

1).

Amplifier:

An electronic ckt which increases strength of weak electrical signal without changing its shape.

classification of amplifiers:

a). Based on transistor configuration

C.E.
C.B.
C.C. } amplifier

Common emitter CE
Common Base CB
Common collector CC

b). Based on frequency response

Audio frequency (A.F.) amplifier

Radio frequency (RF) amplifier

very high freq.

ultra high freq.

micro frequency

} amplifiers.

c). Based on active device

BJT amplifier

FET amplifiers

d). Based on Q point

Class A power amplifier

Class B amplifier

Class AB amplifier

Class C amplifier

e). Based on number of stages

Single stage amplifier
multi stage amplifier

f). Based on coupling mechanism

Direct Coupled

RC Coupled

Transformer Coupled

Inductive Coupled

g). According to Bandwidth

wideband

narrow band amplifier

h). According to the feedback

Positive

Negative

feedback amplifier

i). Based on signal variation

Small signal

large signal

Amplifier

II. Distortion in amplifiers

Different types of distortions in amplifiers

⇒ Difference between the output waveform and the input waveform in an amplifier is called "Distortion".

⇒ Distortion may be caused (due to the nonlinearity in the characteristics of the transistor (or)

Due to the influence of the associated circuit

Types of Distortions in amplifier

(i) Non linear or harmonic distortion

(ii) frequency distortion

(iii) phase or delay distortion

(i) Non linear or harmonic distortion: (new harmonics ^{are produced} _{freq. in amp.})

→ In this type of distortion, the new frequencies are produced in the output, which are not present in the input signal.

→ Intermodulation distortion is also a type of non linear distortion which occurs when the input signal consists of more than one freq.

eg:

If an input signal contains two freq f_1 & f_2

then o/p will contain their harmonics

$$f_1, 2f_1, 3f_1, \dots$$

$$f_2, 2f_2, 3f_2, \dots$$

In addition, there would be components

$(f_1 + f_2)$ & $(f_1 - f_2)$ and also sum and difference

of the harmonics. These sum & difference of the

freq. are called intermodulation freq.

Intermodulation freq. which are undesirable

because they subtract from the original intelligence

(ii) frequency distortion

→ In this type of distortion, the signal

components at different frequencies are amplified

by different amounts.

→ This distortion may be caused by the

various freq. dependent reactances associated with circuit or the active device itself.

(iii). Phase Distortion (or) Delay Distortion:

→ In this type of distortion, the phase shift between input & output waveforms depends upon the signals of different frequencies.

⇒ To make the amplifier free from phase distortion, the freq. must be shifted by an angle θ proportional to freq. As a result the phase of all the components is shifted by the same time interval & the whole wave, shifted as a unit, giving no phase distortion.

$$V_i = V_{m1} \sin(\omega t + \theta_1) + V_{m2} \sin(2\omega t + \theta_2) + \dots$$

phase distortion indicator

$$V_o = A \cdot V_{m1} \sin(\omega t + \theta_1 + \alpha) + A \cdot V_{m2} \sin(2\omega t + \theta_2 + 2\alpha) + \dots$$

III. Small Signal & Large Signal Amplifiers:

→ Amplifier: An electronic ckt which increases strength of weak electrical signal without changing its shape.

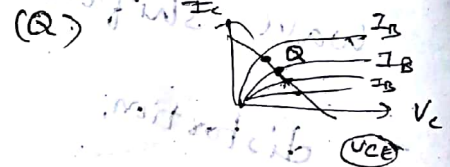
→ Amplifiers are divided into two types based upon signal variation:

1. Small signal Amplifier

2. Large signal amplifier.

Note:

→ In the absence of i/p signal, all voltage & current in the amplifier circuit remain const. these values are called D.C. (or) quiescent values.



→ When an i/p signal is applied, all voltages & currents will vary with respect to quiescent values.

the maximum change in the value of voltage or current w.r.t. D.C. value is called

"Signal Variation".

→ If signal variation is much smaller than

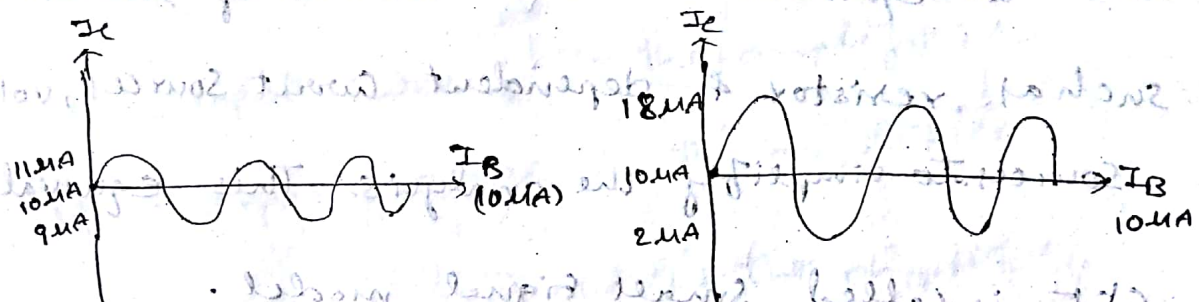
quiescent or D.C. value then it is called

"small signal variation", & such amplifiers

is called small signal Amplifier. $\Delta I_b \ll \Delta I_{cQ}$

→ If signal variation is comparable to quiescent value then it is called "Large signal variation". & such amplifier will be Large signal

Amplifier ($\Delta I_B \approx I_{BQ}$)

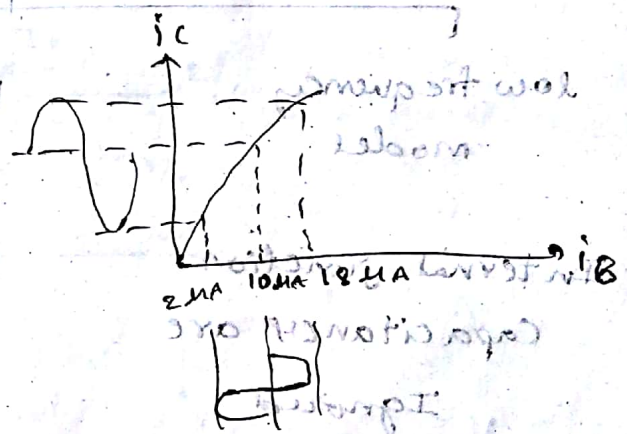
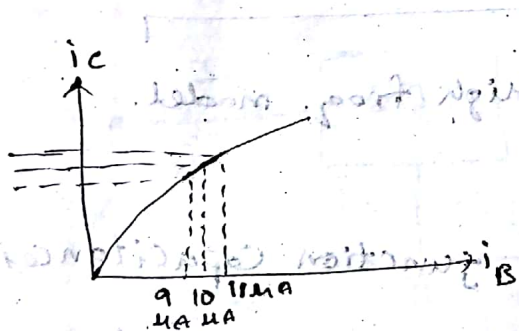


Signal variation: $10 - 9 \mu A = 1 \mu A$

Signal variation: $18 - 10 = 8 \mu A$

Small Signal Amplifier

Large Signal Amplifier



IV

Small signal model of BJT:

→ Transistor behaves as a linear element in small signal amplifier, i.e. it exhibits piecewise linearity. Due to this sinusoidal i/p, results in sinusoidal o/p i.e. o/p signal will be undistorted.

→ In large signal amplifier transistor behaves as a non linear element i.e. equal changes in the

base current do not produce proportion

equal change in collector current:

→ Since transistor behaves as a linear element in small signal amplifier it can be replaced with an equivalent circuit consists of linear elements such as resistor & dependent current sources, voltage sources to simplify the analysis. This equivalent ckt is called small signal model.

Small Signal Model

low frequency model

High freq. model.

Internal junction capacitances are Ignored

junction capacitances are considered.

1) h-parameter model

2) π -model

3) T-model (r -model)

1) High freq. π model

2) High freq. T model

r = resistance

$$\Rightarrow h_i = \left. \frac{V_1}{I_1} \right|_{V_2=0} \quad \text{units: ohms} = \Omega$$

h_i is i/p resistance of BJT when the o/p node is shorted to common node.

$$\Rightarrow h_r = \left. \frac{V_1}{V_2} \right|_{I_1=0} \quad \text{units = no units ratio}$$

h_r is reverse voltage gain of BJT when i/p node is open circuited.

$$\Rightarrow h_f = \left. \frac{I_2}{I_1} \right|_{V_2=0} = \text{no units}$$

h_f is called forward current gain of BJT when the o/p node is shorted to common node.

$$\Rightarrow h_o = \left. \frac{I_2}{V_2} \right|_{I_1=0} = \text{mho } (\Omega^{-1})$$

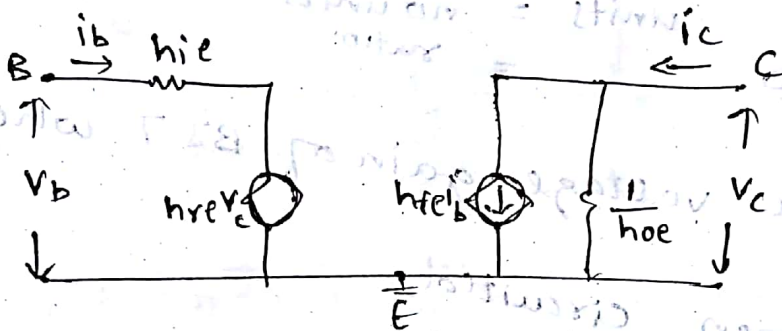
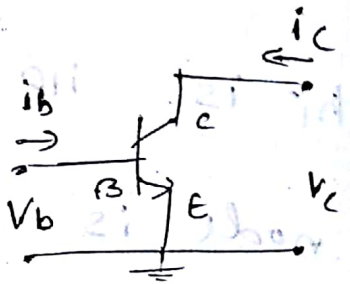
h_o is o/p conductance of BJT when i/p node is open circuited.

VI. hybrid model for ^{basic} C.E, C.C, C.B configuration.

C.E.

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

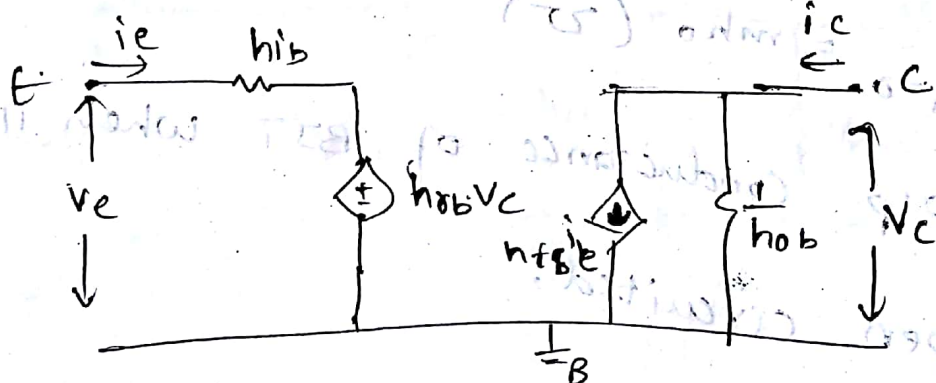
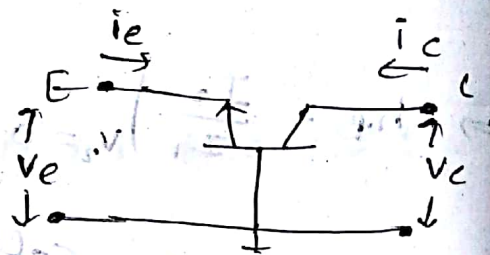
$$i_c = h_{fe} i_b + h_{oe} V_c$$



C.B

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

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



(A) (A)

- Draw the C-E amplifier circuit.
- Draw the hybrid model for C-E amplifier

Circuit & Derive the expression for voltage gain
(or) Analyze the C-E amplifier

Ans:
a.

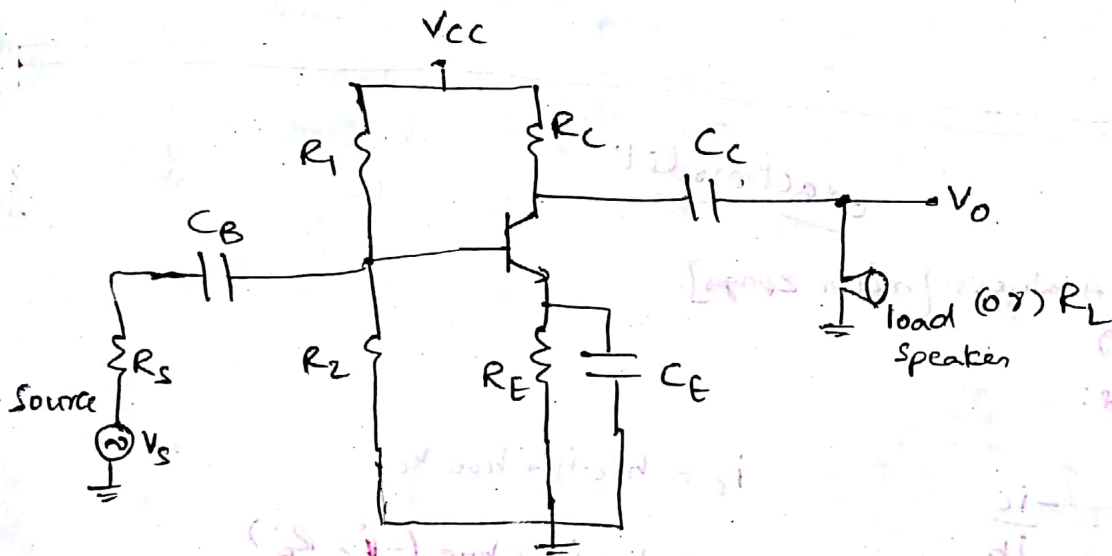


Fig: General amplifier ckt (or) C-E amplifier ckt

Biassing Circuit:

The Resistance R_1 & R_2 , R_C and R_E form the voltage divider biassing circuit for the BJT amplifier. It sets the proper operating point for the C-E amplifier.

C_B : Blocking capacitor
Source coupling capacitor

This capacitor couples the source signal to the base of the transistor. It blocks

any D.C. component present in the signal

and passes only A.C. signal for amplification,

hence the biasing conditions are maintained

Constant.

C_c : Load coupling capacitor

This capacitor couples the output of the amplifier to the load (or) to the next stage of

the amplifier. It blocks D.C. and passes

only A.C. part of the amplified signal into the load.

Emitter Bypass Capacitor C_E

This capacitor bypasses the a.c. emitter current to ground by providing a low reactance path to the amplified a.c. signal.

If it is not inserted, the unbypassed

R_E will cause negative feedback and

reduce the a.c. gain of the amplifier.

Note: steps to Analyze the any Transistor circuit (or) amplifier

Step 1: Draw the Actual circuit diagram.

Step 2: Draw the A.C equivalent circuit.

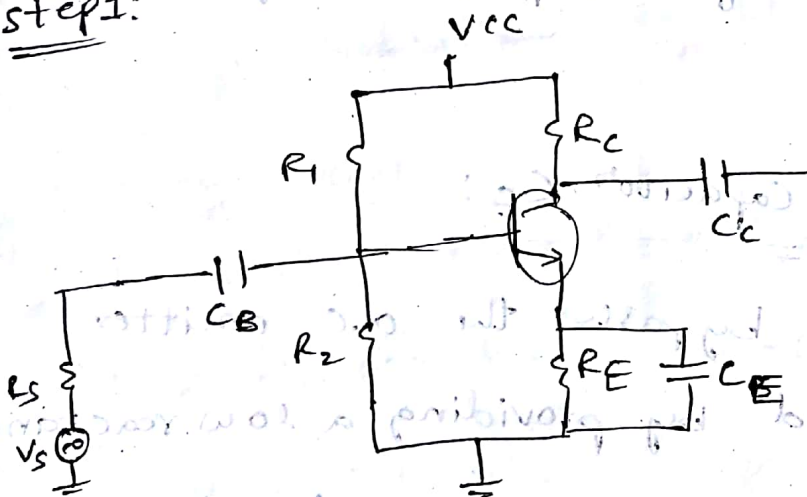
→ Replace coupling capacitors and Bypass capacitors with short circuit.

→ Replace D.C. source By short circuit.
i.e. V_{CC} is grounded.

→ Replace transistor by h-parameter model.

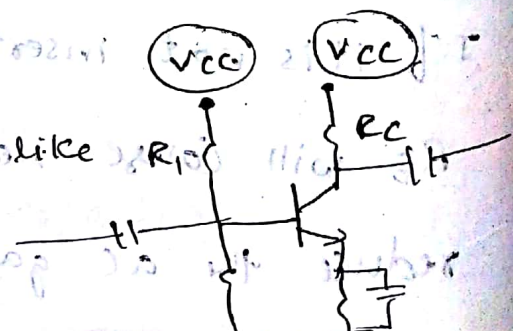
Analysis of C.E. amplifier:

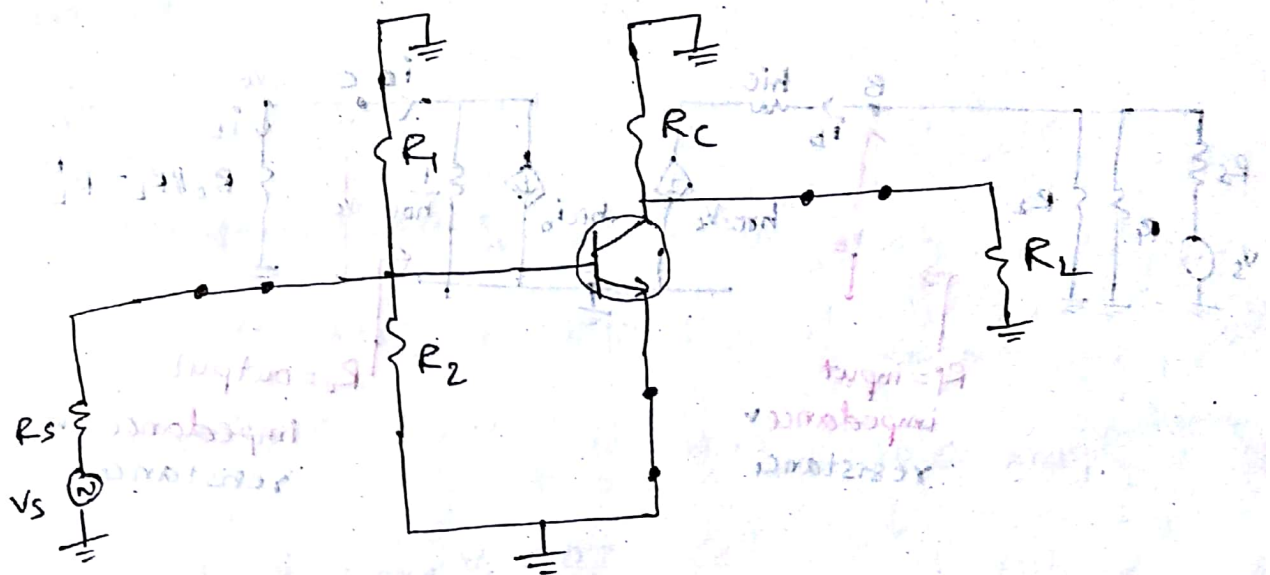
Step 1:



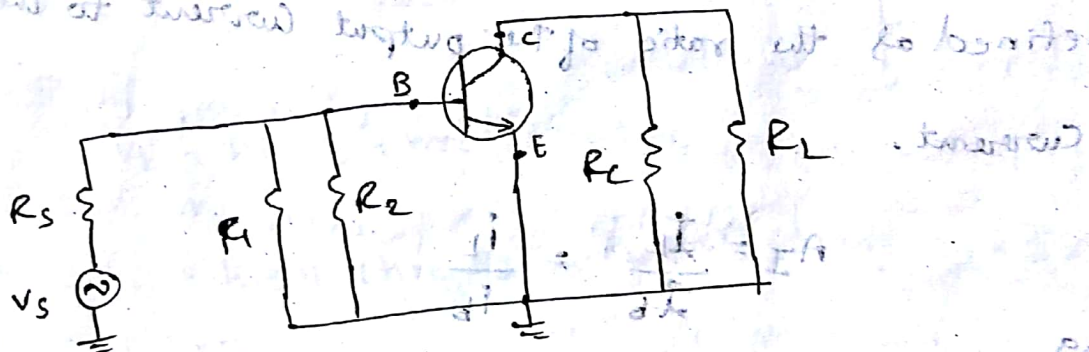
Step 2:

Note: Here V_{CC} we can draw like

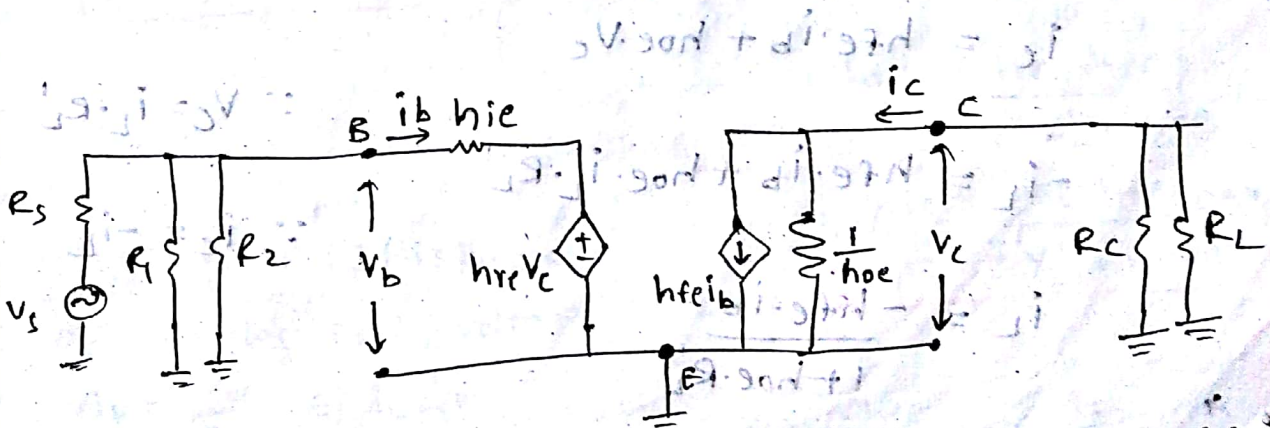
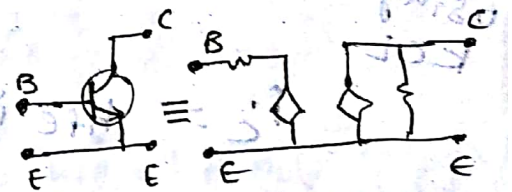


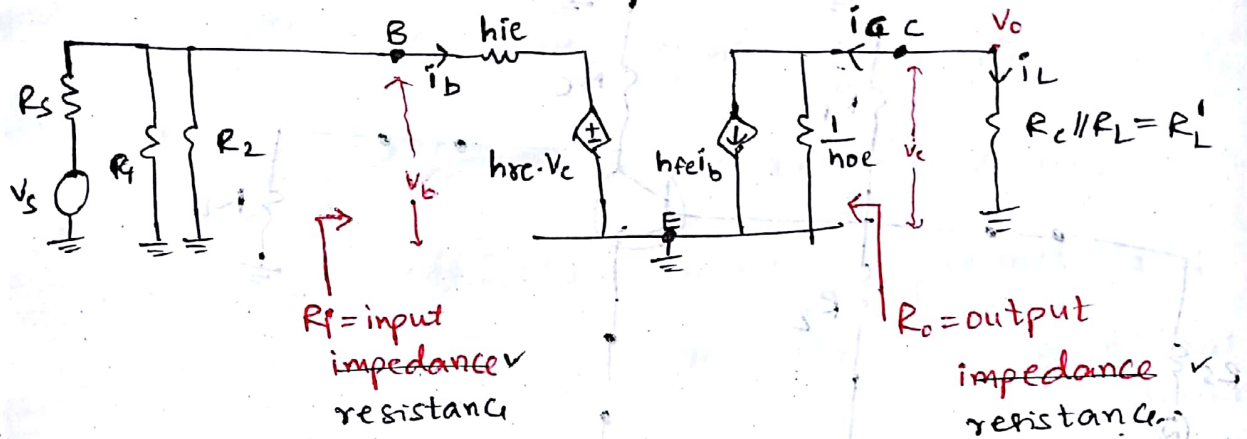


Current gain A_i is the ratio of output current to input current. For a common-emitter amplifier, the current gain is approximately equal to the current gain of the transistor (β).



Replace transistor with h-parameter model:





Current gain A_I :

for a transistor ~~amplifier~~, the current gain A_I is
(BJT)

defined as the ratio of the output current to the input current.

$$A_I = \frac{I_L}{I_b} = \frac{i_L}{i_b}$$

using KCL

$$i_c = h_{fe} \cdot i_b + \frac{V_c}{1/h_{oe}}$$

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

$$-i_L = h_{fe} \cdot i_b + h_{oe} \cdot i_L \cdot R_L' \quad \because V_c = i_L \cdot R_L'$$

$$i_L = \frac{-h_{fe} \cdot i_b}{1 + h_{oe} \cdot R_L'}$$

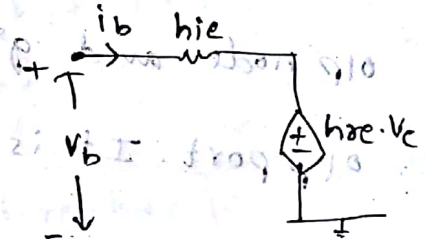
$$\therefore i_c = -i_L$$

$$A_I = \frac{i_L}{i_b} = \frac{-h_{fe}}{1 + h_{oe} \cdot R_L'}$$

Input Resistance: The input impedance (Resistance) seen when looking into the amplifier (BJT) input terminals.

$$Z_i = R_i = \frac{V_b}{i_b}$$

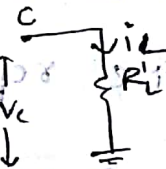
apply KVL:



$$-V_b + h_{ie} \cdot i_b + h_{fe} \cdot V_c = 0$$

we know that

$$V_c = i_c \cdot R_L$$



from ① & ②

$$-V_b + h_{ie} \cdot i_b + h_{fe} \cdot i_c \cdot R_L = 0$$

$$-V_b + h_{ie} \cdot i_b + h_{fe} \cdot A_I \cdot I_b \cdot R_L = 0 \quad \therefore A_I = \frac{I_L}{I_b}$$

$$\frac{V_b}{i_b} = h_{ie} + h_{fe} \cdot A_I \cdot R_L \quad \therefore I_L = A_I \cdot I_b$$

$$Z_i = h_{ie} + h_{fe} \cdot A_I \cdot R_L \quad (\text{or}) \quad Z_i = h_{ie} + h_{fe} R_L \left(\frac{-h_{fe}}{1 + h_{oe} R_L} \right)$$

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

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

$$Z_i = h_{ie} - \frac{h_{fe} \cdot h_{fe}}{Y_L' + h_{oe}} \quad \therefore Y_L' = \frac{1}{R_L}$$

$$A_V = \frac{V_o}{V_b} = \frac{I_L \cdot R_L}{V_b} \quad \therefore A_I = \frac{-h_{fe}}{1 + h_{oe} R_L} = \frac{I_L}{I_b}$$

$$A_V = \frac{I_b \cdot A_I \cdot R_L}{V_b} \Rightarrow \frac{A_I \cdot R_L}{V_b / I_b} \Rightarrow \frac{A_I \cdot R_L}{R_i} \quad \therefore R_i = \frac{V_b}{I_b}$$

$$A_v = \frac{A_{I} \cdot R_L'}{R_i}$$

output resistance:

output resistance is the resistance seen between o/p node and ground. It is the resistance of o/p port. It is calculated using following procedure.

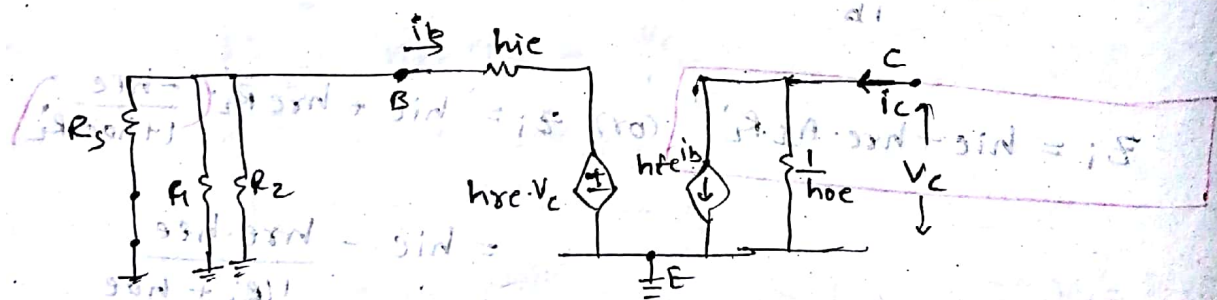
step 1: Disable external sources present in input node. i.e. replace V_s with S.C. (short circuit)

step 2: Remove R_L'

step 3: Apply test voltage V_x at o/p port then

Calculate $R_o = \frac{V_x}{I_x}$ (or) Assume V_c as test voltage

$$\text{then } R_o = \frac{V_c}{I_c}$$



$$i_c = h_{fe} \cdot i_b + h_{oe} \cdot V_c \quad \text{--- (1)}$$

apply KVL at i/p port

$$R_s \cdot i_b + h_{ie} \cdot i_b + h_{fe} V_c = 0$$

$$i_b = \frac{-h_{fe} \cdot V_c}{R_s + h_{ie}}$$

$$R_o = \frac{V_c}{I_c}$$

Need to find i_b value

$$\therefore R_s' = R_s \parallel R_1 \parallel R_2$$

Substitute in ① we get

$$i_c = h_{fe} \cdot \left(\frac{-h_{re} \cdot V_c}{R_s' + h_{ie}} \right) + h_{oe} \cdot V_c$$

$$\frac{i_c}{V_c} = h_{oe} - \frac{h_{re} \cdot h_{fe}}{R_s' + h_{ie}}$$

output Admittance =

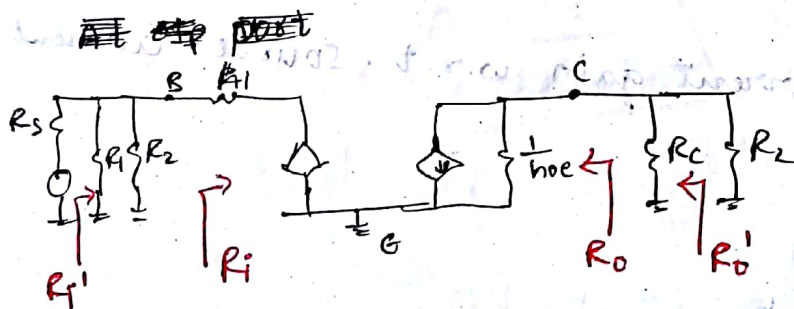
$$Y_o = \frac{1}{R_o} = h_{oe} - \frac{h_{re} \cdot h_{fe}}{R_s' + h_{ie}}$$

output Resistance $R_o = \frac{V_c}{i_c} = \frac{1}{Y_o}$

$$R_o = \frac{1}{h_{oe} - \frac{h_{re} \cdot h_{fe}}{R_s' + h_{ie}}}$$

R_o', R_i'

R_o' is the o/p resistance of the amplifier
including the effect of biasing resistors
(R_c)
 R_1, R_2



$$R_i' = R_1 \parallel R_2 \parallel R_i$$

R_1, R_2, R_i are parallel

$$R_o' = R_c \parallel R_o = \frac{R_c \cdot R_o}{R_c + R_o}$$

R_c, R_o are parallel

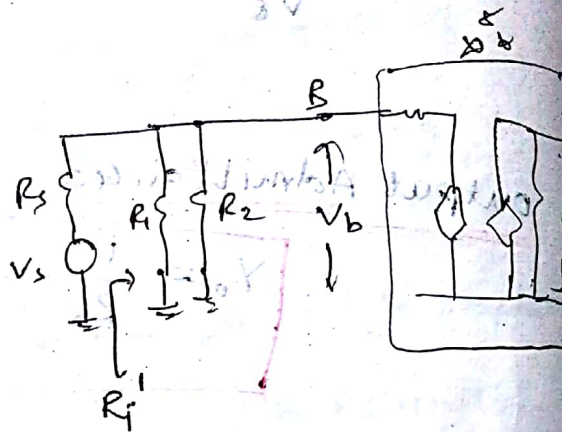
A_{vs} : voltage gain w.r.t. source voltage.

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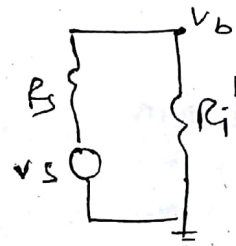
$$A_{vs} = \frac{V_o}{V_s}$$

$$= \frac{V_o}{V_b} \cdot \frac{V_b}{V_s}$$

$$= A_v \cdot \frac{V_b}{V_s}$$



$$V_b = V_s \left[\frac{R_i}{R_s + R_i} \right]$$



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

a good voltage amplifier

should have very high input resistance so that full source voltage appears at i/p to the amplifier.

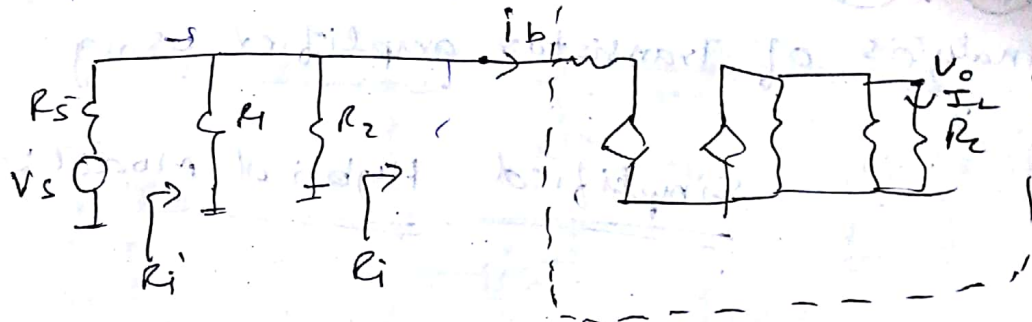
A_{is} : It is current gain w.r.t. source current

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

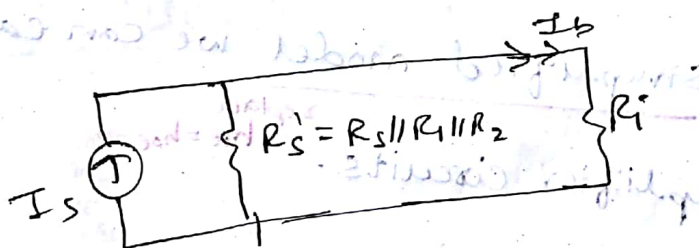
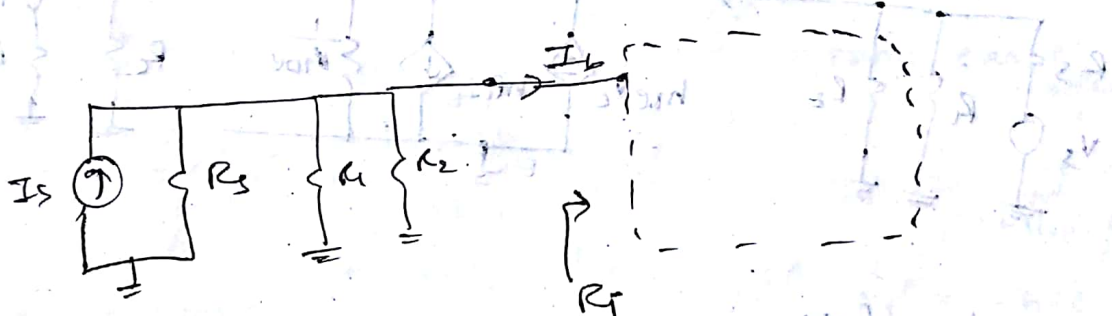
$$= \frac{I_L}{I_b} \cdot \frac{I_b}{I_s}$$

$$= A_i \cdot \frac{I_b}{I_s}$$





we need $\frac{I_b}{I_s}$ so convert voltage source to current source



$$I_b = I_s \left[\frac{R_s'}{R_s' + R_i} \right]$$

$$A I_s = \frac{A I_s' R_s'}{R_s' + R_i}$$

$$A I_s = A I_s' \frac{R_s'}{R_s' + R_i}$$

a good current amp. should have very low input resistance. $I_b R_i \rightarrow 0$ $A I_s = A I_s'$ $\therefore$ maximum amplification

can be provided to source current.

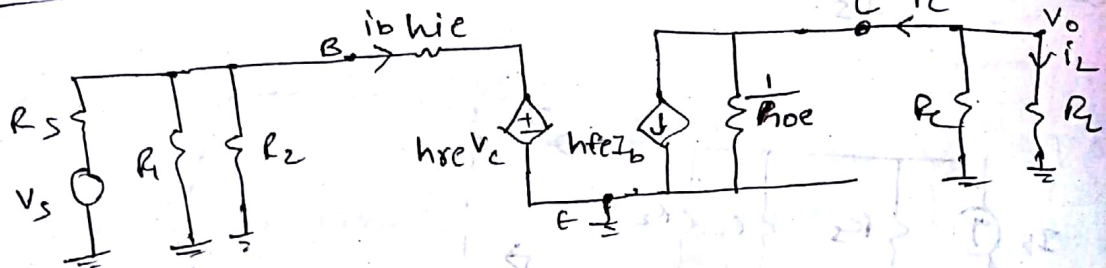
(B) . (B)

Analysis of Transistor amplifier using

Simplified Hybrid Model:-

hybrid model:

exact hybrid model:



Simplified model:

→ By using this simplified model we can easily analyze the amplifier circuits.
 replace $h_{re} = h_{oe} = 0$

→ $1/h_{oe}$ is parallel to R_C ~~and~~

if $1/h_{oe} \gg R_L \parallel R_C$ then h_{oe} may be neglected

If we ~~can~~ neglect h_{oe} the collector I_C is

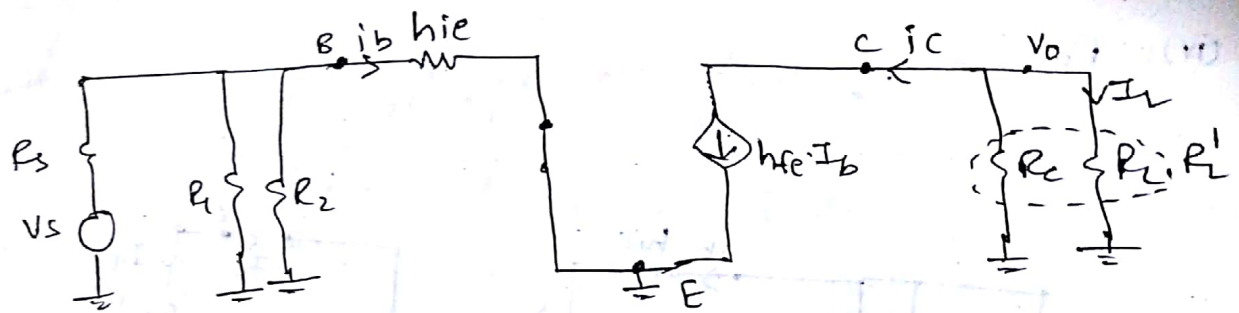
given by $I_C = h_{fe} I_b$.

→ If the load resistance $R_L \parallel R_C$ is small,

It is possible to neglect h_{re} , h_{oe} in the

h parameter equivalent circuit.

→ Approximate Analysis gives accurate results of $h_{oe} \cdot R_L' \leq 0.1$



Analysis of C-E simplified h model:

$$(i) A_I = \frac{I_L}{I_b}$$

$$= \frac{-i_c}{i_b} = \frac{-h_{fe} \cdot i_b}{i_b}$$

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

(or)

from exact model

$$A_I = \frac{-h_{fe}}{1 + h_{oe} \cdot R'_L}$$

$$A_I = -h_{fe}$$

neglect h_{oe} & h_{re}

$$(ii) R_i = \frac{V_b}{i_b}$$

$$= \frac{i_b \cdot h_{ie}}{i_b} = h_{ie}$$

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

(iii).

$$A_v = \frac{V_o}{V_b}$$

$$= \frac{I_L \cdot R'_L}{V_b} = \frac{-h_{fe} \cdot i_b \cdot R'_L}{V_b}$$

$$= \frac{-h_{fe} \cdot i_b \cdot R'_L}{h_{ie} \cdot i_b}$$

$$\boxed{A_v = \frac{-h_{fe} \cdot R'_L}{h_{ie}}}$$

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Analysis of C.C. amplifier (or) $A_v, R_i, R_o, A_i, A_{v_s}$ for C.C. amplifier

Step 1:

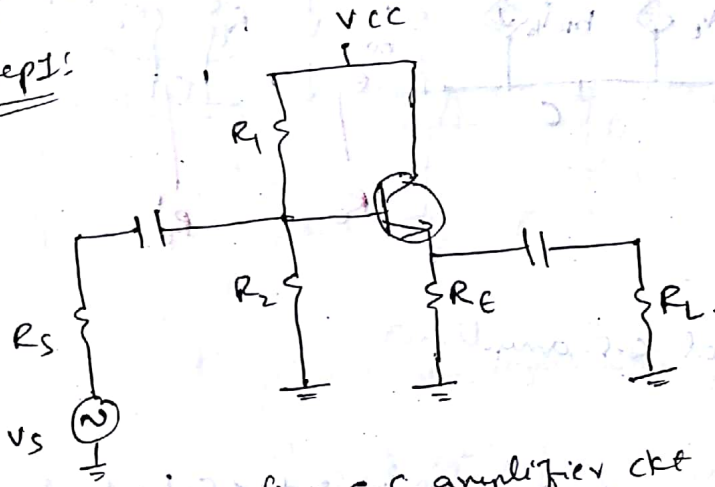
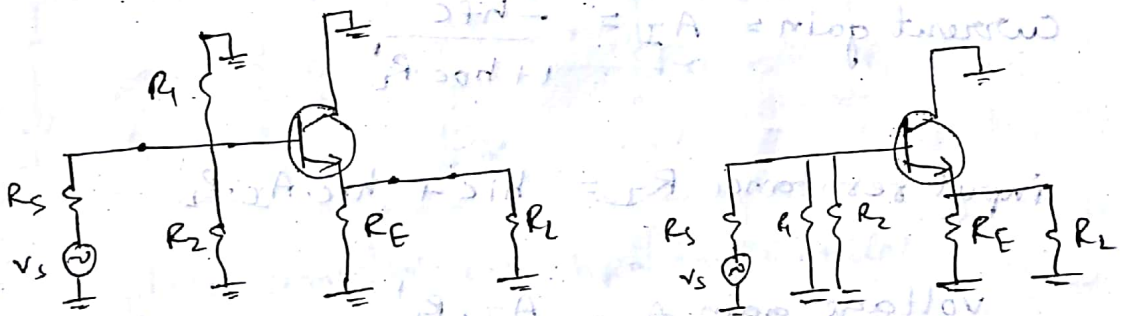


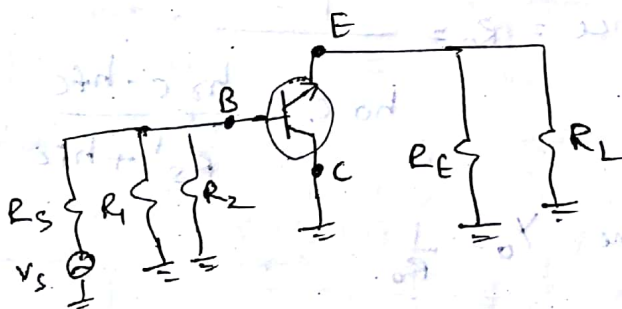
fig: C.C. amplifier ckt

Step 2:

A.C. equivalent of the amplifier ckt:

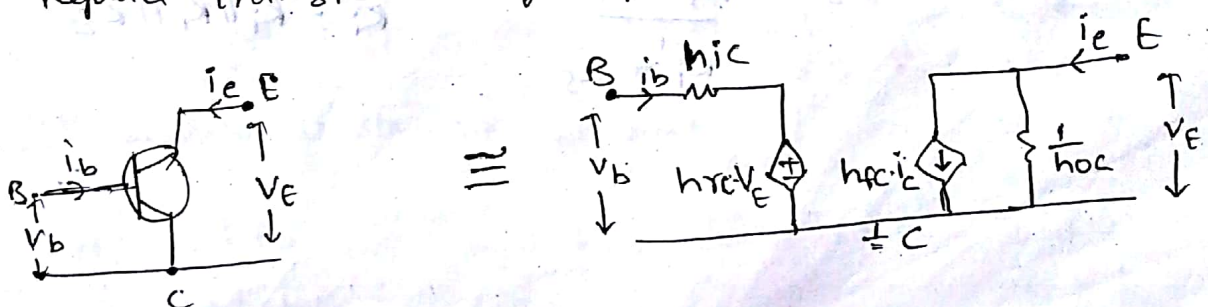


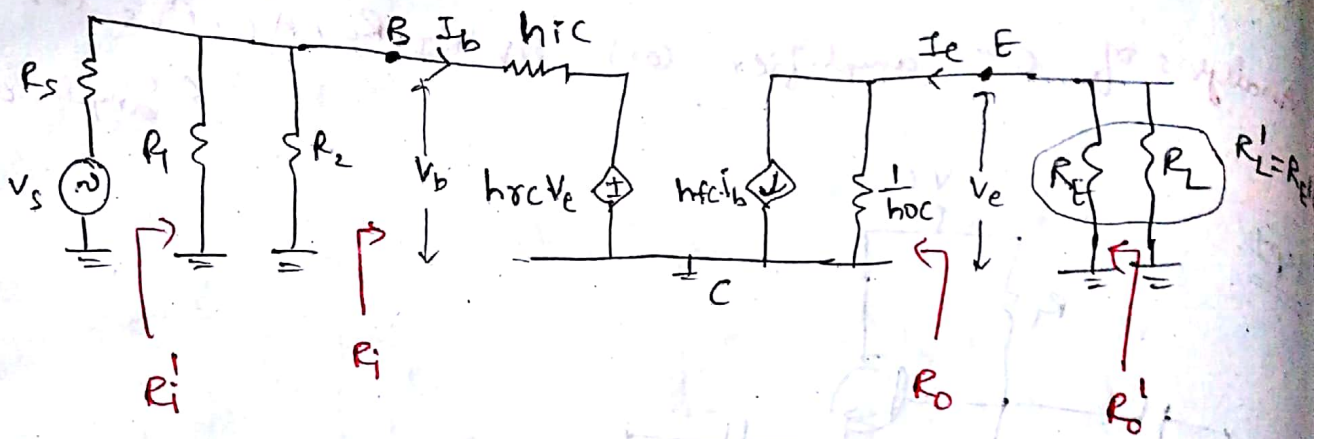
we can redraw as



Step 3:

Replace transistor by h parameter model





hybrid model C.C. amplifier.

Note:

Above hybrid model of C.C. is similar to C.E hybrid model. Calculation of A_I , R_i , A_v all are similar, except notations.

$$\text{Current gain} = A_I = \frac{-h_{fc}}{1 + h_{oc} \cdot R_L'}$$

$$\text{input resistance } R_i = h_{ic} + h_{rc} \cdot A_I \cdot R_L'$$

$$\text{voltage gain } A_v = \frac{A_I \cdot R_L'}{R_i} \quad \text{where } R_L' = R_L \parallel R_E$$

$$\text{output resistance} = R_o = \frac{1}{h_{oc} - \frac{h_{rc} \cdot h_{fc}}{R_s' + h_{ic}}}$$

$$\text{output admittance} = Y_o = \frac{1}{R_o}$$

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

$$R_i' = R_i \parallel R_1 \parallel R_2$$

①. Analysis of C.B. amplifier: (or) Derive expressions

for A_I , A_v , R_i , R_o , A_{v_s} .

step 1:

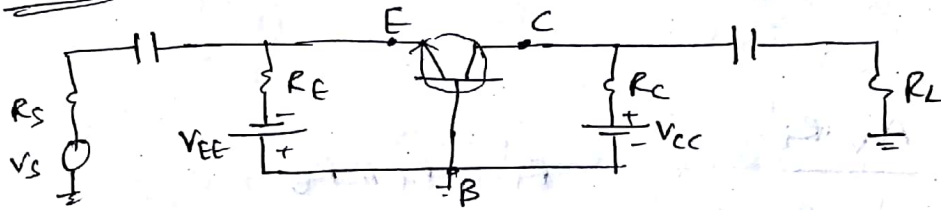
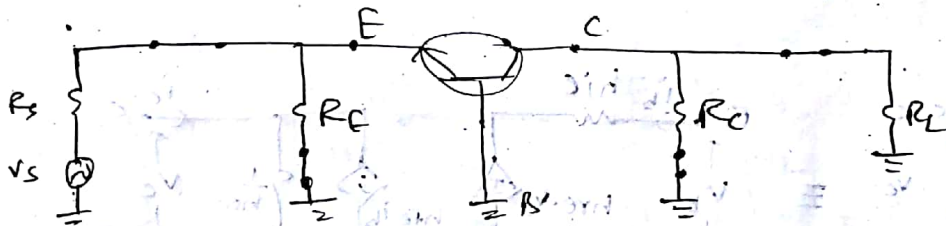
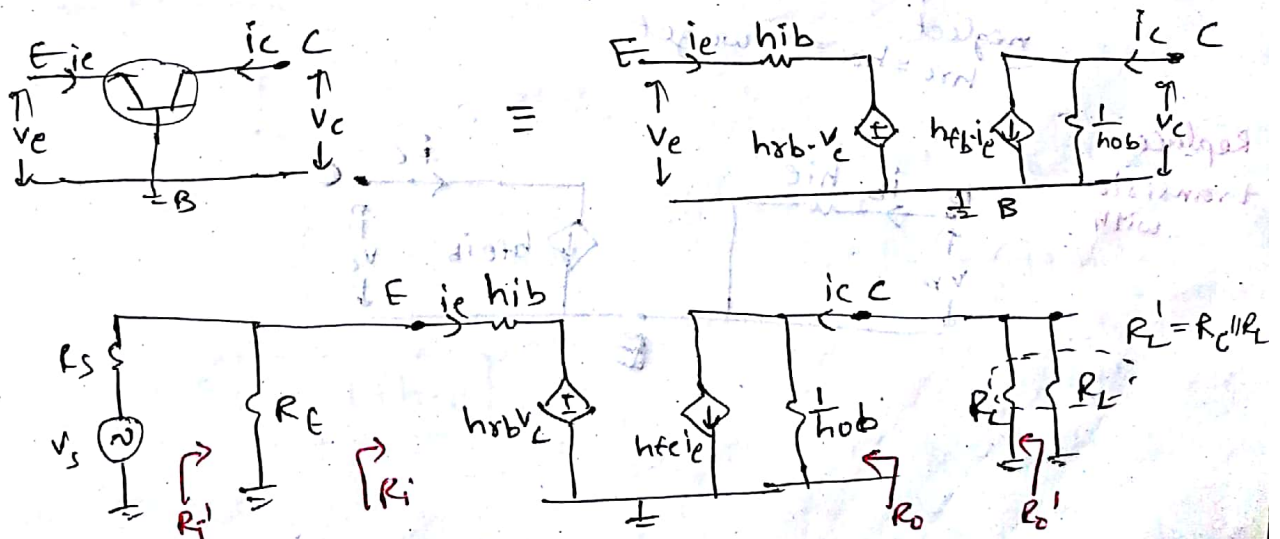


fig: C.B. amplifier ckt.

step 2: AC equivalent of the amplifier ckt.



step 3: Replace transistor with h parameter model.



Note: Calculations are similar except notations.

$$A_I = \frac{-h_{fb}}{1 + h_{ob} \cdot R_L'}$$

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

where

$$R_L' = R_C \parallel R_L$$

$$R_o = \frac{h_{ob} - \frac{h_{rb} \cdot h_{fb}}{R_s' + h_{ib}}}{R_s' + h_{ib}}$$

where
 $R_s' = R_s \parallel R_E$

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

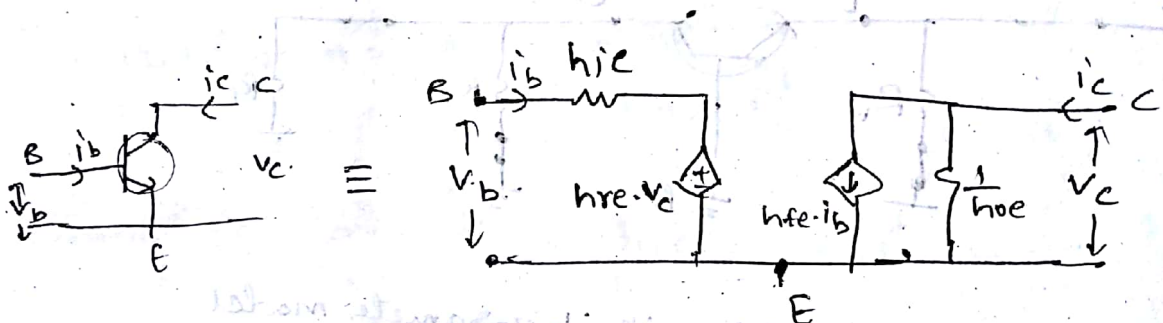
$$R_i' = R_i \parallel R_E$$

②. Analyze C.C. amplifier using Simplified h parameter model. (or) Derive A_i, R_i, A_v, R_o

Note:

for simplified h parameter model for C.E, C.B, C.C. amplifier

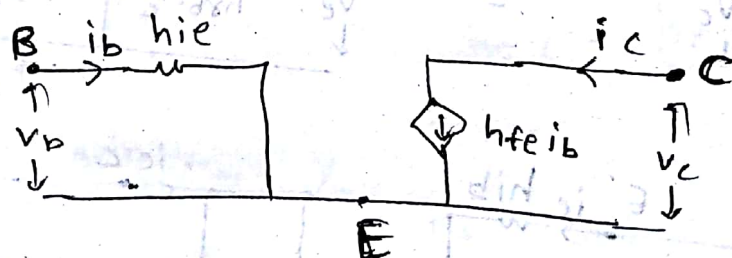
use $\Rightarrow$



Simplified

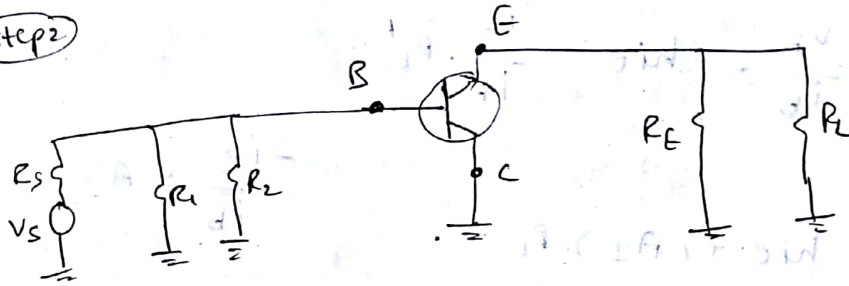
neglect
 $h_{re} = h_{oe} = 0$ we get

Replace
 transistor
 with

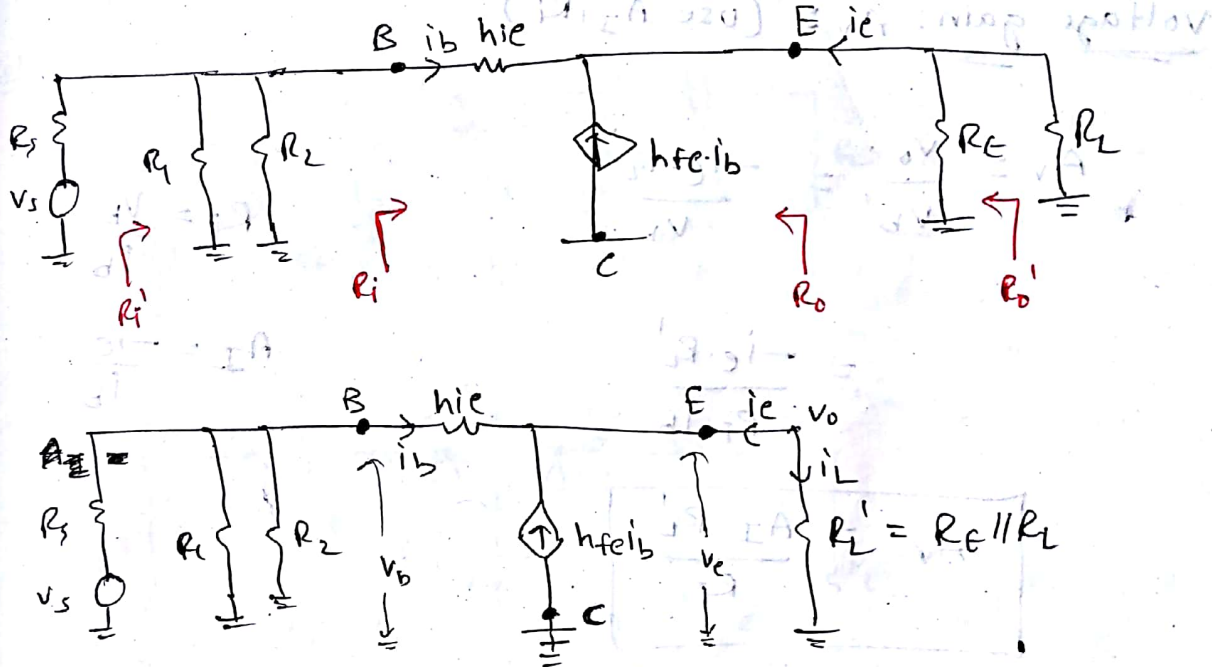


c.c. amplifier:

(step 2)



step 3: Replace with simplified h model



Current gain:

$$A_I = \frac{i_L}{i_b} = \frac{-i_e}{i_b}$$

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

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

KCL

$$i_e + h_{fe}i_b + i_b = 0$$

$$i_e = -i_b(1+h_{fe})$$

input Resistance:

$$R_i = \frac{V_b}{i_b}$$

Apply KVL

$$-V_b + h_{ie}i_b - i_e R_L' = 0$$

$$V_b = h_{ie}i_b - i_e R_L'$$

$$V_b/i_b = h_{ie} + A_I R_L'$$

$$R_i = \frac{v_b}{i_b} = h_{ie} - \frac{i_e \cdot R_L'}{i_b}$$

$$-\frac{i_e}{i_b} = A_I$$

$$R_i = h_{ie} + (A_I) \cdot R_L'$$

$$R_i = h_{ie} + (1+h_{fe}) \cdot R_L'$$

Voltage gain: A_v : (use $A_I \cdot R_i$)

$$A_v = \frac{v_o}{v_b} = \frac{-i_e \cdot R_L'}{v_b}$$

$$= \frac{-i_e \cdot R_L'}{R_i \cdot i_b}$$

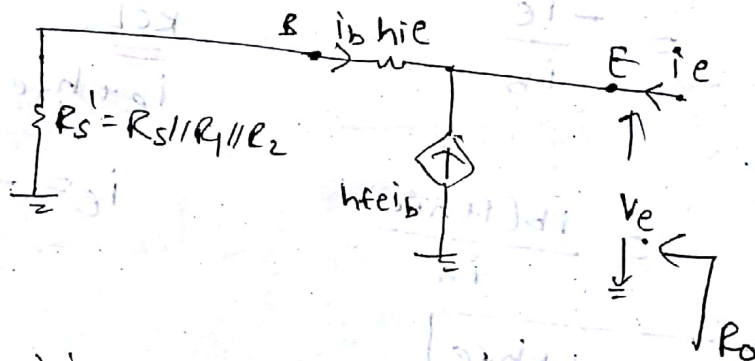
$$R_i = \frac{v_b}{i_b}$$

$$A_I = -\frac{i_e}{i_b}$$

$$A_v = \frac{A_I \cdot R_L'}{R_i}$$

Output Resistance: R_o

$$R_o = \frac{v_e}{i_e}$$



KVL $R_o = \frac{v_e}{i_e}$

$$(R_s' + h_{ie}) i_b + v_e = 0$$

$$v_e = -(R_s' + h_{ie}) i_b$$

KCL $i_b + i_e + h_{fe} i_b = 0$

$$i_e = -(1+h_{fe}) i_b$$

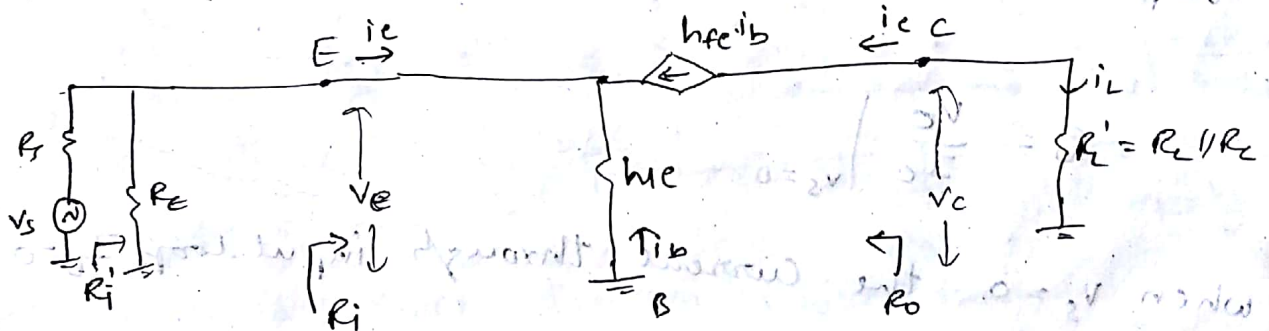
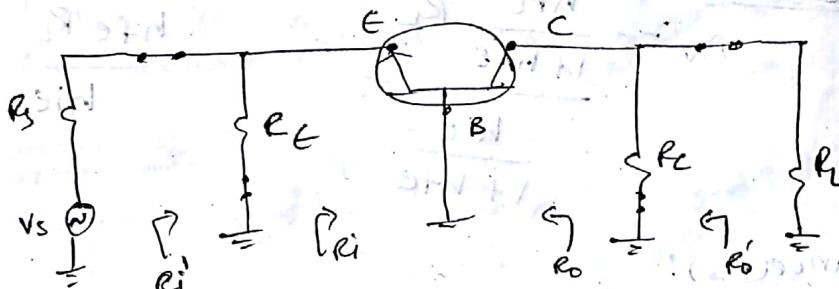
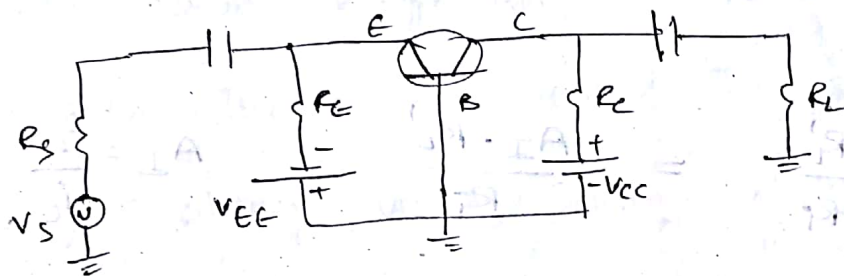
$$R_o = \frac{V_e}{i_e} = \frac{R_s' + h_{ie}}{1 + h_{fe}}$$

$R_o' = R_o$ including biasing resistor R_E :

$$R_o' = R_o \parallel R_E$$

(f). Analyse C.B. amplifier using simplified hybrid model (or) Derive A_I, R_i, A_v, R_o .

Soln



Current gain:-

$$A_I = \frac{i_L}{i_e} = \frac{-i_c}{i_e}$$

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

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

$$h_{fe} i_b + i_b + i_e = 0$$

$$i_e = -i_b(1+h_{fe})$$

Input resistance: (R_i):

$$R_i = \frac{V_e}{i_e}$$

$$= \frac{-h_{ie} \cdot i_b}{-i_b(1+h_{fe})} = \frac{h_{ie}}{1+h_{fe}}$$

voltage gain (A_v):

$$A_v = \frac{V_o}{V_e}$$

$$= \frac{I_o \cdot R_L'}{i_e \cdot R_i}$$

$$= \frac{A_I \cdot R_L'}{R_i}$$

$$A_I = \frac{I_o}{i_e}$$

or)



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

$$= \frac{h_{fe} \cdot R_L'}{h_{ie}}$$

output resistance (R_o):

$$R_o = \left. \frac{V_e}{I_e} \right|_{V_s=0}$$

when $V_s=0$ the current through input loop $I_b=0$

$$\text{then } I_e=0 \text{ then } R_o = \frac{V_c}{I_e} = \infty$$

the output resistance R_o'

$$R_o' = R_o \parallel R_L = \infty \parallel R_L = R_L$$

[open circuit
parallel to
 R_L]

Miller's theorem with an emitter resistance

Note 1: whenever the gain provided by a single stage

amplifier is not sufficient. It is necessary to cascade the number of stages of the amplifier.

Because of instability of the first stage is amplified in the second stage and it is further amplified in the next. This is not desired. The simple & effective way to obtain voltage gain stabilization is to add an emitter resistor R_E .

Miller's theorem:

Note 2: Twoport network

E.g.

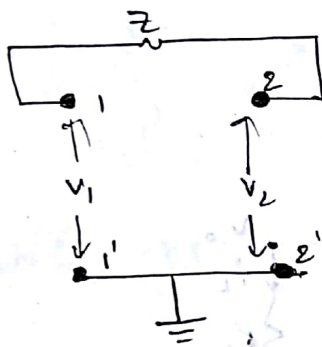
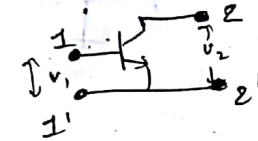


fig 1.

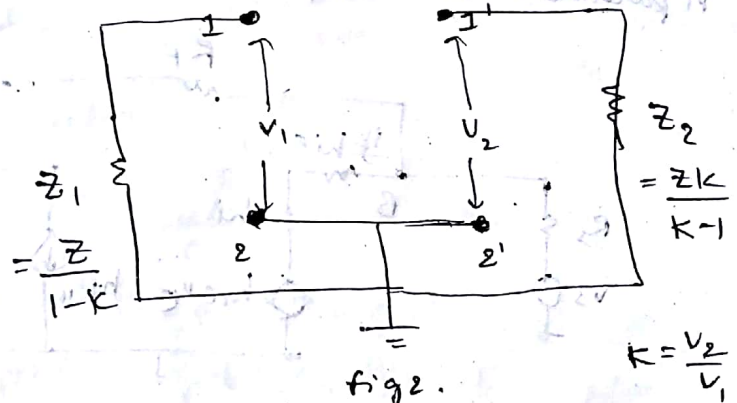


fig 2.

→ In general, the Miller's theorem is used for

Converting any circuit having configuration (fig 1) to another configuration (fig 2).

→ Z is the impedance connected between two nodes node 1, & node 2, It can be replaced by two separate impedances Z_1 & Z_2 .

→ V_1 & V_2 are voltages at node 1 & 2.

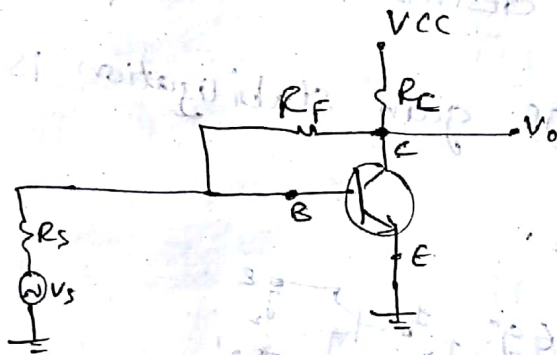
The values of impedances Z_1 & Z_2 are given as

$$Z_1 = \frac{Z}{1-K}$$

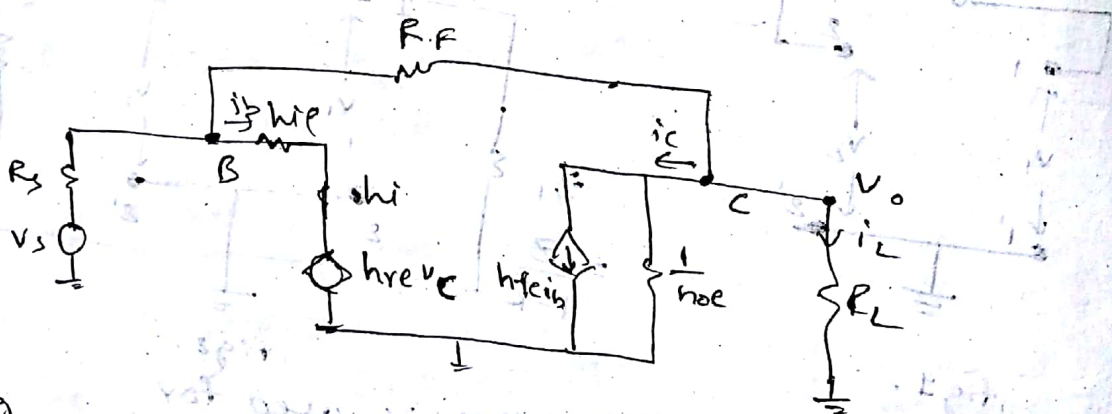
$$Z_2 = \frac{ZK}{K-1}$$

Analysis of CE amplifier with an emitter resistor

Analysis of Common emitter amplifier with collector to base bias.



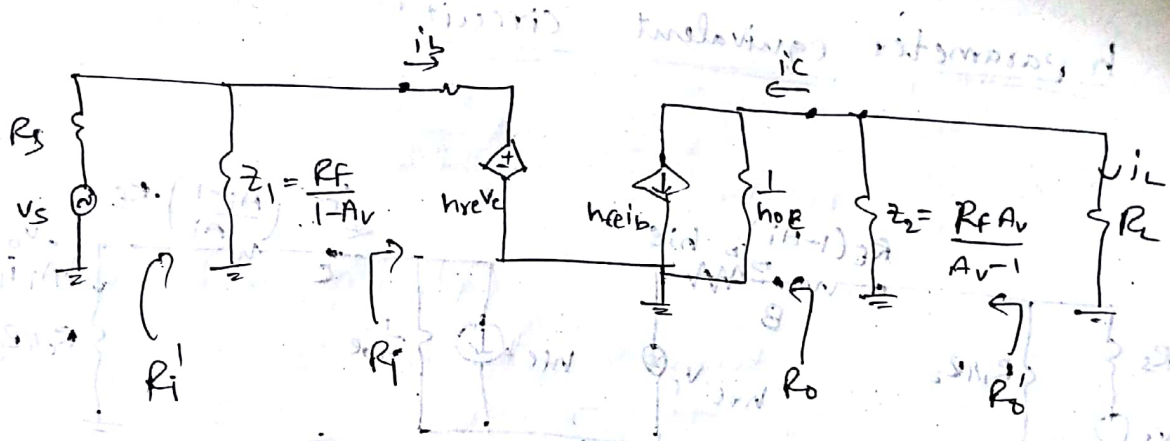
h parameter model:



using miller's theorem

$$Z_1 = \frac{Z}{1-K} = \frac{R_f}{1-A_v}$$

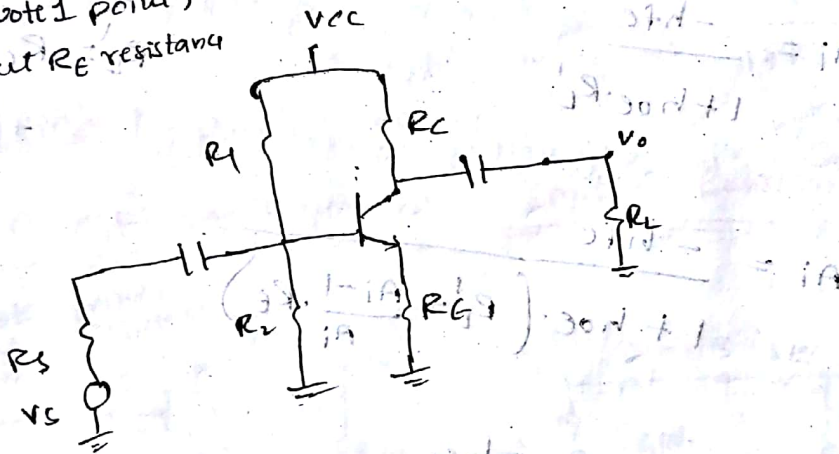
$$Z_2 = \frac{ZK}{K-1} = \frac{R_f A_v}{A_v - 1} \quad K = A_v = \frac{V_c}{V_b} = \frac{V_o}{V_b}$$



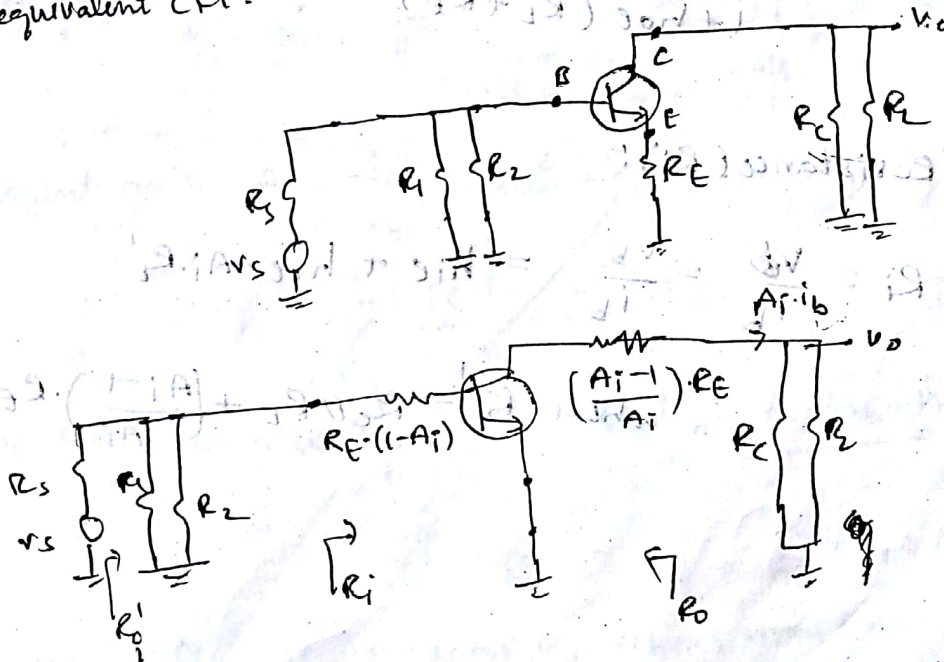
Calculate A_v, R_i, A_i as did in the C.E. configurations.
C.B
C-C

Analysis of C.E. amplifiers with an Emitter Resistance

(write note 1 point)
about R_E resistance

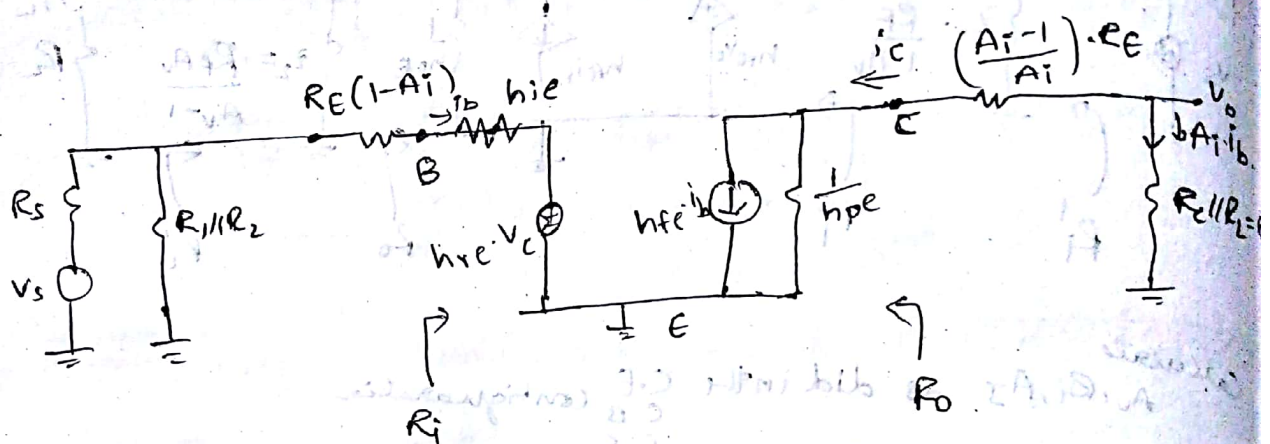


AC equivalent ckt:



R_E is split using dual of miller theorem.

h parameter equivalent circuit!



Current gain (A_i):

$$A_i = \frac{-h_{fe}}{1 + h_{oe} \cdot R_L'}$$

$$A_i = \frac{-h_{fe}}{1 + h_{oe} \cdot \left(R_L' + \frac{A_i - 1}{A_i} \cdot R_E \right)}$$

$$A_i = \frac{h_{oe} \cdot R_E - h_{fe}}{1 + h_{oe} (R_L' + R_E)}$$

Input Resistance (R_i):

$$R_i = \frac{V_b}{i_b} = \frac{V_b}{i_b} = h_{ie} + h_{re} \cdot A_i \cdot R_L'$$

$$\text{where } R_L' = R_C \parallel R_L + \left(\frac{A_i - 1}{A_i} \right) \cdot R_E$$

voltage gain (A_v):

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

Here

$$R_L' = R_L \parallel R_2$$

output Resistance (R_o):

$$R_o = \frac{1}{h_{oe} - h_{fe} h_{ie}}$$

$$R_s' + (h_{ie} + R_E(1 - A_i))$$

where

$$R_s' = R_1 \parallel R_2 \parallel R_3$$

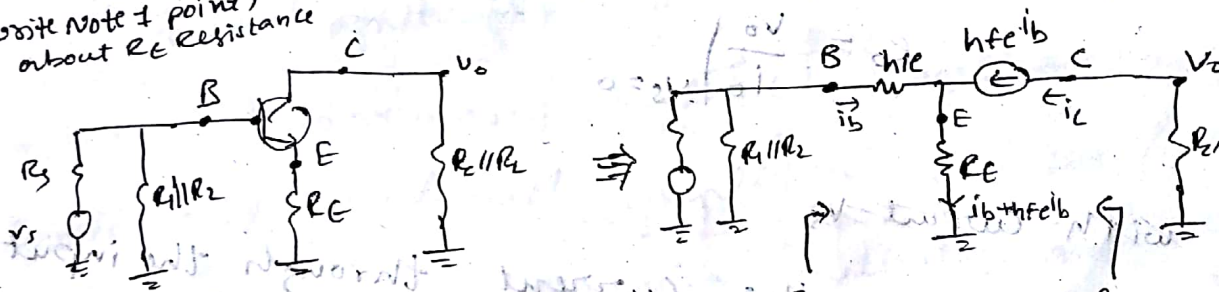
$$A_i = \frac{h_{oe} R_E - h_{fe}}{1 + h_{oe} (R_L' + R_E)}$$

Simplified hparameter model

for C.E. amplifier with Emitter Resistor:

stabilizer (indp) of R_E stability achieved. Due to R_E $R_i \uparrow$ $A_v \downarrow$

(write Note 1 point) about R_E Resistance



Current gain: $A_i = \frac{-i_c}{i_b}$

$$= \frac{-h_{fe} \cdot i_b}{i_b} = -h_{fe}$$

$$\text{input resistance } (R_i) = \frac{v_b}{i_b} = \frac{h_{ie} \cdot i_b + R_E (i_b + h_{fe} i_b)}{i_b}$$

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

input resistance due to factor $R_E (1 + h_{fe})$ may be very much larger than h_{ie} . Hence emitter resistance greatly increases R_i resistance.

Voltage (A_v):

$$A_v = \frac{A_i \cdot R_L}{R_i}$$
$$= \frac{-h_{fe} \cdot R_L}{h_{ie} + (1 + h_{fe}) R_E}$$

output resistance (R_o): It is the resistance of an amplifier without considering the

Source and load (i.e. $V_s = 0$, $R_L = \infty$) It is defined

as a ratio of o/p voltage V_o to output current with $V_s = 0$

$$R_o = \left. \frac{V_o}{I_o} \right|_{V_s = 0}$$

with current V_s

When $V_s = 0$, the current through the input

loop $I_b = 0$, hence I_c & I_o both are zero.

therefore $R_o = \infty$ the output resistance R_o

given as

$$R_o' = R_o \parallel R_L = \infty \parallel R_L$$

$$= R_L$$

multi stage amplifier & Cascode & Cascode amplifier:

for faithful amplification amplifier should have desired voltage gain, current gain and it should match its input impedance with the source and output impedance with load.

Multi stage amplifiers required when

→ When the amplification of a single stage amplifier is not sufficient

→ When the input or output impedance is not of the correct magnitude for a particular application two or more amplifier stages are connected in cascade such amplifier, with two or more stages is also known as multistage amplifier.

→ In multistage amplifier, the output of preceding stage is to be coupled to the input of succeeding stage. For this interstage coupling different types of coupling elements can be employed. These are

- 1). RC coupling
- 2). Transformer coupling
- 3). Direct coupling.

1). RC coupling:

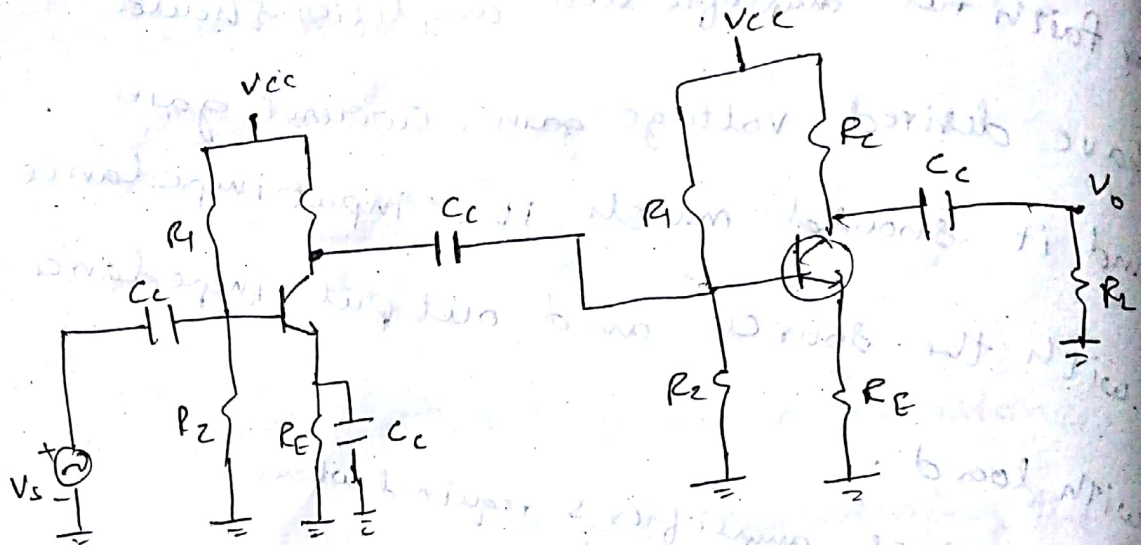


fig: Two stage RC coupled amplifier using transistors.

→ In this, the output signal of first stage is coupled to the input of the next stage through coupling capacitor and resistive load at the output terminal of first stage.

→ The coupling does not affect the quiescent point of the next stage since the coupling capacitor C_c blocks the D.C. voltage of the first stage from reaching the base of the second stage.

USE :-

RC network is broad band in nature.

Therefore it gives a wide band freq. response

with out peak at any frequency and hence used to cover a complete AF amplifier bands.

Drawbacks:

frequency response drops off at very low frequencies due to coupling capacitor & also at high freq. due to shunt capacitors such as stray capacitance.

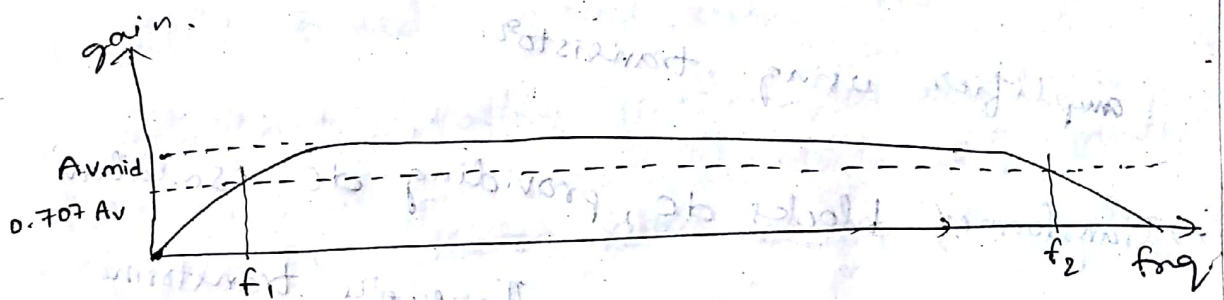


fig: frequency response of RC coupled amplifier.

2). Transformer Coupling:

- In transformer coupling output signal of first stage is coupled to the input of the next stage through an impedance matching transformer.
- This type of coupling is used to match the impedance between output & input cascaded stage.

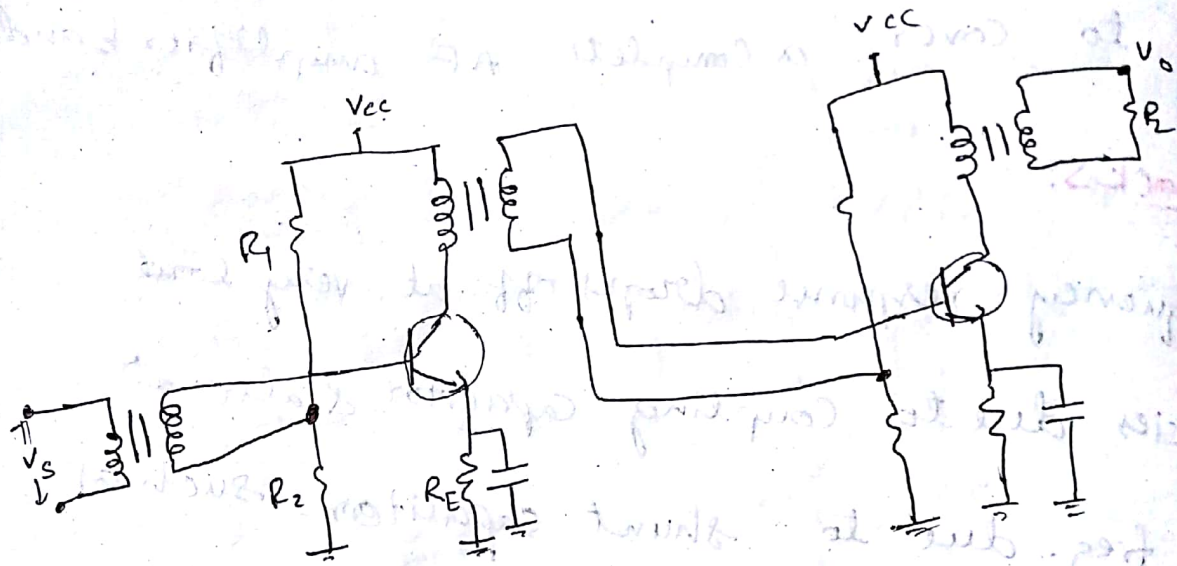
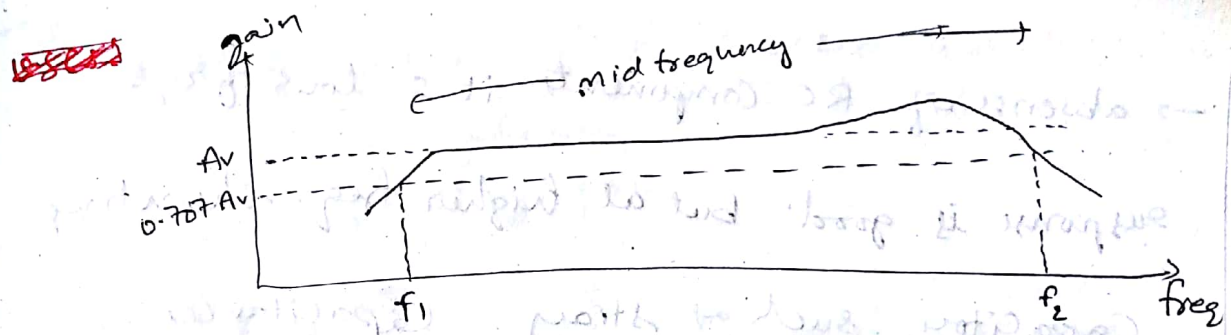


fig: Two stage transformer coupled amplifier using transistor.

- Transformer blocks dc, providing dc isolation between the two stages. Therefore transformer coupling does not affect the quiescent point of the next stage.

Drawback:

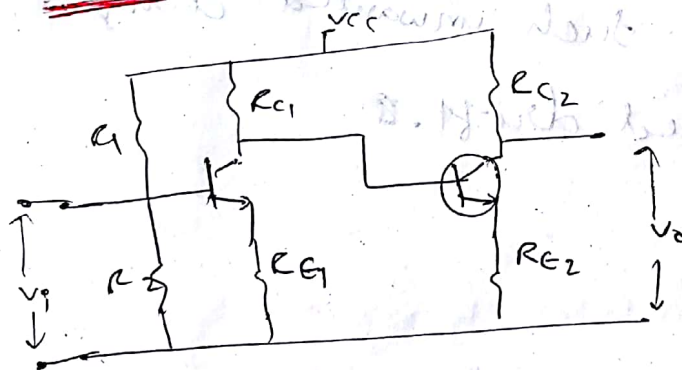
- Its leakage inductance and interwinding capacitance does not allow amplifier to amplify the signals of different freq. equally well.
- Interwinding capacitance of transformer coupled may give rise to resonance at certain freq. which makes amplifier to give very high gain at that frequency.



uses:

- By putting putting shunting capacitors across each winding of the transformer, we can get resonance at any desired RF freq. Such amplifiers are called tuned voltage amplifiers.
- Used in T.V, radio receivers for amplifying RF signals.
- Absence of collector resistance it eliminates unnecessary power loss in the resistor.

Direct Coupling:-



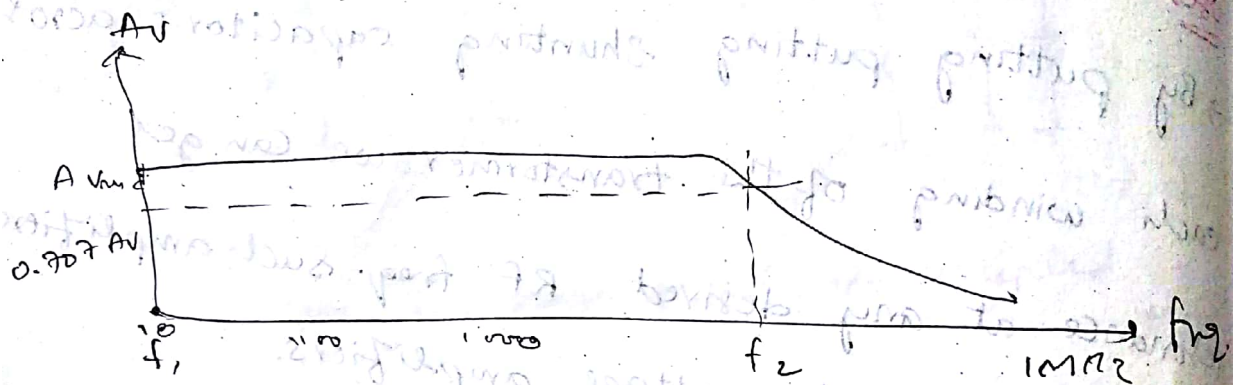
- ⇒ o/p signal of first stage is directly connected to the i/p of next stage. This direct coupling allows the quiescent d.c collector current of first stage to pass through base of the next stage, affecting its biasing condition.

→ absence of RC components it's low freq.

response is good but at higher freq. shunting

Capacitors such as stray capacitance

reduces gain of the amplifier.



Drawback:

→ The transistor parameters V_{BE} , β changes with temperature causing the collector current, voltage change. Because of direct coupling these changes appear at the base of the next stage, and hence in the output. Such unwanted change in the i/p is called drift.

Q. what is the importance of multistage amplifiers?
 what is the need of cascading of amplifiers?

1)

very weak source
 sig.
 micro phone

⇒ amplify

amplified to the level for the operation
 another transducer
 such as
 loud speaker

single stage amplifier
 multistage amplifiers
 cascade amplifiers
 cascode amplifiers
 two stage RC coupled amplifiers

2)

we go for multistage amplifiers:
 cascading
 cascading amplifiers:
 when ever

amplification of

single stage amplifier amplification is not sufficient
 when ever

input & output impedances are not in correct magnitude

Impedance:

CB	CE	CC
i_{ip} low o_{ip} very high	i_{ip} high o_{ip} high	i_{ip} high o_{ip} low

3).

of amplifiers
 Cascading provides:-
 multistage amplifiers

1) faithful amplification of signal

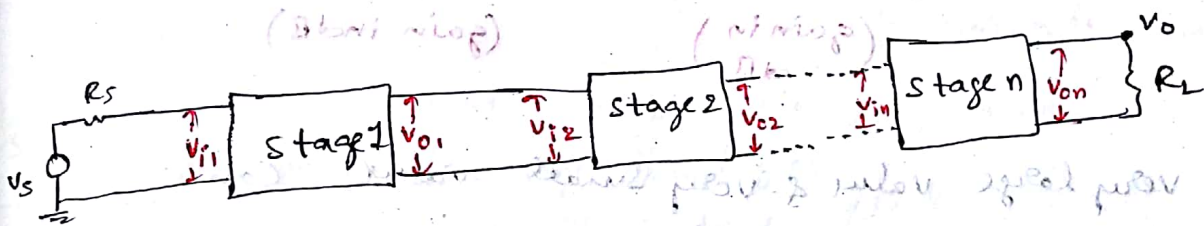
By providing voltage gain
 current gain

2) matching of i_{ip} impedance with the source
 matching of o_{ip} impedance with load.

Can be achieved using multistage amplifiers

②. Advantages of Representation of gain in Decibels.

Multi stage amplifier with "n" number of stages:



voltage gain of the multistage amplifier is given as:

$$A_v = \frac{V_{on}}{V_{i1}}$$

$$= \frac{V_{on}}{V_{in}} = \frac{V_{02}}{V_{i2}} \cdot \frac{V_{01}}{V_{i1}} = (36) \text{ V/V}$$

$$A_{v1} = \frac{V_{01}}{V_{i1}} \quad \text{1st stage}$$

$$A_{v2} = \frac{V_{02}}{V_{i2}} \quad \text{2nd stage}$$

$$A_v = A_{v1} \cdot A_{v2} \cdots A_{vn} \quad \text{--- ①}$$

Representation of gain in dB:-

⇒ The gain of multistage amplifier can be easily calculated if the gain of the individual stages are known in dB.

Apply "log" on ① equation:

$$20 \log A_v = 20 \log A_{v1} \cdot A_{v2} \cdots A_{vn}$$

$$= 20 \log A_{v1} + 20 \log A_{v2} + \cdots + 20 \log A_{vn}$$

$$A_v \quad (\text{in dB}) = A_{v1} + A_{v2} + \cdots + A_{vn} \quad (\text{gain in dB})$$

Advantages:

- 1) overall gain of the amplifier is easily calculated
- 2) individual gains of the amplifier.

overall gain $A_v = A_{v1} + A_{v2} + \dots + A_{vn}$

(gain in dB) (gain in dB)

2) very large values & very small values can be denoted by small figures.

Eg: $A_v = 0.0000001$ this voltage gain can

be represented in dB as

$$A_v(\text{dB}) = 20 \log 0.0000001$$

$$= 20 \log 10^{-7}$$

$$= -140 \log 10$$

$$= -140 \text{ dB}$$

$$A_v = 0.0000001$$

$$A_v = -140 \text{ dB}$$

} Both are same.

37. TOPIC:-

Two stage RC coupled } CE-CE Cascode amplifier
Analysis of } CE-CB Cascode amplifier
CE-CC Cascode amplifier

selection of Configuration in Cascading amplifiers:

→ 3 parts of multistage amplifier.

- (i) I/P stage
- (ii) middle stage
- (iii) O/P stage

→ i/p stage is designed such that its i/p impedance

matches with the source impedance.

O/P stage is designed such that o/p impedance matches with load impedance.

middle stage are designed to produce } voltage gain
current gain
power gain.

→ middle stage: C.E. has voltage, current gain

So Best choice is to use C.E. as middle stage.

O/P stage: C.C. → Because o/p impedance matches with output load

I/P stage: C.B. → Because i/p impedance matches with source imped.

	C.B	C.E.	C.C.
i/p Resistance	very low (20 Ω)	Low (1K Ω)	High (100K Ω)
O/P Resistance	very high (1M Ω)	High (40K Ω)	Low (50 Ω)
Current gain	less than unity	High	High
voltage gain	medium	medium	Low
Application	As a i/p stage multistage amplifier.	for audio big amplification	for impedance matching

3) Two stage RC coupled CE-CE Cascade amplifier.

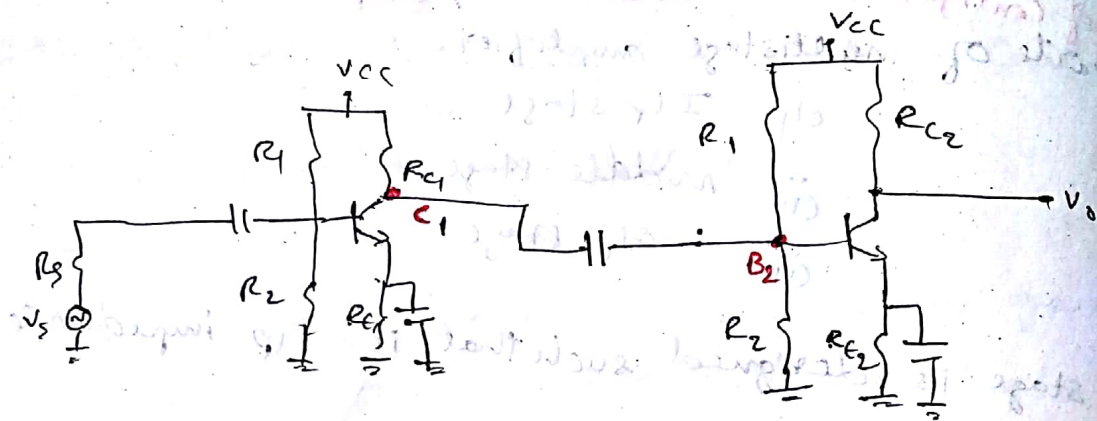
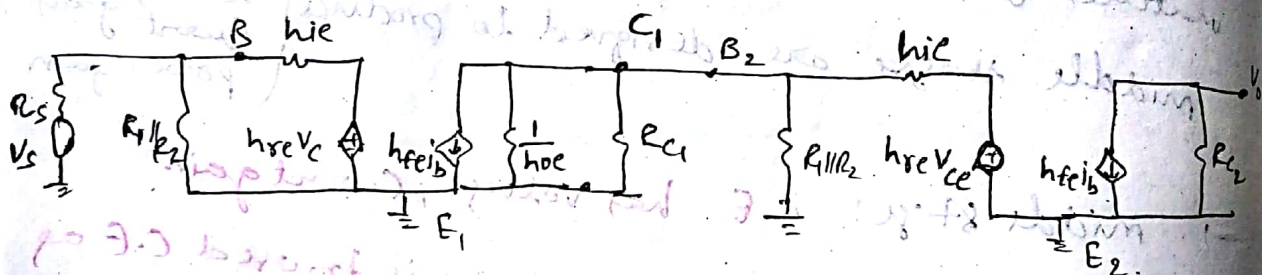


fig: CE-CE cascade amplifier.



h parameter equivalent?

procedure:

1st find A_V , R_i , A_I for 2nd stage then

find A_V , R_i , A_I for 1st stage then

find overall A_V , R_i , A_I for the entire amplifier

Imp. problems

CE-CE cascade amplifier
 CE-CB cascade amplifier
 CE-CC cascade amplifier

1). Calculate $R_i, A_{i1}, A_{v1}, R_{i2}, A_{v2}, A_{i2}$ if the

Circuit parameters are: $R_s = 1k\Omega, R_{E1} = 100\Omega$
 $R_{C1} = 15k\Omega, R_{C2} = 4k\Omega$
 $R_{E2} = 330\Omega, R_1 = 200k\Omega$
 $R_2 = 20k\Omega$

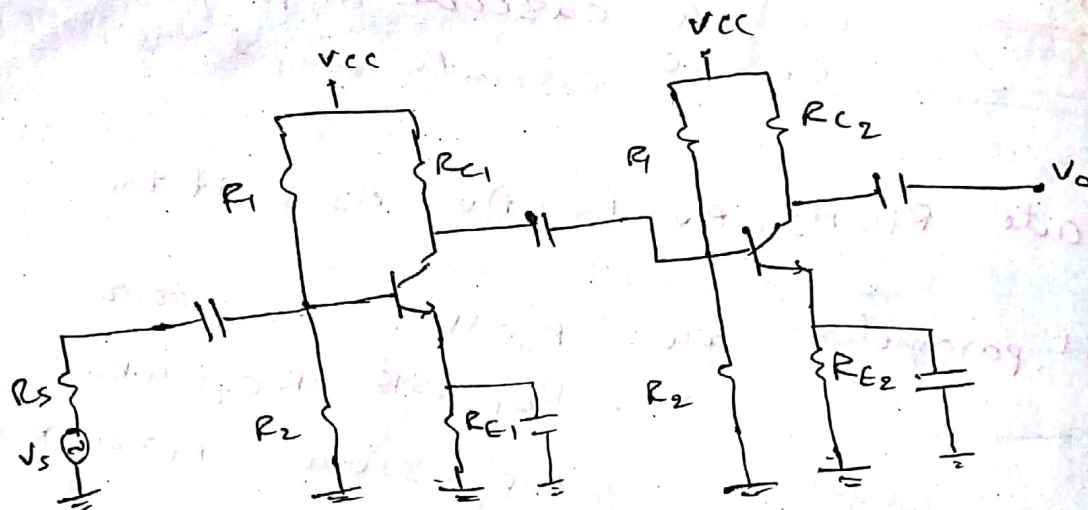
for 1st stage

for 2nd stage

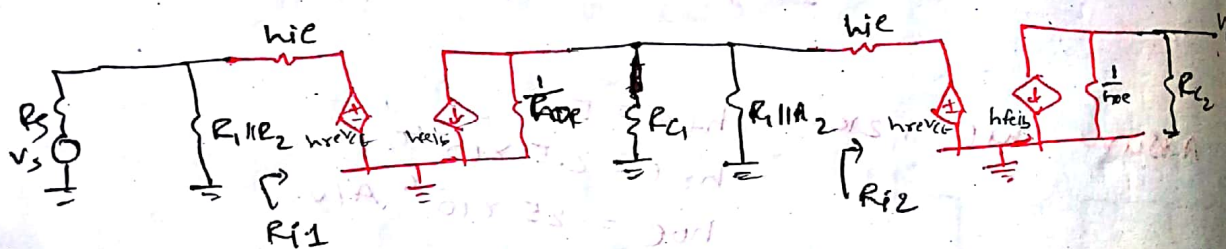
$R_1 = 47k\Omega$
 $R_2 = 47k\Omega$

Assum $h_{ie} = 1.2k\Omega, h_{fe} = 50$
 $h_{re} = 2.5 \times 10^{-4}$
 $h_{oe} = 25 \times 10^{-6} A/V$

Sol:



CE-CE cascade amplifier.



h parameter model

for second stage:

$$h_{oe} \cdot R_{load} = h_{oe} \cdot R_{C2} = 25 \times 10^{-6} \times 4 \times 10^3 = 0.1 \quad \text{we can use approximate analysis}$$

$$\text{current gain} = A_{I2} = -h_{fe}$$

$$= -50$$

$$\text{Input resistance} = R_{i2} = h_{ie} = 1.2 \text{ k}\Omega$$

$$\text{voltage gain} = A_{V2} = \frac{A_{I2} \cdot (R_{C2} \parallel R_L)}{R_{i2}}$$

$$A_V = \frac{A_{I2} \cdot R_{load}}{R_I}$$

$$= \frac{(-50) \cdot (4 \times 10^3)}{1.2 \times 10^3}$$

$$= -166.67$$

for first stage:-

$$h_{oe} \cdot R_{load} = h_{oe} \cdot [R_{C1} \parallel R_{L1} \parallel R_{C2} \parallel R_{L2}]$$

$$= h_{oe} \cdot [15 \times 10^3 \parallel 15 \times 10^3 \parallel 200 \times 10^3 \parallel 1.2 \times 10^3]$$

$$= 25 \times 10^{-6} \times 881.8$$

$$= 0.022 < 0.1$$

So $h_{oe} \cdot R_L < 0.1$ so we can use approximate analysis.

Current gain (A_{I1}):

$$A_{I1} = -h_{fe}$$

$$= -50$$

Input Resistance (R_{i1}) = $h_{ie} = 1.2 \text{ k}\Omega$

$$\text{Voltage gain } (A_{V1}) = \frac{A_{I1} \cdot (R_{C1} \parallel R_{L1} \parallel R_{C2} \parallel R_{L2})}{R_{i1}}$$

$$A_V = \frac{A_I \cdot R_{load}}{R_I}$$

$$= \frac{(-50)(881.8)}{1.2 \times 10^3}$$

$$= -36.74$$

Overall voltage gain: $A_V = \frac{V_o}{V_i}$

$$A_V = A_{V1} \cdot A_{V2} = (-166.67) / (-36.74)$$

$$= 4534.45$$

Overall Voltage gain (A_{VS}):

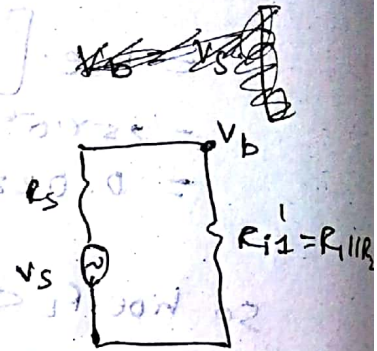
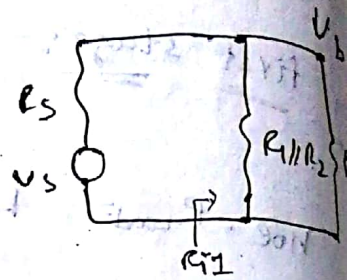
$$A_{VS} = \frac{V_O}{V_S}$$

$$= \frac{V_O}{V_B} \cdot \frac{V_B}{V_S}$$

$$= A_V \cdot \frac{R_{i1}}{R_{i1} + R_S}$$

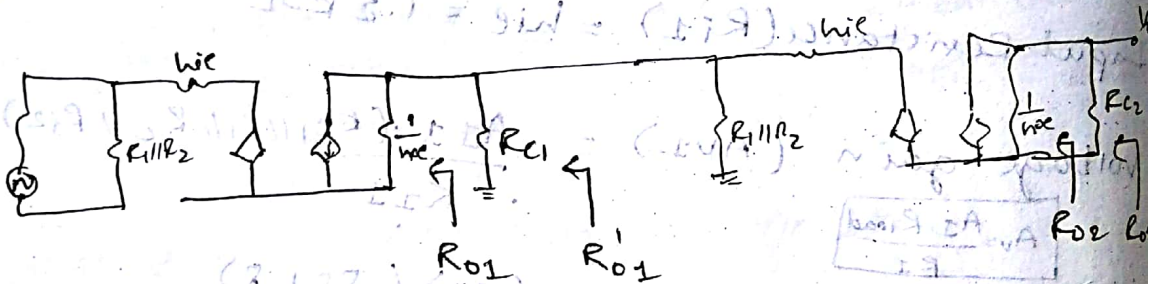
$$= (6123.45) \cdot \left[\frac{200 \times 10^3 \parallel 10 \times 10^3 \parallel 1.2 \times 10^3}{R_{i1} + 1 \times 10^3} \right]$$

$$= 3248.6$$



$$V_B = V_S \cdot \left[\frac{R_{i1}}{R_{i1} + R_S} \right]$$

Output Resistance:



$$R_{o1} = \infty$$

$$R_{o1}' = R_{o1} \parallel R_{C1}$$

$$= \infty \parallel R_{C1} = \infty \parallel 15K = 15K\Omega$$

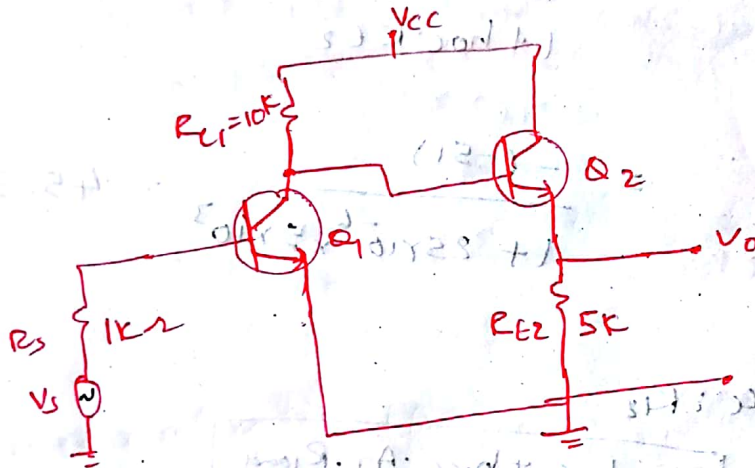
$$R_{o2} = \infty$$

$$R_{o2}' = R_{o2} \parallel R_{C2} = \infty \parallel R_{C2} = \infty \parallel 4K = 4K\Omega$$

C.E - C.C. amplifiers:

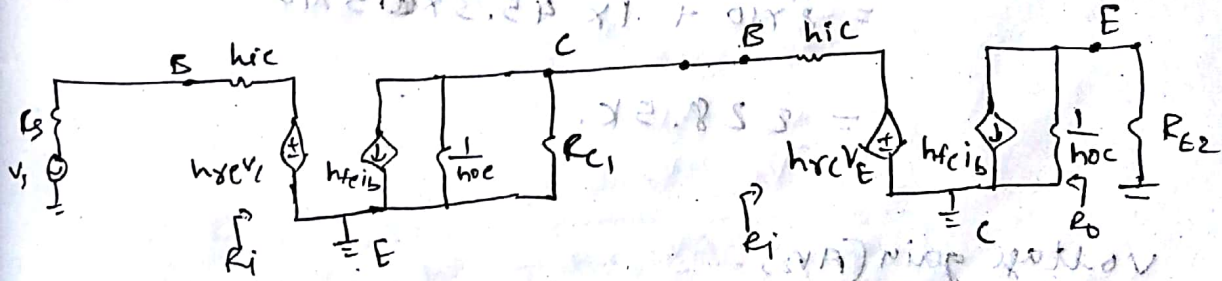
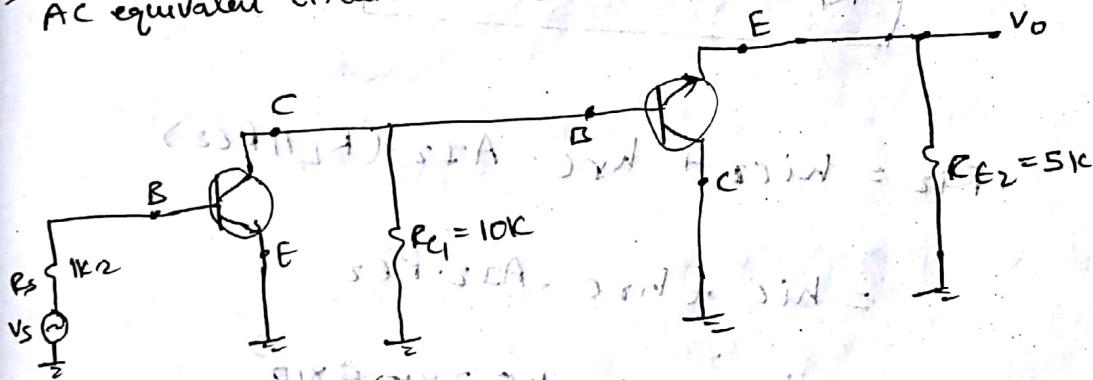
→ A two stage amplifier circuit in a CE-CC configuration as shown in figure.

$$\begin{aligned} h_{ie} &= 2k\Omega & h_{fe} &= 50 & h_{re} &= 6 \times 10^{-4} & h_{oe} &= 25 \mu A/V \\ h_{ic} &= 2k\Omega & h_{fc} &= -51 & h_{rc} &= 1 & h_{oc} &= 25 \mu A/V \end{aligned}$$



sol:

AC equivalent circuit:



for second stage:

$$\begin{aligned} h_{oc} \cdot R_L &= h_{oc} / R_{E2} = 25 \times 10^{-6} / (5 \times 10^3) = 0.125 \\ &= 0.125 > 0.1 \\ &\text{so use exact analysis.} \end{aligned}$$

Current gain $A_{I2} = \frac{-I_{e2}}{I_{b2}} = \frac{-h_{fc}}{1 + h_{oc}(R_{E2} \parallel R_L)}$

$$= \frac{-h_{fc}}{1 + h_{oc} \cdot (R_{E2} \parallel R_L)}$$

$$= \frac{-h_{fc}}{1 + h_{oc} \cdot R_{E2}}$$

$$= \frac{-(-51)}{1 + 25 \times 10^{-6} \times 5 \times 10^3} = 45.3$$

Input Resistance: R_{i2}

$$R_i = h_{ic} + h_{rc} \cdot A_{I1} \cdot R_{load}$$

$$R_i = h_{ic} + h_{rc} \cdot A_{I1} (R_L \parallel R_E)$$

$$R_{i2} = h_{ic2} + h_{rc2} \cdot A_{I2} \cdot (R_L \parallel R_{E2})$$

$$= h_{ic} + h_{rc} \cdot A_{I2} \cdot R_{E2}$$

$$= 2 \times 10^3 + 1 \times 45.3 \times 5 \times 10^3$$

$$= 228.5 \text{ k}\Omega$$

Voltage gain (A_{V2}):

$$A_V = \frac{A_{I2} \cdot (R_L \parallel R_E)}{R_{i2}}$$

$$A_V = \frac{A_{I2} \cdot (R_L \parallel R_E)}{R_{i2}}$$

$$= \frac{(45.3)(5 \times 10^3)}{228.5 \times 10^3} = 0.991$$

Analysis of first stage:

$$\boxed{h_{oe} \cdot R_{load}} = h_{oe} \cdot (R_{C1} \parallel R_{I2})$$

$$= 25 \times 10^{-6} \cdot (10 \times 10^3 \parallel 228.5 \times 10^3)$$

$$= 0.239 > 0.1$$

so use exact analysis.

Current gain $\boxed{A_I = \frac{-h_{fe}}{1 + h_{oe} \cdot R_{load}}}$

$$A_{I1} = \frac{-h_{fe}}{1 + h_{oe}(R_{C1} \parallel R_{I2})}$$

$$A_{I1} = \frac{-50}{1 + 25 \times 10^{-6} \times (10 \times 10^3 \parallel 228.5 \times 10^3)}$$

$$= -40.34$$

Input Resistance:

$$\boxed{R_{I1} = h_{ie} + h_{re} \cdot A_{I1} \cdot R_{load}}$$

$$R_{I1} = h_{ie} + h_{re} \cdot A_{I1} \cdot (R_{C1} \parallel R_{I2})$$

$$= 2 \times 10^3 + 6 \times 10^{-4} \times (-40.34) \times (10 \times 10^3 \parallel 228.5 \times 10^3)$$

$$= 1.768 \text{ k}\Omega$$

Voltage gain $A_v = \frac{A_{I1} \cdot R_{load}}{R_i}$

$$A_{v1} = \frac{A_{I1} \cdot (R_{C1} \parallel R_{i2})}{R_{i1}}$$

$$= \frac{(-40.34) (10 \times 10^3 \parallel 228.5 \times 10^3)}{1.768 \times 10^3}$$

$$= -218.5$$

overall voltage gain:

$$A_v = A_{v2} \cdot A_{v1}$$

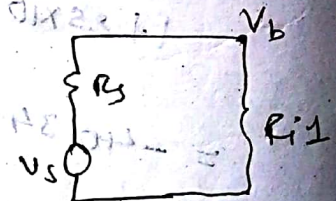
$$= (0.991) (-218.5)$$

$$= -216.5$$

overall voltage gain (A_{vs}):

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

$$= \frac{V_o}{V_b} \cdot \frac{V_b}{V_s}$$



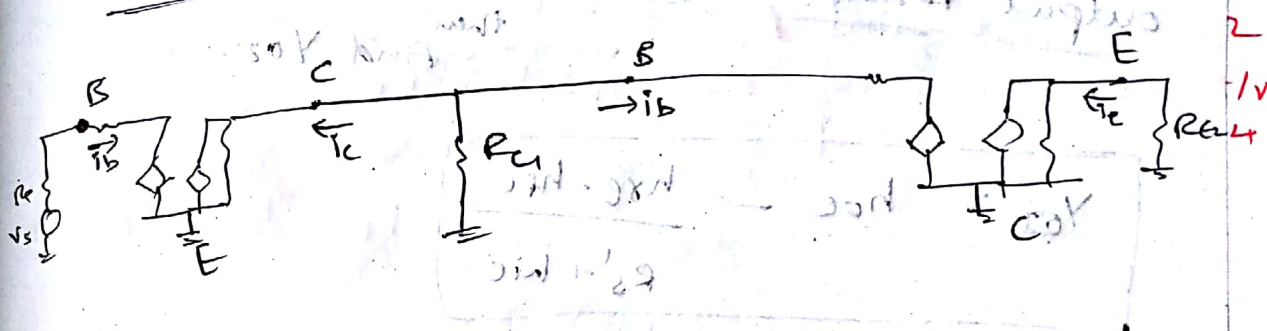
$$= A_v \cdot \frac{V_b}{V_s}$$

$$V_b = V_s \left[\frac{R_{i1}}{R_s + R_{i1}} \right]$$

$$= (-216.5) \cdot \left[\frac{1.768 \times 10^3}{1 \times 10^3 + 1.768 \times 10^3} \right]$$

$$= -138.28$$

Overall Current gain (A_I)



$$A_{I1} = \frac{-i_{C1}}{i_{B1}}$$

$$= -40.34$$

$$A_{I2} = \frac{-i_{C2}}{i_{B2}}$$

$$= 45.3$$

$$A_I = \frac{-i_{C2}}{i_{B1}}$$

$$= \frac{-i_{C2}}{i_{B2}} \cdot \frac{i_{B2}}{-i_{C1}} \cdot \frac{-i_{C1}}{i_{B1}}$$

$$= A_{I2} \cdot \left(\frac{i_{B2}}{-i_{C1}} \right) A_{I1}$$

$$i_{B2} = (-i_{C1}) \cdot \left[\frac{R_{C1}}{R_{C1} + R_{I2}} \right]$$

$$\frac{i_{B2}}{-i_{C1}} = \frac{10 \times 10^3}{10 \times 10^3 + 228.5 \times 10^3}$$

$$A_I = (45.3) \cdot (0.0419) \cdot (-40.34) = -76.56$$

output resistance:- (R_o) :- first find Y_{o1}
then find Y_{o2}

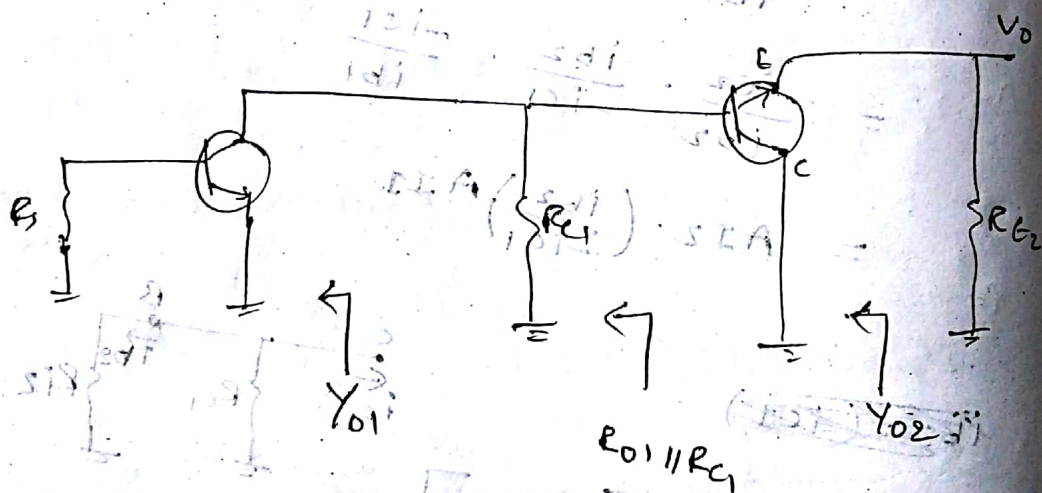
$$Y_{o1} = h_{oe} - \frac{h_{re} \cdot h_{fe}}{R_s' + h_{ie}}$$

$$Y_{o1} = h_{oe} - \frac{h_{re} \cdot h_{fe}}{h_{ie} + R_s}$$

$$= 25 \times 10^{-6} - \frac{6 \times 10^{-4} \times 50}{2 \times 10^3 + 1 \times 10^3}$$

$$= 1.5 \times 10^{-6} \text{ A/V}$$

$$R_{o1} = \frac{1}{Y_{o1}} = 66.7 \text{ K}\Omega$$



$$Y_{o2} = h_{oe} - \frac{h_{re} h_{fe}}{h_{ie} + (R_{o1} \parallel R_{C1})}$$

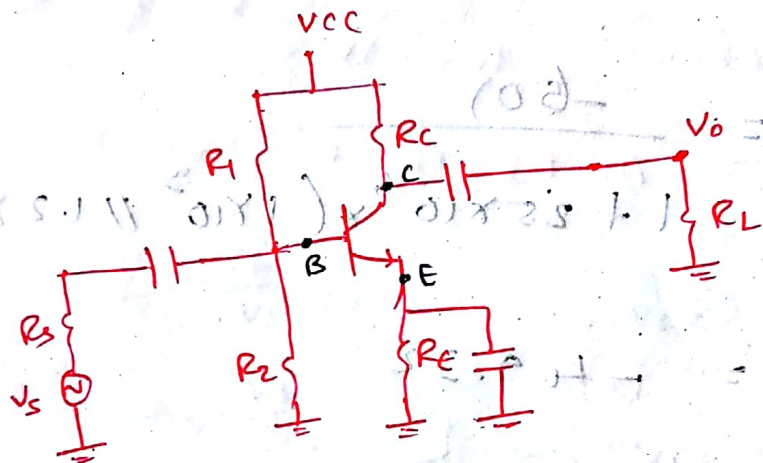
$$h_{ie} + (66.7 \times 10^3 \parallel 10 \times 10^3)$$

$$= 4.79 \text{ mA/V}$$

$$R_{o2} = \frac{1}{Y_{o2}} = 208 \Omega$$

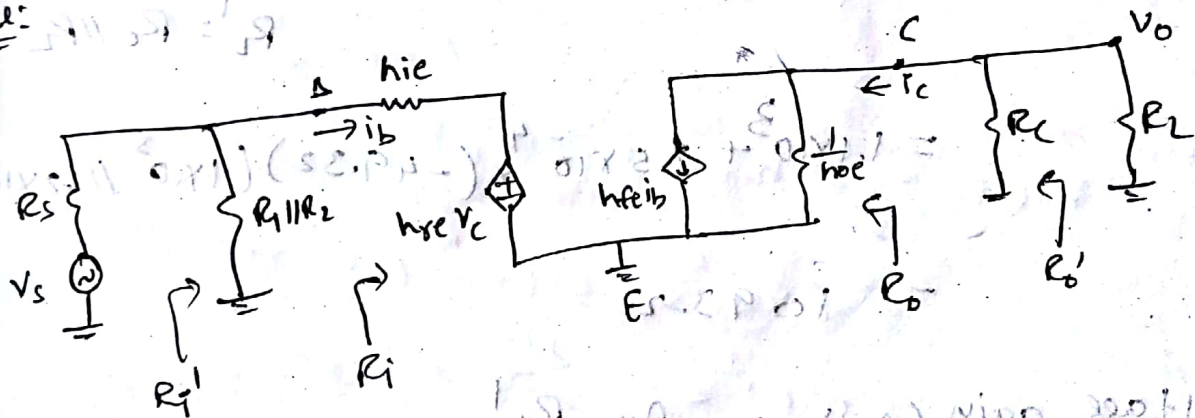
1). Consider a single stage C.E. amplifier

with $R_S = 1k\Omega$, $R_C = 1k\Omega$, $h_{ie} = 1.1k\Omega$
 $R_1 = 50k\Omega$, $R_L = 1.2k\Omega$, $h_{oe} = 25\mu A/V$
 $R_2 = 2k\Omega$, $h_{fe} = 50$, $h_{rc} = 2.5 \times 10^{-4}$



find A_I , R_I , A_{v_i} , A_I , A_{v_s} , R_o .

Sol:



$$\begin{aligned} h_{oe} \cdot R_L &= 25 \times 10^{-6} \times (R_C \parallel R_L) \\ &= 25 \times 10^{-6} \times (1k\Omega \parallel 1.2k\Omega) \\ &= 13.65 \times 10^{-3} \\ &= 13.65 > 0.1 \end{aligned}$$

So use exact model Analysis.

Current gain $A_I = \frac{-h_{fe}}{1 + h_{oe} \cdot R_L'}$

$$R_L' = R_C \parallel R_L$$

$$= \frac{-50}{1 + 25 \times 10^{-6} \times (1 \times 10^3 \parallel 1.2 \times 10^3)}$$

$$= -49.32$$

Input Resistance:

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

$$R_L' = R_C \parallel R_L$$

$$= 1.1 \times 10^3 + 2.5 \times 10^{-4} \times (-49.32) \times (1 \times 10^3 \parallel 1.2 \times 10^3)$$

$$= 1093.2$$

voltage gain (A_v) = $\frac{A_I \cdot R_L'}{R_i}$

$$= \frac{(-49.32) \times (1 \times 10^3 \parallel 1.2 \times 10^3)}{1093}$$

$$= -24.61$$

overall input resistance $R_i' = R_i \parallel R_1 \parallel R_2$

$$= (1093) \parallel 50 \times 10^3 \parallel 2 \times 10^3$$

$$= 696.9 \Omega$$

overall voltage gain:

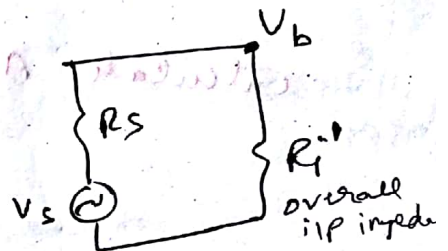
$$A_{VS} = \frac{V_o}{V_s}$$

$$= \frac{V_o}{V_b} \cdot \frac{V_b}{V_s}$$

$$= A_V \cdot \frac{V_b}{V_s}$$

$$= (24.61) \cdot \left[\frac{696.9}{696.9 + 1 \times 10^3} \right]$$

$$= 10.1$$



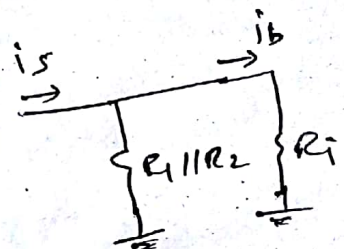
$$V_b = V_s \cdot \left[\frac{R_i'}{R_i' + R_s} \right]$$

Overall Current gain (A_{IS}) with respect to source:

$$A_{IS} = \frac{I_o}{I_s} = \frac{-I_c}{I_s}$$

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

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



$$I_b = I_s \cdot \left[\frac{R_1 \parallel R_2}{R_1 \parallel R_2 + R_i} \right]$$

$$= (-49.32) \cdot \left[\frac{50 \times 10^3 \parallel 2 \times 10^3}{50 \times 10^3 \parallel 2 \times 10^3 + 1093} \right]$$

$$= -31.29$$

2). A common collector circuit as shown in figure. has following components.

$$R_1 = 27K\Omega$$

$$R_L = 47K\Omega$$

$$h_{fe} = 85$$

$$R_2 = 27K\Omega$$

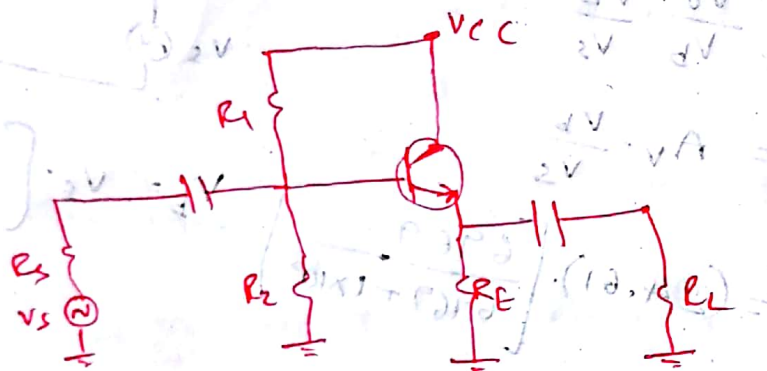
$$R_S = 600\Omega$$

$$h_{oe} = 2\mu A/V$$

$$R_E = 5.6K\Omega$$

$$h_{ie} = 1K\Omega$$

Calculate $A_i, R_i, A_v, R_o, A_{vS}, A_{iS}$



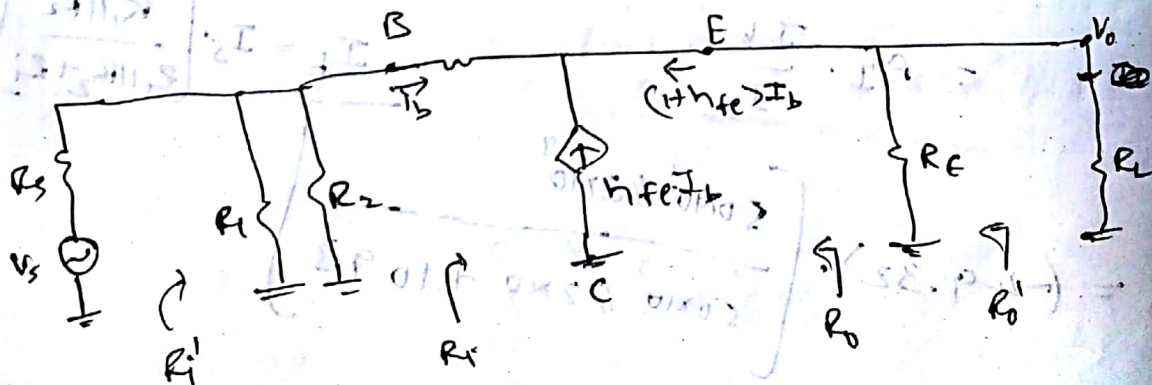
Sol:

Here $h_{oe} R_L = h_{oe} (R_E || R_L)$

$$= 2 \times 10^{-6} \times (5.6 \times 10^3 || 47 \times 10^3)$$

$$= 0.01 < 0.1$$

So go for approximate analysis.



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

$$= 1 + 85 = 86$$

Input Resistance $(R_i) = h_{ie} + (1 + h_{fe}) \cdot R_L$

$$R_i = h_{ie} + (1 + h_{fe})(R_L \parallel R_E)$$

$$= 1 \times 10^3 + (1 + 85)(5.6 \times 10^3 \parallel 47 \times 10^3)$$

$$= 431.33 \times 10^3 \Omega$$

voltage gain $(A_v) = \frac{A_I \cdot R_L}{R_i}$

$$A_v = \frac{A_I (R_L \parallel R_E)}{R_i}$$

$$= \frac{(86)(5.6 \times 10^3 \parallel 47 \times 10^3)}{431.33 \times 10^3}$$

$$= 0.997$$

output Resistance:

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

$$R_o = \frac{(R_s \parallel R_1 \parallel R_2) + h_{ie}}{1 + h_{fe}}$$

$$= \frac{(600 \parallel 27 \times 10^3 \parallel 27 \times 10^3) + 1 \times 10^3}{1 + 85}$$

$$= 18.3 \Omega$$

Overall voltage gain

$$A_{VS} = \frac{A_v \cdot R_i'}{R_i' + R_s}$$

$$= \frac{A_v}{(R_i \parallel R_1 \parallel R_2) + R_s}$$

$$= 0.997 \times \frac{43.33 \times 10^3}{(1.27 \times 10^3) + 27k}$$

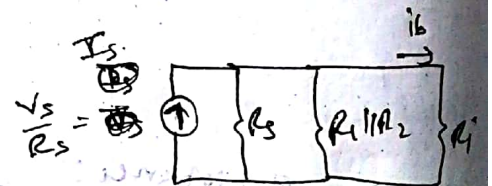
$$= \frac{(13.09 \times 10^3) + 600}{17} = 0.953$$

Overall current gain:

$$A_{IS} = \frac{I_L}{I_S}$$

$$= \frac{I_L}{I_b} \cdot \frac{I_b}{I_S}$$

$$= A_I \cdot \frac{I_b}{I_S}$$



$$A_{IS} = A_I \cdot \left[\frac{R_s \parallel R_1 \parallel R_2}{R_s \parallel R_1 \parallel R_2 + R_i} \right] \cdot \frac{i_b}{I_S} = A_I \cdot \left[\frac{R_s \parallel R_1 \parallel R_2}{R_s \parallel R_1 \parallel R_2 + R_i} \right] \cdot \frac{I_S}{I_S}$$

* Another method is explained after (2 pages) (CC)

* Effect of Coupling Capacitor in two stage

RC coupled amplifier:

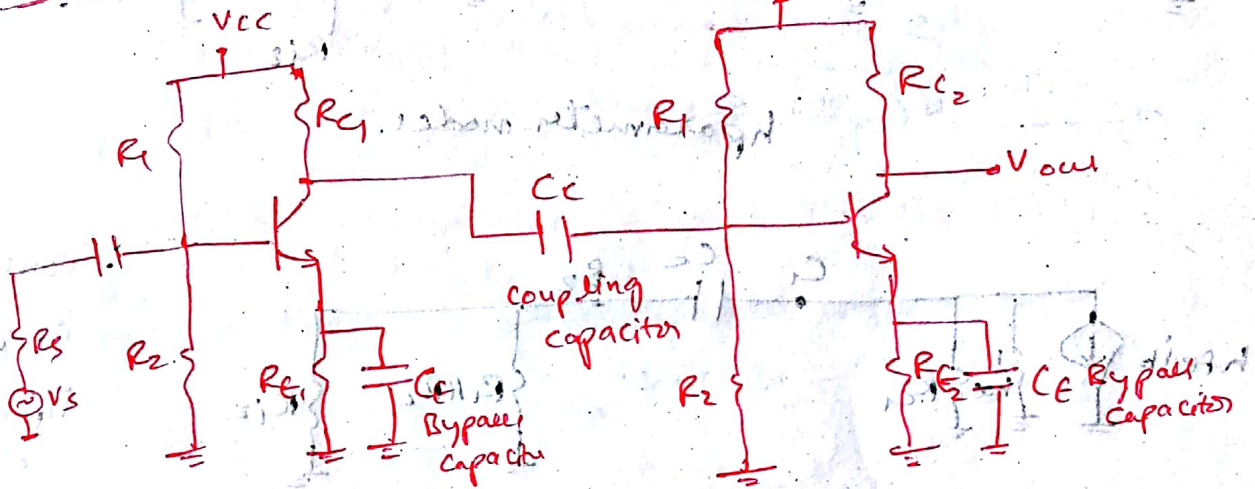
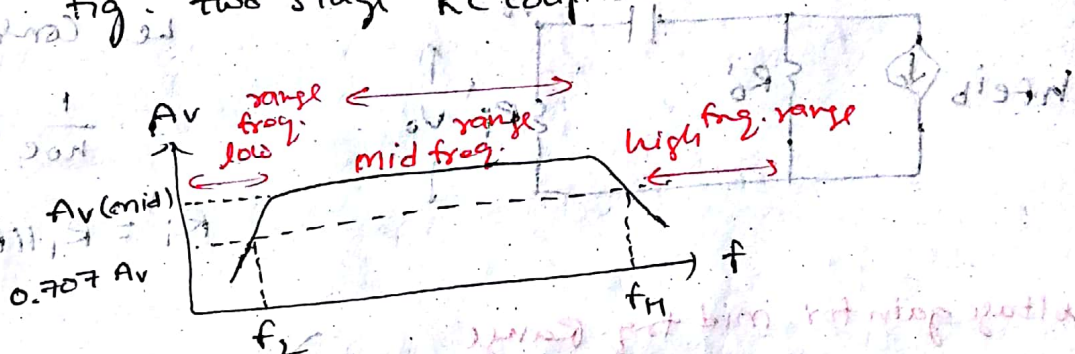


fig: two stage RC coupled amplifier:



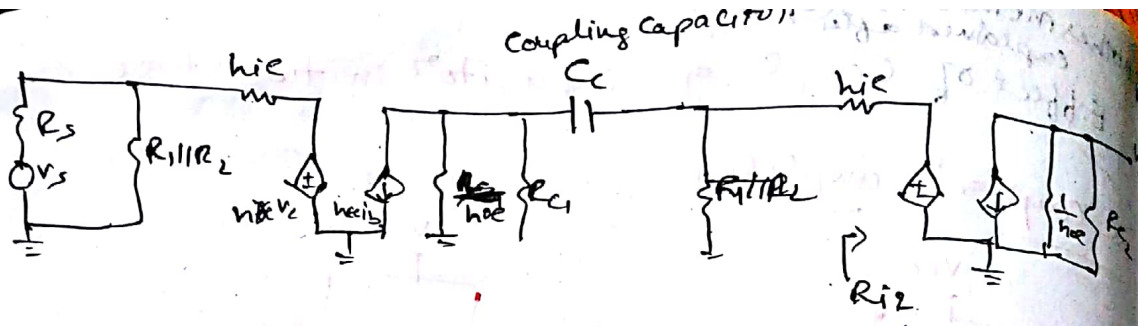
frequency response.

→ To Analyze ^{effect} freq. response of RC coupling due to C_C .

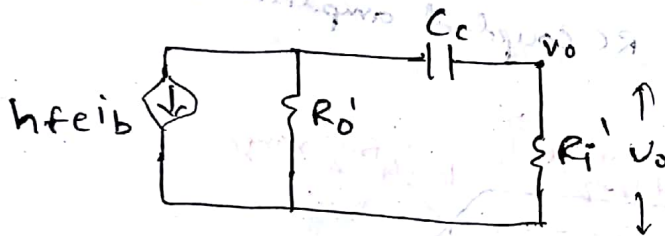
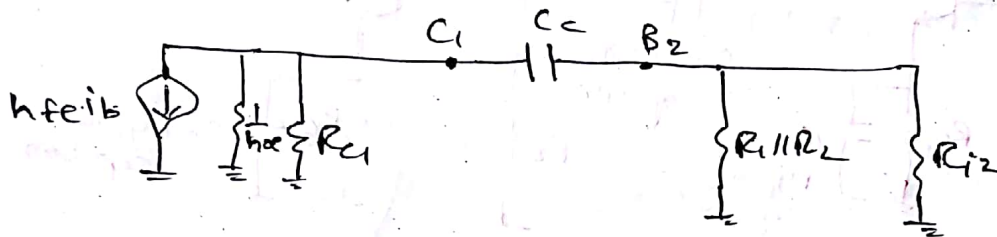
Coupling Capacitor use hparameter model

with C_C (use output section of 1st stage and input section of 2nd stage).

then we get (P.T.O)



h-parameter model.



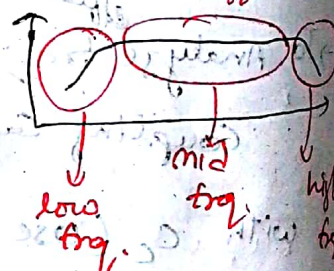
Let Consider

$$\frac{1}{h_{oe}} \parallel R_{C1} = R_0'$$

$$R_i' = R_1 \parallel R_2 \parallel R_{i2}$$

- voltage gain for mid freq. Range
- voltage gain for low freq. Range
- voltage gain for high freq. Range

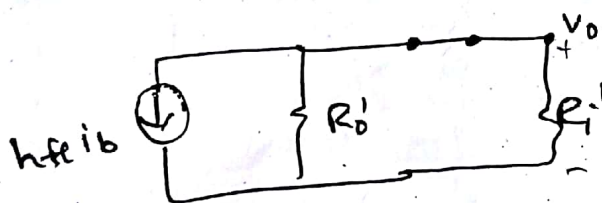
Coupling Capacitor effect.



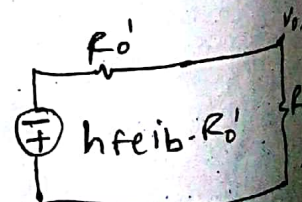
Voltage gain for mid freq. Range:

At mid freq. Range C_c becomes short circuit

then equivalent circuit given as:



$\Rightarrow$
Source
Transformation



$$V_o = (-h_{fe} i_b R_o') \cdot \frac{R_i'}{R_i' + R_o'} \quad \text{(using VA)}$$

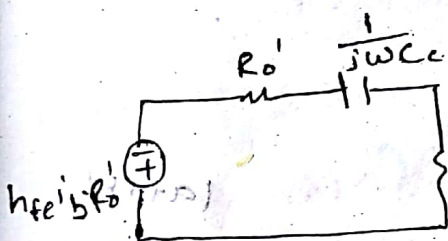
$$\frac{V_o}{V_i} = A_{v_{mid}} = \frac{-h_{fe} i_b R_o' R_i'}{b i_{in} (R_i' + R_o') V_i} \quad \text{--- (1)}$$

voltage gain for low freq. Range:-

At low freq. Range Coupling Capacitor is given as

$$X_c = \frac{1}{2\pi f C_c}$$

equivalent ckt given as.



Apply ~~V_i~~ ~~target~~

voltage Division Rule we get

$$V_o = (-h_{fe} i_b R_o') \cdot \frac{R_i'}{R_i' + (R_o' + \frac{1}{jwC_c})}$$

$$A_{v(low)} = \frac{V_o}{V_i} = \frac{-h_{fe} i_b R_o' R_i'}{R_i' + R_o' + \frac{1}{jwC_c}} \cdot \frac{1}{V_i}$$

$$= \frac{A_{v_{mid}} (R_i' + R_o')}{R_i' + R_o' + \frac{1}{jwC_c}} \quad \text{from eq. (1)}$$

$$A_{v(\text{low})} = \frac{A_{v\text{mid}}}{1 + \frac{j}{j\omega C_c (R_o' + R_i')}} = \frac{A_{v\text{mid}}}{1 - \frac{j}{\omega C_c (R_o' + R_i')}} = \frac{A_{v\text{mid}}}{1 - \frac{j}{2\pi f C_c (R_o' + R_i')}} = \frac{A_{v\text{mid}}}{1 - \frac{j}{f/f_L}}$$

Let $f_L = f_{\text{lower cut off freq}} = \frac{1}{2\pi C_c (R_o' + R_i')}$

$$A_{v\text{low}} = \frac{A_{v\text{mid}}}{1 - j\left(\frac{f_L}{f}\right)}$$

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

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

at $f = f_L$

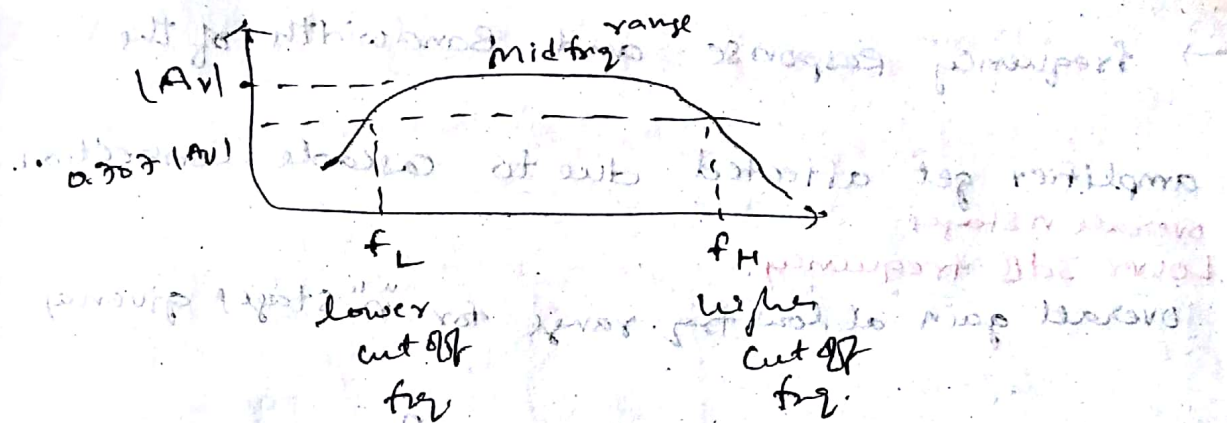
$$|A_{v\text{low}}| = \frac{|A_{v\text{mid}}|}{\sqrt{1 + (1)^2}} = \frac{1}{\sqrt{2}} \cdot |A_{v\text{mid}}|$$

voltage gain at high freq. Range:

$$|A_{v\text{high}}| = \frac{|A_{v\text{mid}}|}{\sqrt{1 + \left(\frac{f}{f_H}\right)^2}}$$

at $f = f_H$

$$|A_{v\text{high}}| = \frac{|A_{v\text{mid}}|}{\sqrt{1 + (1)^2}} = 0.707 A_v$$



at freq. f_L voltage gain drops to 70.7% (3dB)

of voltage gain at mid freq.

at freq. f_H voltage gain drops to 70.7% of voltage gain

$$|A_{v(f_H)}| = \frac{1}{\sqrt{2}} \cdot |A_{v(\text{mid freq})}|$$

Effect of cascading on gain

Effect of cascading on Bandwidth { lower cut off freq.
higher cut off freq.

→ If the number of identical stages are cascaded then overall gain will increase.

$$A_{v(\text{mid})} = A_{v\text{mid}1} \cdot A_{v\text{mid}2} \cdot \dots \cdot A_{v\text{mid}n}$$

$$= |A_{v\text{mid}}|^n$$

Eg: two stages two voltage gain

$$A_{v\text{overall}} = A_{v1} \cdot A_{v2}$$

overall low freq. gain: $|A_{v\text{low}}| = \left| \frac{A_{v\text{mid}}}{\sqrt{1 + (f_L/f)^2}} \right|^n$

high

$$= |A_{v\text{high}}| = \left| \frac{A_{v\text{mid}}}{\sqrt{1 + (f_H/f)^2}} \right|^n$$

→ frequency Response and Bandwidth of the amplifier get affected due to cascade connection.

overall n stages
Lower 3dB frequency:

Overall gain at low freq. range for " n " stages given as

$$(eq.) |A_{v \text{ low}}| = \frac{|A_{v \text{ mid}}|^n}{\sqrt{1 + \left(\frac{f_L}{f}\right)^2}}$$

But at f_L ^{lower} cutoff freq.

$$\left| \frac{A_{v \text{ mid}}}{\sqrt{1 + \left(\frac{f_L}{f}\right)^2}} \right|^n = \frac{1}{\sqrt{2}} \cdot |A_{v \text{ mid}}|^n$$

$$\sqrt{2} = \left[\sqrt{1 + \left(\frac{f_L}{f}\right)^2} \right]^n \quad \text{--- (2)}$$

solve eq (1)

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

Key ~~for~~ ~~the~~

for n stages lower cutoff freq. (f_L) $\frac{f_L}{\sqrt{2^{1/n} - 1}}$

1/y for n stages higher cutoff freq. $f = f_H \cdot \sqrt{2^{1/n} - 1}$

In this way gain, lower cutoff & upper cutoff frequencies are varied i.e. B.W. is also ~~affected~~ ~~changed~~.

- 2) Topics: 1). low freq. Analysis of BJT amplifier
2). Effect of Bypass and Coupling Capacitor.

1). Low freq. Analysis of BJT Amplifier

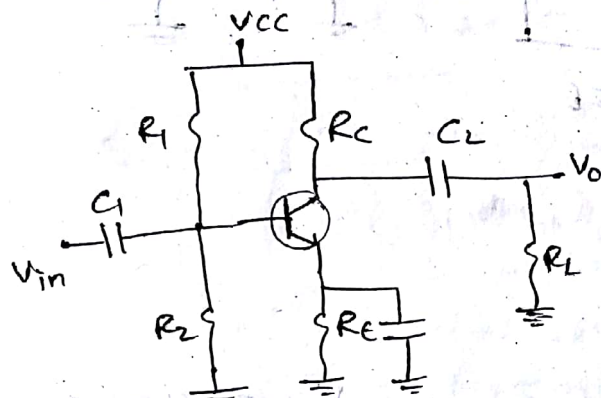
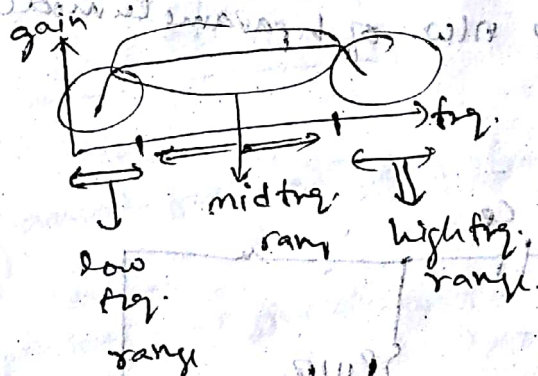


fig: RC coupled common emitter amplifier

→ Amplifier has three RC networks that affect its gain as the freq. reduced below mid freq. range.

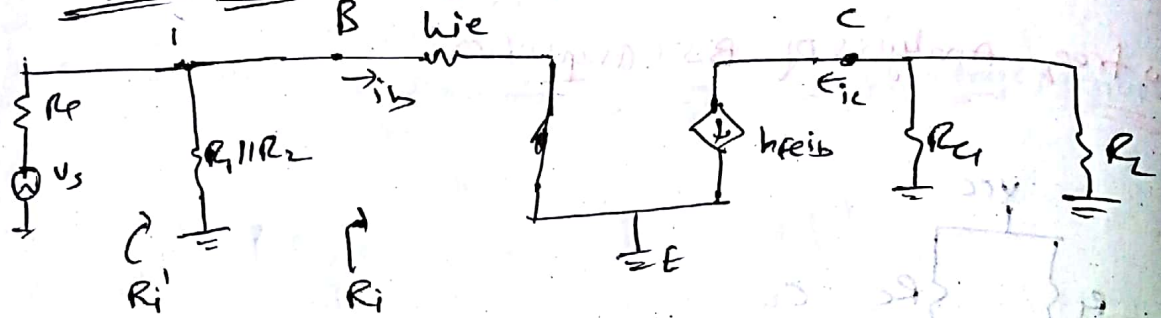


⇒ Three RC networks:

- 1). RC network formed by the input coupling capacitor C_1 and input impedance of the amplifier.
- 2). RC network formed by output coupling capacitor C_2 the resistance looking in at the collector, the load resistance.

3). RC network formed by the emitter bypass capacitor C_E and the resistance looking in at the emitter.

1). Effect of C_E on freq. Response:

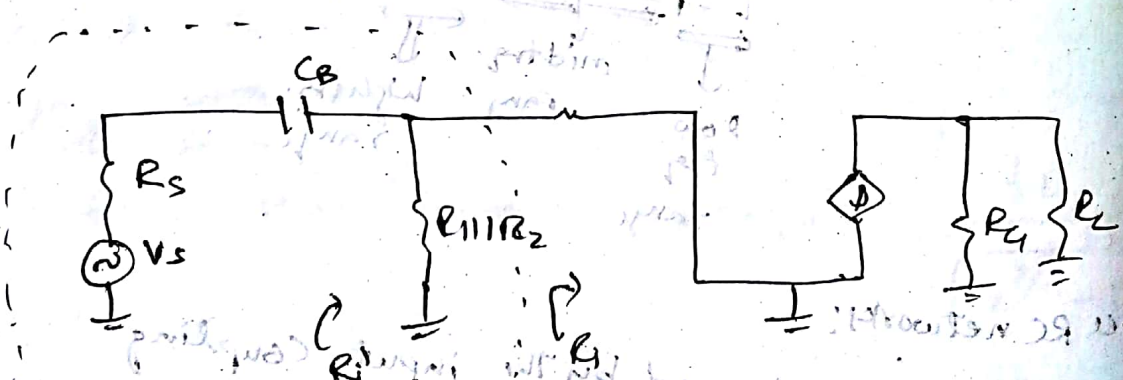


$A_{VS}(\text{Mid freq})$

$$A_{VS} = \frac{A_{V_{mid}} R_i'}{R_i' + R_s} \quad R_i' = R_i \parallel R_1 \parallel R_2$$

Calculation A_{VL} (voltage gain at low freq. region)

Consider i/p n/w of h-parameter model:



$$V_b = v_s \left[\frac{R_i'}{R_i' + R_s + \frac{1}{j\omega C_E}} \right]$$

from eq. ①

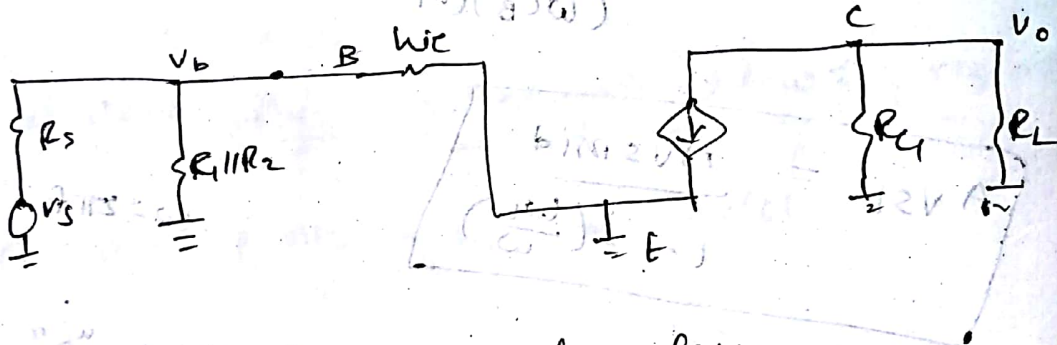
$$W_L = \frac{1}{(R_i + R_s)(C_B)}$$

$$2\pi f_L = W_L$$

$$f_c = \frac{1}{2\pi (R_i + R_s)(C_B)}$$

f_c critical freq. due to effect of C_B = Blocking Capacitor.

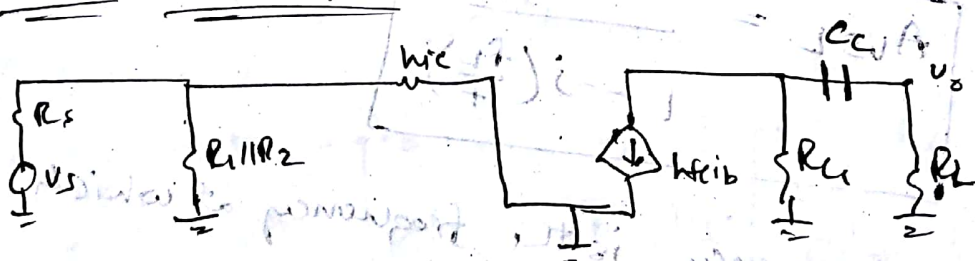
2) Effect of C_C on freq. Response of amplifier.



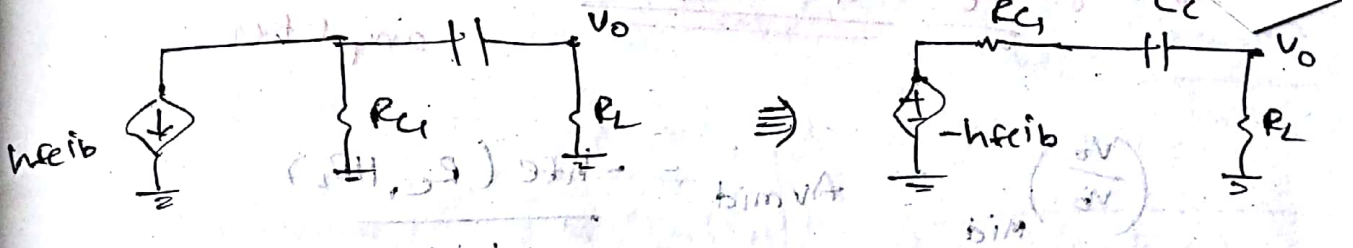
consider ~~operator~~ h-parameter model.

$$\left(\frac{V_o}{V_b}\right)_{mid} = A_{v_{mid}} = \frac{-h_{fe} (R_C || R_L)}{h_{ie}}$$

consider C_C at o/p n/w:



o/p
consider n/w:



voltage Division rule:

$$V_o = (-hfe i_b) \left(\frac{R_L}{R_L + R_C + \frac{1}{j\omega C_C}} \right)$$

$$= \frac{-hfe i_b}{R_L + R_C} \left(\frac{R_L}{1 + \frac{1}{j\omega C_C (R_L + R_C)}} \right)$$

$R_i = h_i$

substitute $\frac{V_b}{i_b} = h_{ie}$

$$\frac{V_o}{V_b} = \frac{A_{v_{mid}}}{1 + \frac{1}{j\omega C_C (R_L + R_C)}} = \frac{A_{mid}}{1 - \frac{j}{\omega C_C (R_L + R_C)}}$$

$$A_{vL} = \frac{A_{v_{mid}}}{1 - j\left(\frac{\omega_L}{\omega}\right)}$$

$$A_{vL} = \frac{A_{mid}}{1 - j\left(\frac{f_L}{f}\right)}$$

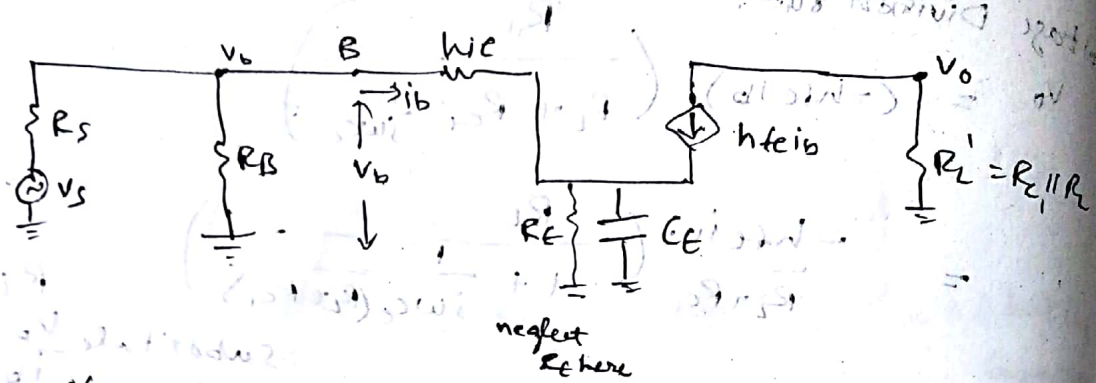
$$\left| \frac{A_{vL}}{A_{mid}} \right| = \frac{1}{\sqrt{1 + \left(\frac{f_L}{f}\right)^2}}$$

$$f_L = \frac{1}{2\pi(R_L + R_C)(C_C)}$$

f_L = critical freq. due to effect of C_C capacitor

3). Effect of C_E (Bypass capacitor) on freq. Response of amplifier:

$$\left(\frac{V_o}{V_b}\right)_{mid} = A_{vmid} = \frac{-h_{fe}(R_C \parallel R_L)}{h_{ie}}$$



$$V_o = -h_{fe} \cdot i_b \cdot R_L'$$

KVL at i/p loop

$$-V_b + h_{ie} i_b + i_b (1 + h_{fe}) (R_E \parallel \frac{1}{j\omega C_E}) = 0$$

then voltage gain (V_o/V_b):

$$V_o = -h_{fe} i_b \cdot R_L'$$

$$V_o = -h_{fe} \cdot R_L' \cdot \left(\frac{V_b}{h_{ie} + (1 + h_{fe}) (R_E \parallel \frac{1}{j\omega C_E})} \right)$$

$$= -h_{fe} \cdot R_L' \cdot \left(\frac{V_b}{h_{ie} + (1 + h_{fe}) (\frac{1}{j\omega C_E})} \right)$$

$$\frac{V_o}{V_b} = \frac{A_{vmid}}{1 + \frac{(1 + h_{fe})}{j\omega C_E (h_{ie} + (1 + h_{fe}) (\frac{1}{j\omega C_E}))}}$$

$$\frac{V_o}{V_b} = \frac{A_{vmid}}{1 - j \frac{(1 + h_{fe})}{\omega (h_{ie} + (1 + h_{fe}) (\frac{1}{j\omega C_E}))}}$$

$$A_{VLS} = \frac{A_{vmid}}{1 - j\left(\frac{\omega L}{\omega}\right)}$$

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

$$\left| \frac{A_{VLS}}{A_{vmid}} \right| = \frac{1}{\sqrt{1 + \left(\frac{f_L}{f}\right)^2}}$$

$$f_L = \frac{(1+h_{fe})}{2\pi(h_{fe})(C_C)}$$

Critical freq. due to C_C effect

Due to C_B, C_C, C_E we obtained three different

critical freq. It is not necessary that all these freq. ~~may~~ should be equal. The n/w, which has higher critical freq. than other two n/w is called dominant n/w. The dominant n/w determines the freq. at which the overall gain of the amplifier begin to drop at -20dB/decade.

eg: $\left| \frac{A_{Vlow}}{A_{vmid}} \right| = \frac{1}{\sqrt{1 + \left(\frac{f_L}{f}\right)^2}}$

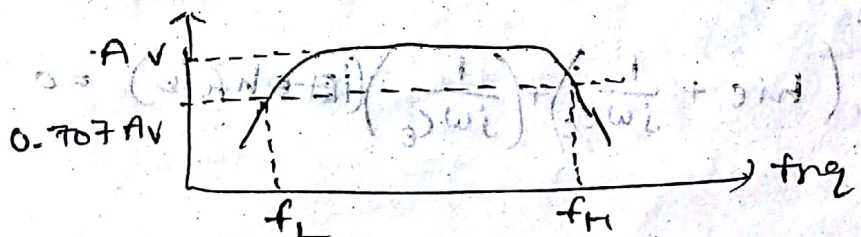
At $f = f_L$

$$\left| \frac{A_{Vlow}}{A_{vmid}} \right| = \frac{1}{\sqrt{1 + \left(\frac{f_L}{f_L}\right)^2}}$$

$$= \frac{1}{\sqrt{2}} = 0.707$$

$$= 70.7\%$$

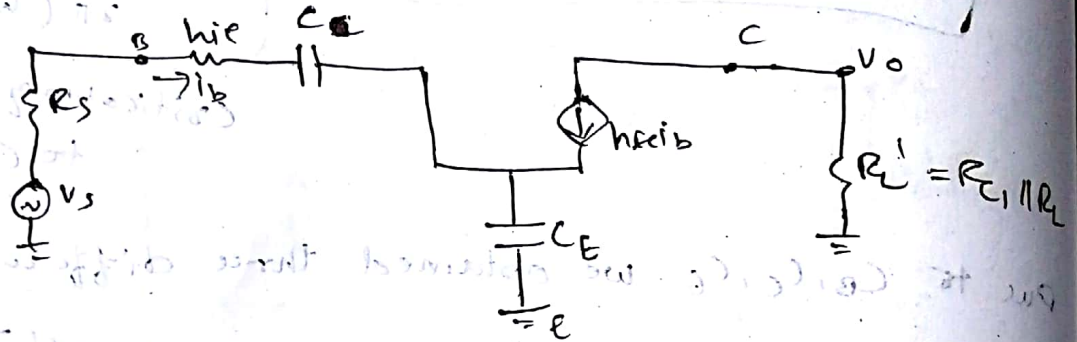
$$= -3dB$$



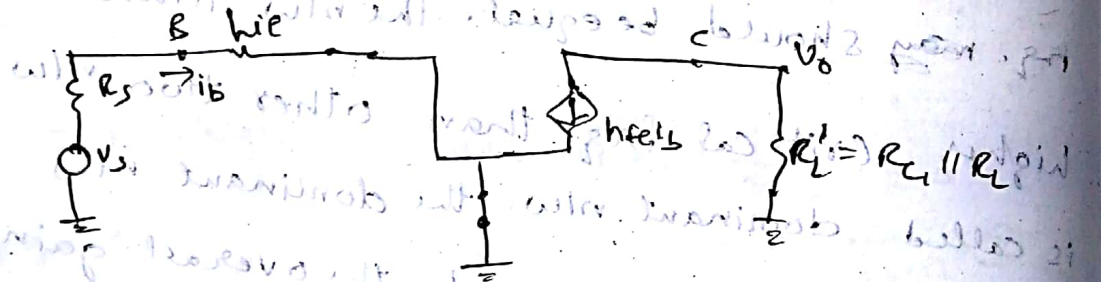
Analysis of Effect of Coupling & Bypass Capacitor

Consider Both Coupling Capacitor

Bypass Capacitor

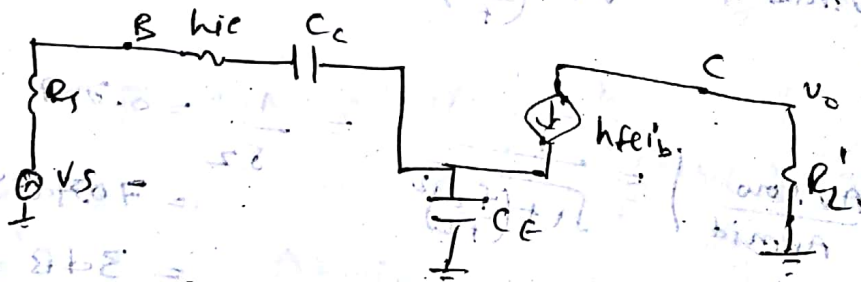


At mid Band freq.



$$\frac{V_o}{V_s} = \frac{-h_{fe} i_b R_L'}{(R_s + h_{ie}) i_b} = \frac{-h_{fe} R_L'}{(R_s + h_{ie})}$$

At low freq:



$$-V_s + i_b \left(h_{ie} + \frac{1}{j\omega C_c} \right) + \left(\frac{1}{j\omega C_E} \right) (i_b + h_{fe} i_b) = 0$$

$$V_s = i_b \left(R_s + h_{ie} + \frac{1}{j\omega C_c} + \frac{1+h_{fe}}{j\omega C_E} \right)$$

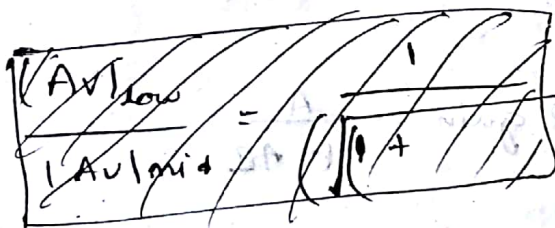
$$\frac{1}{C_{eq}} = \frac{1}{C_c} + \frac{1}{C_E}$$

~~$V_s = i_b \left(R_s + h_{ie} + \frac{1}{j\omega C_{eq}} \right)$~~

$$\left. \frac{V_o}{V_s} \right|_{\text{at low } f} = \frac{-h_{fe} i_b R_L'}{i_b \left(R_s + h_{ie} + \frac{1}{j\omega C_{eq}} \right)}$$

$$= \frac{-h_{fe} i_b R_L'}{(R_s + h_{ie}) \left(1 + \frac{1}{j\omega C_{eq} (R_s + h_{ie})} \right)}$$

$$\left. \frac{V_o}{V_s} \right|_{\text{at low } f} = \frac{|A_{v, \text{mid}}|}{1 + \frac{1}{j\omega C_{eq} (R_s + h_{ie})}} = \frac{|A_{v, \text{mid}}|}{1 - j \left(\frac{1}{\omega C_{eq} (R_s + h_{ie})} \right)}$$



$$\omega_L = \frac{1}{C_{eq} (R_s + h_{ie})}$$

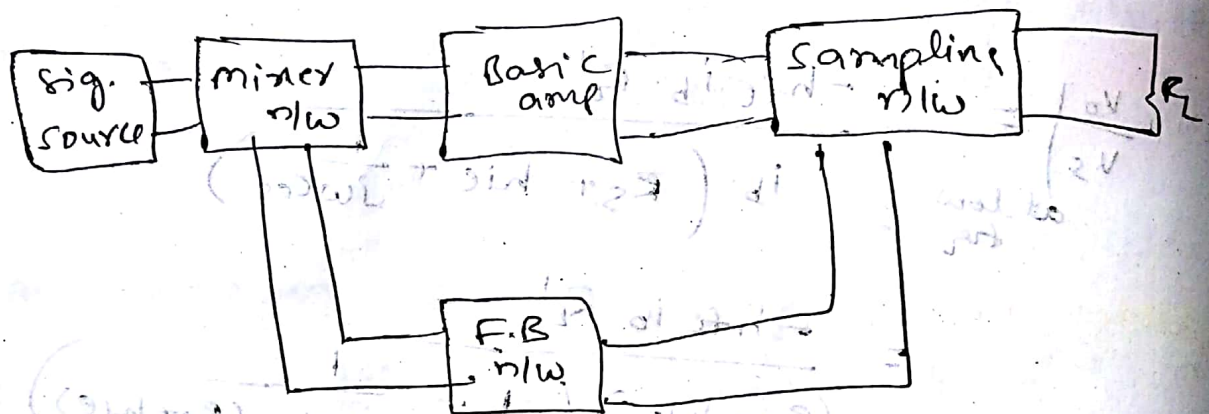
$$\frac{|A_{v, \text{low}}|}{|A_{v, \text{mid}}|} = \frac{1}{1 - j \left(\frac{\omega_L}{\omega} \right)}$$

$$\left| \frac{A_{v, \text{low}}}{A_{v, \text{mid}}} \right| = \left| \frac{1}{1 - j \left(\frac{f_L}{f} \right)} \right| = \frac{1}{\sqrt{1 + \left(\frac{f_L}{f} \right)^2}}$$

Feed back amplifiers & Oscillators.

feed back.

feed back is the process in which a portion of ampl. o/p is given to the i/p det.



Prig. of feed back amplifier

Barkhausen criteria $|AB|=1$ & 360° loop phase difference

-ve FB closed loop voltage gain = $\frac{A}{1+AB}$

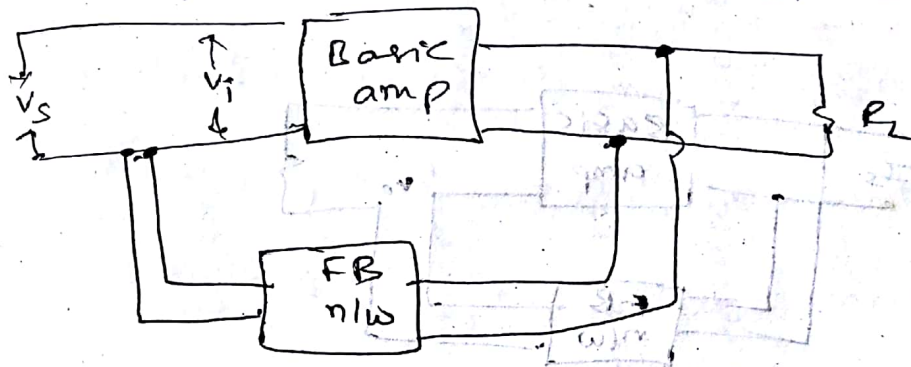
+ve FB

closed loop vol. gain = $\frac{A}{1-AB}$

four types of F.B. amplifiers:

- (i). Voltage series F.B.
- (ii). Voltage shunt FB
- (iii). Current series F.B.
- (iv). Current shunt FB

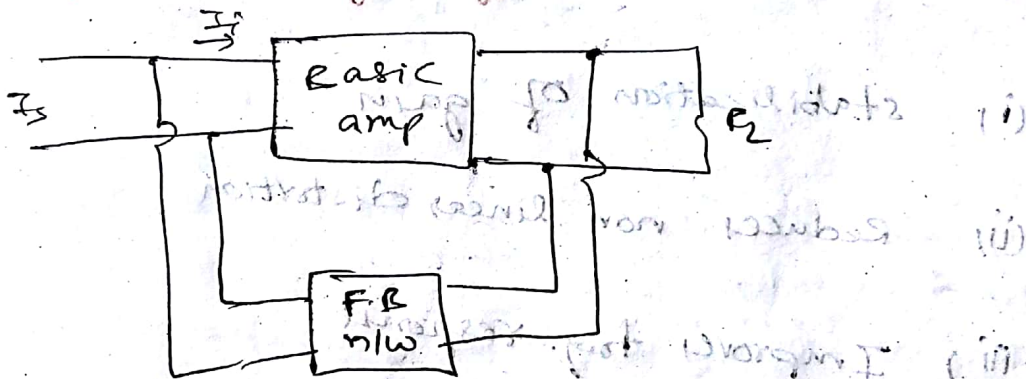
Voltage Series FB: *positive feedback*



$$R_{if} = R_i (1 + AB)$$

$$R_{of} = \frac{R_o}{1 + AB}$$

Voltage Shunt F.B: *negative feedback*

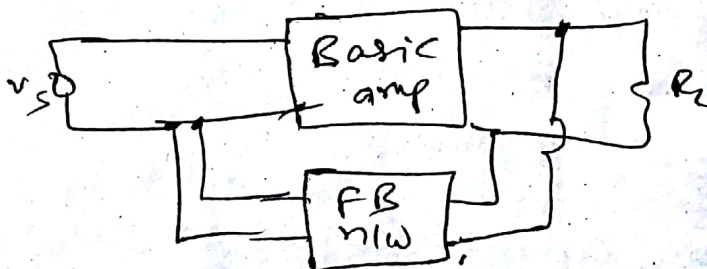


$$B = \frac{I_f}{V_o}$$

$$R_{if} = \frac{R_i}{1 + AB}$$

$$R_{of} = \frac{R_o}{1 + AB}$$

Current Series F.B: *negative feedback*

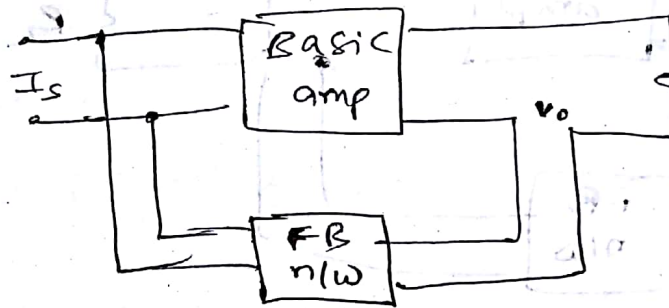


$$B = \frac{V_f}{I_o}$$

$$R_{if} = R_i (1 + AB)$$

$$R_{of} = R_o (1 + AB)$$

Current Shunt F.B. Amp.



$$B = \frac{I_f}{I_o}$$

$$R_{if} = \frac{R_i}{1+AB}$$

$$R_{of} = R_o (1+AB)$$

General Characteristics & effects of -ve FB.

- (i) stabilization of gain
- (ii) Reduces non linear distortion
- (iii) Improves freq. response
- (iv) Changes in o/p impedance
- (v) Increases stability

Distortion with FB $D_{vf} = \frac{D}{1+AB}$

Types of -ve FB amplifier

Improved Characteristics

Representative

B.W.

Nonlinear Distortion

Noise Transmission

Overall gain

	A _v	Incres	Decrese	Decrese	Decrese
1) Voltage series FB	Voltage FB amp				
2) Current series FB	Trans Conductance amp	Incres	Decrese	Decrese	Decrese
3) Current shunt FB	Current amp	Incres	Decrese	Decrese	Decrese
4) Voltage shunt FB	Transmitt amp	Incres	Decrese	Decrese	Decrese

Oscillators:

→ An oscillator is an electric ckt which uses a positive f.b. & generates o/p which oscillates with const. amp at desired freq.

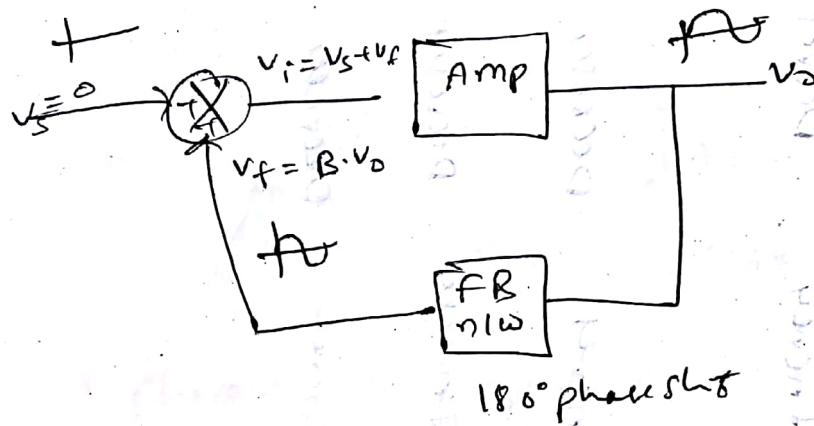


fig: Oscillator fB amp.

Classification oscillators:

According to:

1. Nature of a waveform generated

- (i) sinusoidal oscillators.
- (ii) non sinusoidal.

2. According to fundamental mechanism

- (i) Negative Res. Oscillator
- (ii) feedback oscillator

3. According to freq. generated.

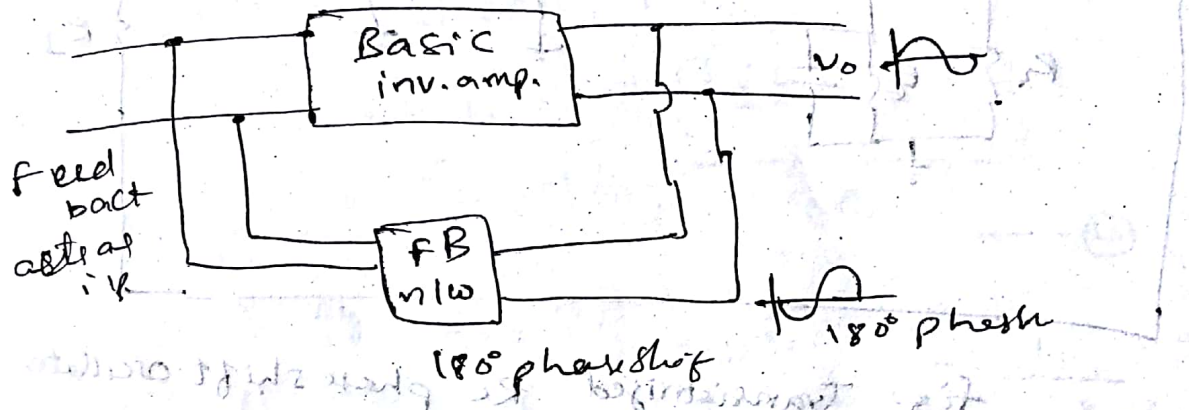
- (i) Audio freq. oscillator
- (ii) Radio freq. oscillator

4. According to circuit components.

- (i) RC
- (ii) LC oscillator
- (iii) Crystal

Conditions for oscillations: Basic

→ In +ve FB the o/p signal & FB signal must be in phase. Then the FB n/w must introduce a phase shift of 180° while FB the voltage from o/p to i/p.



Block diag. of oscillator

$$V_f = -A V_i B$$

$$V_i = V_f$$

$$-AB = 1$$

$$|AB| = 1$$

Barkhausen criteria

⇒ There are two conditions to work the ckt as oscillator.

1). total phase shift around loop is 360° .

2). $|AB| = 1$ i.e. magnitude of the product of open loop gain,

RC phase shift oscillator:

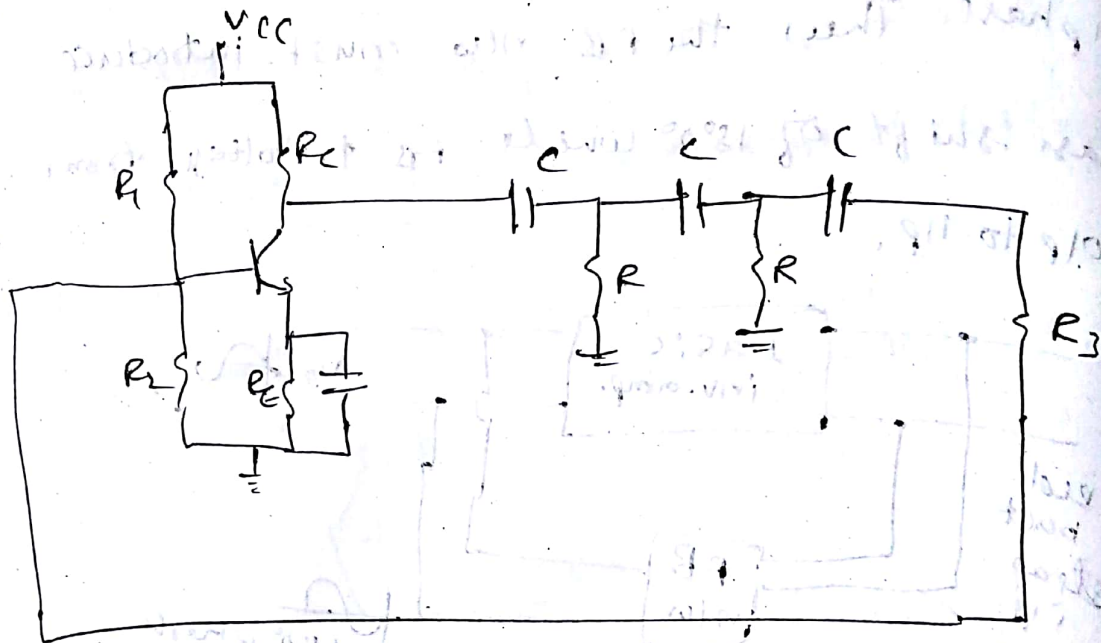


fig: Transistorized RC phase shift oscillator.

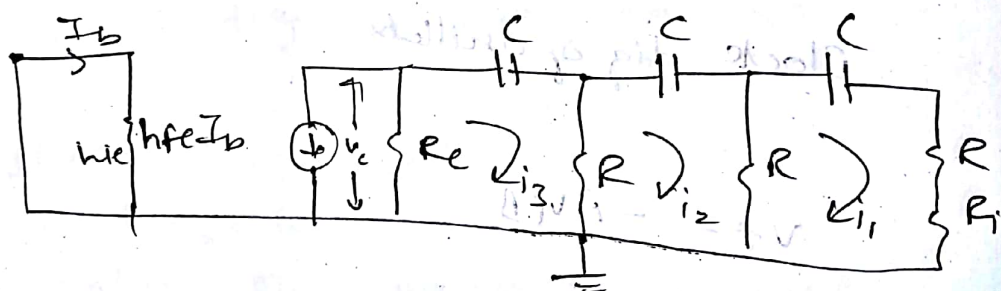


fig: equivalent ckt of RC phase shift oscillator

loop 1:

$$(i_3 + i_c)R_c + i_3 \cdot \frac{1}{j\omega C} + (i_3 - i_2)R = 0 \quad \text{--- (1)}$$

loop 2:

$$(i_2 - i_3)R + i_2 \left(\frac{1}{j\omega C} \right) + (i_2 - i_1)R = 0 \quad \text{--- (2)}$$

loop 3

$$(i_1 - i_2) \cdot R + i_1 \cdot \frac{1}{j\omega C} + i_1 \cdot R = 0 \quad (3)$$

from eq. (3).

$$i_1 \cdot R - i_2 \cdot R + \frac{i_1}{j\omega C} + i_1 \cdot R = 0$$

$$i_2 = i_1 \left[\frac{2R + \frac{1}{j\omega C}}{R} \right] \quad (4)$$

$$i_3 = 3i_1 + \frac{4i_1}{j\omega CR} - \frac{i_1}{\omega^2 C^2 R^2} \quad (5)$$

Substitute (4) & (5) in eq. (1) we get.

$$-i_C R_C = \left[3i_1 + \frac{4i_1}{j\omega CR} - \frac{i_1}{\omega^2 C^2 R^2} \right] \left[R_C + \frac{1}{j\omega C} + R \right]$$

$$-i_C = \frac{i_1}{R_C} \left[3R_C - \frac{R_C}{\omega^2 C^2 R^2} + R - \frac{5}{\omega^2 C^2 R} + \frac{4R_C}{j\omega CR} + \frac{6}{j\omega C} - \frac{1}{j\omega^3 C^3 R^3} \right]$$

equating imag. terms to zero

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

$$\frac{k \cdot h_{fe}}{4k^2 + 23k + 29} = 1$$

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

To obtain min. value of h_{fe} $\frac{d h_{fe}}{d k} = 0$

$$\frac{d \left[4k + 23 + \frac{29}{k} \right]}{d k} = 0$$

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

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

$$k = 2.6925$$

→ for minimum h_{fe} value " k " must be equal

to 2.6925

$$(h_{fe})_{min} = 4(2.6925) + 23 + \frac{29}{2.6925}$$

$$= 10.77 + 23 + 10.77$$

$$(h_{fe})_{min} = 44.34$$

Wien bridge oscillator:

→ This oscillator uses two stage RC coupled C.E. amp. with one RC bridge is called Wien bridge oscillator n/w. which is used to provide F.B.

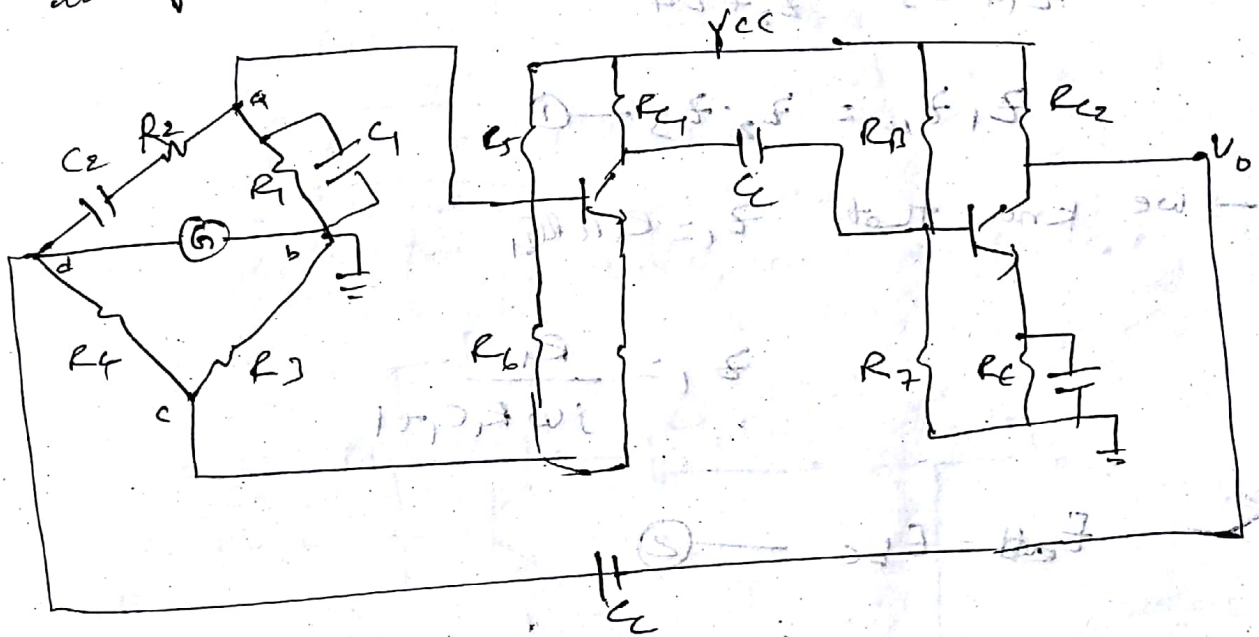


fig: Wien bridge oscillator.

→ under balanced condition the galvanometer is open ckt. i.e. no current flows through the galvanometer.

i.e. under balanced condition

$$I_1 = I_3$$

$$I_2 = I_4$$

from fig.

$$E_{ab} = E_{ad}$$

$$E_{cd} = E_{bc}$$

$$\rightarrow E_{ab} = E_{ad} \quad \text{--- (1)}$$

$$I_1 z_1 = I_2 z_2$$

$$\frac{E}{z_1 + z_3} \cdot z_1 = \frac{E}{z_2 + z_4} \cdot z_2$$

$$\frac{z_1}{z_1 + z_3} = \frac{z_2}{z_2 + z_4}$$

$$z_1 z_4 = z_2 z_3 \quad \text{--- (1)}$$

→ we know that $z_1 = R_1 \parallel R_4$

$$z_1 = \frac{R_1}{j\omega R_1 C_1 + 1}$$

$$E_{ad} = E_{bc} \quad \text{--- (2)}$$

$$I_4 z_4 = \left(R_2 + \frac{1}{j\omega C_2} \right) I_3$$

$$\left(\frac{R_1}{j\omega R_1 C_1 + 1} \right) R_4 = \left(R_2 + \frac{1}{j\omega C_2} \right) I_3$$

$$- \frac{R_1 R_4}{R_3} + R_2 + j\omega R_1 R_2 C_1 + \frac{1}{j\omega C_2} + \frac{R_1 C_1}{j\omega C_2} = 0$$

equaling imag. term to zero

$$j\omega R_1 R_2 C_1 + \frac{1}{j\omega C_2} = 0$$

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

Condition for max. oscillation.

To get max. oscillation, we get equate real part to zero.

$$-\frac{R_1 R_4}{R_3} + R_2 + \frac{R_1 C_1}{C_2} = 0$$

$$\text{If } R_1 = R_2 = R$$

$$C_1 = C_2$$

$$R_4 = 2R_3$$

LC Oscillator: Hartley & Colpitts Oscillator:

Hartley Oscillator:-

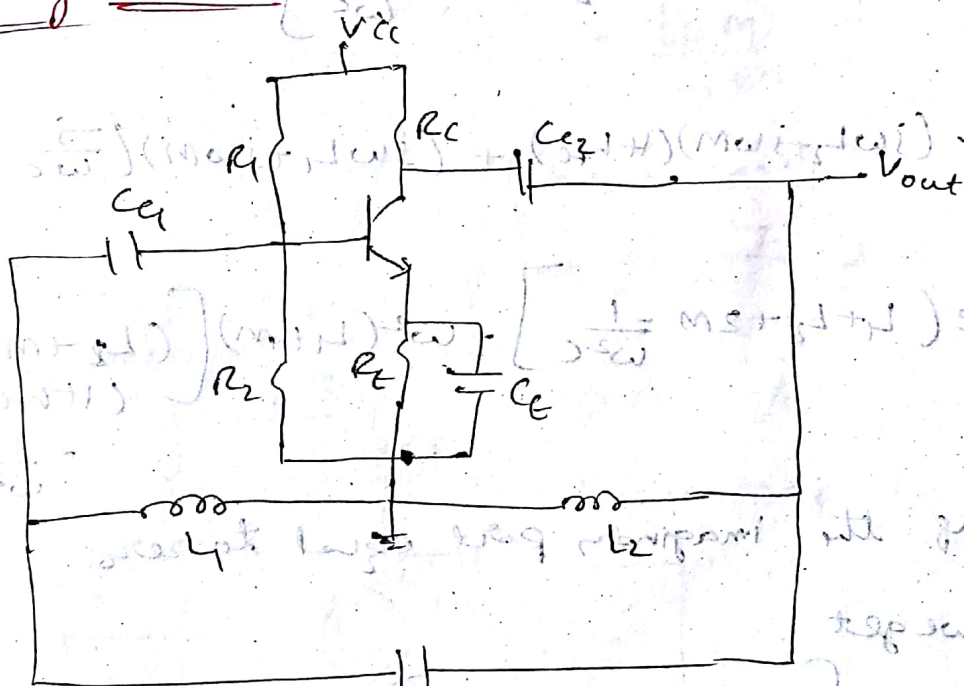


fig: Hartley oscillator

→ In the Hartley oscillator Z_1 & Z_2 are inductive reactances & Z_3 is the capacitive reactance. Suppose M is the mutual inductance b/w the inductor then

$$Z_1 = j\omega L_1 + j\omega M$$

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

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

Substituting these values in general eq.

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

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

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

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

equating the imaginary part equal to zero

we get

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

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

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

Condition for Sustain

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

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

$$= \frac{L_1 + L_2 + 2m}{L_2 + m}$$

$$= (L_1 + m) \times (L_2 + m)$$

$$= \frac{L_1 + m}{L_2 + m}$$

$$h_{fe} = \frac{L_1 + m}{L_2 + m}$$

Colpitts oscillator:-

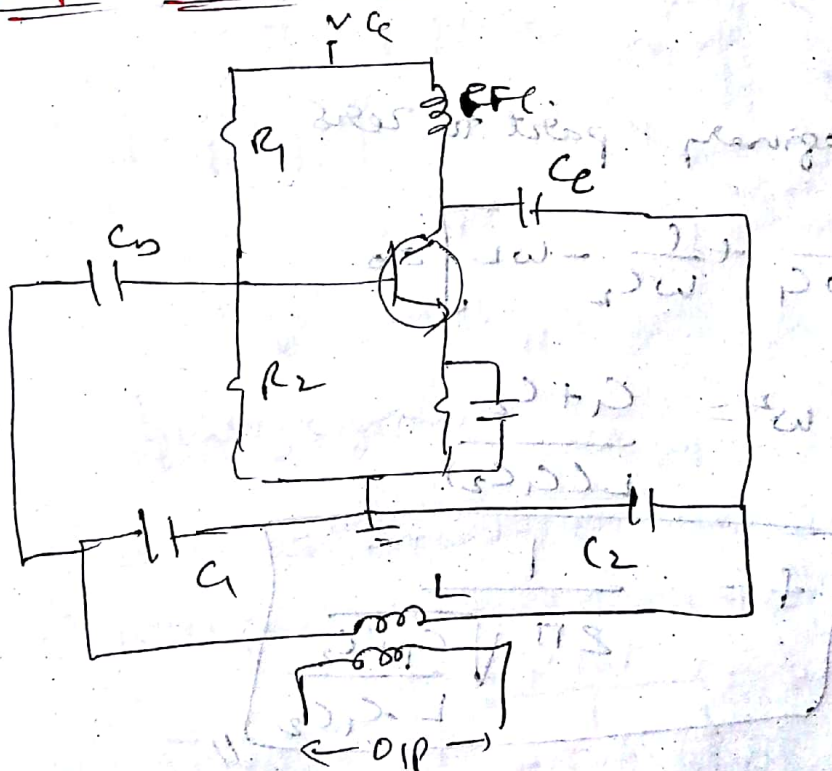


fig: Colpitts oscillator

we know

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

$$z_1 = \frac{1}{j\omega C_1} \quad \text{--- (1)}$$

$$z_2 = \frac{1}{j\omega C_2} \quad \text{--- (2)}$$

$$z_3 = j\omega L \quad \text{--- (3)}$$

sub (1)(2)(3) in above equation we get

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

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

equating imaginary part to zero

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

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

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

Condition for sustained oscillations:

By equating real part to zero

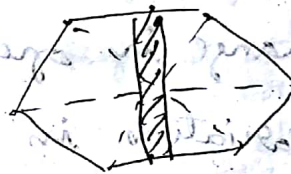
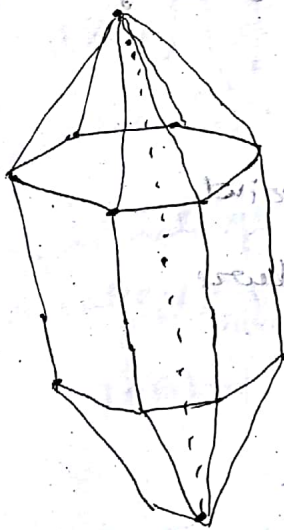
$$\frac{1 + hfe}{\omega^2 C_1 C_2} - \frac{L}{C_1} = 0$$

$$1 + hfe = \frac{L \omega^2 C_1 C_2}{C_1}$$

$$hfe = \frac{C_2}{C_1}$$

Crystal Oscillator:

→ A crystal oscillator is a tuned circuit oscillator using a piezoelectric crystal



quartz crystal

→ X axis cut known as electrical cut

Y axis cut is mechanical cut

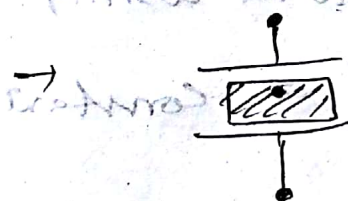
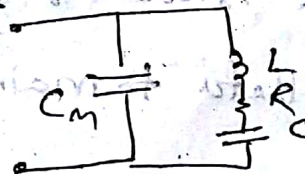


fig: crystal



equivalent ckt.

Series Resonant freq.

$$X_L = X_C$$

$$\omega L = \frac{1}{\omega C}$$

$$\omega^2 LC = 1$$

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

Stability of Oscillator:

→ Two types of stability: (1) Frequency stability

(2) Amplitude stability

→ Frequency stability can be changed by the

following factors.

(i) change in operating point

(ii) variation in temperature

(iii) Due to power supply

(iv) change in o/p load.

(v) change in internal element
Capacitance.

Amplitude stability:

→ Amplitude stability refers to the ability of the oscillator to maintain a constant

→ Amplitude in the O/P wave form. The more

• Const. amp. of the O/P wave form the better the ampl. stability

→ If $|AB| > 1$ the Amplitude stability is not stable.
 $|AB| < 1$

$|AB| > 1$ the Amplitude stability is not stable.
 $|AB| < 1$

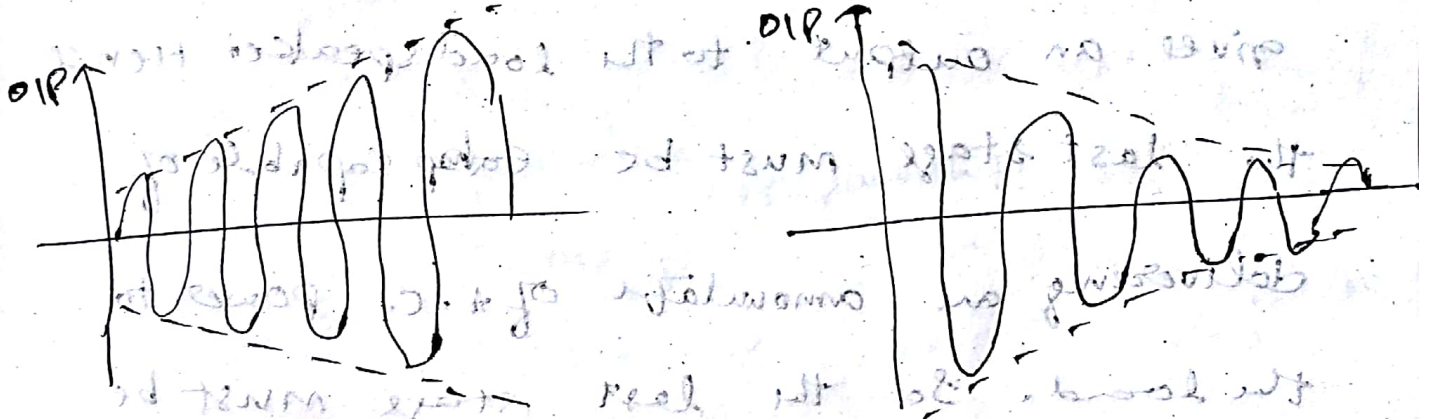
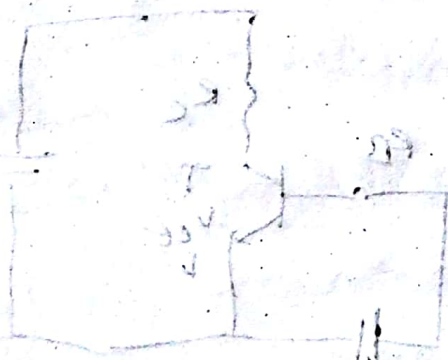
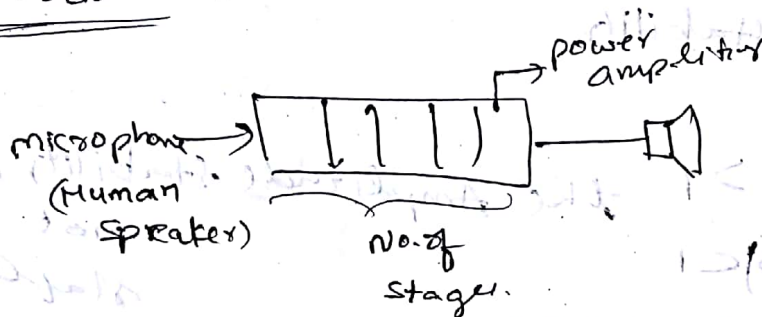


Fig. Amplitude of oscillations are increasing $|AB| > 1$
 Amplitude of oscillations are decreasing $|AB| < 1$



Large signal Amplifiers (or) Power amplifier & Tuned amplifiers

Introduction:



public addressing system

→ It contains multistage amplifier. At last, it gives an output to the load speaker. Hence, the last stage must be capable of delivering an amount of A.C. power to the load. So the last stage must be capable of handling large voltage or large current swings comparatively previous stages.

Load line Concept:

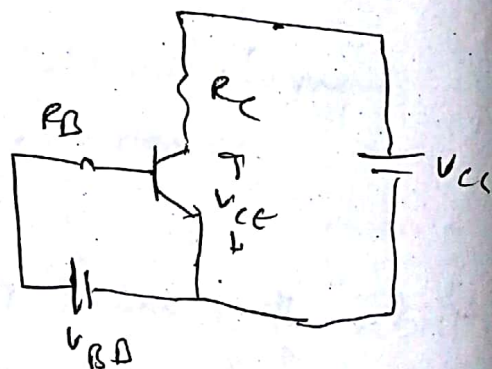
Apply KVL

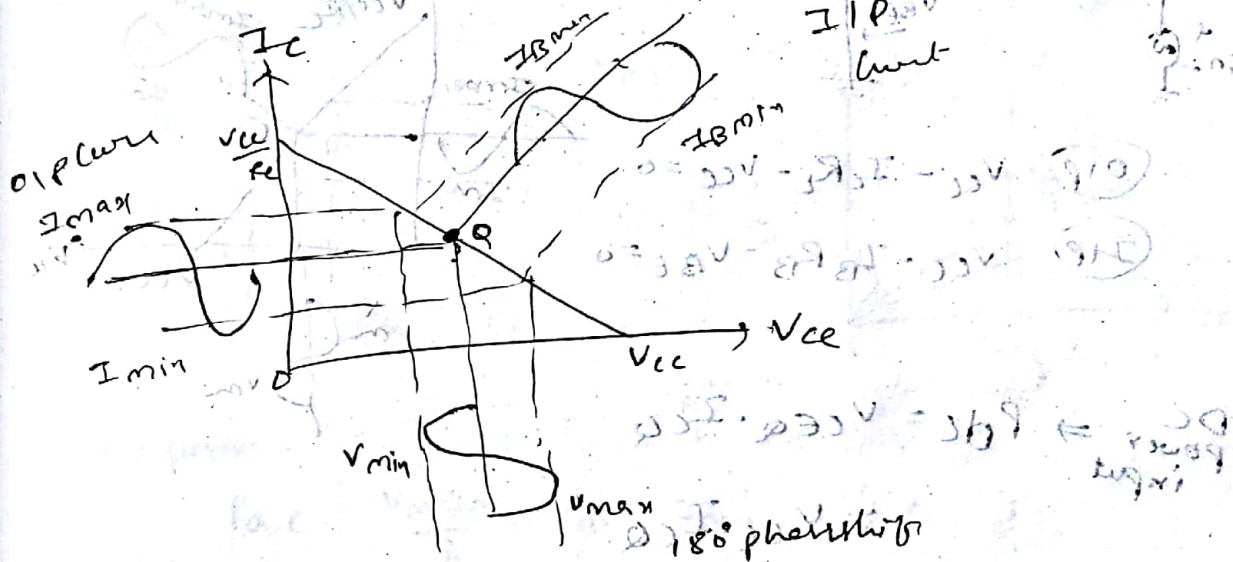
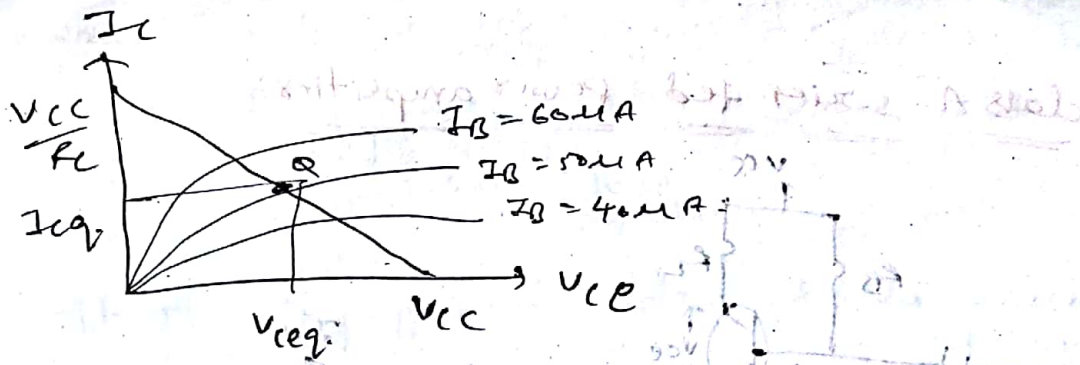
$$V_{CC} - I_C R_C - V_{CE} = 0$$

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

Compare with

$$y = mx + c$$





Classification of power amplifiers:-

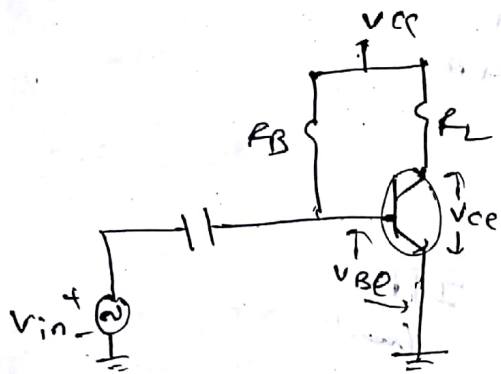
→ Based on the operating point position, analyzing conducting angle the amplifiers are classified as

- (i). class A 360° middle
- (ii). class B 180° cut off
- (iii). class C $< 180^\circ$ below cut off
- (iv). class AB $180^\circ - 360^\circ$ b/w middle & cut off

Note:-

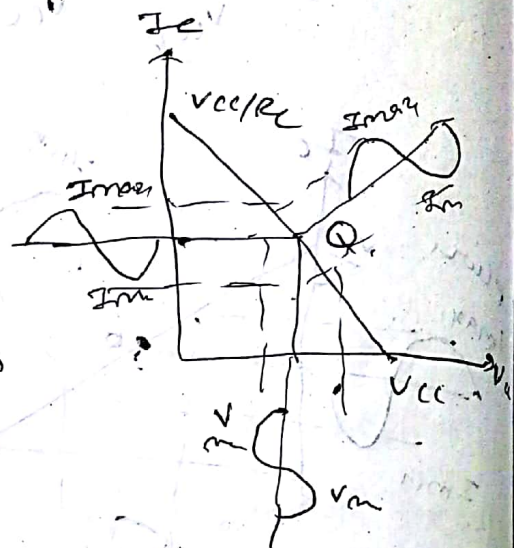
→ The o/p amplitude is amplified by β times
the $I_C = \beta I_B$

class A - series fed power amplifiers:



(OIP) $V_{CC} - I_C R_L - V_{CE} = 0$

(IIP) $V_{CC} - I_B R_B - V_{BE} = 0$



DC power input $\Rightarrow P_{DC} = V_{CEQ} \cdot I_{CQ}$

$= V_{CC} \cdot I_{CQ}$

AC power output $\Rightarrow P_{AC} = V_{rms} \cdot I_{rms}$

$= I_{rms}^2 \cdot R_L$

efficiency $\Rightarrow$

$\eta = \frac{P_{AC}}{P_{DC}} \times 100\%$

$= \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8 \cdot V_{CC} \cdot I_{CQ}} \times 100\%$

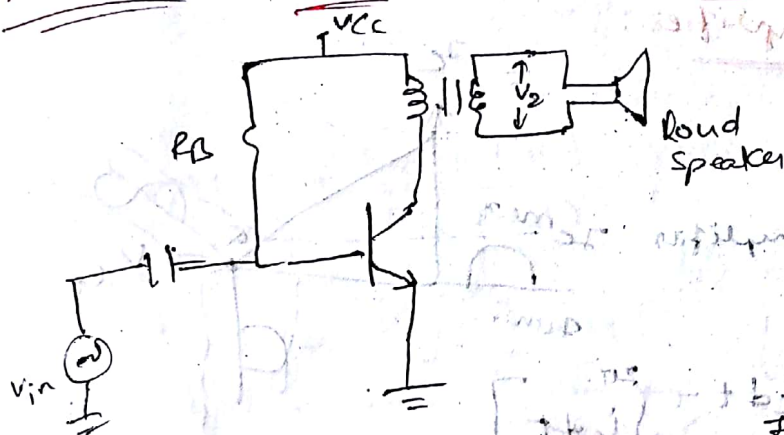
max efficiency $\eta = \frac{(V_{CC} - 0)(2I_{CQ})}{8 \cdot V_{CC} \cdot I_{CQ}} \times 100\%$

$= \frac{1}{4} \times 100\%$

$= 25\%$

$V_{min} = 0$
 $I_{min} = 0$
 $V_{max} = V_{CC}$

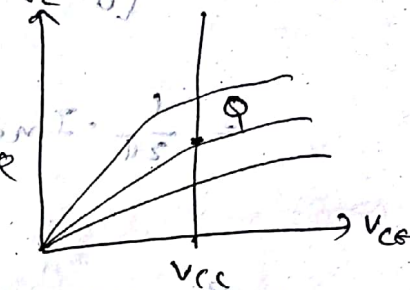
Transformer Coupled class-A power amplifier:



apply KVL.

$$V_{CC} - I_C R_L - V_{CE} = 0$$

$$V_{CEQ} = V_{CC}$$



AC power:

$$P_{ac} = \frac{V_m I_m}{2} = V_{rms} \cdot I_{rms}$$

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

Efficiency: $\eta = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8 \cdot V_{CC} \cdot I_{CQ}}$

$$\eta = \frac{V_m I_m}{V_{CC} I_{CQ}}$$

$$\eta = \frac{(2V_{CC} - 0)(2I_{CQ} - 0)}{8 \cdot V_{CC} \cdot I_{CQ}}$$

$$= \frac{1}{2} \times 100 = 50\%$$

collector efficiency $\eta_c = \frac{P_{out(ac)}}{P_{in(dc)}} \times 100$

Distortion in amplifiers:

Harmonic distortion

Amplitude distortion } $\frac{1^{st} \text{ unit}}{100}$

class B power Amplifier:

for the class B Amplifier from fig.

$$I_{dc} = \frac{1}{2\pi} \left[\int_0^{\pi} i_c dt + \int_{\pi}^{2\pi} i_c dt \right]$$

$$= \frac{1}{2\pi} \cdot I_{max} [-(-1)] = \frac{I_{max}}{\pi} \approx 1.57 I_{max}$$

$$P_{dc} = V_{cc} \cdot \frac{I_{max}}{\pi}$$

$$P_{ac} = V_{cc} \cdot \frac{I_{max}}{4}$$

$$\text{efficiency } \eta = \frac{P_{out(AC)}}{P_{in(dc)}} = \frac{V_{cc} \cdot \frac{I_{max}}{4}}{V_{cc} \cdot \frac{I_{max}}{\pi}}$$

$$= \frac{\pi}{4} = 0.785$$

class B pushpull Amplifier: $\eta = 78.5\%$

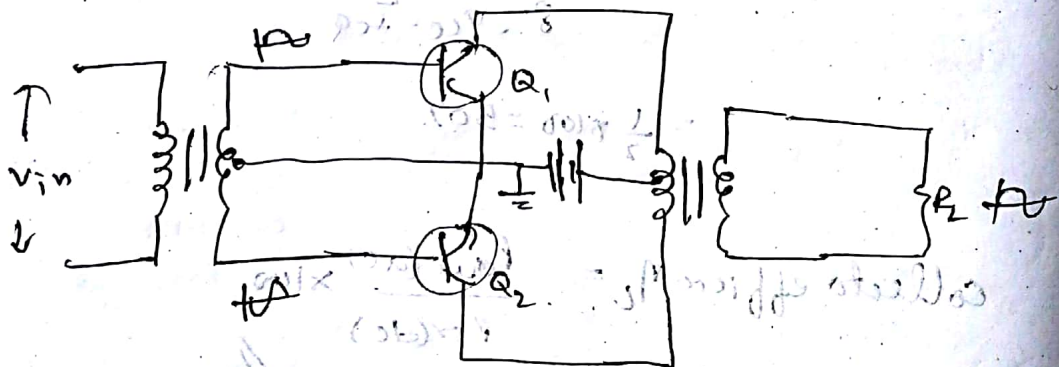


fig: class B pushpull amp.

$$P_{in(dc)} = V_{cc} \cdot I_{dc}$$

$$P_{dc} = \frac{2V_{cc} \cdot I_{max}}{\pi}$$

$$1/4 \quad P_{acmax} = \frac{V_{CC} \cdot I_{max}}{2}$$

$$\eta = \frac{P_{out} (AC)}{P_{in} (DC)}$$

$$= \frac{V_{CC} \cdot I_{max}}{2}$$

$$= \frac{V_{CC} \cdot I_{max}}{2 V_{CC} \cdot I_{max} \cdot \frac{\pi}{4}}$$

$$= 78.5\%$$

Complementary Symmetry class B pushpull amplifiers:

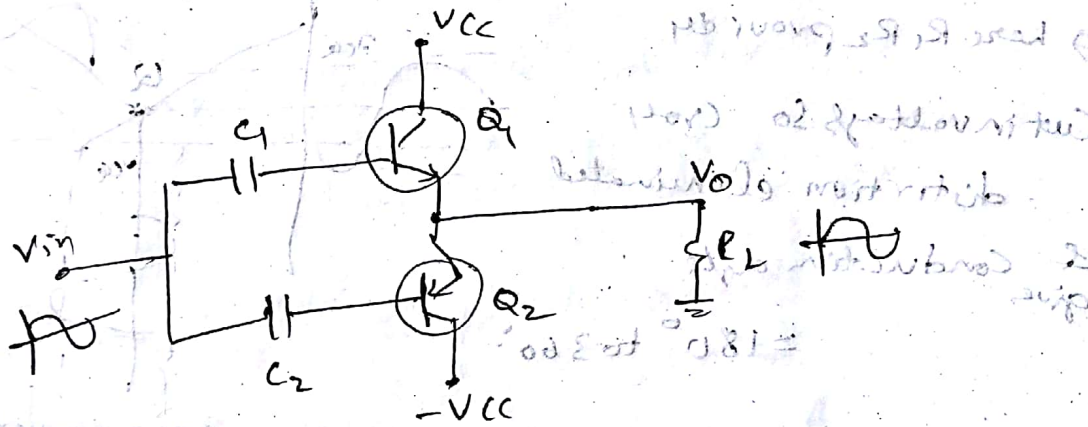
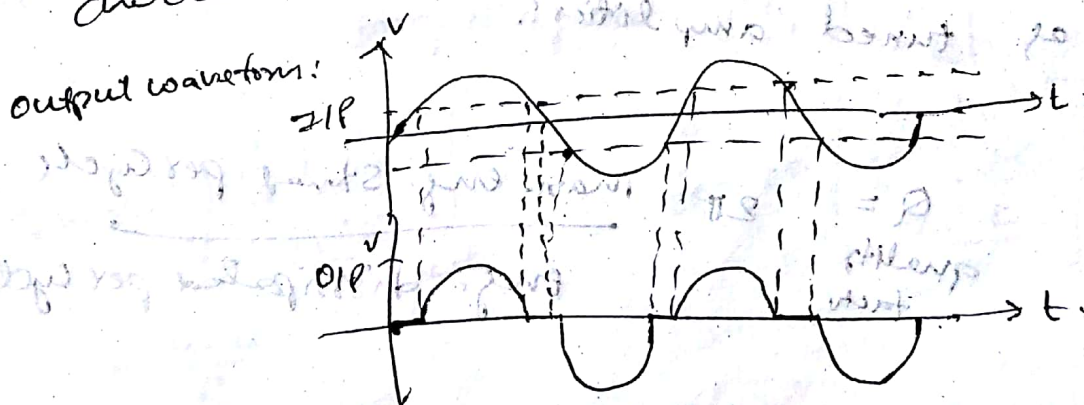


fig: Complementary Sym. pushpull amp.

In Complementary Symmetry two Complementary transistors (PNP, NPN) transistors are used but have some characteristic features and so they are symmetry.



class AB power amplifiers:

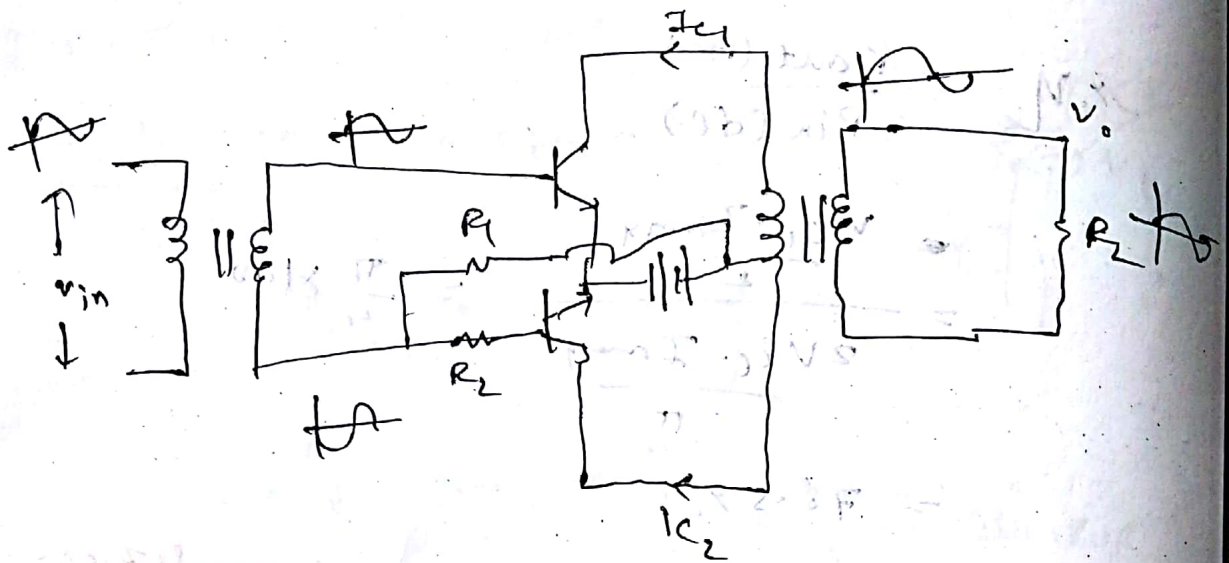
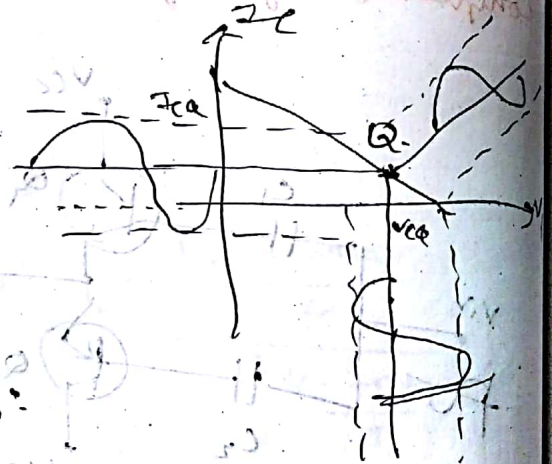


fig: class AB power amplifiers

→ here R_1, R_2 provide

Cut in voltages so cross
distortion eliminated
& conduction angle
give

$$= 180^\circ \text{ to } 360^\circ$$



$$\text{efficiency} = 50 - 78.5\%$$

IP & OP wave

Tuned amplifiers

→ The amplifiers that amplify a particular frequency and reject other freq. are termed as tuned amplifiers.

$$Q = \frac{2\pi \cdot \text{max. enrg. stored per cycle}}{\text{enrg. dissipated per cycle}}$$

quality factor

Tuned amplifier

Small signal

Large signal

Tuned amplifier

amplifier.

Single tuned amplifiers

Double tuned amplifiers

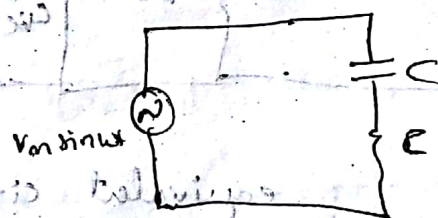
staggered tuned amplifier

Capacitance coupled

Transformer coupled (or)

Inductively coupled.

Q factor of RL & RC ckt:



$$Q = 2\pi \left[\frac{\text{maximum eng. stored per cycle}}{\text{eng. dissipated per cycle}} \right]$$

$$Q = 2\pi \left[\frac{\frac{1}{2} L I_m^2}{\frac{I_m^2 R}{2f}} \right]$$

$$= \frac{\omega \cdot L}{R}$$

$$\boxed{Q = \frac{X_L}{R}}$$

$$Q = 2\pi \left[\frac{\frac{1}{2} \cdot \frac{I_m^2}{\omega^2 C}}{\frac{I_m^2 R}{2f}} \right]$$

$$= \frac{1}{\omega C R}$$

$$\boxed{Q = \frac{X_C}{R}}$$

C.E. Single tuned Capacitively coupled

Amplifier with Tuned ckt in the o/p side:

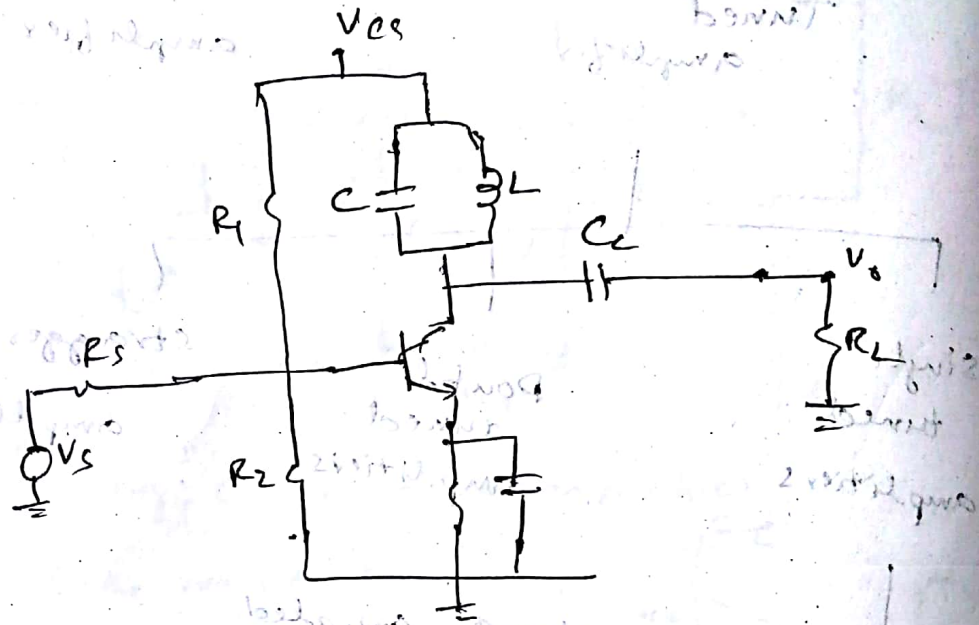
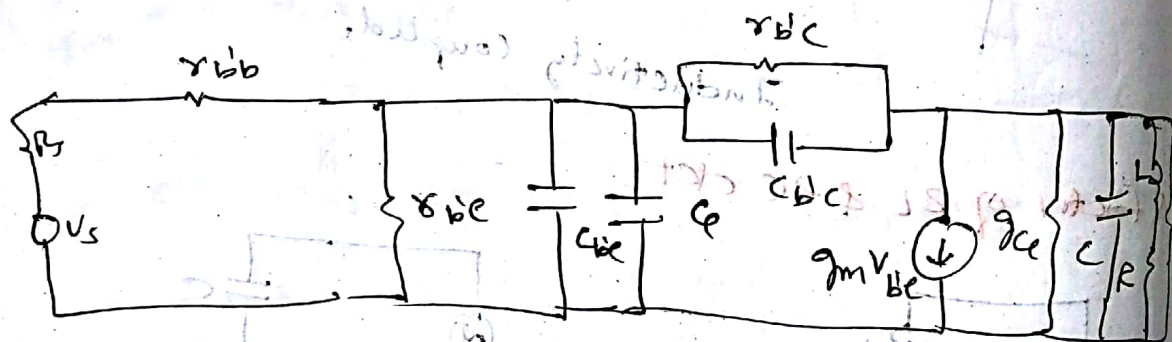


fig: single tuned C.E. amplifier



equivalent circuit of single tuned amplifier

$$C_i = C_{be} + C_{bc}(1 - A)$$

$$g_{ce} = \frac{1}{r_{ce}}$$

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

$$R_o = \frac{1}{h_{oe} - g_m h_{re}}$$

admittance: $Y = \frac{1}{R + j\omega L}$

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

Quality factors

Q. factor of the coil at resonance is,

$$Q_0 = \frac{\omega_0 L}{R}$$

$$R_p = \frac{R^2 + \omega^2 L^2}{R}$$

$$R_p = \frac{\omega^2 L^2}{R}$$

$$\frac{\omega^2 L^2}{R} \gg 1$$

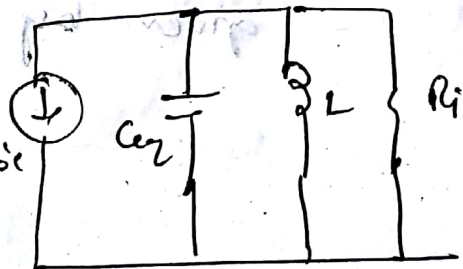
$$L_p = \frac{R^2 + \omega^2 L^2}{\omega^2 L^2}$$

$$R_p = \omega_0 Q_0 L$$

$$Q_0 = \frac{R_p}{\omega_0 L}$$

$Q_{eff} = \text{Susceptance of inductance}$

$\frac{L}{\text{Conductance of shunt resis. } R_i}$



$$Q_{eff} = \frac{R_t}{\omega_0 L} = \omega_0 C_{eq} R_t$$

Voltage gain:

for a single tuned amplifier, the voltage gain is

$$A_v = -g_m \frac{r_{be}}{r_{bb'} + r_{be}} \cdot \frac{R_t}{1 + 2jQ_{eff}\delta}$$

$$\left| \frac{A_v}{A_{res}} \right|$$

$$\frac{1}{\sqrt{1 + (2\delta Q_{eff})^2}}$$

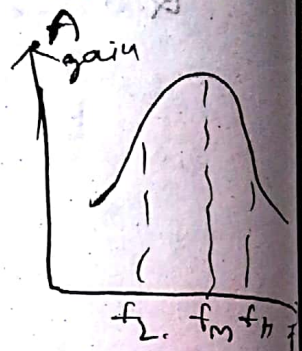
Centre freq. f_r : centre freq. f_r

f_r is given by

$$f_r = \frac{1}{2\pi \sqrt{L_p C_{eq}}}$$

where $L_p = \frac{R^2 + \omega^2 L^2}{\omega^2 L}$

$$C_{eq} = C_{b'c} \left(\frac{A-1}{A} \right) + C$$



Band width (Band width):

Band width of single tuned amplifier is

given by $(B.W) = \frac{1}{2\pi R_t C_{eq}}$

$$= \frac{\omega_0 R_t}{2\pi R_t Q_{eff}}$$

$$= \frac{\omega_0}{2\pi Q_{eff}}$$

$$= \frac{2\pi f_0}{2\pi Q_{eff}}$$

$$\text{Band width} = \frac{2\pi f_0}{2\pi Q_{eff}}$$

$$= \frac{f_0}{Q_{eff}}$$

Bandwidth of single tuned amplifier

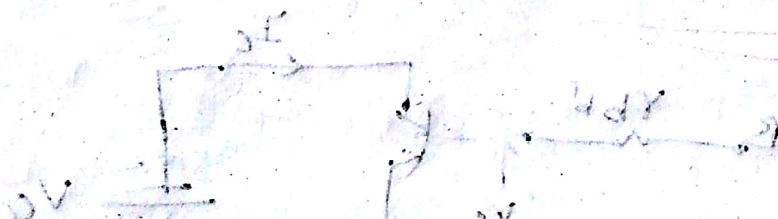
is given by

$$B.W = \frac{f_0}{Q_{eff}}$$

where

$$Q_{effective} = \frac{R_t}{\omega_0 L}$$

$$Q_{eff} = \omega_0 C_{eq} R_t$$



Unit-II

Transistor At High frequency:

Hybrid π Common emitter Transconductance model:

→ The values of h parameters are not constant at high freq. Therefore, it is necessary to analyse transistor at each & every freq. which is impractical.

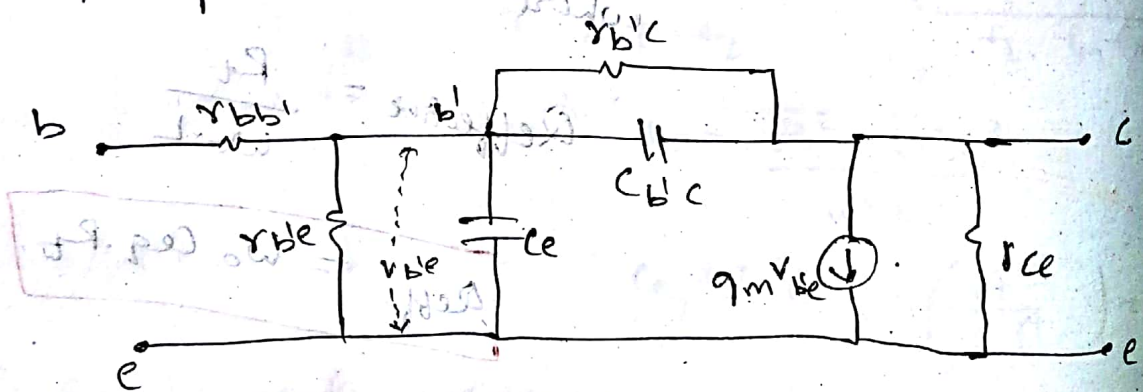
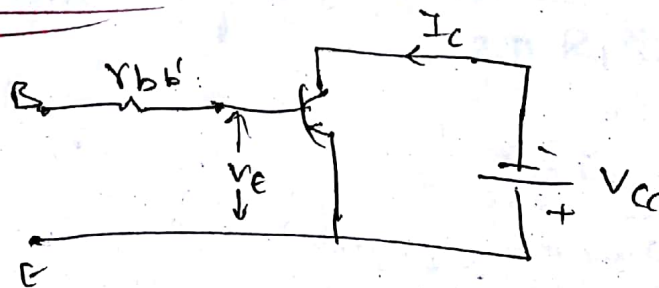


fig: Hybrid- π C.E. Configuration.

Transconductance:



transconductance $g_m = \left. \frac{\partial I_c}{\partial V_{b'e}} \right|_{V_{ce}}$

$$I_C = I_{CO} - \alpha \cdot I_E$$

volt equivalent temperature $V_T = \frac{k \cdot T}{q}$

$$g_m = \frac{\alpha \cdot I_E}{V_T} = \frac{I_{CO} - I_C}{V_T}$$

$$g_m = \frac{I_C \cdot q}{k \cdot T} = \frac{I_C \times 1.6 \times 10^{-19}}{1.38 \times 10^{-23} \cdot T}$$

$$g_m = \frac{I_C (\text{mA})}{26}$$

Input Conductance $g_{b'e}$:

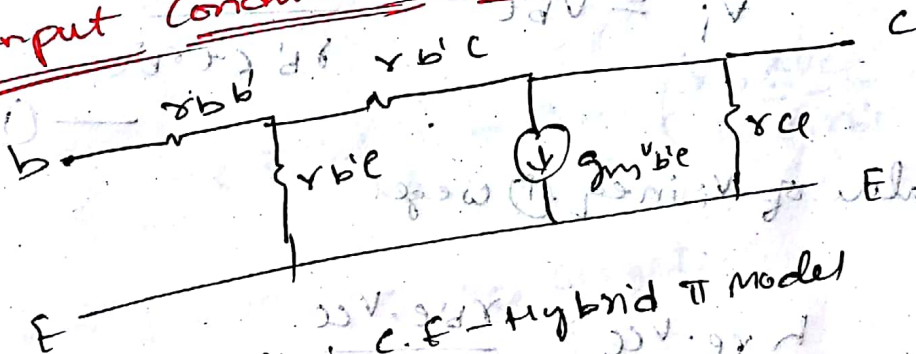


fig: C.E. Hybrid π Model

$$I_C = g_m \cdot v_{b'e}$$

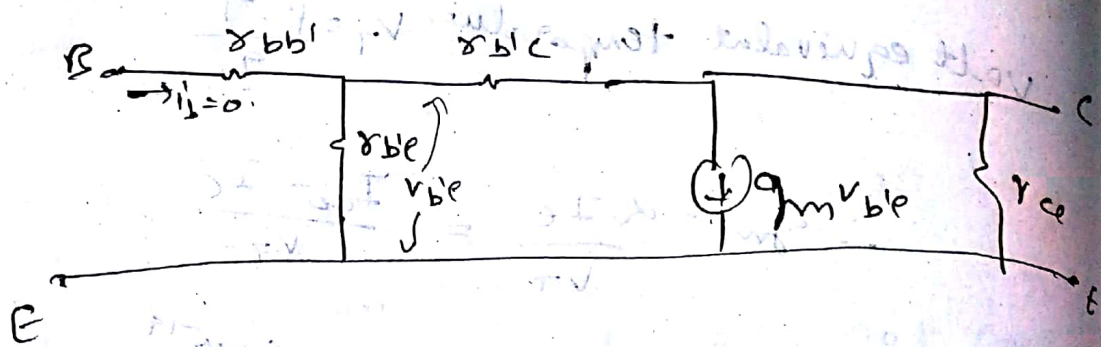
$$\frac{I_C}{I_B} = g_m \cdot r_{b'e} \quad \text{--- (1)}$$

$$h_{fe} = g_m \cdot r_{b'e} \quad \text{--- (2)}$$

$$g_{b'e} = \frac{h_{fe} \cdot V_T}{|I_C|}$$

$$g_{b'e} = \frac{|I_C|}{V_T \cdot h_{fe}}$$

feedback conductance $g_{b'c}$



with $I_B = 0$, V_{ce} can be given as,

$$V_{ce} = I_1 (r_{b'c} + r_{be})$$

$$I_1 = \frac{V_{ce}}{r_{b'c} + r_{be}}$$

$$v_i = v_{be} = \frac{r_{be} \cdot V_{ce}}{r_{b'c} + r_{be}} \quad \text{--- (1)}$$

sub. value of v_i in eq (1) we get

$$h_{re} \cdot V_{ce} = \frac{r_{be} \cdot V_{ce}}{r_{b'c} + r_{be}}$$

$$r_{be} = h_{re} r_{b'c} + h_{re} \cdot r_{be}$$

$$r_{b'c} = \frac{h_{fe} \cdot V_T}{|I_E| \cdot h_{re}}$$

$$g_{b'c} = \frac{|I_E| \cdot h_{re}}{h_{fe} \cdot V_T}$$

$$\frac{|I_E|}{2 \text{ mA} \cdot 26 \text{ mV}} = 94 \mu$$

The Base spreading Resistance $r_{bb'}$:

from the π parameter model:

$$r_{be} = r_{bb'} + r_{b'e}$$

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

$$r_{bb'} = h_{ie} - \frac{h_{fe} \cdot V_T}{I_C}$$

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

The output Resistance r_{ce} :

$$r_{ce} = \frac{V_{ce}}{I_C}$$

$$I_C = \frac{V_{ce}}{r_{ce}} + g_m \cdot v_{b'e} + I_A$$

$$I_C = \frac{V_{ce}}{r_{ce}} + g_m \cdot \left(\frac{r_{b'e} V_{ce}}{r_{b'b} + r_{b'e}} \right) + \frac{V_{ce}}{r_{b'b} + r_{b'e}}$$

Dividing both by V_{ce} we get.

$$\frac{I_C}{V_{ce}} = \frac{1}{r_{ce}} + \frac{h_{fe}}{r_{b'b} + r_{b'e}} + \frac{1}{r_{b'b} + r_{b'e}}$$

$$= \frac{1}{r_{ce}} + \frac{h_{fe}}{r_{b'b} + r_{b'e}}$$

But we know

$$r_{ce} = \frac{V_{ce}}{I_C}$$

$$= \frac{1}{\frac{1}{r_{ce}} + \frac{h_{fe}}{r_{b'b} + r_{b'e}}}$$

$$= \frac{1}{r_{ce}} + \frac{h_{fe}}{r_{b'b}}$$

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

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

C.E. short ckt current gain:-

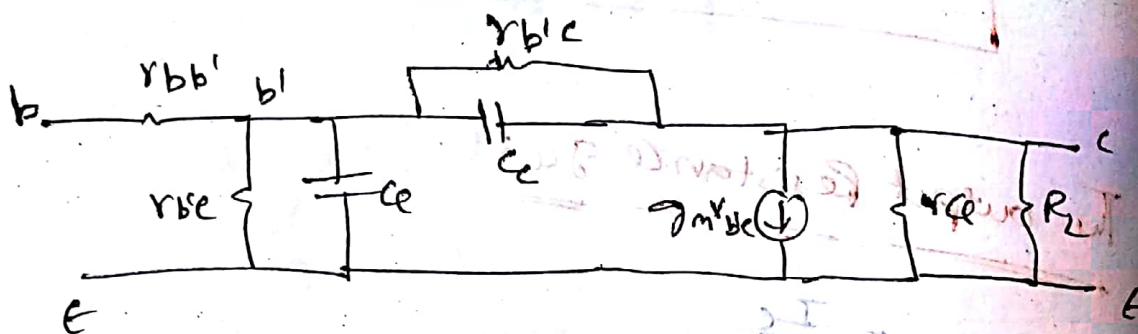
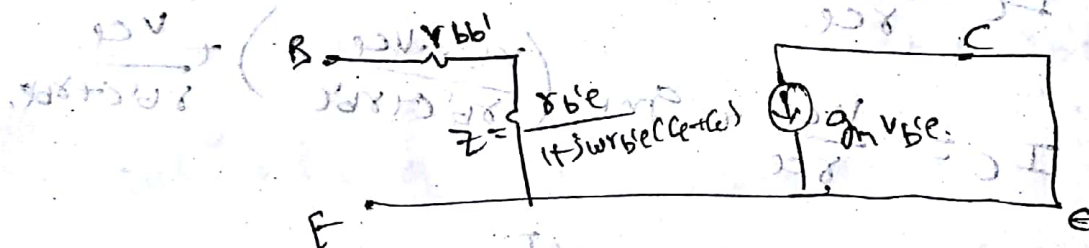


fig. Hybrid- π ckt



$$v_{be} = I_b \cdot Z$$

$$Z = \frac{v_{be}}{I_b}$$

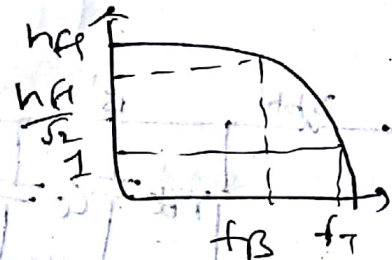
The current gain for the circuit can be given as

$$A_i = \frac{I_L}{I_b} = \frac{-g_m \cdot v_{be}}{I_b}$$

$$A_i = \frac{-g_m \cdot r_{bb'}}{1 + j\omega r_{be} (C_e + C_c)}$$

$$f_B = \frac{1}{2\pi r_{b'e}(C_e + C_c)}$$

$$= \frac{g_{b'e}}{2\pi(C_e + C_c)}$$



$$f_B = \frac{1}{h_{fe}} \cdot \frac{g_m}{2\pi(C_e + C_c)}$$

f_T at gain = 1

$$1 = \frac{h_{fe}}{\sqrt{1 + \left(\frac{f_T}{f_B}\right)^2}}$$

$$f_T = h_{fe} \cdot f_B$$

$$f_T = \frac{g_m}{2\pi(C_e + C_c)}$$

Current gain with Resistive load :-

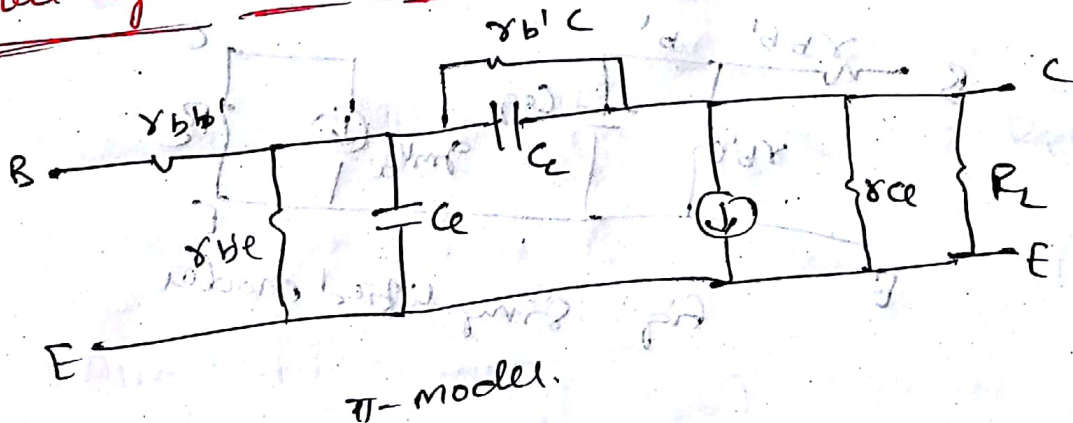


fig: C.E. amplifier hybrid-π model

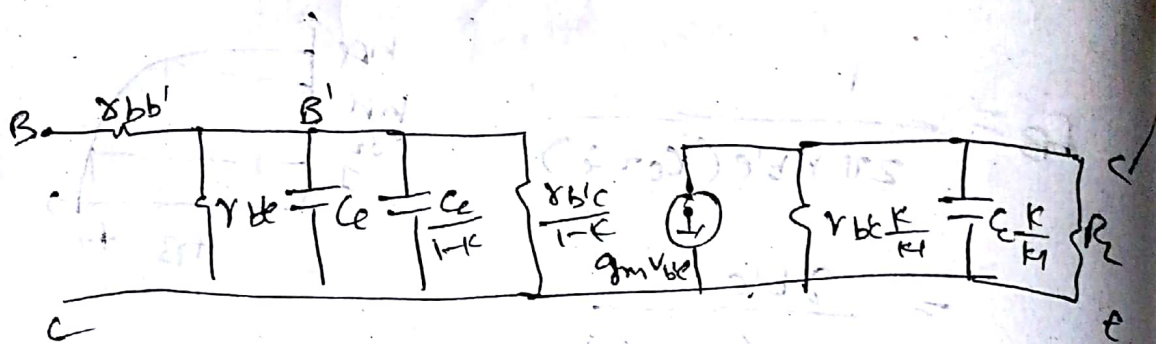


fig: Simplified π model

Amplifier gain $k = \frac{V_o}{V_{be}}$

$$V_o = -g_m \cdot V_{be} \cdot R_L$$

$$\frac{r_{be}}{1-k} = \frac{4 \text{ M}\Omega}{1-(-\infty)}$$

C_e also resolved by Miller's theorem.

$$\frac{j\omega C_e}{1-k} = \frac{j\omega C_e (1+g_m R_L)}{1-k}$$

$$C_{eq} = C_e + C_c (1+g_m R_L)$$

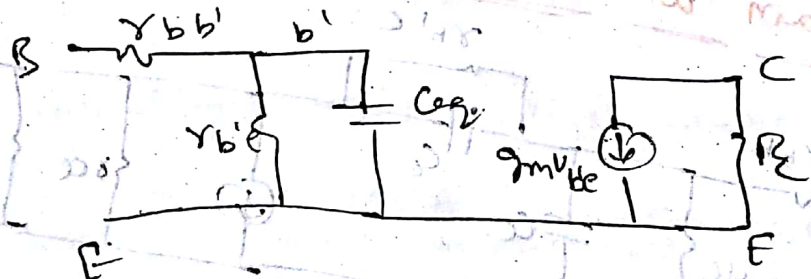


fig: Simplified model

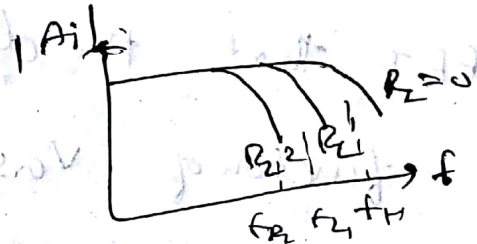
$$A_i = \frac{-g_m \cdot r_{be}}{1 + j\omega r_{be} C_{eq}}$$

$$1 + j\omega r_{be} C_{eq}$$

$$= \frac{-hfe}{1 + j2\pi f r_{be} C_{eq}}$$

$$f_H = \frac{1}{2\pi r_{be} C_{eq}}$$

$$A_1 = \frac{-hfe}{1 + j\left(\frac{f}{f_H}\right)}$$



$$|A_1| = \frac{hfe}{\sqrt{1 + \left(\frac{f}{f_H}\right)^2}}$$

$$f_H = \frac{1}{2\pi r_{be} C_{eq}} = \frac{1}{2\pi r_{be} (C_e + C_c (1 + g_m R))}$$

$$A_1 \quad (R_L = 0) \quad f_H = \frac{1}{2\pi r_{be} (C_e + C_c)} = f_B$$

$$f_B = \frac{1}{2\pi r_{be} (C_e + C_c)} = f_H$$

gain Band width product:

$$|A_{mid} \cdot f_H| = |A_{iso} \cdot f_H| = \frac{-hfe \cdot R_s}{R_s + hie} \cdot \frac{1}{2\pi R_{eq} C_{eq}}$$

$$|A_{iso} \cdot f_H| = \frac{g_m \cdot R_s}{2\pi (R_s + r_{bb'})}$$

$$f_H = \frac{f_T}{1 + 2\pi f_T C_{eq} R_s} \cdot \frac{R_s}{R_s + r_{bb'}}$$

FET amplifier:

from the drain & transfer characteristics of FET

that the drain current is

function of V_{GS}, V_{DS}

$$I_D = f(V_{GS}, V_{DS}) \quad \text{--- (1)}$$

→ If both V_{GS}, V_{DS} are varied the change

in drain current is given approximately by

$$\Delta I_D = \left(\frac{\partial I_D}{\partial V_{GS}} \right) \Delta V_{GS} + \left(\frac{\partial I_D}{\partial V_{DS}} \right) \Delta V_{DS} \quad \text{--- (2)}$$

When $I_D = 0$

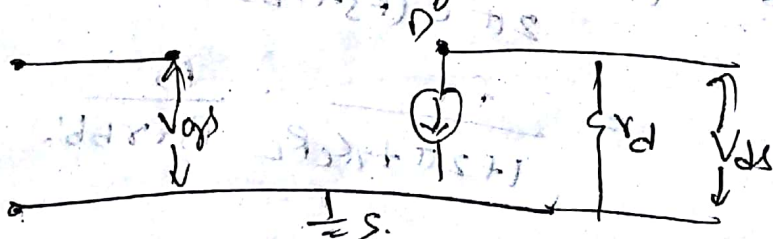
$$0 = g_m V_{GS} + \frac{1}{r_d} V_{DS}$$

$$\frac{V_{DS}}{V_{GS}} = -g_m r_d$$

$$\mu = g_m r_d$$

The small signal model for FET is

Common Source is given as



Fixed bias JFET ckt:

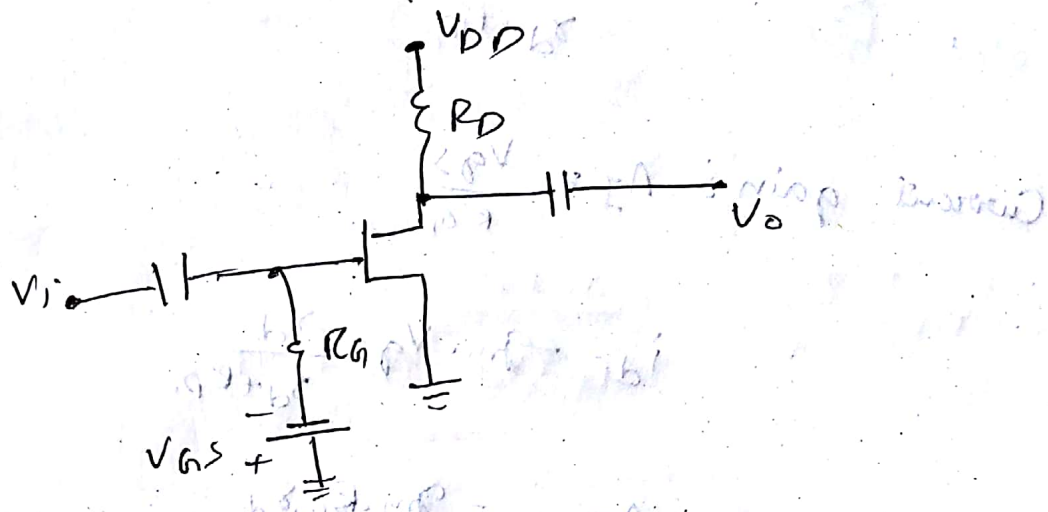
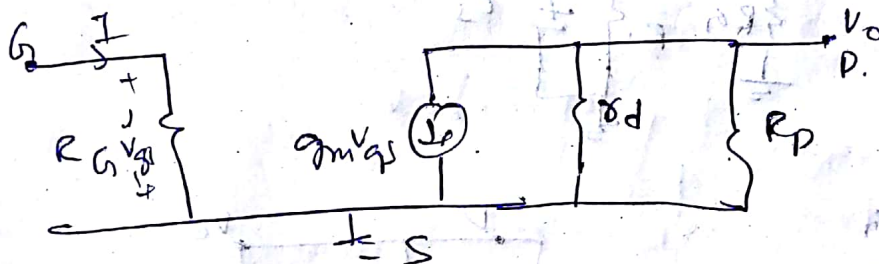


fig: CS amplifier.

for analysis of CS of C-S amplifier first short circuit all capacitors, all D.C. sources



Small signal equivalent model.

our interest is to find A_v, R_i, R_o, A_i

$$R_i = R_G$$

$$R_o = r_d \parallel R_D$$

$$\text{then } V_o = (-g_m V_{GS})(R_D \parallel r_d)$$

$$V_i = V_{GS}$$

$$V_o = -g_m V_i (r_d \parallel R_D)$$

$$= -g_m \cdot r_d \cdot R_D$$

$$r_d + R_D$$

Current gain: $A_I = \frac{V_{gs}}{R_G}$

$$i_d = -g_m \cdot V_{gs} \cdot \frac{r_d}{r_d + R_D}$$

$$A_I = \frac{-g_m \cdot R_G \cdot r_d}{r_d + R_D}$$

Self bias:

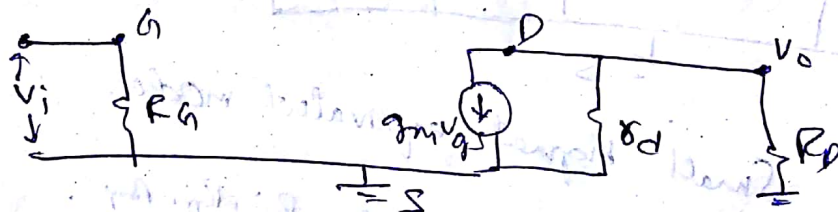
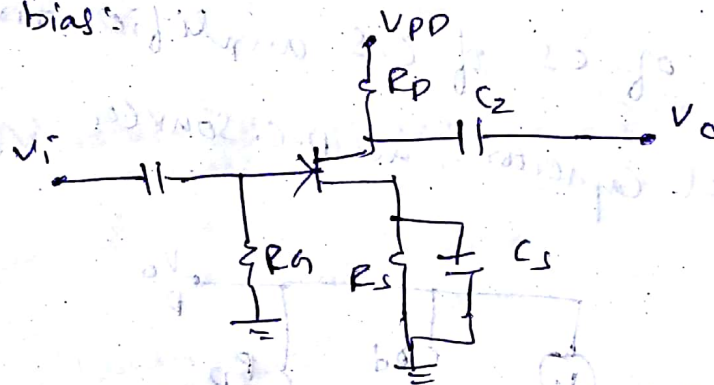
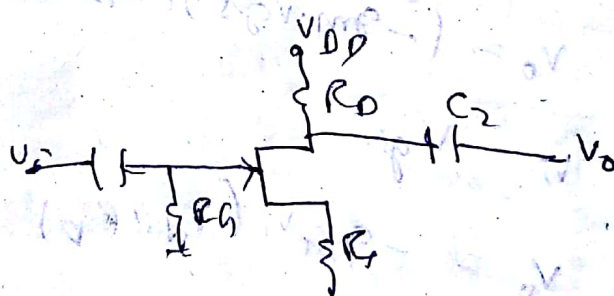
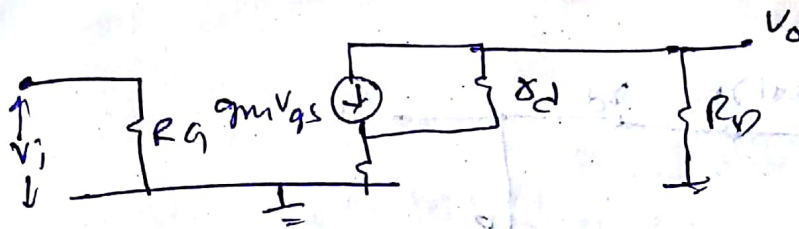


fig: Small signal equivalent

Self bias without source Capacitor





when an unbypassed source

$$V_i = V_{gs} + i_d R_S$$

$$= V_{gs} + g_m V_{gs} R_S$$

$$I_i = \frac{V_{gs}}{R_G} = \frac{V_i}{R_G (1 + g_m R_S)}$$

$$\text{IP Resistance: } R_i = \frac{V_i}{I_i} = R_G (1 + g_m R_S)$$

$$V_o = -i_d (R_D \parallel r_d)$$

$$A_v = \frac{V_o}{V_i} = \frac{-g_m V_{gs} (R_D \parallel r_d)}{V_{gs} (1 + g_m R_S)} = \frac{-g_m (R_D \parallel r_d)}{1 + g_m R_S}$$

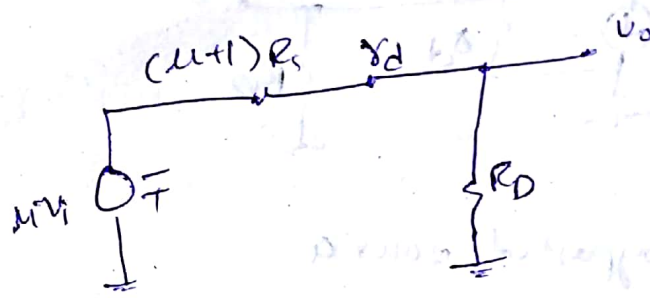
Apply KVL at output loop:

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

$$i_d (R_D + r_d + g_m R_S r_d + R_S) = g_m r_d V_i$$

$$i_d = \frac{\mu V_i}{R_D + r_d + R_S (\mu + 1)}$$

It can be converted into new nlw.
As follows



$$A_v = \frac{V_o}{V_i} = \frac{-\mu \cdot R_D}{R_D + g_d + (\mu+1)R_S}$$

o/p Resistance with i/p zero

$$R_o = g_d + (1+\mu) \cdot R_S$$

Common Drain amplifier:

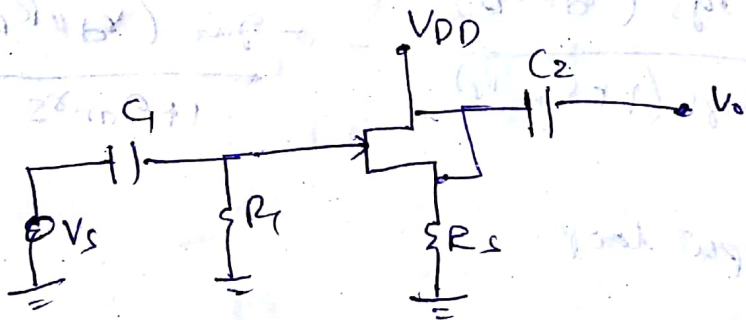


fig: Common Drain amplifier

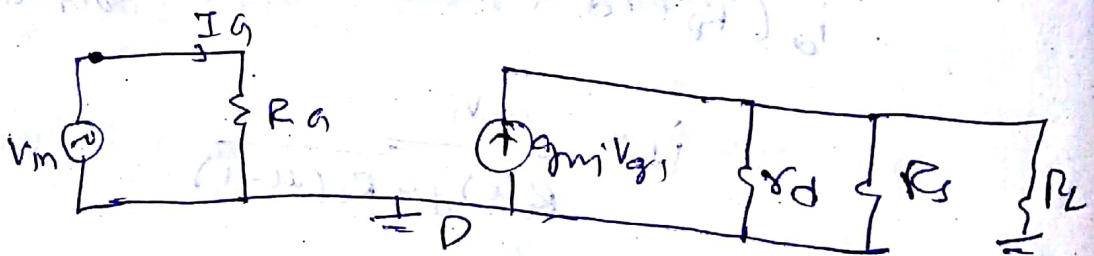


fig: A.C. equivalent ckt

$$V_o = i_d \cdot R_L'$$

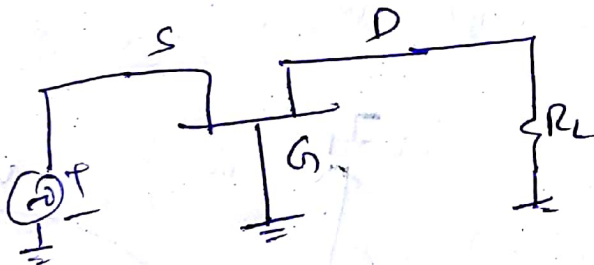
$$V_o = g_m \cdot V_{gs} \cdot R_L'$$

$$= g_m (V_i - V_o) \cdot R_L'$$

$$A_v = \frac{V_o}{V_i} = \frac{g_m \cdot R_L'}{1 + g_m \cdot R_L'}$$

$$R_o = r_d \parallel R_s$$

Common gate amplifier:



Here $V_o = i_d \cdot R_L'$

$$= g_m \cdot V_{gs} \cdot R_L'$$

$$A_v = \frac{V_o}{V_{in}} = g_m \cdot R_L'$$

Input impedance: $\frac{i_{in}}{V_{in}} = g_m = \frac{1}{R_m}$

$$g_m = \frac{1}{R_m}$$

MosFET:

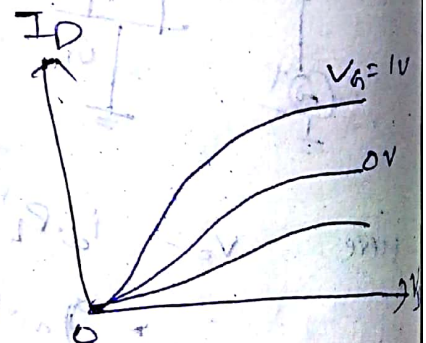
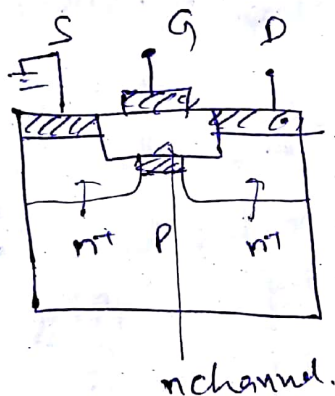
metal oxide semiconductor field effect

transistor:

Types of FET:

- (i) Depletion mode MOSFET
- (ii) Enhancement mode MOSFET.

→ MOSFET is a unipolar junction transistor & known as voltage controlled current device.



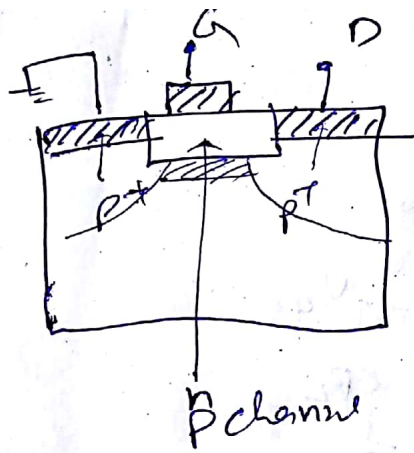
nchannel depletion region MOSFET

nchannel depletion region.

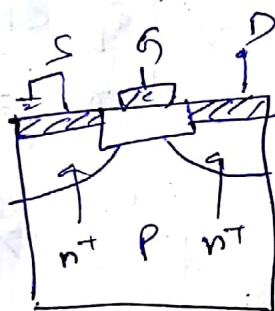
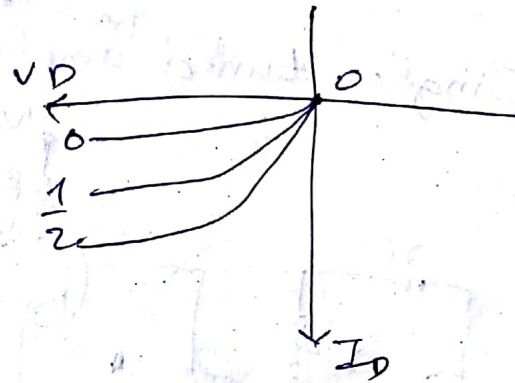
At pinch off

$$I_{DS} = I_{DSS} \left[1 - \left(\frac{V_{GS}}{V_{GS(off)}} \right) \right]^2$$

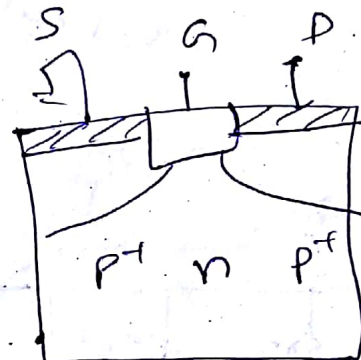
$V_{GS(off)}$ however it is negative



p channel depletion
mosFET

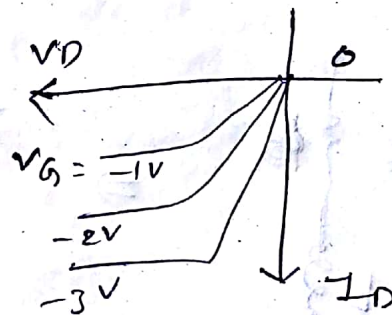
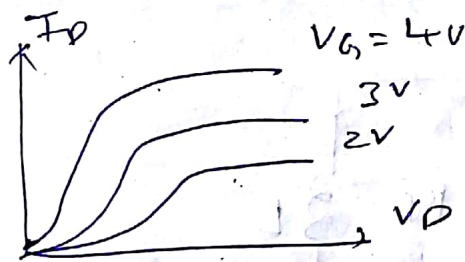


n channel enhancement mosFET



p channel
enhancement mode
mosFET.

characteristics:

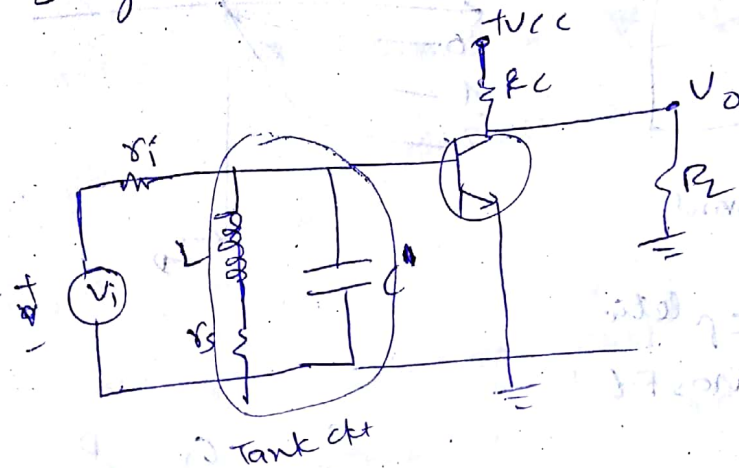


Small V_D linear region

$$I_D = \frac{Z \cdot \mu_n \cdot C_i}{L} (V_G - V_T) \cdot V_D$$

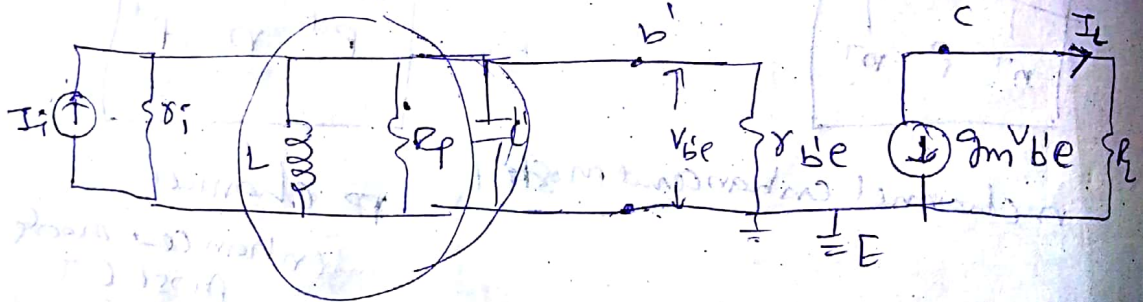
$$g \approx \frac{\delta I_D}{\delta V_D} = \frac{Z \cdot \mu_n \cdot C_i}{L} (V_G - V_T)$$

* Single tuned Transistor amplifier:

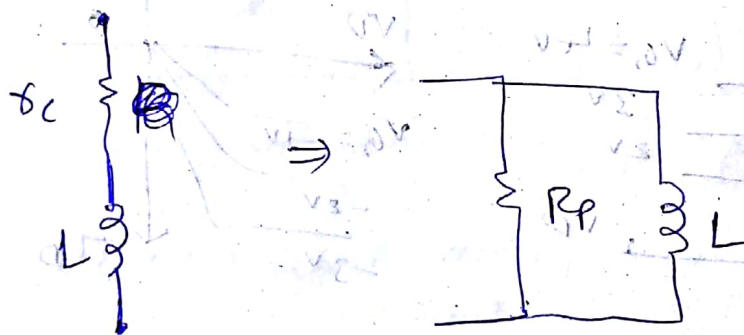


$$r_L \ll R_L$$

$$r_{bb'} = 0$$



Note:



equivalence circuit.

⇒ Admittance are equal.

$$\frac{1}{R_{eq1}} = \frac{1}{r_c + j\omega L}$$

$$\frac{1}{R_{eq2}} = \frac{1}{R_p} + \frac{1}{j\omega L}$$

$$\frac{1}{r_c + j\omega L} = \frac{1}{R_p} + \frac{1}{j\omega L}$$

$$\frac{r_c}{r_c^2 + \omega^2 L^2} - \frac{j\omega L}{r_c^2 + \omega^2 L^2} = \frac{1}{R_p} + \frac{1}{j\omega L}$$

$$\omega L \gg r_c$$

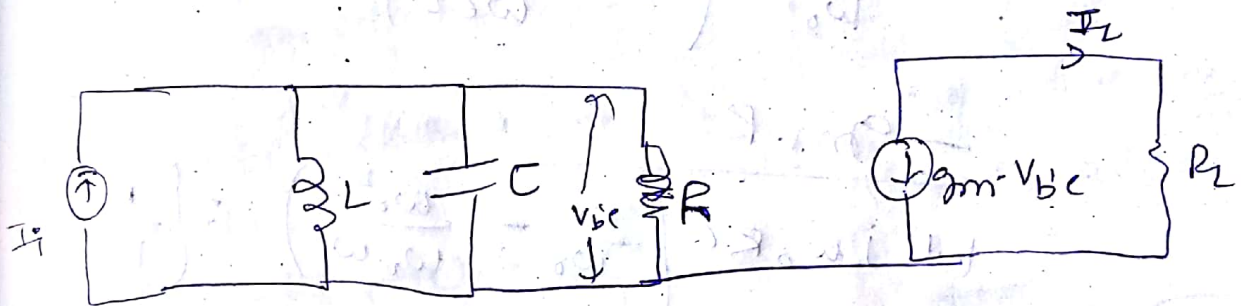
$$\frac{g_c}{\omega^2 L^2} + \frac{1}{j\omega L} = \frac{1}{R_p} + \frac{1}{j\omega L}$$

$$R_p = \frac{\omega^2 L^2}{g_c}$$

$$= \omega L \cdot Q_c$$

$$Q_c = \frac{\omega L}{g_c} \gg 1$$

let $R = r_i \parallel R_p \parallel r_{b'e}$



$$I_o = -g_m \cdot V_{b'e}$$

$$I_i = \frac{V_{b'e}}{Z_{eq}}$$

$$= V_{b'e} \cdot \left(\frac{1}{Z_{eq}} \right)$$

$$I_i = V_{b'e} \cdot \left[\frac{1}{R} + \frac{1}{j\omega L} + j\omega C \right]$$

$$\frac{1}{Z_{eq}} = \frac{1}{j\omega L} + \frac{1}{R} + j\omega C$$

$$A_i = \frac{I_o}{I_i} = \frac{-g_m \cdot V_{b'e}}{V_{b'e} \cdot \left(\frac{1}{R} + \frac{1}{j\omega L} + j\omega C \right)}$$

$$A_i = \frac{-g_m \cdot R}{1 + j(\omega R C - \frac{R}{\omega L})}$$

Current gain
of the
amplifier

$$\omega_0^2 = \frac{1}{LC}$$

Resonant freq. ω_0

$$= \frac{-g_m \cdot R}{1 + j \frac{\omega_0 R C}{\omega_0} \left(\omega - \frac{1}{\omega C L} \right)}$$

$$= \frac{-g_m \cdot R}{1 + j \omega_0 R C \left(\frac{\omega}{\omega_0} - \frac{\omega_0^2}{\omega_0 \cdot \omega} \right)}$$

$$\omega_0^2 = \frac{1}{LC}$$

$$= \frac{-g_m \cdot R}{1 + j \omega_0 R C \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right)}$$

$$A_i = \frac{-g_m \cdot R}{1 + j Q_i \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right)}$$

$$Q_i = \frac{R}{\omega_0 L}$$

$$= \omega_0 R C$$

$$\omega_0^2 = \frac{1}{LC}$$

At $\omega = \omega_0$

$$(A_i)_{\max} = -g_m \cdot R$$

At 3dB freq: $(A_i)_{3dB} = \frac{1}{\sqrt{2}} \cdot (A_i)_{\max}$

$$(A_i)_{3dB} = \frac{-g_m \cdot R}{\sqrt{2}}$$

To calculate ω_H, ω_L (3dB freq.)

$$\frac{1}{\sqrt{2}} \cdot (A_1) = \left| \frac{-g_m \cdot R}{\sqrt{2}} \right|$$

$$\frac{1}{\sqrt{2}} \left[\frac{-g_m \cdot R}{1 + j Q \left(\frac{\omega}{\omega_0} \right) - \frac{\omega_0}{\omega}} \right] = \frac{-g_m \cdot R}{\sqrt{2}}$$

$$1 + Q^2 \left[\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right]^2 = 2$$

This equation is quadratic in ω^2 & has

two positive solutions ω_H, ω_L .

$$B.W = \omega_H - \omega_L = \frac{\omega_0}{Q_1}$$

$$B.W = f_H - f_L = \frac{\omega_0}{2\pi Q_1}$$

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

$$B.W = \frac{1}{2\pi RC}$$

∴ quadratic eq.

$$ax^2 + bx + c = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Double tuned amplifier:-

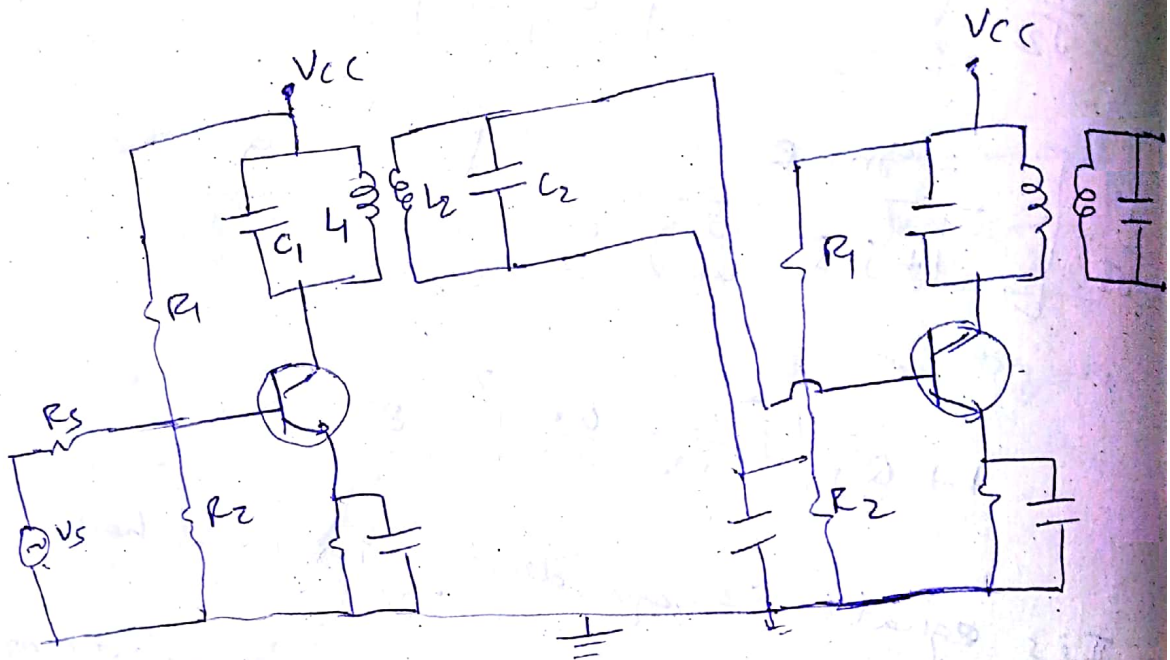


fig. Double tuned amplifier

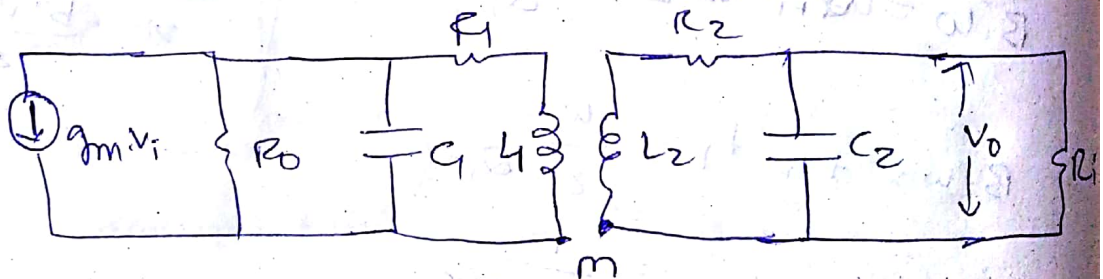
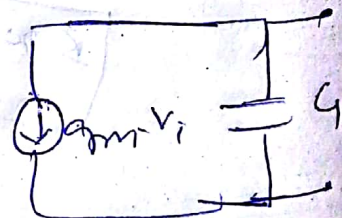
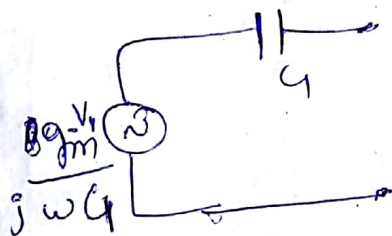


fig: Double tuned amp equivalent ckt

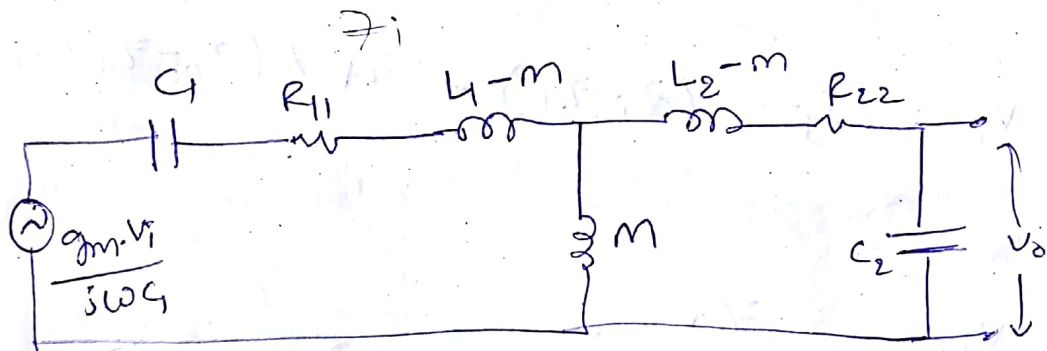
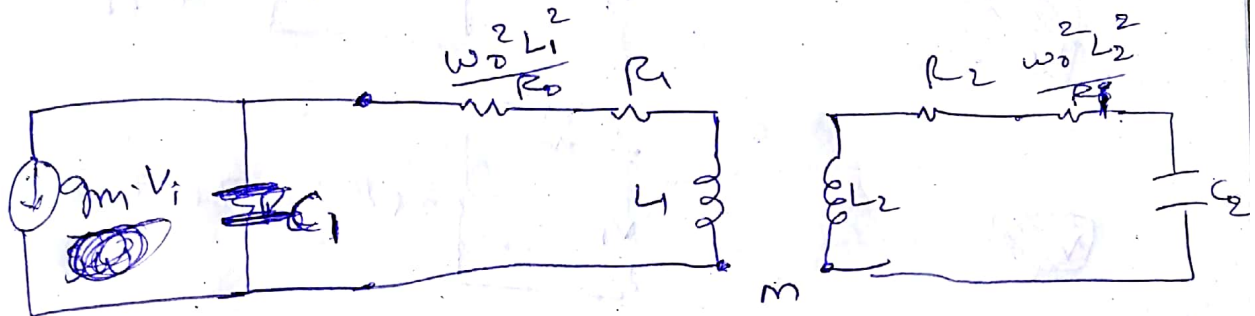


where

$$R_p = \frac{\omega^2 L^2}{R}$$

$$R = \frac{\omega^2 L^2}{R_p}$$

(from series to parallel equivalent circuit)



$$R_{11} = \frac{\omega_0^2 \cdot L_1^2}{R_0} + R_1$$

$$R_{22} = \frac{\omega_0^2 \cdot L_2^2}{R_1} + R_2$$

$$\text{Let } Z_f = j\omega \times m$$

$$\text{Let } Z_i = R_{11} + j\omega L_1 + \frac{1}{j\omega C_1}$$

$$\text{Let } Z_o + Z_i = R_{22} + j\omega L_2 + \frac{1}{j\omega C_2}$$

Double tuned amplifier:-

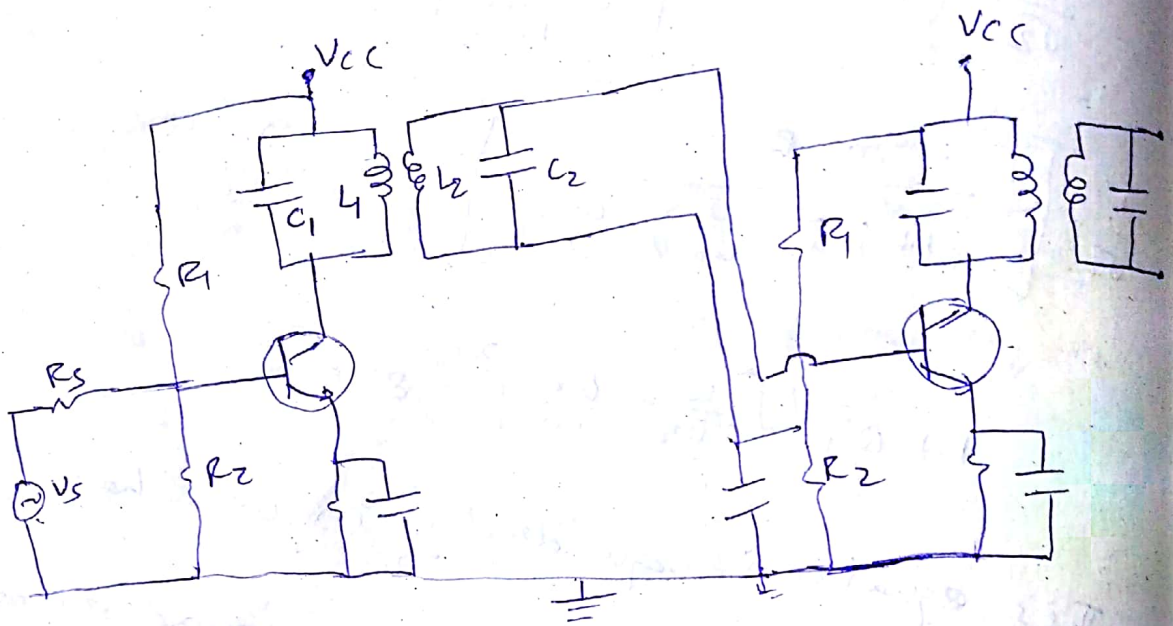


fig: Double tuned amplifier

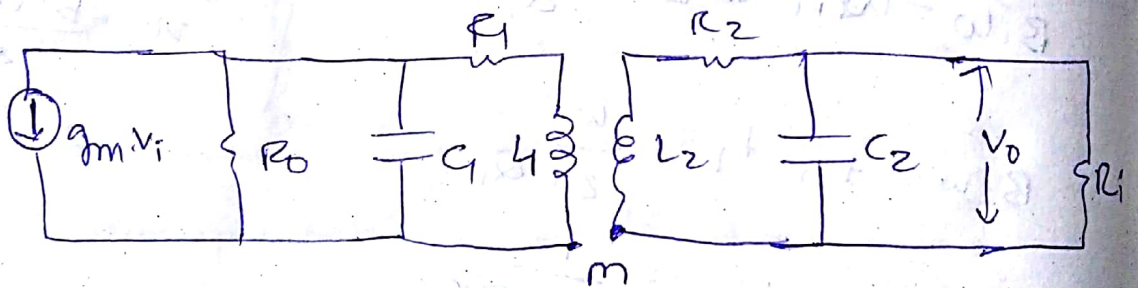
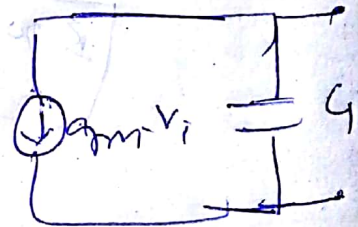
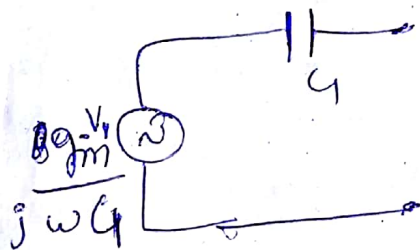


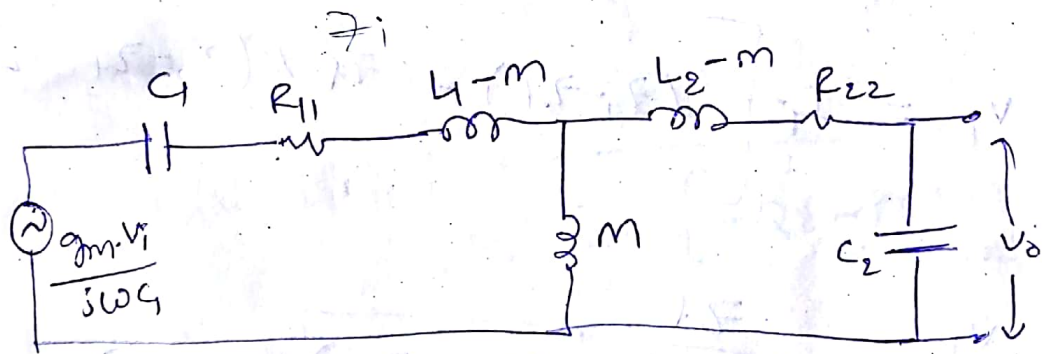
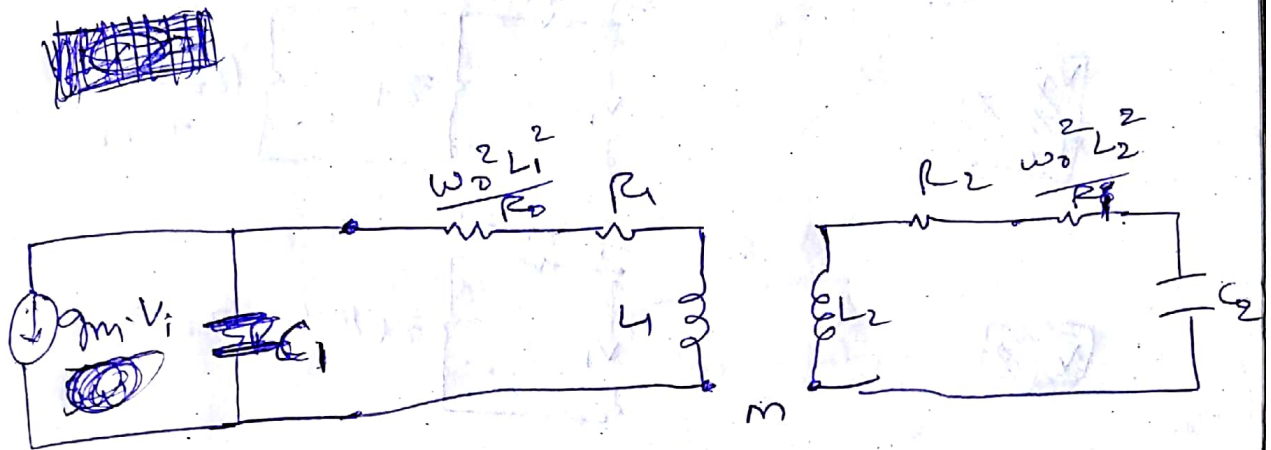
fig: Double tuned amp equivalent ckt



where

$$R_p = \frac{\omega^2 L^2}{R} \quad R = \frac{\omega^2 L^2}{R_p}$$

(from series to parallel equivalent circuit)



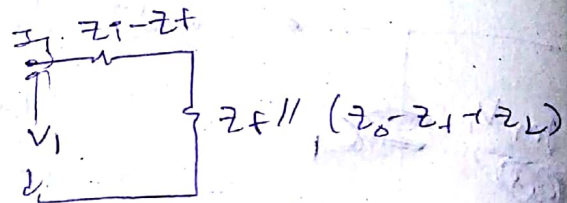
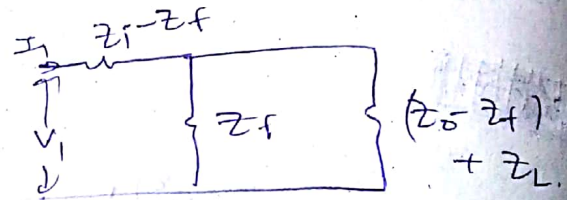
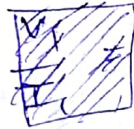
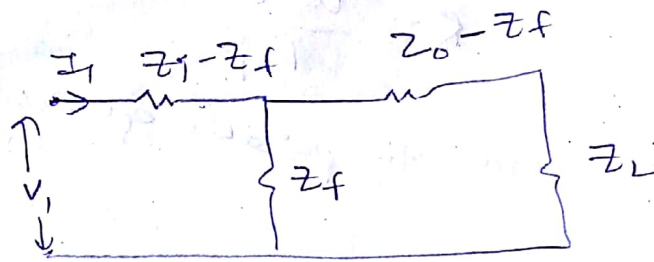
$$R_{11} = \frac{\omega_0^2 \cdot L_1^2}{R_0} + R_1$$

$$R_{22} = \frac{\omega_0^2 \cdot L_2^2}{R_1} + R_2$$

$$\text{Let } Z_f = j\omega_0 M$$

$$\text{Let } Z_i = R_{11} + j\omega L_1 + \frac{1}{j\omega C_1}$$

$$\text{Let } Z_o + Z_i = R_{22} + j\omega L_2 + \frac{1}{j\omega C_2}$$



$$V_1 = I_1 \left[(z_i - z_f) + z_f \parallel (z_o - z_f + z_L) \right]$$

$$\frac{V_1}{I_1} = \frac{z_f}{z_f^2 - z_i(z_o + z_L)} \quad \text{--- (1)}$$

using current division rule $A_1 = \frac{I_2}{I_1} = \frac{-z_f}{z_o + z_L}$

$$V_o = \frac{1}{j\omega_c C_2} \cdot I_2$$

$$= \frac{1}{j\omega_c C_2} \cdot \frac{-z_f}{z_o + z_L} \cdot I_1 \quad \text{--- (2)}$$

$$= \frac{1}{j\omega_c C_2} \cdot \frac{-z_f}{z_o + z_L} \cdot V_1 \left[\frac{z_f^2 - z_i(z_o + z_L)}{z_f} \right]$$

$$\frac{V_o}{V_1} = \frac{1}{j\omega_c C_2} \cdot \frac{-z_f}{z_o + z_L} \cdot \left[\frac{z_f^2 - z_i(z_o + z_L)}{z_f} \right]$$

Sub. z_f, z_i we get

from the fig.

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

$$V_i = \frac{g_m \cdot V_i}{j\omega C_1}$$

$$V_o = \frac{1}{j\omega r C_2} \cdot \frac{-z_f}{z_o + z_L} \cdot \frac{g_m \cdot V_i}{j\omega C_1} \left[\frac{z_f^2 + z_i(z_o + z_L)}{z_f} \right]$$

$$\frac{V_o}{V_i} = \frac{-j}{\omega r C_2} \cdot \frac{j \cdot g_m \cdot V_i}{\omega r C_1} \left[\frac{k \cdot Q^2}{\omega r \sqrt{L_1 L_2} \left[4Q\delta - j \left(\frac{1+k^2 Q^2}{-4Q^2 \delta^2} \right) \right]} \right]$$

$$= g_m \cdot \omega r^2 \cdot L_1 L_2 \cdot \left[\frac{k Q^2}{\omega r \sqrt{L_1 L_2} \left[4Q\delta - j \left(\frac{1+k^2 Q^2}{-4Q^2 \delta^2} \right) \right]} \right]$$

$$= \frac{g_m \cdot \omega r \cdot \sqrt{L_1 L_2} \cdot k Q^2}{4Q\delta - j \left(\frac{1+k^2 Q^2}{-4Q^2 \delta^2} \right)}$$

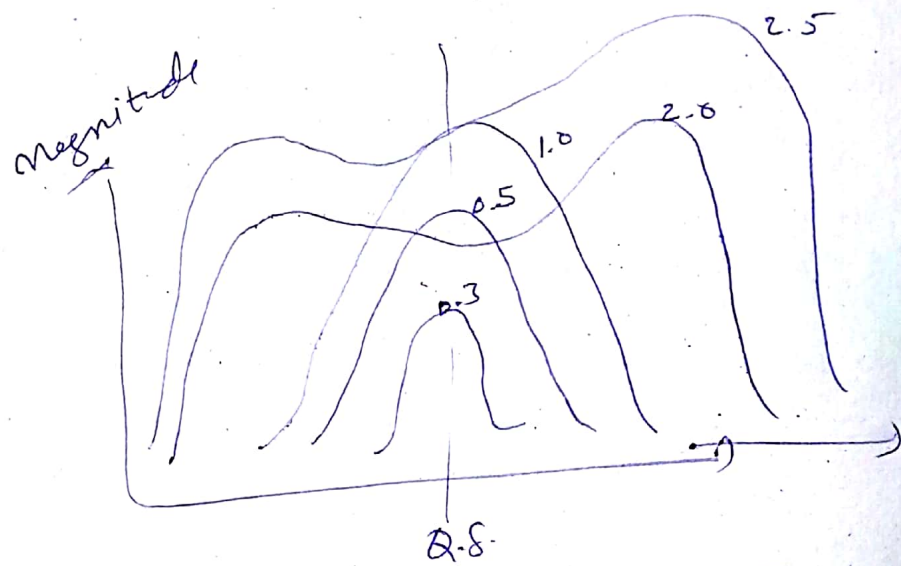
$$\boxed{\frac{1}{\omega r C} = \omega r^2}$$

$$|A_v| = g_m \cdot \omega r \cdot \sqrt{L_1 L_2} \cdot Q \cdot \frac{k \cdot Q}{\sqrt{1+k^2 Q^2 - 4Q^2 \delta^2 + 16Q^2 \delta^2}}$$

δ = freq. deviation

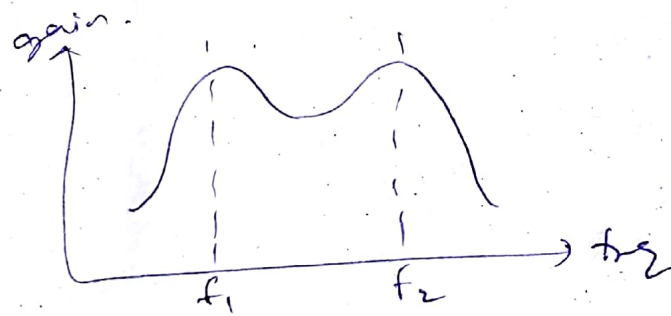
freq. gain peaks can be found by.

$$4Q\delta - j \left(\frac{1+k^2 Q^2}{-4Q^2 \delta^2} \right) = 0$$



$$f_1 = f_r \cdot \left[1 - \frac{1}{2Q} \cdot \sqrt{k^2 Q^2 - 1} \right]$$

$$f_2 = f_r \cdot \left[1 + \frac{1}{2Q} \cdot \sqrt{k^2 Q^2 - 1} \right]$$



Note:

$$Z_T = R_L + j \left(\omega L - \frac{1}{\omega C} \right)$$

Multiply Numerator & Denominator by

$$\omega_r L$$

$$Z_T = \frac{R_L \cdot \omega_r L}{\omega_r L} + j \omega_r L \left(\frac{\omega L}{\omega_r L} - \frac{1}{\omega_r \omega_r L} \right)$$

$$= \frac{\omega_r L}{Q} + j \omega_r L \left(\frac{\omega}{\omega_r} - \frac{\omega_r}{\omega} \right)$$

$$\text{where } Q = \frac{\omega_Y L}{R_{11}}$$

$$\frac{1}{\omega_Y L} = \omega_Y C$$

$$= \frac{\omega_Y L_1}{Q} + j\omega_Y L_1 (2\delta)$$

$$= \frac{\omega_Y L_1}{Q} + (1 + j2Q\delta)$$

$$Z_0 + Z_L = R_{22} + j\left(\omega L_2 - \frac{1}{\omega C_2}\right)$$

$$= \frac{\omega_Y L_2}{Q} + (1 + j2Q\delta)$$

AR
8

JFET:

- provides excellent voltage gain
- I_{ip} impedance high
- o/p current (drain) controlled by i/p voltage (V_{GS})

(BJT) → o/p current (I_C) controlled w.r.t small variations

Base I_B current

output characteristics of JFET:

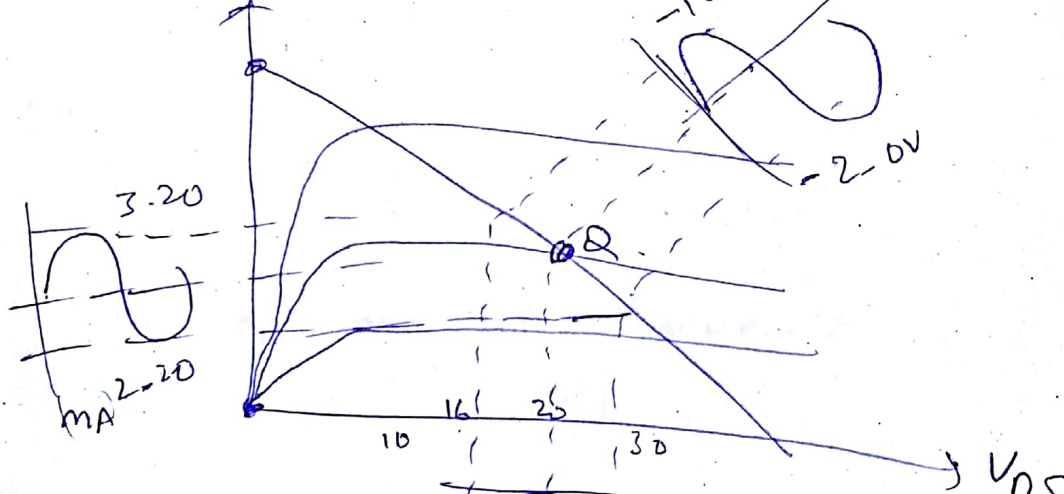
$$V_{DD} = 40V$$

$$V_{DSQ} = 120V$$

$$I_{DQ} = 2.70$$

$$R_D = 8k\Omega$$

$$I_D (mA)$$



o/p of the signal is greater than the i/p signal

180° phase shift

$V-I$ characteristics of JFET

JFET parameters:

① Transconductance:

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

Change in o/p cur. due to change in i/p voltage V_{GS}

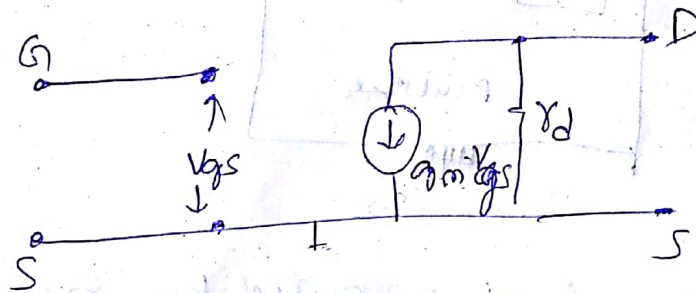
②

Drain Resistance $r_D = \frac{\Delta V_{DS}}{\Delta I_D} \Big|_{V_{GS} \text{ Const}}$

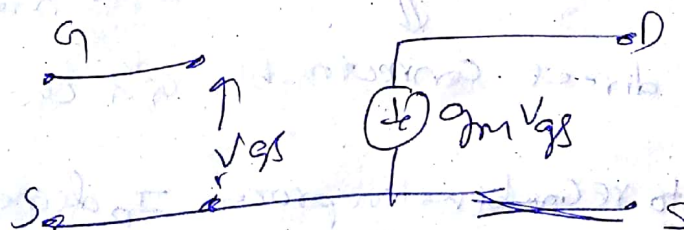
JFET low freq. AC equivalent ckt:

① I/P impedance is represented by open ckt. at the i/p terminal

② O/P impedance is represented by " r_D " Dynamic Res.



AC equivalent ckt of JFET



Approximate model of JFET r_D is open ckt

MOSFET : small size compared to BJT

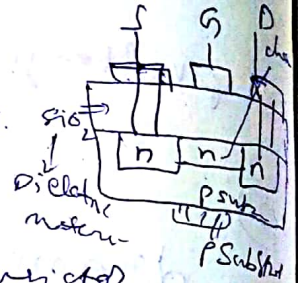
used in VLSI ckt.

I_p Resistance of MOSFET is high.

due to SiO_2 lay.

I G FET

Insulated gate field effect transistor

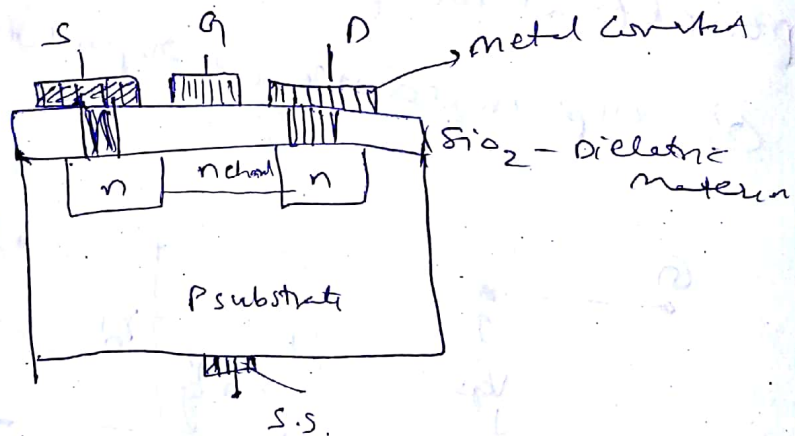


MOSFET

D MOSFET - Depletion MOSFET

E MOSFET - Enhancement MOSFET

Depletion mode MOSFET:
(channel)



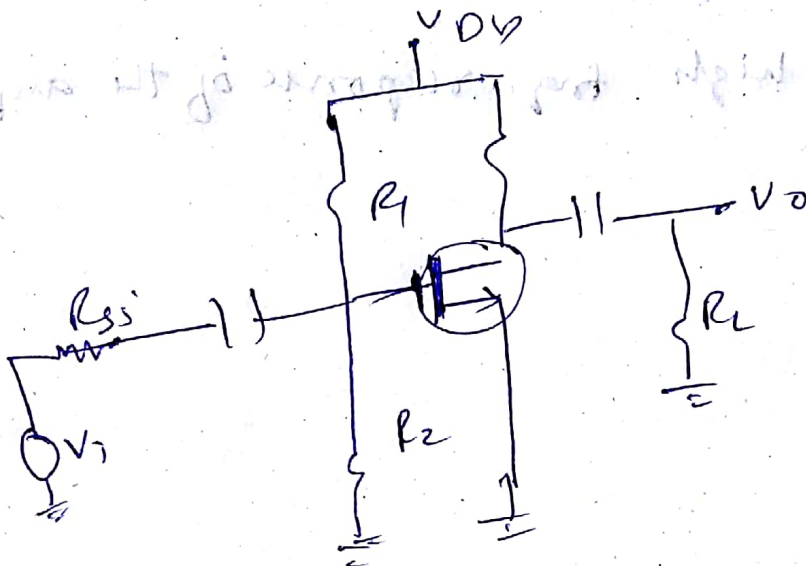
→ gate - nchannel separated by SiO_2 dielectric layer
⇒ high impedance MOSFET

→ no direct connection b/w gate & channel

→ Due to recombination process. I_D decreases

MOSFET:

C.S. amplifier with resistive load :-



$$A_v = \frac{V_o}{V_i} = -g_m \left(\frac{R_1}{R_1 + R_{si}} \right) (V_o \parallel R_D \parallel R_L)$$

$$R_i = R_1 \parallel R_2$$

$$R_o = R_D \parallel V_o \parallel R_L$$