Field Effect Transistors DC biasing

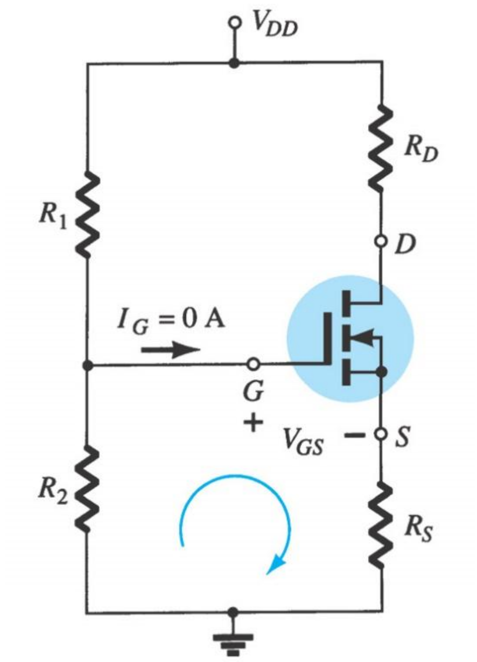
Chapter 7

- **Fixed Bias configuration**
- **Self Bias**
- **Voltage divider bias**
- **Feedback bias**

- **Graphical analysis**

- **Transfer curve**
- **Network equation**
- **Operating point**

+ve



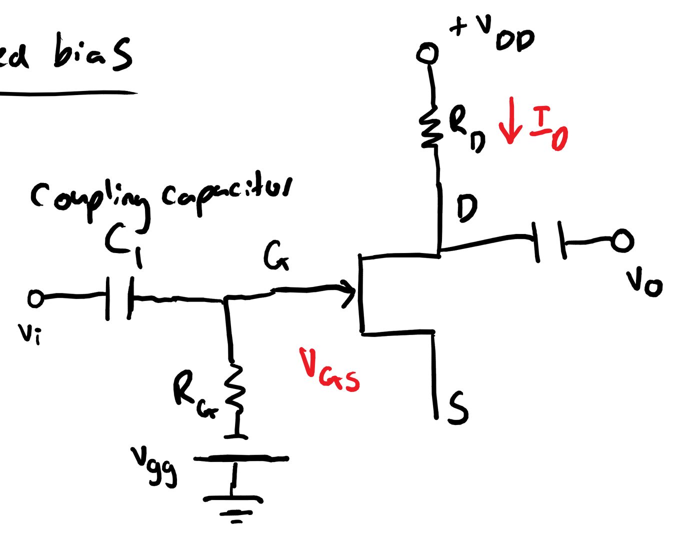
Application of DC supply (V_{DD}) to provide the required polarity and level of DC voltages for the transistors to operate in the region of interest

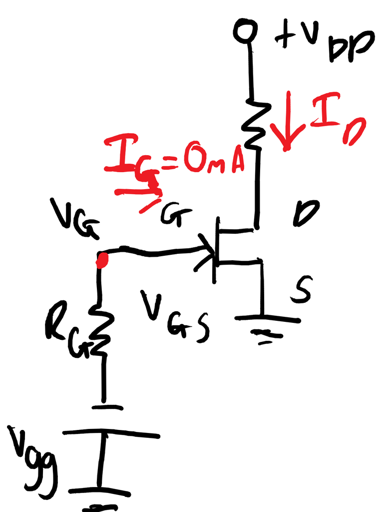
DC biasing

- output biasing
- transfer curve

p-channel

fixed bias





Shockley equation:

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

$$V_G = V_{GG} - I_G R_G$$

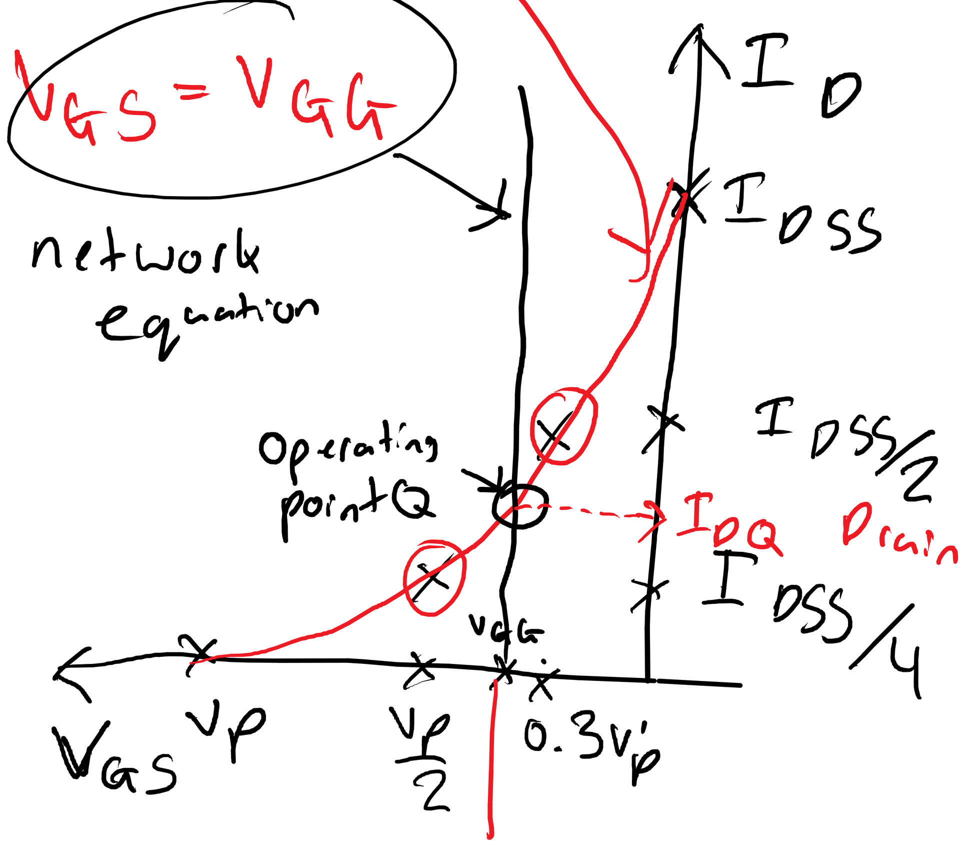
$I_G = 0$

$$V_G = V_{GG}$$

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

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

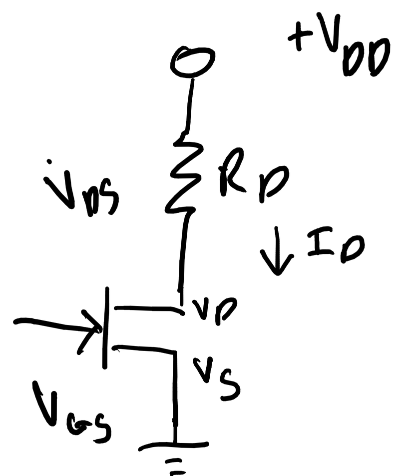
$$\boxed{V_{GS} = V_{GG}}$$



V_{GSQ}

V_{GS} at Q point

fixed bias configuration



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

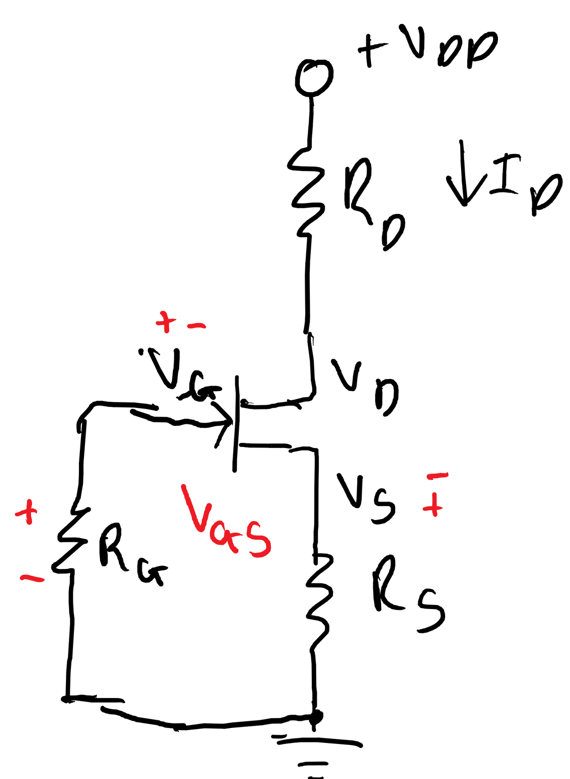
$$I_D = \frac{V_{DD} - V_{DS}}{R_D}$$

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

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

self-bias configuration

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



$$V_{GS} = V_G - V_S \quad (\text{network eq})$$

$$V_G = 0, \; I_G = 0$$

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

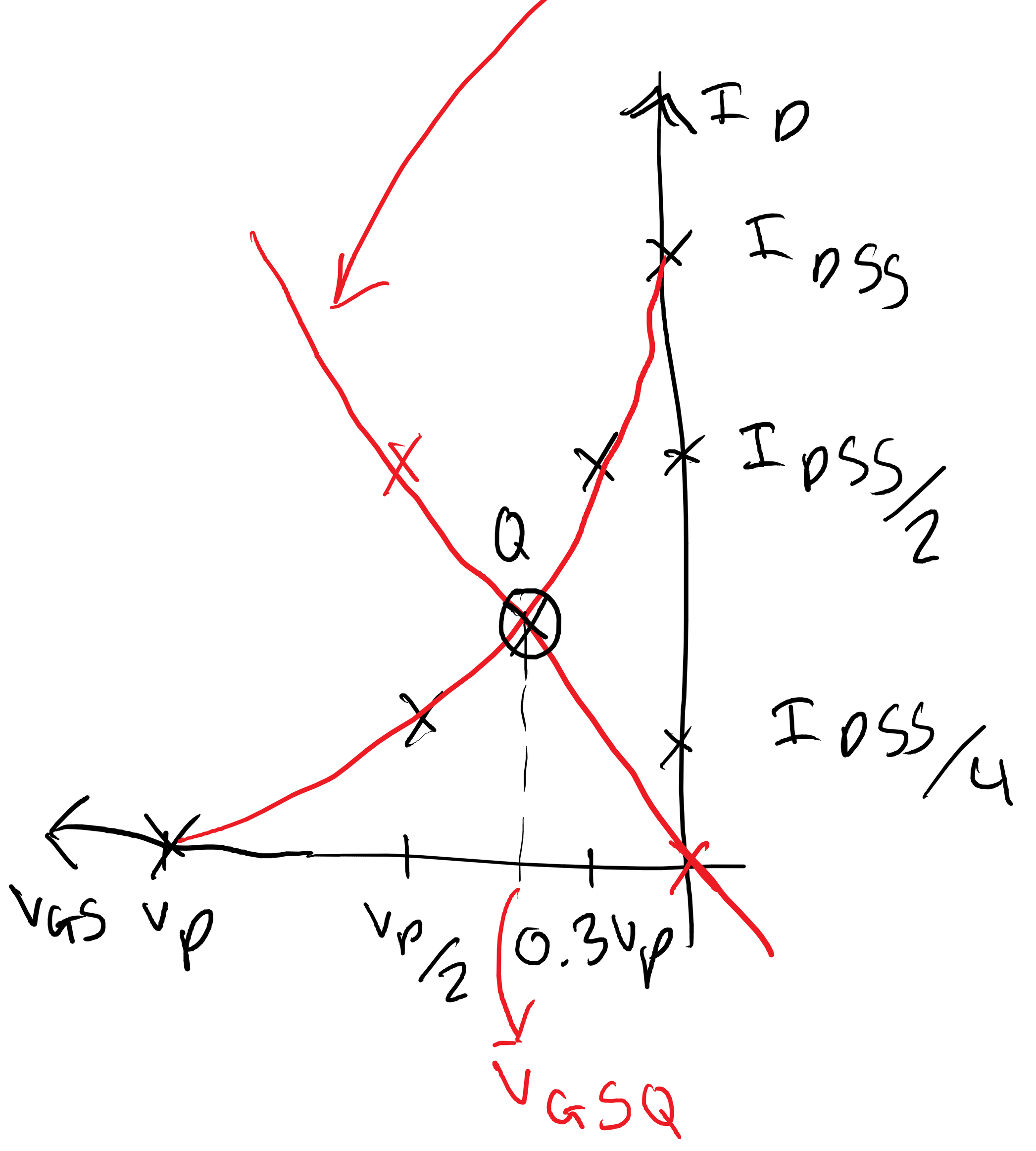
$$V_S = I_S R_S$$

$$I_S = I_D$$

$$V_S = I_D R_S$$

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

network equation



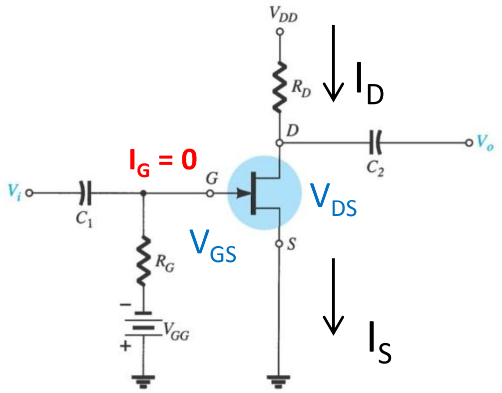
for $I_D = 0$

$$V_{GS} = 0$$

assume $I_D = \frac{I_{DSS}}{2}$

$$V_{GS} = -\frac{I_{DSS}}{2} \times R_S$$

FET DC Biasing Circuits Analysis



- I_D is controlled by V_{GS} Voltage Controlled Transistor
- In all dc analysis of FET's circuits

  I_G =0 mA, gate current = 0
- $I_D = I_S$ Drain Current = Source Current

- Shockley Equation relates input voltage V_{GS} and output current I_D in JFET's and DMOS transistors:

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

- For Enhancement type MOSFET :

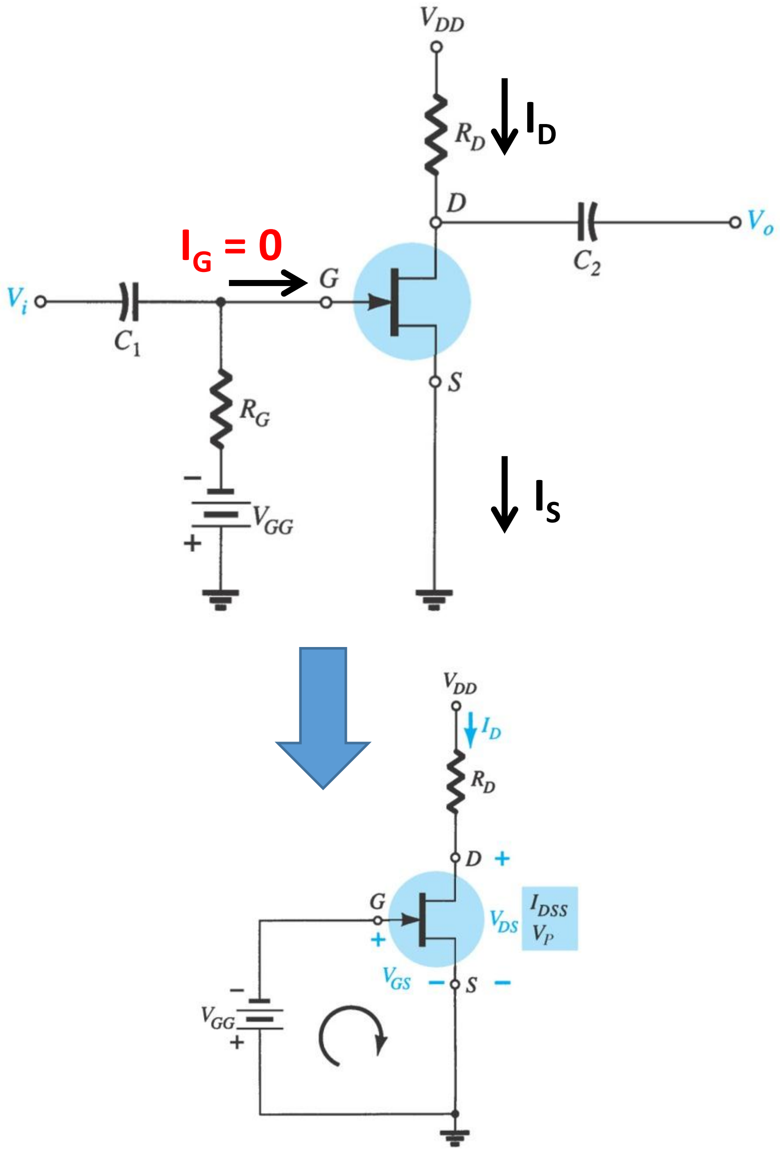
$$I_D= K(V_{GS}-V_T)^2 \qquad \text{..........(2)}$$

- Equations 1 and 2 are applied for JFET and MOSFET devices, they don't change With biasing network configurations.

- It is the network that determine the level of current and voltage associated with the operating point Q.
- DC analysis is the solution of simultaneous equations established by the DEVICE and NETWORK.
- DC analysis can be performed by mathematical or graphical methods.

Fixed –bias configuration for JFET’s

- R_G is placed to ensure that V_i appears at the input of the FET for ac applications and analysis.
- Coupling capacitors are open circuit for DC analysis and short circuit for ac analysis(and applied signals)



JFET Fixed bias DC circuit

DC analysis and mathematical approach:

- I_G = 0mA (Hence V_{GG} appears at the Gate G)

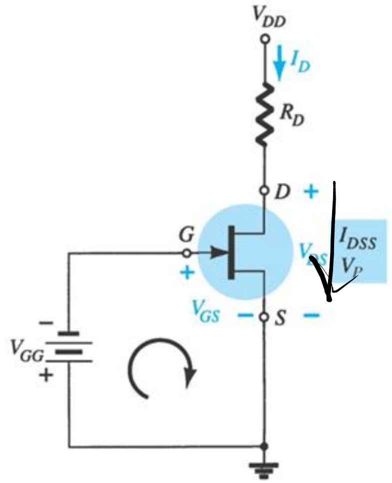
- $V_{RG} = I_G R_G = 0V$
- $-V_{GG}-V_{GS} = 0V$ (input loop)
- $V_{GS} = -V_{GG}$(network Equation)
- Since V_{GG} is fixed supply voltage, hence the name Fixed bias configuration.
- Apply Shockley equation: $I_D = I_{DSS} \left(1- \frac{V_{GS}}{V_P}\right)^2$
- I_{DSS} and V_P are usually obtained from the data sheet, Specified by the manufacturing company.
- V_{GS} is fixed by the V_{GG}(network equation).
- Then I_D can be calculated for the fixed bias circuit using Shockley equation.

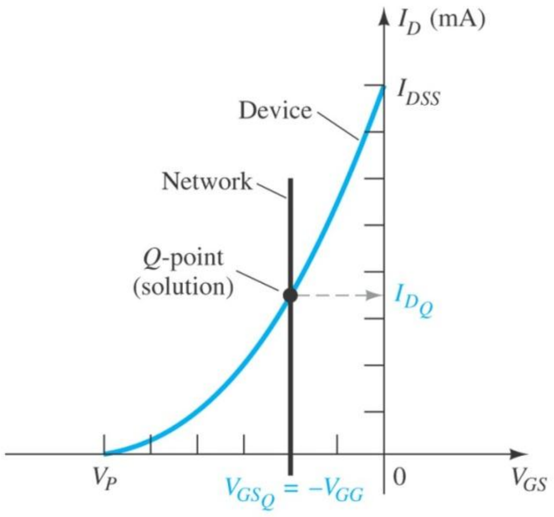
Graphical analysis(plot of Shockley equation)

1. Construct the transfer curve using Shockley equation: $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$
2. Find the network equation for the circuit and superimpose it on the transfer curve.
   $V_{GS} = V_G - V_S = V_G$ as $V_S = 0V$ (fixed bias).

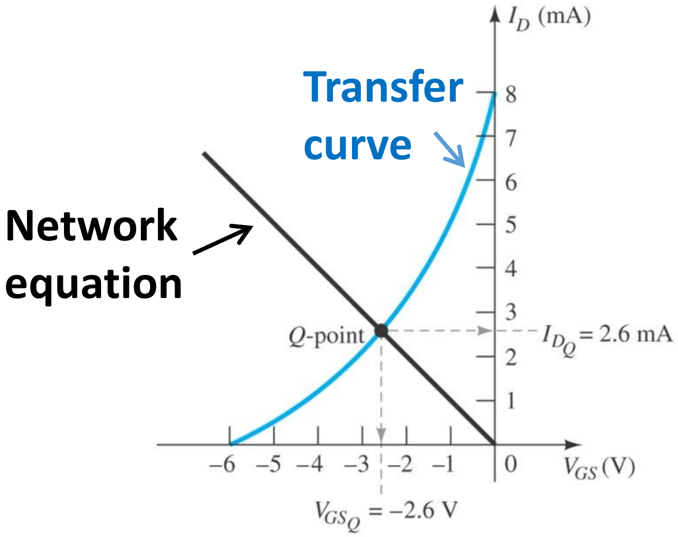
3. The point where the two curves intersect is the common solution to the two equations and it is called the Q operating point.
4. At the Q point, I_{DQ} and V_{GSQ} can be determined, e.g. $I_{DQ} = 2.6mA$, and $V_{GSQ} = -2.6V$
5. The output loop equations

$$V_{DS} = V_{DD} - I_D R_D$$
$$V_{DS} = V_D - V_S$$
$$V_D = V_{DS} + V_S \quad \text{for this case } V_S = 0V$$
$$\text{Then } V_D = V_{DS}$$





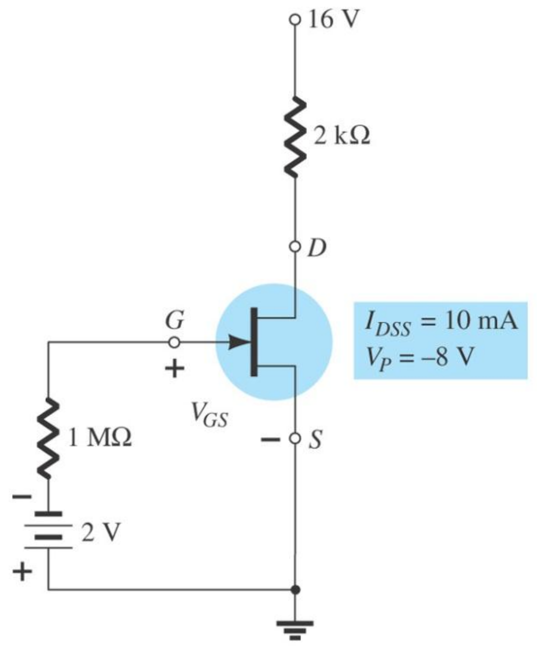
Fixed Bias



Self Bias

Example

Find V_{GSQ}, I_{DQ}, V_{DS}, V_G and V_S for the circuit shown using mathematical and graphical method.



JFET fixed bias circuit

Mathematical method:

Network Equation

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

$I_G = 0mA$

$V_{GS} = V_G = -V_{GG} = -2V = V_{GSQ}$

Shockley Equation

$I_D = I_{DSS}\left(1-\frac{V_{GS}}{V_P}\right)^2 = 10mA\left(1-\frac{-2}{-8}\right)^2 = I_{DQ} = 5.625mA$

Output loop:

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

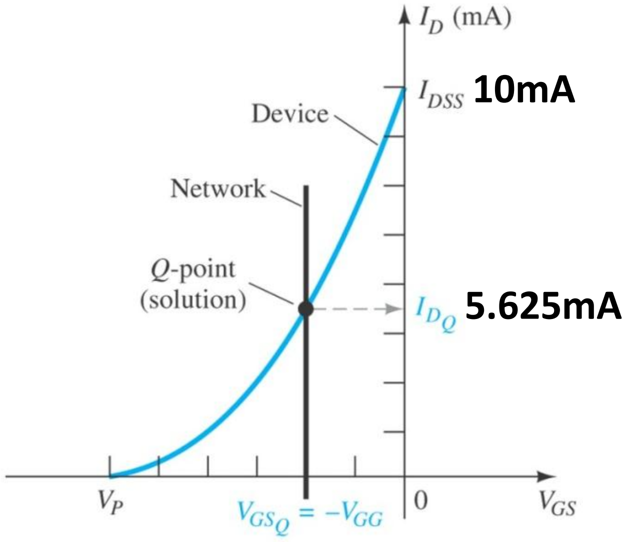
$V_{DS} = V_D - V_S = (V_{DD} - I_D R_D) - 0V$

$V_{DS} = 16 - 5.625\text{x}10^{-3} \text{ x } 2\ 10^3 = 4.75V$

$V_D = V_{DS} + V_S = 4.75 + 0 = 4.75\ V$

$V_G = V_{GS} + V_S = -2V + 0 = -2V$

Vs = 0V ground potential, common source configurations.



$V_{GSQ} = -2V$

Graphical method

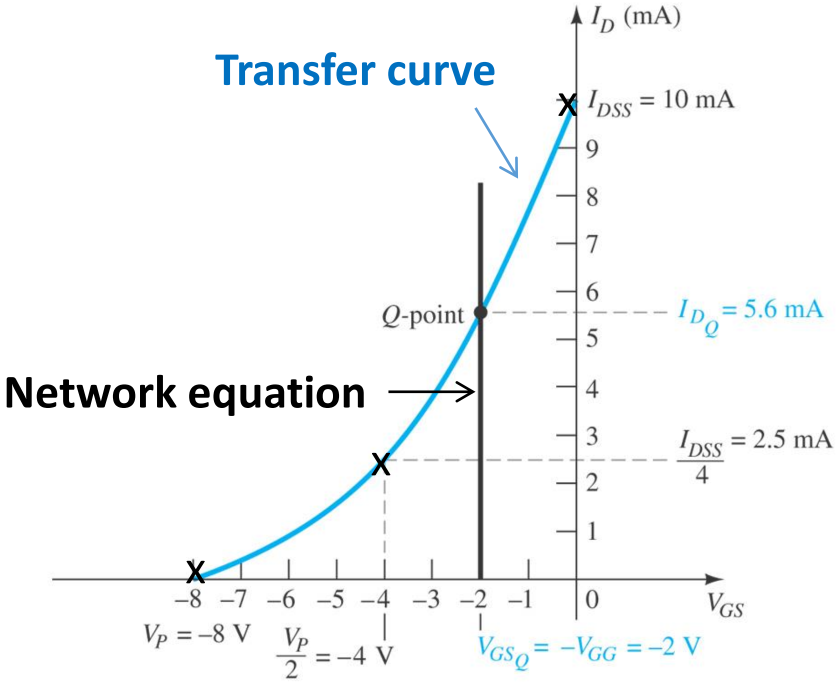
$I_D = I_{DSS}\left(1-\frac{V_{GS}}{V_P}\right)^2$

For V_{GS} = 0V, $I_D = I_{DSS}$ = 10mA
For $V_{GS} = V_P$, I_D = 0mA
For V_{GS} = ½ V_P = -4V, $I_D = I_{DSS}$ / 4 = 2.5 mA
For $I_D = I_{DSS}/2$ = 5mA
$V_{GS} = 0.3V_P$ = 0.3x-8V = -2.4V

Network Equation:
$V_{GS} = V_G - V_S = V_G$ – 0V
V_G = V_{GG} = -2V = V_{GSQ} (Fixed at -2V)

Q point from the intersection of the network equation(black line) and the transfer curve(blue)

V_{GSQ} = -2V and I_{DQ} =5.6mA

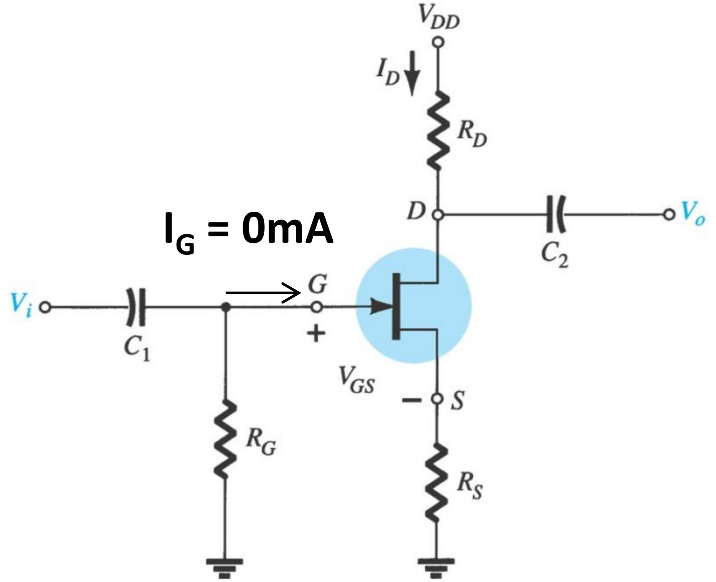


Construction of Transfer Curve

Self- Bias Configuration

One DC supply

V_{GS} is determined by R_S



<u>DC analysis:</u>

I_G = 0mA

R_G can be replaced with short circuit no current flow in R_G, hence the voltage is the same on either end of R_G (ground).

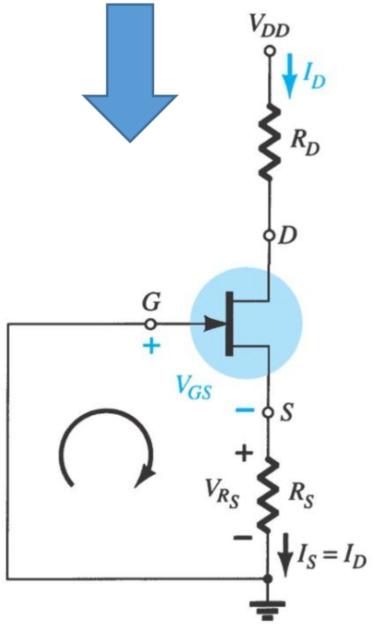
$I_D = I_S$

$V_{RS} = I_D R_S = V_S$

$V_{GS} = V_G - V_S$ but $V_G = 0V$

$V_{GS} = -V_S = -I_D R_S$ (Network equation)

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

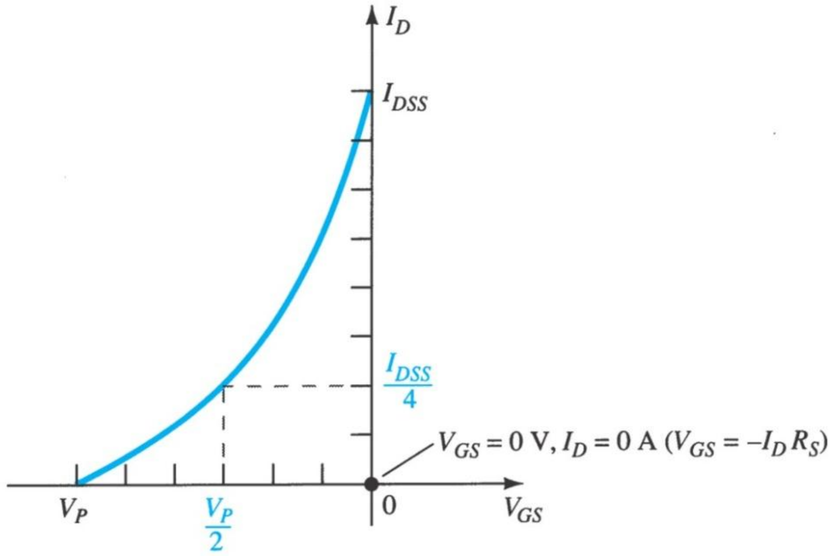


Solve Shockley equation to find I_{DQ} by substituting

$V_{GS} = -I_D R_S$

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

Graphical analysis



1. **Draw the transfer curve using Shockley equation**

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

2. **Superimpose the network equation on the transfer curve;**

$V_{GS} = -I_D R_S$

For I_D =0mA, V_{GS} =0V **1st point**

For $I_D = I_{DSS}/2$

$V_{GS} = -(I_{DSS}\ R_S)/2$ **2nd point**

3. **From the intersection of the straight line defined by the network and transfer curve defined by Shockley equation, the operating point Q is established:**

I_{DQ} and V_{GSQ} can be found.

4. **From the output loop**

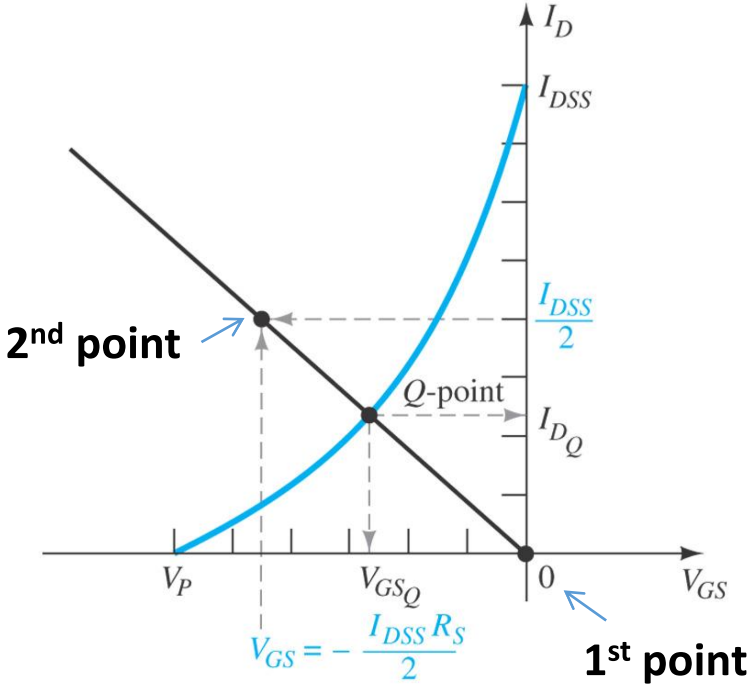
$V_{DD} = V_{RD} + V_{DS} + V_{RS}$

$V_{DS} = V_{DD} - V_{RD} - V_{RS} = V_{DD} - I_D R_D - I_D R_S$ ($I_D = I_S$)

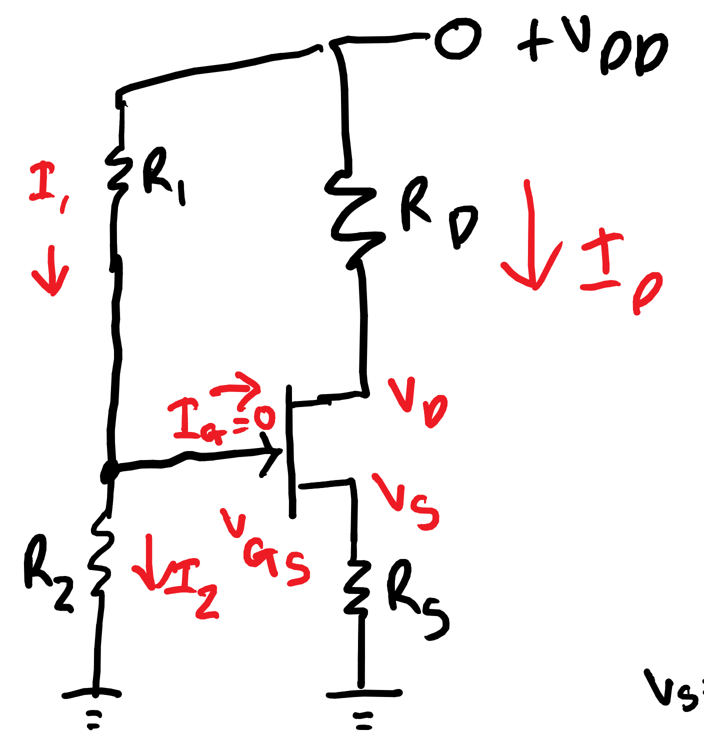
$V_{DS} = V_{DD} - I_D(R_D + R_S)$

$V_S = I_D R_S$, V_G =0V

$V_D = V_{DS} + V_S = V_{DD} - V_{RD}$



Voltage Divider bias



$V_{GS} = V_G - V_S$

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

$V_S = I_D R_S$

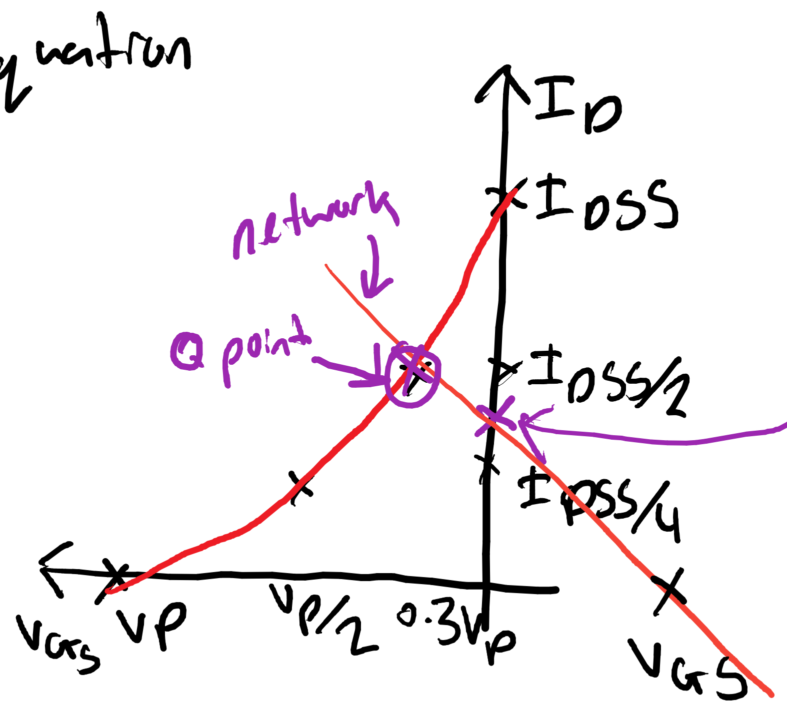
$$V_{GS} = V_{DD}\frac{R_2}{R_1+R_2} - I_D R_S$$

Network eq

- Operating point
- Shockley equation $\boxed{I_D = I_{DSS}\left(1 - \dfrac{V_{GS}}{V_P}\right)^2}$

Transfer curve

- Network equation



$V_{GS} = V_G - V_S$

$I_D = \dfrac{V_G}{R_S}$

$V_G = V_{DD}\left(\dfrac{R_2}{R_1+R_2}\right)$

$V_S = I_D R_S$

$I_D = I_S$

I_{DQ}, V_{GSQ}

$$\boxed{V_{GS} = V_{DD}\frac{R_2}{R_1+R_2} - I_D R_S}$$

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

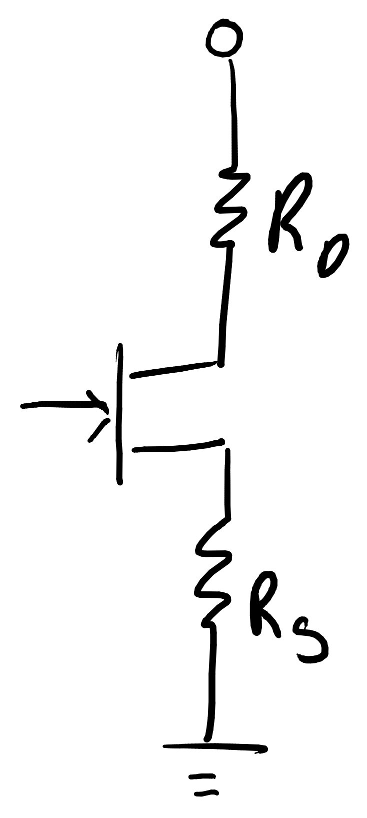
for $I_D = 0$, $V_{GS} = V_G$

$V_{GS} = 0$, $I_D = \dfrac{V_G}{R_S}$ *

$V_{DD} = I_D R_D + V_{DS} + I_D R_S$

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

$$\boxed{I_D = \frac{V_{DD} - V_{DS}}{R_D + R_S}}$$



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

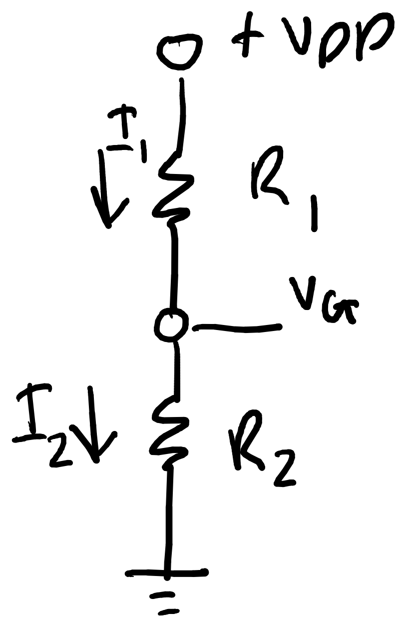
$V_{DS} = V_D - V_S$

$V_D = V_{DD} - I_D R_D$

$V_S = I_D R_S$

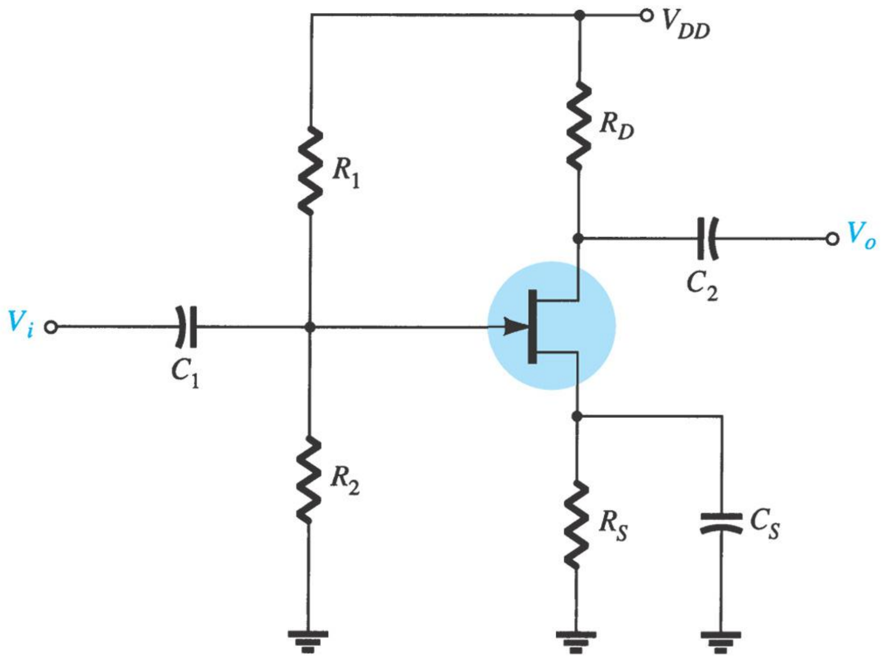
$V_{DS} = (V_{DD} - I_D R_D)$

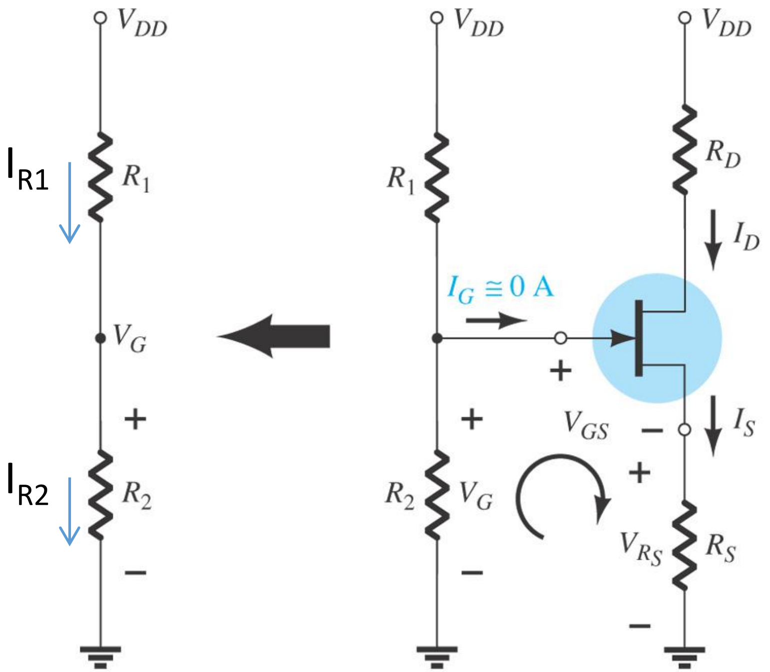
$V_{DD} = V_{DS} + I_D R_D$



$I_1 = I_2 = \dfrac{V_{DD}}{R_1 + R_2}$

Voltage Divider Bias





$I_G = 0mA$

$I_{R1} = I_{R2}$

$V_G = \frac{V_{DD} R_2}{R_2 + R_1}$ **Voltage Divider Rule**

V_G is positive

$V_{GS} = V_G - V_S$

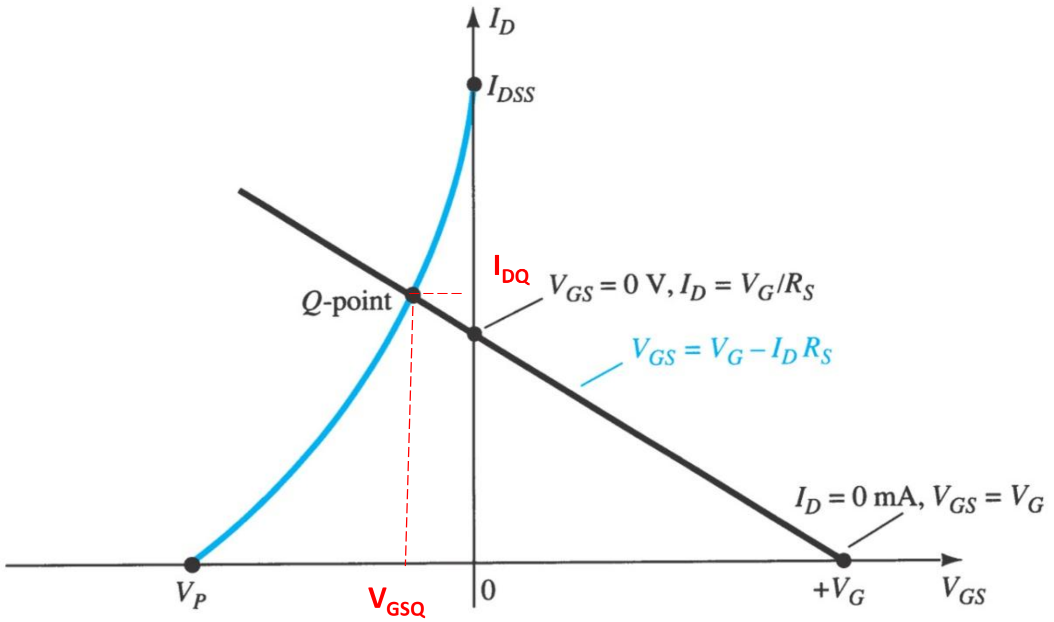
$V_{GS} = V_G - I_D R_S$ **Network equation**

DC equivalent circuit, NO need to Thevenin's….

Transfer Curve

The operating point I_{DQ} and V_{GSQ} can be found by superimposing the *network equation* on the *transfer curve.*

1. $V_{GS} = V_G - I_D R_S$ **Network Equation**
2. For $I_D = 0$, $V_{GS} = V_G$ (1st point)
3. For $V_{GS} = 0V$, $I_D = V_G/R_S$ **(2nd point)**
4. I_{DQ} and V_{GSQ} can be found from the intersection with the transfer curve at the Q point.



Network equation and transfer curve

Output Loop:

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

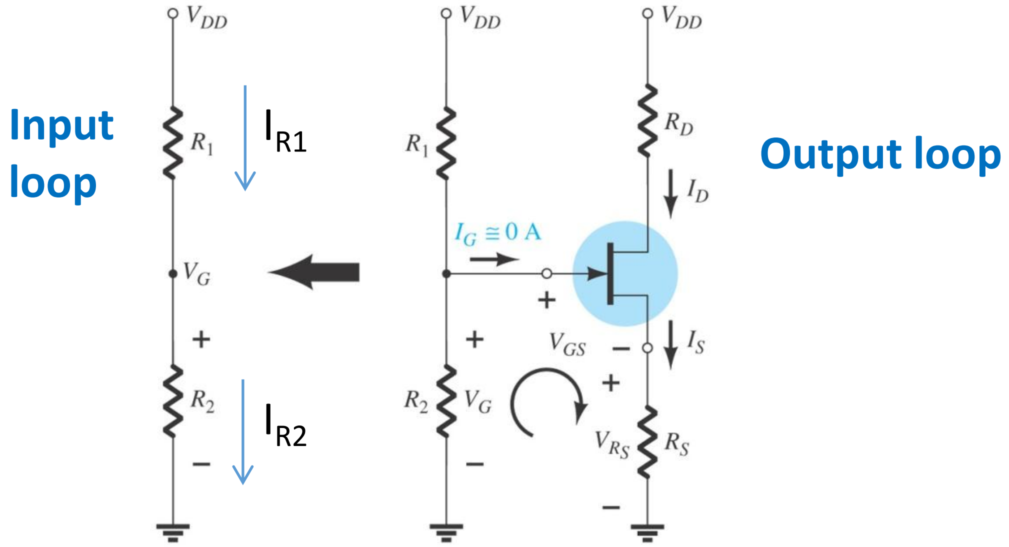
$V_D = V_{DD} - I_D R_D$

$V_S = I_D R_S$

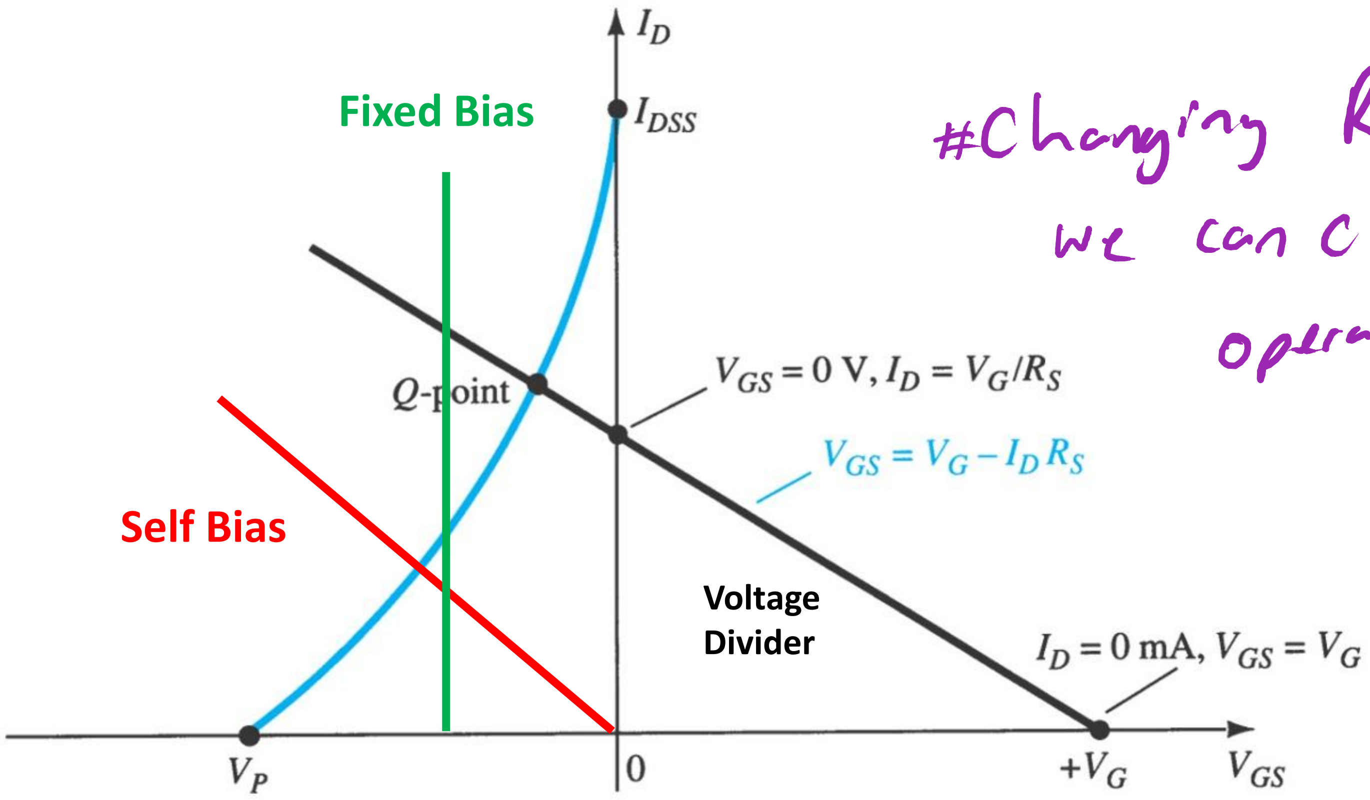
Input loop:

$I_{R1} = I_{R2} = \dfrac{V_{DD}}{R_1+R_2}$

$I_G = 0mA$



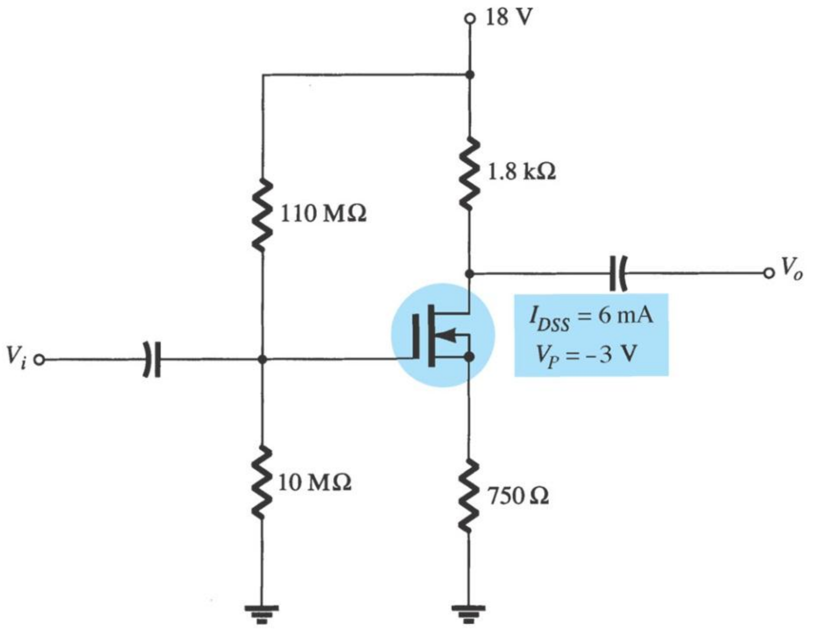
Network equation and biasing configuration



#Changing R_S
we can change the
operating point.

Depletion type MOSFET biasing circuits

Same analysis as JFET
DMOSFET, n channel permit operating point with positive V_{GS} and I_D could be > I_{DSS}



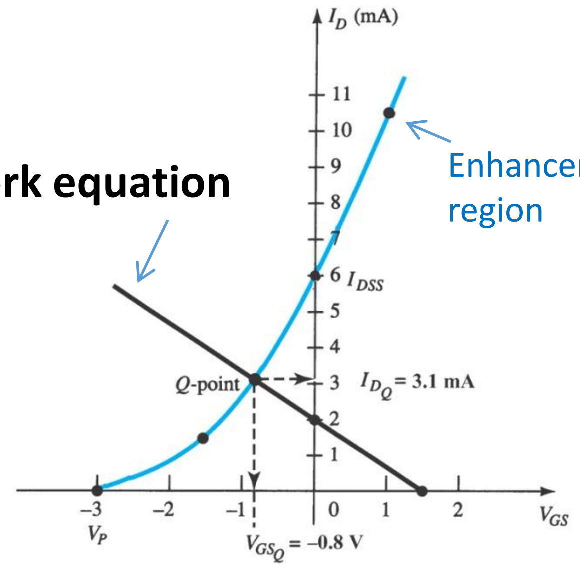
DC analysis:
1. Draw the transfer curve using Shockley equation
For V_{GS} = ½ V_P = -1.5V
$I_D = I_{DSS}/4$ = 1.5mA
I_D = 0, for $V_{GS} = V_P$ = -3V
$I_D = I_{DSS}/2$, $V_{GS} = 0.3V_P$ = -0.9V
$I_D = I_{DSS}$ = 6mA at V_{GS} =0V

For V_{GS} = +1V,   (enhancement region)

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

$$I_D = 6mA\left(1 - \frac{+1V}{-3V}\right)^2 \quad = 10.67mA$$

Network equation



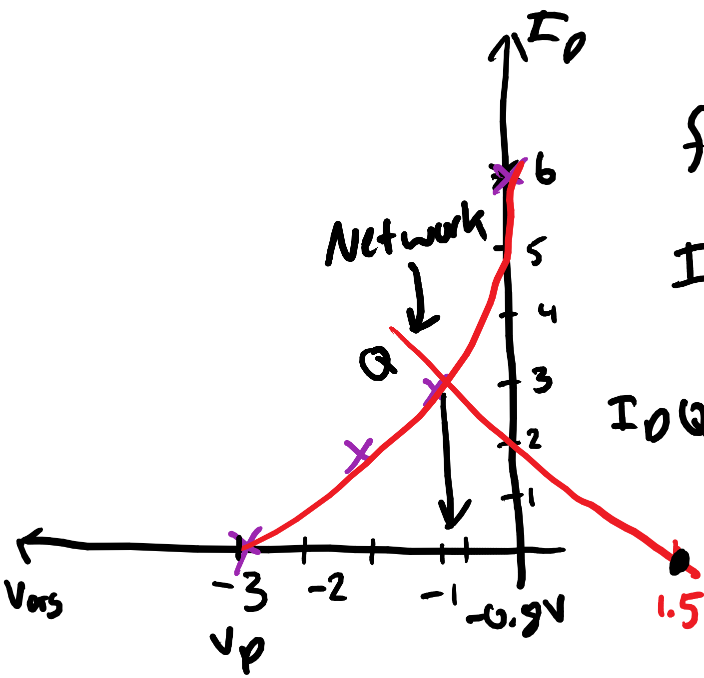
$V_{GS} = V_G - V_S$

$V_G = V_{DD} \dfrac{R_2}{R_1 + R_2} = 18V \dfrac{10M}{10M + 110M}$

$V_G = +1.5V$

$V_S = I_D R_S$

$\boxed{V_{GS} = 1.5 - I_D R_S}$



for V 0

$I_D = \dfrac{1.5}{750\Omega} = 2mA$

$I_DQ = 3.1mA$

Network equation

2. Draw the network equation

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

$V_G = V_{DD} \dfrac{R_2}{R_2+R_1} = \dfrac{18\ x\ 10M}{110M+10M} = 1.5V$

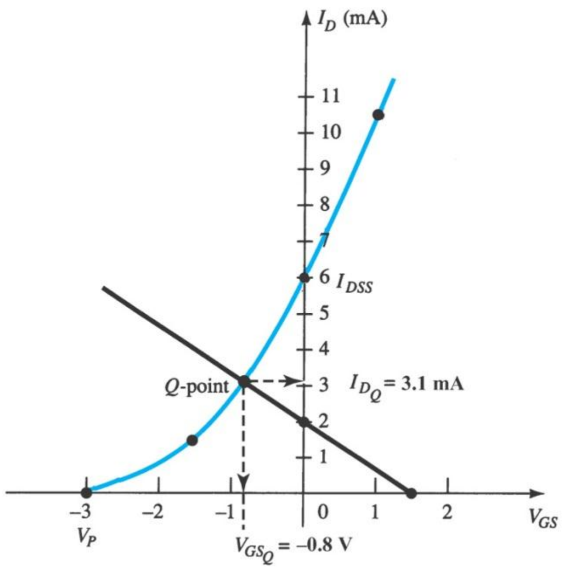
$V_{GS} = 1.5 - I_D \times 750\Omega$

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

Setting $V_{GS} = 0$, $I_D = V_G/R_S = 1.5V/\ 750\ \Omega = 2\ mA$

The intersection of the network equation with transfer curve gives the operating point:

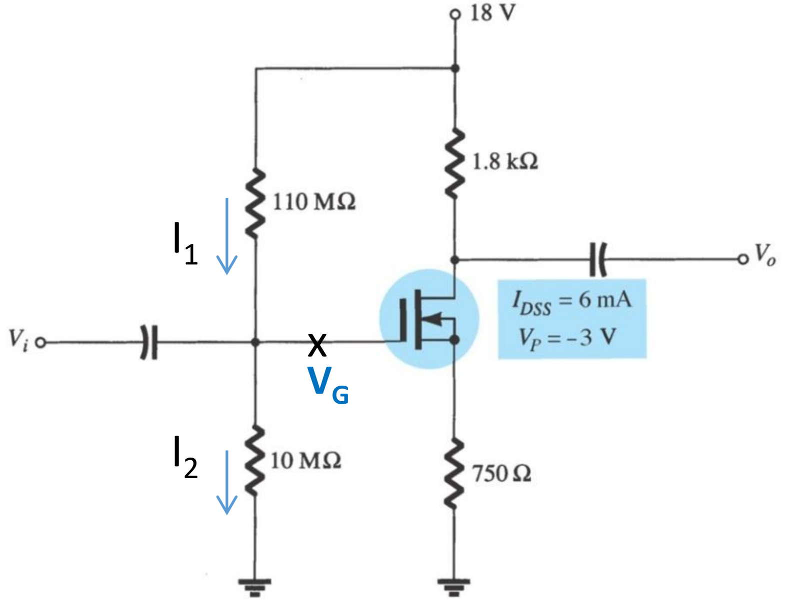
$I_{DQ} = 3.1mA$, $V_{GSQ} = 0.8V$



From the drain source output loop:

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

$V_{DS} = 18 - 3.1\ mA(1.8k + 750\ \Omega) = 10.1\ V$



From the input loop:

$I_1 = I_2 = \dfrac{18V}{110M+10M} = 0.15\mu A$

Enhancement type MOS biasing circuits

EMOSFET's have different transfer curve compared to JFET's and DMOSFET's
Shockley equation does not apply for EMOS.

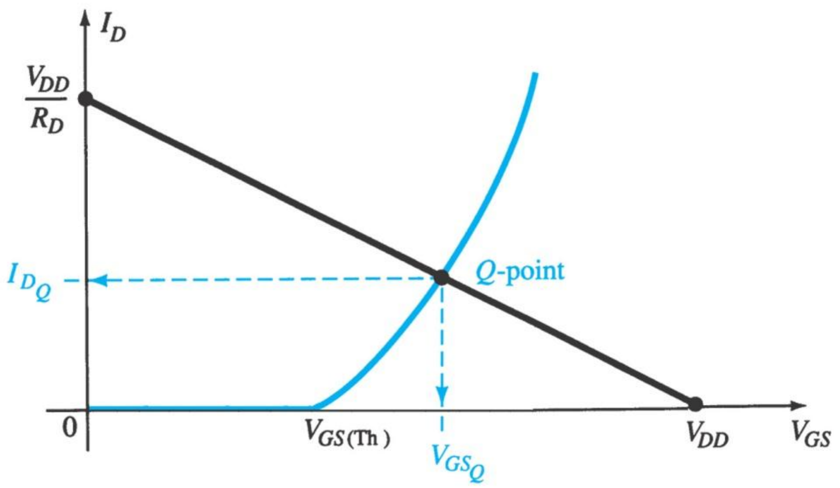
I_D = 0 mA for $V_{GS} < V_T$
For $V_{GS} > V_T$ $\quad I_D = k(V_{GS} - V_T)^2$

From the output characteristics
$V_{DSsat} = (V_{GS}-V_T)$
$V_{DS} > (V_{GS} - V_T)$ Saturation region
$V_{DS} < (V_{GS}-V_T)$ Ohmic Region

To draw the transfer curve V_T is provided from the data sheet, also given is I_D(on) and V_{GS}(on)

Then k can be calculated from:

$$K = \frac{I_{D(on)}}{[V_{GS(ON)} - V_T]^2}$$



Transfer curve(blue), load line(black) and Q point for EMOS

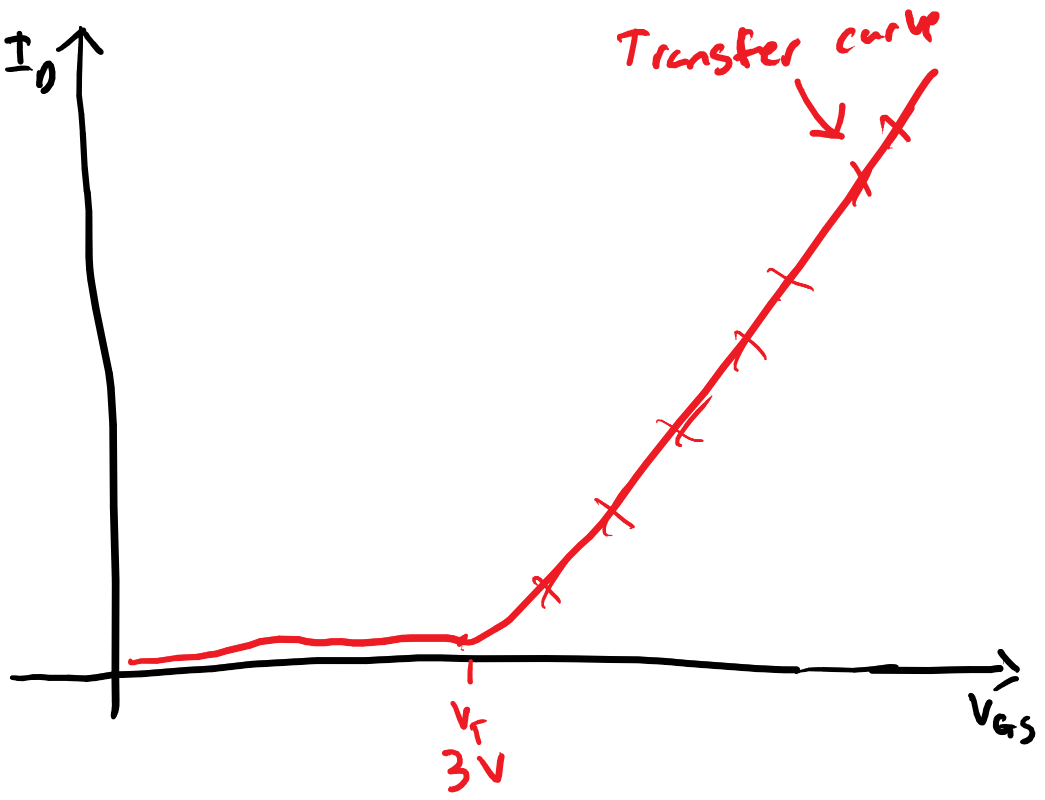
EMOSFET

Transfer Curve

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

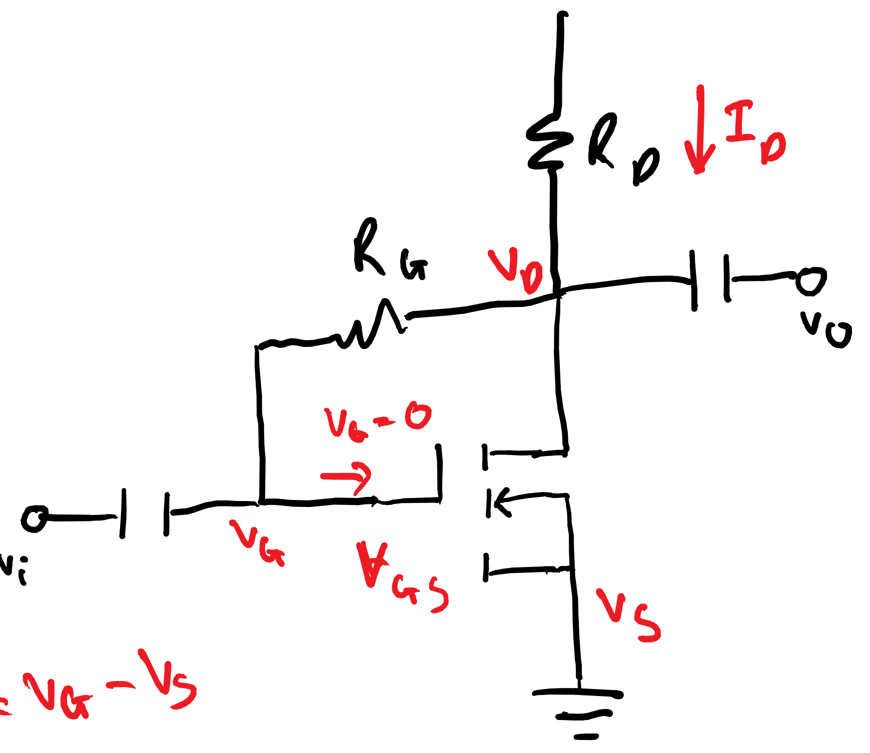
Both k & V_T are given by the data sheet.

for V_{GS} less than V_T, $I_D = 0$



Calculate I_D

$V_{GS} = +3.5V, +4.5V, +5.5V$
$+6.5V$



$V_{GS} = V_G - V_S$

$V_{GS} = V_S$

$V_G = V_D$ (no current flowing in R_G, $I_G = 0$)

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

$V_{DS} = V_D - V_S$

$\boxed{V_{DS} = V_D} - 0$

$V_{DD} = I_D R_D + V_D$

$V_{DD} = I_D R_D + V_G$ substituting

$V_{DD} = I_D R_D + V_{GS}$, $V_{GS} = \boxed{V_{DD} - I_D R_D}$

network equation

$V_{GS} = +3.5V, +4.5V$
$+5.5V + 6.5V$
Calculate I_D

$I_D = 0$ $V_{DS} = V_{GS}$

For $V_{GS} = 0$, $I_D = \dfrac{V_{DD}}{R_D}$

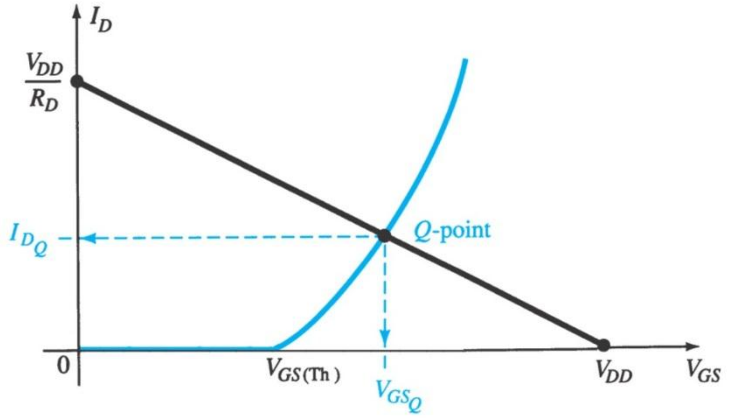
Feedback Bias for EMOS

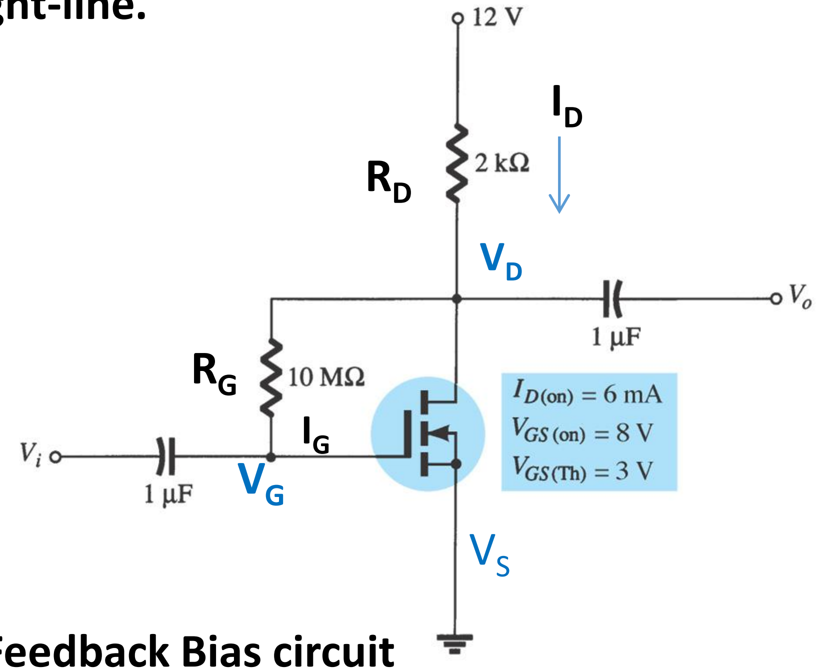
I_G = 0mA
V_{RG} = 0V (= I_G . R_G)
V_D = V_G
V_{DS} = V_{GS} (no current flowing in the 10M resistor)

Output loop:
$V_{DS} = V_{DD} - I_D R_D$
$V_{GS} = V_{DD} - I_D R_D$ (network equation)
i.e. the relationship between V_{GS} and I_D is a straight-line.

Now for I_D = 0
$V_{GS} = V_{DD}$
For V_{GS} = 0V

$$I_D = \frac{V_{DD}}{R_D}$$





Feedback Bias circuit

Voltage Divider Bias

Input loop:

I_G = 0mA   gate is isolated

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

$V_{GS} = V_G - V_S$

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

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

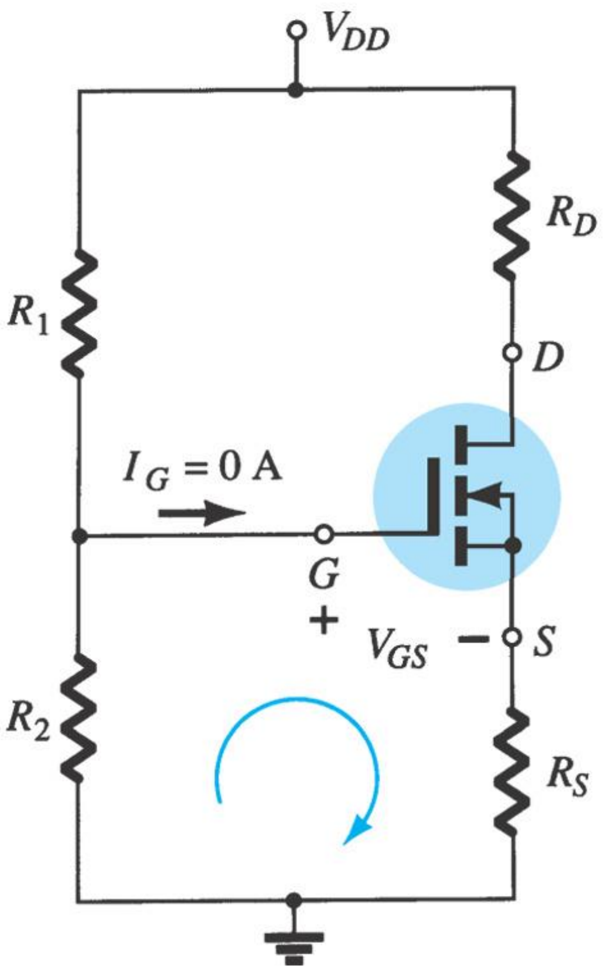
Substitute for V_{GSQ} from network equation into the transfer curve equation to find I_{DQ}

$I_{DQ} = k\{ (V_G - I_{DQ} R_S) - V_T \}^2$

Output loop:

$V_{DD} - V_{RD} - V_{DS} - V_{RS} = 0$

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



EMOSFET biasing circuit