Biasing of FET & MOSFET

In case of BJT, input controlling variable is current (I_B), where as for the FET, voltage is the ~~current~~ controlling variable (V_{GS}).

→ The general rel^n ship that can be applied to d.c analysis of all FET amplifiers are

$$\boxed{I_G \simeq 0 \text{ Amp.}}$$

$$\boxed{I_D = I_S}$$

→ For JFET and depletion-type MOSFETS, Shockley's eq^n is applied to relate the i/p and o/p quantities.

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

→ For enhancement type MOSFET, the following eq^n is applicable

$$\boxed{I_D = K\,(V_{GS} - V_T)^2}$$

Fixed-Bias Configuration:-

The simplest of biasing arrangement for n-channel JFET appears below.

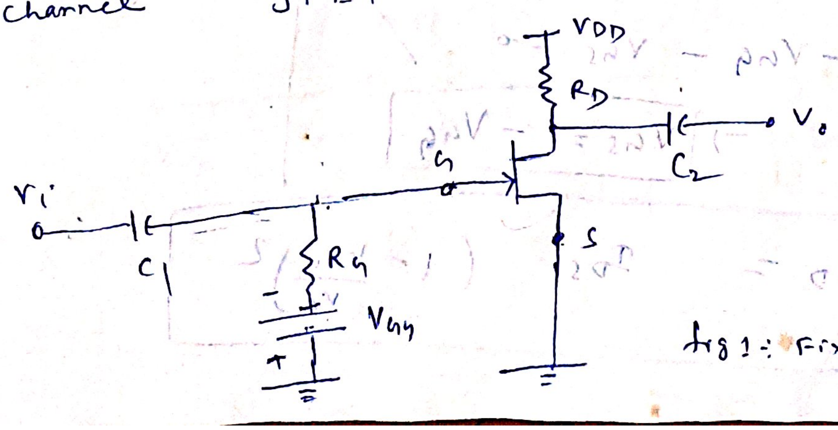


fig 1:- Fixed bias Configuration

It can be solved using mathematical or graphical approach.

For d.c analysis,

Capacitor C_1 & C_2 are open ckted. $V_i = 0$.

The resistor R_G is present to ensure V_i appears at the i/p to FET amplifier.

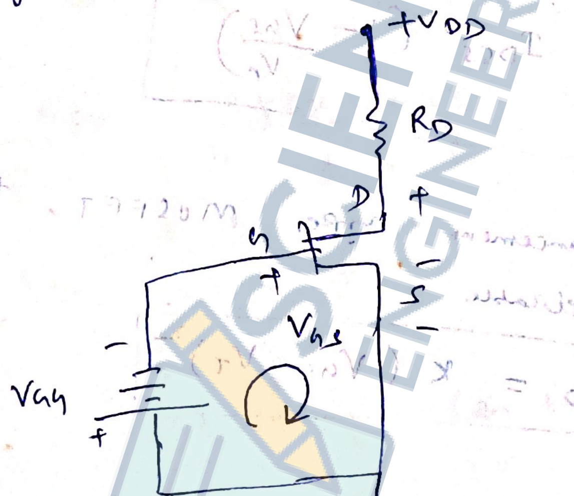
But for d.c analysis, $V_i = 0$,

$$I_G = 0.$$

$$V_{RG} = I_G R_G = 0\,V.$$

The zero-voltage drop across R_G permits replacing R_G by a short-ckt equivalent.

So fig(1) can be redrawn as shown below.



Since V_{GG} is a fixed dc supply, V_{GS} is fixed in magnitude, resulting in the designation 'fixed-bias configuration'

Applying KVL,

$$-V_{GG} - V_{GS} = 0$$

$$\Rightarrow \boxed{V_{GS} = -V_{GG}}$$

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

Graphical method :-

If I_{DSS}, V_P is given for a FET

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

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

$$I_D = \frac{I_{DSS}}{4}$$

So the point is $\left(\frac{V_P}{2}, \frac{I_{DSS}}{4}\right)$.

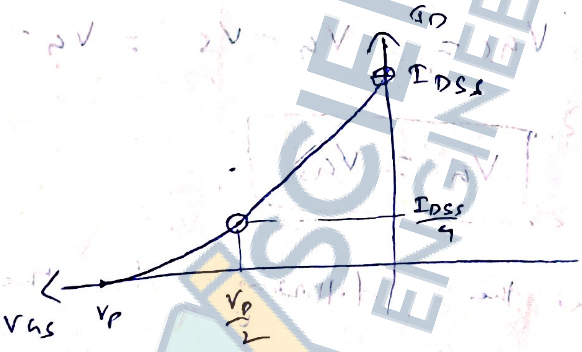
So we have 3 points, ~~I_{DSS}, V_P~~ (

$(0, I_{DSS})$

$(V_P, 0)$

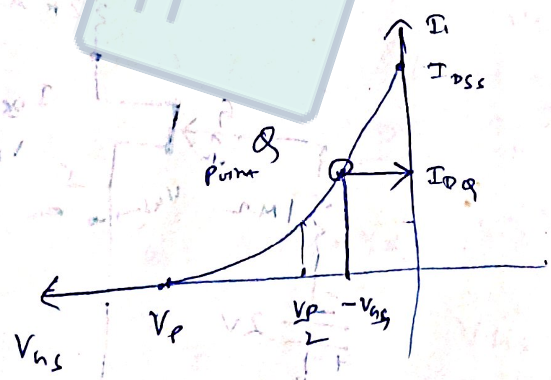
$\left(\frac{V_P}{2}, \frac{I_{DSS}}{4}\right)$

we can plot the graph.



Then at $V_{GS} = -V_{GG}$, we can get the I_D.

i.e I_{DQ}



V_{GS} = const

x = const

i.e line parallel to y-axis

Intersection of 2 lines gives the soln of 2 unknowns V_{GS} & I_D.

→ Then drain-to-source voltage of the o/p section can be determined by applying Kirchhoff's Voltage law.

$$V_{DD} - I_D R_D - V_{DS} = 0$$

$$\Rightarrow \boxed{V_{DS} = V_{DD} - I_D R_D}$$

V_S = Source voltage w.r.to ground = 0

$$\boxed{V_S = 0}$$

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

$$\Rightarrow \boxed{V_D = V_{DS}}$$

Similarly, $V_{GS} = V_G - V_S = V_G - 0$

$$\Rightarrow \boxed{V_G = V_{GS}}$$

Ex:-1) Determine the following for the n/w

(a) V_{GSQ}

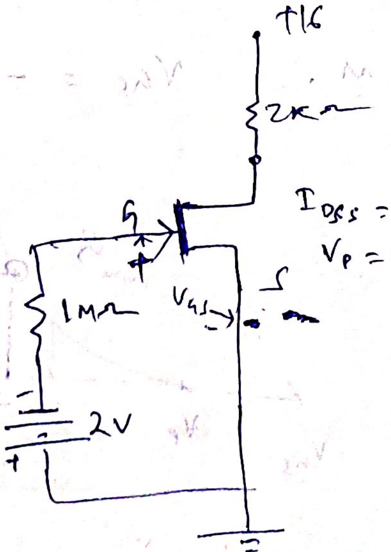
(b) I_{DQ}

(c) V_{DS}

(d) V_D

(e) V_G

(f) V_S



$I_{DSS} = 10mA$

$V_P = -8V$

(Q) Mathematical approach :-

Applying KVL in the i/p loop,

$$-2 - V_{GS} = 0$$

(a) $\Rightarrow \boxed{V_{GS} = -2\,V}$

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

$$= 10 \times 10^{-3}\left(1 - \frac{(-2)}{(-8)}\right)^2$$

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

$$= \frac{\cancel{10}^{5} \times 10^{-3} \times 9}{\cancel{16}_{8}}$$

$$= \frac{45}{8}\,mA$$

(b) $\boxed{I_{DQ} = 5.625\,mA}$

(c) $$V_{DS} = V_{DD} - I_D R_D$$

$$= 16 - 5.625 \times 10^{-3} \times 2 \times 10^{3}$$

$$\boxed{V_{DS} = 4.75\,V}$$

(d) $$V_{DS} = V_D - V_S = V_D - 0$$

$$\Rightarrow V_D = V_{DS} = 4.75V$$

$$\boxed{V_D = 4.75\,V}$$

(e) $$V_{GS} = V_G - V_S = V_G - 0$$

$$\Rightarrow V_G = V_{GS} = -2V$$

$$\boxed{V_{GS} = -2V}$$

(f) $V_S = 0$ (Grounded)

Graphical approach :-

Given $I_{DSS} = 10mA$, $V_P = -8V$.

At $V_{GS} = \frac{V_P}{2}$, $I_{DSS} = \frac{I_{DSS}}{4}$.

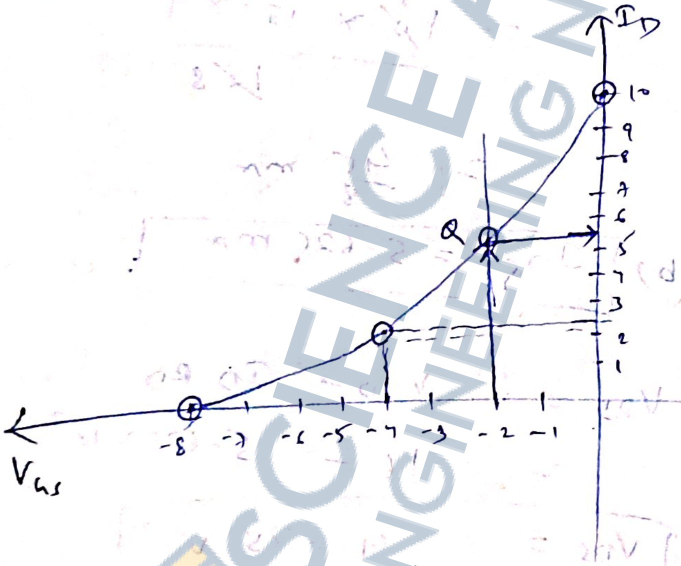
So we have 3 points,

$I_{DSS} \rightarrow (0, 10 mA)$

$V_P \rightarrow (-8, 0)$

$\left(\frac{V_P}{2}, \frac{I_{DSS}}{4}\right) \rightarrow (-4, 2.5 mA)$

So we can plot the graph



→ Then $\boxed{V_{GS} = -V_{GG} = -2V}$ = Eqⁿ of line parallel to y-axis at x = -2.

→ At $V_{GS} = -2V$, draw a vertical line, where it cuts the graph, draw a horizontal line, it cuts I_D i.e $\boxed{I_{DQ}}$ i.e $\boxed{5.6 mA}$.

→ (a) $V_{GS} = -2V$

(b) $I_{DQ} = 5.6mA$.

(c) $V_{DS} = V_{DD} - I_D R_D = 16 - 5.6 \text{ (mA)} \times 2 \text{ (kΩ)}$

$= 4.8V$

(d) $V_{DS} = V_D - V_S = \cancel{V_D} \; V_D - 0$

$\Rightarrow V_D = V_{DS} = 4.8\,V.$

(e) $V_{GS} = V_G - V_S = V_G - 0$

$\Rightarrow V_G = V_{GS} = -2V.$

(f) $V_S = 0V.$

:- The mathematical and graphical approaches generate solutions are quite close.

Self-bias Configuration :-

Self-bias configuration eliminates the need of 2 d.c supplies. The controlling gate-to-source voltage is now determined by the voltage across a resistor R_S introduced in the source leg of the configuration as shown below.

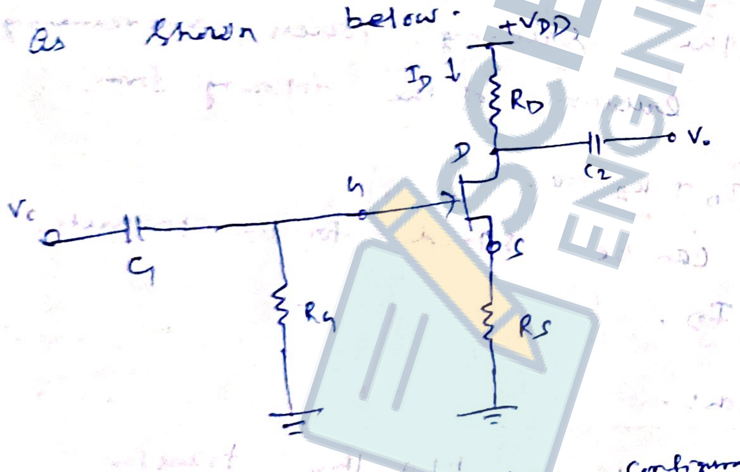
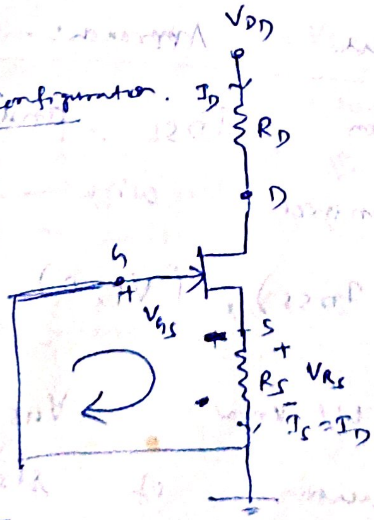


fig 11 - JFET self bias configuration.



For d.c analysis, the capacitors can again be replaced by 'open ckts' and resistor 'R_G' replaced by short-ckt equivalent since $I_G = 0A$.

fig 2:- D.C analysis of the self bias configuration.

Applying KVL

$$-V_{GS} - V_{RS} = 0$$

$$\Rightarrow \boxed{V_{GS} = -V_{RS}}$$

And $\boxed{V_{RS} = I_D R_S}$

$$\therefore \boxed{V_{GS} = -I_D R_S}$$

Note:- In this case V_{GS} is a function of the output current I_D and not fixed in magnitude as occured for the fixed-bias configuration.

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

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

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

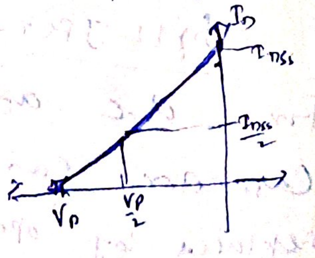
By performing the squaring process and rearranging, we obtain an equation of the following form.

$$I_D^2 + K_1 I_D + K_2 = 0.$$

Quadratic eqn can be solved for the appropriate solution for I_D.

Graphical Approach:-

For given I_{DSS} and V_P, Plot the transfer characteristics with 3 points.



$$(0, I_{DSS}),\ (V_P, 0),\ \left(\frac{V_P}{2}, \frac{I_{DSS}}{4}\right)$$

→ We know $V_{GS} = -I_D R_S$, which is a equation of straight line on the same graph.

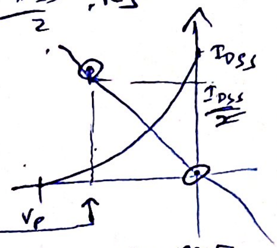
→ To draw straight line we need 2 points.

First point, $I_D = 0$, $V_{GS} = 0 \cdot R_S = 0$

$(0, 0)$.

2nd point, $I_D = \frac{I_{DSS}}{2}$, $V_{GS} = -\frac{I_{DSS}}{2} \cdot R_S$

$\left(-\frac{I_{DSS}}{2} \cdot R_S, \frac{I_{DSS}}{2}\right)$



The intersection of transfer characteristic and straight line gives Q point.

Applying KVL on o/p loop.

$$V_{DD} - I_D R_D - V_{DS} - I_D R_S = 0 \quad (\because I_D = I_S)$$

$$\Rightarrow \boxed{V_{DS} = V_{DD} - I_D(R_D + R_S)}$$

$$\boxed{V_S = I_D R_S}$$

$$\boxed{V_G = 0}$$

$$\boxed{V_D = V_{DD} - I_D R_D}$$

Also/or

$V_{GS} = V_G - V_S$

$V_{GS} = 0 - V_S$

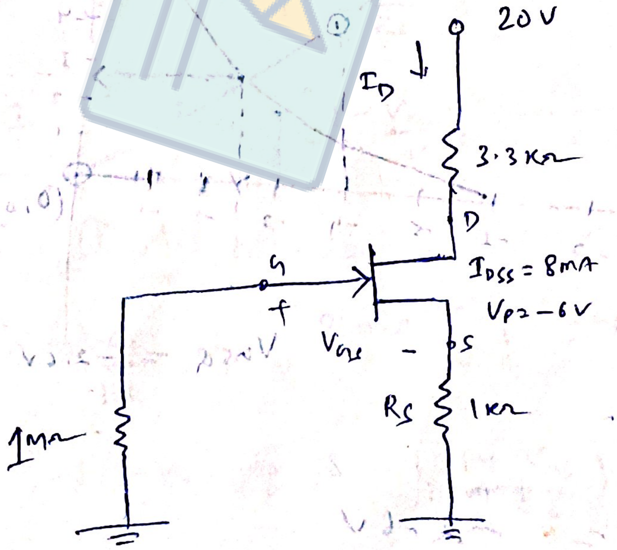
$\Rightarrow \boxed{V_S = -V_{GS}}$

True $V_{GS} = -I_D R_S$

$V_S = +I_D R_S$

$\Rightarrow V_{GS} = -V_S$

Ex-2 :-



Determine

(a) V_{GSQ}

(b) I_{DQ}

(c) V_{DS}

(d) V_S

(e) V_G

(f) V_D

Ans:- Graphical method:-

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

At $I_D = \frac{I_{DSS}}{2} = \frac{8}{2} = 4mA$,

$$V_{GS} = -4 \times (1k\Omega)$$

$$\boxed{V_{GS} = -4V}$$

Point on the straight line $(-4, 4)$

To plot transfer characteristics:-

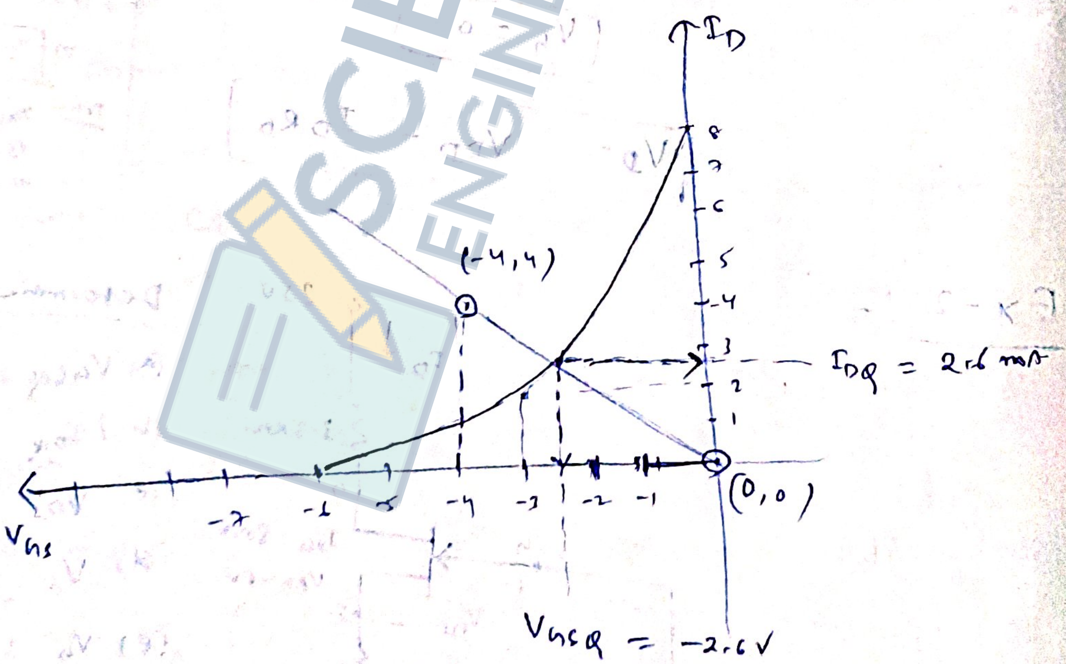
At $V_{GS} = \frac{V_P}{2}$, $I_D = \frac{I_{DSS}}{4}$

$V_{GS} = -\frac{6}{2}$, $I_D = \frac{8}{4}$

1) $(-3, 2)$

2) $(0, I_{DSS}) = (0, 8)$

3) $(V_P, 0) = (-6, 0)$



(a) $V_{GSQ} = -2.6V$

(b) $I_{DQ} = 2.6mA$

(c) $V_{DS} = V_{DD} - I_D(R_D + R_S)$

$= 20 - 2.6\times\cancel{10^{-3}}(3.3+1)\times\cancel{10^{3}}$

$= 20 - 2.6 \times 4.3$

$= 20 - 11.18$

$\boxed{V_{DS} = 8.82\,V}$

(d) $V_S = I_D \times R_S$

$= 2.6\times10^{-3} \times 1\times10^{3}$

$= 2.6\,V$

(e) $V_G = 0\,V$ ($\because I_G = 0$)

(f) $V_D = V_{DD} - I_D R_D$

$= 20 - 2.6\times\cancel{10^{-3}} \times 3.3\times\cancel{10^{3}}$

$= 20 - 8.58$

$= 11.42\,V$

Mathematical Approach :-

$V_{GS} = -I_D R_S$

$\Rightarrow I_D = \dfrac{-V_{GS}}{R_S}$ —— ①

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

Solving eq ① & ②

$\dfrac{-V_{GS}}{1K} = 8\,mA\left(1 - \dfrac{V_{GS}}{-6}\right)^2$

$\Rightarrow -V_{GS} = 8\left(1 + \dfrac{V_{GS}}{6}\right)^2$

$= 8\left(\dfrac{6+V_{GS}}{6}\right)^2 = \dfrac{\cancel{8}^{4}(36 + V_{GS}^2 + 12V_{GS})}{\cancel{36}\;18}$

$\Rightarrow$

$\Rightarrow -18V_{GS} = 144 + 4V_{GS}^2 + 48V_{GS}$

$\Rightarrow 4V_{GS}^2 + 66V_{GS} + 144 = 0$

$V_{GS} = -2.58$ or -13.9

-13.9 is not possible (greater than V_P)

$\boxed{V_{GS} = -2.58\ V}$

$I_D = \frac{-V_{GS}}{R_S} = \frac{-(-2.58V)}{1k\Omega} = +2.58\ mA$

$\boxed{I_D = +2.58\ mA}$

(c) $V_{DS} = V_{DD} - I_D(R_D + R_S)$

$= 20 - 2.58(3.3+1)$

$V_{DS} = 8.906\ V$

(d) $V_S = I_D \times R_S = +2.58\times10^{-3} \times 1\times10^{3}$

$= 2.58\ V$

(e) $V_G = 0\ V$ $(\because I_G = 0)$

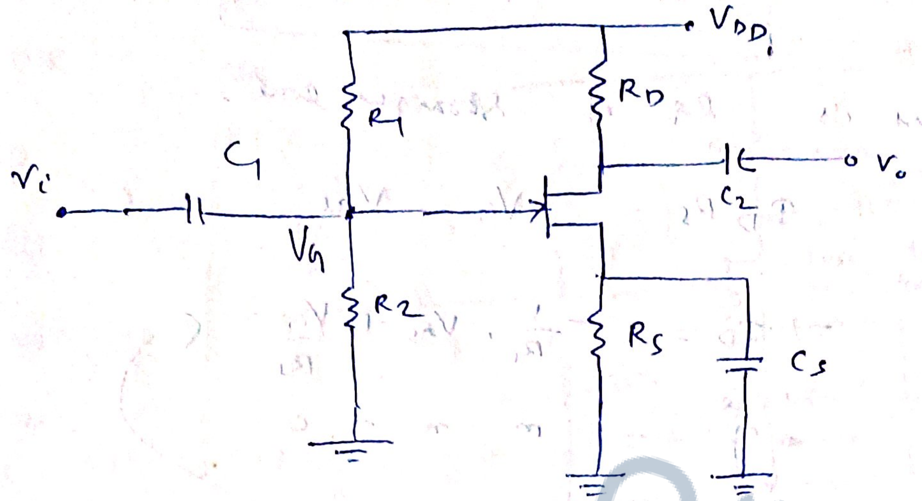
(f) $V_D = V_{DD} - I_D R_D$

$= 20 - 2.58\times10^{-3} \times 3.3\times10^{3}$

$= 20 - 8.514$

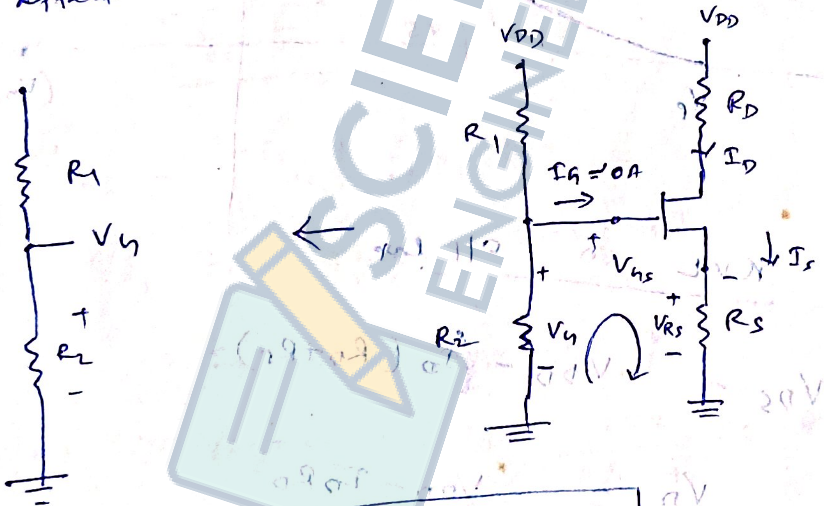
$\boxed{V_D = 11.481\ V}$

Voltage - divider biasing :-



(voltage divider bias arrangement)

The basic construction for voltage - divider bias for FET is exactly same as that for BJT, but d.c analysis of each is quite different. $I_G = 0$ for FET amplifiers, but the magnitude of I_B for common - emitter BJT amplifier can affect the d.c level of current and voltage



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

Applying KVL

$$V_G - V_{GS} - V_{RS} = 0$$

$$\Rightarrow \cancel{V_G = V_{GS} + V_{RS}}$$

$$\Rightarrow V_{GS} = V_G - V_{RS}$$

$$\Rightarrow \boxed{V_{GS} = V_G - I_D R_S}$$

This is eqn of straight line.

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

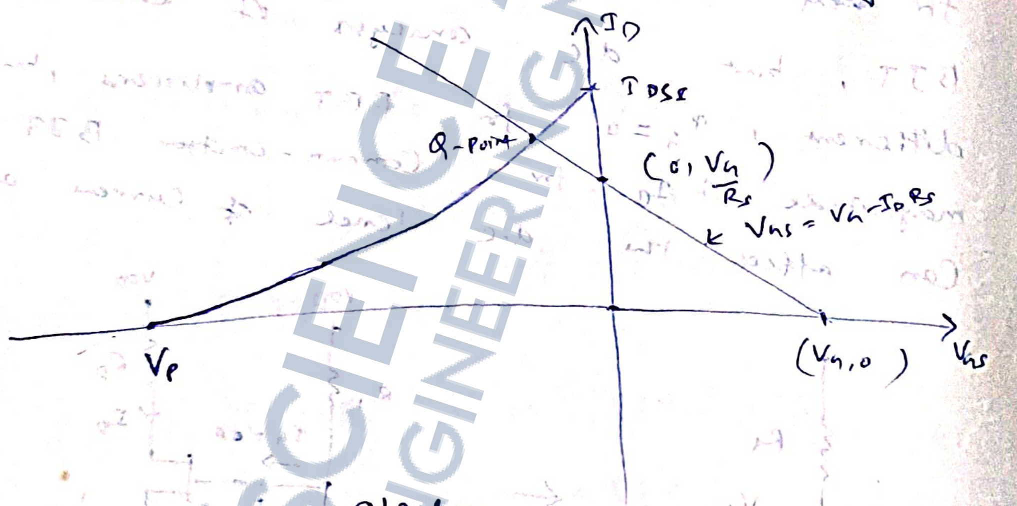
$$\Rightarrow I_D = -\frac{1}{R_S} \cdot V_{GS} + \frac{V_G}{R_S}$$

$$y = m \; x + c$$

To get the points,

At $V_{GS} = 0$, $I_D = \frac{V_G}{R_S}$, $\left(0, \frac{V_G}{R_S}\right)$

At $I_D = 0$, $V_{GS} = V_G$ $(V_G, 0)$



Applying KVL in O/P loop

$$V_{DS} = V_{DD} - I_D (R_D + R_S)$$

$$V_D = V_{DD} - I_D R_D$$

$$V_S = I_D \cdot R_S$$

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

Ex-3 :- Determine the following for the n/w

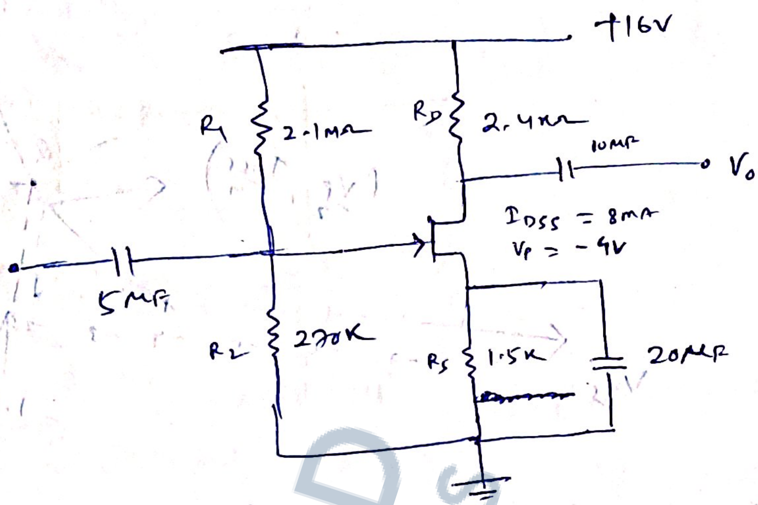
(a) I_{DQ} & V_{GSQ}

b. V_D

c. V_S

d. V_{DS}

e. V_{DG}



Ans:- $V_G = \frac{V_{DD}}{(R_1+R_2)} \cdot R_2$

$= \frac{16}{2.1\times10^6 + 270\times10^3} \times 270\times10^3$

$= \frac{16\times 270}{2100+270}$

$\boxed{V_G = 1.82V}$

$V_{GS} = V_G - I_D R_S$

$V_{GS} = 1.82 - I_D(1.5)\times10^3$

At $I_D = 0$, $V_{GS} = 1.82V$.

At $V_{GS} = 0$, $I_D = \frac{1.82}{1.5\times10^3} = 1.21$ mA.

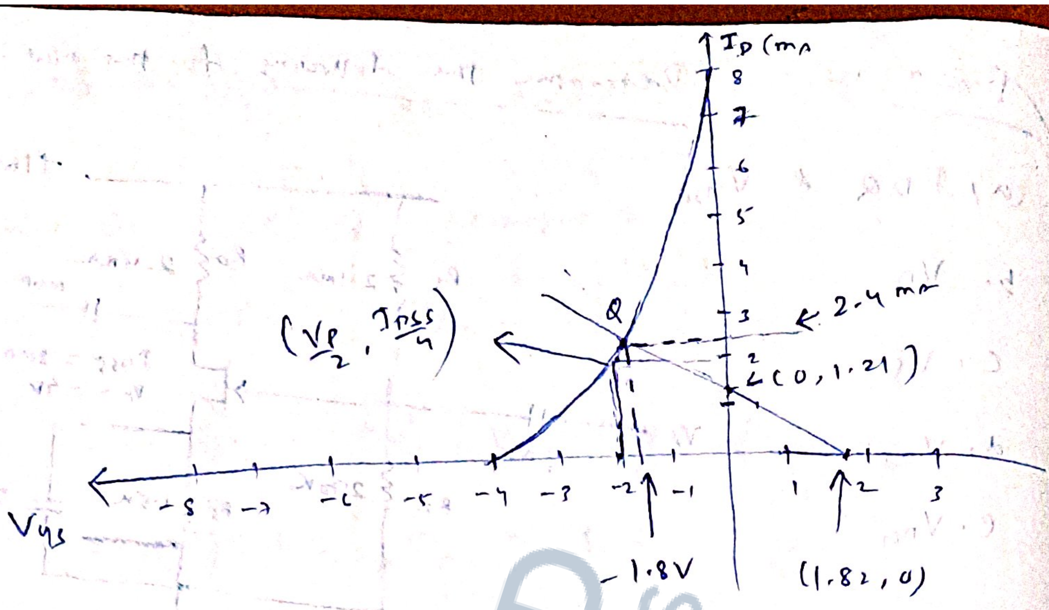
To draw the transfer characteristic.

1) $(V_P, 0) = (-4, 0)$

2) $(0, I_{DSS}) = (0, 8)$

3) $(\frac{V_P}{2}, \frac{I_{DSS}}{4}) = (-2, 2)$

After drawing the transfer characteristics. The straight line is drawn which has



the end Points $(V_G, 0)$, $\left(0, \frac{V_G}{R_S}\right)$

$= (1.82V, 0), (0, 1.21 \text{ mA})$

where the straight line intersects the transfer characteristics, we got the Q - point.

(a) $(-1.8V, 2.4\text{mA})$

$\uparrow$ V_{GSQ} $\uparrow$ I_{DQ}

(b) $V_D = V_{DD} - I_D R_D$

$= 16 - 2.4 \times 2.4 \times 10^{-3} \times 10^3$

$\boxed{V_D = 10.24V}$

(c) $V_S = I_D \cdot R_S = 2.4 \times 1.5 = 3.6V$

$\boxed{V_S = 3.6V}$

(d) $V_{DS} = V_D - V_S$

$= 10.24 - 3.6$

$\boxed{V_{DS} = 6.64V}$

(e) $V_{DG} = V_D - V_G$

$\Rightarrow \quad V_{DG} = 10.24 - 1.82$

$$\boxed{V_{DG} = 8.42\ V}$$

Mathematical Approach:-

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

$$= \frac{16}{(2.1\times10^{6} + 270\times10^{3})} \times 270\times10^{3} = 1.82\ V$$

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

$$V_{GS} = 1.82 - I_D \times 1.5\times10^{3} \quad \text{—— (1)}$$

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

$$= 8\times10^{-3}\left(1 - \frac{V_{GS}}{-4}\right)^2$$

$$I_D = 8\times10^{-3}\left(1 + \frac{V_{GS}}{4}\right)^2 \quad \text{—— (2)}$$

Equating I_D of (1) & (2)

$$\frac{1.82 - V_{GS}}{1.5\times10^{3}} = 8\times10^{-3}\,\frac{(4+V_{GS})^2}{16}$$

$$\Rightarrow \quad 1.82 - V_{GS} = \frac{\cancel{12}^{\,3}}{\cancel{16}_{\,4}}\left(16 + V_{GS}^2 + 8V_{GS}\right)$$

$$\Rightarrow \quad 7.28 - 4V_{GS} = 48 + 3V_{GS}^2 + 24V_{GS}$$

$$\Rightarrow \quad 3V_{GS}^2 + 28V_{GS} + 40.72 = 0$$

Solving $V_{GS} = -1.80$ or -7.53

-7.53 is not possible since it is less than V_P.

$$\boxed{V_{GS} = -1.8\ V}$$

From eqn ①, $I_D = \dfrac{1.82 - V_{GS}}{1.5 \times 10^3}$

$= \dfrac{1.82 - (-1.8)}{1.5 \times 10^3}$

$\boxed{I_D = 2.41\ mA}$

Then Rest process is same as that done is graphical method. ie

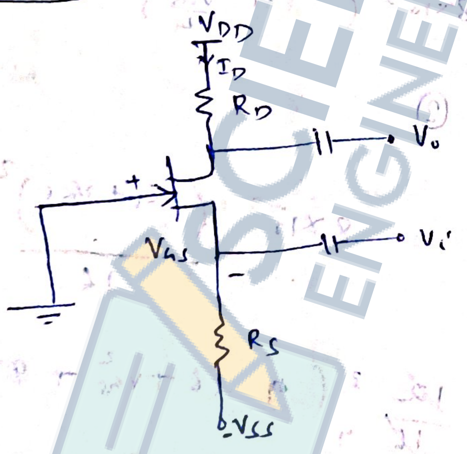
(b) $V_D = V_{DD} - I_D R_D$.

(c) $V_S = I_D \cdot R_S$

(d) $V_{DS} = V_D - V_S$

(e) $V_{DG} = V_D - V_G$

Common - Gate Configuration :-



→ $-V_{GS} - I_S R_S + V_{SS} = 0$

$\Rightarrow V_{GS} = V_{SS} - I_S R_S$

$I_S = I_D$

$\Rightarrow \boxed{V_{GS} = V_{SS} - I_D R_S}$

At $I_D = 0$, $V_{GS} = V_{SS}$

$V_{GS} = 0$, $I_D = \frac{V_{SS}}{R_S}$.

$V_{DD} - I_D R_D - V_{DS} - I_D R_S + V_{SS} = 0$

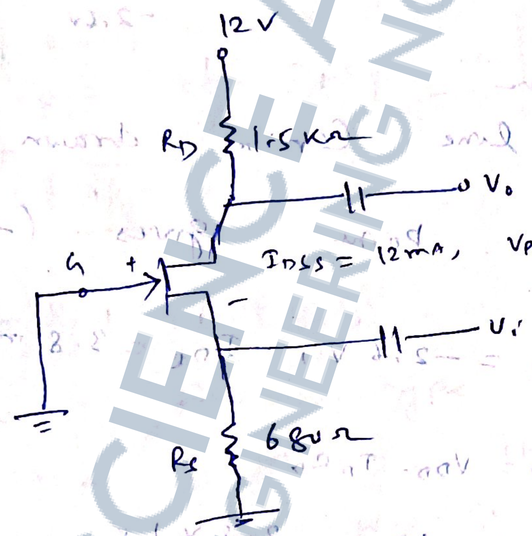
$$\Rightarrow \boxed{V_{DS} = V_{DD} + V_{SS} - I_D (R_D + R_S)}$$

$$\boxed{V_D = V_{DD} - I_D R_D}$$

$V_S - I_D R_S + V_{SS} = 0$

$$\Rightarrow \boxed{V_S = -V_{SS} + I_D R_S}$$

Ex:- 4



Ans :- $V_{GS} = V_{SS} - I_D R_S = 0 - I_D R_S$

$V_{GS} = -I_D R_S$.

Eqn of line passing through origin.

One point is (0,0).

For any arbitrary point, $I_D = 6\,mA$, $V_{GS} = -6 \times 680 \times 10^{-3}$

$V_{GS} = -4.08\,V$

To draw transfer characteristics,

At $V_{GS} = \frac{V_P}{2}$, $I_D = \frac{I_{DSS}}{4}$

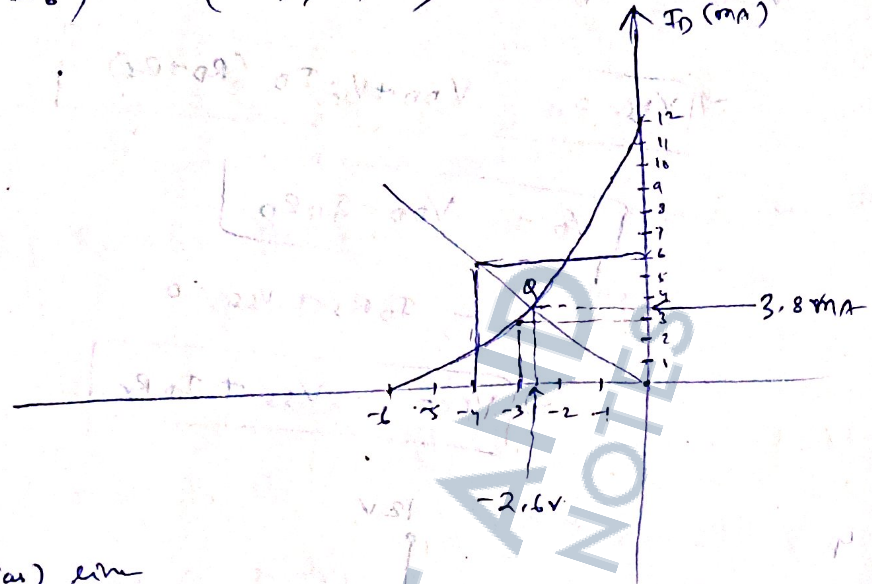
$\Rightarrow V_{GS} = \frac{-6}{2}$, $I_D = \frac{12\,mA}{4}$

$\Rightarrow V_{GS} = -3\,V$, $I_D = 3\,mA$

3 points are

$(\,0, V_P)$, $(-3, 3)$, $(I_{DSS}, 0)$

$(0, -6)$ $(-3, 3)$, $(12, 0)$



Straight (Bias) line can be drawn $(0,0)$, $(-4.08, 6)$

Intersecting point gives $(-2.6V, 3.8)$

(a) $V_{GS} = -2.6\,V$, $I_{DQ} = 3.8\,mA$

(b) $V_D = V_{DD} - I_D R_D$

$= 12 - 3.8 \times 1.5$

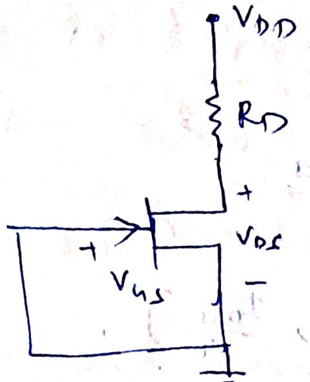
$V_D = 6.3V$

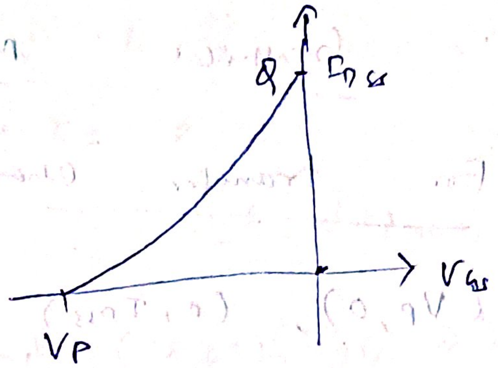
(c) $V_G = 0$

(d) $V_S = I_D \times R_S = 3.8 \times 10^{-3} \times 680\Omega = 2.584$

(e) $V_{DS} = V_D - V_S = 6.3 - 2.58 = 3.72V$

Special Case $V_{GS_Q} = 0V$.





$$\boxed{I_{DQ} = I_{DSS}}, \text{ at } V_{GS} = 0V$$

$$V_{DD} - I_D R_D - V_{DS} = 0$$

$$\Rightarrow \boxed{V_{DS} = V_{DD} - I_D R_D}$$

$$\boxed{V_D = V_{DD} - I_D R_D = V_{DS}}$$

$$\boxed{V_S = 0V}$$

Depletion-type MOSFET

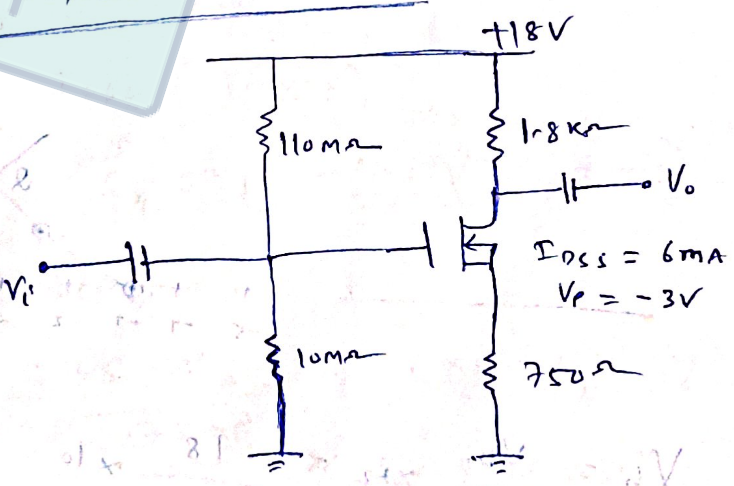
The analysis of depletion type MOSFET is similar to that of JFET. The primary difference between the two is the fact that depletion type MOSFET, additionally permit operating points with +ve value of V_{GS} and levels of I_D that exceeds I_{DSS}

Ex-5:-

Determine

(a) I_{DQ}, V_{GSQ}

(b) V_{DS}



Ans :- <u>Graphical method :-</u>

<u>For transfer characteristics</u>

$(V_P, 0)$, $(0, I_{DSS})$, $\left(\frac{V_P}{2}, \frac{I_{DSS}}{4}\right)$.

Since transfer characteristics lies on +ve side of V_{GS}, to find a point,

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

For a arbitrary, +ve value of V_{GS} (+1 V)

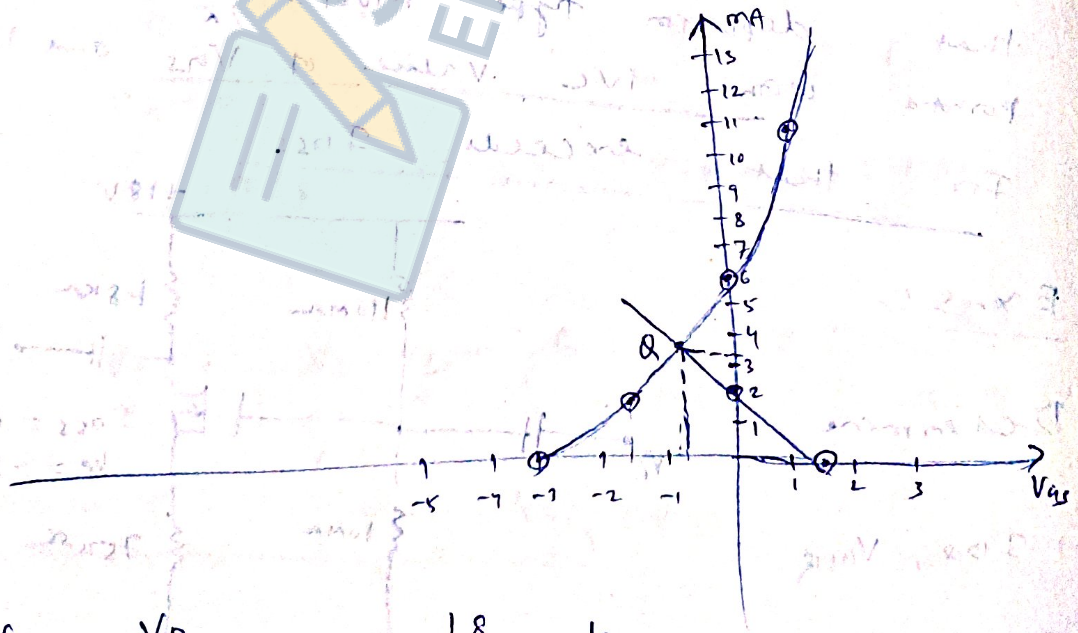
$$I_D = I_{DSS}\left(1 - \frac{1}{-3}\right)^2 = \left(1+\frac{1}{3}\right)^2 \times 6 \times 10^{-3}$$

$$I_D = 10.67 \text{ mA}$$

$\therefore$ 4th point (1, 10.67)

So, $\therefore$ 4 points are

(−3, 0) (0, 6), (−1.5, 1.5), (1, 10.67)



$$V_G = \frac{V_{DD}}{R_1 + R_2} \times R_2 = \frac{18}{110+10} \times 10 = 1.5 \text{ V}$$

$V_{GS} = V_G - I_D R_S$

At $I_D = 0$, $V_{GS} = V_G = 1.5V$

At $V_{GS} = 0$, $I_D = \frac{V_G}{R_S} = \frac{1.5}{750\Omega} = 2\,mA$.

Points for straight line (bias) $(1.5, 0)$ $(0, 2)$

Intersection of 2 curves given, (V_{GS}, I_D)

$(-0.8V, 3.1mA)$

$V_{DS} = V_{DD} - I_D(R_D + R_S)$

$= 18 - 3.1(1.8 + .75)$

$= 10.095$

$\boxed{V_{DS} \simeq 10.1\,V}$

Mathematical approach:-

$V_G = \frac{V_{DD}}{R_1+R_2} \times R_2 = \frac{18}{110+10} \times 10 = 1.5V$.

$V_{GS} = V_G - I_D R_S$

$V_{GS} = 1.5 - I_D \times 750$

$\Rightarrow I_D = \frac{1.5 - V_{GS}}{750}$ —— (1)

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

$I_D = 6 \times 10^{-3}\left(1 - \frac{V_{GS}}{-3}\right)^2$ —— (2)

equating (1) & (2),

$\frac{1.5 - V_{GS}}{.75 \times 10^3} = 6 \times 10^{-3}\left(1 + \frac{V_{GS}}{3}\right)^2$

$\Rightarrow 1.5 - V_{GS} = \cancel{6}^{2} \times .75 \frac{(3 + V_{GS})^2}{\cancel{9}\,3}$

$\Rightarrow \quad 1.5 - V_{GS} = \frac{\cancel{2}\times\cancel{3}}{\cancel{4}_2}\left(\frac{9+V_{GS}^2+6V_{GS}}{\cancel{3}}\right)$

$\Rightarrow \quad 3 - 2V_{GS} = 9 + V_{GS}^2 + 6V_{GS}$

$\Rightarrow \quad V_{GS}^2 + 8V_{GS} + 6 = 0$

$V_{GS} = -0.83 \; , \; -7.16\,V$.

-7.16 is not possible

$\therefore \boxed{V_{GSQ} = -0.83V}$

$I_D = \frac{1.5 - V_{GS}}{750} = \frac{1.5+0.83}{750} = 3.1\,mA$.

$\boxed{I_{DQ} = 3.1\,mA}$

$V_{DS} = V_{DD} - I_D(R_D + R_S)$

$= 18 - 3.1\times10^{-3}(1.8 + .75)\times10^3$

$\boxed{V_{DS} = 10.1V}$

Ex-6 :- Repeat example 5, with $R_S = 150\,\Omega$

The transfer Characteristic remains same,

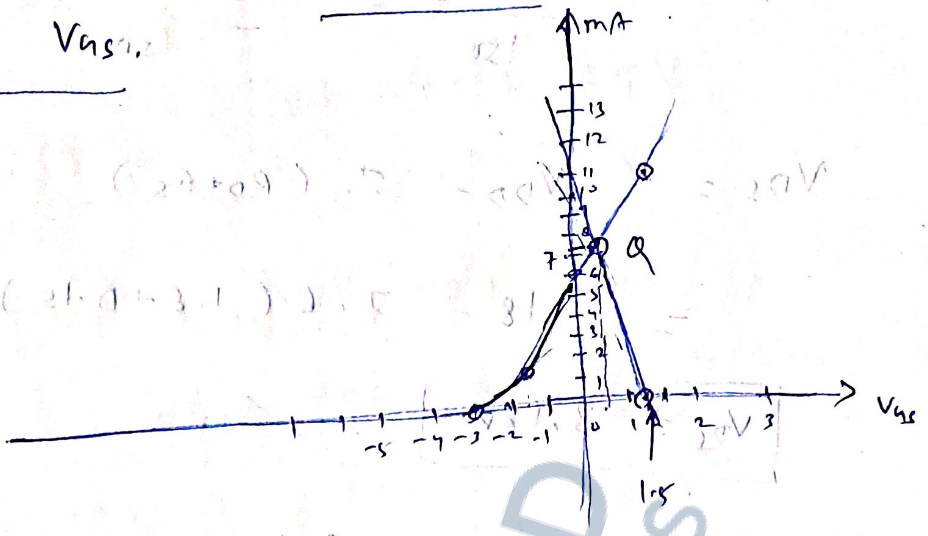
For bias line

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

$I_D = 0, \quad V_{GS} = V_G = 1.5V$

$V_{GS} = 0, \quad I_D = \frac{V_G}{R_S} = \frac{1.5}{150} = \frac{1}{100} = 10\,mA$.

Note:- In this case Q Point results in a drain current exceeds I_{DSS} with +ve value for V_{GS}.



Intersection of bias line, the transfer curve
↓ Joining points

gives $(1.5, 0)$ & $(0, 10)$

↳ V_{GSQ}, I_{DQ} $(+0.35\,V, 7.6\,mA)$

Mathematical approach :-

$$I_D = \frac{1.5 - V_{GS}}{150} \quad \text{——} \ (1)$$

$$I_D = 6 \times 10^{-3}\left(1 + \frac{V_{GS}}{3}\right)^2 \quad \text{——} \ (2)$$

$$\frac{1.5 - V_{GS}}{150} = 6 \times 10^{-3}\frac{(3 + V_{GS})^2}{9}$$

$$\Rightarrow 1.5 - V_{GS} = \frac{.15 \times 10^{\cancel{3}} \times \cancel{6}^{2} \times 10^{\cancel{-3}}\,(9 + V_{GS}^2 + 6V_{GS})}{\cancel{9}\,3}$$

$$\Rightarrow (1.5 - V_{GS}) \times 10 = 9 + V_{GS}^2 + 6V_{GS}$$

$$\Rightarrow 15 - 10V_{GS} = 9 + V_{GS}^2 + 6V_{GS}$$

$$\Rightarrow V_{GS}^2 + 16V_{GS} - 6 = 0$$

$$V_{GS} = 0.36\,V, \ -16.36\,V$$

$$\therefore \boxed{V_{GS} = 0.36\,V}$$

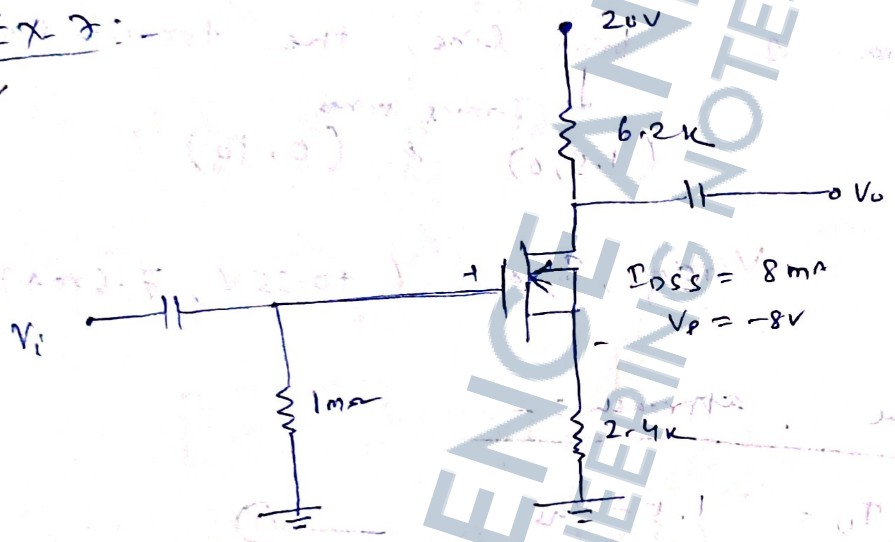
$$I_D = \frac{1.5 - V_{GS}}{150} = \frac{1.5 - 0.36}{150} = 7.6\ mA$$

$$V_{DS} = V_{DD} - I_D(R_D + R_S)$$

$$= 18 - 7.6(1.8 + 0.15)$$

$$\boxed{V_{DS} = 3.18V}$$

Ex 7:-



Ans :- The self bias configuration results in,

$$-V_{GS} - I_D R_S = 0$$

$$\Rightarrow V_{GS} = -I_D R_S.$$

At $\boxed{I_D = 0,\ V_{GS} = 0}$

At $V_{GS} = -6V$, (Any arbitrary point)

$$I_D = \frac{-V_{GS}}{R_S} = \frac{+6}{2.4 \times 10^3} = 2.5\ mA$$

(0, 0) and (−6, 2.5) are the points of the bias line.

To draw the transfer characteristics.

$(V_P, 0)$, $(0, I_{DSS})$ i.e $(-8, 0)$, $(0, 8)$

At $V_{GS} = \frac{V_P}{2}$, $\frac{I_{DSS}}{4}$ i.e $(-4, 2\,mA)$

For a +ve point,

At $\boxed{V_{GS} = +2V}$

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

$$= 8 \times 10^{-3}\left(1 - \frac{2}{-8}\right)^2$$

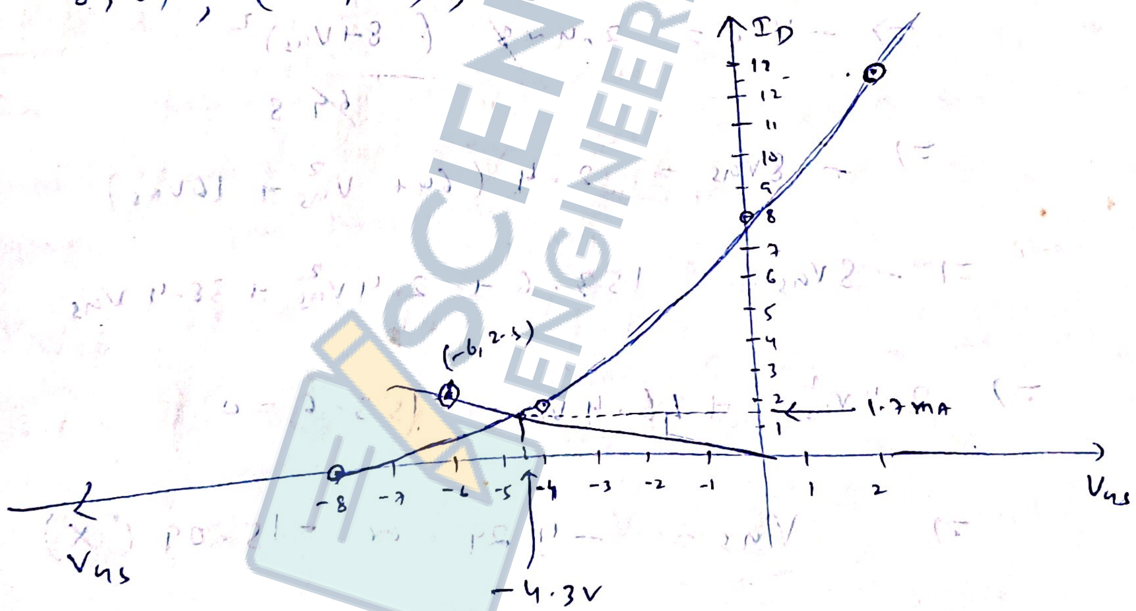
$$= 8 \times 10^{-3}\left(1 + \frac{1}{4}\right)^2$$

$$= 8 \times 10^{-3}\left(\frac{25}{16}\right)$$

$$\boxed{I_D = 12.5\,mA}$$

(4 points are)

$(-8, 0)$, $(-4, 2)$, $(0, 8)$ $(2, 12.5)$



Intersection of 2 curves, gives the Q-point

$(-4.3V, 1.7\,mA)$

Mathematical approach

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

$$V_{GS} = -I_D \cdot 2.4\times10^3 \quad — ①$$

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

$$= 8\times10^{-3}\left(1-\frac{V_{GS}}{-8}\right)^2$$

$$I_D = 8\times10^{-3}\left(1+\frac{V_{GS}}{8}\right)^2 \quad — ②$$

Equating ① & ②,

$$\frac{-V_{GS}}{2.4\times10^3} = 8\times10^{-3}\left(1+\frac{V_{GS}}{8}\right)^2$$

$$\Rightarrow -V_{GS} = 2.4\times\cancel{8}\frac{(8+V_{GS})^2}{\cancel{64}\ 8}$$

$$\Rightarrow -8V_{GS} = 2.4(64+V_{GS}^2+16V_{GS})$$

$$\Rightarrow -8V_{GS} = 153.6 + 2.4V_{GS}^2 + 38.4V_{GS}$$

$$\Rightarrow 2.4V_{GS}^2 + 46.4V_{GS} + 153.6 = 0$$

$$\Rightarrow V_{GS} = -4.24 \text{ or } -15.09\ (\times)$$

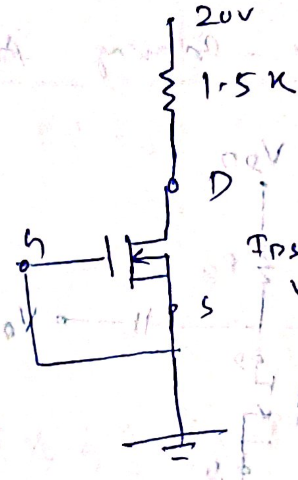
$$V_{GS} = -4.24\ V$$

$$I_D = -\frac{V_{GS}}{R_S} = \frac{-(-4.24)}{2.4\times10^3} = 1.76\ mA$$

$$Q\ (-4.24\ V,\ 1.76\ mA)$$

Ex-8 :- Determine V_{DS} for the N/W

2 marks



$I_{DSS} = 10mA$

$V_P = -4V$

Ans :- $V_{GS} = 0V$

Since $V_{GS} = 0$,

$I_D = I_{DSS} = 10mA$

$Q(0, 10mA)$

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

$= 20 - 10\times10^{-3} \times 1.5 \times 10^{3}$

$= 20 - 15$

$\boxed{V_{DS} = 5V}$

Enhancement-type MOSFETS

For ~~n-channel~~ n-channel, enhancement type MOSFET, the drain current is zero for levels of gate-to-source voltage less than the threshold level ~~V_{GS}~~. For levels of V_{GS} greater than $V_{GS(Th)}$ the drain current is defined by

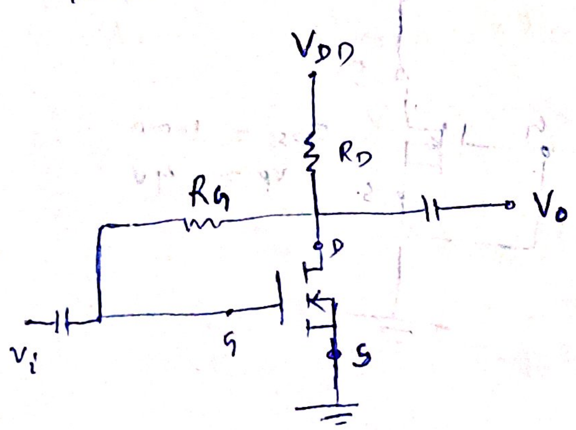
$$\boxed{I_D = K(V_{GS} - V_{GS(Th)})^2} \quad (1)$$

and

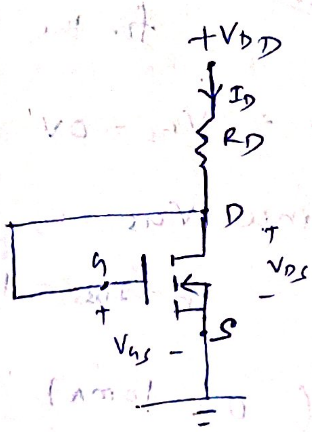
$$\boxed{K = \frac{I_D(on)}{[V_{GS}(on) - V_{GS(Th)}]^2}} \quad (2)$$

$I_D(on)$, $V_{GS}(on)$, $V_{GS(Th)}$ specified in specification sheet.

Feedback - Biasing Arrangement :-



Feedback Biasing Arrangement



D.C equivalent of the n/w.

Since $I_G = 0$, $V_{R_G} = 0$, so the d.c equivalent can be drawn as shown above.

(Current zero means D & G are at same potential)

$$\boxed{V_D = V_G}$$

(∵ Direct connection exist betn D & G)

$$\boxed{V_{DS} = V_{GS}} \quad (∵ D = G)$$

O/P ckt, $V_{DS} = V_{DD} - I_D R_D$

$$\Rightarrow \boxed{V_{GS} = V_{DD} - I_D R_D} \quad (∵ V_{DS} = V_{GS})$$ ①

OR

$V_{DD} - I_D R_D - \cancel{I_G R_G}^{\to 0} - V_{GS} = 0$

$\Rightarrow V_{GS} = V_{DD} - I_D R_D$

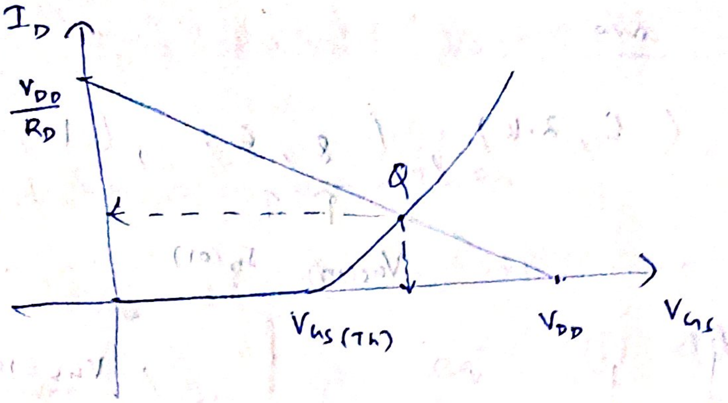
also $V_{DS} = V_{DD} - I_D R_D$

$\therefore V_{GS} = V_{DS}$

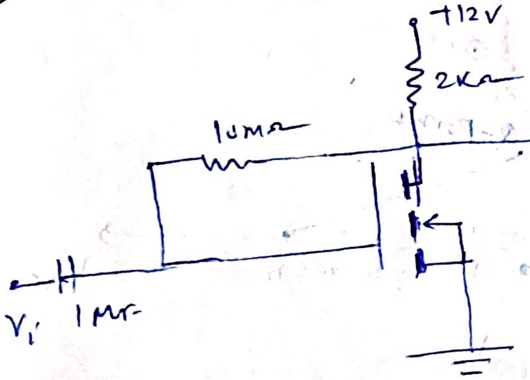
Eqn ① is a eqn of a straight line

At $I_D = 0$, $V_{GS} = V_{DD}$

At $V_{GS} = 0$, $I_D = \frac{V_{DD}}{R_D}$



Ex:- 9 Determine I_{DQ} & V_{DSQ} for enhancement-type MOSFET



$I_D(on) = 6mA$

$V_{GS}(on) = 8V$

$V_{GS(Th)} = 3V$

Ans:- $K = \dfrac{I_D(on)}{[V_{GS(on)} - V_{GS(Th)}]^2}$

$= \dfrac{6 \times 10^{-3}}{(8-3)^2}$

$= \dfrac{6}{25} \times 10^{-3}$

$K = 0.24 \times 10^{-3} \dfrac{A}{V^2}$

To draw transfer characteristics, we need points,

At arbitrary point $V_{GS} = 6V$, (bet^n 3 to 8V) $\uparrow V_{Th}$ $\uparrow V_{GS(on)}$

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

$= 0.24 \times 10^{-3}(6-3)^2$

$I_D = 2.16 mA$

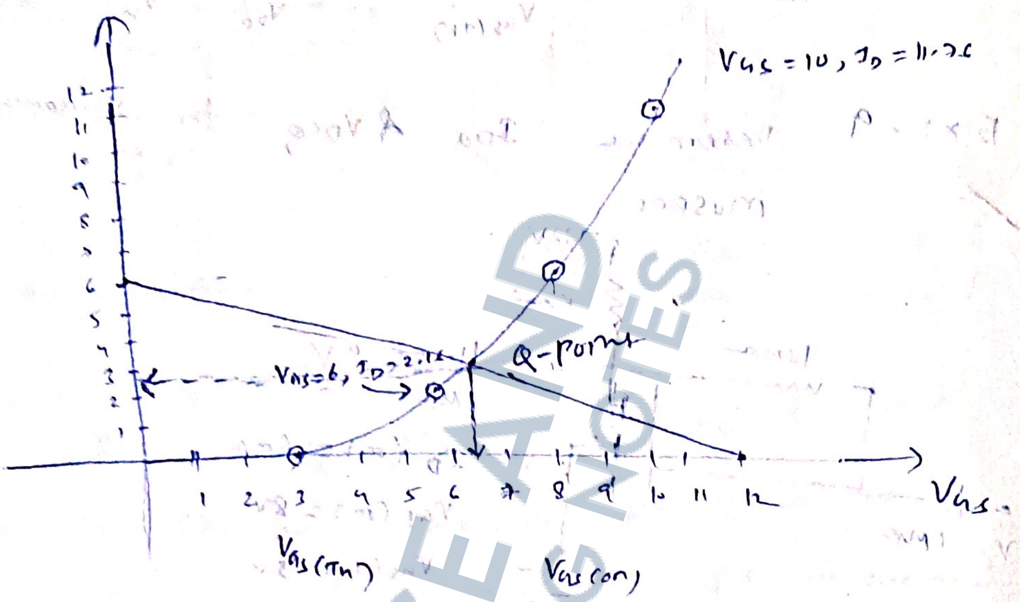
Arbitrary point, $V_{GS} = 10V$, ($> V_{GS(Th)}$), $I_D = 0.24 \times 10^{-3}(10-3)^2$

$I_D = 11.76 mA$

4 points are

$(V_{th}, 0)$, $(6, 2.16)$, $(8, 6)$, $(10, 11.76)$
$(3, 0)$

$\uparrow$ $V_{GS(on)}$ $\uparrow$ $I_D(on)$



To draw the Bias line $(V_{GS} = V_{DD} - I_D R_D)$

$I_D = 0$,
$V_{GS} = V_{DD}$
i.e $(V_{DD}, 0)$

At $V_{GS} = 0$
$I_D = \frac{V_{DD}}{R_D}$
i.e $\left(0, \frac{V_{DD}}{R_D}\right)$

$(V_{DD}, 0)$, $\left(0, \frac{V_{DD}}{R_D}\right)$

i.e $(12, 0)$, $\left(0, \frac{12}{2}\right)$

i.e $(12, 0)$ $(0, 6\ mA)$

The intersection of transfer characteristics & Bias line gives Q-point $(6.4V, 2.75mA)$

Mathematical Approach:-

$$K = \frac{I_D(on)}{[V_{GS(on)} - V_{GS(Th)}]^2} = 0.24\times10^{-3}\ \frac{A}{V^2}.$$

$$I_D = K(V_{GS} - V_{Th})^2$$

$$\Rightarrow I_D = 0.24\times10^{-3}(V_{GS}-3)^2 \quad \text{——} ①$$

$$V_{GS} = V_{DD} - I_D R_D$$

$$V_{GS} = 12 - I_D\, 2\times10^3 \quad \text{——} ②$$

Equating I_D of eqⁿ ① & ②

$$0.24\times10^{-3}(V_{GS}-3)^2 = \frac{12-V_{GS}}{2\times10^3}$$

$$\Rightarrow 0.48(V_{GS}^2 + 9 - 6V_{GS}) = 12 - V_{GS}$$

$$\Rightarrow 0.48V_{GS}^2 + 4.32 - 2.88V_{GS} = 12 - V_{GS}$$

$$\Rightarrow 0.48V_{GS}^2 - 1.88V_{GS} - 7.68 = 0$$

$V_{GS} = 6.4\,V$ or $-2.49\,V$ (Not possible)

$V_{GS} > V_{th}$, $\boxed{V_{GS} = 6.4\,V}$

$V_{GS} > 3\,V$

$$\therefore I_D = \frac{12-V_{GS}}{2\times10^3} \quad (\text{from eq}^n\ ②)$$

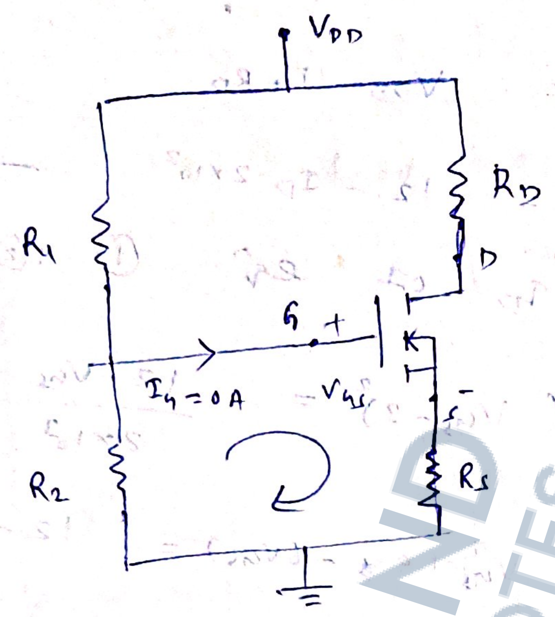
$$= \frac{12-6.4}{2\times10^3}$$

$$= \frac{5.6}{2}\times10^{-3}$$

$$\boxed{I_D = 2.8\,mA}$$

$\therefore$ Q point $(6.4\,V,\ 2.8\,mA)$

Voltage - Divider Biasing Arrangement :-



The fact that $I_G = 0\,mA$, results in the following eqn for V_{GG} as derived from an application of the voltage-divider rule,

$$V_{GG} = \frac{V_{DD}}{R_1+R_2} \times R_2 \quad \text{——— (1)}$$

Applying Kirchhoff's 2nd voltage law around the loop,

$$V_G - V_{GS} - V_{R_S} = 0$$

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

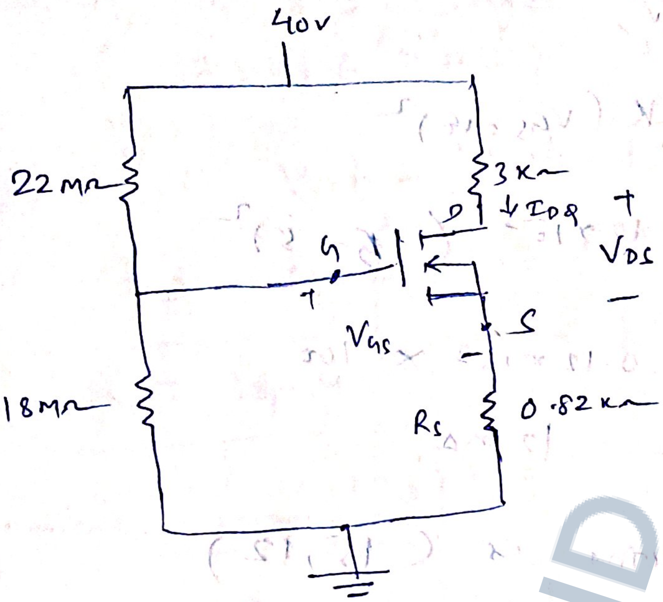
$$\boxed{V_{GS} = V_G - I_D R_S} \quad \text{——— (2)}$$

For O/P section.

$$V_{DD} - I_D R_D - V_{DS} - I_D R_S = 0$$

$$\Rightarrow \boxed{V_{DS} = V_{DD} - I_D (R_D + R_S)}$$

Ex-10



$V_{GS(Th)} = 5V$

$I_D(on) = 3mA$

at $V_{GS}(on) = 10V$.

Sol:-

To draw the ~~transfer characteristics~~ Bias Line

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

when $I_D = 0$, $V_{GS} = V_G$,

$$V_G = \frac{V_{DD}}{R_1 + R_2} \times R_2 = \frac{40}{22+18} \times 18 = 18V.$$

∴ when $I_D = 0$, $V_{GS} = V_G = 18V$ (18V, 0)

when $V_{GS} = 0$, $I_D = \frac{V_G}{R_S} = \frac{18V}{0.82K\Omega}$

$= 21.95\ mA$.

The points of bias line are

(0, 21.95 mA), (18V, 0)

To draw transfer characteristics

At $V_{GS} = V_{Th}$, $I_D = 0$, i.e. (5, 0)

$$K = \frac{I_D(on)}{(V_{GS(on)} - V_{GS(Th)})^2} = \frac{3 \times 10^{-3}}{(10-5)^2} = 0.12\ \frac{mA}{V^2}$$

At $V_{GS}(on)$, $I_D(on) = 3mA$, i.e. (10, 3 mA)

At $V_{GS} = 15V$,

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

$$= 0.12 \times 10^{-3}\,(15 - 5)^2$$

$$= 0.12 \times 10^{-3} \times 100$$

$$I_D = 12\,mA$$

$\therefore$ point is $(15, 12)$

At $V_{GS} = 20V$,

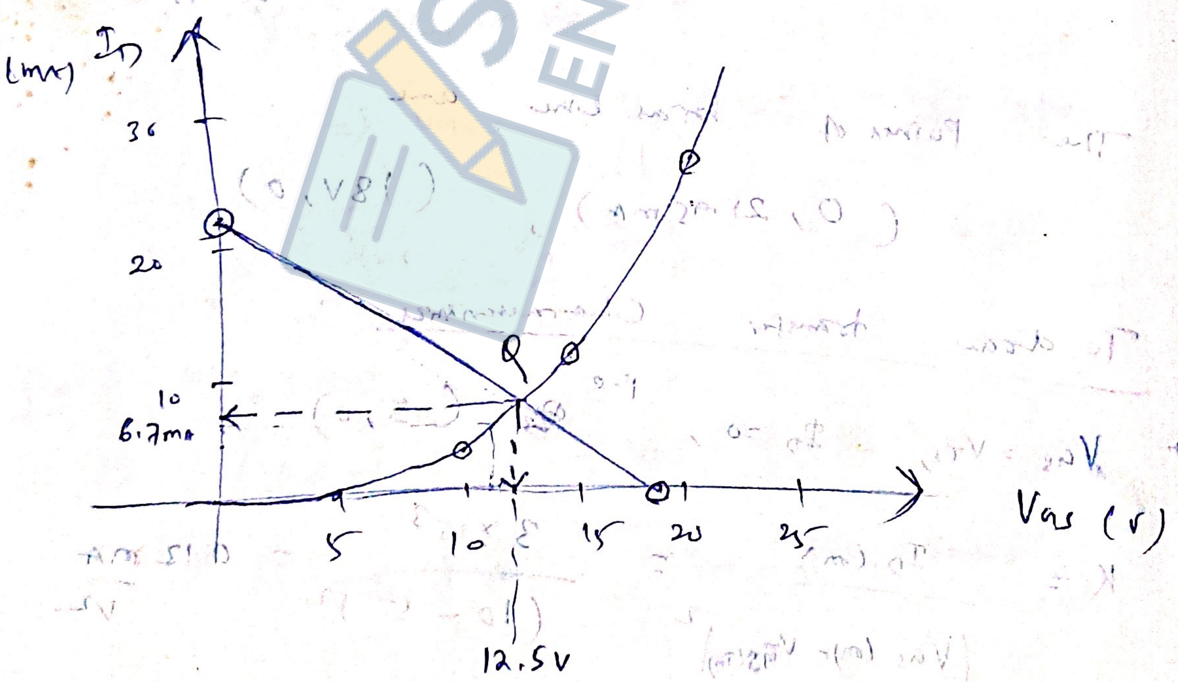
$$I_D = 0.12 \times 10^{-3}(20-5)^2$$

$$I_D = 27\,mA$$

$\therefore$ Point is $(20, 27)$

$\therefore$ 4 points on transfer characteristics are

$(5,0)$, $(10,3)$, $(15,12)$, $(20,27)$



Now the bias line is drawn. The

Intersection of 2 curves gives the Q point at (12.5V, 6.7 mA)

$$V_{DS} = V_{DD} - I_D (R_D + R_S)$$

$$= 40 - 6.7 \times 10^{-3} (3 + 0.82) \times 10^{3}$$

$$\boxed{V_{DS} = 14.4\,V}$$

Mathematical Approach:-

$$K = \frac{I_{D(on)}}{V_{GS(on)} - V_{GS(Th)}} = 0.12 \frac{mA}{V^2}$$

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

$$I_D = 0.12 \times 10^{-3} (V_{GS} - 5)^2 \quad \text{——— (1)}$$

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

$$V_G = \frac{V_{DD}}{R_1 + R_2} \times R_2 = \frac{40}{22+18} \times 18 = 18\,V.$$

$$V_{GS} = 18 - I_D \times 0.82 \times 10^{+3} \quad \text{——— (2)}$$

Equating I_D of eqn (1) & (2), we have

$$0.12 \times 10^{-3} (V_{GS} - 5)^2 = \frac{18 - V_{GS}}{0.82 \times 10^3}$$

$$\Rightarrow 0.0984 (V_{GS}^2 + 25 - 10V_{GS}) = 18 - V_{GS}$$

$$\Rightarrow .0984 V_{GS}^2 + 2.46 - 0.984 V_{GS} = 18 - V_{GS}$$

$$\Rightarrow .0984 V_{GS}^2 + 0.016 V_{GS} - 15.54 = 0$$

$$\Rightarrow V_{GS} = 12.48\,V \text{ or } -12.64\,V \text{ (Not possible)}$$

$$\therefore \boxed{V_{GS} = 12.48V}$$

$$I_D = \frac{18 - 12.48}{0.82 \times 10^3}$$

$$\boxed{I_D = 6.73\ mA}$$

$$V_{DS} = V_{DD} - I_D(R_D + R_S)$$

$$= 40 - 6.73(3 + 0.82)$$

$$\boxed{V_{DS} = 14.3V}$$