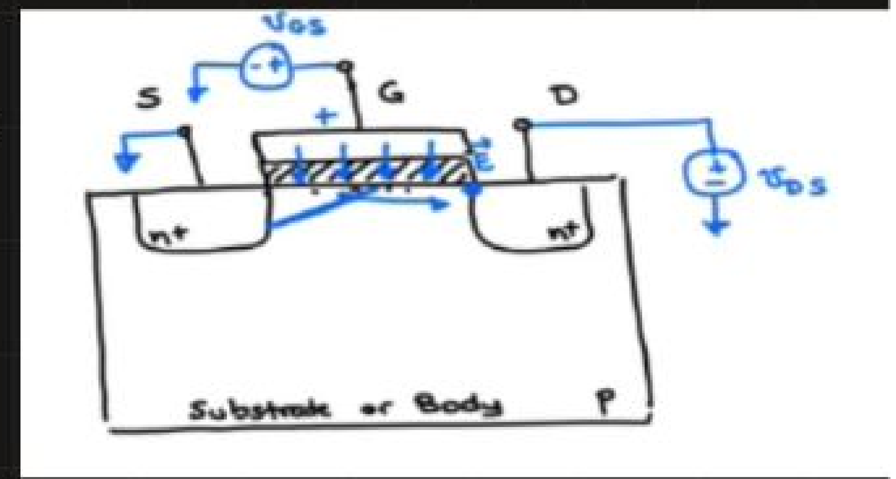
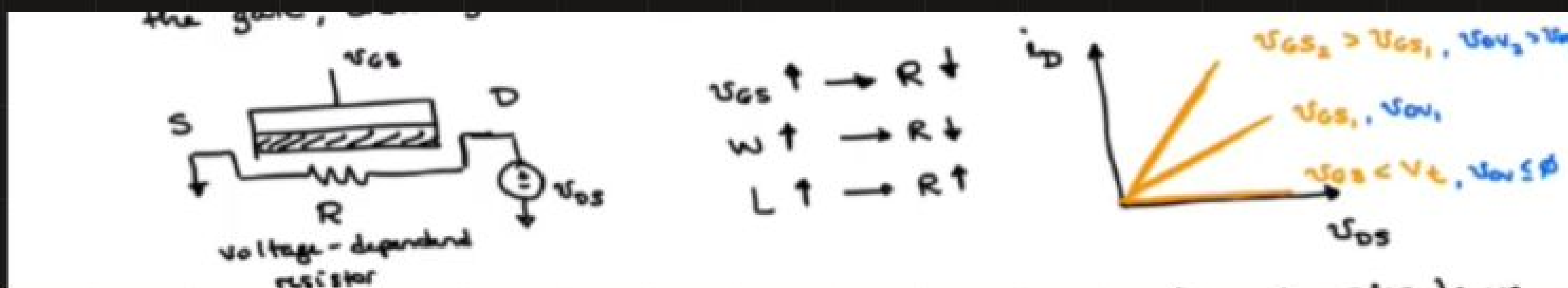
* Principle of operation:

→ Gate (V_{GS}) Voltage (input) controls drain-to-source current (output) i_{DS} or i_D



1) For $V_{GS}=0$, no current flows ($i_D=0$) ⇝ transistor is off.

2) as V_{GS} increases, electrons are attracted towards the region underneath the gate, filling avalible holes and creating an inversion layer underneath the gate, creating a resistive path between drain and source.



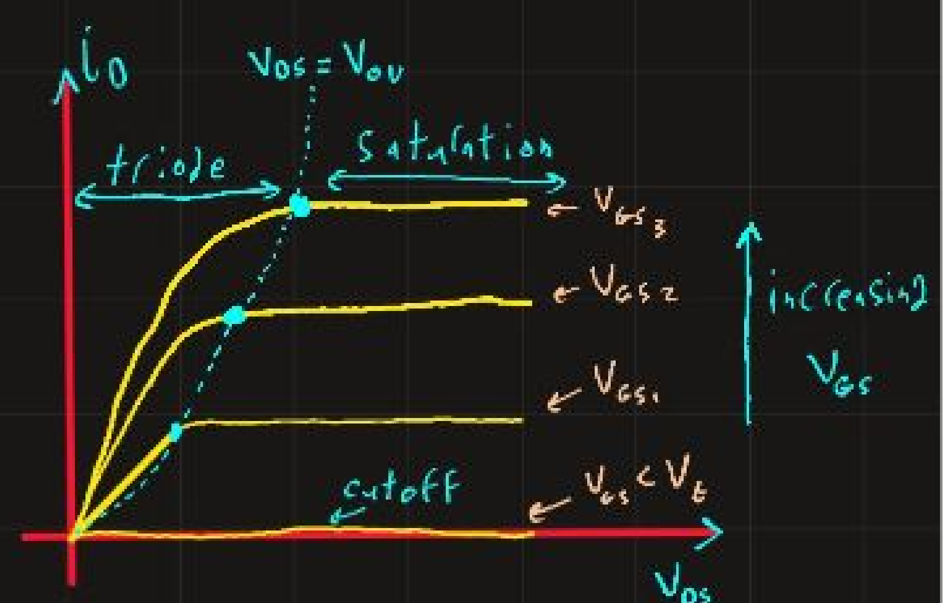
• V_t: threshold voltage ⇝ min voltage V_{GS} needed to create an inversion layer "Channel"

• V_{ov}: overdrive voltage ⇝ amount of voltage applied at the gate in exess of V_t ($V_{ov}=V_{GS}-V_t$)

⇝ $V_t>0$ for nMos, $V_t<0$ for PMos, typically $|V_t| \le 1$ v

3) as V_{DS} ↑↑ the i_D ↑↑ untile reaching a certain max V_{DS} for current V_{GS}, after this point the transistor enters the saturation region ⇝ i_D is constant for further increase in V_{DS}.

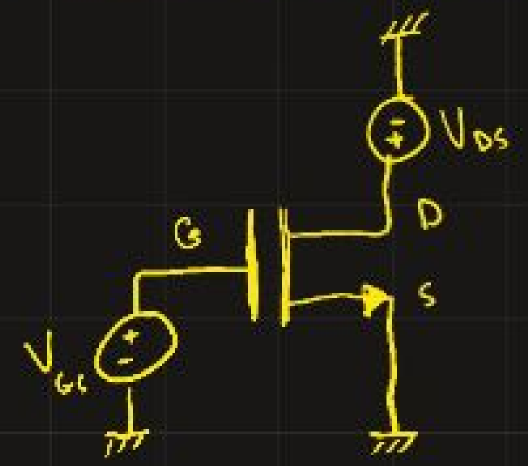
this is due to "Channel Pinch-off"

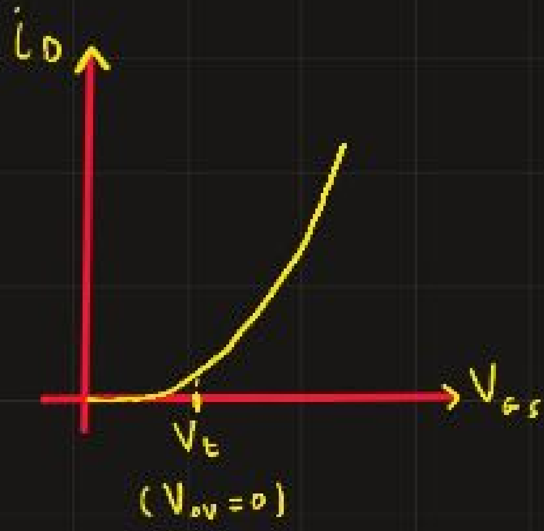


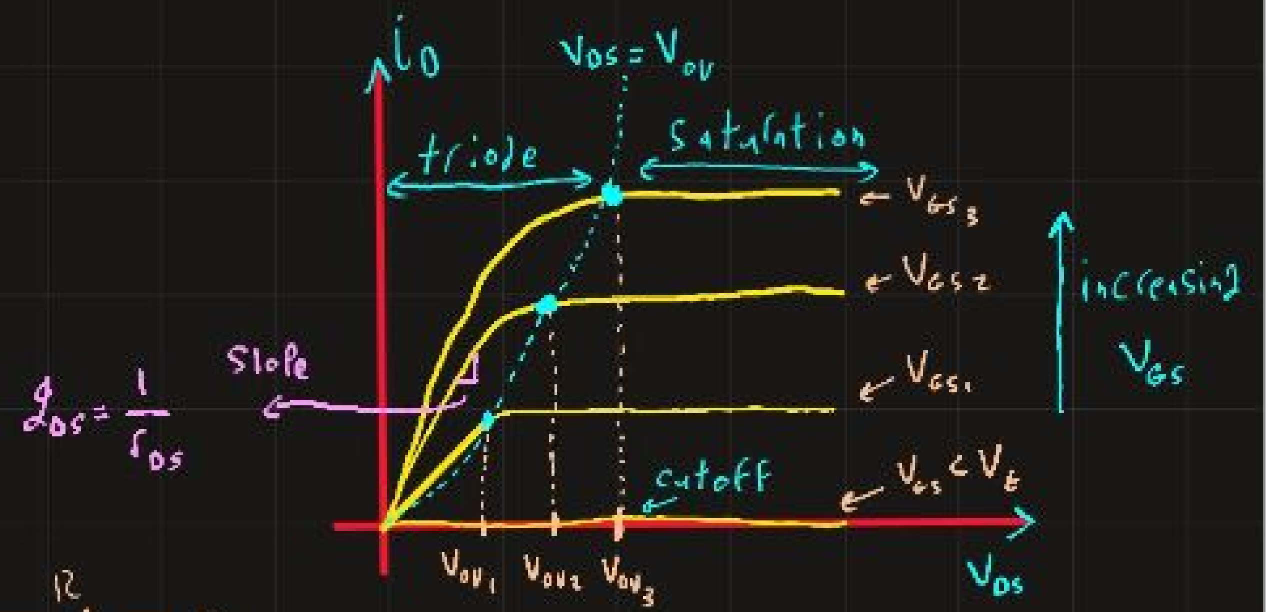
→ for linear amplification will use transistor in saturation region.

as i_D increases linearly with increasing V_{GS} in saturation region.

IV Characteristics:







→ $V_{GS} < V_t$ ⇝ no channel → cutoff → $i_D = 0$

→ $V_{GS} > V_t$ ⇝ a channel is indused → $V_{DS} < V_{ov}$: triode region ⇝ Voltage Controled resistor ⇝ $i_D \propto (V_{GS}, V_{DS})$

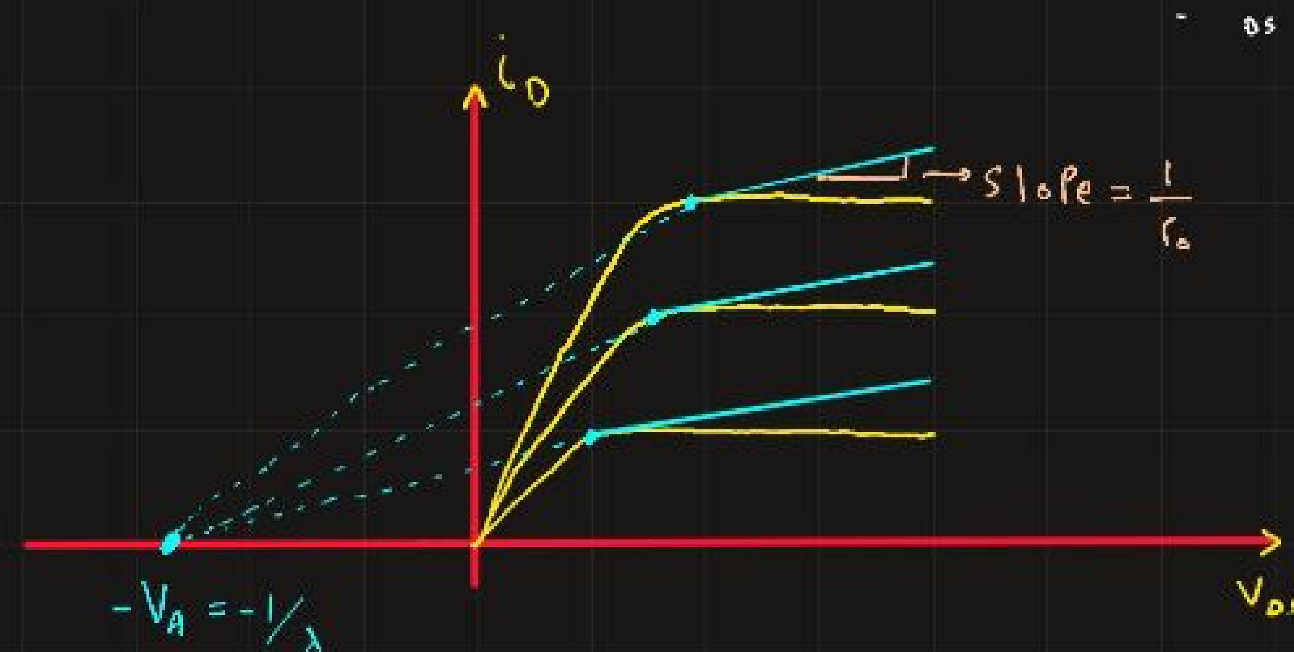
→ $V_{DS} > V_{ov}$: saturation region → Voltage-Controled current source

trans conductance device ⇝ $i_D \propto V_{GS}$

$\cdot\, i_D = \frac{1}{2} k_n (V_{GS} - V_t)^2$

* Channel Length modulation:

→ in saturation region we draw the function as constant, meaning "i_D doen't increas as V_{DS} increases" "i_D indep. of V_{DS}"
this isn't true, there will be a small change in i_D as V_{DS} changes
due to internal resistance between source-drain.



→ to account this change we use λ.

$\cdot\, i_D = \frac{1}{2} k_n (V_{GS} - V_t)^2$

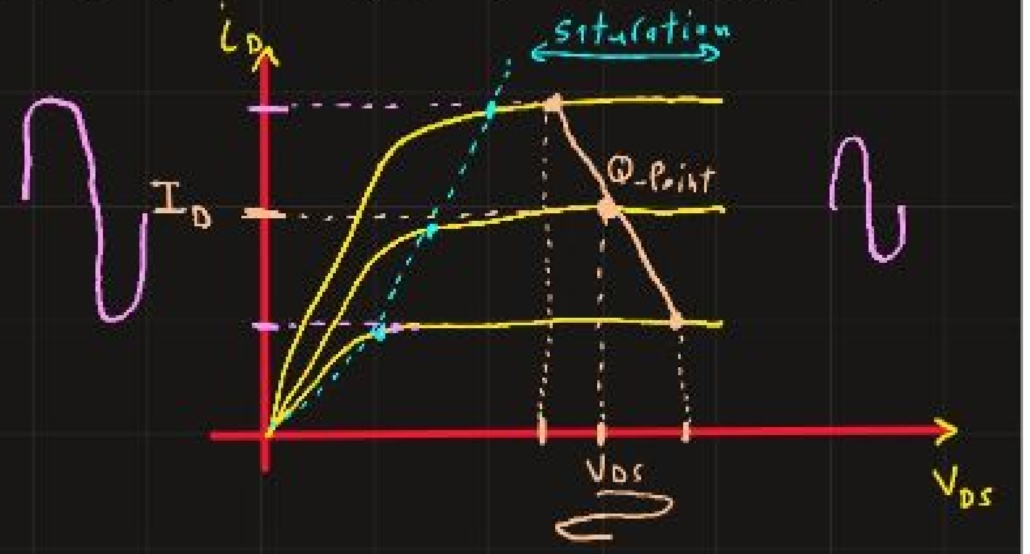
λ: channel-length modulation parameter (V^{-1})

⇝ $i_D = \frac{1}{2} k_n (V_{GS} - V_t)^2 (1 + \lambda V_{DS})$

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

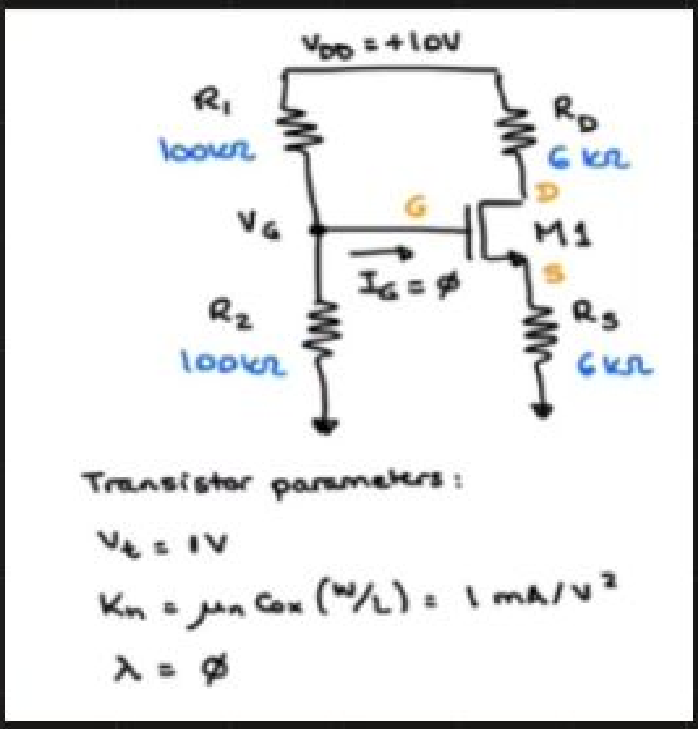
⋆ Mosfet as amplifier :

- used in Saturation region ($i_D = K_n V_{GS}^2$) ⇝ Small changes in V_{GS} results in large changes in i_D.
- first we set the Q-Point in the Prefered region" at the midle of the saturation region to avoid entering the triode region.



- Q-Point is set using DC baising circuit (V_{DS}, I_D)
- the Changes in i_D results in changing in V_{DS} .
- All the changes (V_{GS}, i_D, V_{DS}) is around the Q-Point .

⋆ DC Analsys example :



Find Q-Point (V_{GS} , I_D , V_{DS})

→ Assume M1 in Saturation.

- $V_G = \frac{100}{100+100}(10) = 5v$
- $I_D = \frac{1}{2} K_n (V_{GS} - V_t)^2$

$\therefore V_{GS} = V_G - V_S = 5 - 6 I_D$

$\therefore I_D = \frac{1}{2}(5 - 6I_D - 1)^2 \rightsquigarrow \therefore I_D = 0.89\ mA$, $I_D = 0.5\ mA$

. First solution: $I_D = 0.89\ mA$

→ $V_S = 6 I_D = 5.34v$

→ $V_{GS} = 5 - 5.34 = -0.34$ ∴ rejected $V_{GS} < 0$

. Second Soulation : $\boxed{I_D = 0.5\ mA}$

→ $V_S = 6 I_D = 3v$

→ ∴ $\boxed{V_{GS} = 5 - 3 = 2}$ ∴ accepted

. $V_{DS} = V_D - V_S = 10 - 6(0.5) - 6(0.5)$

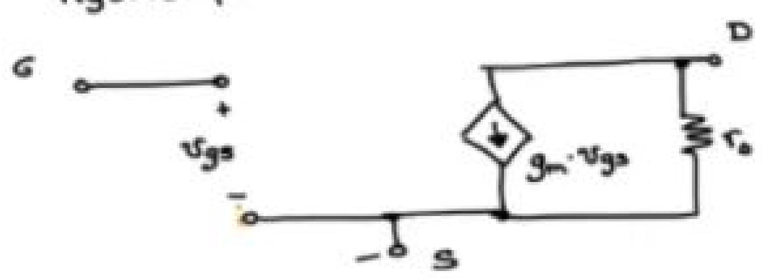
∴ $\boxed{V_{DS} = 4v}$

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

$4 > 2 - 1$

★ Small Signal Model :

Hybrid-pi model



$$i_D = \frac{1}{2}(\mu_n C_{ox})\left(\frac{W}{L}\right)(v_{GS} - V_t)^2 = \frac{1}{2} K_n \cdot V_{ov}^2$$

$$g_m = \frac{\partial i_D}{\partial v_{gs}} = K_n \cdot V_{ov} = \frac{2 I_D}{V_{ov}} = \sqrt{2 K_n \cdot I_D}$$

Therefore,

$$\boxed{\begin{aligned} g_m &= (\mu_n C_{ox})\left(\frac{W}{L}\right)(v_{GS} - V_t) \\ &= \frac{2 I_D}{v_{GS} - V_t} \\ &= \sqrt{(\mu_n C_{ox})\left(\frac{W}{L}\right) I_D} \end{aligned}}$$

← no I_D

← no process parameters (no K_n)

← no v_{GS} (no V_{ov})

Taking into account channel-length modulation (i.e., finite r_o):

$$i_D = \frac{1}{2} K_n V_{ov}^2 (1 + \lambda \cdot v_{DS}) \qquad \lambda = \frac{1}{V_A}$$

$$r_o = \left[\frac{\partial i_D}{\partial v_{DS}}\right]^{-1} = [\lambda \cdot I_D]^{-1} = \frac{1}{\lambda \cdot I_D} = \boxed{\frac{|V_A|}{I_D}}$$