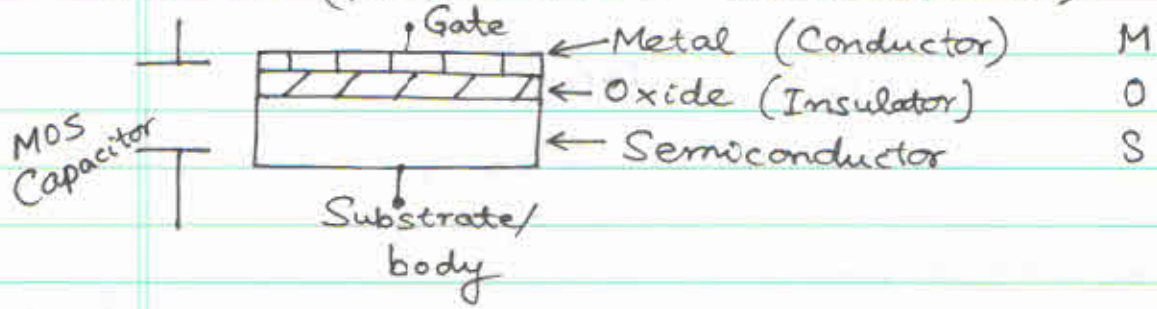
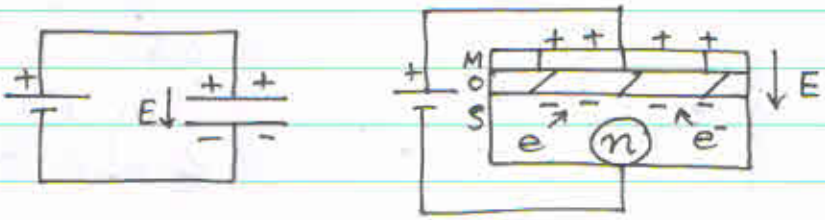
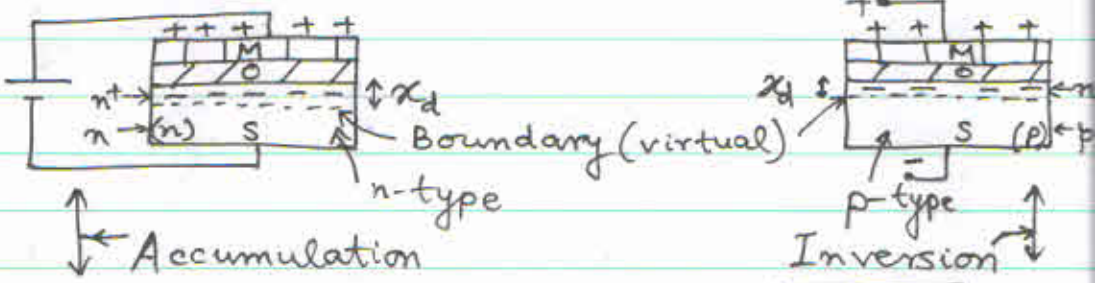
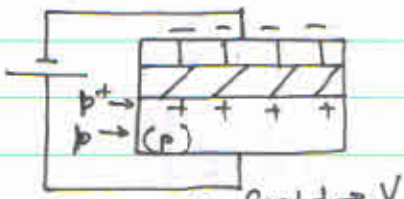
FETs & MOSFETs

1. MOS (Metal Oxide Semiconductor):

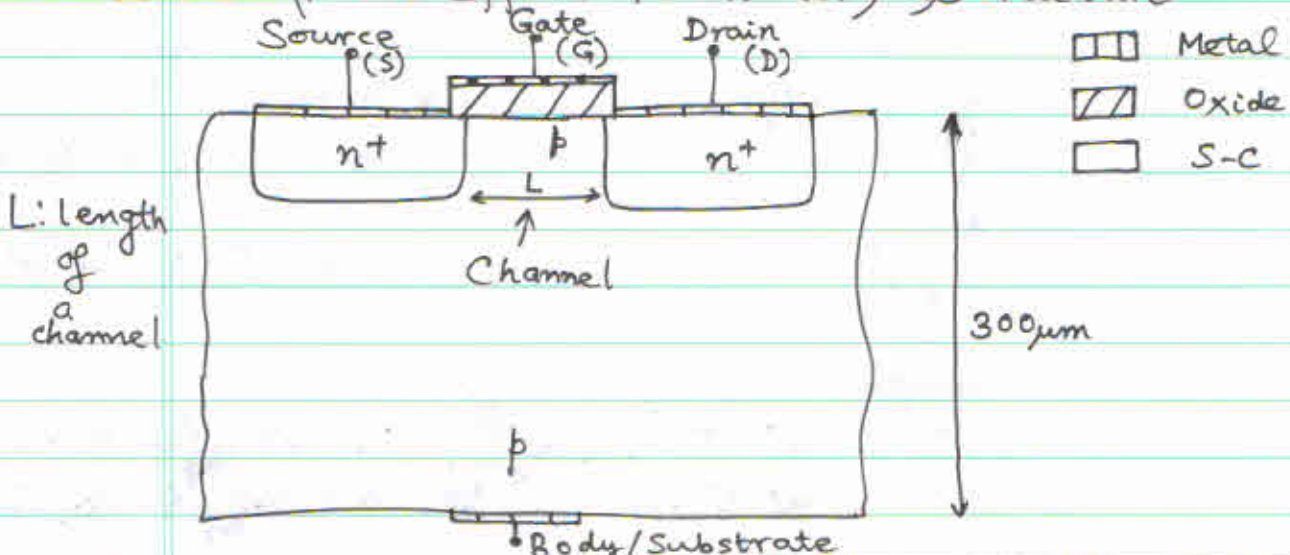








2. MOS FET (Field Effect Transistor): a) Structure



(Study the 3-D structure from the text book).

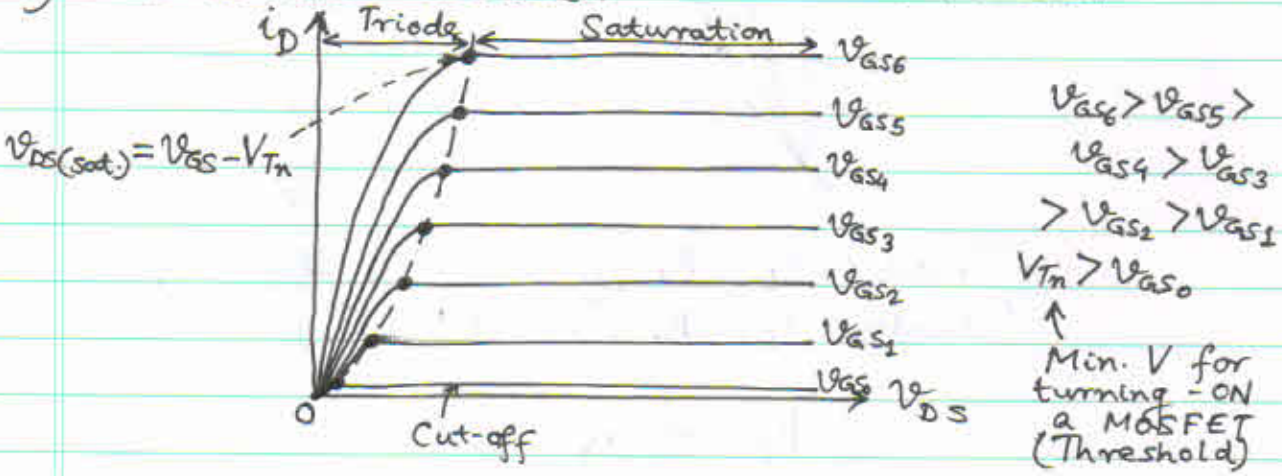
Metal (or conductor): Gold, aluminum, polysilicon

Oxide: Silicon di-oxide (SiO_2) or silicon nitride (Si_3N_4) (or insulator)

Semiconductor: Silicon

b) Equivalent circuits: MOSFET

c) V-I characteristics: n-channel MOSFET



d) MOSFET equations (for drain current): n-channel

i) Triode/non-saturation:

$$i_D = \underbrace{\frac{1}{2} \cdot \frac{W}{L} \cdot \mu_n \cdot C_{ox}}_{K_n} \left[2 (v_{GS} - V_{Tn}) v_{DS} - v_{DS}^2 \right]$$

(v_{DS}: const.)

K_n (or transconductance parameter).

ii) Saturation:

$$i_D = K_n (v_{GS} - V_{Tn})^2$$

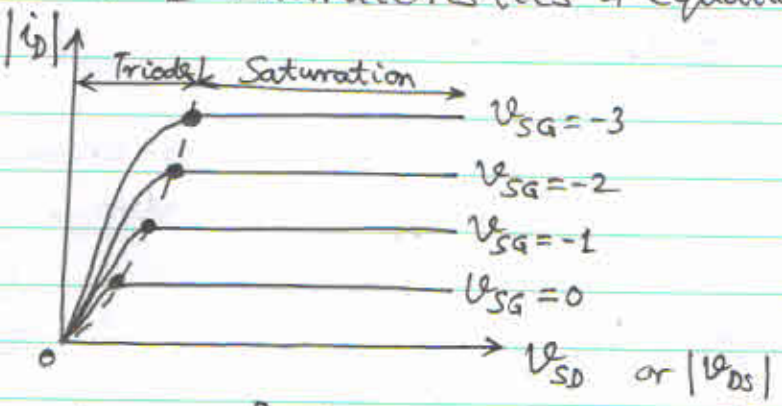
μ_n: Mobility of e^-
C_{ox}: Gate oxide capacitance.
W: Width of a MOSFET
L: Channel length
V_{Tn}: Threshold voltage (n-ch)

e) MOSFET related equations:

$$r_o = \left.\frac{\Delta v_{DS}}{\Delta i_D}\right|_{v_{GS}=\text{const.}} = \infty$$ (Small-signal resistance)

$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}}$$ (ϵ ← ϵ, t_{ox} ← d) (Capacitance per unit area)

f) MOSFET V-I charateristics & equations: p-ch.



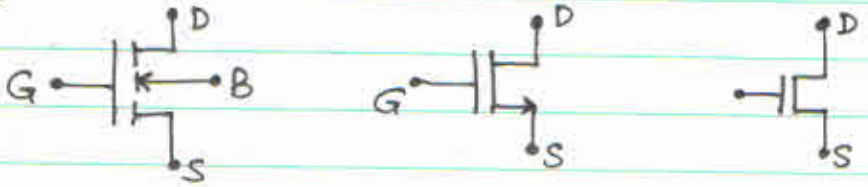
Triode: $i_D = K_p \left[2(v_{SG} + V_{Tp}) v_{SD} - v_{SD}^2\right]$

Saturation: $i_D = K_p (v_{SG} + V_{Tp})^2$

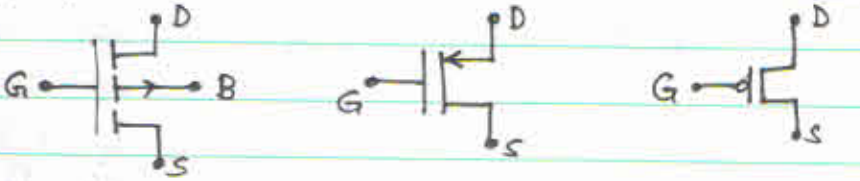
$$K_p = \frac{1}{2} \cdot \mu_p \cdot C_{ox} \cdot \frac{W}{L}$$

h) Symbols: (Enhancement type MOSFETs)

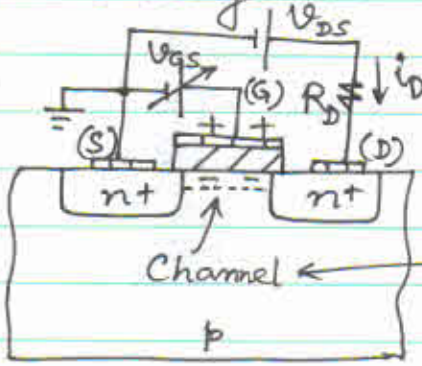
i) n-channel



ii) p-channel



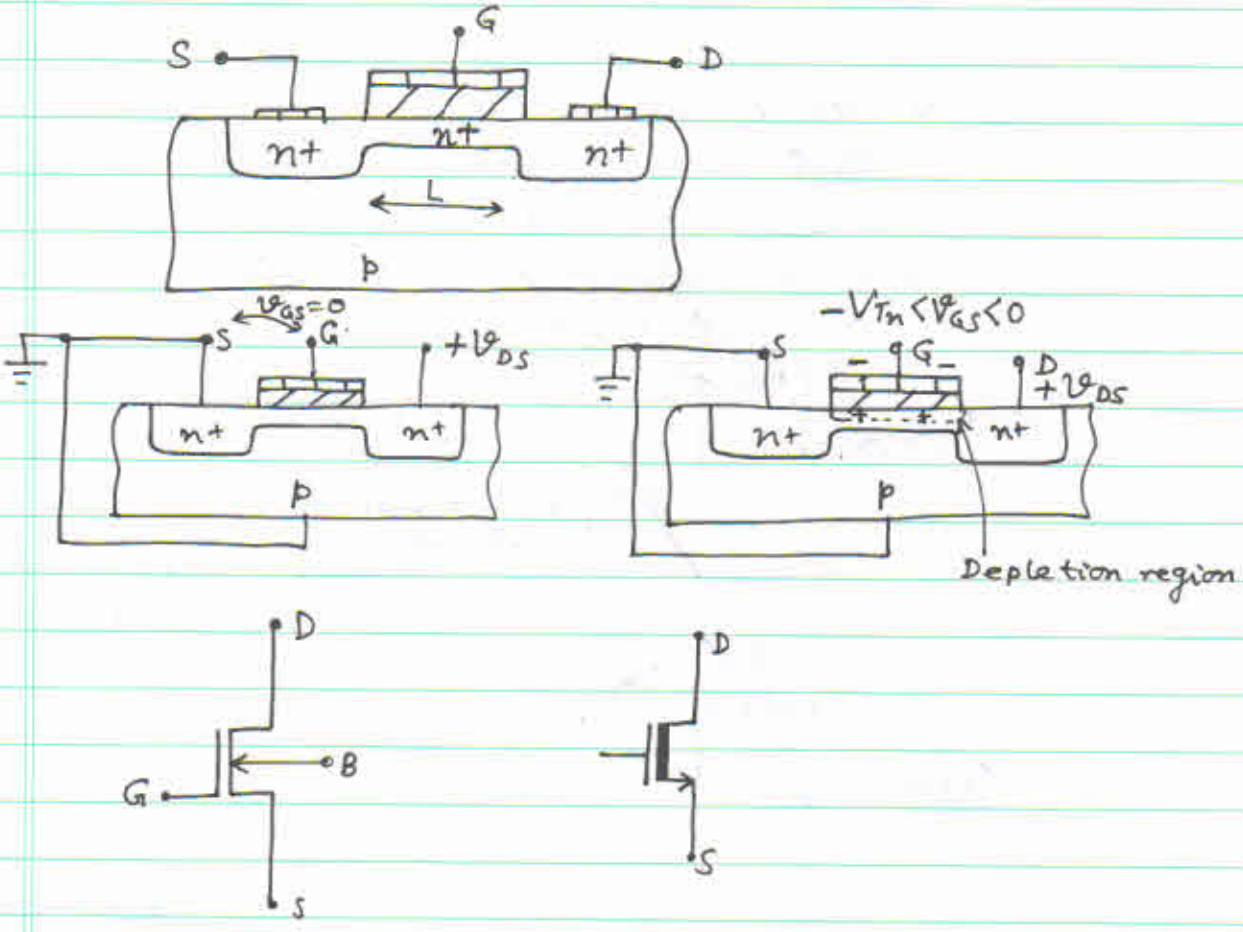
i) MOSFET biasing : n-channel

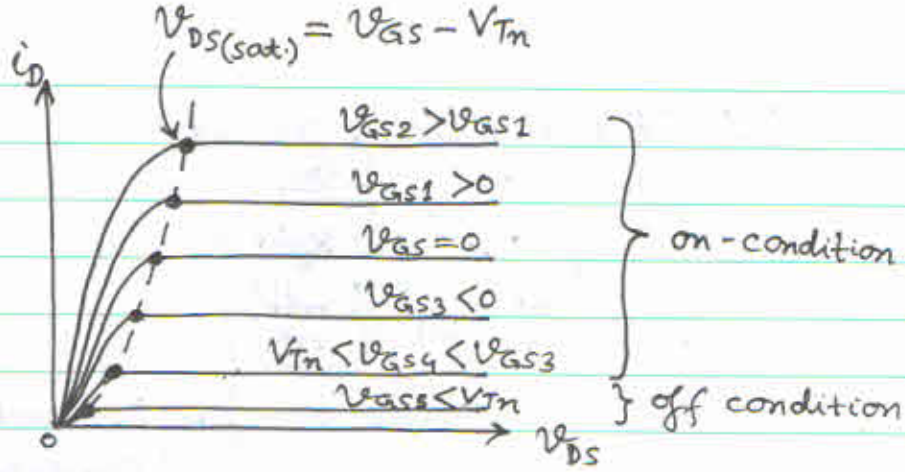


Formed due to inversion layer
Conductive path between D & S

j) MOSFET types : 1) Enhancement (normally off-type)
2) Depletion (normally on-type)

k) Depletion MOSFET: n-channel





For a depletion mode n-channel MOSFET, a $-v_{GS}$ below $|V_{Tn}|$ turns-'off' the device. Otherwise, the MOSFET is naturally remains 'on'.

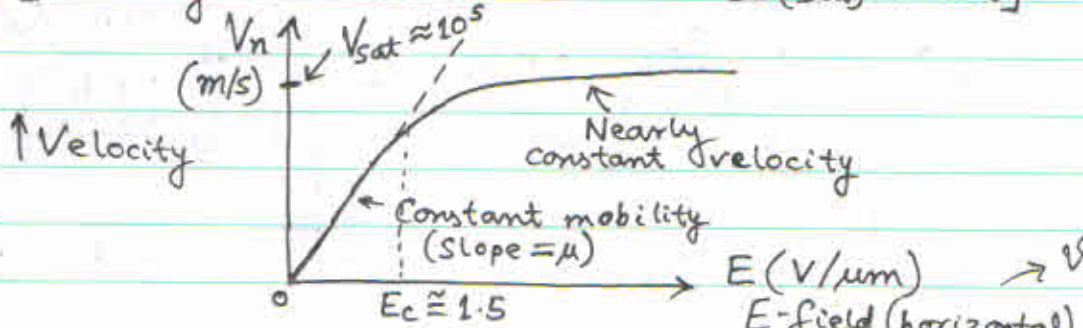
i) Short-channel effects: L is reduced below 2μm

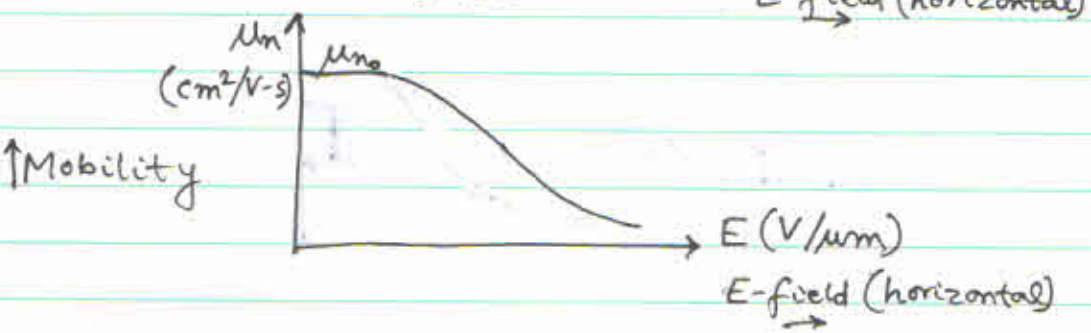
1) V_{Tn} depends on L & v_{DS} (directly proportional) v_{GS}
2) μ depends on E-field in the inversion layer. (vertical) (inversely proportional).

3) Velocity saturation:

$v_{DS}\uparrow$ E-field (horizontal)$\uparrow$ Velocity of carriers reaches a constant value (with further $v_{DS}\uparrow$)

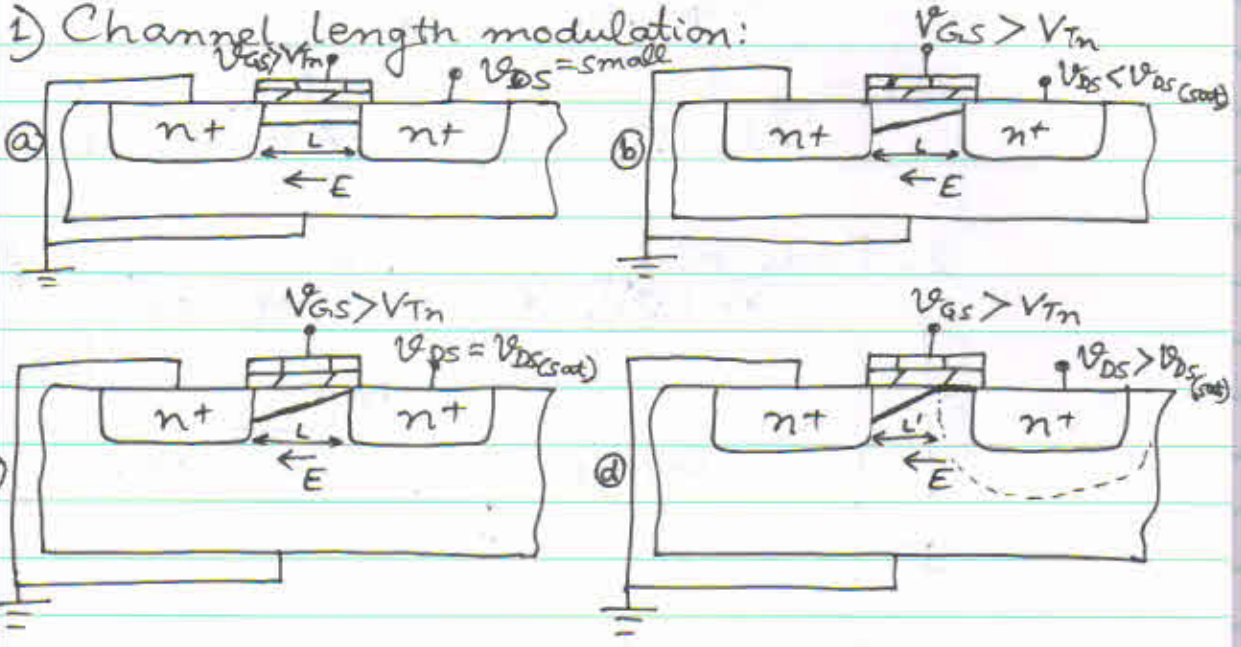
[Velocity saturation lower $V_{DS(sat)}$ value]





m) Other MOSFET behavior:

1) Channel length modulation:



Regions of operation:

a) Triode

b) Triode

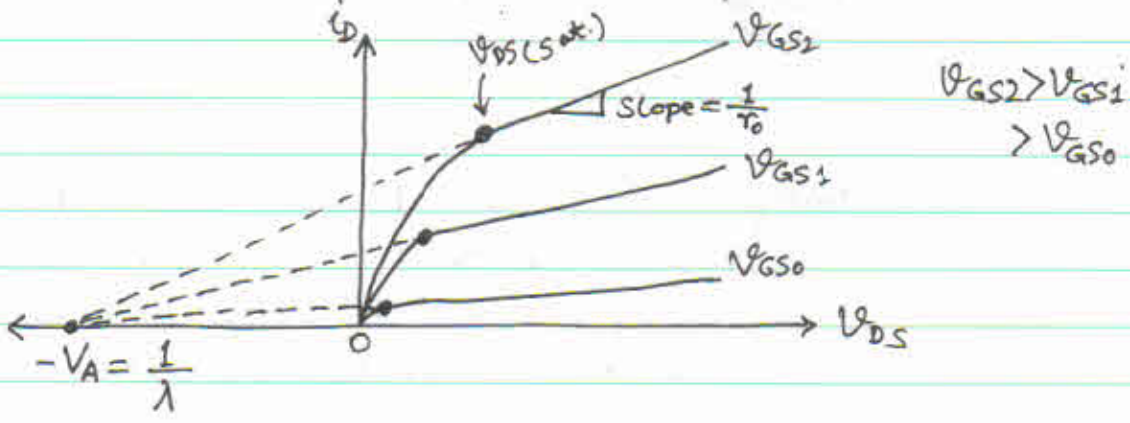
c) Triode - saturation transition

d) Saturation

The eq^n for i_D is modified to: (due to channel length modulation)

$$i_D = K_n \left[(v_{GS} - V_{Tn})^2 \left(1 + \lambda . v_{DS}\right) \right]$$

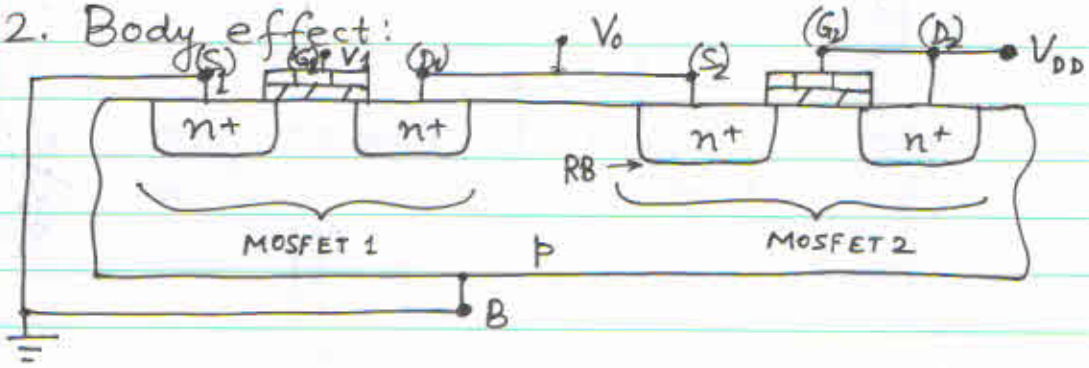
Ch. len. mod. parameter



$$r_o = \left.\frac{\partial v_{DS}}{\partial i_D}\right|_{v_{GS}=\text{constant}}$$

$$\Rightarrow r_o = \frac{1}{\lambda . K_n (V_{GS_Q} - V_{Tn})^2} = \frac{1}{\lambda . I_{D_Q}} = \frac{V_A}{I_{D_Q}}$$

2. Body effect:



If, both the MOSFETs are conducting, the voltage at the (S_2) of MOSFET2 is not at 0V (or Gnd)

$\therefore$ $V_{S_2} \approx$ +ve V

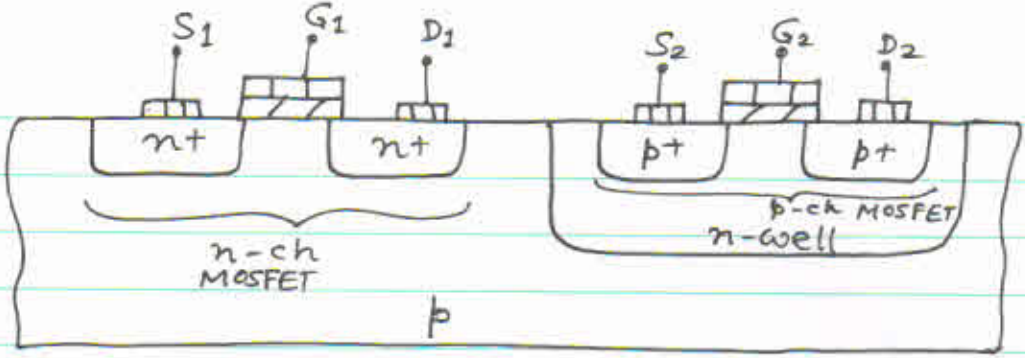
Junction between S_2 & B gets reverse biased (w.r.t. Gnd). This increases the V_{Tn} of MOSFET 2, which is called a body effect (or V_T shift).

$$V_{Tn} = V_{Tno} + \gamma \left[\sqrt{2.\phi_f + v_{SB}} - \sqrt{2.\phi_f}\right]$$

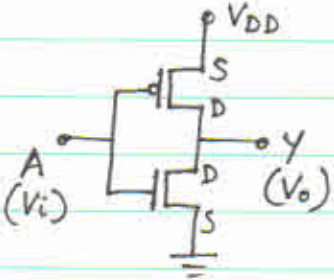
- V_{Tno}: Original threshold voltage
- γ: Body effect parameter, $0.5\,V^{\frac{1}{2}}$
- v_{SB}: Source to Body voltage
- ϕ_f: Semiconductor parameter, $\sim 0.35V$

n) Complementary MOSFETs: CMOS : NMOS + PMOS

↳ Uses both n-channel MOSFETs (NMOS) & p-channel MOSFETs (PMOS) together in an integrated circuit.



CMOS Inverter (NOT Gate):



or