# Transistor Amplifier

Lec-4

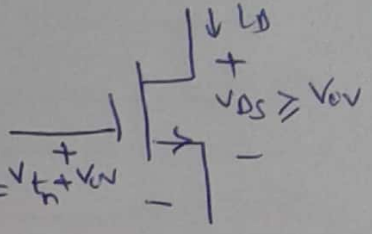
## 7.1 Basic Amplifier operations

For operates in saturation region $V_{DS} \geq V_{GS} - V_{Tn}$ or $V_{DS} \geq V_{OV}$ or $V_{GD} \leq V_{tn}$

$$i_D = \frac{1}{2} K_n [V_{GS} - V_{tn}]^2$$

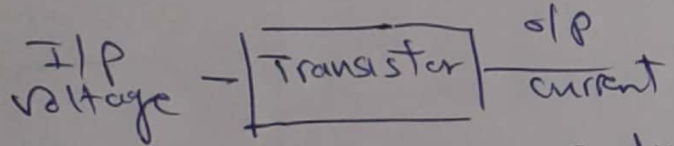
$$= \frac{1}{2} K_n V_{OV}^2 = \frac{1}{2} K_n' \frac{W}{L} V_{OV}^2$$

$$= \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{tn})^2$$

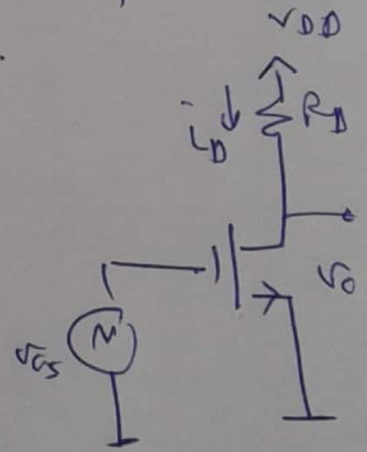



$i_D$ is independent on $V_{DS}$

## 7-1-2. obtaining a voltage Amplifier



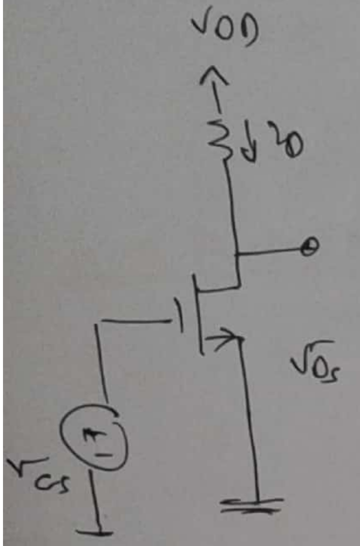

So it is basically Transconductance amplifier
To convert Transconductance amplifier to voltage amplifier, we need to pass output current Through a resistor at o/p.

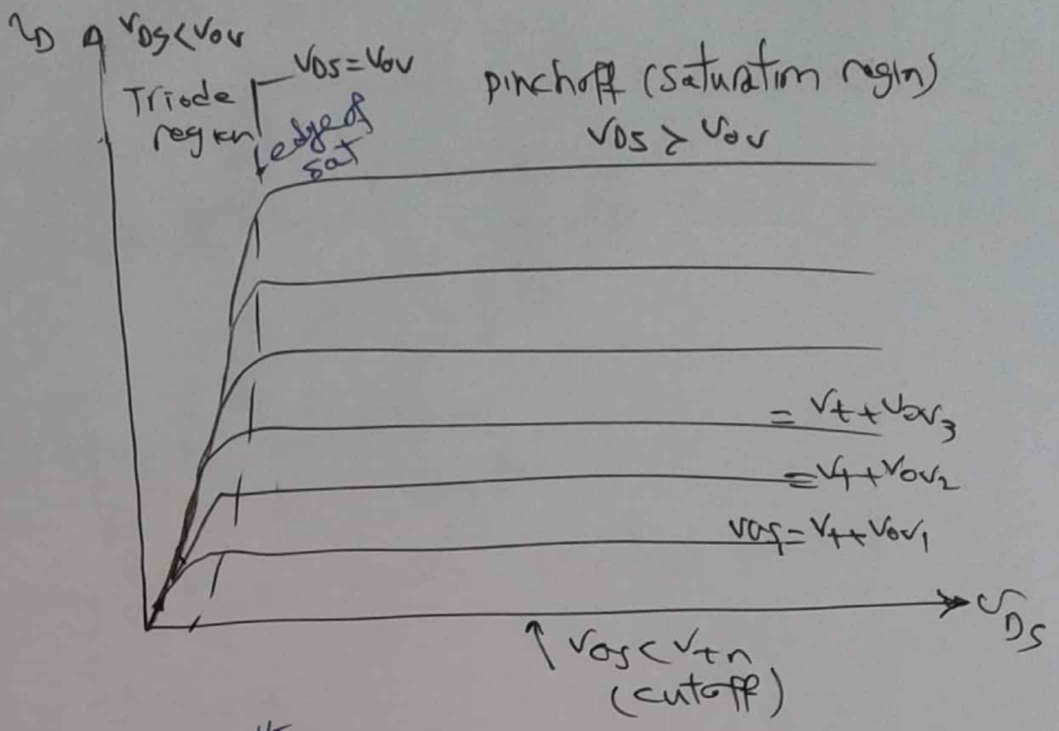


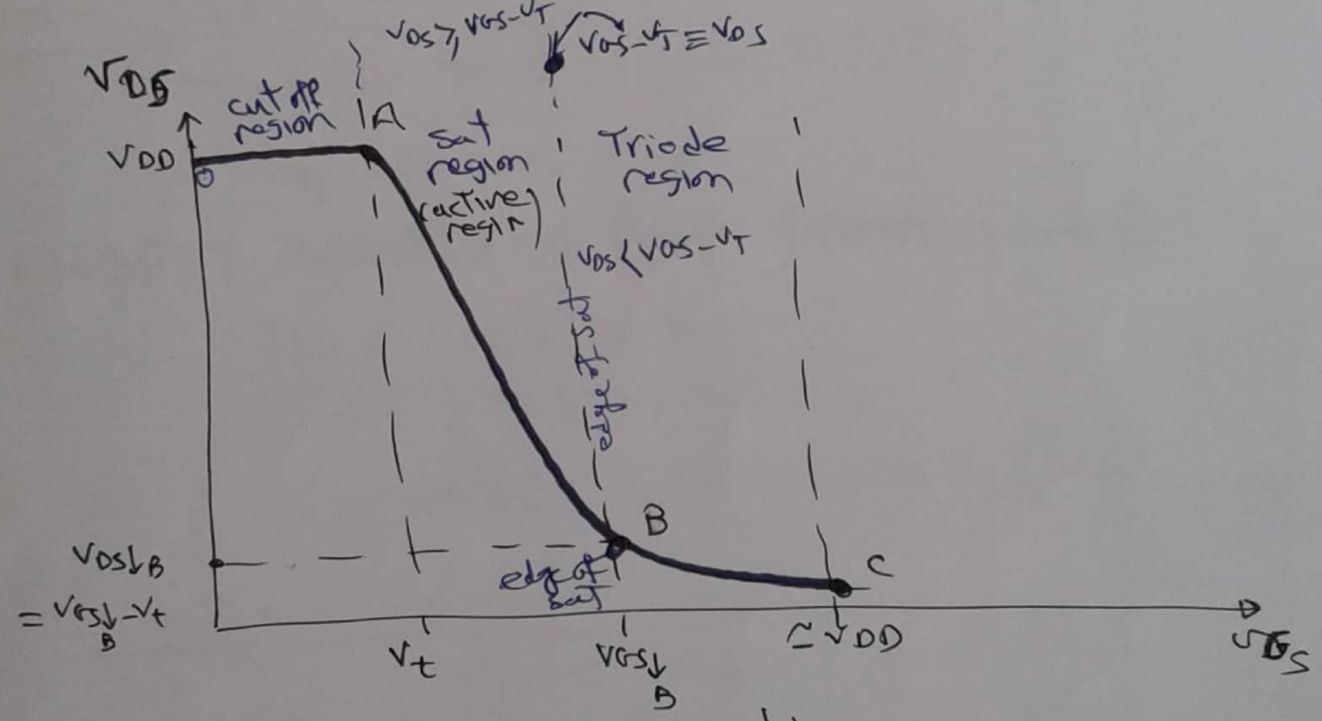

$$V_{DS} \equiv V_O = V_{DD} - I_D R_D$$

when $I_D = 0$

$\therefore V_O = V_{DD}$







## 7.1.3 Voltage-Transfer characteristics

عبارة عن علاقة بين $V_{GS}$ و $V_{DS}$

في منطقة الـ cut-off مفيش أي $i_D =$ صفر وفي المقابل $V_{GS}$ بيتغير وأقل من $V_t$

$$\therefore V_{DS} = V_{DD} - \underbrace{i_D}_{0} R_s = V_{DD}$$

① **From O → A** $\quad V_{GS} < V_T \quad \therefore i_D = 0 \quad V_{DS} = V_{DD}$

② **A − B** as $V_{GS}$ exceeds $V_t$ Transistor will be on, $i_D$ is present

$$\therefore V_{DS} = V_{DD} - i_D R_s$$

as $i_D \uparrow \quad V_{DS} \downarrow$

Transistor still in saturation until $V_{DS}$ become less Than $V_{GS}-V_T$

at $V_{DS} \leq V_{GS}-V_T$ start to go to Triode [edge of Saturation]

from $A \rightarrow B$

Transistor in saturation

$V_{DS} \downarrow$ , $V_{GS} \uparrow$

when $V_{DS}|_B = V_{GS}|_B - V_T$ reached point B

when $V_{DS} < V_{GS}-V_T$

Transistor go To Triode region

so $V_{DS}$ decrease slowly

# MOSFET operats as Amp from $A \rightarrow B$

$\because$ $V_{DS} = V_{DD} - I_D R_D$

$I_D = \frac{1}{2} K_n (V_{GS}-V_T)^2$

$\therefore$ $V_{DS} = V_{DD} - \frac{1}{2} K_n R_D (V_{GS}-V_T)^2 \longrightarrow \boxed{1}$

at edge of saturation (B)

$V_{GS} \equiv V_{GS}|_B$

$\because V_{DS} = V_{GS} - V_P$ so $V_{DS}|_B = V_{GS}|_B - V_T$

sub into eq 1

$V_{DS}|_B = V_{GS}|_B - V_T = V_{DD} - \frac{1}{2} K_n R_D (V_{GS_B} - V_T)^2$.

$V_{GS}|_B - V_t = V_{DD} - \frac{1}{2} K_n R_D [V_{GS_B}^2 - 2 V_{GS_B} V_T + V_T^2]$

$\therefore \frac{1}{2} K_n R_D [V_{GS_B}^2 - 2 V_{GS_B} V_t + V_t^2] + V_{GS_B} - (V_T + V_{DD}) = 0$

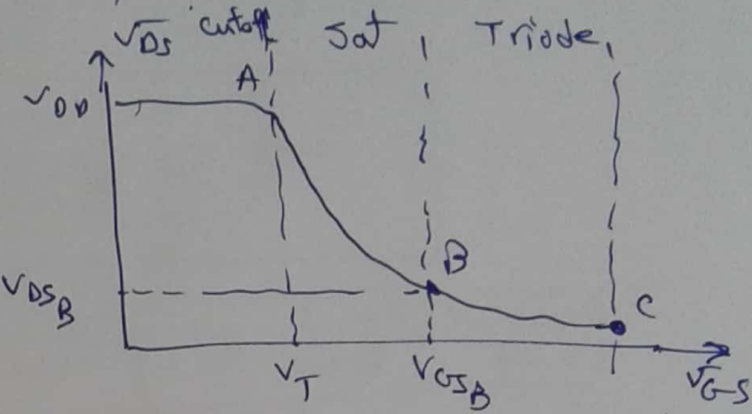
$\therefore V_{GS_B}^2 - 2 V_{GS_B} V_t + V_t^2 + \frac{V_{GS_B}}{\frac{1}{2} K_n R_D} - \frac{(V_T + V_{DD})}{\frac{1}{2} K_n R_D} = 0$

1. $0 \to A$ Cutoff

$V_{DS} = V_{DD}$, $I_D = 0$

2. $A \to B$ Sat

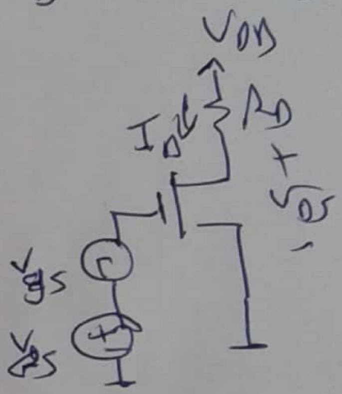
$$I_D = \frac{1}{2} k_n' \frac{W}{L} [V_{GS} - V_T]^2$$




at edge of Sat

~~$V_{GS_B}$~~

$$V_{GS_B} \simeq V_T + \frac{\sqrt{2 V_{DD} k_n R_D + 1} - 1}{k_n R_D}$$




3. at edge of Sat

$$V_{DS_B} = V_{GS_B} - V_t \simeq \frac{\sqrt{2 V_{DD} k_n R_D + 1} - 1}{k_n R_D}$$

3. From B — C Triode

$$I_D = k_n' \frac{W}{L}\left[ (V_{GS} - V_T) V_{DS} - \frac{V_{DS}^2}{2} \right]$$

$$V_{DS} = V_{DD} - I_{D,\,Triode} R_D$$

$$V_{DS} = V_{DD} - R_D k_n' \frac{W}{L}\left[ (V_{GS} - V_T) V_{DS} - \frac{V_{DS}^2}{2} \right]$$

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$$\therefore \underbrace{V_{GSB}^2}_{a} - \underbrace{\left(2V_t - \frac{2}{K_nR_D}\right)}_{b} V_{GSB} - \underbrace{\frac{2(V_t + V_{DD})}{K_nR_D}}_{c} = 0$$

$$\boxed{\begin{gathered} ax^2 + bx + c = 0 \\ x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \end{gathered}}$$

$$\therefore V_{GSB} = \frac{\left(2V_t - \frac{2}{K_nR_D}\right) \pm \sqrt{\left(2V_t - \frac{2}{K_nR_D}\right)^2 + \frac{8(V_t + V_{DD})}{K_nR_D}}}{2}$$

الجزء الذي تحت الجذر

$$M = \left(2V_T - \frac{2}{K_nR_D}\right)^2 + \frac{8(V_T + V_{DD})}{K_nR_D}$$

$$= 4V_T^2 - \frac{8V_T}{K_nR_D} + \frac{4}{K_n^2R_D^2} + \frac{8(V_T + V_{DD})}{K_nR_D}$$

$$= 4V_T^2 - \cancel{\frac{8V_T}{K_nR_D}} + \frac{4}{K_n^2R_D^2} + \cancel{\frac{8V_T}{K_nR_D}} + \frac{8V_{DD}}{K_nR_D}$$

$$= 4V_T^2 + \frac{4}{K_n^2R_D^2} + \frac{8V_{DD}}{K_nR_D}$$

$$= 4\left[V_T^2 + \frac{2V_{DD}}{K_nR_D} + \frac{1}{(K_nR_D)^2}\right]$$

when neglect $V_T$ since it is very small ($V_t^2$ can be neglected)

$$\therefore M \simeq 4\left[\frac{2V_{DD}}{K_nR_D} + \frac{1}{(K_nR_D)^2}\right]$$

$$\simeq 4\left[\frac{2V_{DD}K_nR_D + 1}{(K_nR_D)^2}\right]$$

توحيد المقامات $(K_nR_D)^2$

$$\therefore V_{GSB} \simeq \frac{\left(2V_t - \frac{2}{K_nR_D}\right)}{2} \pm \frac{\sqrt{M}}{2}$$

$$\simeq V_t - \frac{1}{K_nR_D} \pm \frac{1}{2}\sqrt{\frac{4(2V_{DD}K_nR_D + 1)}{(K_nR_D)^2}}$$

edge of saturation

$$V_{GSB} \simeq V_T - \frac{1}{K_nR_D} \pm \frac{1}{K_nR_D}\sqrt{2V_{DD}K_nR_D + 1}$$

+ علشان أهزاع تبين

$$\therefore V_{GSB} \simeq V_T - \frac{1}{K_nR_D} + \frac{1}{K_nR_D}\sqrt{2V_{DD}K_nR_D+1}$$ ✓

$$V_{GS_B} \simeq V_T + \frac{1}{K_nR_D}\left[\sqrt{2V_{DD}K_nR_D+1} - 1\right]$$

$$\boxed{V_{GSB} \simeq V_T + \frac{\sqrt{2V_{DD}K_nR_D+1}-1}{K_nR_D}} \quad \# \quad \boxed{6}$$

$\therefore$ at point B — الحد الفاصل بين saturation و Triode

$V_{DS_B} = V_{GS_B} - V_T = V_{ov_B}$

$$\boxed{V_{DS\downarrow_B} \simeq V_{ov_B} = \frac{\sqrt{2V_{DD}K_nR_D+1}-1}{K_nR_D}} \quad \boxed{7}$$

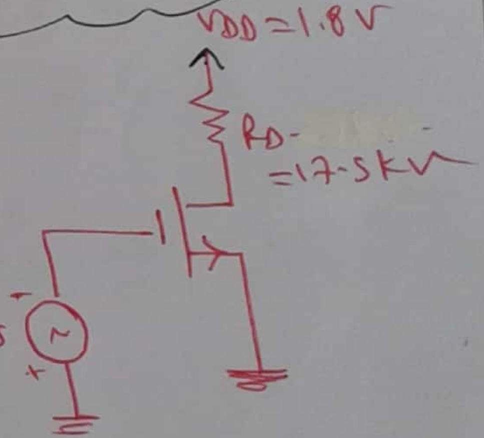
$= V_{GS} - V_T$

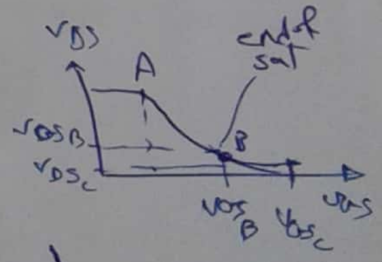
**Ex**

$V_{DD} = 1.8\,V$
$R_D = 17.5\,K\Omega$
$V_t = 0.4\,V$
$K_n = 4\,mA/V^2$

(a) Determine coordinates of end point of saturation $(V_{GS_B}, V_{DS_B})$

(b) Determine $V_{DS\downarrow_C}$ assuming $V_{GS_C} = V_{DD}$




$$\therefore V_{GSB} \simeq V_T + \frac{\sqrt{2V_{DD}K_nR_D+1}-1}{K_nR_D}$$

$$V_{GS\downarrow_B} = 0.4 + \frac{\sqrt{2*1.8*4*17.5+1}-1}{0.4*17.5}$$

$$= 0.4 + \frac{\sqrt{252+1}-1}{70} = 0.4 + \frac{\sqrt{253}-1}{70}$$

(a) $\left\{ \begin{array}{l} V_{GS\downarrow_B} = 0.612942\,V \quad \# \\ \therefore V_{DSB} = V_{GSB} - V_T = 0.61294 - 0.4 = 0.21294\,V \quad \# \end{array} \right\}$ (A) since region from B to C is Triode

$$\therefore i_D = k_n\left[(V_{GS}-V_T)V_{DS} - \frac{V_{DS}^2}{2}\right]$$

$$\therefore V_{DS} = V_{DD} - i_D R_D$$

$$V_{DS} = V_{DD} - k_n R_D\left[(V_{GS}-V_T)V_{DS} - \frac{V_{DS}^2}{2}\right]$$

$$\therefore V_{DS_C} = V_{DD} - k_n R_D\left[(V_{GS_C}-V_T)V_{DS_C} - \frac{V_{DS_C}^2}{2}\right]$$

$$V_{DS_C} = 1.8 - 4*17.5\left[(1.8-0.4)V_{DS_C} - \frac{V_{DS_C}^2}{2}\right]$$

$$V_{DSC} = 1.8 - 70\left[1.4V_{DSC} - \frac{V_{DSC}^2}{2}\right]$$

$$V_{DSC} = 1.8 - 98V_{DSC} + 35V_{DSC}^2$$

$$\therefore 35V_{DS_C}^2 - 99V_{DSC} + 1.8 = 0$$

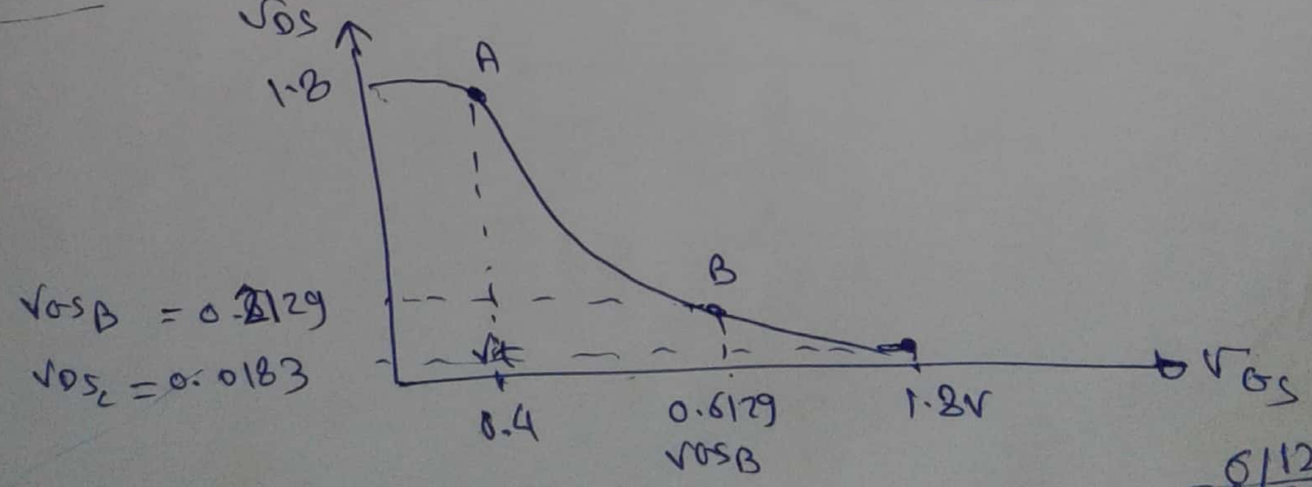
$$V_{DSC} = \frac{+99 \pm \sqrt{99^2 - 4*35*1.8}}{2*35}$$

$$V_{DSC} = 1.4142857 \pm 1.39598$$

$$V_{DSC} < \begin{matrix} 2.81027\ V \times\times \\ 0.0183057\ V \checkmark \end{matrix}$$ because at Triode $V_{DS}$ is very small

وحيث أن $V_{DSc}$ عند النقطة c تكون أقل ما يمكن نختار 0.018

$$\therefore V_{DSC} = 0.018305\ V \quad \#$$

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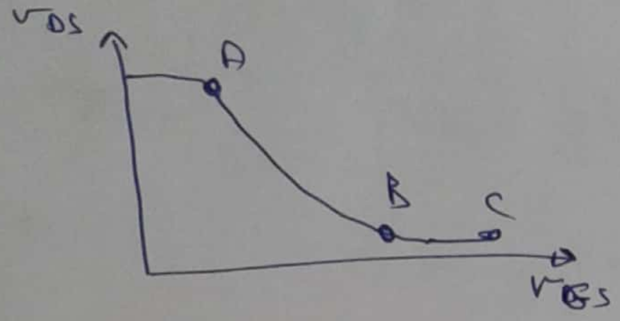
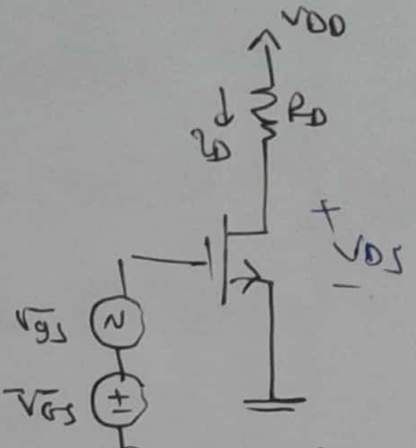
## 7.1.9 Obtaining Linear Amplification by biasing the Transistor




circuit

**from A → B (sat)**

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

From circuit

$$v_{DS} = V_{DD} - i_D R_D$$

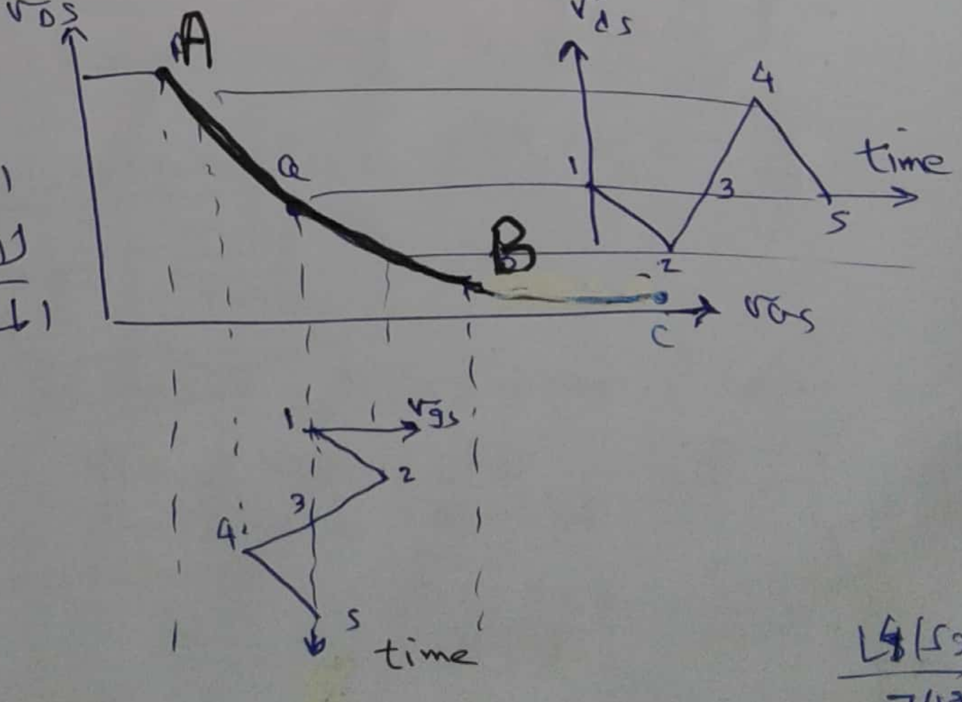
$$v_{DS} = V_{DD} - \frac{1}{2} k_n R_D (v_{GS} - V_t)^2 \longrightarrow$$

$$\text{since } \underbrace{v_{GS}}_{ac+DC} = \underbrace{V_{GS}}_{DC} + \underbrace{v_{gs}}_{ac}$$

$$\therefore v_{GS}(t) = V_{GS}(t) + v_{gs}(t)$$

نبحث عن نقطة Q-point وهي نقطة التشغيل التي تعتبر أساساً على مبدأ DC analysis ويجب أن تتوسط منتصف B-A لكي يتم تكبير موجة $v_{gs}$ ac دون تشويه (deformation)

نلاحظ أن Q يجب أن تكون في الوسط حتى لا يحدث تشويه لموجة $v_{ds}$ المكبرة.



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$$\because \; V_{DS} = V_{DD} - \frac{1}{2} k_n R_D (V_{GS} - V_T)^2$$

voltage gain $A_v = \left.\frac{\partial V_{DS}}{\partial V_{GS}}\right|_{V_{GS} = V_{GS}}$

$$A_v = \frac{\partial}{\partial V_{GS}} \left[ V_{DD} - \frac{1}{2} k_n R_D (V_{GS} - V_T)^2 \right]_{V_{GS} = V_{GS}}$$

$$= 0 - \frac{1}{\cancel{2}} k_n R_D * \cancel{2} (V_{GS} - V_T)$$

$$= - k_n R_D (V_{GS} - V_T)$$

$$\boxed{A_v = - k_n R_D V_{OV}} \text{ — } \boxed{1}$$

## Remarks

1. gain $A_v \propto k_n, R_D, V_{OV}$
2. gain is $-ve$, so o/p will have $180^\circ$ phase shift with input
3. $A_v = \frac{o/p}{I/p} = \frac{v_{ds}}{v_{gs}}$

$$\because \; I_D = \frac{1}{2} k_n V_{OV}^2 \text{ — } (2)$$

from (2) $\quad k_n V_{OV} = \frac{2 I_D}{V_{OV}} = \frac{I_D}{V_{OV}/2}$

sub into eq (1)

$$A_v = - k_n V_{OV} R_D = - \frac{2 I_D}{V_{OV}} \cdot R_D = - \frac{I_D R_D}{V_{OV}/2}$$

$$A_v = - \frac{I_D R_D}{V_{OV}/2} \text{ — } (3)$$

نلاحظ أن the gain هي عن الجهد ع المقاوم $R_D$ مقسوما على $V_{OV}/2$

$$\because \; V_{DS} = V_{DD} - I_D R_D \text{ — } (4)$$

$$\therefore - I_D R_D = V_{DS} - V_{DD}$$

sub into (3)

$$A_v = \frac{V_{DS} - V_{DD}}{V_{OV}/2} \text{ — } \boxed{5}$$

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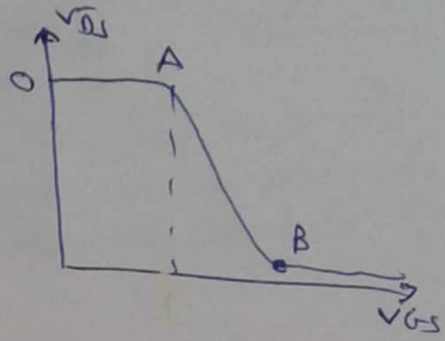
$$A_v = \frac{-I_D R_D}{V_{ov}/2} = -\frac{V_{DD}-V_{DS}}{V_{ov}/2} = -K_n R_D V_{ov} \qquad \boxed{6}$$




حيث إن أعظم ميل يقع عند النقطة
B ونفس الـ gain أعلى عندها
ولكن المخرج سوف يتشوه. لذا تفضل
أن نأخذ جزء من gain ونتركه ونقبل نقطة Q
في منتصف المسافة بين A و B

$$\because A_v = -\frac{V_{DD}-V_{DS}}{V_{ov}/2}$$

$$A_{v\,max}\downarrow = -\frac{V_{DD}-V_{DS_B}}{V_{ov_B}/2}$$

$$|A_{v\,max}| = \frac{V_{DD}-V_{DS_B}}{V_{ov_B}/2}$$

وحيث إن عند النقطة B والتي تفصل بين Triode & Sat تكون
فيه

$$V_{DS_B} = V_{GS_B} - V_t$$

$$V_{DS_B} = V_{ov_B}$$

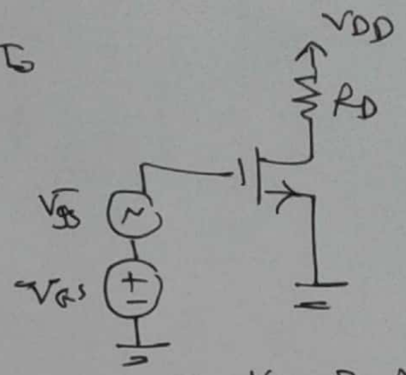
$$\therefore |A_{v\,max}| = \frac{V_{DD}-V_{ov_B}}{V_{ov_B}/2} = 2\,\frac{V_{DD}-V_{ov_B}}{V_{ov_B}}$$

ونحصل على $V_{ov_B}$ من معادلة (رقم 6 ص 5/12)

$$\therefore V_{ov_B} = V_{GS_B} - V_T = \frac{\sqrt{2K_n R_D V_{DD}+1}-1}{K_n R_D}$$

To maximize the gain, The point Q must be close as possible to point B but The near To point B make a problem of signal swing

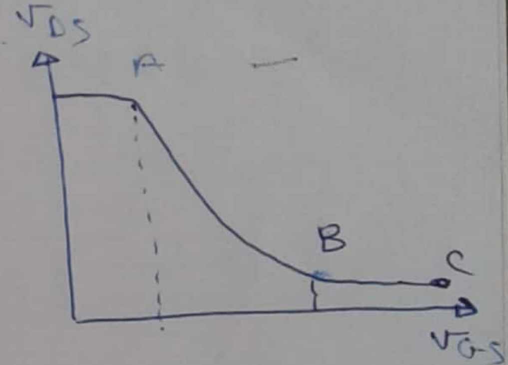
(Ex) The Transistor is specified To have $V_t = 0.4$
$K_n' = 0.4\,mA/V^2$
$W/L = 10$
let $V_{DD} = 1.8\,V$
$R_D = 17.5\,k\Omega$
$V_{GS} = 0.6\,V$




(a) for $v_{gs} = 0$ (and hence $v_{ds} = 0$), find $V_{OV}$, $I_D$, $V_{DS}$ & $A_v$
(b) what is The maximum symmetrical signal swing allowed at the drain? Hence find the maximum allowable amplitude of a sinusoidal $v_{gs}$.

(a) since $V_{GS} = 0.6\,V$

$\therefore V_{OV} = V_{GS} - V_t = 0.6 - 0.4 = 0.2$ #




assume the tr operates in Saturation

$$I_D = \frac{1}{2} K_n' \frac{W}{L} (V_{GS} - V_t)^2$$
$$= \frac{1}{2} K_n' \frac{W}{L} V_{OV}^2$$
$$= \frac{1}{2} * 0.4 \frac{mA}{V^2} * 10 * 0.2^2$$
$$I_D = 0.08\,mA \quad \#$$

$$V_{DS} = V_{DD} - I_D R_D = 0.4\,V \quad \#$$
$$= 1.8 - 0.08 * 17.5$$

check $\left.\begin{array}{l} V_{DS} = 0.4 \\ V_{GS} - V_T = V_{OV} = 0.2 \end{array}\right\}$ so $V_{DS} > V_{GS} - V_T$ sat

طريقة ١ $\left\{ \begin{array}{l} A_v = -K_n V_{OV} R_D = -K_n' \frac{W}{L} V_{OV} R_D = -14\,V/V \\ = -0.4 * 10 * 0.2 * 17.5 \end{array} \right.$

طريقة ٢ $\Rightarrow A_v = \dfrac{-I_D R_D}{V_{OV}/2} = -\dfrac{0.08 * 17.5}{0.2/2} = -14\,V/V$ #

طريقة ٣ $\Rightarrow A_v = -\dfrac{V_{DD} - V_{DS}}{V_{OV}/2} = -\dfrac{1.8 - 0.4}{0.2/2} = -14\,V/V$

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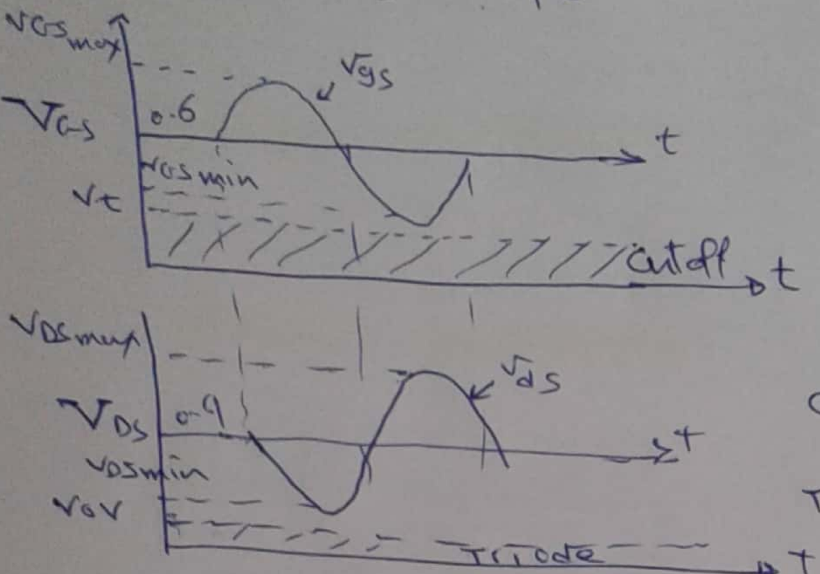
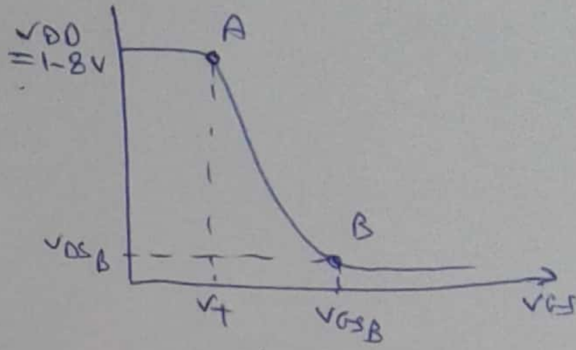
(b)

شكل الحل سيكون كالتالي




بحيث الـ [illegible] الـ $v_{gs}$ [illegible] الـ
عند $V_{GS}-V_t$ والا سيدخل الى cutoff
بحيث الـ [illegible] الـ
عند $V_{DS}-V_{OV}$ والا سيدخل إلى Triode

وهي شرط مهمة جداً لـ [illegible] ب ضرب دول $v_{ds} < v_{gs}$

$$\because V_{OV} = 0.2 \qquad V_{DS} = 0.4V$$

$$v_{ds} \text{ must be} = \pm(0.4-0.2) = \pm 0.2$$

$$\because |A_v| = \frac{v_{ds}}{v_{gs}} \qquad \boxed{v_{ds} = A_v v_{gs} \;\Big|\; v_{gs} = \frac{v_{ds}}{|A_v|}}$$

$$+14 = \frac{0.2}{v_{gs}}$$

$$\therefore v_{gs} = \frac{0.2}{14} = 14.285\,mV \; \text{\#}$$

وهي لحد الآن [illegible] دول مع ضرب $V_{GS}$ (الجزء الـ DC level)

For saturation $V_{DS_{min}} \geq V_{GS_{max}} - V_t$

$$V_{DS} - v_{ds} \geq V_{GS} + v_{gs} - V_t$$

$$0.4 - |A_v| v_{gs} \geq 0.6 + v_{gs} - 0.4$$

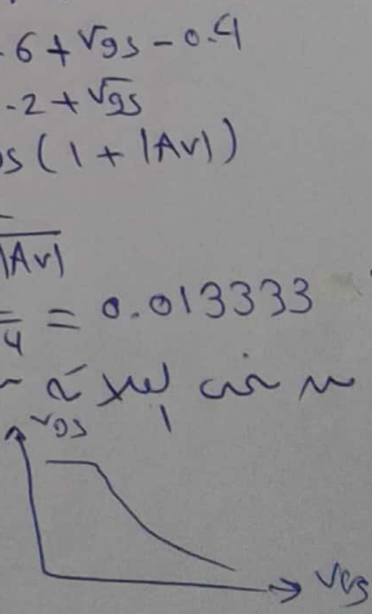
$$0.4 - |A_v| v_{gs} \geq 0.2 + v_{gs}$$

$$0.4 - 0.2 \geq v_{gs}(1 + |A_v|)$$

$$v_{gs} \leq \frac{0.2}{1+|A_v|}$$

$$v_{gs} \leq \frac{0.2}{1+14} = 0.013333\ V$$

[illegible] من العلاقة بين $V_{GS}$ و $V_{DS}$ كده
$V_{GS_{min}}$ [illegible] كده $V_{DS_{max}}$
والعكس بالعكس

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$\therefore \; V_{GSmax} = V_{GS} + \hat{v}_{gs}$

$= 0.6 + 0.01333$

$V_{GSmax} = 0.61333 \text{ mV}$ #

$V_{GSmin} = V_{GS} - \hat{v}_{gs}$

$= 0.6 - 0.01333$

$V_{GSmin} = 0.58667 \text{ V}$ #

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$V_{DSmax} = V_{DS} + \hat{v}_{ds}$

$= V_{DS} + |A_v| \hat{v}_{gs}$

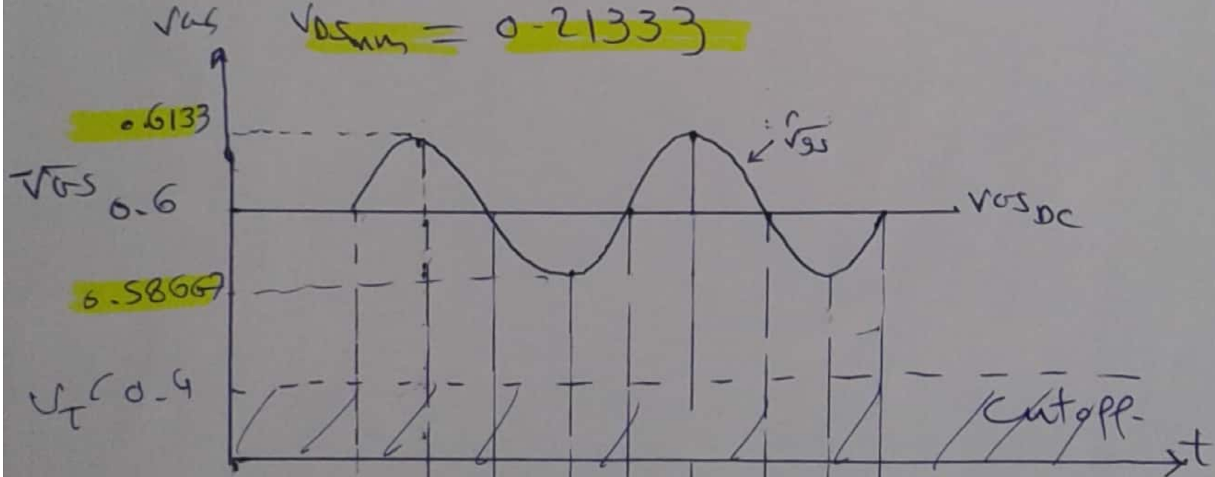
$= 0.4 + 14 * 0.01333$

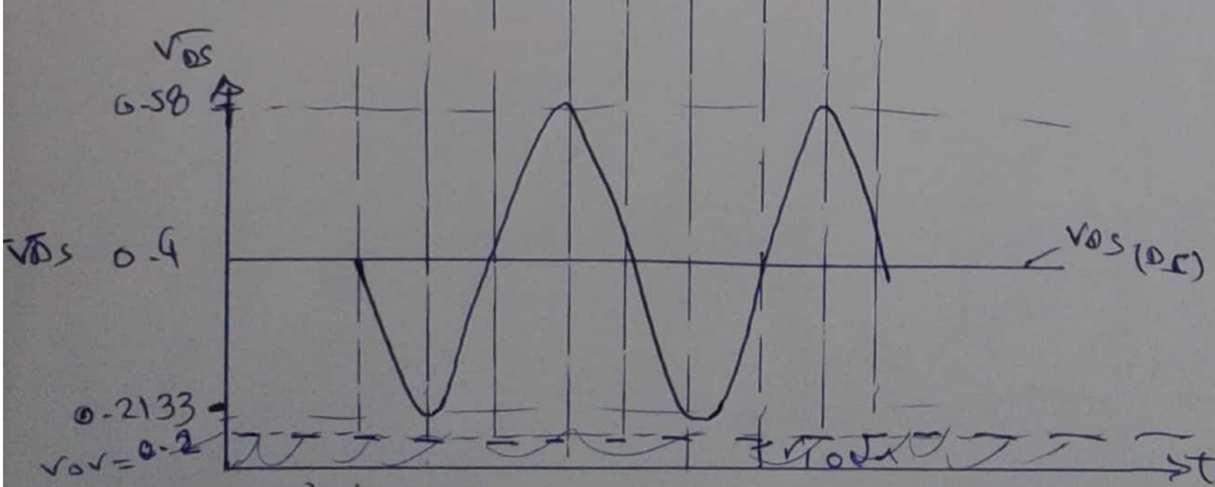
$V_{DSmax} = 0.58662$

$V_{DSmin} = V_{DS} - \hat{v}_{ds} = V_{DS} - |A_v| \hat{v}_{gs}$

$= 0.4 - 14 * 0.01333$

$V_{DSmin} = 0.21333$




نلاحظ انه طالما ان الجزء السالب من vDS لم يتجاوز قيمة vov
فإن الموجة لم يحدث لها تشويه ولم يدخل إلى منطقة Triode

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