MOSFET

↳ active device
control flow of e

Metal oxide Semiconductor
Field-Effect Transistor

ch btw D & S

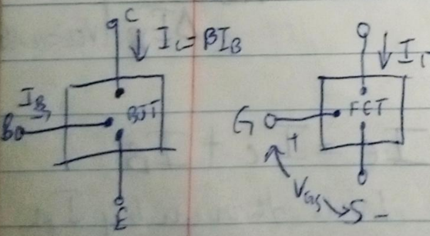
1.) Depletion type < n-channel, p-channel
2.) Enhancement type < n, p

↳ no channel btw D & S
(D: drain, S: source)

~~Construction & Working of Enhancement-Type MOSFET~~

Field-Effect Transistors

BJT → 3 terminal ← FET



BJT → current control device
FET → Voltage control device

BJT → bipolar
FET → Unipolar (e or holes)

n-channel & p-channel
npn | pnp
(e^-) | (holes)

FET → amp. & switching

FET
- JFET
  - n-channel
  - p-channel
- MOSFET
  - D MOSFET (n-c, p-c)
  - E MOSFET (n-c, p-c)

FET history

Julius Edgar Lilienfeld 1926
Oskar Heil in 1934

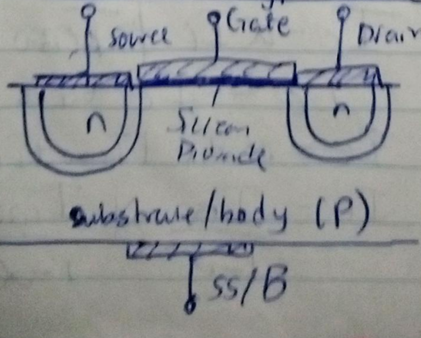
MOSFET
↳ D. Kahng (1959)

"Field-Effect"

E.F. $\xrightarrow{\text{controls}}$ conduction path of o/p

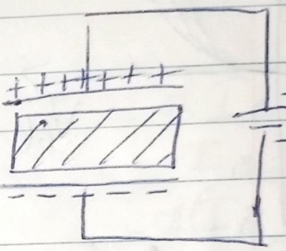
FET has high input impedances
FETs are more Temp. stable
FETs are smaller than BJTs

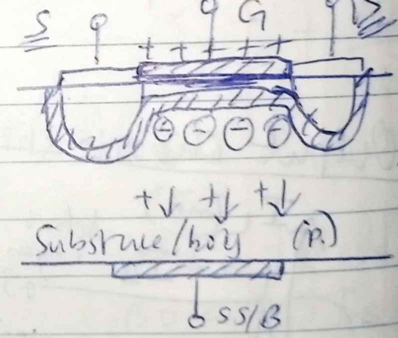
Construction & Working of Enhancement-Type MOSFET



(SiO_2)
Silicon Dioxide → 1000
↳ also called gate oxide

major c.c = holes
min c.c = e^-
mobile c.c = Immobile ions
↳ charge neutrality is maintained





Inversion ⇒
$V_{GS} > 0V$ ⇒
Conductive channel is formed between Source and Drain.

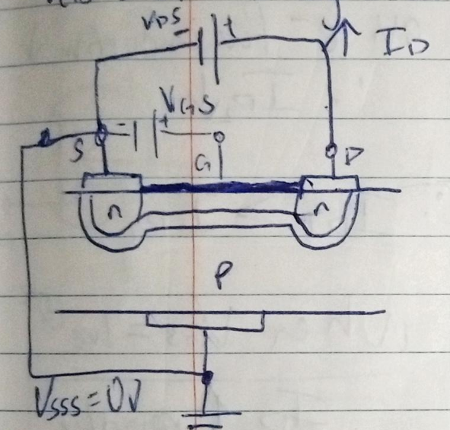
↑V_{GS} ⇒ width of channel ↑

if V_{GS} > particular voltage
⇒ current flow (I_D)

Threshold voltage

V_T is the votage that results in the significant amount of current to flow from source to drain.

$V_{GS} > V_T \Rightarrow$ Significant



$V_{GSS} \to V_{GS}$

$V_{GS} > V_T \Rightarrow$ Sig $\uparrow I_D$

$V_{GD} = V_{GS} - V_{DS}$

Case 1 : $V_{DS} = 0$

$V_{GD} = V_{GS}$ uniform d-s

Case 2 : $V_{DS} > 0V$

$V_{GD}\downarrow \neq V_{GS}$
not

D $\to$ (+)ve channel reduces on right side

Vo saturation

Case 3 : $V_{DS} = V_{GS} - V_T$

$V_{GD} = V_T$

channel will become extremely narrow on right side (Pinch-OFF)

Drain Characteristics of Enhancement-Type MOSFET

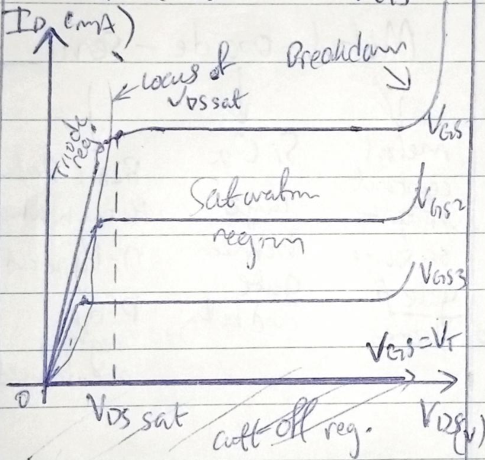
↳ Output channel

o/p i = I_D

o/p V = V_{DS}

i/p voltage

Control Variable = V_{GS}



Case 1 :- $V_{GS1} > V_T$

$V_{eff} = V_{GS1} - V_T$

$V_{DS\,sat} = V_{GS1} - V_T$

I_D = Constant (Pinch-off)

$V_{DS} = 0_V \Rightarrow V_D = V_S$

$\uparrow V_{DS} \Rightarrow I_D \uparrow$

$V_{GD} = V_{GS} - V_{DS}$

$V_{DS} = V_{GS} - V_T$

$\therefore V_{GD} = V_T$

say $V_{GS} = 2V$

& $V_T = 1V$

$V_{DS} = V_{GS} - V_T$

$V_{ef} = 2 - 1 = 1V$

Case II :-

$V_{GS2} < V_{GS1}$

$\rho_2 < \rho_1$

$R_2 > R_1$

slope 2 < slope 1

Saturation Region →

region in which I_D is constant

↳ $V_{DS} \geq V_{GS} - V_T$

$I_D = K(V_{GS} - V_T)^2$
↓
constant

$K = \dfrac{I_{D(on)}}{(V_{GS} - V_T)^2}$

in A/V^2

Triode Region

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

$\cancel{I_D = 2k[(V_{GS}-V_T)V_1}$

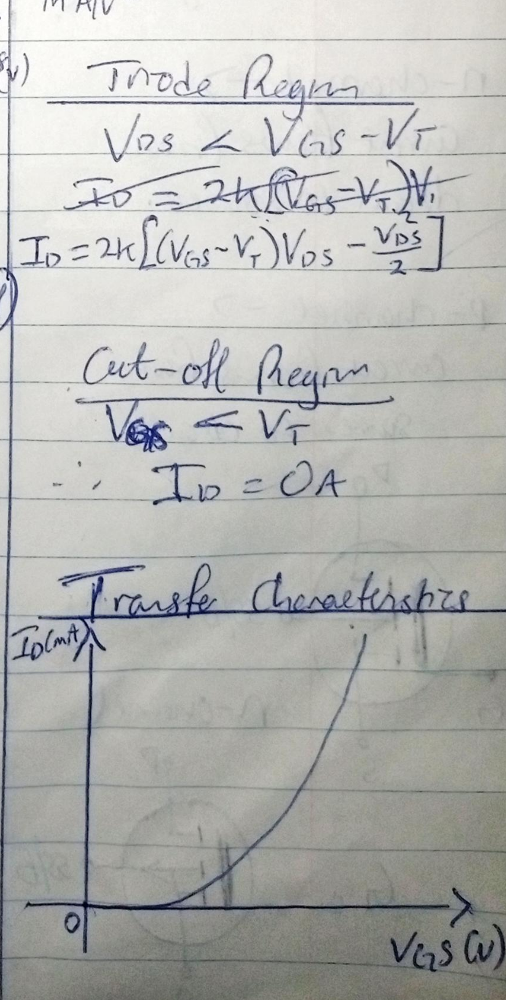
$I_D = 2k\left[(V_{GS}-V_T)V_{DS} - \frac{V_{DS}}{2}\right]$

Cut-off Region

$V_{GS} < V_T$

$\therefore I_D = 0A$

Transfer Characteristics



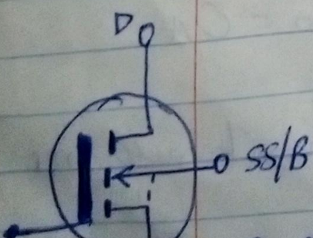
SiO_2 works as an insulator. Due to this the input impedance at the gate terminal is high and no current flows through ~~great~~ gate terminal (gate current must be 0 for maximum current)

why ~~drain~~ Gate is insulated from Drain, substrate & source.

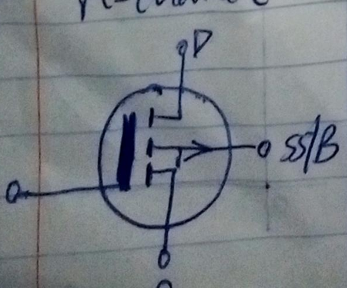
→ we use SiO_2 to separate controlling terminal (gate) from the substrate, so that gate current will become zero. As a result, Z_{in} is higher ∴ gain higher

n-channel → current flows from drain to source.

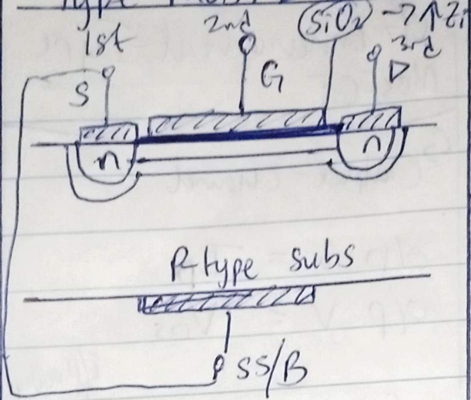
p-channel → current flows from source to drain.



n-channel



Construction of Depletion-Type MOSFET

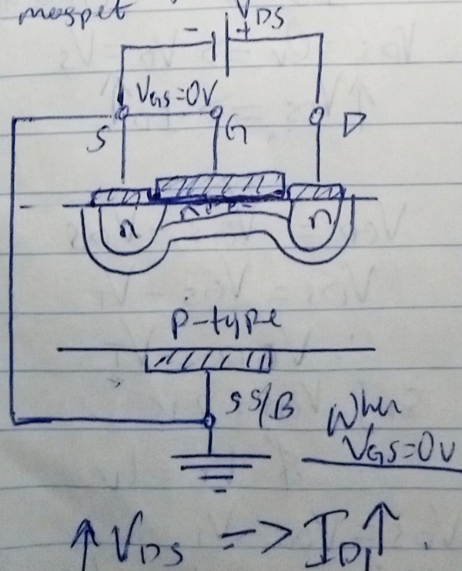


Metal-oxide-Semi

- Metal ↓ metal contact of ~~gate~~ of source gate & drain
- Oxide ↓ SiO_2 layer between gate and body
- Semi ↓ Basic structure through which n-type and P-type regions are diffused

Working of Depletion-Type MOSFET

n-channel Depletion-type mosfet ≃ n-channel JFET



When $V_{GS}=0V$

$\uparrow V_{DS} \Rightarrow I_D \uparrow$

$V_{DS} = V_D - V_S$

$V_{DS}\uparrow \Rightarrow V_D \uparrow$

I_D now becomes constant

I_{DSS} → when $V_{GS}=0V$

When $V_{GS} = -1V$;

av. e^- for conduction ↓

∴ $I_{D_2}\downarrow$

∴ $I_{D_1} > I_{D_2}$

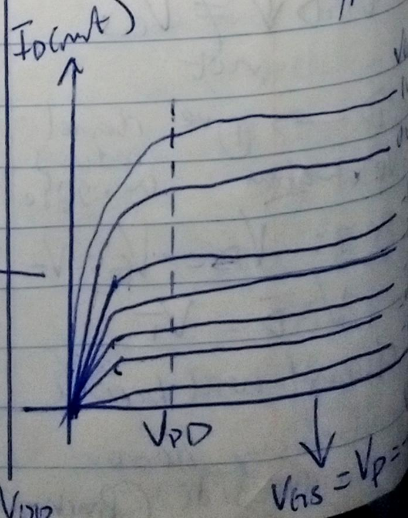
When $V_{GS} = 1V$ (+)

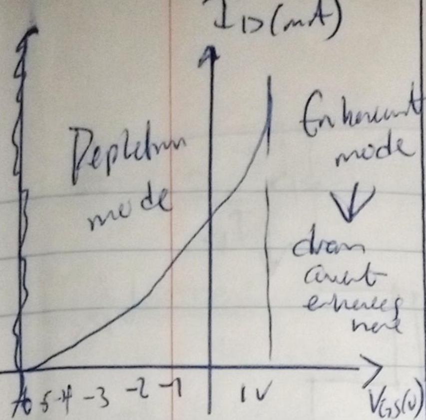
$I_D \uparrow$ rapidly

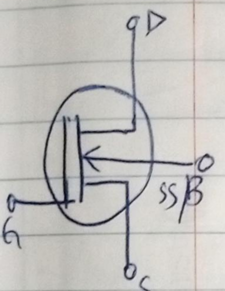
Drain & Transfer Characteristics of Depletion-Type MOSFET

Drain char.

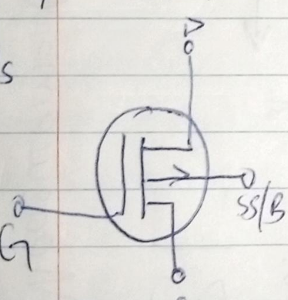
o/p I_D Vs V_{DS} o/p for various V_{GS} i/p V







n-channel DMOSFET



P-channel DMOSFET

Example

1) Does the current of an Enhancement-type MOSFET increase at the same rate as a depletion-type MOSFET for the conduction region?

E

$$I_D = k(V_{GS} - V_T)^2$$

$$\frac{dI_D}{dV_{GS}} = 2k(V_{GS} - V_T)$$

D

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

Pinch-off voltage

$$\frac{dI_D}{dV_{GS}} = \frac{2I_{DSS}}{V_P^2}(V_{GS} - V_P)$$

∴ Same rate

Since

$$c(V_{GS} - c) \rightarrow c(V_{GS} - c)$$

E MOSFET

2.) Given $k = 0.4 \times 10^{-3}\, A/V^2$ and $I_D(on) = 3.5mA$ with $V_{GS(on)} = 4V$, determine V_T.

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

$$V_T = -\sqrt{\frac{I_D}{k}} + V_{GS}$$

$$V_T = -\sqrt{\frac{3.5 \times 10^{-3}}{0.4 \times 10^{-3}}} + 4$$

$$= -\sqrt{\frac{35}{4}} + 4$$

$$= 1.042V$$

D MOSFET

3.) Given $I_D = 4mA$ at $V_{GS} = -2V$, determine the saturation current if $V_P = -4V$

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$I_{DSS} = \frac{I_D}{\left(1 - \frac{V_{GS}}{V_P}\right)^2}$$

$$= \frac{4 \times 10^{-3}}{\left(1 - \left(\frac{-2}{-4}\right)\right)^2}$$

$$= 16 \times 10^{-3}$$

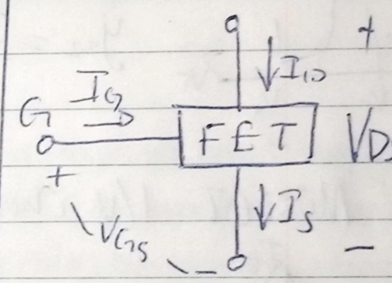
$$= 16mA$$

Introduction to FET Biasing

output / input

$$I_D = f(V_{GS})$$

Relationship is non-linear



$$I_G \simeq 0A$$

$$\therefore I_D = I_S$$

JFET & DMOSFET

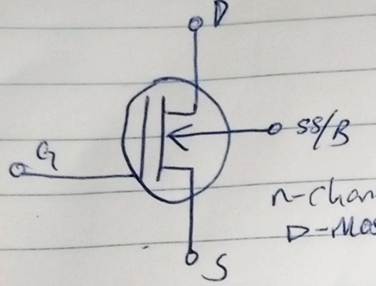
$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

Shockley's equation

EMOSFET

$$I_D = k(V_{GS} - V_T)^2$$

Introduction to Depletion-Type MOSFET BIASING



n-channel D-MOSFET

Operating point

$Q\text{-pt} \equiv (V_{GSQ}, I_{DQ})$

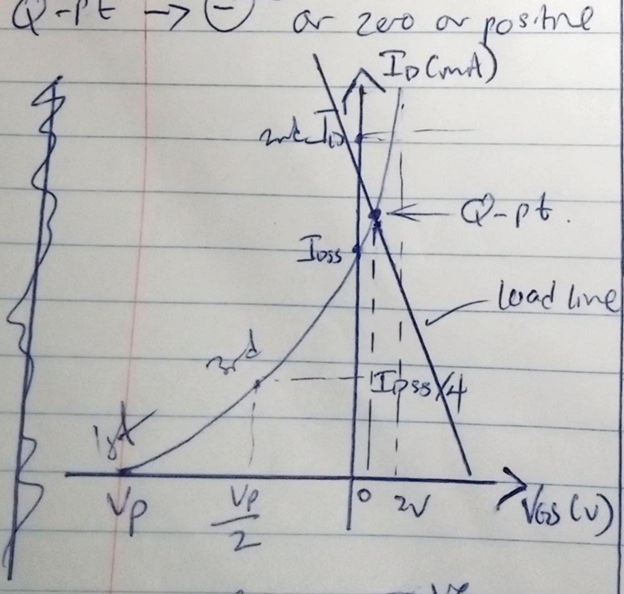
$\Rightarrow$ Transfer char. & load line plot to get Q point

$V_{GS} < 0v$

$V_{GS} = 0$ $\qquad I_{DSS}$ X max (not)

$V_{GS} > 0$

Q-pt → $\ominus$ve or zero or positive



$V_{GSQ} \rightarrow \oplus$ve

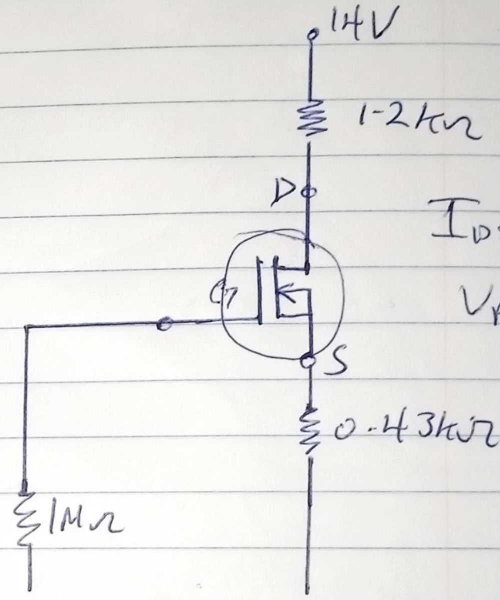
$I_{DQ} \rightarrow \oplus$ve

Self-Bias Configuration of Depletion-Type MOSFET

Problem: For the self-bias configuration determine

a) I_{DQ} and V_{GSQ}

b) V_{DS} and V_D



$I_{DSS} = 6mA$

$V_P = -4V$

To plot graph points For transfer characteristics

Case 1 when $I_D = 0$

$$0 = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$\Rightarrow V_{GS} = V_P = -4V$$

Case 2 when $V_{GS} = 0$.

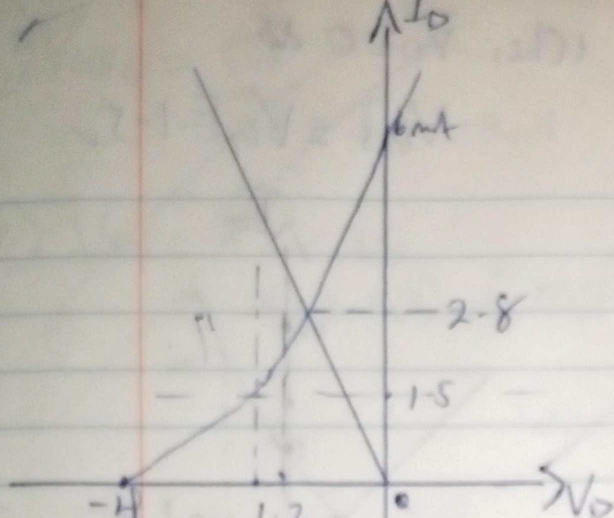
$$I_D = I_{DSS}(1-0)^2$$

$$= I_{DSS} = 6mA$$

Case 3 when $V_{GS} = \frac{V_P}{2}$

$$I_D = I_{DSS}\left(1 - \frac{V_P}{2V_P}\right)^2$$

$$I_D = 6/4 = 1.5mA$$



For load line:

$$V_G - V_{GS} - I_S(R_S) = 0$$

$$I_S = I_D$$

$$V_G = 0$$

$$\therefore \; 0 - V_{GS} - I_D(0.43) = 0$$

$$V_{GS} = -0.43 I_D$$

$$V_{GS} = -R_S I_D$$

$$\therefore I_{DQ} = 2.8mA$$

$$V_{GSQ} = 1.2V$$

b.) V_{DS} and V_D

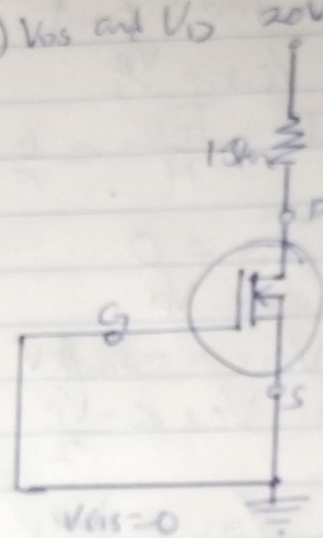
$$V_D = 14 - I_D r_D$$
$$= 14 - (2.8mA)(1.2k\Omega)$$
$$= 10.64V$$

$$V_{DS} = V_D - V_S$$
$$= 10.64 - I_S r_S$$
$$= 10.64 - (2.8 \times 0.43)$$
$$= 9.436 V$$

Special Case

1.) For the network shown, determine the Q-point.

b) V_{DS} and V_D



$I_{DSS} = 10mA$

$V_P = -4V$

$V_{GS} = 0$

$$V_{GSQ} = 0V$$

$$I_{DQ} = I_{DSS} = 10mA$$

b) $V_D = 20 - (1.5)(10)$
$= 5V$

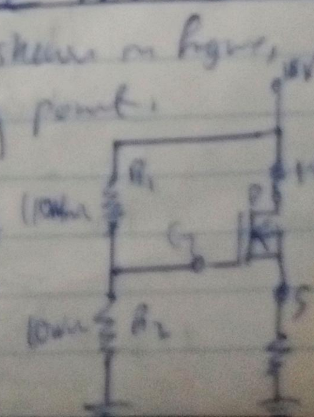
$$V_{DS} = V_D - V_S$$
$$= V_D - 0$$
$$= V_D = 5V$$

Voltage-Divider Biasing of Depletion-Type MOSFET

For the network shown in figure, determine operating point.

$I_{DSS} = 6mA$

$V_P = -3V$



For transfer curve;

Case 1; when $V_{GS} = 0$;

$$I_D = I_{DSS} = 6mA$$

Case 2: when $V_{GS} = \frac{V_P}{2}$

$$I_D = \frac{I_{DSS}}{4} = \frac{6}{4} = 1.5mA$$

Case 3; when $I_D = 0$

$$V_{GS} = V_P$$

$$V_{GS} = -3\cancel{mA}V$$

Case 4, when $V_{GS} < -\frac{V_P}{2}$

Say $V_{GS} = 1V$

$$I_D = 10.67mA$$

For load line;

$$V_{GS} = V_G - V_S$$

$$V_{GS} = V_G - I_D R_S$$

$$I_D = -\frac{V_{GS}}{R_S} + \frac{V_G}{R_S}$$

To get intercept $\frac{V_G}{R_S}$,

$$V_G = \frac{R_2}{R_1 + R_2} V_{DD}$$

$$V_{DD} = 20V$$

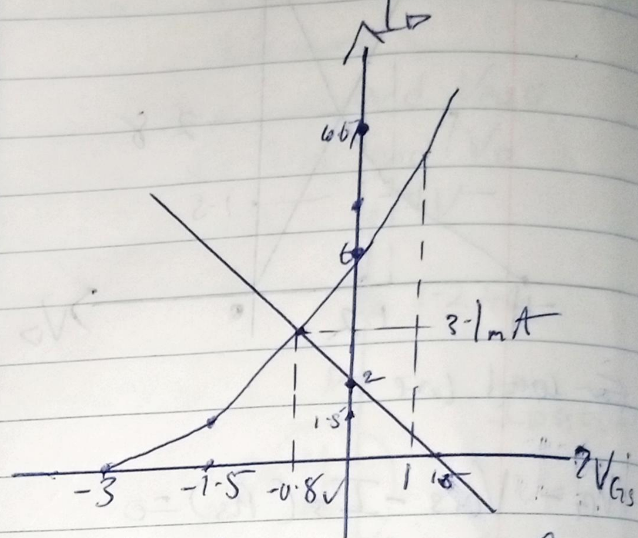
$$V_G = \left(\frac{10}{110+10}\right) 18 = 1.5V$$

$$\therefore \frac{V_G}{R_S} = \frac{1.5}{250} = 2mA$$

$\therefore$ When $V_{GS} = 0$, $I_D = 2mA$

When $I_D = 0$

$$V_{GS} = V_G = 1.5V$$



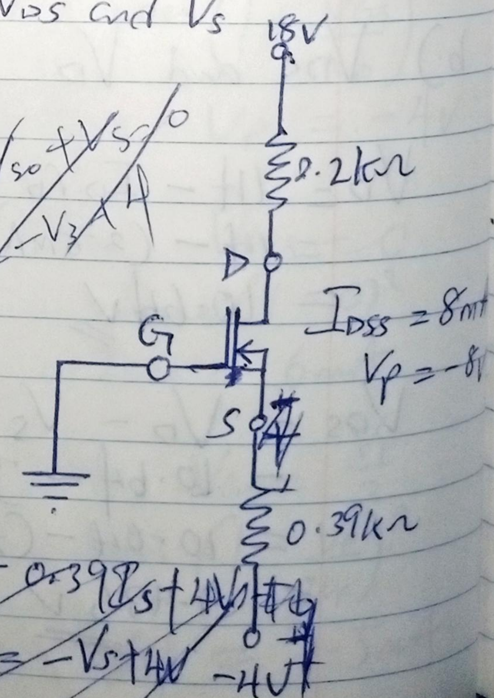
$\therefore$ Operating point is at $(-0.8V, 3.1mA)$

Class Activities

For the network shown in figure, determine

a.) I_{DQ} and V_{GSQ}

b.) V_{DS} and V_S



~~$-4V + V_{SO} + V_S = 0$~~

~~$V_{SO} - V_S + 4$~~

~~$-V_S - 0.39 I_S + 4V = 0$~~

~~$V_{SO} = -V_S + 4V$~~

1) $V_{GS_Q} = 0V$

∴ $I_{DQ} = I_{DSS} = 8mA$

2.) $V_{DS} = V_D - V_S$

$= 18 - 2.2(8) - (0.39(8)+4)$

$=$

Case 1 : when $V_{GS} = 0$

$I_D = 8mA$

Case 2 : When $I_D = 0$

$V_{GS} = V_P = -8V$

Case 3 : when $V_{GS} = V_P/2 = -4V$

then $I_D = 8/4 = 2mA$

Case 4 ; when $V_{GS} < -V_P/2$

Say $V_{GS} = 2V$

∴ $I_D = 12.5mA$

For load line ;

$\cancel{V_{GS} = V_G + V_S}$ -

$V_{GS} = V_G - V_S + 4$

$V_G = 0$

$V_{GS} + V_S = 4$

$V_{GS} + I_D r_S = 4$

$I_D = \frac{-V_{GS}}{r_S} + \frac{4}{r_S}$

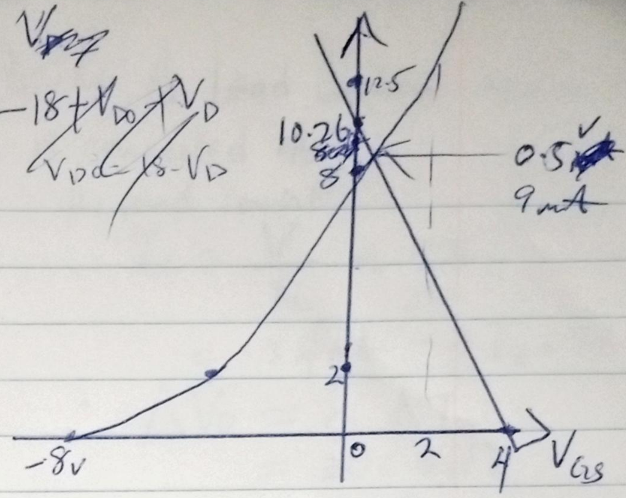
Intercept at $\frac{4}{r_S} \Rightarrow \frac{4}{0.39}$
when $V_{GS} = 0$ $= 10.26mA$

at when $I_D = 0$; $V_{GS} = 4$

$\cancel{V_{DD}}$

$\cancel{-18 + V_{DD} + V_D}$

$\cancel{V_{DD} = 18 - V_D}$



∴ $V_{GSQ} = 0.5V$; $I_{DQ} = 9mA$

$\cancel{V_{DS}}$

$V_S = 0.39(9) - 4$

$= 3.51 - 4 = -0.49V$

$V_{DS} = V_D - V_S$

$= 18 - 2(9) + 0.49$

$= -1.31V$

Introduction to Enhancement-Type MOSFET Biasing

EMOSFET (4 points)

$I_D = k(V_{GS} - V_T)^2$

$V_{GS(on)}$ $I_{D(on)}$ V_T

$P_1 \equiv (V_T, 0A)$

$P_2 \equiv (V_{GS(on)}, I_{D(on)})$ $V_{GS(on)}$ ↑

$P_3 \equiv (V_{GS1}, I_{D1})$ $V_T < V_{GS1} < V_{GS(on)}$

$P_4 \equiv (V_{GS2}, I_{D2})$ ↪ $V_{GS2} > V_{GS(on)}$