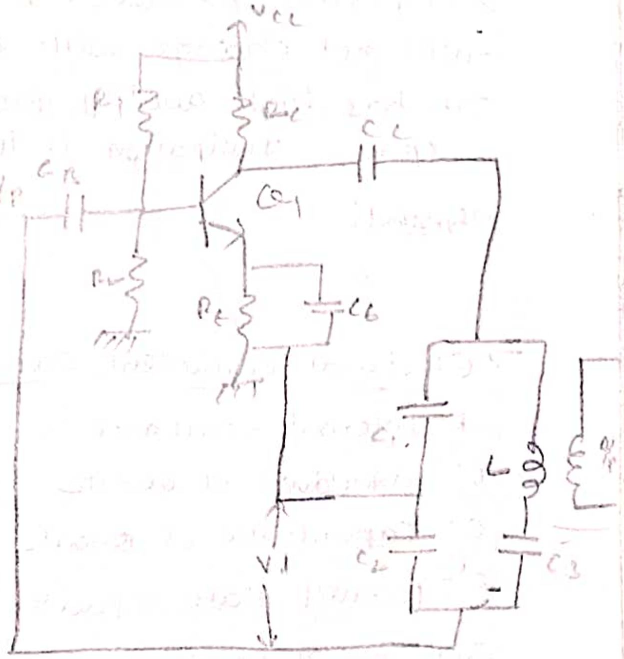
- Small size as compared to oscillator

→ **Disadvantages:**

- Difficult to design
- poor isolation.
- f_0 cannot be stable due to internal capacitances of Transistor.

→ **CLAPP OSCILLATOR:**

- Provide frequency stability.
- Uses one extra capacitor.
- LC Oscillator.



- It has internal capacitance and, Cin & Cout.

i.e., Cin appear in series with C_1 & Cout appear in series with C_2.

$\therefore$

$C_1' = C_1 + C_{in}$

$C_2' = C_2 + C_{out}$

$$\therefore f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{L}\left(\frac{1}{c_1'} + \frac{1}{c_2'}\right)}$$

'fo' is not stable, to eliminate that problem additional ca is connected.

∴ C_3 is selected to be smaller than $c_1' + c_2'$.

In LC oscillator, $x_1 + x_2 + x_3 + x_4 = 0$

$$\therefore f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{L}\left(\frac{1}{c_1'} + \frac{1}{c_2'} + \frac{1}{c_3}\right)}$$

→ $\frac{1}{c_3} >> \frac{1}{c_1'} + \frac{1}{c_2'}$

$$\therefore f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{L}\left(\frac{1}{c_3}\right)}$$

$$\boxed{f_0 = \frac{1}{2\pi\sqrt{Lc_3}}}$$ //

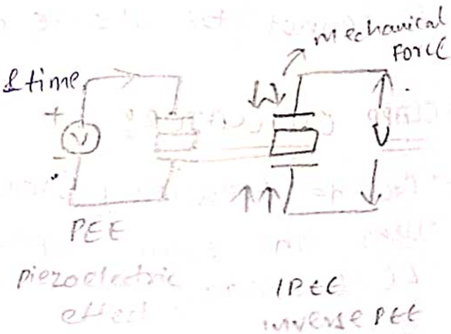
* CRYSTAL OSCILLATOR:-

- It is fixed frequency oscillator.
- Frequency is highly stable
- LC oscillator
- Quartz crystal is used in place of inductor.

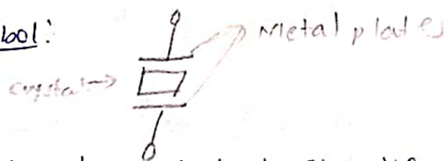
→ Quartz → piezoelectric material, converts electrical energy to mechanical ~~and~~ vice versa.

→ Properties of Quartz material:-

- will not change with temparature & time
- It has high quality factor, Q (power dissipation is low)



→ symbol:



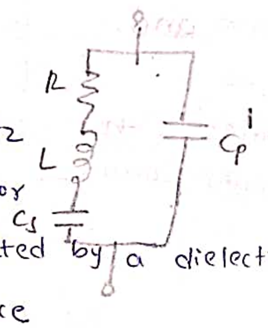
→ Electrical equivalent circuit:

R: Internal resistance

L: Inductance of Quartz

C: Capacitance of Quartz

c': Parallel plate capacitor



L = Mechanical Mass

C = Quartz thickness

R = Resistive loss

c' = due to metal plates/electro

- Two metal plates seperated by a dielectric crystal slab

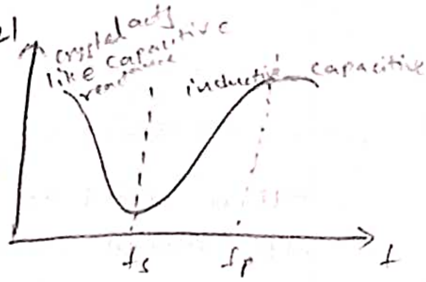
C_s (or) C : Series capacitance

C_p (or) c' : parallel capacitance

Behaviour of crystal impedance vs frequency

→ f_s = series reasonance frequency

→ f_p = parallel resonance frequency



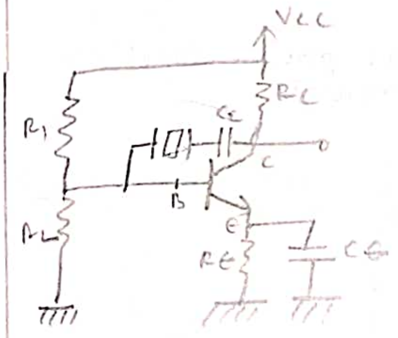
⇒ series resonant condition occurs when $X_L = X_{C_s}$ (or) $X_L = X_C$ under this condition the impedance is minimum.

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

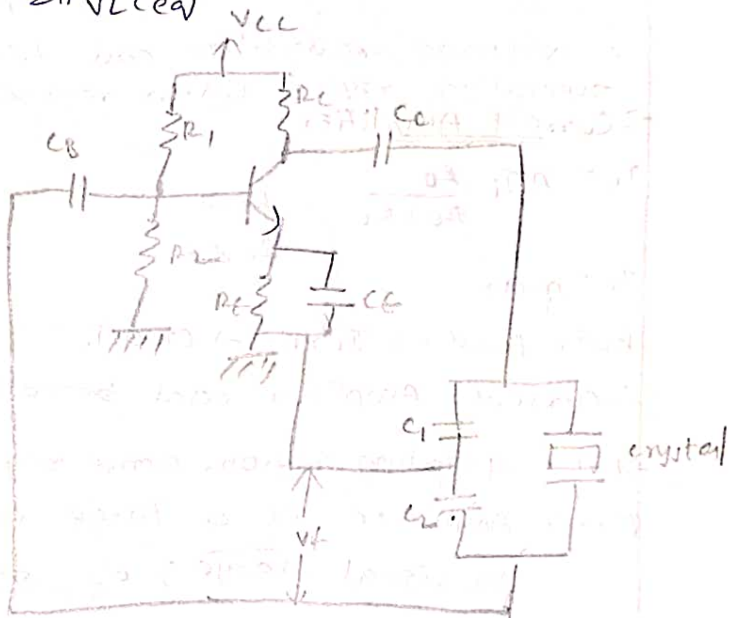
→ Parallel resonant condition occurs when the reactance of series resonant lay equals to the reactance of the ~~making~~ mounting capacitor C_p'.

Under parallel resonance, $C_{eq} = \frac{C_p' C_s}{C_p' + C_s}$

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



oscillator at series resonance

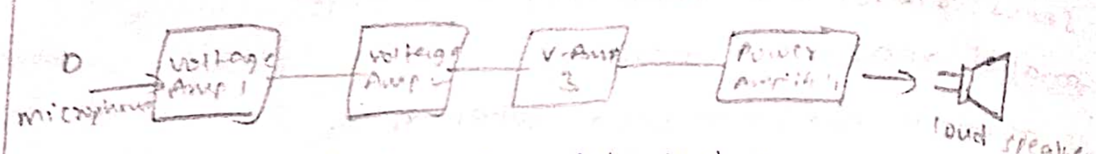


oscillator at b/w f_s & f_p

$f_s < f < f_p$.

2/2/23

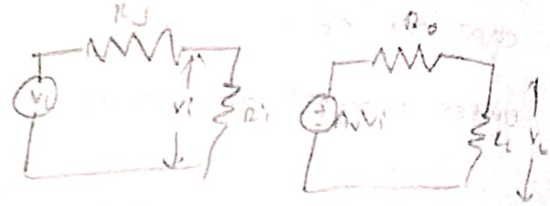
4. POWER AMPLIFIERS



- It is used to deliver a substantial amount of power to load
- It should convert DC power into AC power Efficiently.
- power conversion efficiency, power dissipation.
- to get maximum power at load

$$power = \frac{V^2}{R_L} = I^2 R_L$$

→ **Voltage Amplifier:**



$$V_L = A_V \cdot V_i \cdot \frac{R_L}{R_L + R_o}$$

$R_o <<$

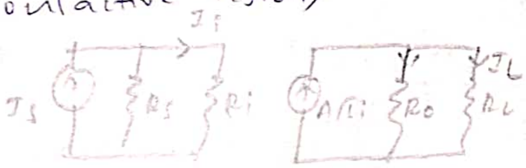
$R_L >>$

$\therefore V_L = A_V V_i$ is large but $P_L = \frac{V_L^2}{R_L}$ is moderate value.

∴ voltage amplifier can't be used as power Amplifier.

→ operating region - linear region (active region)

→ **Current Amplifier:**



$$I_L = A_I I_i \frac{R_o}{R_o + R_L}$$

$R_o >>$

$R_L <<$

$I_L = max$

but, $power = I_L^2 \times R_L \Rightarrow$ small.

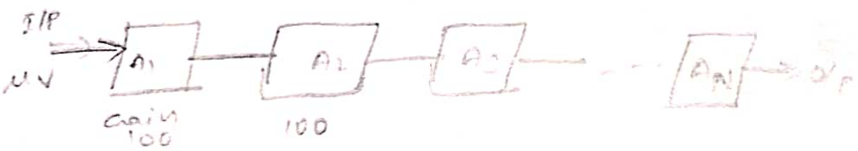
∴ Current Amplifier can't be used as power Amplifier.

→ BJT operating region: Active region (linear region)

power Amplifier is a large signal amplifier,

∴ I/p signal - large ; o/p signal - large

large (Not of mV & μV)

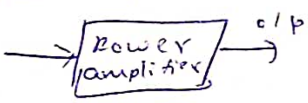


o/p of 1st amp $= 1 \times 10^{-6} \times 100 = 10^{-4}$ V

o/p of 2nd amp $= 10^{-4} \times 100 = 10^{-2}$ V

o/p of 3rd amp $= 10^{-2} \times 100 = 1$ V

I/p of 4th amp = 1V



∴ used in speakers.

∴ Last stage can be considered as power Amplifier.

→ Difference b/w V, I & P amplifiers:

V.I Amplifiers	Power Amplifiers
1. I/p signal strength: small	1. I/p signal strength: Large
2. Operating region: Active region (linear region)	2. Operating region: linear/Non-linear.
3. Method used: Mathematical i.e., h-model, hybrid-π model etc. . Graphical	3. Method used: . Graphical
4. Parameter Analysis: A_i, A_v, R_i, R_o	4. Parameter analysis: η, Distortion.

→ low o/p impedance
→ large power dissipation Transistor...

→ Types of power Amplifiers:

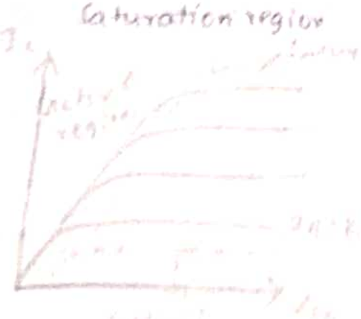
Basic concept:

① [C|B|C] J_E J_C — FB RB — Active region

② [C|B|C] J_E J_C — FB FB — Saturation region

③ [C|B|C] J_E J_C — RB RB — cut off region.

O/P characteristics



→ Operating point:

Q(Ic, Vcc)

Voltage & current amplifier

- operation: Active (or) linear region

- Power Amplifier → linear & non-linear region.

① Class A Amplifier: position of the operating point Q: Middle of AC load line line.

∴ Operates in linear region/Active region

② Class B Amplifier: operating point Q moves either in upward direction (saturation region) / in downward direction (cut off region)

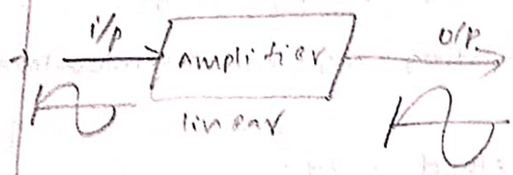
∴ operates in non-linear region.

③ class AB Amplifier - operating point Q is slightly above cutoff / slightly below saturation.

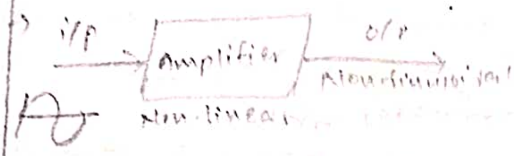
∴ Operates in non-linear region.

④ class C Amplifier: operating point Q is in deep cut off (or) deep saturation. ∴ operates in non-linear region

DISTORTION IN POWER AMPLIFIER:



- If it operates in linear region, then there will be no distortion.
- frequency does not change. i.e., $f_{in} = f_{o/p}$.



① Frequency distortion

f_1, f_2, f_3 - - - - A_1, A_2, A_3 ; f_1 f_2 f_3

- different gains.

② phase distortion is also known as "delay distortion".

f_1, f_2, f_3 —— f_1 f_2 f_3 ; ϕ_1 ϕ_2 ϕ_3 different phases.

③ Harmonic Distortion: This is due to production of new frequen in the o/p, which are not present in the i/p. These new frequencies (or) harmonics are generated when transistor operates in non linear region.

- when Transistor operates in linear region the relationship b/w i_c & i_b

$$\boxed{i_c = \beta i_b}$$

- consider non linear region (or) Non linear function

$$y = f(x)$$

$$y = a_0 + a_1 x + a_2 x^2 + \dots$$

ily

$$i_c = \underset{\text{DC current}}{I_c} + a_1 i_b + a_2 i_b^2 + a_3 i_b^3 + \dots$$

Let $i_b = \cos\omega_0 t$ - signal of fundamental frequency ω_0 in rad/se

$$i_c = I_c + a_1 \cos\omega_0 t + a_2 \cos^2\omega_0 t + a_3 \cos^3\omega_0 t + \dots$$

$$i_c = I_c + a_1 \cos\omega_0 t + a_2 \left(\frac{1+\cos 2\omega_0 t}{2}\right) + a \dots$$

$$i_c = I_c + \left[\frac{a_2}{2} + \dots\right] + a_1 \cos\omega_0 t + \frac{a_2}{2}\cos 2\omega_0 t + \dots$$

$$i_c = I_c + \underbrace{\left[\frac{a_2}{2} + \dots\right]}_{I_0} + B_1 \cos\omega_0 t + B_2 \cos 2\omega_0 t + B_3 \cos 3\omega_0 t + \dots$$

$\Rightarrow$ I_0 = Averge value due to distortion

B_1 = Amplitude of 1st fundamental component

B_2 = " " 2nd Harmonic Component

mathematically,

D_2 = 2nd Harmonic distortion = $\left|\frac{B_2}{B_1}\right|$

D_3 = 3rd Harmonic distortion = $\left|\frac{B_3}{B_1}\right|$

- Total Harmonic distortion: $D = \sqrt{D_2^2 + D_3^2 + \dots + D_n^2}$

$$D = \sqrt{\frac{B_2^2 + B_3^2 + \dots + B_n^2}{B_1^2}}$$

- Fundamental AC power due to fundamental frequency

$$P_1 = I^2_{rms,1} R_O$$

$$P_1 = \left(\frac{B_1}{\sqrt{2}}\right)^2 R_O = \frac{B_1^2}{2} R_O$$

$$P_T = \frac{B_1^2}{2} R_O + \frac{B_2^2}{2} R_O + \frac{B_3^2}{2} R_O + \dots$$

$$= \frac{B_1^2}{2} R_O \left[1 + \frac{B_2^2}{B_1^2} + \frac{B_3^2}{B_1^2} + \dots\right]$$

$$= \frac{B_1^2}{2} R_O \left[1 + D_2^2 + D_3^2 + \dots\right]$$

$$\boxed{P_T = P_1 (1 + D^2)}$$

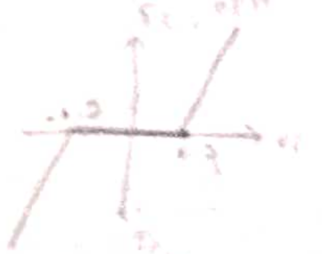
CROSS OVER DISTORTION:

If $V_{in} > 0.7V$
$\Rightarrow I_C$ = FB

If $V_{in} < 0.7V$
$\Rightarrow I_C$ = RB

If $V_i < -0.7V$
$\Rightarrow I_C$ = FB

If $V_i > -0.7V$
$\Rightarrow I_C$ = RB

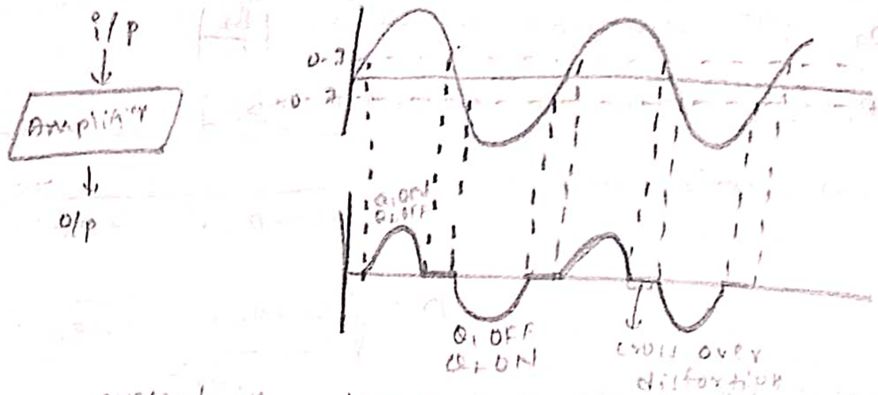


It means of $-0.7V < V_i < 0.7 \Rightarrow I_C$ = RB
I_C = R.B

- under this condition there will not be any o/p for
o/p = zero

Dead zone: The region of i/p voltage for which o/p is zero is called as "Dead Zone".

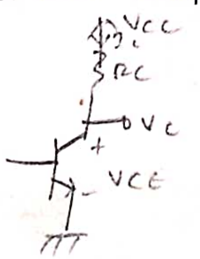
- Cross over distortion is a type of distortion, which is caused by switching b/w devices driving a load. It is most commonly seen in complimentary or push-pull class B amplifiers.



-present in class-B push-pull Amplifier.

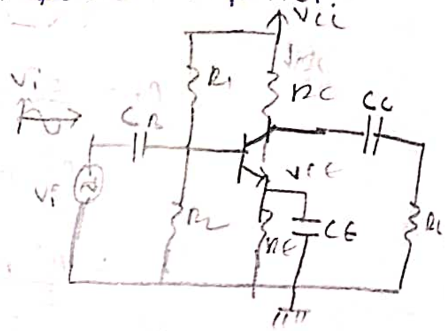
CLASS A POWER AMPLIFIER

→ Direct coupled / series fed class A power Amplifier.



→ $V_{CC} = I_C R_C + V_{CE}$

→ $V_{CE} = V_{CC} - I_C R_C$



- Qpoint is in center of load line
- V_i → in order of volts
- BJT amplifier is in Active region / Linear region

→ case-i: V_i +ve cycle

→ I_B - increases

→ $I_C = \beta I_B \Rightarrow I_C (\uparrow)$

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

$I_C R_C (\uparrow) \therefore V_{CE} (\downarrow)$

phase shift = 180°

case-ii: V_i → -ve cycle

$I_B - \downarrow$

$I_C - \downarrow$

$I_C R_C \downarrow$

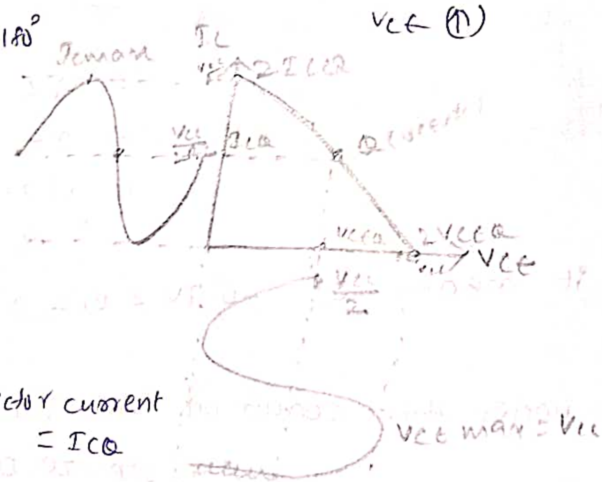
$\therefore V_{CE} = V_{CC} - I_C R_C$

$V_{CE} (\uparrow)$

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

$V_{CEmax} = V_{CC} / I_C = 0$

$I_{C max} = \frac{V_{CC}}{R_C} \Big/ V_{CE} = 0$



NOTE: if $V_i = 0V$

→ Due to DC biasing, collector current $= I_{CQ}$

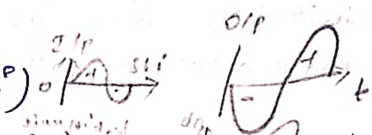
→ Collector to Emitter voltage $= V_{CEQ}$

$\therefore$ power dissipation $= I_{CQ} \times V_{CEQ}$ (more)

$\therefore$ power dissipation is more on power drain.

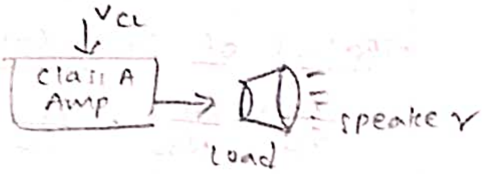
⇒ characteristics of class-A Amplifier:

- o/p current flows for entire cycle (0° → 360°)
- Does not have non linear Distortion



- Nature of i/p signal does not changed at o/p.
- Q point lies in the middle of load line. (Active region)
- Low conversion efficiency = 25%.

P_{dc} — P_{ac} [10w — 2.5w]



- power dissipation is high when i/p is not applied.
- provides undistorted o/p (operates in linear region)
- conduction angle : 360°

Advantages	Disadvantages
No distortion	Low efficiency
No Thermal run away	power Drain

→ Efficiency 'η' of class A Amplifier:

- Efficiency, $\eta = \frac{\text{o/p power}}{\text{i/p power}} = \frac{P_{ac}}{P_{dc}}$

→ $\boxed{P_{dc} = V_{CC} \times I_{CQ}} = V_{CC} \cdot \frac{V_{CC}}{2R_C} = \frac{V_{CC}^2}{2R_C}$

→ o/p power $\boxed{P_{ac} = V_{CE\,rms} \times I_{C\,rms}}$

From graph I_C peak to peak is $I_{C(p-p)} = \frac{V_{CC}}{R_C} - 0 = \frac{V_{CC}}{R_C}$

∴ peak value of I_C $I_{C(p)} = \frac{V_{CC}}{2R_C}$

$V_{CE\,rms} = \frac{V_{CE(P)}}{\sqrt{2}} = \frac{V_{CC}}{2\sqrt{2}}$

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

$V_{CEQ\,rms} = \frac{V_{CC}}{2\sqrt{2}}$

$P_{ac} = \frac{V_{CC}}{2\sqrt{2}R_C} \cdot \frac{V_{CC}}{2\sqrt{2}} = \frac{V_{CC}^2}{8R_C}$

$I_{CQ} = \frac{V_{CC}}{2R_C}$

$I_{C\,rms} = \frac{V_{CC}}{2\sqrt{2}R_C}$

∴ $\eta = \frac{P_{ac}}{P_{dc}} = \frac{V_{CC}^2/8R_C}{V_{CC}^2/2R_C} = \frac{1}{4}$.

∴ $P_{ac} = \frac{V_{CC}^2}{8R_C}$

$\eta = 0.25$

$\boxed{\eta = 25\%}$

P_{dc}	P_{ac}
10 w	2.5 w

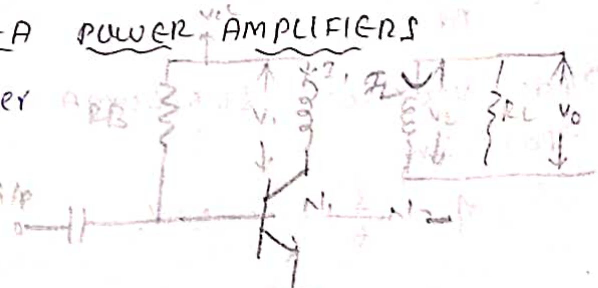
7.5w dissipated.

→ A class-A power amplifier is one in which the o/p current flows for the entire cycle of AC input supply.

* TRANSFORMER COUPLED CLASS-A POWER AMPLIFIERS

- In direct coupled class A power Amplifier, with no i/p, I_C flows through R_C & R_E.

∴ power dissipation is more.



- In transformer coupled class A power amplifier with no i/p, dc current will not flow from primary to

① RC

②-Au

②-Ar

③ CE

④ -

⑤ -)

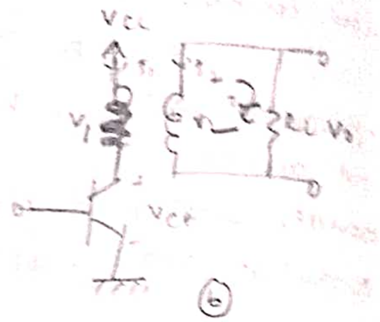
⑥ -)

->

secondary. ∴ No current through R_C
⇒ No power dissipation.

-> **Basics of Transformer:**

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}, \quad \frac{I_1}{I_2} = \frac{N_2}{N_1}$$



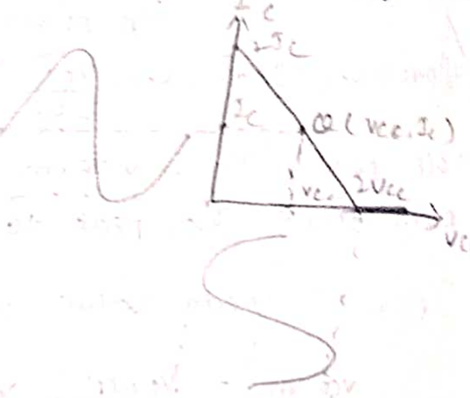
-> $R_L = \frac{V_2}{I_2}$, $R_{LP} = \frac{V_1}{I_1} = \frac{V_2 \cdot \frac{N_1}{N_2}}{I_2 \frac{N_2}{N_1}}$

$$R_{LP} = \frac{V_2}{I_2}\left(\frac{N_1}{N_2}\right)^2 = R_L \cdot \left(\frac{N_1}{N_2}\right)^2 \quad ; \quad \frac{N_1}{N_2} = \text{Turns Ratio}$$

∴ Transformer coupling will work by choosing turns ratio for impedance matching (to avoid loading effect).

-From fig ⑥ if no i/p, --- no drop across primary. $V_{CE} = V_{CC}$

- $I_{C(P-P)} = 2I_C$; $V_{CE(P-P)} = 2V_{CC}$
- $I_{C(P)} = I_C$; $V_{CE(P)} = V_{CC}$
- $I_{C\,rms} = \frac{I_C}{\sqrt{2}}$; $V_{CE\,rms} = \frac{V_{CC}}{\sqrt{2}}$



∴ $P_{ac} = V_{rms} \cdot I_{rms} = \frac{V_{CC} I_{CC}}{2}$

$P_{dc} = V_{CC} \times I_{CQ} = V_{CC} I_C$.

∴ η of transformer coupled $= \frac{P_{ac}}{P_{dc}} = \frac{V_{CC} I_{CC}/2}{V_{CC} I_{CC}}$

$= 1/2$

$\boxed{\eta = 50\%}$

dc - ac
10W 5W

∴ DC power dissipation decreases and η increases.

① A T/F coupled class A power amplifier supplies 3W power to speaker. If supply voltage is 30V and I_{CQ} is 200mA, then find η of this amplifier.

sol: $\eta = \frac{P_{ac}}{P_{dc}}$

-> $P_{dc} = V_{CC} \times I_{CQ} = 30 \times 200\text{mA} = 6 \times 10^3 \times 10^{-3} = 6W$

-> $P_{ac} = 3W$

∴ $\eta = \frac{3}{6} = \frac{1}{2} = 50\%$.

2) If series fed direct coupled class A Amplifier supplies 0.8 W power to speaker, if supply voltage is 30V & I_{CQ} is 200mA, find η.

$P_{ac} = 0.8\,W$, $P_{dc} = V_{CC} \times I_{CQ} = 30 \times 200 = 6W$

$$\therefore \eta = \frac{0.8}{6} = \frac{8}{60} = 0.13$$

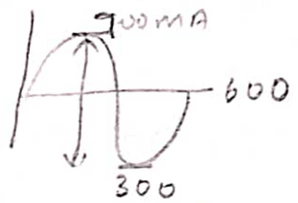
$$\boxed{\eta = 13\%}$$

3) single stage class-A has 20V (V_{CC}), $I_{CQ} = 600mA$, $V_{CEQ} = 10V$, $R_L = 16\Omega$ M. AC o/p current varies by 300mA. find

i) Power supplied by DC source to Amplifier.

ii) efficiency of Amplifier.

sol: $\therefore \eta = \frac{P_{ac}}{P_{dc}}$



$\rightarrow P_{ac} = V_{rms} \cdot I_{rms} = I_{rms}^2 \times R_L$

$$= \left(\frac{300}{\sqrt{2}}\right)^2 \times 16 \times 10^{-6}$$

$$= \frac{90000}{2} \times 16 \times 10^{-6}$$

$$= 4.5 \times 16 \times 10^{-2}$$

$$= 72 \times 10^{-2}$$

$$\boxed{P_{ac} = 0.72W}$$

$I_{C(p-p)} = 900 - 300 = 600mA$

$I_C(p) = \frac{600}{2} = 300mA$

$I_{Crms} = \frac{300}{\sqrt{2}} mA$

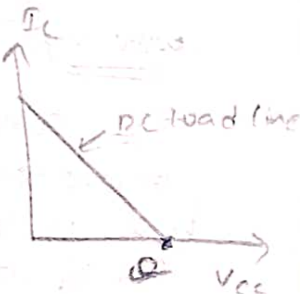
$\rightarrow P_{dc} = V_{CC} \times I_{CQ} = 20 \times 600 \times 10^{-3} = 12W$

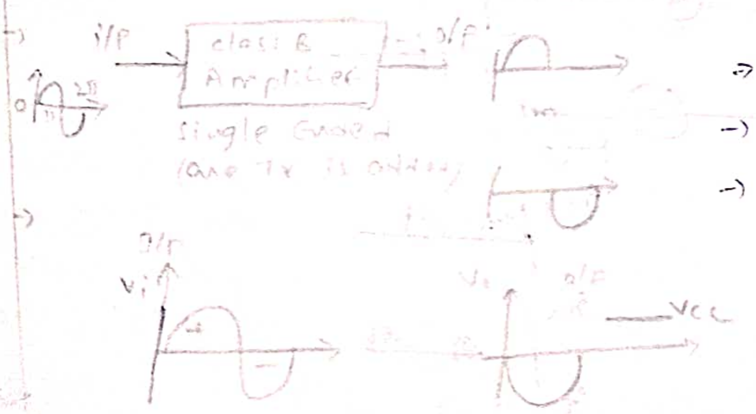
$$\therefore \eta = \frac{P_{ac}}{P_{dc}} = \frac{0.72}{12} = 6 \times 10^{-2}$$

$$\boxed{\eta = 6\%}$$

$\rightarrow$ Class B - Power Amplifier:

- Q-point is in cut off region.
- No biasing is used (R_1 & R_2 are not used)
- η is very high (78.5%)
- Conduction angle is 180°



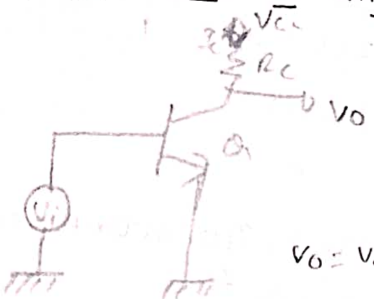


$\rightarrow$ No power drain

$\rightarrow$ It has lot of distortion

$\rightarrow$ Information at o/p: 50%.

-> Single Ended class B Amplifier:



$V_0 = V_{cc} - I_C R_C$

Case - 1 :

During positive half cycle.

Q_1 = Emitter Junction = FB } Active
- Collector junction - RB } region

$I_C R_C \uparrow \therefore V_0 = V_{cc} - I_C R_C$

$V_0 \downarrow$

$\therefore$ we get o/p with 180° phase shift.

Case-2 :

- During -ve cycle

Q_1: Emitter junction - RB
- Collector junction - RB

$I_C = 0 \therefore V_0 = V_{cc}$

$\Rightarrow V_{cc} = V_0$

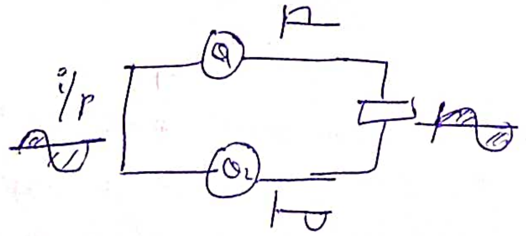
~~Working~~ PUSH PULL CLASS B POWER AMPLIFIER:

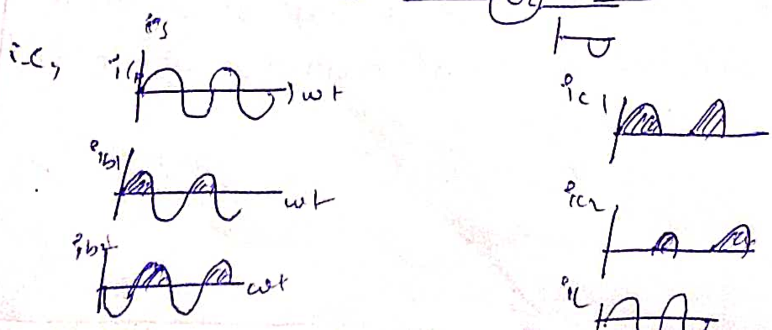
- push pull circuit requires the two transforems:
i) driver transformer ii) O/p transformer.

- Both the transistors are in CE configuration, i/p is al at primary of 1st transformer.
- centre tapping at 2ndary of 1st transformer is under tapping at primary of 2nd transformer is connected to

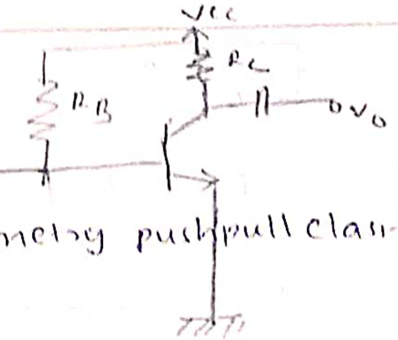
working:

→ Q_1 conducts for +ve half cycle producing the +ve half cycle across load & Q_2 conducts for -ve half cycle producing -ve half cycle across load. Thus we get a full cycle for full i/p cycle.





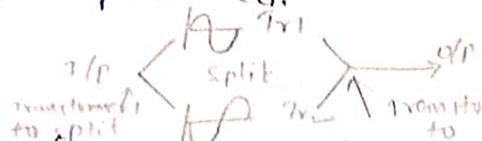
PUSH PULL CLASS B POWER AMPLIFIERS:



- Two transistors used
  [2-NPN → Push pull class B Amplifier]
  [1-NPN & 1-PNP → Complimentary symmetry push pull class B Amplifier]

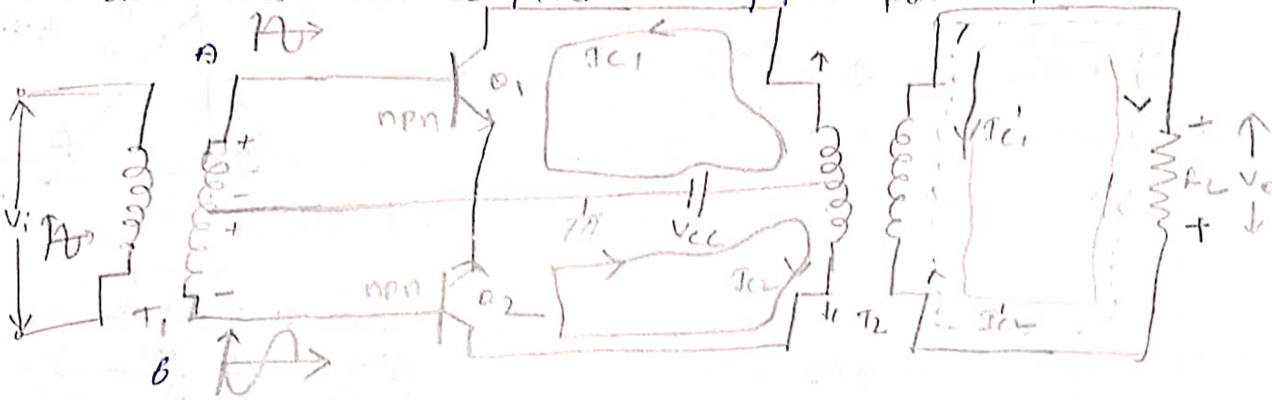
→ push pull mode 
→ During +ve cycle: Q_1 ON, Q_2 OFF
→ During -ve cycle: Q_1 OFF, Q_2 ON

. Comple input is processed.

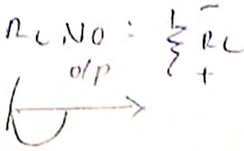
→ working 

Tr1 = Transistor one (Q_1)
Tr2 = Transistor two (Q_2)

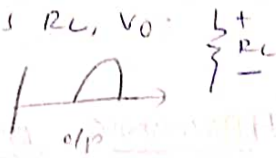
- We use Transformer coupled class B push pull Amplifier.

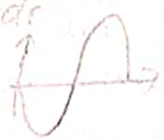


→ During +ve cycle - Q_1 = Active
Q_2 = OFF

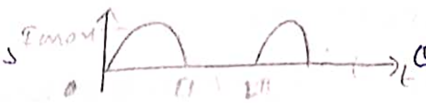
, I_c' across R_L, Vo: 

→ During -ve cycle - Q_2 = Active
Q_1 = OFF

, I_{c2}' across R_L, Vo: 

→ phase shift = 180° 

EFFICIENCY:

- During +ve half cycle Q_1 works 

- During -ve half cycle Q_2 works 

- $I_{DC}\ Q_1 = \frac{I_{cmax}}{\pi}$ (half cycle)

- $I_{DC}\ Q_2 = \frac{I_{cmax}}{\pi}$

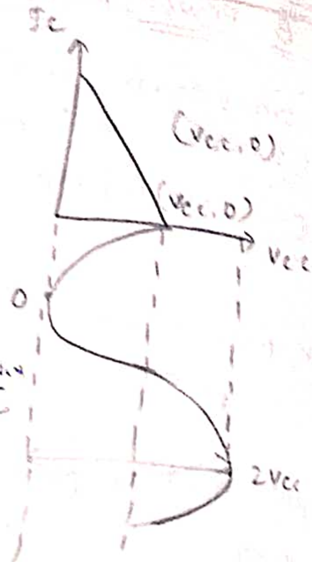
- $I_{DC}(Q_1 \& Q_2) = \frac{2I_{cmax}}{\pi} \left[\frac{I_{cmax}}{\pi} + \frac{I_{cmax}}{\pi}\right]$

$$I_{dcQ_1} = \frac{1}{2\pi}\int_0^{2\pi} I_{cmax}\sin\theta\, d\theta$$
$$= \frac{1}{2\pi} \cdot I_{cmax}\left[-\cos\theta\right]_0^{\pi}$$
$$= \frac{1}{2\pi} I_{cmax}\left[-(-1-1)\right]$$
$$= \frac{I_{cmax}}{\pi}$$

$V_{DC} = V_{CC}$

* $P_{DC} = V_{DC} \times I_{DC}$

$P_{DC} = V_{CC} \times \frac{2 I_{cmax}}{\pi}$



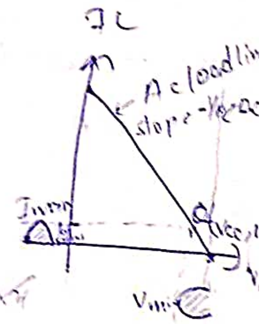
* $P_{ac} = V_{rms} \times I_{rms}$

→ $V_{p-p} = 2V_{cc} - 0 = 2V_{cc}$

→ $V_{peak} = V_{cc}$ ⇒ $V_{rms} = \frac{V_{cc}}{\sqrt{2}}$; $I_{rms} = \frac{I_{cmax}}{\sqrt{2}}$

→ $P_{ac} = \frac{V_{cc}}{\sqrt{2}} \times \frac{I_{cmax}}{\sqrt{2}}$

$P_{ac} = \frac{V_{cc}}{(2)} \times I_{cmax}$



∴ Efficiency, $\eta = \frac{P_{ac}}{P_{dc}}$

$= \frac{V_{cc} \times I_{cmax}}{2} \times \frac{\pi}{V_{cc} \times 2 I_{cmax}}$

$= \frac{\pi}{4}$

$= \frac{3.14}{4}$

$\eta = 0.785$

$\boxed{\% \eta = 78.5\%}$

i.e., if DC power = 100W

AC power = 78.5W

→ power dissipation:

$\frac{dP_d}{dV_m} = \frac{2}{\pi} \frac{V_{cc}}{R'_L} - \frac{2V_m}{2R'_L}$

$P_{dmax} = \frac{2}{\pi^2} \frac{V_{cc}^2}{R'_L}$ ⇒ $\frac{2}{\pi} \frac{V_{cc}}{R'_L} = \frac{V_m}{R'_L}$

⇒ $\boxed{V_m = \frac{2}{\pi}}$

Thus, the minimum possible theoritical efficiency in case of push pull class B power amp is 78.5% which is much higher than transformer coupled class A.

HARMONIC DISTORTION:

Due to nonlinear distortion, the collector current of the two transistors can be expressed interms of harmonic components as:

$i_{c1} = I_{CQ} + B_0 + B_1 \cos\omega_0 t + B_2 \cos 2\omega_0 t + B_3 \cos 3\omega_0 t + \cdots$

- The collector current for the second transistor can be obtained by replacing 'ωt' by '$\omega t \pm \pi$'

∴ $i_{c2} = I_{CQ} + B_0 + B_1 \cos(\omega_0 t + \pi) + B_2 \cos(2\omega_0 t + 2\pi) + B_3 \cos(3\omega_0 t \ldots$
$+ \cdots$

$i_{c2} = I_{CQ} + B_0 - B_1 \cos(\omega_0 t) + B_2 \cos 2\omega_0 t - B_3 \cos 3\omega_0 t + \cdots$

∴ $i_L = i_{c1} - i_{c2}$

$i_L = 2B_1 \cos\omega_0 t + 2B_3 \cos 3\omega_0 t + \ldots$

Here even harmonic i.e. 2nd, 4th, ... are eliminated.

Ily DC component also get eliminated.

$\therefore$ Total distortion is less and D.C component flowing is zero.

$$\% D_3 = \left|\frac{B_3}{B_1}\right| \times 100 \;;\; D_5 = \left|\frac{B_5}{B_1}\right| \times 100$$

$\therefore$ total harmonic distortion $\% D = \sqrt{D_3^2 + D_5^2 + D_7^2 + \ldots} \times 100$

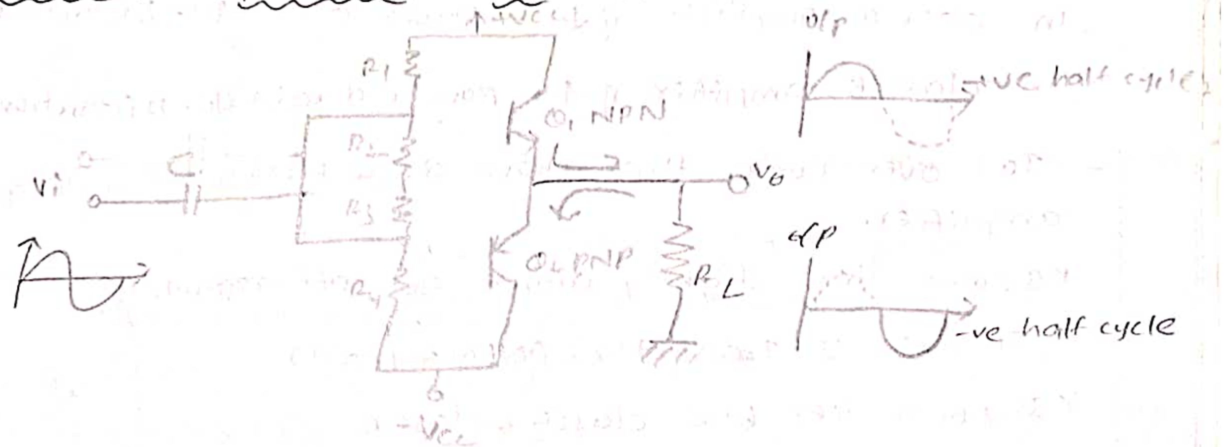
Advantages and Disadvantages:

- Transistor efficiency is much higher than class A power amplifier.
- No i/p signal, the power dissipation is zero.
- Even harmonic gets cancelled, this reduces the harmonic distortion.
- Due to transformer coupling, impedance matching is possible.

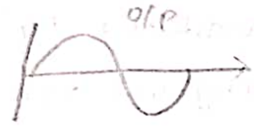
-Disadvantages:

- Two centre tapped transformers are necessary.
- The transformers make the circuit bulky and hence costlier.
- Frequency response is poor.

* COMPLEMENTARY SYMMETRY - PUSH PULL CLASS B POWER AMPLIFIER



- Q-point is in cut-off region.
- No biasing is used
- $\eta = 78.5\%$



+ve half cycle $\rightarrow$ Q_1 = ON, Q_2 = OFF $\Rightarrow$ +ve o/p

- Two transistors are used:
  - One is NPN &
  - One is PNP

-ve half cycle $\rightarrow$ Q_2 = ON, Q_1 = OFF $\Rightarrow$ -ve o/p

$$P_{dc} = \frac{V_{cc} \times 2 I_{cmax}}{\pi}$$

- efficiency,

$$P_{ac} = \frac{V_{cc}}{\sqrt{2}} \times \frac{I_{cmax}}{\sqrt{2}}$$

$$\therefore \eta = \frac{P_{ac}}{P_{dc}} = \frac{V_{cc} I_{cmax}}{V_{cc} 2 I_{cmax}} = \frac{\pi}{4}$$

$$\eta = \frac{P_{ac}}{P_{dc}} = \frac{\cancel{V_{cc}} \times \cancel{I_{cmax}}}{\sqrt{2}\sqrt{2}} \times \frac{\pi}{2 \cancel{V_{cc} I_{cmax}}} = 0.785$$

$\% \eta = 78.5 \%$

Advantages:

- As the circuit is transformer less, its weight, size and cost less.
- Due to common collector configuration impedance matching is possible.
- The frequency response improves due to transformer less class B amplifier.

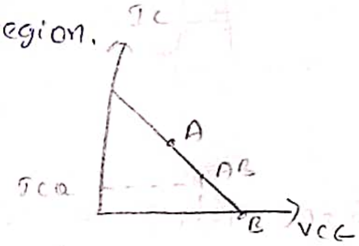
Disadvantages:

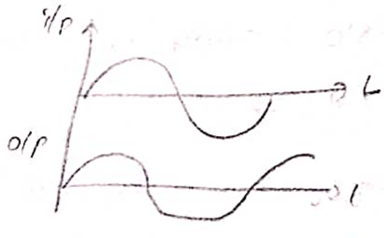
- The circuit needs two seperate voltage supplies.
- It is quite difficult to get a pair of Transistors (NPN PNP) that have similar characteristics.
- The harmonics will be developed if there is any unbalance in the two transistors, which results in the increase of distortion.

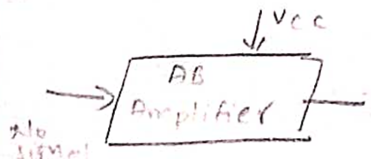
* CLASS AB AMPLIFIER:

- In class-A Amplifier - $\eta \downarrow$ - power drain (↑) - Distortion (↓) (linear region)
- In class-B Amplifier - $\eta \uparrow$ - power drain (↓) - Distortion (↑) (Non-linear region)
- To over come the above draw backs, we will go for class AB amplifier.

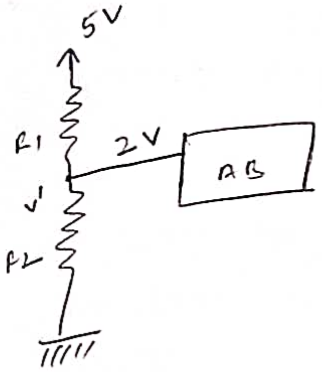
* Q point lies slightly above cut off region.
* It uses 2 Transistors (NPN & PNP)
* Q point lies b/w class A & class B
* It conducts in between 180° → 360°
* Biasing voltage keeps Transistor slightly above cut off region.
* Biasing can be given with help of R, (or) diode etc,

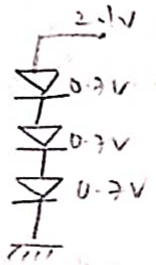






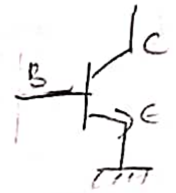
with out i/p, due to Vcc, small amount of I_C flows through the circuit.





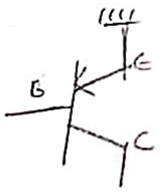
$V' = \frac{R_2}{R_1+R_2} \cdot 5V$

- chose R_1 & R_2
∴ we get 2V at Base of Transistor.
- replace R_2 by diodes to get 2V.

* 

NPN

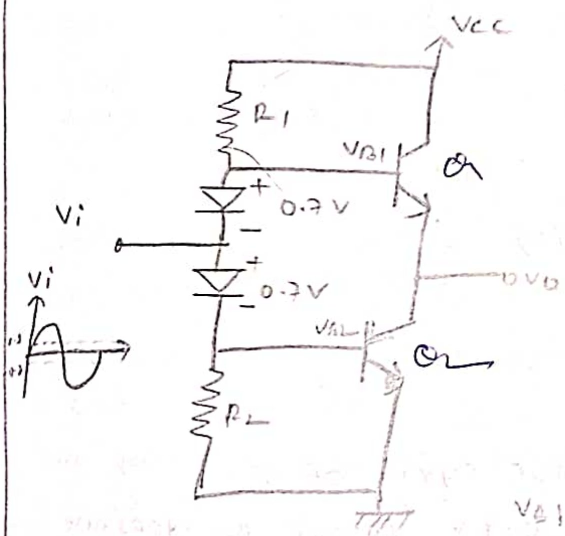
- if $V_B \geq 0.7 \rightarrow$ Transistor conducts
  if $V_B < 0.7$ Transistor does not conducts.

* 

PNP

if $V_B \leq -0.7$ Transistor conducts
if $V_B > -0.7$ Transistor does not conducts.

- Class AB uses both Transistors.



<u>case-1:</u>

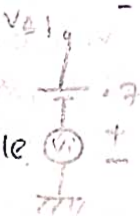
- No i/p is applied,
  i.e., V_{o} is grounded
  Vcc is applied.

$V_{B1} = 0.7V$ Q1-ON, Q2-ON
$V_{B2} = -0.7V$

<u>case-2:</u>

- along vcc, During +ve cycle of V_i

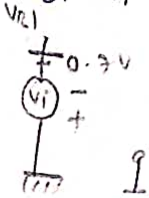
$V_{B1} = 0.7 + V_i$ - increases
⇒ I_C increases (NPN)



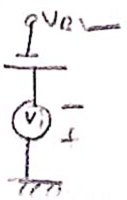
and (PNP)
$V_{B2} = -0.7 + V_i$ ∴ increases
⇒ Q_2 does not conduct
∴ I_{C2} = zero (no current)

<u>case-3:</u>

along Vcc, During -ve cycle of V_i



$V_{B1} = 0.7 - V_i$ (↓)
I_{C1} = zero (no current)



$V_{B2} = -0.7 - V_i$ (↓)
⇒ Q_2 conducts
∴ I_{C2} - increases

<u>case-4:</u>

if $-0.7 < V_i < 0$ (during -ve cycle)
<u>Ex:</u> $V_i = -0.5V$
$V_{B1} = 0.7V - 0.5V = 0.2V$, Q_1: OFF
$V_{B2} = -0.7 - 0.5 = -1.2V$, Q_2: ON

case - 5:

if $0 < v_{in} < 0.7$

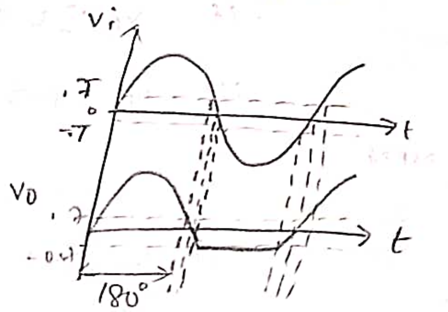
Ex: $V_C = 0.5\,V$

$V_{B1} = 0.7 + 0.5 = 1.2V \Rightarrow Q_1 = ON$

$V_{B2} = -0.7 + 0.5 = -0.2 \Rightarrow Q_2 = OFF$

In class AB we will not come across Dead zone.

∴ Cross over distortion is eliminated.



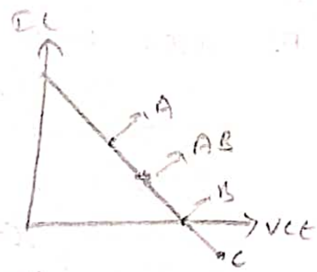
→ conduction angle

$>180^\circ$ & $<360^\circ$

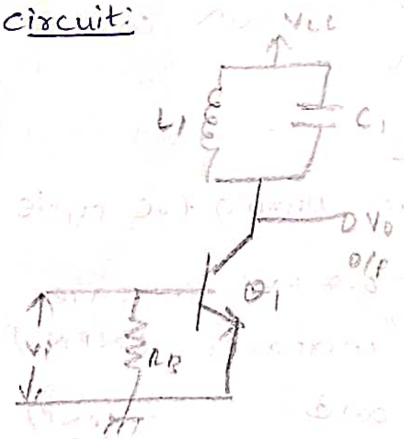
∴ phase is $180+\phi$

Class C Amplifier:

- It is deeply biased.
- Q point is below cutoff region.
- conduction angle is less than 180°
- very high efficiency ($\simeq 90\%$)
- high distortion, is due to nonlinearity



circuit:

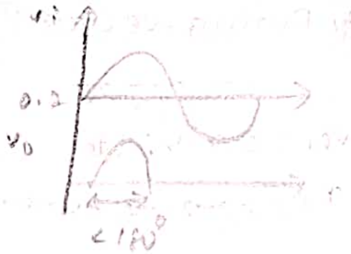


case-i:

During +ve cycle of vi:

if $v_i < 0.7\,V$ $V_B = v_i$, Q_1 does not condu

$v_i \geq 0.7\,V$ $V_B = v_i \Rightarrow Q_1$ conducts



case-ii:

During -ve half cycle

$V_B = -V_C$

∴ $Q_1 = OFF$

$O/p = zero$

Advantages:

$\eta = 90\%$

- It can be used in RF application, high power o/p with small size.

Disadvantages)

- Non linearity
- Audio frequency can't be generated
- Distortion is more

Applications:

- RF Amplifier
- RF Oscillator
- Tuned amplifier.

Working: As shown in figure

- Resistor 'Rb' connects to transistor 'Q' base. This resistor try to pull the base of transistor further downwards and set the operating pointer dc bias point below cut-off point in dc load line.

- Here, the transistor will start conducting only after the input signal amplitude has risen above the base emitter voltage (0.7v).

- LC circuits are used either for generating signals at a particular frequency (or) picking out a signal at a particular frequency.

- A series of current pulses is produced by the transistor acording to i/p.

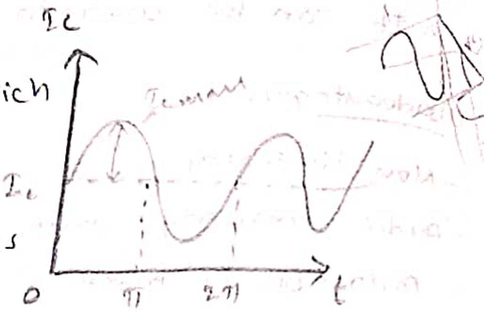
- The tank circuit oscillates in the frequency of i/p signal by selecting proper value of L & C.

- For transferring the power to the load from the tank circuit, a coupling transformer is used.

- The operating point is placed some way below the cutoff point in the DC-loadline and so only a fraction of the i/p waveform is available at o/p.//

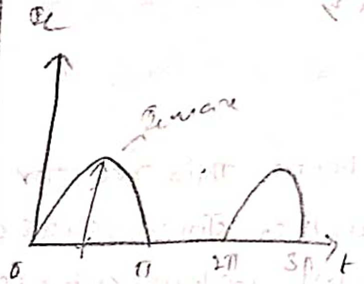
class-A power Amplifier:

A class A amplifier is one in which the operating point and the i/p signal are such that the current in the o/p circuit flows at full times.



collector current wave form for Transistor operating in class A

class-B Amplifier:

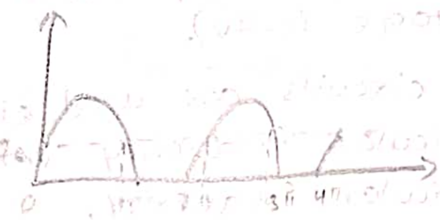


class B

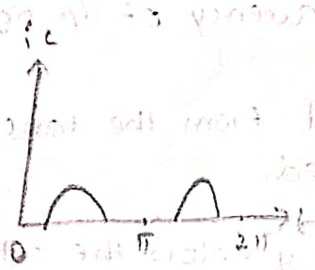
- In which the operating point is at extreme end of its characteristic. It provides an o/p signal varying over one-half the input signal cycle (or) for 180° of i/p signal.

class AB Amplifier:-

Operating point is in b/w class A and class B. The o/p signal swing occurs b/w 180° and 360°.



class C Amplifier:



class C

operating point is so choosen (below the cut off) so that o/p current is zero for more than one half of i/p signal.

summary of power Amplifier

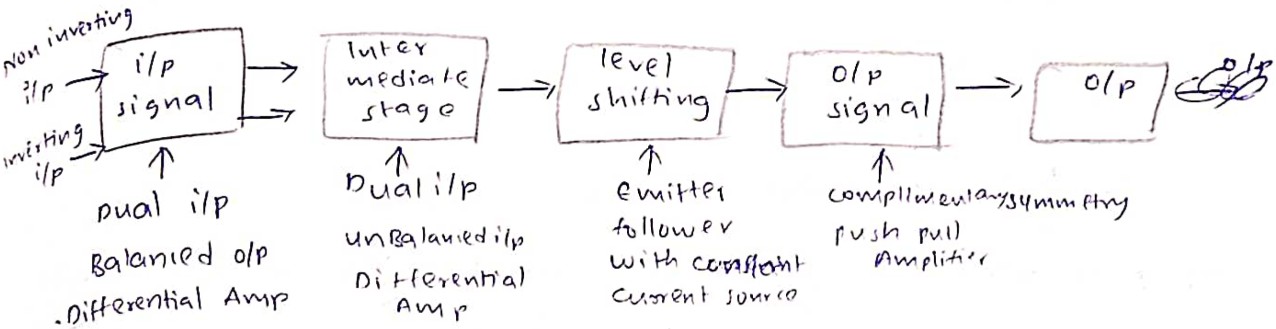
	class A	class B	class AB	class C
powerdrain	YES	NO	NO	NO
Q point	Middle	cutoff	slightly above cut off	deeper inside cutoff
conduction angle	0-360°	180°	180°-360°	<180°
Efficiency	50%	78.5%	>A & <B	90%
Distortion	NO	cross over distortion	NO COD	High.

5. OPERATIONAL AMPLIFIER

-> operational Amplifier : $+, -, \times, \div, \log$, Antilog, $\sqrt{\ }$

-> 741 IC [linear Integrated circuit]

Block Diagram:

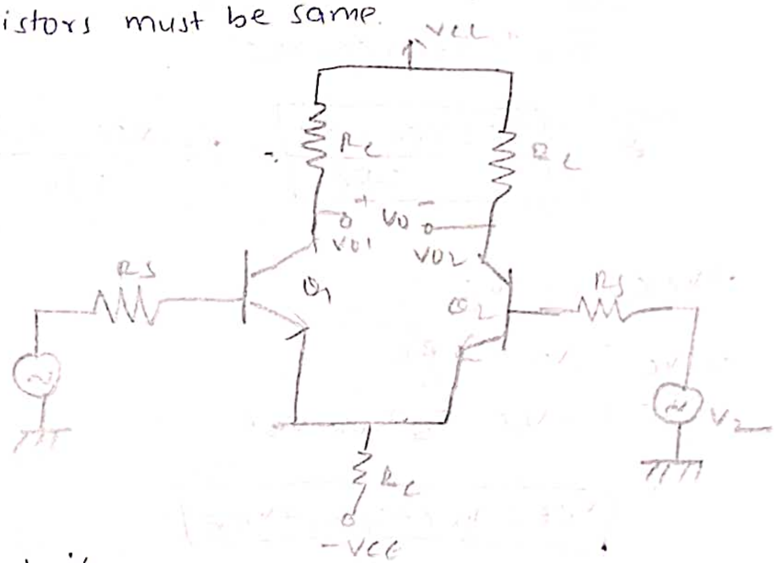


Differential Amplifier:

-Properties of both transistors must be same.

i.e, Q_1 Q_2

β_1 β_2



β-large => $I_B \downarrow\downarrow$ $I_C \sim I_E$

$V_{BE} = V_{BE_2} = V_{BE}$

$I_C = \beta I_B$

-On basis of i/p and o/p, it has 4 mode of configurations.

① Dual i/p
Balanced o/p

② Dual i/p
unbalanced o/p

③ Single i/p
Balanced o/p

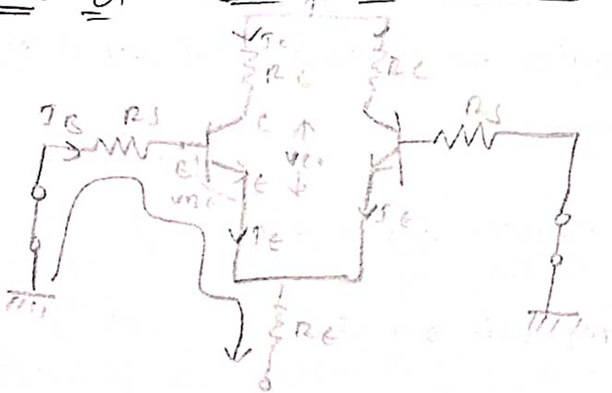
④ single i/p
unbalanced o/p

AC & DC analysis of Differential amplifier:

-> AC analysis => A_V, R_i & R_o

-> DC analysis => Q point

* DC analysis of Differential Amplifier:



KVL,

$$I_B R_S + V_{BE} + 2I_E R_E - V_{EE} = 0$$

β is very high

$\Rightarrow I_C \sim I_E$

$\beta I_B \simeq I_E$

$I_B \simeq \frac{I_E}{\beta}$

$\therefore \frac{I_E}{\beta} R_S + V_{BE} + 2I_E R_E - V_{EE} = 0$

As β is very high, $\frac{I_E}{\beta}$ is very small $\Rightarrow \frac{I_E}{\beta} R_S$ may be neglible

$$V_{BE} + 2I_E R_E - V_{EE} = 0$$

$$2I_E R_E = V_{EE} - V_{BE}$$

$$\boxed{I_E = \frac{V_{EE} - V_{BE}}{2R_E}} \Rightarrow I_C = \frac{V_{EE} - V_{BE}}{2R_E}$$

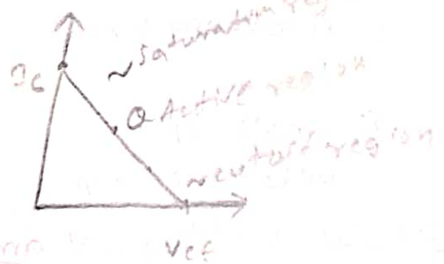
$\rightarrow V_{CE} = V_C - V_E$

and $V_C = V_{CC} - I_C R_C$

$V_E = -V_{BE} - I_B R_S \simeq -V_{BE}$

$$\therefore \boxed{V_{CE} = V_{CC} - I_C R_C + V_{BE}}$$

As Q point $= f(V_{CE}, I_C)$



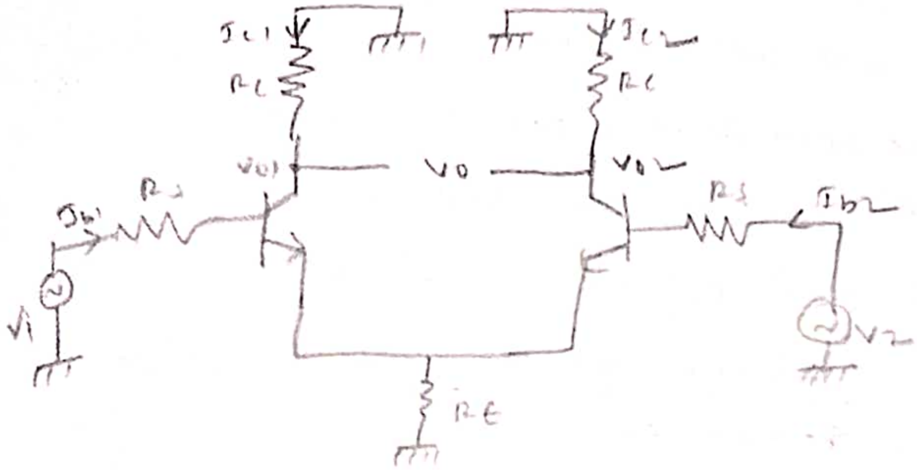
AC ANALYSIS OF DIFFERENTIAL AMPLIFIER:

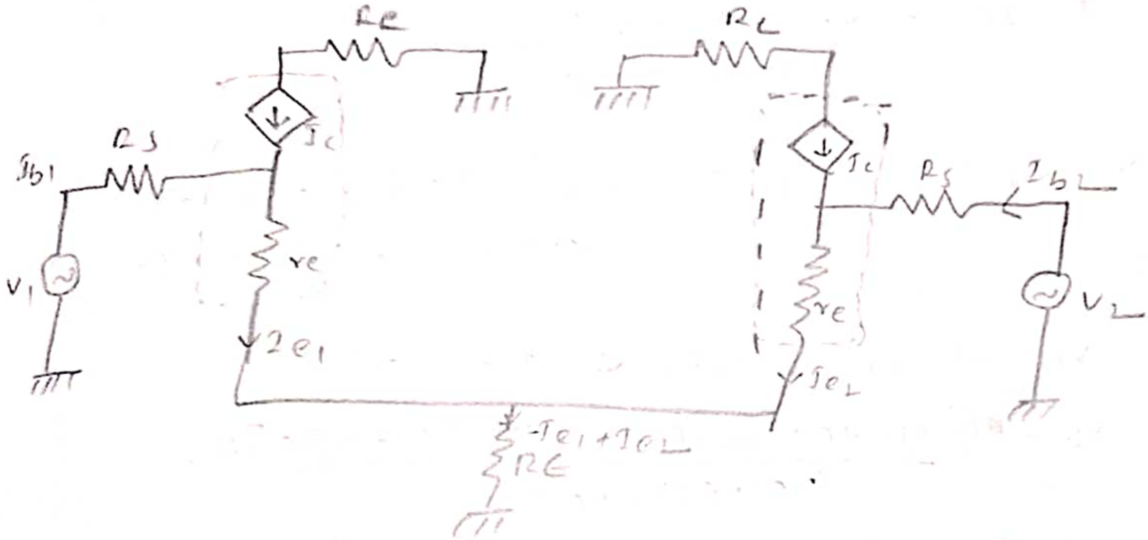
To find voltage gain, Input resistance & Output resistance.

$\rightarrow V_O = V_{O2} - V_{O1}$

$\rightarrow$ I_C = dependent current generator

$\rightarrow I_C = \beta I_B \therefore I_C$ depends on I_B





$r_e = \frac{V_T}{I_E}$ (I_E = dc Emitter Current)

$I_c = \beta I_b$

$V_1 = I_{b1} R_s + I_{e1} r_e + R_E (I_{e1} + I_{e2})$

$V_1 = \underbrace{\frac{I_{e1}}{\beta} R_s}_{\text{neglected}} + I_{e1}(r_e + R_E) + I_{e2} R_E$

$\boxed{V_1 = (r_e + R_E) I_{e1} + I_{e2} R_E}$ —①

$V_2 = I_{b2} R_s + I_{e2} r_e + (I_{e1} + I_{e2}) R_E$

$= \frac{I_{e1}}{\beta} R_s + I_{e2} r_e + (I_{e1} + I_{e2}) R_E$

$\boxed{V_2 = I_{e2}(r_e + R_E) + R_E I_{e1}}$ —②

solving eq① & ② we can get I_{e1} & I_{e2}

$R_E I_{e1} + (r_e + R_E) I_{e2} = V_2$ —②

$(r_e + R_E) I_{e1} + R_E I_{e2} = V_1$ —①

③ Multiplying on both sides by (r_e+R_E)

④ multiplying on both sides by R_E

$$\Rightarrow R_E(r_e+R_E)I_{E1} - (r_e+R_E)^2 I_{E2} = V_2(r_e+R_E)$$

$$R_E(r_e+R_E)I_{E1} - R_E^2 I_{E2} = V_1 R_E$$

$$\therefore I_{E2}\left[(r_e+R_E)^2 - R_E^2\right] = V_2(r_e+R_E) - V_1 R_E$$

$$I_{E2} = \frac{V_2(r_e+R_E) - V_1 R_E}{(r_e+R_E)^2 - R_E^2} \quad \text{—⑤}$$

$$\text{Hly} \quad I_{E1} = \frac{V_1(r_e+R_E) - V_2 R_E}{(r_e+R_E)^2 - R_E^2} \quad \text{—⑥}$$

→ $V_o = V_{o2} - V_{o1}$, where $V_{o2} = -I_{E2}R_C = -I_{C2}R_C$

$V_{o1} = -I_{E1}R_C = -I_{C1}R_C$

$$\therefore V_o = -I_{E2}R_C + I_{E1}R_C = R_C(I_{E1} - I_{E2})$$

$$V_o = \frac{\left[V_1(r_e+R_E) - V_2 R_E - V_2(r_e+R_E) + V_1 R_E\right]R_C}{(r_e+R_E)^2 - R_E^2}$$

$$= \frac{\left[V_1(r_e+R_E+R_E) - V_2(r_e+2R_E)\right]R_C}{(r_e+R_E+R_E)(r_e+R_E-R_E)}$$

$$= \frac{\left[(V_1-V_2)\cancel{(r_e+2R_E)}\right]R_C}{\cancel{(r_e+2R_E)}(r_e)}$$

$$V_o = \frac{(V_1-V_2)R_C}{r_e}$$

$$\therefore \boxed{\frac{V_o}{V_1-V_2} = \frac{R_C}{r_e}}$$

→ Differential voltage gain $= \dfrac{V_o}{V_1-V_2}$

− voltage gain of dual i/p balanced o/p differential amplifier is

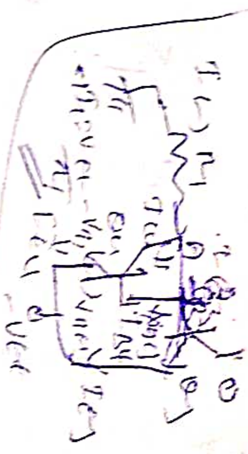
$$A_d = \frac{V_o}{V_1-V_2}$$

→ Input resistance and O/p resistance:

$$\text{Input resistance} = \frac{V_1}{I_{B1}}\Big|_{V_2=0}$$

$$I_{E1} = \frac{V_1(r_e+R_E) - V_2 R_E}{(r_e+R_E)^2 - R_E^2}$$

$$I_{C1} = \frac{V_1(r_e+R_E)}{(r_e+R_E)^2 - R_E^2}$$



RC phase shift ...

→ $I_{E1} = (1+\beta) I_{b1}$

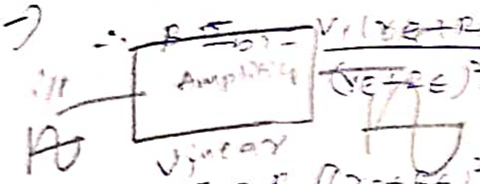
* Distortion in power amplifier

→ Harmonic distortion

$\boxed{I_{C1} = \beta I_{b1}}$ $\beta >> 1$

→ A

→ $\therefore R_{E} = \frac{V_i(r_E + R_E)}{(r_E + R_E)^2 - R_E^2}$ i.e. if ... the transistor operates in linear region, then there is no distortion.



$\frac{V_{linear}}{I_{b1}} = \beta \frac{[(r_E + R_E)^2 - R_E^2]}{(r_E + R_E)}$

$r_E = \frac{V_T}{I_E}$ small

$r_E << R_E$

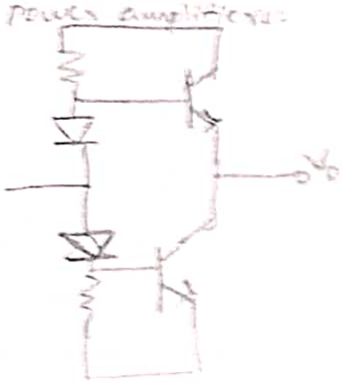
$\frac{V_i}{I_{b1}} = \beta \frac{[r_E^2 + 2 r_E R_E]}{(r_E + R_E)}$

→ Push pull class B amplifier

→ Complimentary symmetry $R_i = \beta \frac{[2 r_E R_E]}{R_E}$ push-pull class B power amplifiers.

→ class AB power amplifier.

$\boxed{R_i = 2\beta r_E}$ ... PNP transistors.

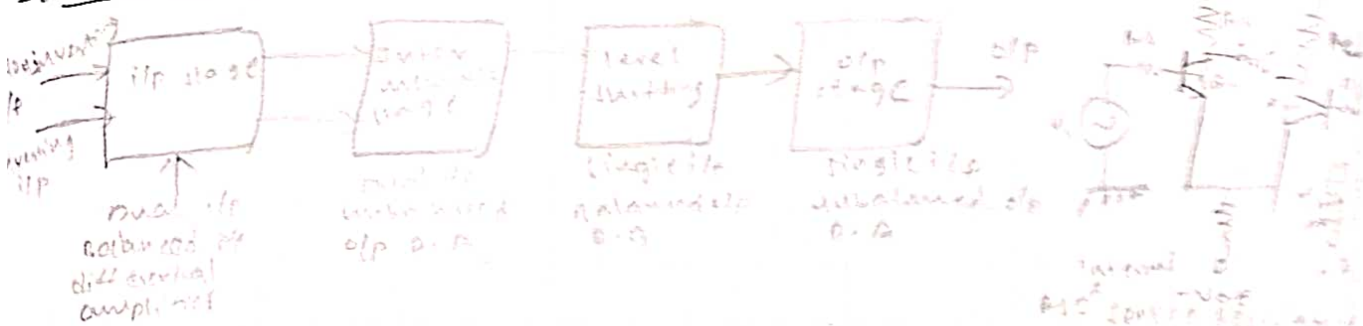


similary, $R_{i2} = 2\beta r_E$

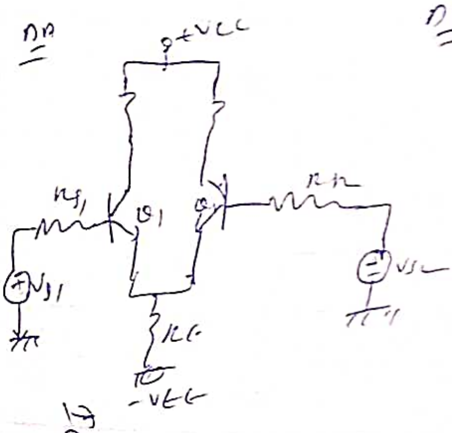
and o/p resistance, $R_O = R_C$ //

Operational Amplifier:

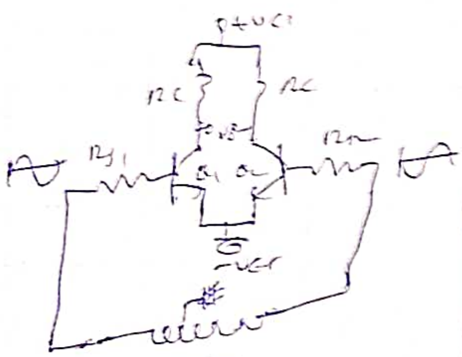
- Block Diagram:



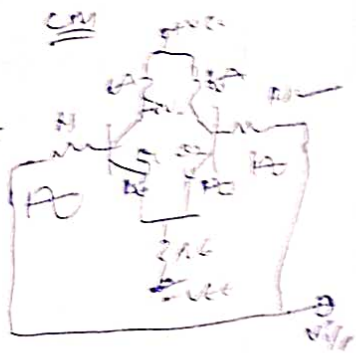
DA

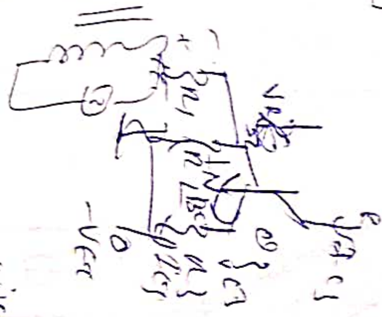


DM



CM





→ $-IR_1 - IR_2 + V_{EE} = 0$

$V_{EE} = I(R_1 + R_2)$

$\boxed{I = \frac{V_{EE}}{R_1 + R_2}}$

→ $V_{B3} = I R_2$

$= \frac{V_{EE} R_2}{R_1 + R_2}$

→ $V_{BE} = V_B - V_3$

$I_{E3} = \frac{V_{B3} - V_{BE} + V_{EE}}{R_3}$

$= V_{EE} - V_{BE} + V_{EE}$

① GAI & ΓAI

② shorders D.T

③ AI learning → repeated guesses

④ Dinner → ④ Evaluate ✓ set weight

~~choose~~ ~~which~~ should be delo

⑤ Oven temperature → Logistic Regression.

⑥ Advantage of CML → Modern ~~lap(AI)~~ / small data ④ ③

⑦ Rainfall → ~~class ML~~ DNN

⑧ Future of AI → CS / Automation → ①

⑨ ML is subset → AI

⑩ fires → sigmoid function

⑪ perceptron i/p layer / nodes

⑫ Game → un~~supervised~~ / supervised learning → ②

⑬ region → AF / HL

⑭ minimum of HL →

⑮ image recogni...