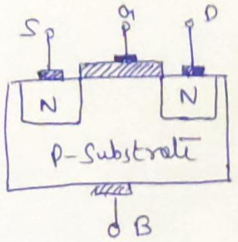
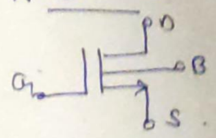
Unit-II

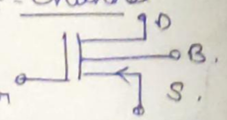
- FET Amplifiers :-

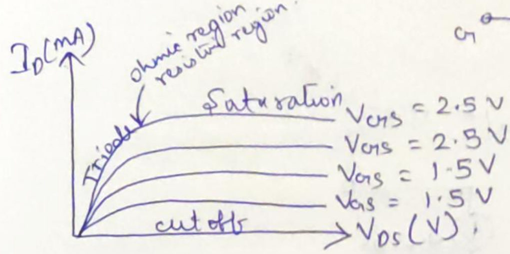


N-Channel



P-Channel





Cut off

$i_D = 0$

Triode Region

$$i_D = K_n\left(2(V_{GS} - V_{th})V_{DS} - V_{DS}^2\right)$$

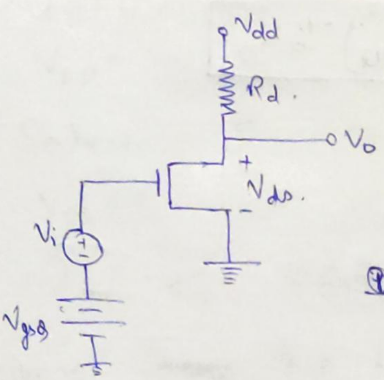
for $V_{DS} < V_{GS} - V_{TH}$

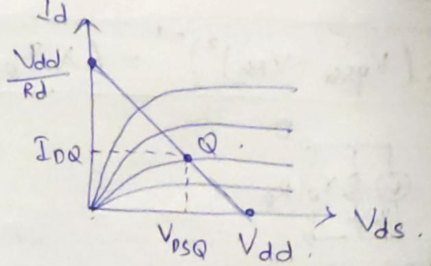
$$K_n = \frac{W\mu_n C_{ox}}{2L}$$

MOSFET
- Depletion type (Normally ON)
- Enhancement (Normally OFF)

Saturation Region.

$$i_D = K_n(V_{gs} - V_{th})^2 \text{ for } V_{DS} \geq V_{GS} - V_{th}$$





In Saturation Region

$$i_D = K_n(V_{gs} - V_{th})^2 \text{ for } V_{ds} \geq V_{gs} - V_{th}. \quad V_{th} = V_{tn}$$

In triode Region.

$$i_D = K_n\left(2(V_{gs} - V_{th})V_{ds} - V_{ds}^2\right) \text{ for } V_{ds} < V_{gs} - V_{th}.$$

$$K_n = \frac{\mu_n C_{ox}}{2L} \qquad C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} \quad \begin{matrix} \rightarrow \text{permittivity} \\ \rightarrow \text{thickness} \end{matrix}$$

$$g_m = \frac{i_d}{V_{gs}} = 2K_n(V_{gsQ} - V_{tn}) \text{ (small signal equiv.)}$$

From saturated current expression

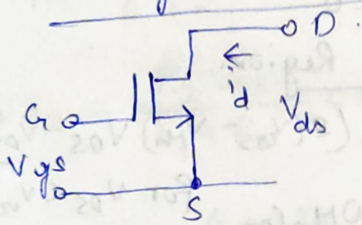
$$(V_{gs} - V_{th})^2 = \frac{i_{DQ}}{K_n}$$

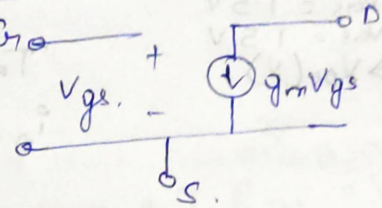
$$V_{gs} - V_{th} = \sqrt{\frac{i_{DQ}}{K_n}}$$

$$g_m = 2K_n\sqrt{\frac{i_{DQ}}{K_n}}$$

$$\boxed{g_m = 2\sqrt{K_n\, i_{DQ}}}$$

Small signal Equivalent circuit ← $V_{in} < 26\,mV$



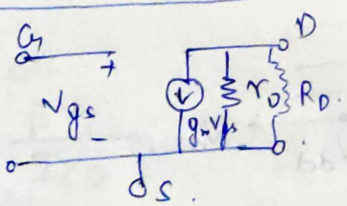


With channel length modulation effect.

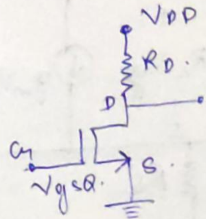
$$i_D = K_n\left[(V_{gs} - V_{th})^2(1 + \lambda V_{ds})\right]$$ [λ = channel length Modulation factor]

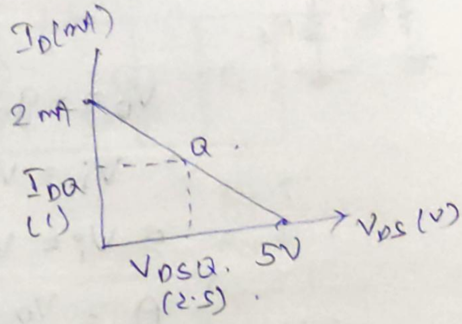
$$r_o = \left(\frac{\partial i_D}{\partial V_{ds}}\right)^{-1}$$

$$\therefore \boxed{r_o = \left(\lambda K_n (V_{gsQ} - V_{th})^2\right)^{-1} = (\lambda I_{DQ})^{-1} = r_o}$$



Q) Find the load line and Q point for a MOSFET circuit having $V_{GSQ} = 2.12\ V$, $V_{DD} = 5V$, $R_D = 2.5\ k\Omega$, $V_{tn} = 1V$, $K_n = 0.80\ mA/V^2$





$V_{DD} = I_D R_D + V_{DS}$

$$i_{DQ} = K_n (V_{gsQ} - V_{tn})^2$$
$$= 0.80 (2.12 - 1)^2$$
$$= 0.8 (1.12)^2$$
$$= 1\ mA$$

$$V_{DSQ} = V_{DD} - I_{DQ} R_D = 5 - 1(2.5)$$
$$= 2.5\ V$$

Cut off pt

$I_D = 0$

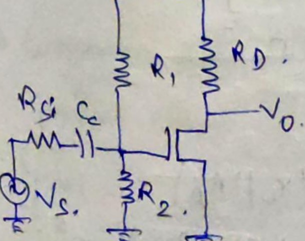
$V_{DD} = V_{DS} = 5V$

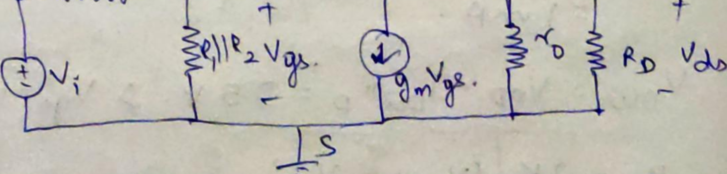
Saturation pt

$V_{DS} = 0$

$$I_D = \frac{V_{DD}}{R_D} = \frac{5}{2.5} = 2\ mA$$

Common Source Amp - (with bypass cap.) (R_S ✗ consider)
without (R_S ✓ consider)



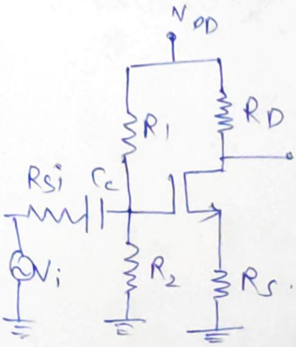


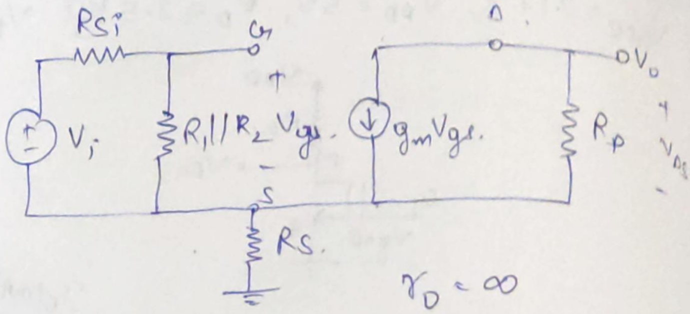
$$V_o = -g_m V_{gs} (r_o \| R_D)$$

$$V_{gs} = V_i \frac{R_1 \| R_2}{(R_1 \| R_2) + R_{Si}}$$

$$A_V = \frac{V_o}{V_i} = -g_m (r_o \| R_D) \left(\frac{R_1 \| R_2}{R_{Si} + R_1 \| R_2} \right)$$

▲ Common Source (without C_B (with R_S))





$r_D = \infty$

$$V_D = -g_m V_{gs} R_D$$

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

$$\Rightarrow V_i = V_{gs}(1 + g_m R_S)$$

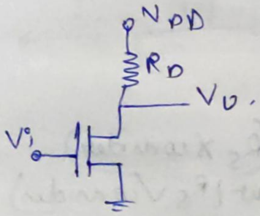
$$A_V = \frac{V_O}{V_i} = \frac{-g_m \cancel{V_{gs}} R_D}{\cancel{V_{gs}}(1 + g_m R_S)}$$

$$= \frac{-g_m R_D}{1 + g_m R_S}$$

If $g_m R_S >> 1$

$$A_V = -\frac{R_D}{R_S}$$

Q) Find small A_v of MOSFET Amp. $V_{gsQ} = 2.12\ V$, $V_{DD} = 5V$, $R_D = 2.5\ K\Omega$, $V_{tn} = 1V$, $K_n = 0.80\ mA/V^2$, $\lambda = 0.02\ V^{-1}$ operate in saturation.



$$V_o = -g_m V_{gsQ} R_D$$

$$V_i = V_{gsQ} + g_m V_{gsQ}$$

$$r_o = (\lambda I_{DQ})^{-1}$$

$$= [0.02(1)]^{-1}$$

$$= 50\ K\Omega$$

$$I_{DQ} = K_n(V_{gsQ} - V_{tn})^2$$

$$= 1\ mA$$

$$V_{DSQ} = V_{DD} - I_{DQ} R_D = 2.5\ V > V_{gs} - V_{tn}$$

$$g_m = 2K_n(V_{gsQ} - V_{tn})$$

$$= 2(0.80)(2.12 - 1)$$

$$= 1.6 \times 1.12$$

$$\approx 1.79\ m$$

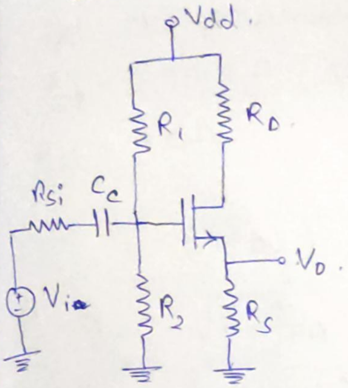
$$V_o = -g_m V_{gsQ} [r_o || R_D]$$

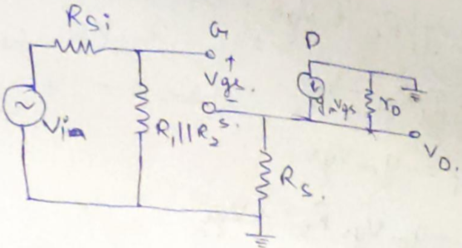
$$= -1.79 \times 2.12 \left(\frac{50 \times 2.5}{52.5}\right) \times 10^3$$

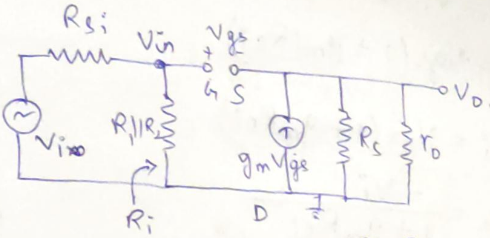
$$A_V = \frac{V_o}{V_{gs}} = -g_m (r_o || R_D) = -1.79 \times \frac{50 \times 2.5}{52.5} \times 10^3$$

$$= -4.26$$

Source Follower :- (CD)







$R_i \uparrow$

$R_o \downarrow$

$A_V \simeq 1$

A_I = High

$$V_o = g_m V_{gs} (r_o || R_s)$$

$$\therefore V_{in} = V_{gs} + V_o$$

$$= V_{gs} + g_m V_{gs} (r_o || R_s)$$

$$\Rightarrow V_{gs} = \frac{V_{in}}{1 + g_m (r_o || R_s)}$$

$$V_{in} = \frac{V_i R_i}{R_i + R_{si}} \qquad [R_i = R_1 || R_2]$$

$$V_{gs}(1 + g_m (r_o || R_s)) = \frac{V_i R_i}{R_i + R_{si}}$$

$$\Rightarrow V_i = \frac{V_{gs} [1 + g_m (r_o || R_s)] (R_i + R_{si})}{R_i}$$

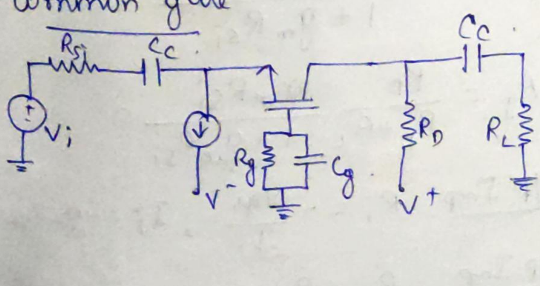
$$A_v = \frac{V_o}{V_i} = \frac{g_m \cancel{V_{gs}} (r_o || R_s) R_i}{\cancel{V_{gs}} [1 + g_m (r_o || R_s)] (R_i + R_{si})}$$

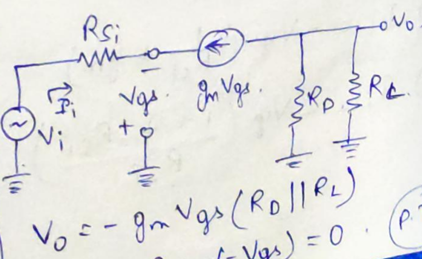
$$\Rightarrow \boxed{A_v = \frac{g_m (r_o || R_s) R_i}{[1 + g_m (r_o || R_s)] (R_i + R_{si})}}$$

$$\begin{bmatrix} g_m (r_o || R_s) >> 1 \\ R_{si} << R_i \end{bmatrix}$$

$$\therefore A_v \approx 1.$$

Common gate





$$V_o = - g_m V_{gs} (R_D || R_L)$$

$$V_i - I_i R_{si} - (-V_{gs}) = 0$$

(P.T.O)

$\Rightarrow V_i - I_i R_{si} + V_{gs} = 0$.

$\Rightarrow V_i = I_i R_{si} - V_{gs}$.

Now, $I_i = -g_m V_{gs}$.

$\therefore V_i = -g_m V_{gs} R_{si} - V_{gs}$.

$\Rightarrow V_i = -V_{gs}(1 + g_m R_{si})$

$\Rightarrow -V_i = V_{gs}(1 + g_m R_{si})$

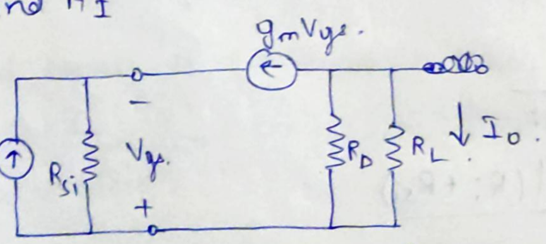
$\Rightarrow V_{gs} = \dfrac{-V_i}{1 + g_m R_{si}}$

$$\therefore A_V = \frac{V_o}{V_i} = \frac{\cancel{-} g_m \cancel{V_{gs}} (R_D \| R_L)}{\cancel{-}(g_m R_{si} + 1) \cancel{V_{gs}}}$$

$$\Rightarrow \boxed{A_V = \frac{g_m (R_D \| R_L)}{1 + g_m R_{si}}}$$

Using Norton's equiv. ckt.

To find A_I



$$I_o = -g_m V_{gs} \cancel{(R_D \| R_L)} \left(\frac{R_D}{R_D + R_L}\right).$$

At i/p KCL,

$I_i - (-V_{gs}/R_{si}) - (-g_m V_{gs}) = 0$

$\Rightarrow I_i + V_{gs}/R_{si} + g_m V_{gs} = 0$.

$\Rightarrow \cancel{I_i = -V_{gs}(g_m \times R_{si})}$

$\Rightarrow I_i = -V_{gs}\left(\dfrac{1}{R_{si}} + g_m\right)$.

$\Rightarrow I_i = -V_{gs}\left(\dfrac{1 + g_m R_{si}}{R_{si}}\right)$

$$A_I = \frac{\cancel{-} g_m \cancel{V_{gs}} \left(\frac{R_D}{R_D + R_L}\right)}{\cancel{-} \cancel{V_{gs}} \left(\frac{1 + g_m R_{si}}{R_{si}}\right)}$$

$$A_I = \frac{g_m \left(\frac{R_D}{R_D + R_L}\right) R_{si}}{1 + g_m R_{si}}$$

$$A_I = \frac{R_D}{R_D + R_L} \cdot \frac{g_m R_{si}}{1 + g_m R_{si}}$$

I/P Imp $R_i = -\dfrac{V_{gs}}{I_i}$, $I_i = -g_m V_{gs}$

O/P Imp. $R_o = R_D$.

Q) Calculate the small signal voltage gain of source follower ckt. Ckt parameters are $V_{dd} = 12V$, $R_1 = 162\ k\Omega$, $R_2 = 463\ k\Omega$, $R_S = 0.75\ k\Omega$, $V_{TH} = 1.5V$, $K_n = 4\ mA/V^2$, $\lambda = 0.01\ V^{-1}$, $R_{si} = 4\ k\Omega$.

$$r_o = (\lambda I_{DQ})^{-1}$$

$$g_m = 2\sqrt{K_n I_{DQ}}$$

$$I_{DQ} = K_n(V_{gs} - V_{th})^2$$

$$g_m = 2K_n(V_{gs} - V_{th})$$

$$I_{DQ} = 4(8.88 - 1.5)^2$$
$$= 217.8\ mA$$
$$= 0.217\ A$$

$$r_o = (\lambda I_{DQ})^{-1}$$
$$= (0.01 \times 0.217)^{-1}$$
$$= 460.8$$

$$V_{GSQ} = \frac{V_{dd} R_2}{R_1 + R_2}$$
$$= \frac{12 \times 463}{162 + 463}$$
$$= 8.88\ V$$

$$V_G = \frac{R_2}{R_1 + R_2} V_{DD}$$

$$V_G = V_{gs} + I_D R_S$$

$$I_D = K_n(V_{gs} - V_{th})^2$$

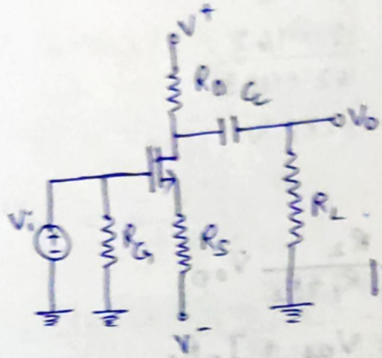
$$V_G = V_{gs} + K_n(V_{gs} - V_{th})^2 R_S$$

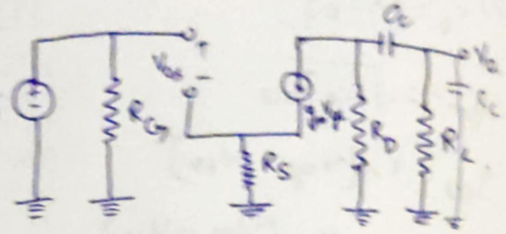
$$V_G = V_{gs} + K_n(V_{gs}^2 + V_{th}^2 - 2V_{gs}V_{th})R_S$$

$$V_G = V_{gs} + K_n V_{gs}^2 R_s + K_n V_{th}^2 R_s - 2K_n R_s V_{gs}$$

Q) For common gate amplifier determine v_o, if $I_{DQ} = 1\,mA$, $V^+ = 5V$, $V^- = -5V$, $R_g = 100\,k\Omega$, $R_D = 4\,k\Omega$, $R_L = 10\,k\Omega$, $V_{tn} = 1V$, $K_n = 1\,mA/V^2$, $\lambda = 0$, $R_{si} = 50\,k\Omega$, $I_i = 100 \sin \omega t\ \mu A$.

- **Frequency Response of CS amp**





$$|V_o|_{max} = g_m V_{gs} (R_D \| R_L)$$

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

$$\therefore |A_v|_{max} = \frac{|V_o|_{max}}{|V_i|_{max}}$$

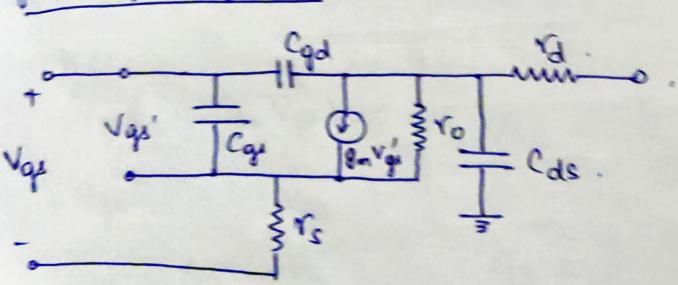
$$= \frac{g_m \cancel{V_{gs}} (R_D \| R_L)}{\cancel{V_{gs}} (1 + g_m R_S)}$$

$$\therefore |A_v|_{max} = \frac{g_m (R_D \| R_L)}{1 + g_m R_S}$$

$\tau_S = (R_D + R_L)\, C_C$. $f_L = \frac{1}{2\pi \tau_S}$

$\tau_P = (R_D + R_L)\, C_L$

- **High Frequency Response:**



$I_d = g_m V_{gs}'$

$V_{gs} = V_{gs}' + (g_m V_{gs}') r_s$

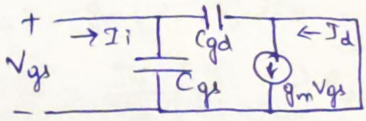
$\therefore V_{gs} = (1 + g_m r_s) V_{gs}'$

$\Rightarrow V_{gs}' = \frac{V_{gs}}{1 + g_m r_s}$

$$\therefore I_d = g_m \left(\frac{V_{gs}}{1 + g_m r_s} \right)$$

$$= \left(\frac{g_m}{1 + g_m r_s} \right) V_{gs} = g_m' V_{gs}$$

* Short Circuit Current gain :-



At input node, KCL.

$$I_i = \frac{V_{gs}}{1/j\omega C_{gs}} + \frac{V_{gs}}{1/j\omega C_{gd}}$$

$$= V_{gs}[j\omega(C_{gs} + C_{gd})]$$

At output node, KCL.

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

$$\Rightarrow V_{gs}\, j\omega C_{gd} + I_d = g_m V_{gs}$$

$$\Rightarrow I_d = V_{gs}(g_m - j\omega C_{gd})$$

$$I_i = \frac{I_d \cancel{V_{gs}}[j\omega(C_{gs} + C_{gd})]}{\cancel{V_{gs}}(g_m - j\omega C_{gd})}$$

$$\Rightarrow I_i = \frac{I_d[j\omega(C_{gs} + C_{gd})]}{g_m - j\omega C_{gd}}.$$

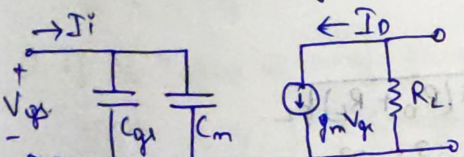
$$\therefore A_I = \frac{I_d}{I_i} = \frac{g_m - j\omega C_{gd}}{j\omega(C_{gs} + C_{gd})} \qquad \omega C_{gd} << g_m.$$

$$= \frac{g_m}{j\omega(C_{gs} + C_{gd})} = \frac{g_m}{j2\pi f(C_{gs} + C_{gd})} = \frac{1}{j(f/f_T)}$$

$$\text{where } f_T = \frac{g_m}{2\pi(C_{gs} + C_{gd})}$$

If we consider. miller capacitance,

$$C_m = C_{gd}(1 + g_m R_L)$$



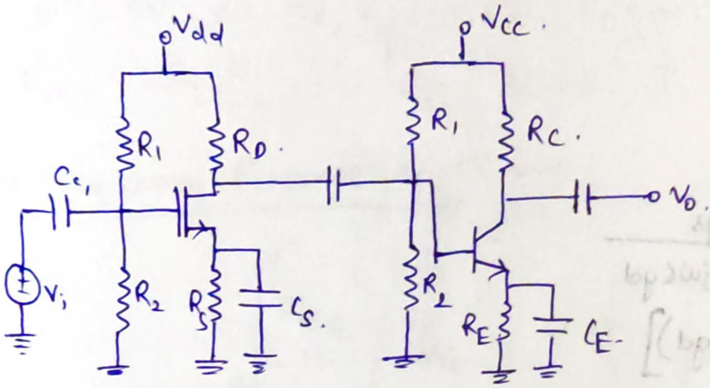
$$I_i = \frac{V_{gs}}{1/j\omega C_{gs}} + \frac{V_{gs}}{1/j\omega C_m}$$

$$I_i = V_{gs}\, j\omega(C_{gs} + C_m).$$

$$I_D = g_m V_{gs}.$$

$$\therefore A_I = \frac{I_D}{I_i} = \frac{g_m \cancel{V_{gs}}}{\cancel{V_{gs}}\, j\omega(C_{gs} + C_m)} = \frac{g_m}{j\omega(C_{gs} + C_m)} = \frac{g_m}{2\pi f\omega(C_{gs} + C_m)}$$

- **BiFET Amp.**



BiFET, A_v is less than 2 BJT.

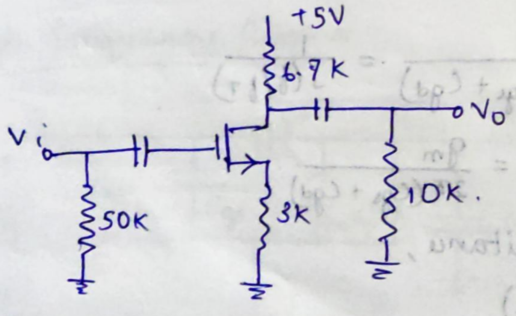
It is preferred over BJT. becoz, BJT has

1) Larger space
2) High Power consumption
3) Noisier
4) Speed ↑

It is preffered over MOSFET, becoz MOSFET has

1) Lower space
2) Low Power consumption
3) Noise is low
4) A_v is less.
5) Speed ↓

Q)



Find C_c if $f_L = 20\,kHz$

$f_L = \frac{1}{2\pi \tau_s}$

$\tau_s = (R_D + R_L) C_c$.

$C_c = \frac{1}{2\pi (R_D + R_L) f_L}$.

$= \frac{10^{-3} \times 10^{-3}}{2 \times 3.14 \times 16.7 \times 20}$

$= 0.00476 \times 10^{-6} = 4.76\, \beta$.

$= 0.0048\ \mu F$.