Unit I

Basic MOS Device physics

* General Consideration

MOSFET as a switch

N-type MOSFET symbol is as shown in Fig 1. It has four terminals: Gate (G), Source (S), Drain (D) and substrate (B) also called as Body or Bulk.
Source and drain are interchangeable because the device is symmetric.

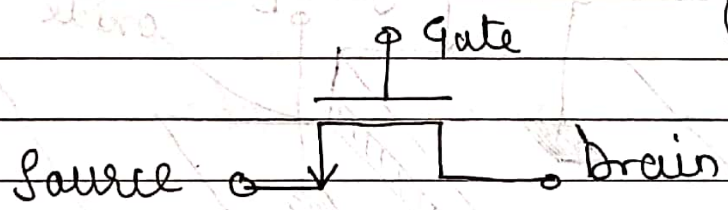


Fig 1. Simple view of MOS device.

As MOSFET is voltage controlled device. When V_g is high, the transistor "Connects" the source and the drain together. Current will flow from drain to source and hence transistor will remain "ON".
& when V_g is "low", the transistor isolates the source and the drain, & hence transistor will remain "OFF".

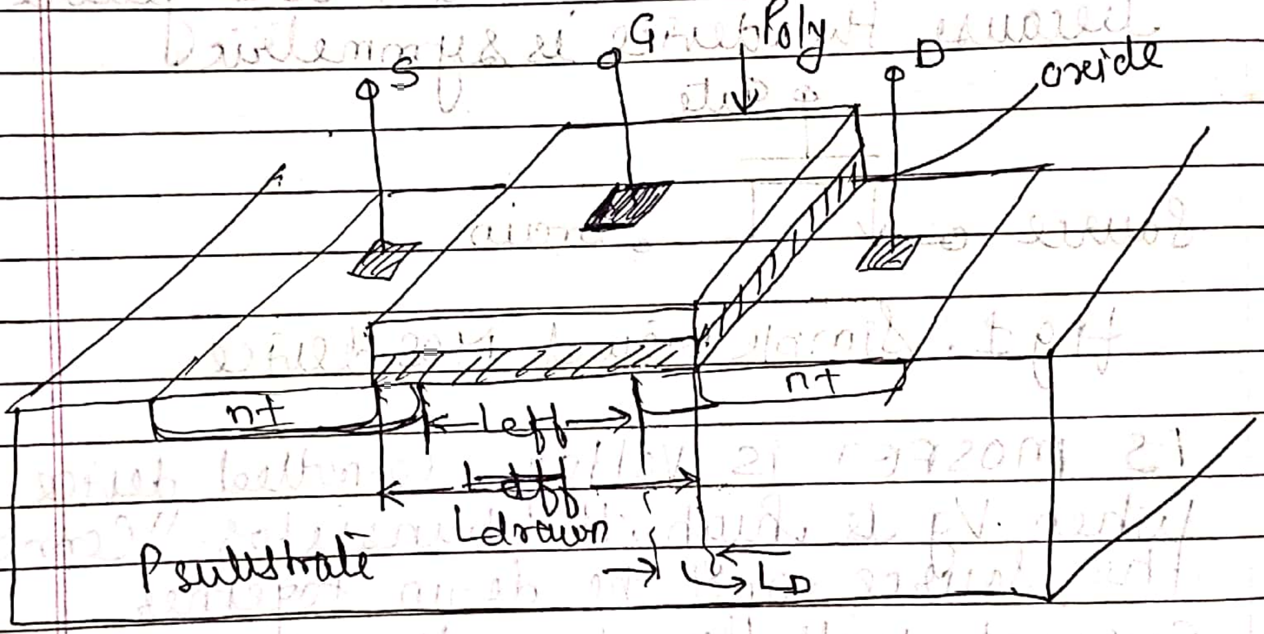
What value of V_G does the device turn on?

$V_g = V_{tn}$ in n-type $\quad V_{tn} = 0.7$

$= |V_{tp}|$ in p-type $\quad V_{tp} = -0.7$ or $|V_{tp}|$

$V_{th_p} = 0.7$, $V_{th_p} = 0.7$

MOSFET Structure



Structure of MOS device (n-type MOS) (NMOS)

- Fig shows the simplified structure of an n-type MOS (NMOS) device. Fabricated on a p-type substrate (also called the "bulk" or the "body"). The device consists of two heavily doped n regions forming the source and drain terminals, a heavily doped (conductive

$L_{eff} \approx 0.15$ um.

piece of polysilicon (often simply called "poly") operating as the gate, and a thin layer of silicon dioxide (SiO_2) insulating the gate from the substrate.

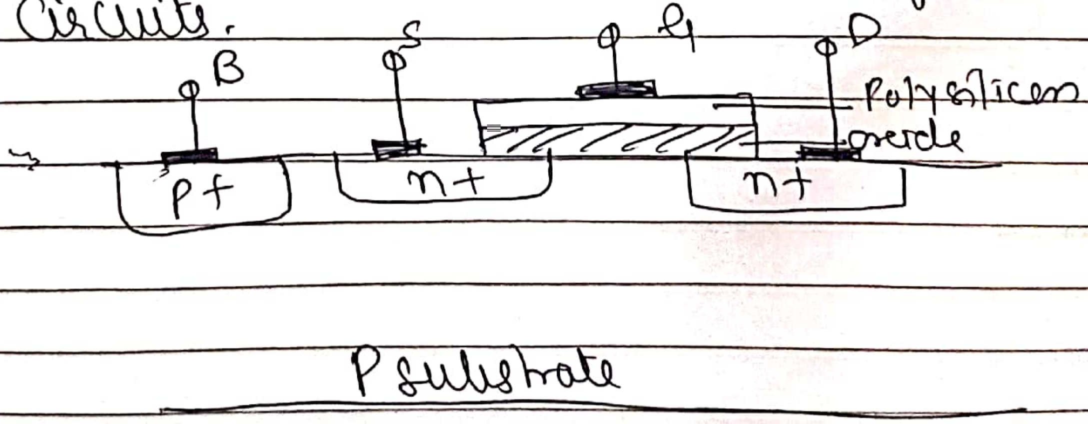
- The dimension of the gate along the source drain path is called the length L and that perpendicular to the length is called the width W. Since during fabrication the S/D junctions "side-diffuse", the actual distance between the source and the drain is slightly less than L.
- To avoid confusion, we write.

$$L_{eff} = L_{drawn} - 2L_D,$$

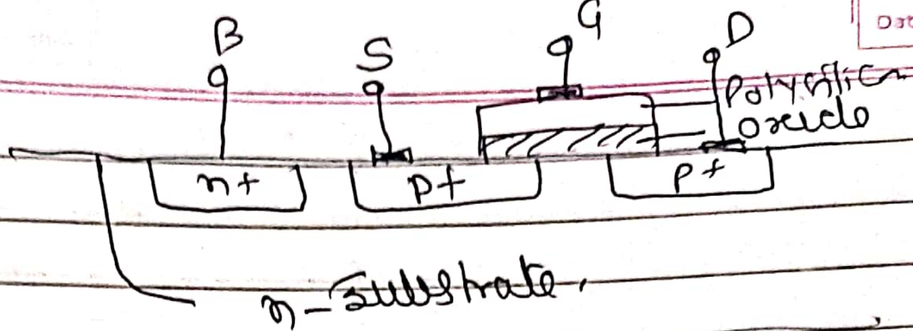
Where L_{eff} is the "effective" length, L_{drawn} is the total length, and L_D is the amount of side diffusion

~~Leff is the "effective"~~

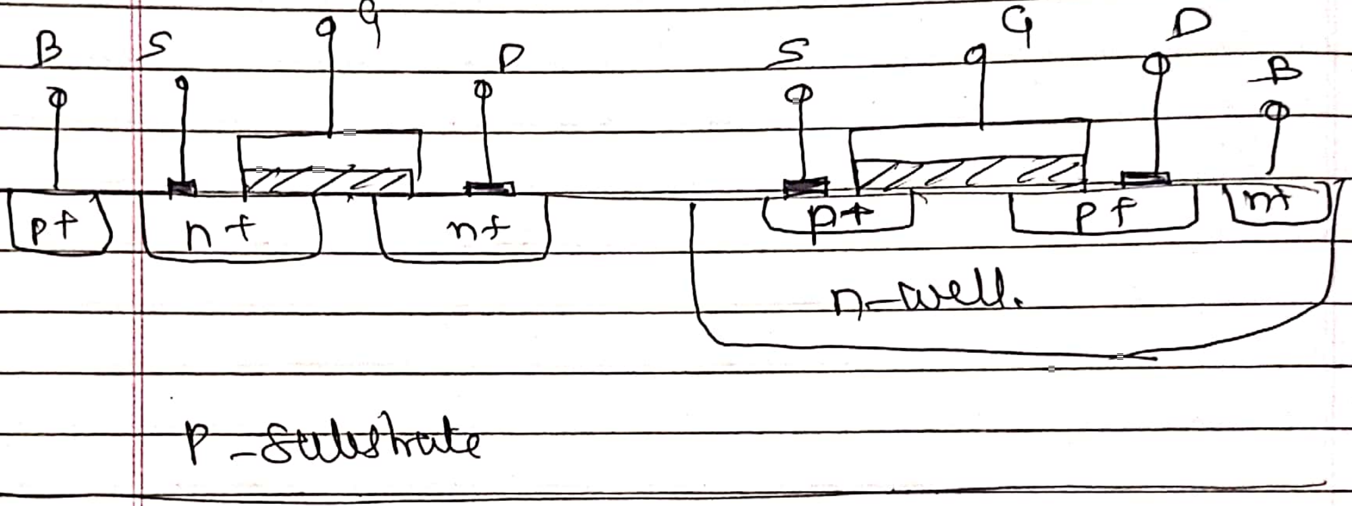
L_{eff} and the gate oxide thickness, t_{ox} plays an important role in the performance MOS circuits.



Substrate Connection

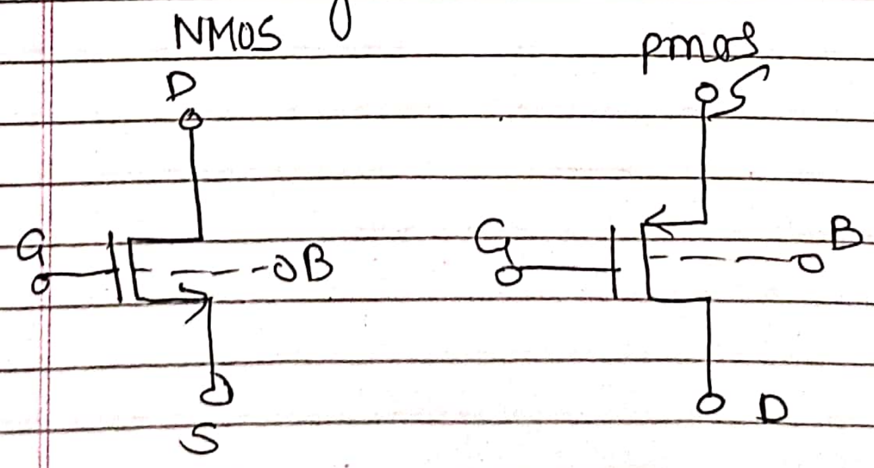


Simple PMOS device



pmos inside an n-well.

MOS symbols



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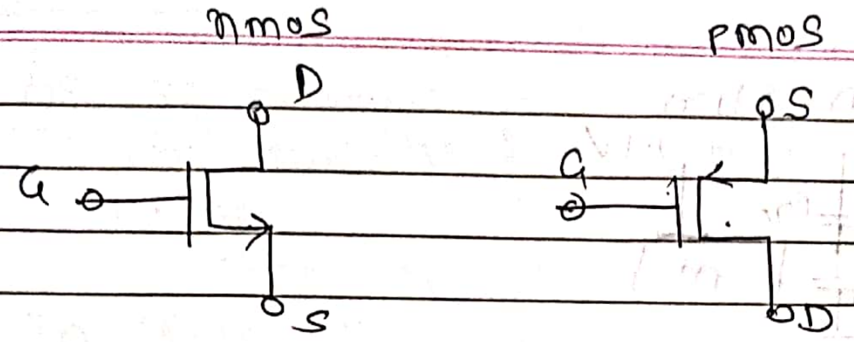
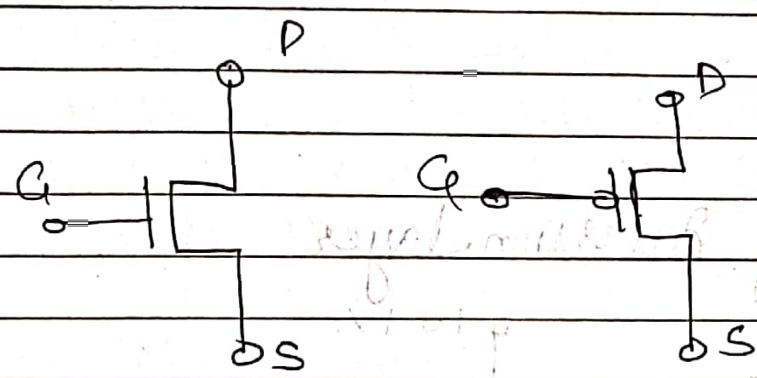
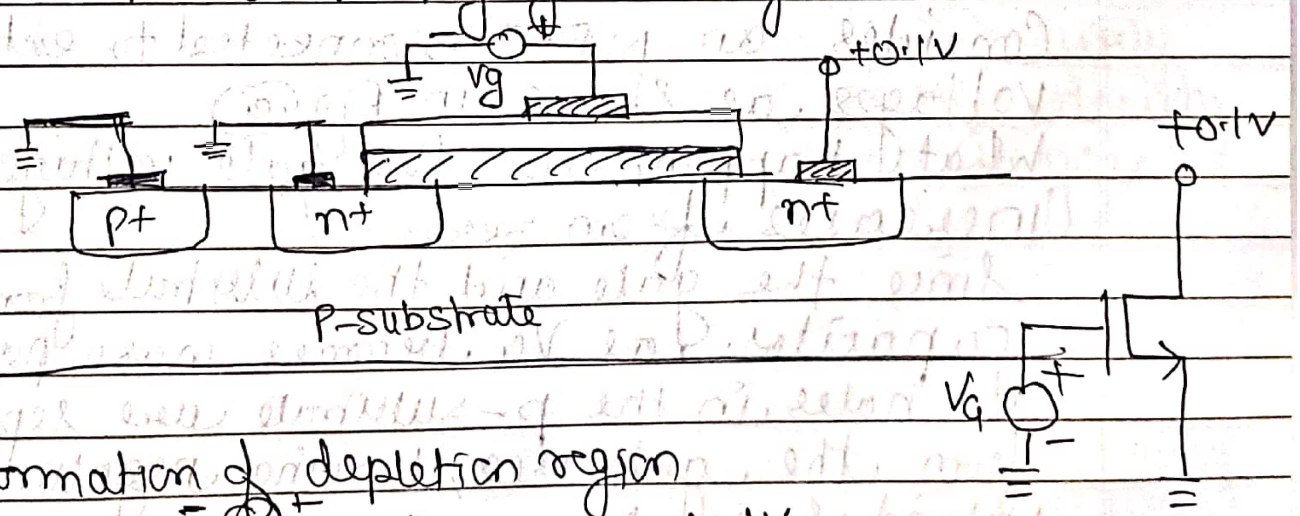


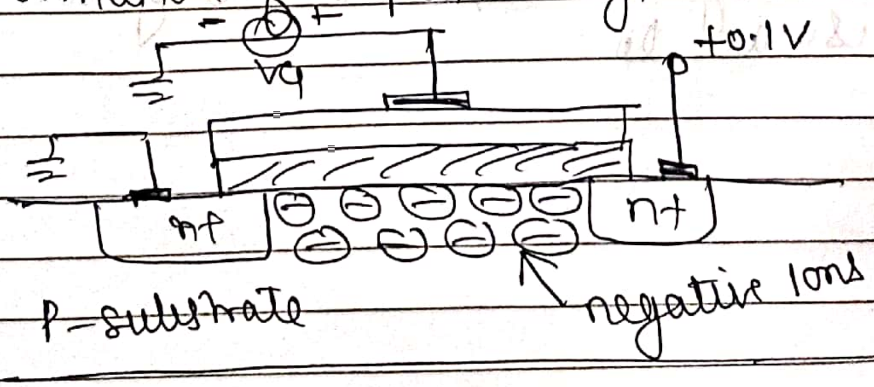


MOS I/V Charac

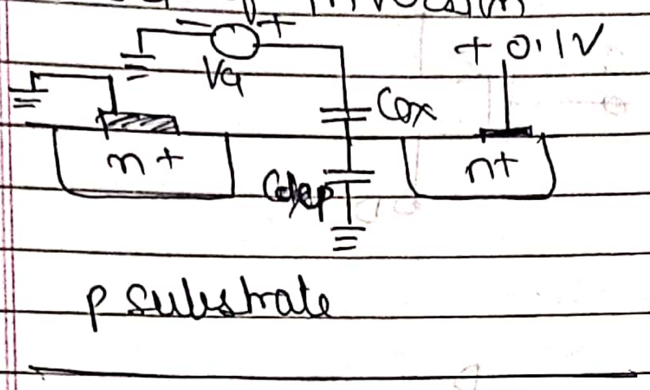
(a) MOSFET driven by gate voltage



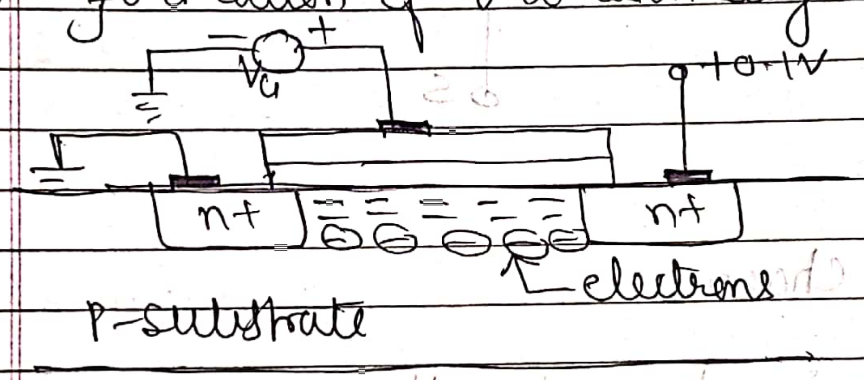
(b) Formation of depletion region



c) Onset of inversion



d) Formation of Inversion layer



Consider an NFET connected to external voltages as shown in Fig (a)
What happens as the gate voltage V_G, increases from zero.
Since the gate and the substrate from a capacitor. as V_G becomes more positive, the holes in the p-substrate are repelled from the gate area, leaving negative ions behind so as to.

As V_g increases so width of the depletion region and the potential at the oxide silicon interface.

The structure resembles two capacitors in series. the gate oxide capacitor and the depletion region capacitor.

When the interface potential reaches a sufficiently positive value, electron flow from the source to the interface and eventually to the drain

Thus a channel of charge carriers is formed under the gate oxide betn S & D and the transistor is "turned on".

We also say the interface is "inverted". The value of V_G for which this occurs is called the "threshold voltage" V_{TH}.

If V_G rises further, the charge in the depletion region remains relatively constant while the channel charge density continues to increase, providing a greater current from S to D

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Threshold voltage - Body effect

$$V_t = V_{tmos} + V_{fb} \quad -(1)$$

$$V_{tmos} = 2\phi_b + \frac{Q_b}{C_{ox}} \quad -(2)$$

$$\therefore V_t = 2\phi_b + \frac{Q_b}{C_{ox}} + V_{fb}$$

$$\& \; V_{fb} = 2\phi_b + V_{fb} + \frac{Q_b}{C_{ox}}$$

$$Q_b = \sqrt{2\varepsilon_{si} q \cdot N_A \cdot 2\phi_b}$$

As the body effect substrate voltage V_{sb} is added

As body effect substrate voltage V_{sb} is added.

$$V_t = 2\phi_b + V_{fb} + \frac{\sqrt{2\varepsilon_{si} q \cdot N_A (2\phi_b + |V_{sb}|)}}{C_{ox}}$$

$$V_t = 2\phi_b + V_{fb} + \gamma \left[\sqrt{2\phi_b + |V_{sb}|}\right] \quad -(3)$$

where $\gamma = \frac{\sqrt{2\varepsilon_{si} q \cdot N_A}}{C_{ox}}$

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$$

V_{to} threshold voltage for $V_{sb} = 0$, V_{to}

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$$V_{to} = V_{fb} + 2\phi_b + \frac{\sqrt{2\varepsilon_{si} q N_A (2\phi_b)}}{C_{ox}}$$

$$V_{fb} + 2\phi_b = V_{to} - \frac{\sqrt{2\varepsilon_{si} \cdot q \cdot N_A (2\phi_b}}{C_{ox}} \quad (4)$$

put (4) in (3)

$$V_t = V_{to} - \frac{\sqrt{2\varepsilon_{si} q N_A (2\phi_b)}}{C_{ox}} + \gamma\left(\sqrt{2\phi_b + |V_{sb}|}\right)$$

$$V_t = V_{to} - \gamma\sqrt{2\phi_b} + \gamma\left(\sqrt{2\phi_b + |V_{sb}|}\right)$$

$$\boxed{V_t = V_{to} + \gamma\left[\sqrt{2\phi_b + |V_{sb}|} - \sqrt{2\phi_b}\right]}$$

Threshold voltage body effect

* Threshold (V_{tg}) Temp dependance

$$V_t = \phi_{ms} + \left(2\phi_F + \frac{Q_b}{C_{ox}}\right) - \frac{Q_{ss}}{C_{ox}}$$

$$V_t = \frac{Q_b}{C_{ox}} + 2\phi_F + \phi_{ms} - \frac{Q_{ss}}{C_{ox}}$$

$$Q_b = \sqrt{2\varepsilon_{si} q N_A (2\phi_F + V_{SB})}$$

Condition $V_{SB} = 0$ (no body effect)

$$Q_b = \sqrt{2 q N_A \varepsilon_{si} (2\phi_F)}$$

$$V_t = \frac{\sqrt{2 q N_A \varepsilon_{si} (2\phi_F + V_{SB})}}{C_{ox}} + 2\phi_F + \phi_{ms} - \frac{Q_{ss}}{C_{ox}}$$

$$V_t = \sqrt{\frac{2\epsilon_{si} q N_A (2\phi_F)}{C_{ox}}} + 2\phi_F + \phi_{ms} - \frac{Q_{ss}}{C_{ox}} \quad -(1)$$

$\phi_{ms}, Q_{ss}, C_{ox}$ – independent of temp.

∴ diff above V_t w.r.t temp T

$$\frac{dV_t}{dT} = \sqrt{\frac{2\epsilon_{si} q N_A (2)}{C_{ox}}} \left(\frac{d\sqrt{\phi_F}}{dt}\right) + 2\frac{d\phi_F}{dt} + 0 + 0 - -$$

$$= \sqrt{\frac{2\epsilon_{si} q \cdot N_A (2)}{C_{ox}}} \cdot \frac{1}{2\sqrt{\phi_F}} \cdot \frac{d\phi_F}{dT} + 2\left(\frac{d\phi_F}{dt}\right)$$

$$\frac{dV_T}{dt} = \left[2 + \frac{\sqrt{2\epsilon_{si} q \cdot N_A (2)}}{2 \cdot C_{ox} \sqrt{\phi_F}}\right] \left(\frac{d\phi_F}{dt}\right) \quad (2)$$

$$\left\{ n_i = \sqrt{N_c N_v}\, \exp\left(\frac{-E_g}{2kT}\right) \right\}$$

$$\boxed{\phi_F = \frac{kT}{q} \ln \frac{N_A}{n_i}}$$

$$\phi_F = \frac{kT}{q} \ln \frac{N_A}{\left[\sqrt{N_c N_v}\, \exp\left(\frac{-E_g}{2kT}\right)\right]}$$

$$\boxed{\phi_F = \frac{kT}{q} \ln \left[\left(\frac{N_A}{\sqrt{N_c N_v}}\right) \exp\left(\frac{E_g}{2kT}\right)\right]} \quad -(3)$$

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diff ϕ_F w.r.t T

$$\frac{d\phi_F}{dt} = \underbrace{\frac{KT}{q}}_{I}\left[\underbrace{\ln\left(N_A \exp\left(\frac{E_g}{2KT}\right)\right)}_{II} - \ln\left(\sqrt{N_c N_v}\right)\right]$$

$$\frac{d\phi_F}{dt} = -\frac{E_g}{2qT} + \frac{\phi_F}{T}$$

$$\cancel{= -\frac{1}{T}\left[\frac{E_g}{2qT} + \frac{\phi_F}{T}\right]}$$

$$\frac{d\phi_F}{dt} = -\frac{1}{T}\left[\frac{E_g}{2q} - \phi_F\right]$$

diff V_t w.r.t T

$$\frac{dV_T}{dT} = \frac{d\phi_F}{dT} * \left[2 + \frac{\sqrt{2qN_A\epsilon_{si}(2)}}{2C_{ox}\sqrt{\phi_F}}\right]$$

$$\frac{dV_T}{dT} = \frac{d\phi_F}{dT}\left[2 + \frac{\sqrt{qN_A\epsilon}}{C_{ox}\sqrt{\phi_F}}\right]$$

$$r = \frac{\sqrt{2q\epsilon_{si}N_A}}{C_{ox}}$$

$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}}$$

$$\frac{d\phi_F}{dT} = -\frac{1}{T}\left[\frac{E_g}{2q} - \phi_F\right]$$

$$\frac{dV_T}{dT} = \underbrace{-\frac{1}{T}\left[\frac{E_g}{2q} - \phi_F\right]}_{d\phi/dT}\left[2 + \frac{r}{\sqrt{2\phi_F}}\right]$$

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$1A^\circ = 10^{-10} m$
$= 10^{-8} cm$

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$$\frac{dV_T}{dT} = \frac{d\phi}{dT}\left[2 + \frac{r}{\sqrt{2\phi_F}}\right]$$

Numerical Based on Threshold Temp dependence

1) Assume $T = 300^\circ k$, $N_A = 10^{15}/cm^3$ $t_{ox} = 100 \times 10^{-8} cm$ ($100A^\circ$)
Find $\frac{dV_t}{dT}$. (change in threshold voltage)

Solut^n

given
$T = 300^\circ k$
$N_A = 10^{15}/cm^3$
$t_{ox} = 100 \times 10^{-8}$ cm

$n_i = 1.45 \times 10^{+10} cm^{-3}$ at $300^\circ k$
$q = 1.602 \times 10^{-19} C$

$$\phi_F = \frac{KT}{q} \ln\left[\frac{N_A \cdot \exp\left(\frac{E_g}{2kT}\right)}{\sqrt{N_C N_V}}\right]$$

$$\phi_F = \frac{KT}{q} \ln\frac{N_A}{n_i}$$

$$= \frac{KT}{q} = 0.02586 V$$
$$= 0.026 V = 26 mV$$

$$\phi_F = 26 \times 10^{-3} \ln\frac{10^{15}\ \cancel{cm^{-3}}}{1.45 \times 10^{+10}\ \cancel{cm^{-3}}}$$

$$\boxed{\phi_F = 0.28 V}$$

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$$\boxed{\frac{E_g}{2q} = 1.12\,eV}$$ $1\,eV = 1.602 \times 10^{-19}\,J$

$$\frac{E_g}{2q} = 1.602 \times 10^{-19} \times 1.12$$
$$= 0.56\ J$$

$$\frac{d\phi}{dT} = -\frac{1}{T}\left[\frac{E_g}{2q} - \phi_F\right]$$
$$= -0.96\,mV/^{\circ}K$$

$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = \frac{\epsilon_0 \epsilon_r}{t_{ox}} = \frac{8.85 \times 10^{-14}\,F/cm \times 3.9}{100 \times 10^{-8}\,cm}$$

$$= 3.45 \times 10^{-7}\,F/cm^2$$

$$\gamma = \frac{\sqrt{2q\,\epsilon_{si}\,N_A}}{C_{ox}}$$

$\gamma \rightarrow$ dioxide Constan

$$\boxed{\epsilon_r = 11.7}$$

$$\epsilon = \epsilon_0 \epsilon_r = 8.85 \times 10^{-14}\,F/cm \times 11.7$$

$$\gamma = \frac{\sqrt{2 \times 1.6 \times 10^{-19}\,C \times 1.035 \times 10^{-12}\,F/cm \times 10^{15}/cm^{-3}}}{3.45 \times 10^{-17}\,F/cm}$$

$$= 527.5 \times 10^{6}$$

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$$\frac{r}{\sqrt{2\phi_F}} = \frac{5.275 \times 10^{-7}}{\sqrt{2 \times 0.28}}$$

$$= 0.070$$

$$\frac{r}{\sqrt{2\phi_F}} = 0.070$$

$$\frac{dV_T}{dT} = -1.9 \ mV/^\circ k$$

$$\frac{dV_T}{dT} = \underbrace{\frac{-1}{T}\left[\frac{E_g}{2q} - \phi_F\right]}_{\frac{d\phi_F}{dT}}\left[2 + \frac{r}{\sqrt{2\phi_F}}\right]$$

$$= -0.96 \ mV/^\circ k \ [2.07]$$

$$= -1.98 \ mV/^\circ k$$

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Small Signal Model for MOS Transistor (Equivalent Model)

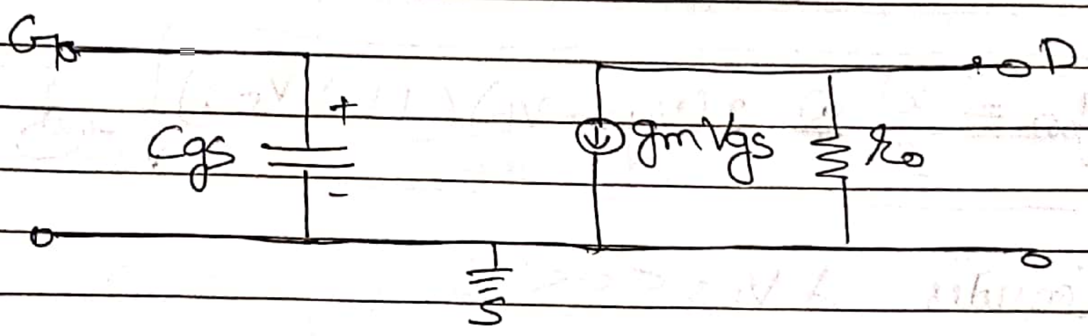

fig. Basic MOS small signal Model without parasitic Component.

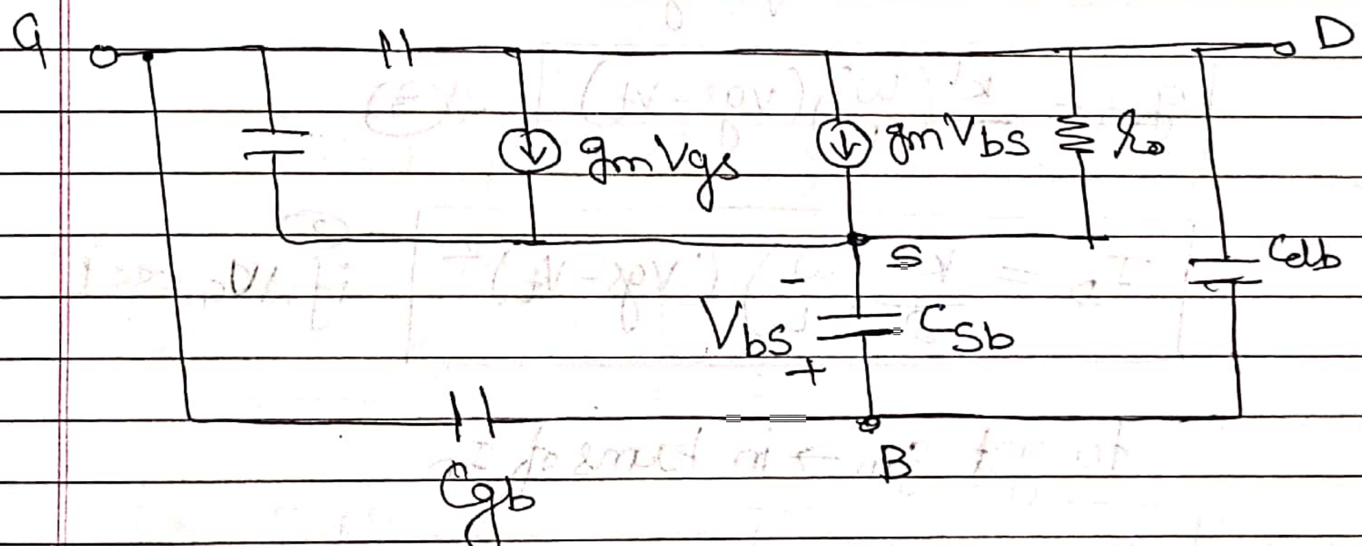

fig. Basic MOS Small Signal Model with including parasitic component.

(1) To find transconductance. (g_m) :→ $\therefore \lambda = \frac{1}{}$

$$I_D = \frac{K'}{2} \frac{W}{L} (V_{gs} - V_t)^2 \underbrace{(1 + \lambda V_{DS})}_{\text{Channel length modulation parameters consideration}}$$

$$g_m = \frac{\partial I_D}{\partial V_{GS}} \quad \text{— (1)}$$

$$\boxed{g_m = \frac{k'}{2}\cdot\frac{W}{L}\, 2(V_{gs}-V_t)(1+\lambda V_{DS})} \quad \text{— (2)}$$

Consider $\lambda V_{DS} <<< 1$

$$g_m = \frac{k'}{\cancel{2}}\,\frac{W}{L}\,\cancel{2}(V_{gs}-V_t)$$

Now in terms of $(V_{gs}-V_t)$

$$\boxed{g_m = k'\left(\frac{W}{L}\right)(V_{gs}-V_t)} \quad \text{— (3)}$$

$$\boxed{I_D = \frac{k'}{2}\left(\frac{W}{L}\right)(V_{gs}-V_t)^2} \quad \text{— (2)} \quad \text{if } \lambda V_{G1} <<< 1$$

to get $g_m \rightarrow$ in terms of I_D

$$\boxed{(V_{gs}-V_t) = \sqrt{\frac{2 I_D}{k'(W/L)}}}$$

$$\therefore\ g_m = k'(W/L)\cdot\sqrt{\frac{2 I_D}{k'(W/L)}}$$

$$\boxed{g_m = \sqrt{2 I_D\, k'(W/L)}} \quad \text{— (3)}$$

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$\Rightarrow$ to get $\left(\frac{g_m}{I_d}\right)$

$$\frac{g_m}{I_D} = \sqrt{\frac{2 I_D k'(W/L)}{I_D}}$$

$$= \sqrt{\frac{2k'(W/L)}{I_D}}$$

$$\frac{g_m}{I_D} = \sqrt{\frac{2k'(W/L)}{\frac{k'}{2}(W/L)(V_{gs}-V_t)^2}}$$

$$= \sqrt{\frac{4\cancel{k'}\cancel{(W/L)}}{\cancel{k'}\cancel{(W/L)}(V_{gs}-V_t)^2}}$$

$$\boxed{\frac{g_m}{I_D} = \frac{2}{V_{gs}-V_t}} \quad (4)$$

(2) For Body transconductance (g_{mb}) $\left(\frac{g_m}{I_c}\right)$

$$\frac{g_m}{I_c} = \frac{1}{V_T}$$

$$\boxed{\frac{g_m}{I_c} = \frac{q}{KT}}$$

$$g_m = \frac{dI_c}{dV_{BE}}$$

$$= \frac{d}{dV_{BE}}\left[I_c \exp\left(\frac{V_{BE}}{V_T}\right)\right]$$

$$\boxed{g_m = \frac{I_c}{V_T}}$$

$g_{mb} \rightarrow$ Body transconductance

$$g_{mb} = \frac{\partial I_D}{\partial V_{BS}} \quad \text{— (1)}$$

V_t depend on V_{BS}

$$= \frac{k'}{\cancel{2}} \frac{W}{L} \cancel{2}(V_{GS} - V_t) \frac{d}{dV_{BS}} V_T \; (1+\lambda V_{DS})$$

$$g_{mb} = \frac{k'}{9}\left(\frac{W}{L}\right)(V_{gs} - V_t)(1+\lambda V_{DS})\left(-\frac{dV_T}{dV_{BS}}\right)$$

$$\boxed{g_{mb} = -k'\left(\frac{W}{L}\right)(V_{gs} - V_t)(1+\lambda V_{DS})\frac{dV_T}{dV_{BS}}} \quad \text{— (2)}$$

but

$$\boxed{V_T = V_{t0} + \underbrace{r\left(\sqrt{2\phi_F + V_{SB}} - \sqrt{2\phi_F}\right)}_{\text{with body effect}}} \quad \text{— (3)}$$

if $V_t = V_{t0}$ $\rightarrow$ no body effect

$$\frac{dV_t}{dV_{BS}} = r \frac{1}{2\sqrt{2\phi_F + V_{SB}}} \cdot \frac{dV_{SB}}{dV_{BS}}$$

$$\frac{dV_t}{dV_{BS}} = \frac{r}{2\sqrt{2\phi_F + V_{SB}}}(-1)$$

$$\boxed{\frac{dV_t}{dV_{BS}} = \frac{-r}{2\sqrt{2\phi_F + V_{SB}}} = -\chi \rightarrow g_{mb}}$$

put in eqn (2)

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$$x \to g_{mb} = \underbrace{-K' \frac{W}{L} (V_{gs} - V_t)(1 + \lambda V_{DS})}_{g_{mb}} \left(\frac{-\gamma}{2\sqrt{2\phi_F + V_{SB}}} \right)$$

$$= K' \frac{W}{L} (V_{gs} - V_t)(1 + \lambda V_{DS}) \left(\frac{\gamma}{2\sqrt{2\phi_F + V_{SB}}} \right)$$

$\lambda V_{DS} << 1$

$$\boxed{g_{mb} = \frac{\gamma k' \left(\frac{W}{L}\right)(V_{gs} - V_t)}{2\sqrt{2\phi_F + V_{SB}}}} \quad -4$$

from eq^n (4) from transconducta

$$V_{gs} - V_t = \sqrt{\frac{2 I_D}{k'(W/L)}}$$

$$g_{mb} = \frac{\gamma k'(W/L) \sqrt{\frac{2 I_D}{k'(W/L)}}}{2\sqrt{2\phi_F + V_{SB}}}$$

$$\boxed{g_{mb} = \gamma \sqrt{\frac{I_D k'(W/L)}{2(2\phi_F + V_{SB})}}} \quad -5$$

for $\frac{g_{mb}}{g_m} = \frac{\left[\gamma \sqrt{\frac{I_D k(W/L)}{2(2\phi_F + V_{SB})}} \right]}{\sqrt{2 I_D k'(W/L)}}$

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$$\frac{g_{mb}}{g_m} = \frac{\gamma}{\sqrt{2(2\phi_F + V_{SB})} \cdot \sqrt{2}}$$

$$\boxed{\frac{g_{mb}}{g_m} = \frac{\gamma}{2\sqrt{2\phi_F + V_{SB}}}} = X$$

★ <u>MOS transistor Capacitance</u>

$$C_{gs} = \frac{2}{3} W L C_{ox}$$

$$C_{gd} = 0$$

$$C_{sb} = \frac{C_{sbo}}{\sqrt{\left(1 + \frac{V_{SB}}{\phi_0}\right)}}$$

$$C_{db} = \frac{C_{dbo}}{\sqrt{1 + \frac{V_{DB}}{\phi_0}}}$$

$$C_{gb} = \frac{C_{gbo}}{\sqrt{1 + \frac{V_{gb}}{\phi_0}}}$$

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Input Resistance

$$r_i = \infty$$

$$r_i = \frac{V_i}{i_g} = \frac{V_i}{0} = \infty$$

$i_G = 0$

Output Resistance

$$r_o = \frac{\Delta V_{DS}}{\Delta I_D} = \frac{V_A}{I_D}$$

$\boxed{V_A = \frac{1}{\lambda}}$ $\therefore r_o = \frac{1}{\lambda I_D}$

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

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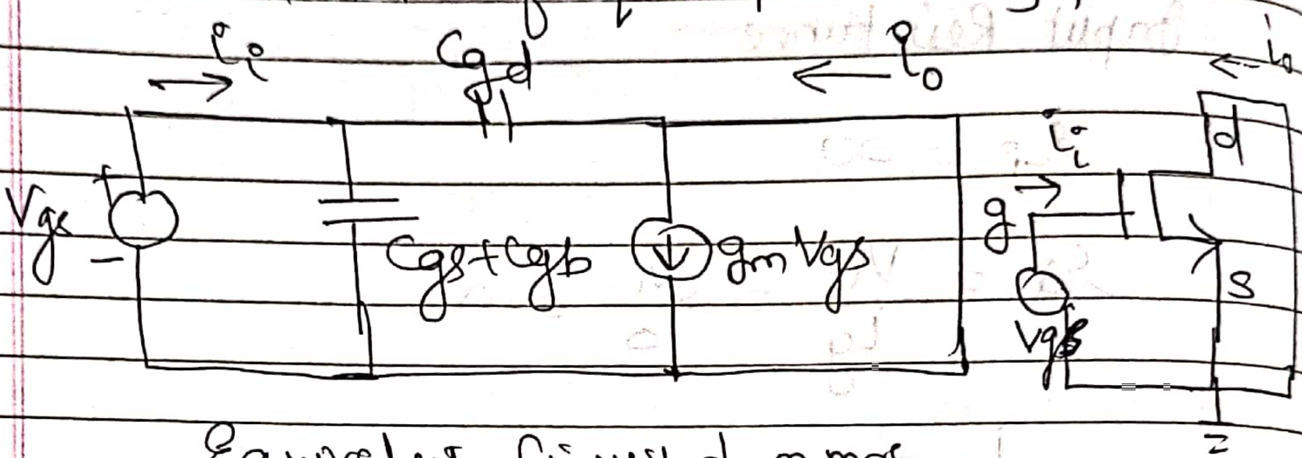
MOS transistor freq Response :→ f_T



Equivalent Circuit of nmos

(C_{sb}, C_{db}, r_o → has no effect) can be neglected

$V_{sb} = V_{ds} = 0$ (neglect r_o, C_{sb}, C_{db})

$i_i = s((C_{gs}+C_{gb}) + C_{gd}) \cdot V_{gs}$ → i/p side

$i_o \cong g_m V_{gs}$ — (1) → o/p side

$$\frac{i_o}{i_i} = \frac{g_m \cancel{V_{gs}}}{s((C_{gs}+C_{gb})+C_{gd}) \cancel{V_{gs}}}$$

$s = j\omega$

$$\frac{i_o}{i_i} = \frac{g_m}{j\omega((C_{gs}+C_{gb}+C_{gd})} \quad \text{— (2)}$$

β

$\frac{i_o}{i_i}(j\omega) = \beta j\omega$

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$$|\beta(j\omega)| = 1 \quad \text{at } \omega = \omega_t$$

$$\boxed{\left|\frac{i_o}{i_i}(j\omega)\right| = 1}$$

$$1 = \frac{g_m}{\omega_T(C_{gs}+C_{gb}+C_{gd})}$$

$$\omega = \omega_T = \frac{g_m}{(C_{gs}+C_{gb}+C_{gd})} \quad \text{— (3)}$$

$$f_T = \frac{g_m}{2\pi(C_{gs}+C_{gb}+C_{gd})} \quad \text{— (4)}$$

$$\boxed{2\pi f_T = \omega_T}$$

Now we know that $\therefore$

$$\boxed{g_m = k'\frac{W}{L}(V_{gs}-V_t)}$$

$$C_{gs} = \frac{2}{3}WLC_{ox}$$

$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}}$$

$$k' = \mu_n C_{ox}, \quad C_{gs} >> C_{gb}+C_{gd}$$

$$f_T = \frac{\cancel{g_m}\, k'\cancel{W}/L\,(V_{gs}-V_t)}{2\pi\left(\frac{2}{3}\cancel{W}LC_{ox}\right)}$$

$$= \frac{\mu_n \cancel{C_{ox}}\cancel{W}\,(V_{gs}-V_t)}{2\pi\times\frac{2}{3}\cancel{W}L^2\cancel{C_{ox}}}$$

A^o angstrom
$1 \overset{\circ}{A} = 10^{-10}$ m

$$F_T = \frac{3}{4\pi} \frac{\mu n}{L^2} (vgs - vt)$$

F_T in terms of $vgs - vt$

$$\boxed{F_T = 1.5 \frac{\mu n}{2\pi L^2} (vgs - vt)} \quad 5$$

Que Derive the complete small signal model for an nmos transistor with $I_D = 100\ uA$, $V_{SB} = 1V$, $V_{ds} = 2V$, device parameter are $\phi_F = 0.3V$, $W = 10\ um$, $L = 1\ um$, $\gamma = 0.5\sqrt{V}$, $K' = 200\ uA/V^2$, $\lambda = 0.02\ V^{-1}$, $t_{ox} = 100 A^o$, $\varphi_0 = 0.6V$, $C_{SB_0} = C_{db_0} = 10\ FF$, overlap capacitance from gate to source and gate to drain 1 fF, assume $C_{gb} = 5\ fF$.

given :→

$I_D = 100\ uA$	$L = 1\ um$
$V_{SB} = 1V$	$\gamma = 0.5\sqrt{V}$
$V_{ds} = 2V$	$k' = 200\ uA/V^2$
$\phi_F = 0.3V$	$\lambda = 0.02\ V^{-1}$
$W = 10\ um$	$t_{ox} = 100 A^o$
$\phi_0 = 0.6V$	$C_{SB_0} = C_{db_0} = 10\ FF$
$C_{gb} = 5\ fF$	

$$V_{gs} - V_t = \sqrt{\frac{2 I_D}{k'(W/L)}} = \sqrt{\frac{2 \times 100 \times 10^{-6}}{200 \times 10^{-6} \times 10}}$$

$$= 0.316\ V$$

As $V_{gs} > V_t$, V_t can be neglected

$\therefore V_{gs} = 0.316\ V$

~~Vgs~~ ~~Vgs-Vt~~ Vds Vgs-Vt

0.316-0.7 -1 0.316-0.7

$\cancel{0.7}$ 1 > 0.384

0.700

0.316

0.384

Tr is in Sat region

(1) $g_m = \sqrt{2k'(W/L)I_D}$

$= \sqrt{2\times 200\times10^{-6}(10)\times 10\times10^{-6}}$

$= 0.632$ mA/V

~~Body transconductance~~

(2) $g_{mb} = \gamma\sqrt{\dfrac{I_D k'(W/L)}{2(2\phi_F + V_{SB})}}$

$= 0.5\sqrt{\dfrac{100\times10^{-6}(200\times10^{-6})(10\times10^{-6})}{2(2\times0.6+1)}}$

$= 125$ uA/V

(3) O/P Resistance r_o

$r_o = \dfrac{1}{\eta g_m} = 15.82\ \Omega$ $\eta = 100$

$r_o = \dfrac{1}{\lambda I_D} = 0.5\ M\Omega$

(4) Parasitic capacitance

$C_{sb} = \dfrac{C_{sbo}}{\sqrt{1+\frac{V_{sb}}{\phi_0}}} = \dfrac{10\,pf}{\sqrt{1+\frac{1}{0.6}}} = 6.12\,fF$

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$$C_{db} = \frac{C_{db0}}{\sqrt{\left(1+\frac{V_{db}}{X_0}\right)}} = \frac{C_{db0}}{\sqrt{1+\frac{V_{ds}+V_{sb}}{X_0}}}$$

$$= 4.48\ fF$$

$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = \frac{8.85\times10^{-14}\times3.9}{100\times10^{-8}} = 3.4\ fF/\mu m^2$$

$$C_{gd} = 1\ fF$$

$$f_T = \frac{1}{2\pi}\ \frac{g_m}{C_{gs}+C_{gb}+C_{gd}} = 128\ fF/163\ fF$$

$$C_{gs(ov)} = 1\ fF$$

$$C_{gs(CV)} = \frac{2}{3} W L C_{ox}$$

$$= \frac{2}{3}\times10\times1\times10^{-12}\times3.45\times10^{-15}$$

$$= 23\ fF$$

$$C_{gs} = C_{gs(ov)} + C_{gs(CV)}$$

$$= 1 + 23 = 24\ fF$$

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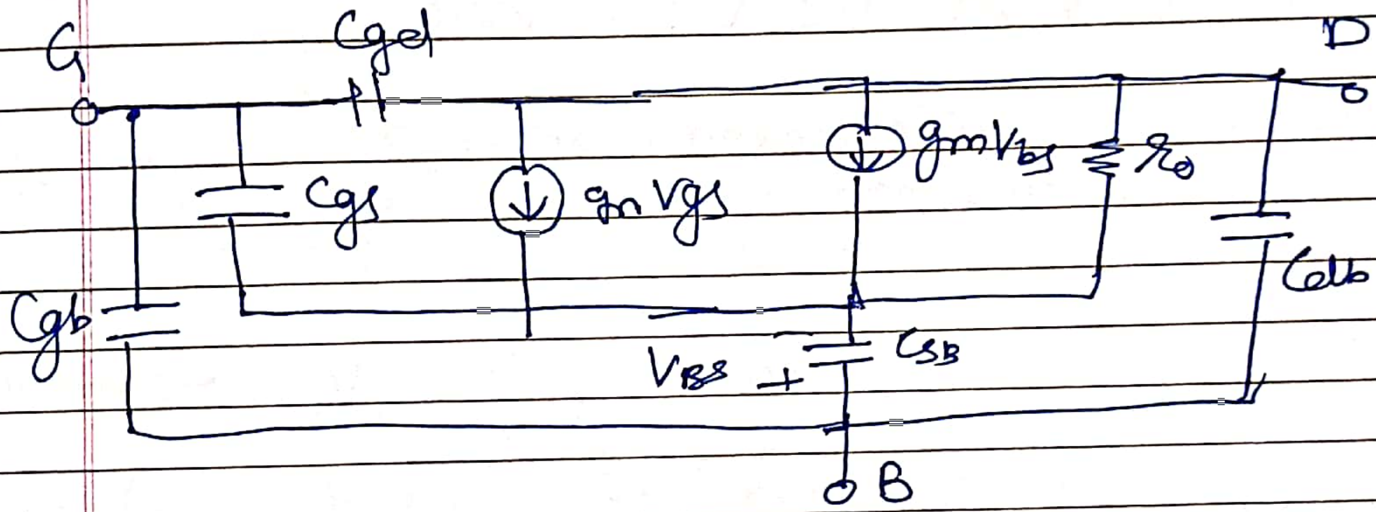
$f_T = 3.87\,GHz \rightarrow 3.4\,GHz.$

$$f_T = \frac{3}{4\pi} \frac{\mu_n}{L^2} (V_{gs} - V_t)$$

$$f_T = 1.5 \frac{\mu_n}{2\pi L^2} (V_{gs} - V_t)$$



Q.2)
1·16 $V_{gs} = 1V$, $V_{DS} = 2V$, $V_{SB} = 1V$. & $X = 0.7V$
$C_{sb0} = C_{db0} = 20\,fF$, $C_{gb} = 5\,fF$, $W = 10\,\mu m$
$L = 1\,\mu m$, $K' = 194\,\mu A/V^2$, $\lambda = 0.024/V$ $t_{ox} = 80\,A^0$
$V_{t0} = 0.6V$, $\gamma = 0.094$, $\phi_F = 0.3V$, derive and sketch Complete small signal circuit with above parameter overlap capacitance from gate to source and gate to drain is 2fF.

$V_t = ?$ g_{mb} $C_{gdov} = 2$.

I_D r_o C_{gsov}

g_m C_{sb}

V_{DB}

C_{db}:

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3) An nmos transistor has parameter $W = 10\ \mu m$ $L = 1\ \mu m$, $k' = 194\ \mu A/V^2$, $\lambda = 0.024/V$, $t_{ox} = 80 A^\circ$, $\phi_F = 0.3V$, $V_{to} = 0.6V$, $N_A = 5\times10^{15}/cm^3$

Ignore velocity saturation effect.

(a) Sketch I_D, V_{ds}, characteristic for V_{ds} from 0 to 3V

$V_{gs} = 0.5V, 1.5V, 3V$. Assume $V_{sb} = 0$.

(b) Sketch $I_D = V_{gs}$ characteristic for $V_{ds} = 2V$ and V_{gs} = varies from 0 to 2V with $V_{sb} = 0, 0.5, 1V$.

Solution:→ $V_t = V_{to}$ as $V_{sb} = 0$

Drain Current eq^n for non Saturation

$$I_D = \frac{k' W}{2 L}\left[2(V_{gs} - V_t)V_{DS} - V_{DS}^2\right]$$

Drain Current eq^n for Saturation

$$I_D = \frac{k' W}{2 L}\left[(V_{gs} - V_t)^2 (1 + \lambda V_{DS})\right]$$

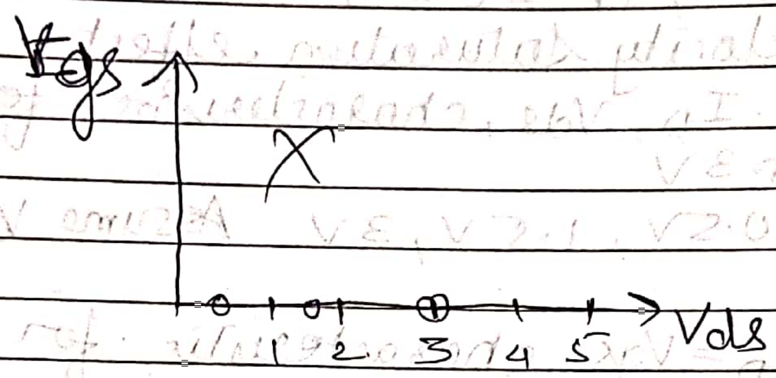
eq both we get

$$\frac{k' W}{2 L} = \frac{194\times10^{-6}\times 10\times\cancel{10^{-6}}}{\cancel{2}\times 1\times\cancel{10^{-6}}}$$

$$= 970\ \mu A/V^2$$

$$I_{D(non\ sat)} = 970\ \mu A\left[2(V_{gs} - 0.6)V_{ds} - V_{ds}^2\right] \quad -(1)$$

$$I_{D\,sat} = 970\times10^{-6}\left[(V_{gs}-0.6)^2(1+0.029\times V_{ds})\right]\ \mu A \quad -②$$



a) At $V_{gs} = 0.5\,V$ $\quad V_{to} = 0.6\,V$

$V_{ds} = 0\,V$		$V_{ds} = 1\,V$		$V_{ds} = 2\,V$		$V_{ds} = 3\,V$	
V_{ds}	$V_{gs}-V_t$	V_{ds}	$V_{gs}-V_t$	V_{ds}	$V_{gs}-V_t$	V_{ds}	$V_{gs}-V_t$
0	$0.5-0.6$	1	$0.5-0.6$	2	$0.5-0.6$	3	0.5…
$0 > -0.1$		$1 > -0.1$		$2 > -0.1$		>	
Sat		Sat		Sat		Sat	
$\therefore I_D = 9.7\,\mu A$		$I_D = 9.9\,\mu A$		$I_D = 10.16\,\mu A$		$10.39\,\mu A$	

b) At $V_{gs} = 1.5\,V$ $\quad V_{to} = 0.6\,V$

$V_{ds} = 0\,V$		$V_{ds} = 1\,V$		$V_{ds} = 2\,V$		$V_{ds} = 3\,V$	
V_{ds}	$V_{gs}-V_t$	V_{ds}	$V_{gs}-V_t$	V_{ds}	$V_{gs}-V_t$	V_{ds}	$V_{gs}-V_t$
	$1.5-0.6$		$1.5-0.6$				
$0 < 0.9$		$1 > 0.9$		$2 > 0.9$		$3 > 0.9$	
non sat		Sat		Sat		Sat	
$I_D = 0$		$I_D = 0.8\,mA$		$0.8\,mA$		$I_D = 0.84\,mA$	

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(c) $V_{gs} = 3V$ $\quad V_{to} = 0.6V$

$V_{ds} = 0V$ $\quad V_{ds} = 1V$ $\quad V_{ds} = 2V$ $\quad V_{ds} = 3V$

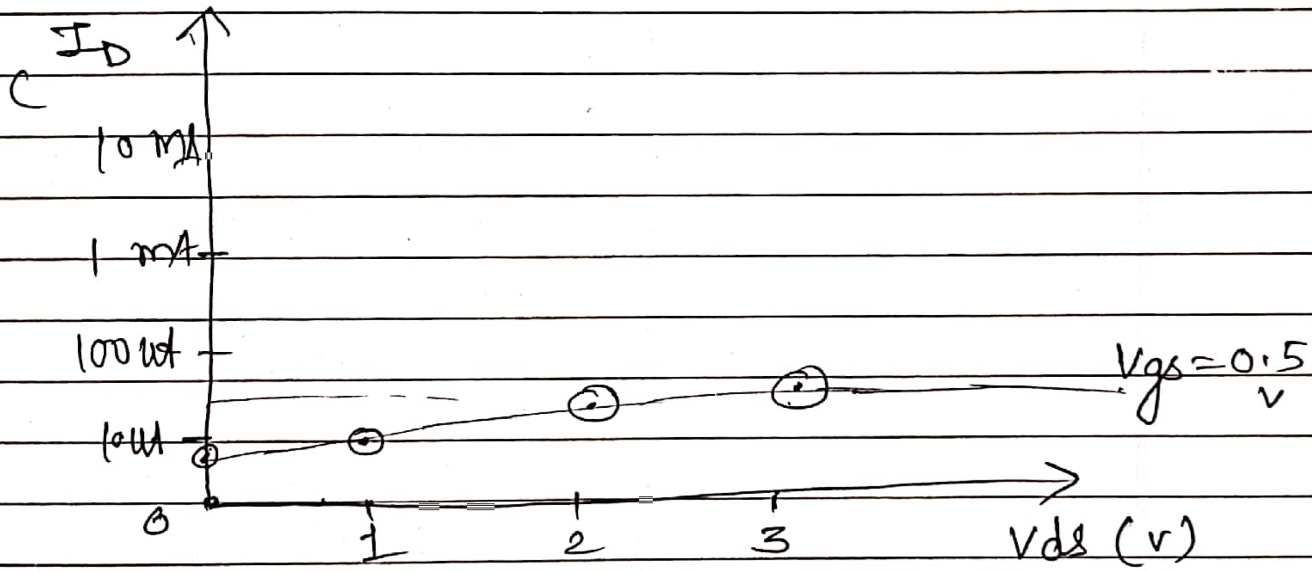
$V_{ds} \quad V_{gs} - V_t$ $\quad V_{ds} \quad V_{gs} - V_t$ $\quad V_{ds} \cdot V_{gs} - V_t$ $\quad V_{ds} \quad V_{gs} - V_t$

$3 - 0.6$

$0 < 2.4$

non sat $\quad$ non sat $\quad$ non sat $\quad$ sat

$I_D = 0$ $\quad I_D = 3.6mA$ $\quad I_D = 5.4mA$ $\quad 5.9mA$.



(b) I_D, V_{gs}.

$V_{ds} = 2V$

$V_{gs} = 0$ to $2V$, $0, 1, 2V$

$V_{sb} = 0, 0.5, 1V$,

$V_{sb} = 0$, $V_t = V_{to}$, $V_{ds} = 2V$

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