UNIT-VI: Small Signal Low frequency Transistor Amplifier models:

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Two-port devices and Network parameters:- 15-4-81

A transistor can be treated as a two-port network. The terminal behaviour of any two port network can be specified by the terminal voltages V_1 and V_2 at ports 1 and 2, respectively and currents i_1 and i_2, entering ports 1 and 2, respectively as shown in fig (a). Of these four variables V_1, V_2, i_1, and i_2, two can be selected as independent variables and the remaining two can be expressed in terms of these independent variables. This leads to various two-port parameters out of which the following three are more important.

(i) Z-parameters or Impedance parameters.

(ii) Y- parameter or Admittance parameters.

(iii) H- parameters or Hybrid parameters.

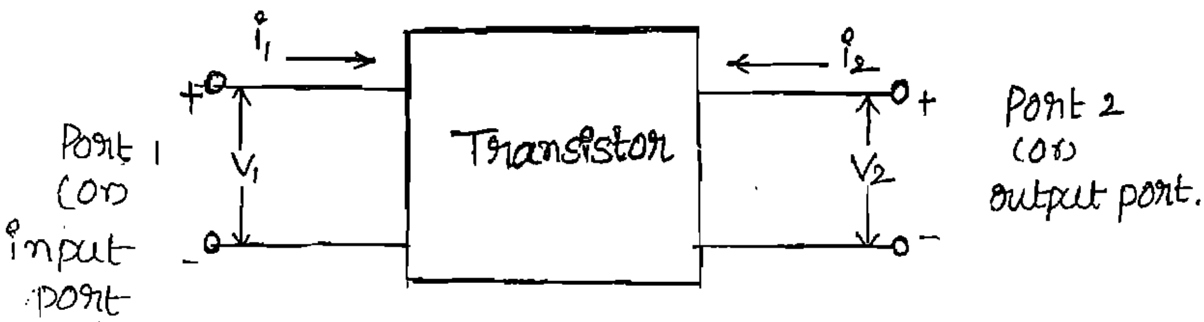


fig (a). Two port Network.

* Hybrid parameters or h- parameters :-

If the input current i_1 and the output voltage V_2 are taken as independent variables, the input voltage V_1 and output current i_2 can be written as

$$V_1 = h_{11} i_1 + h_{12} V_2$$

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

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

$$h_{11} = \left[\frac{V_1}{i_1}\right] \text{ with } V_2 = 0.$$

= input impedance with output port short circuited.

$$h_{22} = \left[\frac{i_2}{V_2}\right] \text{ with } i_1 = 0$$

= output admittance with input port open circuited.

$$h_{12} = \left[\frac{V_1}{V_2}\right] \text{ with } i_1 = 0$$

= reverse voltage transfer ratio with input port open circuited.

$$h_{21} = \left[\frac{i_2}{i_1}\right] \text{ with } V_2 = 0.$$

= forward current gain with output port short circuited.

The dimensions of h-parameters are as follows :-

h_{11} - Ω

h_{22} - mhos

h_{12}, h_{21} - dimensionless.

As the dimensions are not alike, i.e, they are hybrid in nature, these parameters are called as hybrid parameters.

An alternative subscript notation recommended by IEEE is commonly used:

i = 11 = input ; o = 22 = output

f = 21 = forward transfer,

r = 12 = reverse transfer.

∴ $h_{ie} = h_{11e}$ = short circuit input impedance.

$h_{oe} = h_{22e}$ = open circuit output admittance.

$h_{re} = h_{12e}$ = open circuit reverse voltage transfer ratio.

$h_{fe} = h_{21}$ = short circuit forward current gain.

The Hybrid model for Two-port network :-

$$V_1 = h_i i_1 + h_r V_2$$

$$i_2 = h_f i_1 + h_o V_2$$

2

(4)

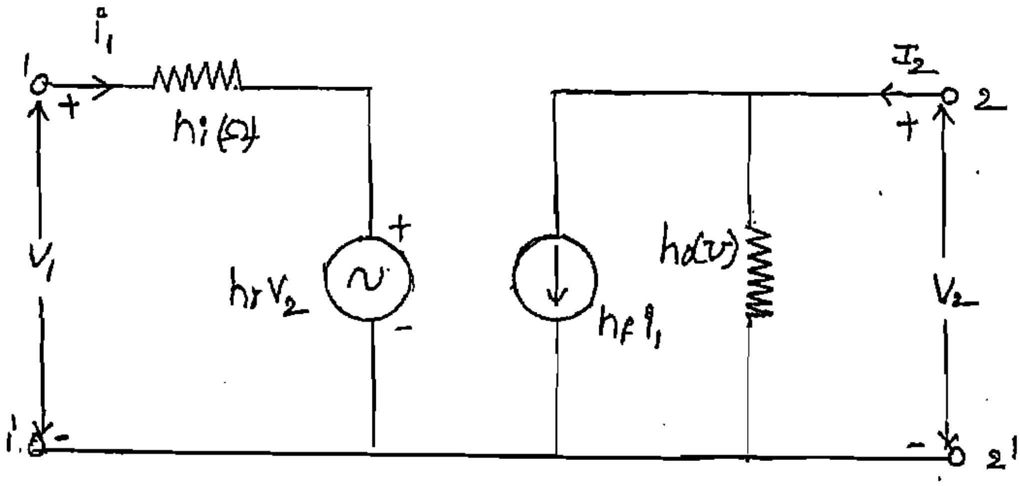


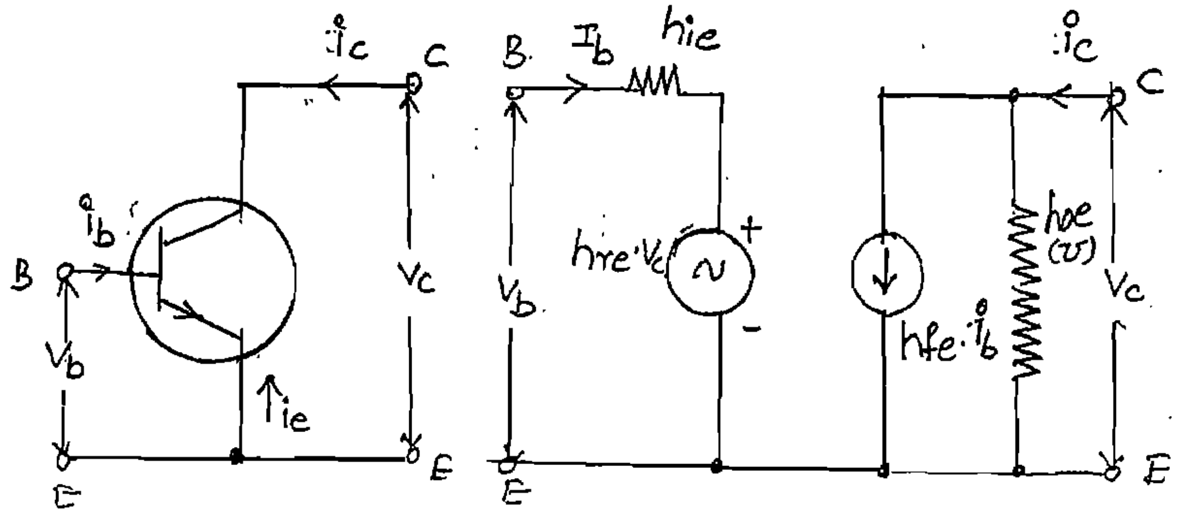
fig (a). Hybrid model for a two port network.

Hybrid model for the transistor in three different configurations:-

* CE configurations:-

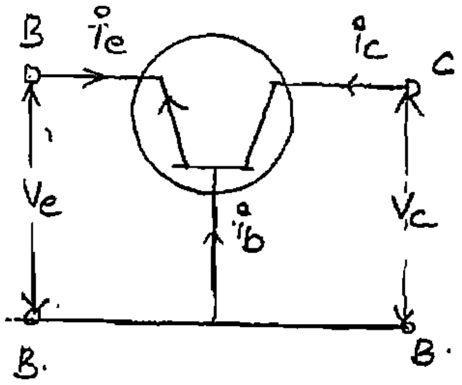
$V_b = h_{ie} \cdot i_b + h_{re} \cdot V_c$

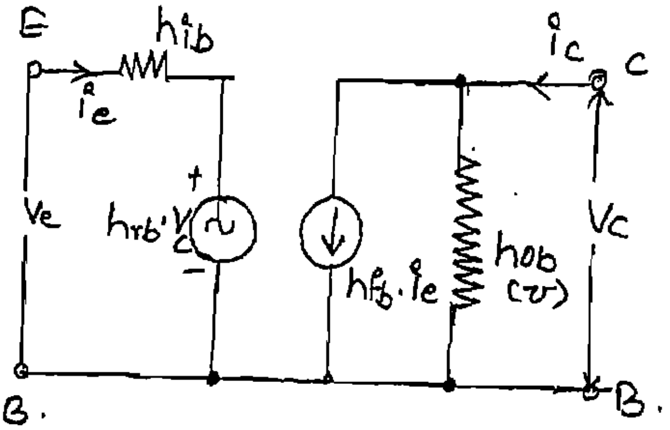
$i_c = h_{fe} \cdot i_b + h_{oe} \cdot V_c$



CB configuration :-

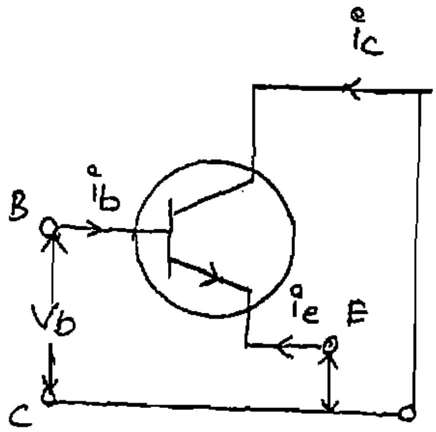
$$V_e = h_{ib} \cdot i_e + h_{rb} \cdot V_c$$
$$i_e = h_{fb} \cdot i_e + h_{ob} \cdot V_c$$

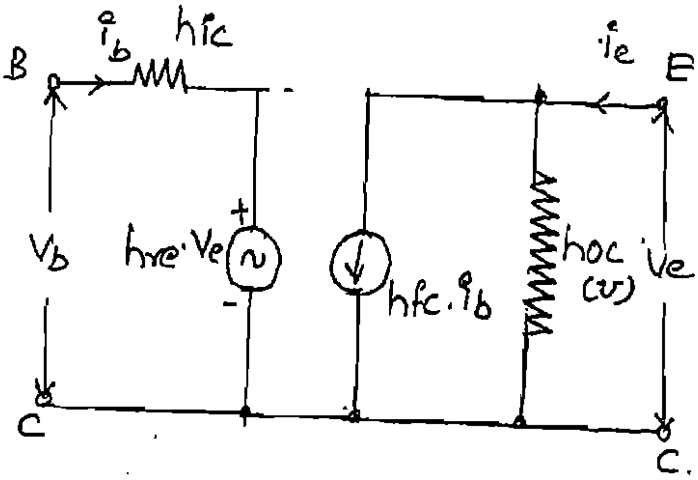




CC configuration :-

$$V_b = h_{ic} \cdot i_b + h_{rc} \cdot V_e$$
$$i_e = h_{fc} \cdot i_b + h_{oc} \cdot V_e .$$





Advantages of H- parameters :-

→ H- parameters are real numbers upto radio frequencies.

→ They are easy to measure

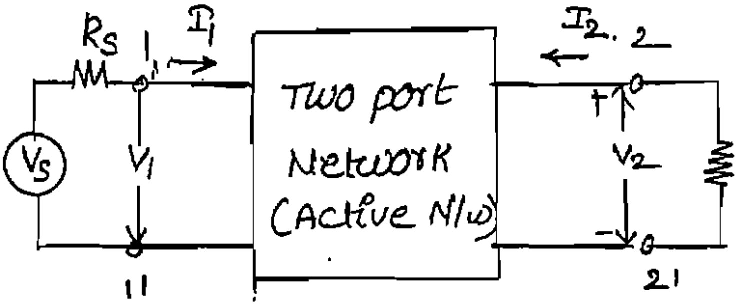
→ They are convient to use in circuit analysis and design.

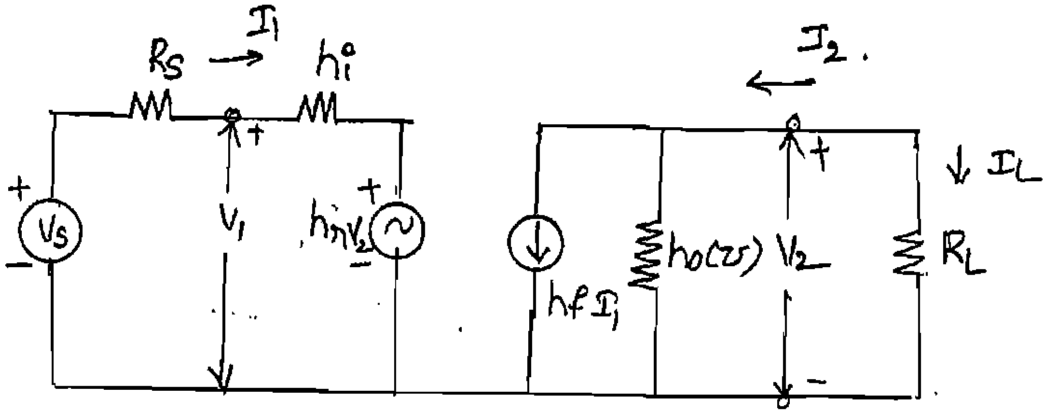
→ Easily convertable one configuration to another.

→ They can determine from the transistor static characteristic curves.

* Analysis of transistor amplifier circuit using H-parameters (Exact analysis):-

A transistor amplifier can be constructed by connecting an external load and signal source and biasing the transistor property as shown in below fig.





$$I_C = h_{fe} i_b + h_{oe} V_C$$

$$= h_{fe} i_b + h_{oe}(-I_C R_L)$$

$$I_C = h_{fe} i_b - h_{oe} I_C R_L$$

$$I_C(1 + h_{oe} R_L) = -h_{fe} i_b.$$

$$A_I = \frac{-I_C}{I_b} = \frac{-h_{fe}}{1 + h_{oe} R_L}.$$

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

2. Input Impedence (Z_i):-

It is defined as the ratio of input voltage (V_s) to the input current (I_b)

$$Z_i = \frac{V_s}{I_b}$$

$$V_b = h_{ie} I_b + h_{re} V_c.$$

$$Z_i = \frac{h_{ie} I_b + h_{re} V_c}{I_b}.$$

$$= h_{ie} + h_{re} \frac{V_c}{I_b}.$$

$$V_c = -I_C R_L.$$

$$V_c = A_I I_b R_L \qquad \left[\because A_I = \frac{-I_C}{I_b}\right]$$

$$Z_i = h_{ie} + h_{re} \frac{A_I I_b R_L}{I_b}$$

7. Power gain:-

$$A_p = \frac{P_2}{P_1} = \frac{-V_2 I_2}{V_1 I_1}$$

$$= A_V A_I \quad \left[\because A_V = \frac{A_I R_L}{Z_i}\right]$$

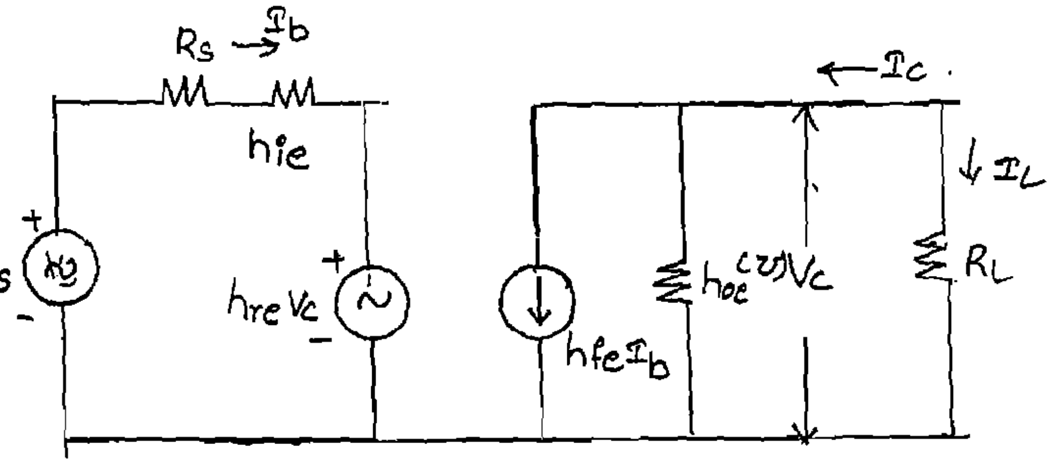
$$= \frac{(A_I)^2 R_L}{Z_i}$$

$$\therefore A_p = \frac{(A_I)^2 R_L}{Z_i}$$

Analysis of CE Amplifier using Exact H-model:-

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

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



1. Current gain (A_I):- It is defined as the ratio of output current (I_L) to the input current (I_b).

$$A_I = \frac{I_L}{I_b} = -\frac{I_c}{I_b}.$$

from the above circuit.

$$V_c = -I_c R_L$$

1. Current gain (A_I) :-

It is defined as the ratio of output current to input current

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

$$A_I = \frac{-I_2}{I_1} \quad \text{—①} \quad [\because I_L = -I_2]$$

From the above ckt.

$$I_2 = h_f I_1 + h_o V_2 \quad \text{—②}$$

$$V_2 = -I_2 R_L$$

sub in eq ②.

$$I_2 = h_f I_1 + h_o(-I_2 R_L)$$

$$I_2 = h_f I_1 - h_o I_2 R_L$$

$$I_2 + h_o I_2 R_L = h_f I_1$$

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

$$A_I = \frac{-I_2}{I_1} = \frac{-h_f}{1 + h_o R_L}.$$

$$\therefore A_I = \frac{-h_f}{1 + h_o R_L}.$$

2. Input impedence (Z_i) :-

It is defined as the ratio of input voltage (V_1) to the input current (I_1).

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

from the input circuit $V_1 = h_i I_1 + h_r V_2$.

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

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

$$V_2 = -I_2 R_L$$

$$V_2 = A_I \cdot I_1 \cdot R_L \qquad \left[\because A_I = -\frac{I_2}{I_1}\right]$$

$$Z_i = h_i + h_r \frac{A_I \cdot I_1 R_L}{I_1}$$

$$Z_i = h_i + h_r A_I R_L \qquad \left[\because A_I = \frac{-h_f}{1 + h_o R_L}\right]$$

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

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

$$\boxed{Z_i = h_i - \frac{h_f h_r}{Y_0 + h_o}}$$

Note:- Input impedence is a function of load impedance

3. voltage gain:-

It is defined as the ratio of output voltage (V_2) to input voltage (V_1).

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

$$V_2 = -I_2 R_L = A_I I_1 R_L$$

$$A_V = \frac{A_I I_1 R_L}{V_1} = \frac{A_I R_L}{Z_i} \qquad \left[\because Z_i = \frac{V_1}{I_1}\right].$$

4. Output admittance (Y_o):-

It is defined as the ratio of output current (I_2) to output voltage V_2.

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

with $V_S = 0$, & $R_L = \infty$

$$I_2 = h_f I_1 + h_o V_2.$$

dividing above eq with V_2 we get

$$\frac{I_2}{V_2} = h_f \frac{I_1}{V_2} + h_o. \quad \text{—— (1)}$$

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

with $V_S = 0$, By apply KVL to i/p circuit

$$R_S I_1 + h_I I_1 + h_r V_2 = 0.$$

$$I_1 (R_S + h_I) = -h_r V_2.$$

$$\frac{I_1}{V_2} = \frac{-h_r}{R_S + h_I} \quad \text{— (2)}$$

sub (2) in eq (1).

$$Y_o = h_f \left(-\frac{h_r}{R_S + h_I}\right) + h_o.$$

$$\boxed{Y_o = h_o - \frac{h_r h_f}{R_S + h_I}}$$

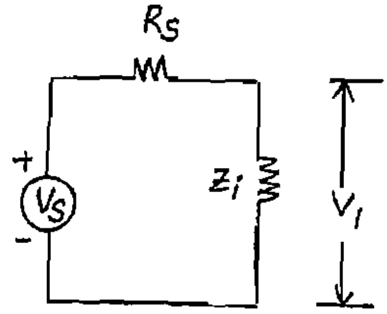
Note:- output admittance is a function of source resistance.

5. Voltage amplification (A_{VS}) taking into account the resistance R_S of the source :-

$$A_{VS} = \frac{V_2}{V_S}$$

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

$$= A_V \frac{Z_i}{Z_i + R_S}$$



$$A_{VS} = \frac{A_I R_L}{Z_i} * \frac{Z_i}{Z_i + R_S}$$

(from the thevinons equivalent theorem)

$$V_1 = \frac{V_S Z_i}{Z_i + R_S}$$

$$\frac{V_1}{V_S} = \frac{Z_i}{Z_i + R_S}$$

$$\boxed{A_{VS} = \frac{A_I R_L}{Z_i + R_S}}$$

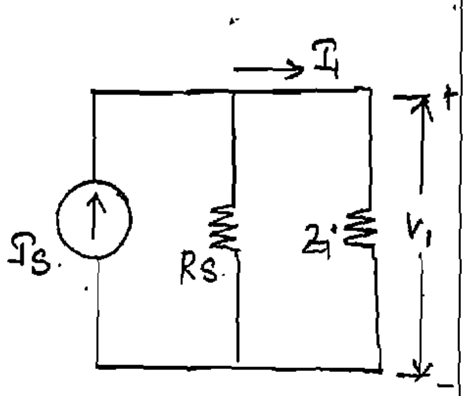
Note :- If $R_S = 0$ then $A_{VS} = A_V$

⑥ current amplification factor :-

$$A_{IS} = \frac{I_2}{I_S}$$

$$= -\frac{I_2}{I_1} \cdot \frac{I_1}{I_S}$$

$$= A_I \frac{I_1}{I_S}$$



from the figure $I_1 = \frac{I_S R_S}{R_S + Z_i}$

$$\frac{I_1}{I_S} = \frac{R_S}{R_S + Z_i}$$

$$\boxed{\therefore A_{IS} = A_I \frac{R_S}{R_S + Z_i}}$$

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

$= h_{ie} + h_{re}\left(\frac{-h_{fe}}{1+h_{oe}R_L}\right)R_L \quad \left[\because A_I = -\frac{h_{fe}}{1+h_{oe}R_L}\right]$

$$\boxed{Z_i = h_{ie} - \frac{h_{re}h_{fe}}{Y_0 + h_{oe}}}$$

③. Voltage gain (A_V):- It is defined as the ratio of output voltage (V_c) to the input voltage (V_s).

$$A_V = \frac{V_c}{V_s}.$$

$$V_c = -I_c R_L = A_I I_b R_L$$

$$A_V = \frac{A_I I_b R_L}{V_s}.$$

$$\boxed{\therefore A_V = \frac{A_I R_L}{Z_i}}$$

④ output admittance:- It is defined as the ratio of output current (I_L) to the input voltage (V_c).

$$Y_0 = \frac{I_L}{I_c} = \frac{-I_c}{V_c}.$$

$V_S = 0, \; R_L = \infty$

$$I_c = h_{fe} I_b + h_{oe} V_c$$

diving the above equation with V_c.

$$\frac{I_c}{V_c} = h_{fe}\frac{I_b}{V_c} + h_{oe} \quad \text{--- ①}$$

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$V_s = 0$, By apply KVL to i/p circuit

$$R_s I_b + h_{ie} I_b + h_{re} V_c = 0.$$

$$I_b (R_s + h_{ie}) = - h_{re} V_c.$$

$$\frac{I_b}{V_c} = -\frac{h_{re}}{R_s + h_{ie}} \quad \text{—} (2)$$

sub (2) in eq (1). we get

$$Y_0 = -\frac{h_{fe} h_{re}}{R_s + h_{ie}} + h_{oe}$$

$$\therefore Y_0 = h_{oe} - \frac{h_{re} h_{fe}}{R_s + h_{ie}}$$

Conversation formulas for the parameters of three transistor parameters :-

1. From CE to CB:-

* $h_{ib} = \frac{h_{ie}}{h_{fe} + 1}$

* $h_{rb} = \frac{h_{ie} h_{oe}}{1 + h_{fe}} - h_{re}$

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

* $h_{ob} = \frac{h_{oe}}{1 + h_{fe}}$.

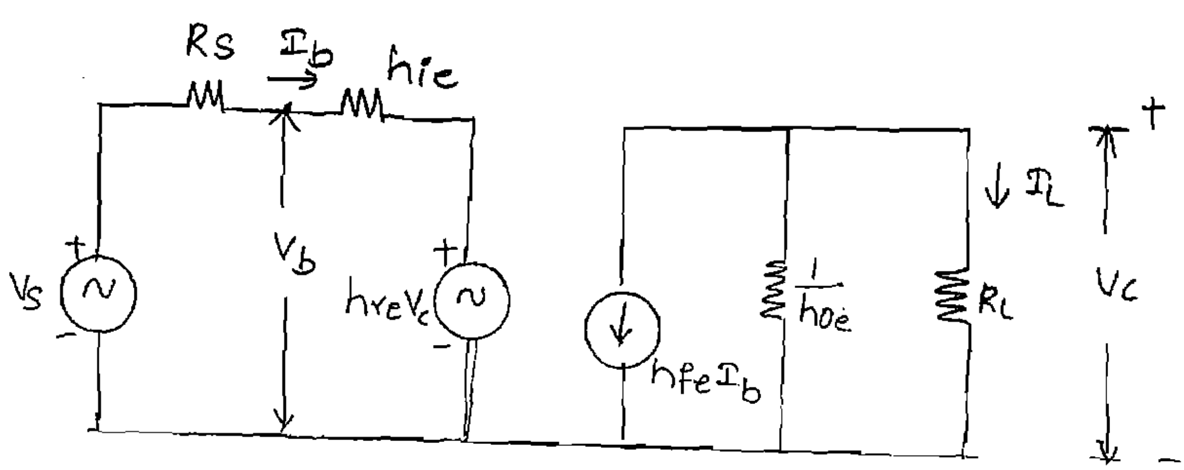
2. from CB to CE :-

* $h_{ic} = h_{ie}$
* $h_{rc} = 1 - h_{re}$
* $h_{fc} = -(1+h_{fe})$
* $h_{oc} = h_{oe}$

3. from CB to CC :-

* $h_{ic} = \frac{h_{ib}}{1+h_{fb}}$
* $h_{rc} = \frac{h_{ib}h_{ob}}{1+h_{fb}} - h_{rb}$
* $h_{fc} = \frac{-h_{fb}}{1+h_{fb}}$
* $h_{oc} = \frac{h_{ob}}{1+h_{fb}}$

Analysis of transistor amplifier using approximate H-model :-



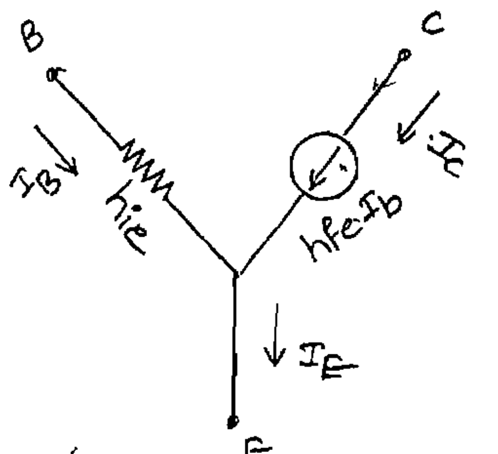
From the equivalent circuit $\frac{1}{h_{oe}}$ is an parallel with R_L. The typical values of H-parameters.

1. h_{oe} can be neglected by comparing with the load resistance R_L i.e $h_{oe} << 1$

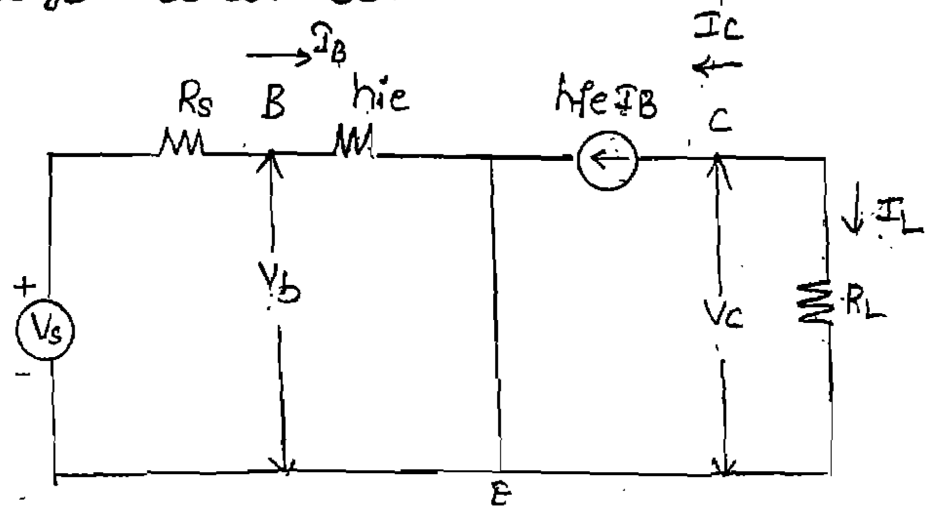
2. $h_{re} \cdot V_c = h_{re} h_{fe} I_b R_L$ $\left(\because V_c = I_c \cdot R_L ;\ \because I_c = h_{fe} I_b \right)$

$h_{re} h_{fe} \approx 0.01$

$\therefore$ $h_{re} V_c$ are also neglected.



Analysis of CE Amplifier using approximate H-model:-



1. Current gain :-

$$A_I = \frac{I_L}{I_B} \quad (I_L = -I_C)$$

$$A_I = -\frac{I_C}{I_B}$$

from the figure $I_C = h_{fe} I_B$ then

$$A_I = -\frac{h_{fe} I_B}{I_B}$$

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

2. Input impedance :-

$$z_i = \frac{V_b}{I_B}$$

from the figure $V_b = h_{ie} I_B$

then

$$z_i = \frac{h_{ie} I_B}{I_B}$$

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

3. Output admittance :-

$$Y_0 = \frac{\text{o/p current}}{\text{o/p voltage}}$$

$$= \frac{I_L}{V_C} \Big| V_S = 0.$$

$V_S = 0$ i.e $I_b = 0$

$Y_0 = 0$ then.

$$\boxed{R_0 = \infty}. \quad R_0 = \frac{1}{Y_0} = \frac{1}{0}$$

4. Voltage gain (A_V) :-

$$A_V = \frac{V_C}{V_b}$$

($\because V_C = I_L \cdot R_L$, $V_b = h_{ie} I_B$.

$= -I_C R_L$)

$= -h_{fe} I_B R_L$).

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

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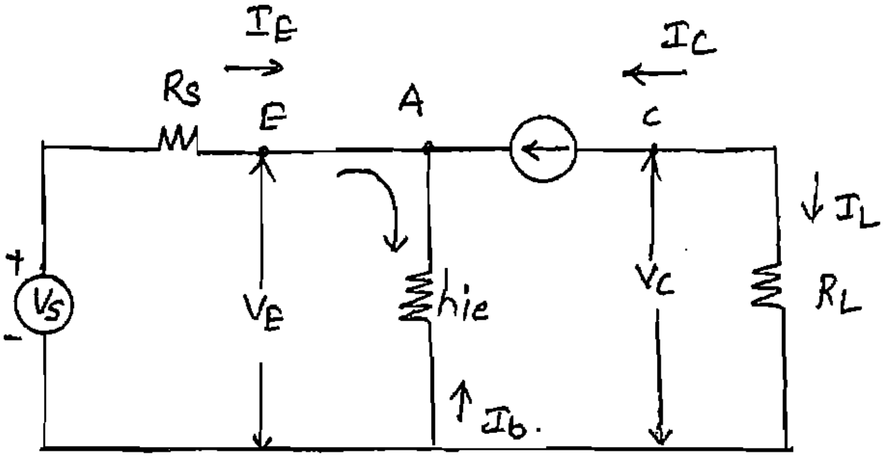
Analysis of CB Amplifier using approximate H-model :-



The figure shows the equilant circuit of CB using simplified model or approximate model base is grounded.

1. current gain :-

$$A_I = \frac{o/p\ current}{I/p\ current}$$

$$= \frac{I_L}{I_E} \quad (I_L = -I_C)$$

$$= \frac{-I_C}{I_e} \quad \text{--- (1)}$$

from fig $I_C = h_{fe} I_b$ --- (2)

Apply KCl at node A.

$$I_b + I_C + I_E = 0$$

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

$$I_E = -I_B(1+h_{fe}) \quad \text{--- (3)}$$

sub in eq (3), (2) in eq (1).

we get.

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

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

$$\boxed{A_V = -h_{fb}}$$

2. Input Impedance :-

$$Z_i = \frac{V_E}{I_E}.$$

from fig $V_E = -h_{ie} I_B$.

and $I_E = -I_B(1+h_{fe})$.

$$Z_i = \frac{-h_{ie} I_B}{-I_B(1+h_{fe})}$$

$$Z_i = \frac{h_{ie}}{1+h_{fe}}$$

$$\boxed{Z_i = h_{ib}.}$$

3. Output Impedance :-

$$Z_o = \frac{o/p \text{ voltage}}{o/p \text{ current}}$$

$$= \frac{V_C}{I_L} \Big| V_S = 0.$$

$$= \frac{V_C}{-I_C}$$

$V_S = 0$, i.e $I_C = 0, I_b = I_C = 0$

$$\boxed{Z_0 = \infty}$$

4. Voltage gain :-

$$A_V = \frac{o/p \text{ voltage}}{i/p \text{ voltage}} = \frac{V_C}{V_E}.$$

from fig $V_C = I_L R_L = -I_C R_L$

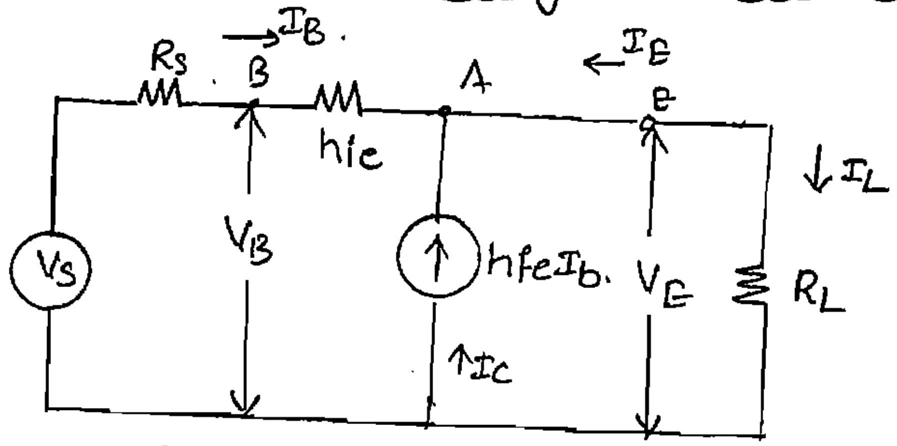
$= -h_{fe} I_B R_L$

$V_E = -h_{ie} I_B$.

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

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

Analysis of CC amplifier using simplified H-model:-



The figure shows equilant circuit of CC Amplifier using simplified h-model with collector is grounded.

1. Current gain:-

$$A_I = \frac{\text{o/p current}}{\text{i/p current}}$$

$$A_I = \frac{I_L}{I_B} = \frac{-I_E}{I_B}$$

Apply KCL at node A.
we get.

$I_C + I_b + I_e = 0$. $[I_C = h_{fe} I_B)$

$I_b(1+h_{fe}) + I_e = 0$

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

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

$A_I = 1+h_{fe}$

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

2. Input impedance:-

$$Z_i = \frac{\text{i/p voltage}}{\text{i/p current}} = \frac{V_b}{I_b}$$

Apply KVL.

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

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

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

$$Z_i = \frac{I_B(h_{ie} + (1+h_{fe})R_L)}{I_B}$$

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

3. voltage gain :-

$$A_V = \frac{\text{o/p voltage}}{\text{I/p voltage}}$$

$$= \frac{V_E}{V_b}$$

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

$$V_E = I_L R_L$$

$$= I_B(1+h_{fe})R_L \quad \{\because I_L = -I_E = (1+h_{fe})I_B\}.$$

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

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

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

$$\boxed{A_V = \frac{A_I R_L}{Z_i}}$$

output impedance :-

$$Z_0 = \frac{\text{o/p voltage}}{\text{o/p current}}$$

$$= \frac{V_E}{I_E}\bigg|_{V_S=0}.$$

$V_S=0$ i.e $I_C=0, I_B=0, I_E=0$.

then

$$\boxed{Z_0 = \infty}$$

comparisons of Transistor amplifier configuration

S.NO	characteristics	CB	CE	CC
1.	i/p Resistance	verylow (20Ω)	low (1KΩ)	high (500KΩ).
2.	o/p resistance.	very high (1MΩ)	high (40 KΩ)	low (50Ω)
3.	i/p current	I_E	I_B	I_B.
4.	o/p current	I_C	I_C	I_E
5.	i/p voltage applied b/w	Emitter and base	Base & E ~~Collector~~	Base & collector.
6.	o/p voltage taken b/w	C & B	C & E	E & C
7.	current amplification factor	$\alpha = \frac{I_C}{I_E}$	$\beta = \frac{I_C}{I_B}$	$\gamma = \frac{I_E}{I_B}$
8.	current gain	less than unity	high (20-few-100s)	high (20-few 100s)
9.	voltage gain	medium	medium	low (≈1)
10.	application	As i/p stage of multistage amplifiers	for Audio signal amplification	for impedance matching, buffer amplifier.

Small signal model of FET:-

The drain current of FET is a function of drain to source voltage (V_{DS}) and gate to source voltage(V_{GS})

i.e $I_D = f(V_{DS}, V_{GS})$ — ①

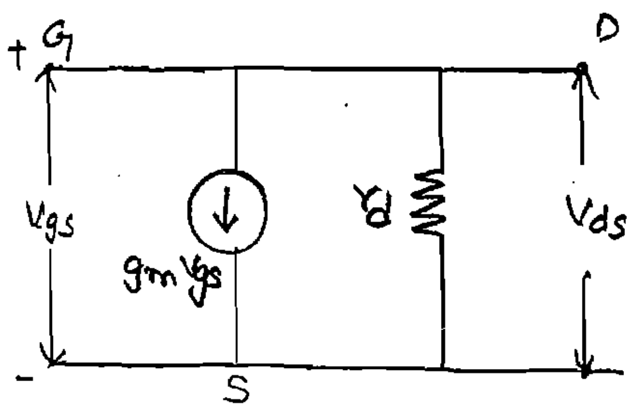
If both drain & gate voltages are valied. The change in drain current are give approximately by first two turns in the tailors series expressions of eq ①.

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

In small signal notation as for BJT $\Delta I_D = i_d$, $\Delta V_{GS} = V_{gs}$ and $\Delta V_{DS} = V_{ds}$, so eq ② can be written as.

$$i_d = g_m V_{gs} + \frac{1}{r_d} V_{ds} \quad — ③.$$

from eq ③ $i_d = 0$. It can be verified that μ, r_d & g_m are related by $\mu = r_d \cdot g_m$.



fig(a). current source model.

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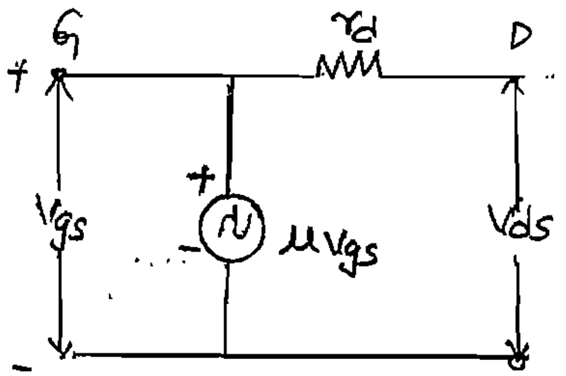

fig (b). voltage source model.

from eq (3). $g_m = \frac{i_d}{V_{gs}} \Big|_{V_{ds} = \text{Constant}}$

$$r_d = \frac{V_{ds}}{i_d} \Big|_{V_{GS} = \text{constant}}$$

FET amplifiers :-

→ FET amplifiers provide an excellent voltage gain with the added feature of high input impedance.

→ They have low power consumption with a good frequency range and minimum size and weight.

→ The noise output level is low.

→ FET amplifiers are classified into three types. They are :-

1. common source amplifiers.
2. Common drain amplifier
3. common gate amplifier.

1. common source amplifier:-

In a simple common source amplifier is shown in fig (a). and the associated small signal equivalent circuit using the voltage source model of FET is shown in fig (b).

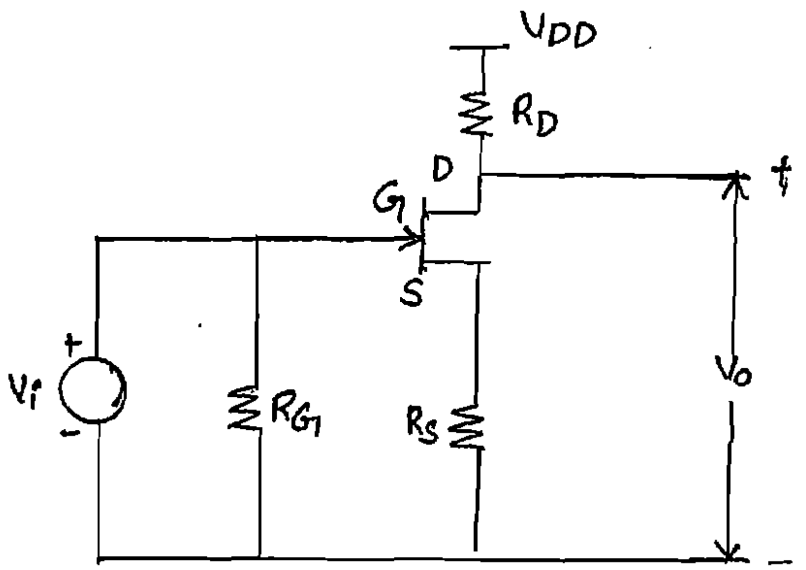

fig (a). common source amplifier.

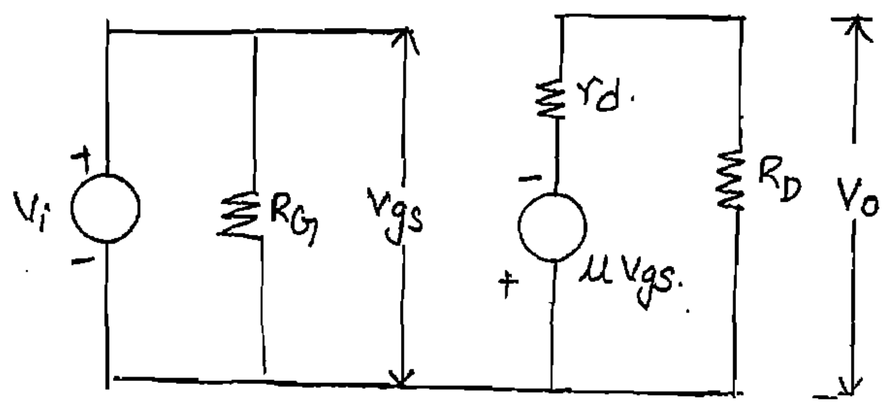

fig (b). Small signal equivalent ckt of CS Amplifier.

Voltage gain:- From the small signal equivalent ckt of CS Amplifier.

The output voltage $V_o = \frac{-\mu V_{gs} R_D}{r_d + R_D}$

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where $V_{gs} = V_i$, the input voltage.

Hence voltage gain $A_v = \frac{o/p \text{ voltage}}{I/p \text{ voltage}}$.

$$A_V = \frac{\frac{-\mu V_i R_D}{r_D + R_D}}{V_i}$$

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

2. Input impedance :- from the fig (b). Input impedance

$$\boxed{Z_i = R_G}$$

Note:- for voltage devider bias as in CE Amplifier of BJT $R_G = R_1 \| R_2$

3. Output Impedance :-

output impedance is the measured at the output terminals with input voltage $V_i = 0$. from fig (b) $V_i = 0$, $V_{GS} = 0$ and hence $\mu V_{gs} = 0$.

$$Z_o = r_d \parallel R_D.$$

Normally $R_D >> r_d$.

then neglected r_d.

$$\boxed{Z_o = R_D.}$$

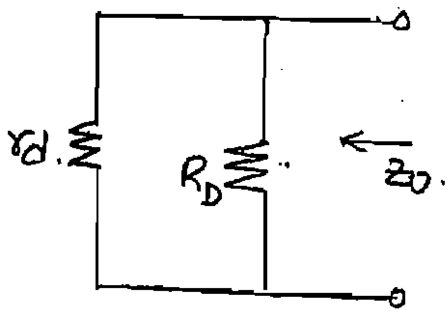


fig (c). Calculation of o/p Impedance.

Common drain Amplifier :-

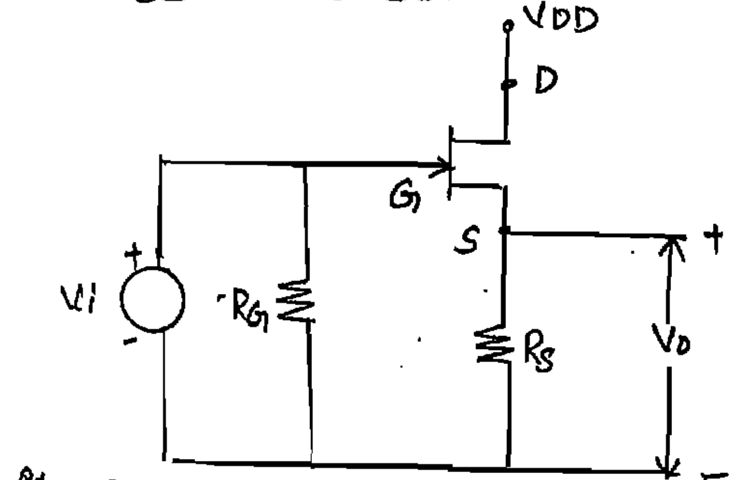


fig (a). Common Drain amplifier.

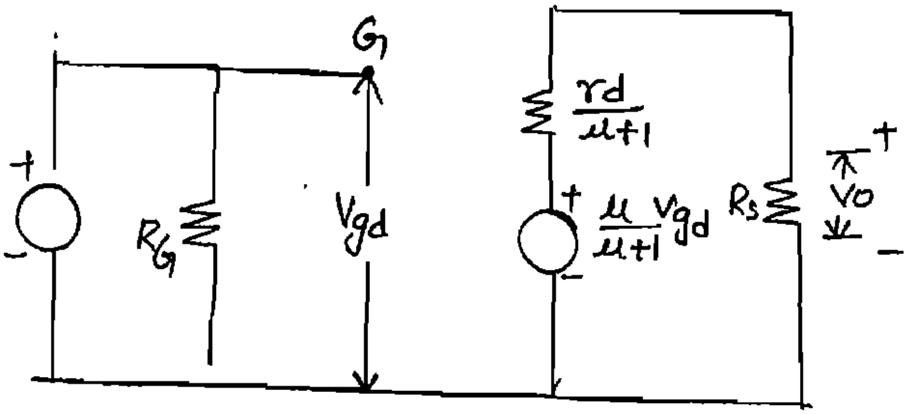


fig (b). Small signal equivalent ck of CD Amplifier.

A simple common drain amplifier as shown in fig (a). and the associated small signal equivalent circuit using the voltage source model of FET shown in fig (b).

The voltage V_{GD} is more easily determined than V_{GS}. The voltage source in the o/p circuit is expressed interms of V_{GD}.

The o/p voltage $V_0 = \dfrac{\frac{\mu}{\mu+1} V_{gd} R_S}{\frac{r_d}{\mu+1} + R_S}$

where $V_{GD} = V_i$. i.e input voltage.

Hence the voltage gain $A_V = \dfrac{\text{o/p voltage}}{\text{i/p voltage}} = \dfrac{V_o}{V_i}$

$$A_V = \dfrac{\dfrac{\frac{\mu}{\mu+1} V_{gd} R_S}{\frac{r_d}{\mu+1} + R_S.}}{V_{gd}.}$$

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

From fig (b). Input impedance $\boxed{Z_i = R_G}$

From fig (b). output impedance measured at o/p terminals with i/p voltage $V_i = 0$. i.e $V_i = 0$, $V_{GD} = 0$;

$\frac{\mu}{\mu+1} V_{gd} = 0$.

So $Z_0 = \dfrac{r_d}{\mu+1} \parallel R_S$

where $\mu >> 1$

$Z_0 \simeq \dfrac{r_d}{\mu} \parallel R_S = \dfrac{1}{g_m} \parallel R_S$

$Z_0 = \dfrac{1}{g_m} \parallel R_S$.

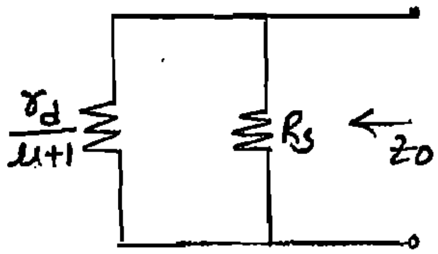
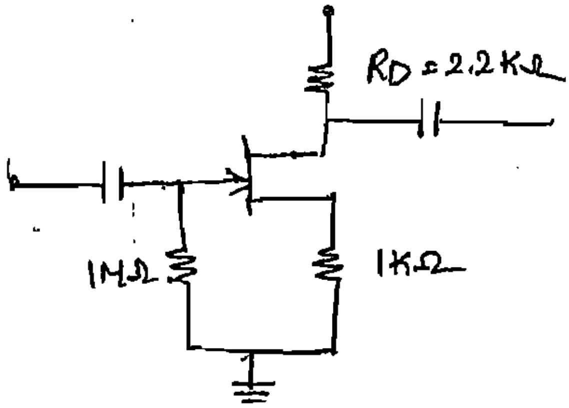


fig (c). calculation of o/p impedance.

① For CS amplifier as shown in fig (a) operating points by $V_{GSQ} = -2.5V$ $V_P = -6V$ & $I_{DQ} = 2.5mA$ with $I_{DSS} = 8mA$ calculate g_m, r_d, A_V, Z_i, Z_o.



Sol:-

$$g_m = g_{mo}\left(1 - \frac{V_{GS}}{V_P}\right)$$

$$g_{mo} = \left|\frac{-2I_{DSS}}{V_P}\right|$$

$$= \left|\frac{-2 \times 8 \times 10^{-3}}{-6}\right| = 2.6 \times 10^{-3}$$

$$g_m = 2.6 \times 10^{-3}\left(1 - \frac{-2.5}{-6}\right)$$

$$\boxed{g_m = 1.5 \times 10^{-3}}$$

$$r_d = \frac{V_{gs}}{i_d} = \frac{-2.5}{2.5mA} = -10^{+3}$$

$$\boxed{r_d = -1000}$$

$$A_V = \frac{-\mu R_D}{r_d + R_D}$$

$$= \frac{1.5\,(2.2) \times 10^{+3}}{-1000 + 2.2 \times 10^{+3}}$$

$$\boxed{A_V = 2.75}$$

$Z_o = R_D = 2.2K\Omega$

$Z_i = R_G = 1M\Omega$.

$$\left[\begin{aligned} \mu &= r_d\, g_m \\ &= -1000\,(1.5 \times 10^{-3}) \\ &= -1.5 \end{aligned}\right]$$

(2). The amplifier utilizes n-channel FET using source self bias circuit for which $V_p = -2V$, $I_{DSS} = 1.65mA$. It is desired to bias at $I_D = 0.8mA$, $A_V = 20dB$ using $V_{DD} = 4V$, assumed $r_d >> R_D$ find (i) V_{GS}, (ii) g_m, (iii) R_S (iv) R_D.

Sol:- Given data.

$V_p = -2V$, $I_{DSS} = 1.65mA$

$I_D = 0.8mA$, $A_V = 20dB$, $V_{DD} = 4V$.

W.K.T $g_m = g_{mo}\left(1 - \frac{V_{GS}}{V_P}\right)$

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$\frac{0.8\times10^{-3}}{1.65\times10^{-3}} = \left(1 + \frac{V_{GS}}{2}\right)^2.$$

$$0.6963 = 1 + \frac{V_{GS}}{2}.$$

$$\boxed{V_{GS} = -0.614}\ V$$

$$g_{mo} = \left|\frac{-2I_{DSS}}{V_P}\right| = \left|\frac{-2(1.65\times10^{-3})}{-2}\right| = 1.65\times10^{-3}.$$

$$g_m = 1.65\times10^{-3}\left(1 - \frac{(-0.614)}{-2}\right]$$

$$\boxed{g_m = 1.143\,mS}.$$

$$R_S = \frac{V_{GS}}{I_D} = \frac{-0.614}{0.8\times10^{-3}} \Rightarrow \boxed{R_S = -767.5\Omega}.$$

W.K.T $A_V = 20 \log \left(\frac{V_O}{V_I} \right)$.

$$20 = 20 \log \left(\frac{V_O}{V_{GS}} \right).$$

$$\frac{20}{20} = \log \left(\frac{V_O}{-0.614} \right)$$

$$\frac{V_O}{-0.614} = e^1$$

$$\boxed{V_O = -1.668\ V}$$

$$R_D = \frac{V_O}{I_D} = -\frac{1.668}{0.8 \times 10^{-3}}$$

$$\boxed{R_D = -2086.06\Omega}$$

③. For CS Amplifier $V_{GS} = -2V$, $I_{DSS} = 8mA$, $V_P = -8V$, $y_{os} = 20\mu S$, $R_G = 1M\Omega$, $R_D = 5.1K\Omega$ Calculate g_m, r_d, Z_i, Z_o, A_V.

| $R_D = Z_o = 5$

W.K.T $g_m = g_{mo} \left[1 - \frac{V_{GS}}{V_P} \right]$

$$g_{mo} = \left| \frac{-2 I_{DSS}}{V_P} \right| = \left| -\frac{2(8 \times 10^{-3})}{-8} \right|$$

$$g_{mo} = 2 \times 10^{-3}$$

$$g_m = 2 \times 10^{-3} \left(1 - \frac{-2}{-8} \right)$$

$$= 2 \times 10^{-3} (0.75)$$

$$\boxed{g_m = 1.5\ mS}$$

$Z_O = R_D = 5.1K\Omega$.

$Z_i = R_G = 1M\Omega$

$$r_d = \frac{1}{Y_{os}}$$

$$= \frac{1}{20 \times 10^{-6}}$$

$$= 50{,}000.$$

$$\mu = r_d \cdot g_m$$

$$= 50000 \times (1.5 \times 10^{-3})$$

$$= 75$$

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

$$= \frac{-75\,(5.1 \times 1000)}{50000 + (5.1 \times 1000)}$$

$$\boxed{A_V = -6.941}$$

* Comparison of CS, CD and CG JFET amplifiers :-

S.NO	CS Amplifier	CD Amplifier	CG Amplifier.
1.	Source terminal is common to i/p and o/p parts	Drain terminal is common to i/p and o/p parts	Gate is common to input and output parts.
2.	phase inversion exists between i/p and o/p	NO phase inversion exists between input and output.	NO phase inversion exists between i/p and o/p
3.	The voltage gain $A_V = \frac{-\mu R_D}{r_d + R_D}$	$A_V = \frac{\mu R_S}{r_d + R_S(\mu+1)}$	$A_V = \frac{g_m r_d R_L}{r_d + R_L}$
4.	output, input impedance at low frequency. $Z_o = R_D$	$Z_o = \frac{1}{g_m} \parallel R_S$ $Z_i = R_G$	$Z_o = \frac{r_d R_L}{r_D + R_L}$ $Z_i = \frac{1}{g_m}$
5.	$Z_i = R_G$		
6.	voltage gain is (-)ve	voltage gain is (+)ve	voltage gain is +(ve)
7.	The CS amplifier is popular as voltage amplifier	The CD is also called as source follower. It is popular as a current source	The common gate amplifier is not popular
8.	Distortion exists for relatively large input.	Distortion is less due to the presence of bypass capacitor	Distortion exists for large inputs.

Comparison between JFET and MOSFET :-

Parameter	JFET	MOSFET
Mode of operation	It can be operated in only depletion mode	It can be operated in depletion and enhancement modes.
Gate biasing :-	Gate is forward biased	Gate is biased in forward and also in reverse.
input impedance (Z_i) :-	Z_i is high but is less than that MOSFET ($Z_i \approx 10^8 \Omega$)	Z_i is high and also higher than JFET ($Z_i \approx 10^{12} \Omega$).
Drain resistance (r_d) :-	r_d for JFET is high than that of MOSFET	r_d is less than that of JFET.
Ease of manufacturing	manufacturing of JFET is less easy comparable to MOSFET	It is to easy to manufacture JFET.
Effect of electric field :-	the transverse electric field across the reverse biased Gate-Source junction control the conductivity of the channel.	the transverse electric field across the insulati layer on the semiconductor material controls t conductivity of the channel.
Leakage gate current	It is of the order of nano ampere	It is of the order of pico ampere.

Parameter	JFET	MOSFET
Ease of handling the device	JFETs are rugged	MOSFETs are susceptib to overload voltage and needs special handlin
offset voltage	It is small in JFET	It is zero in MOSFET.
suitability in IC technology	Inferior to MOSFET for suitability in IC technology.	suitable for IC technology particularly CMOSFETs.
power dissipation	considerable	negligible
Type of channel	Both P & N channel JFETs exist	Both P & N channel MOSFETS exist.
g_m	0.1 to 10 mA/V	0.1 to 20 mA/V
	0.1 to 1 MΩ	1 to 50KΩ.