Microelectronics Design

Assignment -1

Member- 1

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T-5

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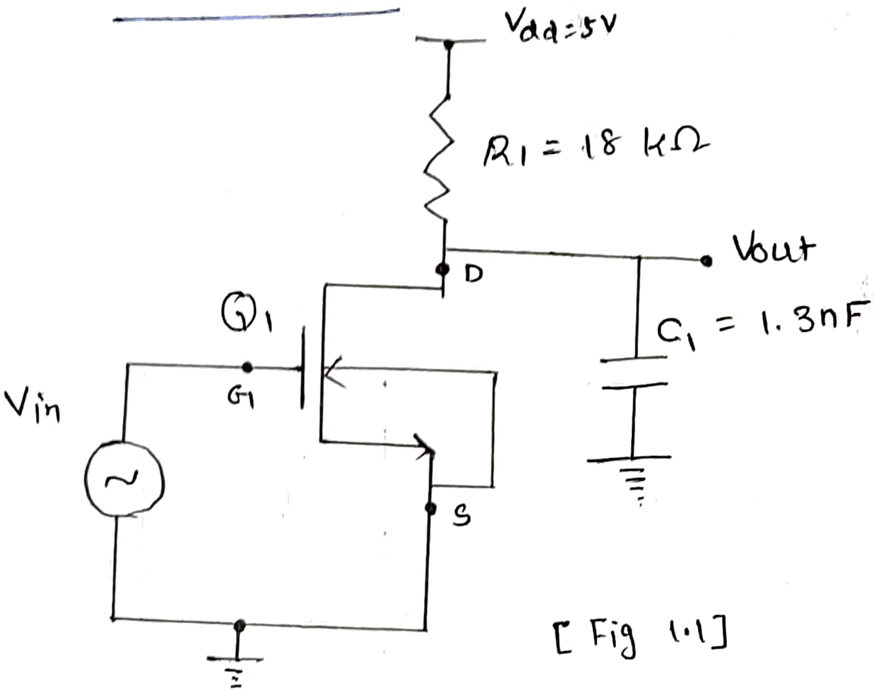
Problem - 1 :-



[Fig 1.1]

Note :- → Here input signal amplitude is 1V, and V_{ov} = 0.2 V, this small overdrive voltage will not work for such large signal so output signal will be clipped off on positive side

→ So in calculation, MOSFET to work we will be using modified V_{ov} obtained from VTC (Voltage transfer charecteristics.

→ And further results will be obtained on the basis of this V_{ov}.

→ Also 1V + 1V = 2V swing is too large, so there will be some non-linearity in output swing.

→ which can be observed by plotting output voltage spectrum, attached at last.

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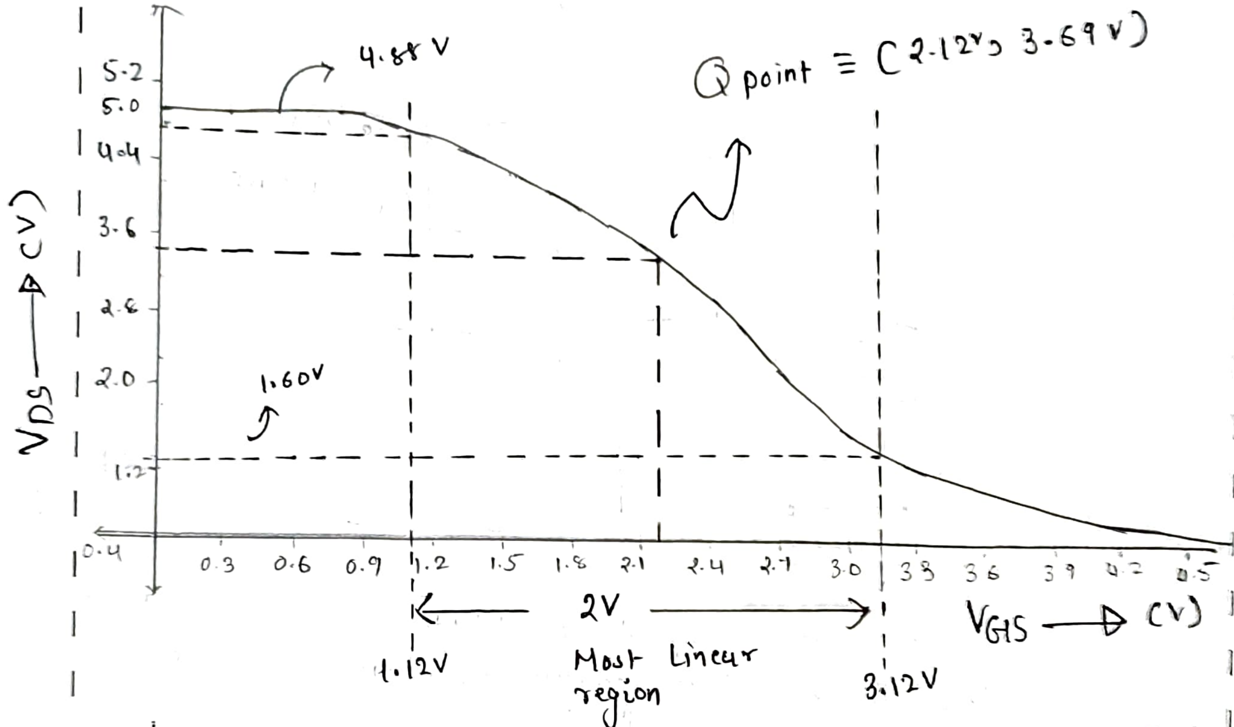
* Voltage transfer characteristics



Note :- Some values may slightly differ with SPICE simulation due to hand-drawing.

⇒ At Q-point (DC bias point) :-

$$\boxed{V_{GS} = 2.12\ V}$$

$$\boxed{I_D = 72.77\ \mu A}$$

$$\boxed{V_{DS} = 3.69\ V}$$

$$I_D = \frac{V_{DD} - V_{DS}}{R_D} = \frac{5 - 3.69}{18 \times 10^3} = 72.77\ \mu A$$

$V_{th} = 0.669$ V

$V_{ov} = 2.12 - 0.669$

$$\boxed{V_{ov} = 1.451\ V}$$

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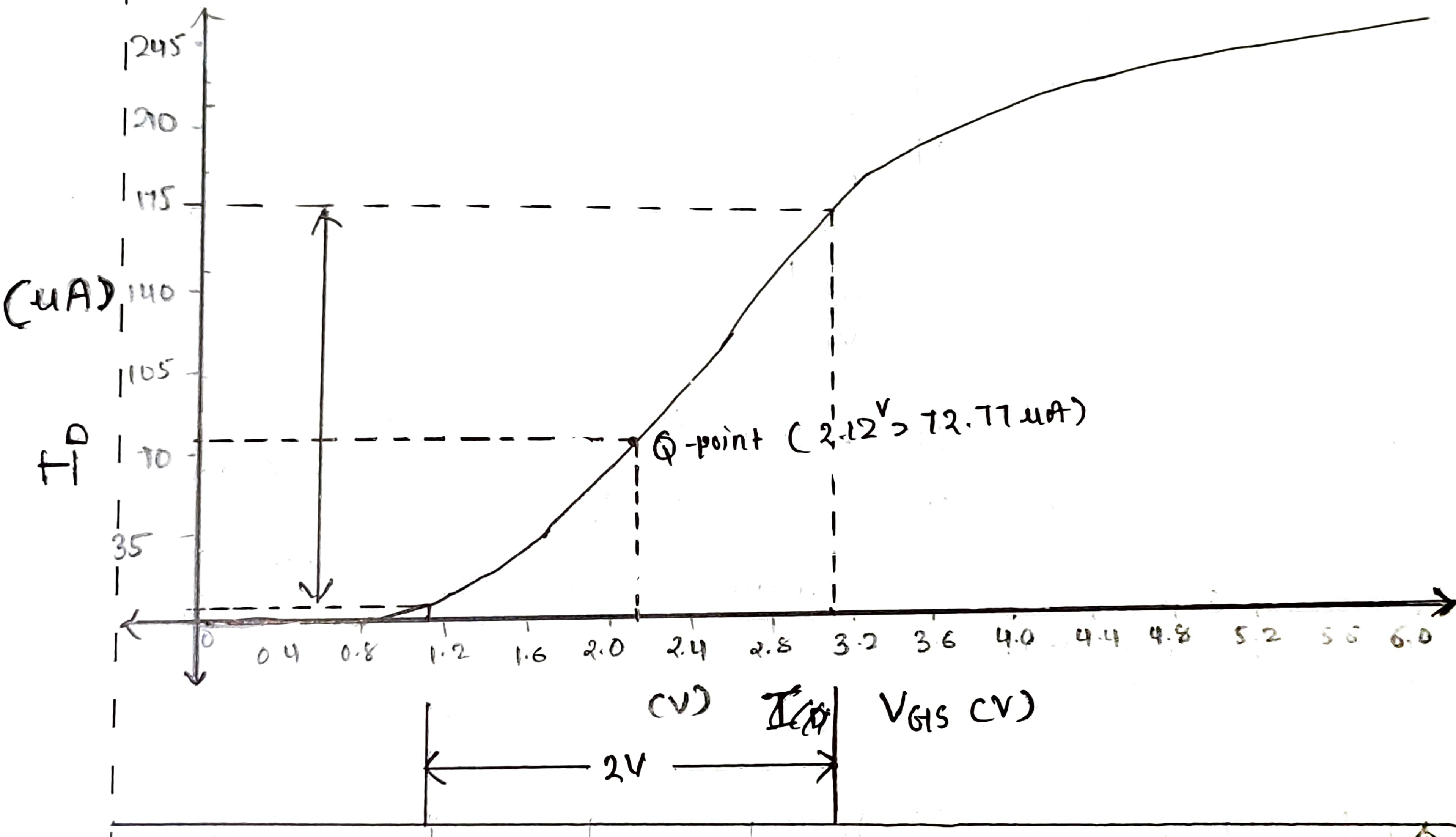
* Output characteristics :-



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$$g_m = \frac{2 I_D}{V_{ov}}$$

I_D (simulated) = 12.6513 μA

V_{ov} = 2.12688 − 0.669
(V_{gs}) − (V_{th})

V_{ov} = 1.4579 V

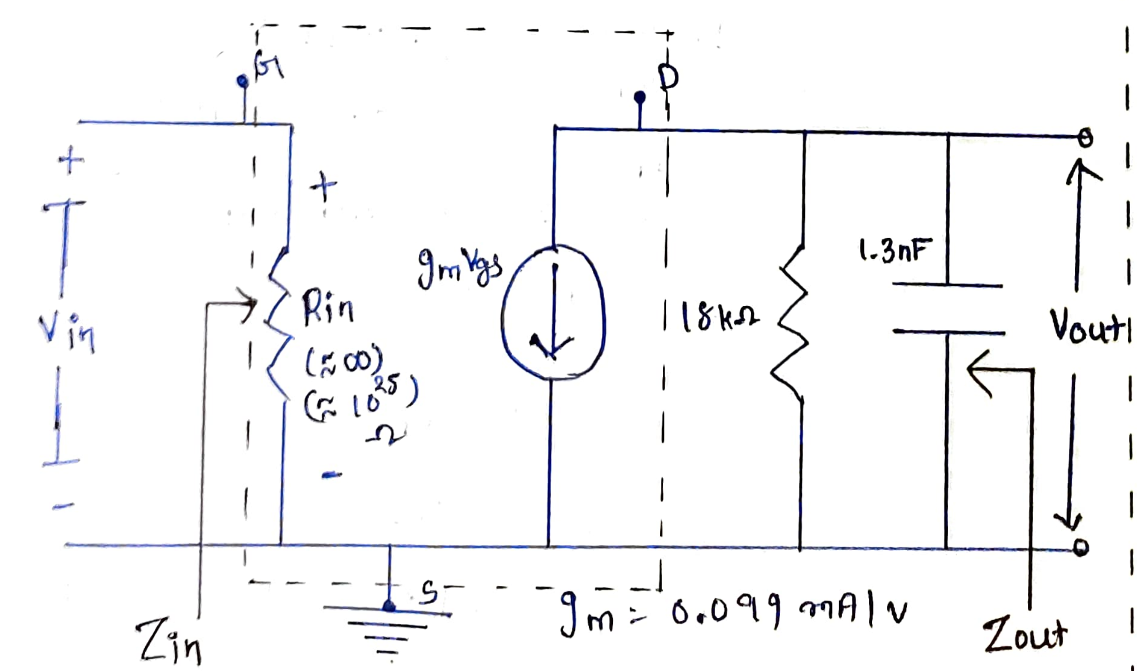
g_m = 0.099 mA/V

A_v (simulated) = −1.7500

A_v (calculated) = $-g_m R_D$
$= -0.099 \times 18 \times 10^3 \times 10^{-3}$ V/V
= −1.782
which is pretty close to simulated value.

Note:- Here channel length modulation is neglected because in 500 nm library provided, there is no mention of 'LAMBDA' (λ), so by considering default value of LAMBDA = 0, $\boxed{r_0 = \infty}$.

* Small Signal Model :-



* Rin here will be non infinite for this model, its bode plot can be found here.

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$$R_{out} = Z_{out} = R_D \parallel X_C$$

$$= \frac{(R_D)\left(\frac{1}{sC}\right)}{R_D + \frac{1}{sC}}$$

$$= \frac{R_D}{1 + sCR_D} \ \Omega$$

it has pole at $s = \frac{-1}{CR_D}$,

$$|Z_{out}| = \frac{R_D}{\sqrt{1 + (\omega C R_D)^2}} = \frac{R_D}{\sqrt{1 + (\omega C R_D)^2}} \ \Omega$$

$$\measuredangle Z_{out} = -\tan^{-1}\left(\frac{1}{\omega C R_D}\right)$$

$|Z_{out}|$ at 50 Hz (calculated) = 17.99 kΩ

$|Z_{out}|$ at 50Hz (simulated) = 17.99 kΩ

From the simulation Z_{in} at 50 Hz is order of 10^{13} so in small signal analysis it can be estimated as <u>open circuit</u>.

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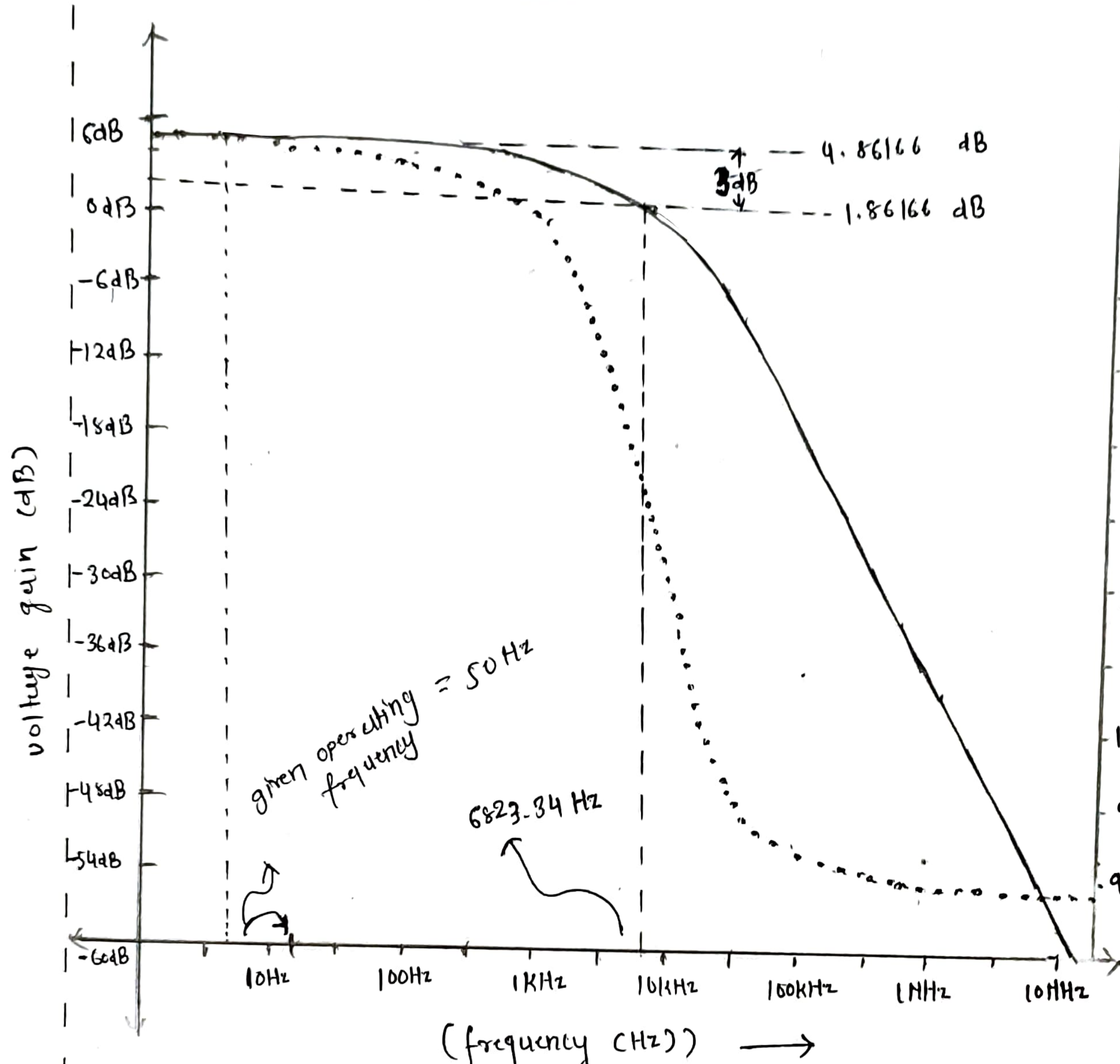
* Frequency Response.

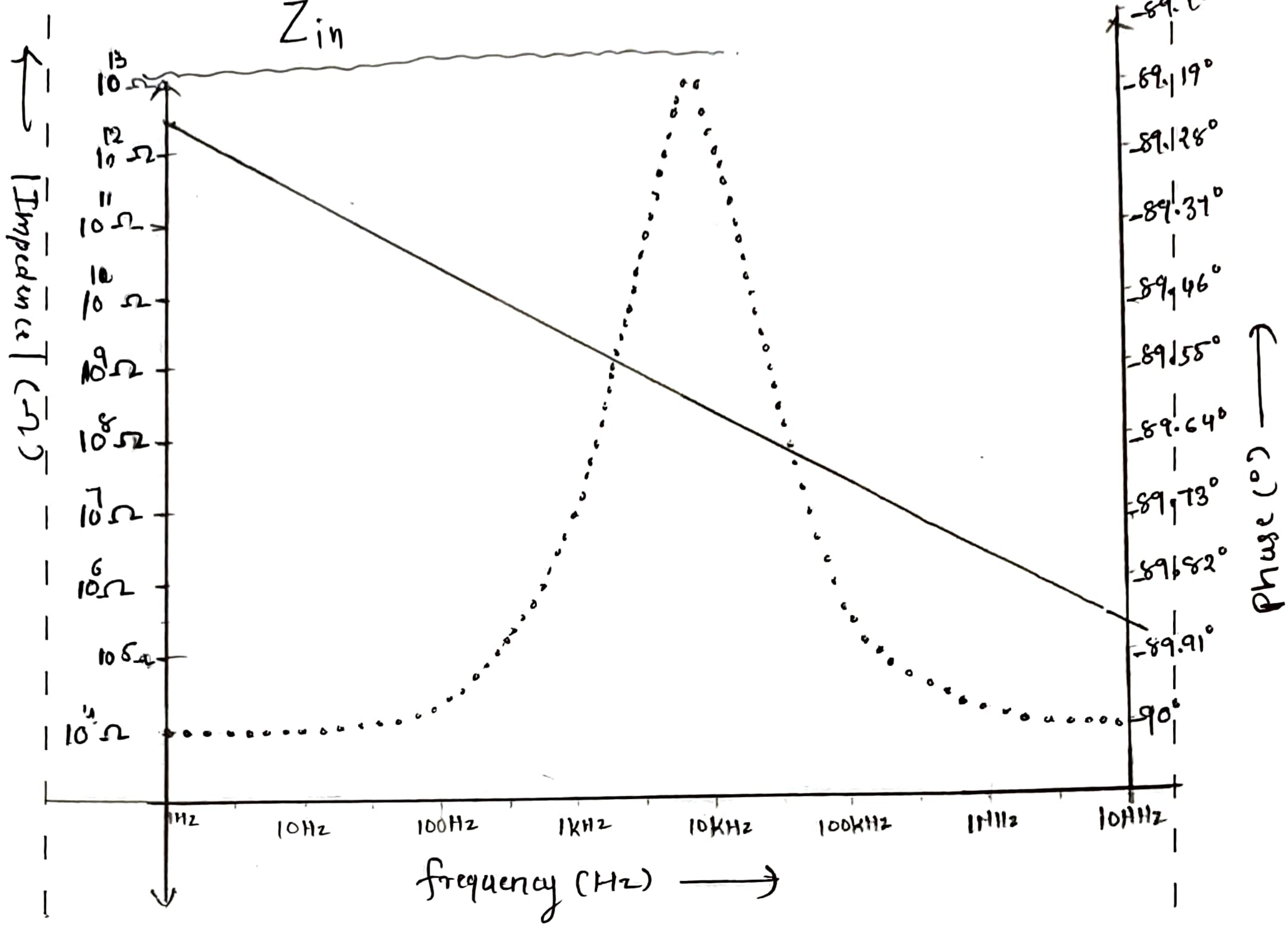


⇒ Here it can be seen that, gain decreases with increase in frequency, because Rout decreases with frequency so,

$A_v = -g_m R_{out}$, $R_{out} \downarrow \Rightarrow A_v \downarrow$

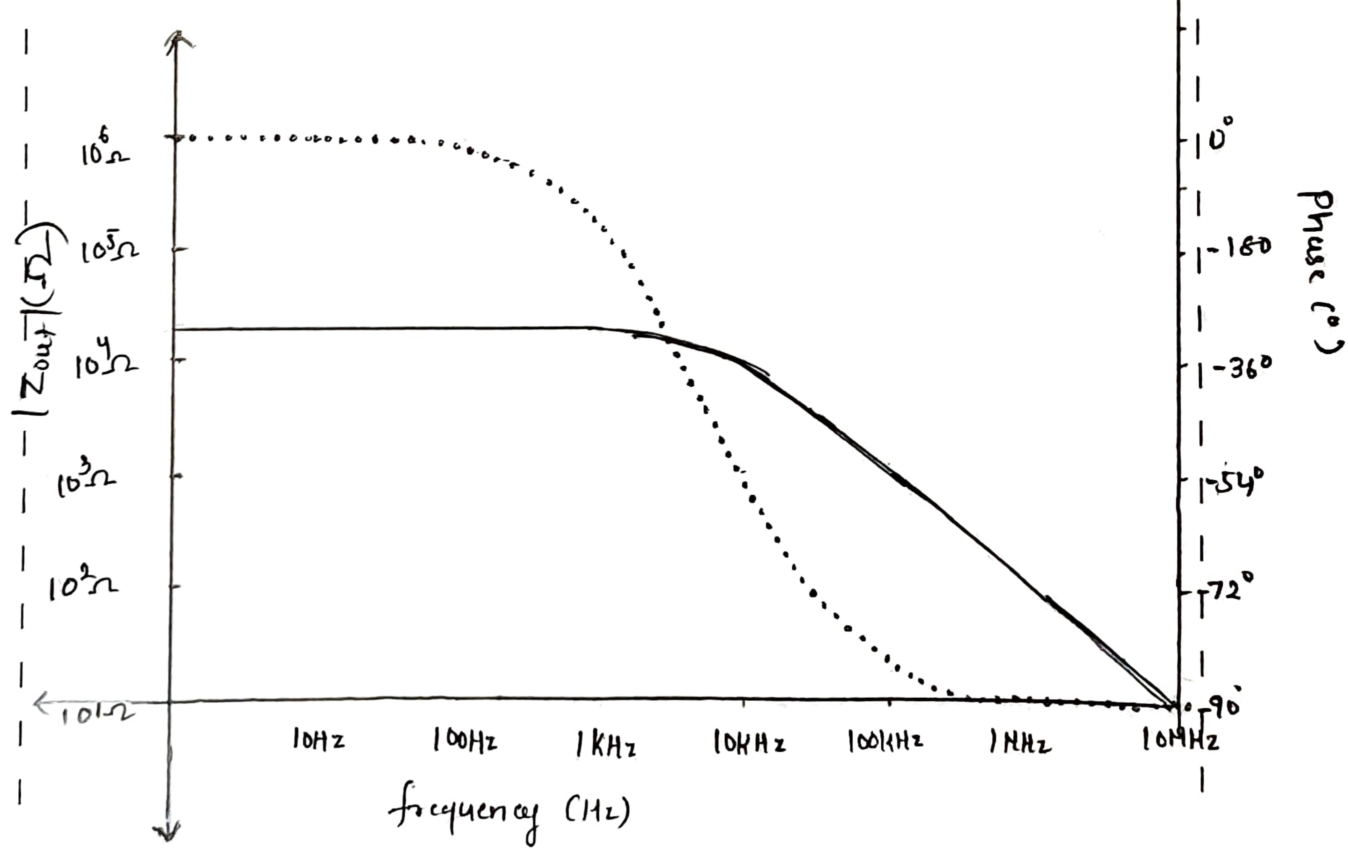
* Input Resistance (Impedence)

Zin



* Output Resistance (Impedence)

Zout



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Question-1

1. Finding DC Operating Point/Transfer Charecteristics

```
* DC operating point

.model NMOS NMOS
.model PMOS PMOS
.lib C:\Users\devan\Documents\LTspiceXVII\lib\cmp\standard.mos
.INCLUDE mue1.txt
M1 Vout in 0 0 NMOS
R1 N001 Vout 18k
V1 N001 0 5
C1 Vout 0 1.3n
V2 in 0 2.12688

.dc V2 0 10 0.0001
.backanno
.end
```

2. Finding Frequency Response

```
* Frequency Response
M1 Vout in 0 0 NMOS
R1 N001 Vout 18k
V1 N001 0 5
C1 Vout 0 1.3n
V2 in 0 2.12688 AC 1
.model NMOS NMOS
.model PMOS PMOS
.lib C:\Users\devan\Documents\LTspiceXVII\lib\cmp\standard.mos
.INCLUDE mue1.txt

.ac dec 1000 1 10Meg
.MEASUE AC vo FIND mag(V(vout)/V(in)*0.707945784) AT=1m
.MEASURE AC f FIND frequency WHEN mag(V(vout)/V(in))={mag(vo)}
.MEAS AC v1 FIND V(vout)/V(in) AT=50

.backanno
.end
```

3. Output Charecteristics:

```
* Output Charecteristics
```

```
.model NMOS NMOS
.model PMOS PMOS
.lib C:\Users\devan\Documents\LTspiceXVII\lib\cmp\standard.mos
.INCLUDE mue1.txt
M1 Vout in 0 0 NMOS
R1 N001 Vout 18k
V1 N001 0 5
C1 Vout 0 1.3n
V2 in 0 2.12688

.dc V2 0 10 0.0001
.backanno
.end
```

4. Input Impedence:

```
* Frequency Response
M1 Vout in 0 0 NMOS
R1 N001 Vout 18k
V1 N001 0 5
C1 Vout 0 1.3n
V2 in 0 2.12688 AC 1
.model NMOS NMOS
.model PMOS PMOS
.lib C:\Users\devan\Documents\LTspiceXVII\lib\cmp\standard.mos
.INCLUDE mue1.txt

.ac dec 1000 1 10Meg

* Finding Input Impedence
* Now plot -V(in)/I(V2)

.backanno
.end
```

5. Output Impedence

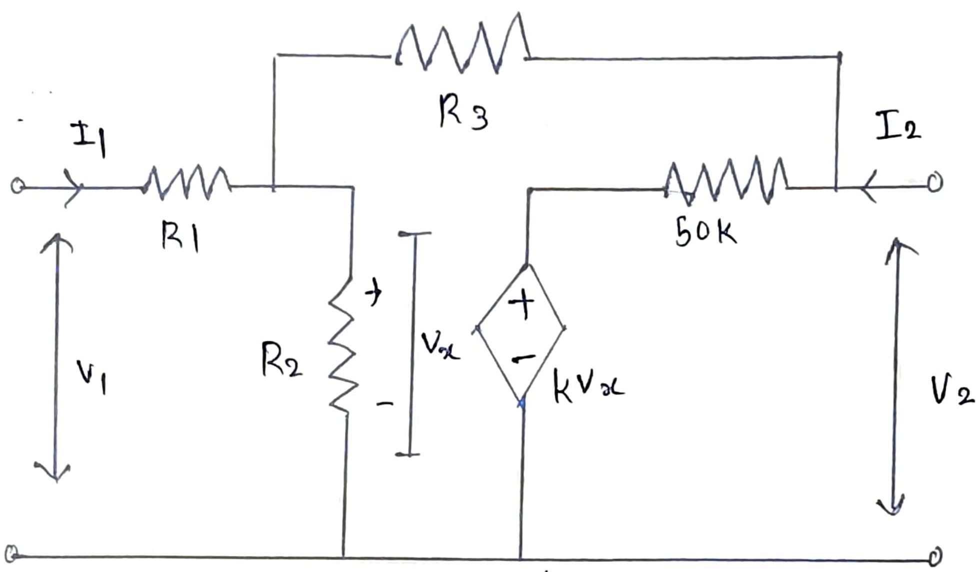
```
* C:\Users\devan\Documents\ASSNMNT1- FILES\Q1.asc
M1 Vout 0 0 0 NMOS
R1 N001 Vout 18k
V1 N001 0 5
C1 Vout 0 1.3n
V2 Vout 0 SINE(0) AC 1
.model NMOS NMOS
.model PMOS PMOS
.lib C:\Users\devan\Documents\LTspiceXVII\lib\cmp\standard.mos
.INCLUDE mue1.txt
.ac dec 1000 1 10Meg

* Finding Output Impedence
* Plot -V(vout)/I(V2)
```

```
.backanno
.end
```

:- PROBLEM - 2 :-

* Circuit Diagram :-



Here

$R1 = 55\ k\Omega$
$R_2 = 45\ k\Omega$
$R_3 = 30\ k\Omega$
$k = 14$

} According to ID no. & Test no.

* Finding z parameters :-

↳ Equation of z parameters

$$\begin{cases} V_1 = Z_{11} I_1 + Z_{12} I_2 \\ V_2 = Z_{21} I_1 + Z_{21} I_1 \end{cases}$$

↳ $V_1, V_2 \rightarrow$ dependent variable

↳ $I_1, I_2 \longrightarrow$ independent variable.

(1) Finding Z_{11}, Z_{21} :-

↳ By applying voltage at input side and keeping open circuit at output port.

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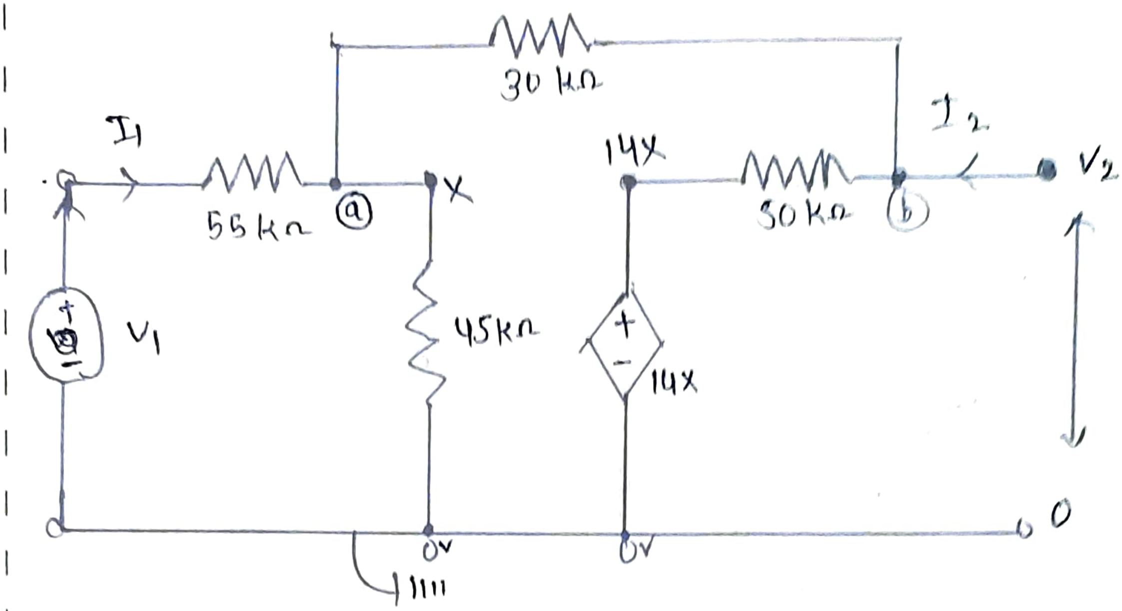

Writing KCL at (a),

$$I_1 = \frac{X}{\cancel{\ }45K} + \frac{X - V_2}{30K} \quad \text{--- (1)}$$

$$I_1 = \frac{V_1 - X}{55K} \quad \text{--- (2)}$$

From (1) and (2),

$$\frac{V_1 - X}{55K} = \frac{X}{45K} + \frac{X - V_2}{30K}$$

$$\Rightarrow \frac{V_1 - X}{11} = \frac{X}{9} + \frac{X - V_2}{6} \quad \text{--- (3)}$$

KCL at node (b)

$$\frac{V_2 - 14X}{50K} = \frac{X - V_2}{30K}$$

$$3V_2 - 42X = 5X - 5V_2$$

$$8V_2 = 47X$$

$$\boxed{X = \frac{8V_2}{47}}$$

Putting value of X in Eqn (3)

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$$\frac{V_1 - \frac{8V_2}{47}}{11} = \frac{8V_2}{47 \times 9} + \frac{\frac{8V_2}{47} - V_2}{6}$$

$$\frac{V_1}{11} = \frac{8V_2}{47 \times 11} + \frac{8V_2}{47 \times 9} - \frac{39V_2}{6 \times 47}$$

$$\boxed{V_1 = -1.1430\, V_2} \quad \text{--- } (5)$$

Putting value of (5) in (2)

$$I_1 = \frac{V_1 - \frac{8V_2}{47}}{55\text{k}}$$

$$I_1 = \frac{V_1 + \frac{8}{47}\left(\frac{V_1}{1.1430}\right)}{55\text{k}}$$

$$I_1 = \frac{V_1\left(1 + \frac{8}{47 \times 1.1430}\right)}{55\text{k}}$$

$$\boxed{Z_{11} = \frac{V_1}{I_1} = 47.871\ \text{k}\Omega}$$

Putting value of V_2 in (2)

$$I_1 = \frac{-1.1430\, V_2 - \frac{8V_2}{47}}{55\text{k}}$$

$$\boxed{Z_{21} = \frac{V_2}{I_1} = -41.882\ \text{k}\Omega}$$

* Finding Z_{22} and Z_{12} :-

↳ By applying voltage at output port and keeping open circuit at input port.

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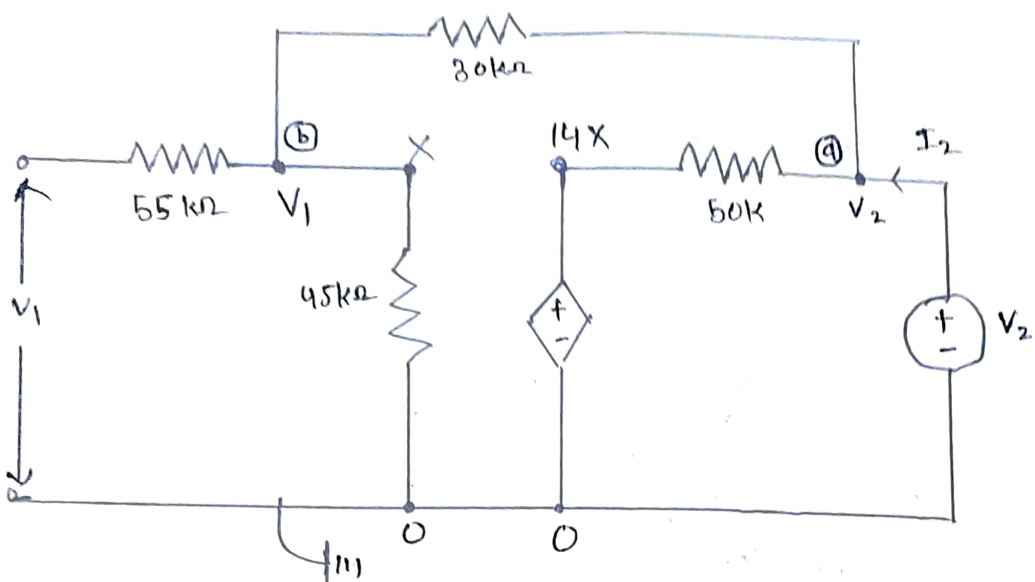

As there is no current passing through 55kΩ Resistor, $\boxed{V_1 = X}$

$$\frac{V_2 - X}{30k} = \frac{X - 0}{45K} \Rightarrow \frac{V_2 - X}{2} = \frac{X}{3}$$

$$3V_2 - 3X = 2X$$

$$\boxed{X = \frac{3V_2}{5}} \quad \cdots (1)$$

$$I_2 = \frac{V_2 - V_1}{30k} + \frac{V_2 - 14X}{50K}$$

$$= \frac{V_2 - X}{30k} + \frac{V_2 - 14X}{50k}$$

Using (1),

$$I_2 = \frac{V_2 - \frac{3V_2}{5}}{30k} + \frac{V_2 - 14 \cdot \frac{3V_2}{5}}{50k}$$

$$I_2 = V_2 \left(\frac{2}{5 \cdot 30k} - \frac{37}{5 \cdot 50K} \right)$$

$$I_2 = V_2 \times (-1.3467 \times 10^{-4})$$

$$Z_{22} = \frac{V_2}{I_2} = -7425.7425\ \Omega$$

$$\boxed{Z_{22} = -7.425\ k\Omega}$$

$V_1 = x$

$$V_1 = \frac{3V_2}{5}$$

$$V_1 = \frac{3}{5}(-7.425\times10^{3})I_2$$

$$\frac{V_1}{I_2} = \frac{3}{5}\times(-7425.7425)$$

$$= -4455.44 \ \Omega$$

$$\boxed{Z_{12}} = \boxed{-4.455 \ k\Omega}$$

$$\boxed{Z_{11} = 47.871 \ k\Omega}$$

$$\boxed{Z_{12} = -4.455 \ k\Omega}$$

$$\boxed{Z_{21} = -41.882 \ k\Omega}$$

$$\boxed{Z_{22} = -7.425 \ k\Omega}$$

From Z-parameter obtaining

$\boxed{1}$ h-parameter :-

$$h_{11} = \frac{\Delta Z}{Z_{22}} = \frac{\begin{vmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{vmatrix}}{Z_{22}} = 72.99 \ k\Omega$$

$$\boxed{h_{12}} = \frac{Z_{12}}{Z_{22}} = 0.6$$

$$\boxed{h_{21}} = \frac{-Z_{21}}{Z_{22}} = -5.6399$$

$$\boxed{h_{22}} = \frac{1}{Z_{22}} = -1.346\times10^{-4} \ S$$

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2 ABCD parameters

$$A = t_{11} = \frac{Z_{11}}{Z_{21}} = -1.14303$$

$$B = t_{12} = \frac{\Delta Z}{Z_{21}} = 12943.306 = 12.943\ k\Omega$$

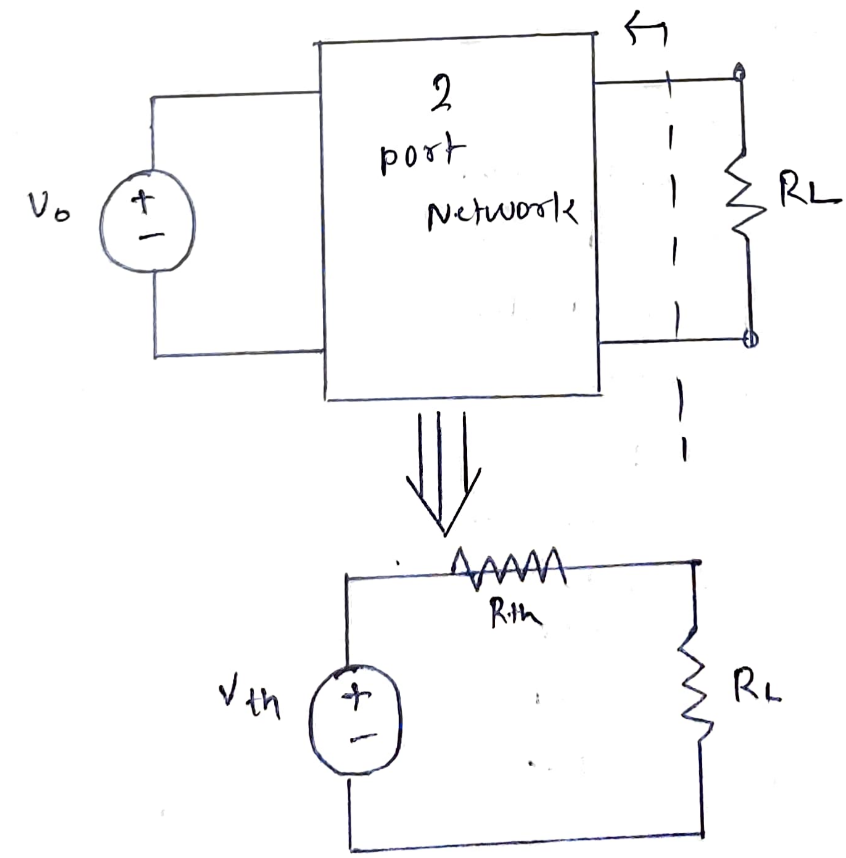
$$C = t_{21} = \frac{1}{Z_{21}} = -2.387 \times 10^{-5}\ S$$

$$D = t_{22} = \frac{Z_{22}}{Z_{21}} = 0.1773$$

* Finding Load Resistance for max. power transform :-

→ In linear circuit, when $Z_{load} = Z_{th}^{*}$, max. power can be transferred.

→ we can find thevenin equivalen ~~to~~ of 2-port network with input voltage supplied, about output port.



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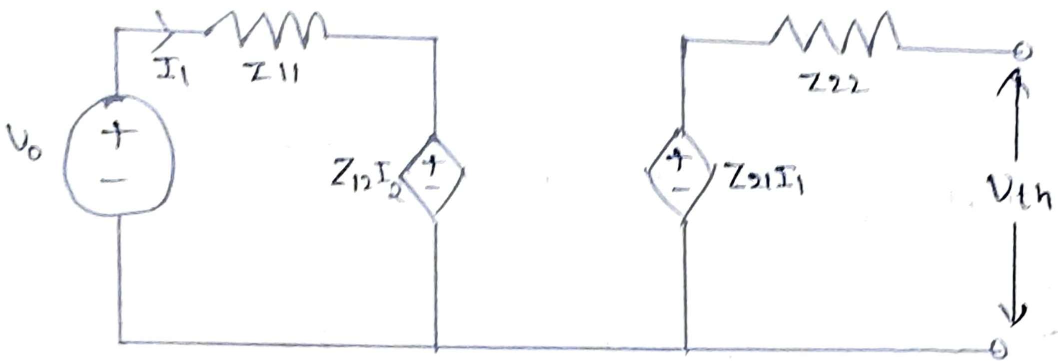
* Open circuiting output voltage (Ri)



Here $I_2 = 0$ as output side is opencircuited,

so, $V_{th} = Z_{21} I_1$ --- (1)

applying KVL at input side loop.

$$V_0 - Z_{11} I_1 - Z_{12}(0) = 0$$

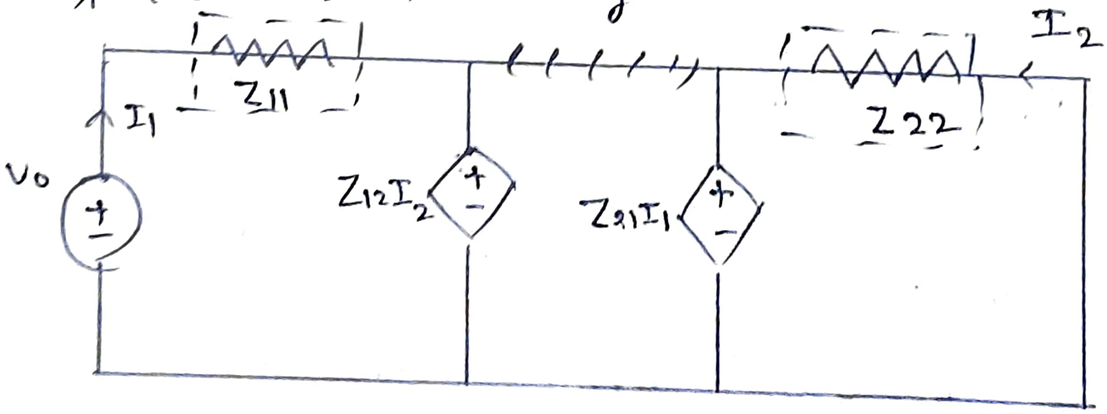
$$V_0 = Z_{11} I_1$$

$$\Rightarrow I_1 = \frac{V_0}{Z_{11}}$$

putting value of I_1 in (1)

$$\boxed{V_{th} = \frac{Z_{21} V_0}{Z_{11}}}$$

* Now short-circuiting output port.



Applying KVL in output side loop.

$$Z_{21} I_1 + Z_{22} I_2 = 0$$

$$I_1 = \frac{-Z_{22} I_2}{Z_{21}} \quad \text{---} (1)$$

Applying KVL in input side loop.

$$V_0 - Z_{11} I_1 - Z_{12} I_2 = 0$$

$$V_0 - Z_{11}\left(-\frac{Z_{22} I_2}{Z_{21}}\right) - Z_{12} I_2 = 0$$

$$V_0 = Z_{12} I_2 - \frac{Z_{11} Z_{22} \cdot I_2}{Z_{21}}$$

$$V_0 = I_2 \left(\frac{Z_{12} Z_{21} - Z_{11} Z_{22}}{Z_{21}} \right)$$

$$I_{sc} = I_2 = V_0 \left(\frac{Z_{21}}{Z_{12} Z_{21} - Z_{11} Z_{22}} \right)$$

i.e. short circuit current.

$$R_{th} = \frac{V_{th}\,(V_{oc})}{I_{sc}}$$

$$= \frac{\frac{Z_{21}(V_0)}{Z_{11}}}{\left(V_0 \left(\frac{Z_{21}}{Z_{12} Z_{21} - Z_{11} Z_{22}} \right) \right)}$$

$$\boxed{R_{th} = \frac{Z_{12} Z_{21} - Z_{11} Z_{22}}{Z_{11}}}$$

When Rload becomes equal to Rth, Power accross becomes maximum, according to Maximum Power Transfer Equation.

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Putting values of parameters

$$R_{th} = \frac{(-4.455k)(-41.882k) - (47.871k)(-7.025k)}{47.871k}$$

$$\boxed{R_{th} = 11.322\,k\Omega}$$

which is quite close to simulated result $R_{th}\big|_{simulated} = 11.323\ k\Omega$

$$\Rightarrow \boxed{R_{Load} = 11.322\,k\Omega}$$

* RESULTS:-

Z - Parameter	Calculated (kΩ)	Simulated (kΩ)
Z_{11}	47.871 kΩ	47.871 kΩ
Z_{12}	−4.455 kΩ	4.455 kΩ
Z_{21}	−41.882 kΩ	−41.882 kΩ
Z_{22}	−7.425 kΩ	−7.425 kΩ

h - parameter	Calculated	Simulated
h_{11}	72.99 kΩ	72.99 kΩ
h_{12}	0.6	0.6
h_{21}	−5.6399	−5.64
h_{22}	-1.346×10^{-4} S	-1.3467×10^{-4} S

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ABCD-Para.	Calculated	Simulated
A	-1.1403	-1.14032
B	12.943 kΩ	12.943 kΩ
C	-2.387×10^{-5} S	-2.3877×10^{-5} S
D	0.1773	0.177304

Load Resistance for max. power transfer

	Calculated	Simulated
R_{load}	11.322 kΩ	11.323 kΩ

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Question-2

1. Finding Z_{11} and Z_{21}

```
*Z11 and Z21

R1 N001 V1 55k
R2 0 N001 45k
R3 N002 V2 50k
R4 N001 V2 30k
E1 N002 0 N001 0 14
V1 V1 0 1
V2 NC_01 NC_02 V
. op
. backanno
. end
```

2. Finding Z_{12} and Z_{22}

```
* Z12 and Z22

R1 N001 V1 55k
R2 0 N001 45k
R3 N002 V2 50k
R4 N001 V2 30k
E1 N002 0 N001 0 14
V1 NC_01 NC_02 1
V2 V2 0 1
. op
. backanno
. end
```

3. Finding h_{11} and h_{21}

```
* h11 and h21

R1 N001 V1 55k
R2 0 N001 45k
R3 N002 V2 50k
R4 N001 V2 30k
E1 N002 0 N001 0 14
V1 V1 0 1
V2 V2 0 0
. op
. backanno
. end
```

4. Finding h_{12} and h_{22}

```
* h12 and h22

R1 N001 V1 55k
R2 0 N001 45k
R3 N002 V2 50k
R4 N001 V2 30k
E1 N002 0 N001 0 14
V1 NC_01 NC_02 1
V2 V2 0 1
. op
. backanno
. end
```

5. Finding `A` and `C` parameter

```
* A and C

R1 N001 V1 55k
R2 0 N001 45k
R3 N002 V2 50k
R4 N001 V2 30k
E1 N002 0 N001 0 14
V1 V1 0 1
V2 NC_01 NC_02 1
. op
. backanno
. end
```

6. Finding `B` and `D` Parameters

```
* B and D

R1 N001 V1 55k
R2 0 N001 45k
R3 N002 V2 50k
R4 N001 V2 30k
E1 N002 0 N001 0 14
V1 V1 0 1
V2 V2 0 0
. op
. backanno
. end
```