Lecture three

Q1)For the n channel MOS transistor shown in figure (1), the threshold voltage V_T is 0.8 V. Neglect the channel length modulation effects $\boldsymbol{\lambda}$. When the drain voltage V_D =1.6 V, the drain current I_D =0.5 mA. If V_D is adjusted to be 2.0 V by changing the value of R and V_{DD} , what is the value of drain current I_D in mA?

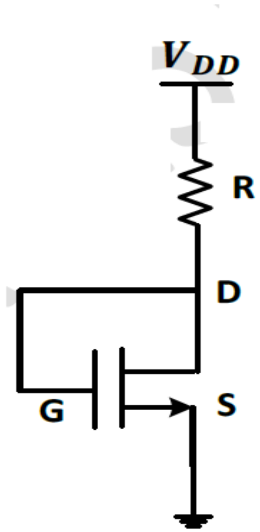


Figure (1) NMOS

Solution:-

Given:-

V_T = 0.8 V , V_{D1} =1.6 V, V_{D2} =2.0 V, I_{DS1} =0.5 mA, $\boldsymbol{\lambda}$=0

For given figure we notice that gate connected to drain to gate so

V_{GS}= V_{DS}= V_D

In saturation I_D is given by:-

I_{DS} = $\frac{1}{2} M_n C_{OX} \frac{W_n}{L_n} (V_{GS2} - V_T)^2 (1 + \boldsymbol{\lambda} V_{DS})$

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

$$\frac{I_{Ds2}}{I_{Ds1}} = \frac{K(V_{GS2} - V_T)^2}{K(V_{GS1} - V_T)^2}$$

$$\frac{I_{Ds2}}{I_{Ds1}} = \frac{(2.0-0.8)^2}{(1.6-0.8)^2}=2.25$$

I_{Ds2}=2.25× 0.5 =1.125 mA

Q2)An enhancement N-type transistor V_T = $0.7\,V$ has its source terminal grounded and 1.5 V applied to the gate. In what region does the device operate for:-

a- V_D = $0.5V$, b- V_D = $1.5V$ c- V_D = $3.0V$?

Solution:-

V_T = $0.7\ V$ V_s = $0.0V$, V_G = $1.5V$

a- V_D = $0.5V$, V_{Ds} = $0.5V$, V_{GS} = $1.5V$

V_{GS} - V_T = $1.5V$ - $0.7V$ = $0.8V$, V_{Ds} = $0.5V$,

$V_{Ds} < V_{GS}$ - V_T (Ohmic Region) b- V_D = $1.5V$, V_{Ds} = $1.5V$, V_{GS} = $1.5V$

V_{GS} - V_T = $1.5V$ - $0.7V$ = $0.8V$, V_{Ds} = $1.5V$

$V_{Ds} > V_{GS}$ - V_T (Saturation Region)

c- V_D = $3.0V$, V_{Ds} = $3.0V$, V_{GS} = $1.5V$

V_{GS} - V_T = $1.5V$ - $0.7V$ = $0.8V$, V_{Ds} = $3.0V$

$V_{Ds} > V_{GS}$ - V_T (Saturation Region)

Q3)When gate to source voltage (V_{GS}) of a MOSFET with threshold voltage (V_T)of = $400. mV$, working in the saturation is $900. mV$, the drain current is observed to be $1.0\ mA$ .Neglecting the channel width modulation effect an assuming that the MOSFET is operating at saturation, What is the value of the drain current for an applied V_{GS} of $1400. mV$?

Solution:-

V_T = $400.mV \rightarrow V_T$ = 0.4 V

Voltage applied at gate V_{GS} = $900.mV$ = 0.9 V

I_{DS} =1 mA

Find the drain current for

V_{GS} = $1400.mV$

MOSFET is operating in saturation

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

$1 \times 10^{-3} = K(0.9 - 0.4)^2$

$K = \frac{1 \times 10^{-3}}{(0.5)^2} = 4 \times 10^{-3} \frac{A}{V^2}$

For $V_{GS} = 1.4\ V$

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

$I_{DS} = 4 \times 10^{-3} \times (1.4 - 0.4)^2 = 4\ mA$

Q4) In CMOS inverter shown if transconductance parameters of NMOS and PMOS transistor are:-

K_n=K_p= $M_n C_{OX} \frac{W_n}{L_n}$= $M_p C_{OX} \frac{W_p}{L_n}$ = $40\ MA/V^2$

And threshold voltage V_T = $1.0\ V$ what is the value of current I ?

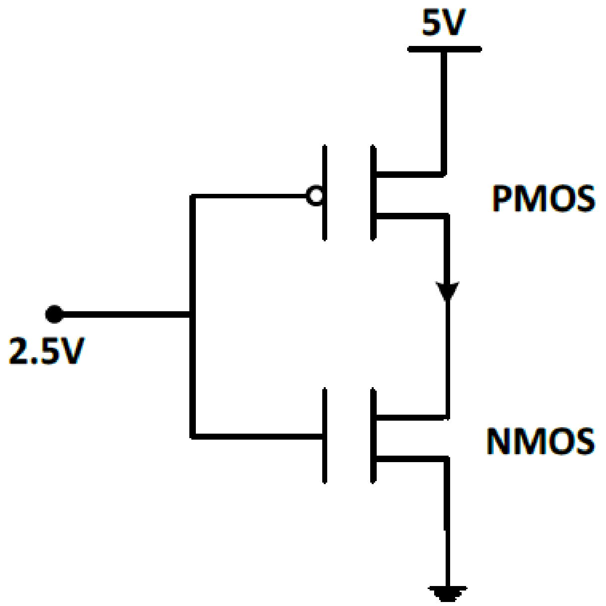


Figure (2)
CMOS

Solution:-

K_n=K_p= $40\ MA/V^2$

V_T = $1.0\ V$

The device in saturation. So the current is given by:-

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

I_{DS}=$\frac{40}{2}(2.5 - 1)^2$=$45\ MA$

Q5)In the circuit shown in figure(3) both enhancement mode NMOS transistor have the following characteristics :- $K_n = M_n C_{OX} \frac{W_n}{L_n} = 1\, mA/V^2$, $V_T = 1.0\ V$. Assume that the channel length modulation parameter $\boldsymbol{\lambda}$ is zero and the body is shorted to source. What is the minimum supply voltage V_{DD} (in volts) needed to ensure that transistor M_1 operates in saturation mode of operation?

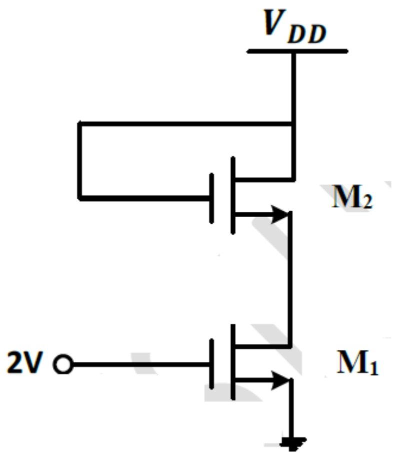


Figure (3)
NMOS

Solution:-

In the given circuit M_1 operates in saturation. Both MOSFET are NMOS

K_n= $M_n C_{OX} \frac{W_n}{L_n}$= $1\ mA\ /V^2$

V_T = 1.0 V

Both MOSFETs are in series so the same current will flow through them.

For M_1 V_{GS1} = 2 V

If M_1 is assumed in saturation, then

I_{D1}= $\frac{1}{2} K_n (V_{GS1} - V_T)^2$

Minimum V_{DS1} required for M_1 to operate in saturation

V_{DS1}= $V_{GS1} - V_T$= $2 - 1 = 1V$

For M_2

$V_{DD} = V_{GS2} + V_{DS1} \rightarrow V_{GS2}$ = $V_{DD} - 1$

I_{D2}= $\frac{1}{2} K_n (V_{GS2} - V_T)^2$

I_{D1}= I_{D2}

$\frac{1}{2} K_n (V_{GS1} - V_T)^2$ = $\frac{1}{2} K_n (V_{GS2} - V_T)^2$

$V_{GS1} - V_T = V_{GS2} - V_T$

$V_{GS1} = V_{GS2}$

$2 = V_{DD} - 1$
$V_{DD} = 3\text{V}$

Q6) The current in enhancement mode NMOS transistor biased in saturation mode was measured to be $1\ mA$ at drain source voltage $5\ \mathrm{V}$. When the drain source voltage was increased to $6\ \mathrm{V}$ while keeping gate source voltage same. The drain current increased to $1.02\ \mathrm{mA}$. What is the value of the channel length modulation parameter?

Solution:-

N MOS transistor

Biased in saturation I_D , V_{DS}= 5 V

Drain current in saturation including the effect of channel length modulation parameter $\boldsymbol{\lambda}$

$$I_D = \frac{1}{2} M_n C_{OX} \frac{W_n}{L_n} (V_{GS2} - V_T)^2 (1 + \boldsymbol{\lambda} V_{DS})$$

So, we can write the ratio of two current

$$\frac{I_{D2}}{I_{D1}} = \frac{1 + \boldsymbol{\lambda} V_{DS2}}{1 + \boldsymbol{\lambda} V_{DS1}}$$

$$\frac{1.02}{1} = \frac{1+6\boldsymbol{\lambda}}{1+5\boldsymbol{\lambda}}$$

1.02 +5.1 $\boldsymbol{\lambda}$= 1. +6. $\boldsymbol{\lambda}$

0.02 =0.9 $\boldsymbol{\lambda}$

$\boldsymbol{\lambda}=\frac{0.02}{0.9}=0.022\ V^{-1}$

Q7) Consider an n-channel MOSFET with gate source voltage (V_{GS}= 1.8 V). Assume that $\frac{W_n}{L_n}$= 4 , $M_n C_{OX}$=$70 \times 10^{-6}\ AV^{-2}$

The threshold voltage is 0.3 V, and the channel length modulation parameter is $0.09\,V^{-1}$. In saturation region what is the value of the drain conduction ($\frac{\partial I_D}{\partial V_{DS}}$)(in micro Siemens)

Solution:-

Given:-

N MOSFET

V_{GS}= 1.8 V, $\frac{W_n}{L_n}$= 4 , $M_n C_{OX}$=70 $\times 10^{-6}$ AV^{-2} ,V_{TN}=0.3 V, $\boldsymbol{\lambda}$= 0.09 V^{-1}

$I_D = \frac{1}{2} M_n C_{OX} \frac{W_n}{L_n} (V_{GS} - V_T)^2 (1 + \boldsymbol{\lambda} V_{DS})$

$g_d = \frac{\partial I_D}{\partial V_{DS}} = \frac{1}{2} M_n C_{OX} \frac{W_n}{L_n} (V_{GS} - V_T)^2 \boldsymbol{\lambda}$

$g_d = \frac{1}{2} \times 70 \times 10^{-6} \times 4 \times (1.8 - 0.3)^2 \times 0.09$

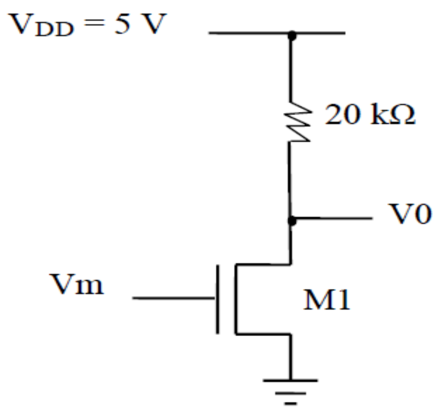
$$g_d = 28.35 \times 10^{-6}$$

$$g_d = 28.35\ \mu\ siemens$$

Q8)For M_1 MOSFET transistor shown in figure (4), K_n= $25\ \mu A/V^2$, V_T = $1.0\ V$, $\boldsymbol{\lambda}$=0,when V_m= $5.0\ V$, V_o= $1.0\ V$. Determine:-

a- Transistor mode of operation.

b- Transistor $\frac{W}{L}$ ratio



V_{DD} = 5 V
20 kΩ
V0
Vm
M1

Solution:-

Given

K_n= 25 $\mu A/V^2$, V_T = 1.0 V, $\boldsymbol{\lambda}$=0,when V_m= 5.0 V, V_o= 1.0 V

V_{DS}= V_o= 1.0 V

V_{GS}= V_m= 5.0 V

$V_{GS} - V_T$=5.0 – 1.0 = 4.0 V , V_{DS}= 1.0 V

$V_{DS} < V_{GS} - V_T \rightarrow$ Ohmic mode

In Ohmic mode the current

$$I_{DS} = \frac{V_{DD} - V_o}{R}$$

$$I_{DS} = \frac{5-1}{20} = 0.2\, mA$$

$$I_{DS} = K_N \frac{W}{L}\left(V_{GS} - V_T - \frac{V_{DS}}{2}\right) V_{DS}$$

$$200 \mu A = 25\, \mu A/V^2 \times \frac{W}{L} \times \left(5 - 1 - \frac{1}{2}\right) V \times 1\, V$$

$$\frac{W}{L} = 2$$