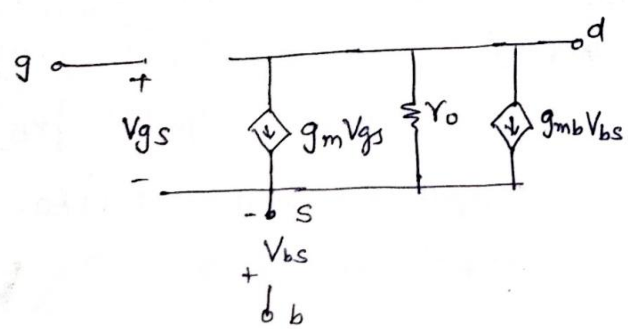
Solution: Tutorial Sheet-8

1) Draw the low frequency small signal model for n-Channel MOS transistor. Derive the expressions for model parameters.

= Low fregnency small signal model of nMOS transistor



g_m = transconduce parameter ~~which~~

r_o = Resistance due to CLM effect

g_{mb} = transconductance parameter (it is due to body bias effect)

<u>g_m in triode/linear region:-</u>

$$I_{DS} = \frac{k_n}{2}\left[2(V_{GS} - V_{to,n})V_{DS} - V_{DS}^2\right]$$

$$g_m = \frac{\partial I_{DS}}{\partial V_{GS}}$$

$$= \frac{k_n}{2}\left[2(1-0)V_{DS} - 0\right]$$

$$\boxed{g_m = k_n V_{DS}}$$ (for linear region)

g_m in sat^n region:-

$$I_{DS} = \frac{k_n}{2}(V_{GS} - V_{to,n})^2$$

$$g_m = \frac{\partial I_{DS}}{\partial V_{GS}} = \frac{k_n}{\cancel{2}}\cancel{2}(V_{GS} - V_{to,n})$$

$$\boxed{g_m = k_n (V_{GS} - V_{to,n})}$$

$$g_m = k_n V_{OV}$$

where

$$V_{OV} = V_{GS} - V_{to,n}$$

↳ It is overdrive voltage.

Parameter r_o:-

→ It is present in only sat^n region because CLM effect occures in sat^n region.

$$r_o = \frac{1}{\frac{\partial I_D}{V_{DS}}}$$

$$I_{DS} = \frac{k_n}{2}(V_{GS} - V_{to})(1 + \lambda V_{DS})$$

$$\frac{\partial I_{DS}}{\partial V_{DS}} = \underbrace{\frac{k_n}{2}(V_{GS} - V_{to,n})}_{\approx I_{DS}} \lambda \cong \lambda I_{DS}$$

$$\Rightarrow \boxed{r_o = \frac{1}{\lambda I_{DS}}}, \quad I_{DS} \cong \frac{k_n}{2}(V_{GS} - V_{to,n})^2$$

g_{mb}: In sat^n region.

$$I_{DS} = \frac{k_n}{2}(V_{GS} - V_{t,n})^2$$

$$g_{mb} = \frac{\partial I_D}{\partial V_{BS}}$$

$$= \frac{k_n}{\cancel{2}} \cdot \cancel{2}(V_{GS} - V_{t,n}) \cdot \left(-\frac{\partial V_{t,n}}{\partial V_{BS}}\right)$$

$$= g_m \frac{\partial V_{t,n}}{\partial V_{SB}} \quad \left[\because V_{BS} = -V_{SB}\right]$$

We know that

$$V_{t,n} = V_{to,n} + \gamma\left[\sqrt{|-2\phi_f| + V_{SB}} - \sqrt{|-2\phi_f|}\right]$$

$$\frac{\partial V_{t,n}}{\partial_{SB}} = 0 + \gamma\left[\frac{1}{2}\frac{1}{\sqrt{|-2\phi_f| + V_{SB}}} - 0\right]$$

$$= \frac{\gamma}{2\sqrt{|-2\phi_f| + V_{SB}}}$$

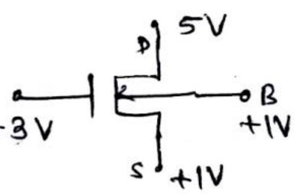
$$\Rightarrow \boxed{g_{mb} = \frac{g_m}{2} \cdot \frac{\gamma}{\sqrt{|-2\phi_f| + V_{SB}}}}$$

2) Determine the values of small signal parameters for the n-channel MOSFET with the following biasing conditions:

   a. V_D=5V, V_S=1V, V_B=1V, V_G=3V.
   b. V_D=5V, V_S=2V, V_B=1V, V_G=3V.

   Use $|2\emptyset_f| = 0.6V$, $\gamma = 0.4\,V^{1/2}$, lemda= 0.1 per volt, $\mu_n C_{ox} = 25 m$A/V², W/L=15 and V_{t0} = 1V.

Que. 3 :- $\boxed{a}$



$V_{GS} \geq V_{to}$ for ON.

$3-1 \geq 1$, True

For satⁿ, $V_{DS} \geq V_{GS} - V_{to,n}$

$5-1 \geq 3-1-1$

$4 \geq 1$, condⁿ is satisfied.

Device is operating in satⁿ.

(i) $g_m = k_n (V_{GS} - V_{to,n})$

$= \mu_n C_{ox} \frac{W}{L} (3-1-1)$

$= 25 \times 10^{-3} \times 15 \times 1$

$g_m = 375$ mA/V

(ii) $I_{DS,sat^n} = \frac{K_n}{2}(V_{GS} - V_{to})^2$

$= \frac{25\times10^{-3}\times15}{2}(3-1-1)^2$

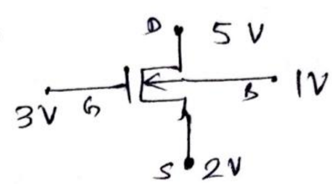
$= 187.5 \text{ mA}$

$r_o \cong \frac{1}{0.1\times187.5\times10^{-3}}$

$r_o \cong 53.3\,\Omega$

(iii) $g_{mb} = 0$, ~~due~~ $V_{SB} = 0$.

Q.3 (b):



$V_{SB} = 2-1 = 1\,V$.

$V_{to} = V_{to} + \gamma\left[\sqrt{|-2\phi_f + V_{SB}|} - \sqrt{|-2\phi_f|}\right]$

$= 1 + 0.4\left[\sqrt{0.6+1} - \sqrt{0.6}\right]$

$= 1 + 0.4[1.2649 - 0.774]$

$= 1.19636\,V$

$\because V_{GS} = 3-2 \geq 1.19$ ✗ ~~ON~~

~~Sat,~~

~~$V_{DS} > V_{GS} - V_t$~~

$\Rightarrow$ ~~V_{GS}~~ $\ngtr$

$V_{GS} < 1.19$ (Transistor is off)

$g_m = 0$

$r_o = \infty$

$g_{mb} = 0$

3) Find the small signal voltage gain, input and output resistances of the common source amplifier with resistive load.

Sol.: Using small signal low frequency model, you may derive the followings

$$\text{Voltage gain} = -g_m (r_o \,||\, R_D)$$

$$\text{Output Resistance} = r_o \,||\, R_D$$

$$\text{Input resistance} = \infty$$

4) In the circuit of Fig. 1, determine the small signal low-frequency voltage gain, input resistance and output resistance. Consider V_{GG} =4.4 V, k_n = 0.25mA/V^2, lemda = 0.02V^{-1}, V_{SB}=0V.

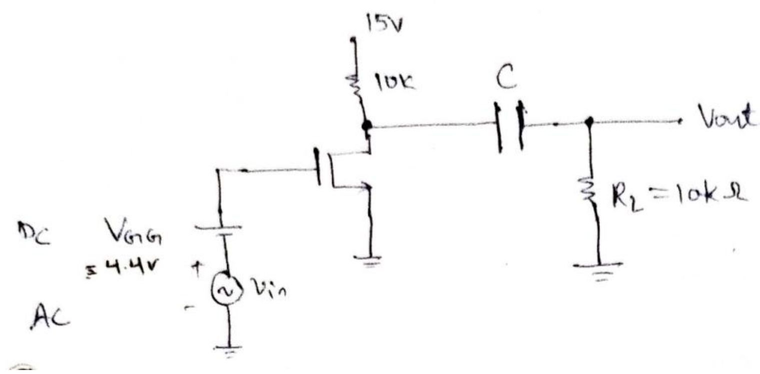
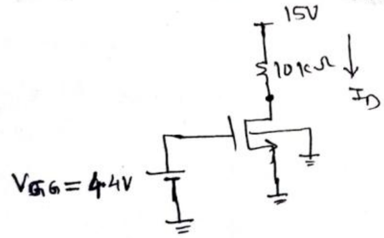


Fig. 1

DC equivalent ckt:-



$I_D =$

$$I_D = \frac{k_n}{2}(V_{GS} - V_t)^2$$

(neglected CLM effect for simplicity)

$$I_D = \frac{0.25 \times 10^{-3}}{2}(4.4 - 1.5)^2$$

$$I_D = 1.051 \text{ mA}$$

$$I_D = \frac{15 - V_D}{10k}$$

$$V_D = 15 - 10 \times 10^3 \times I_D$$

$$= 15 - 10 \times 1.051$$

$$V_D = 4.49 \text{ V}$$

Sat^n cond^n:-

$$V_{DS} \geq V_{GS} - V_{TO}$$

$$4.49 \geq 4.4 - 1.5 \checkmark$$

→ Calculated values are correct.

$$g_m = k_n(V_{GS} - V_{TO})$$

$$g_m = 0.25(4.4 - 1.5) \text{ mA/V}$$

$$\boxed{g_m = 0.725 \text{ mA/V}}$$

, $\boxed{\text{Overdrive voltage} = V_{GS} - V_{TO}}$

$$r_o = \frac{1}{\lambda I_D}$$

$$= \frac{1}{0.02 \times 1.051 \times 10^{-3}}$$

$$r_o = 47.57 \text{ k}\Omega$$

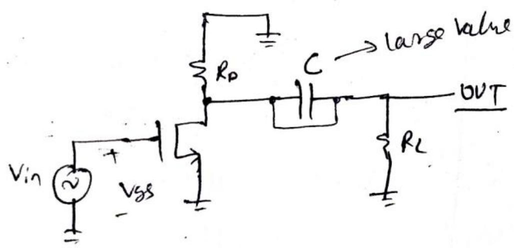
AC analysis:

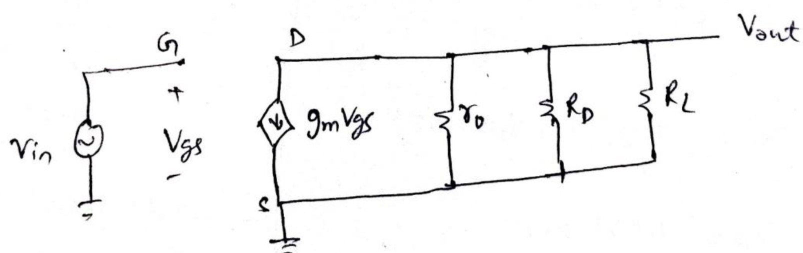
Deactivate all the dc sources.

→ [redacted]

→ Assume coupling capacitors are sufficiently large so act as short circuits at the signal frequencies of interest.

$\underline{\underline{Z_c = \frac{1}{j\omega C}}}$ small





$V_{out} = -g_m V_{in} \times R_{eq}.$

$\boxed{A_v = -g_m R_{eq}}$, $R_{eq} = r_o \| R_L \| R_D$

$R_{eq} = 10 \| 10 \| 47.57 = 5 \| 47.57$

$= 4.13\ K\Omega$

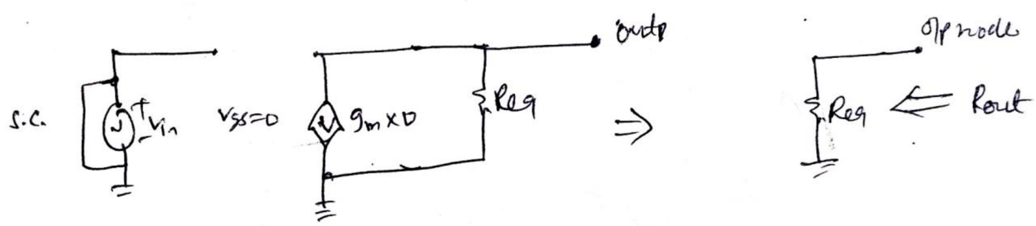
$A_V = -g_m R_{eq} = 0.725 \times 4.13 = \underline{\underline{-2.995}}$

<u>Input resistance:-</u>

$R_{in} = \infty$

<u>Output resistance:</u> - Deactive all the sources.

- Apply 1V source at the o/p and find current delivered by it.



$$\boxed{R_{out} = (R_D \| r_o \| R_L) = 4.13\ K\Omega}$$