ECSE-2210 Microelectronics Technology
Class Activity 29 – Solution

1. An n-channel MOS transistor has a threshold voltage of 2 V and the following parameters:
   $\varepsilon_{Si} \approx 3 \times \varepsilon_{ox} = 1 \times 10^{-12}$ F/cm; $\mu_n = 1000$ cm^2/Vs; $x_{ox} = 500$ Å; $Z = 15$ μm; $L = 1$ μm.
   For a gate voltage $V_G = 4$ V calculate the following:

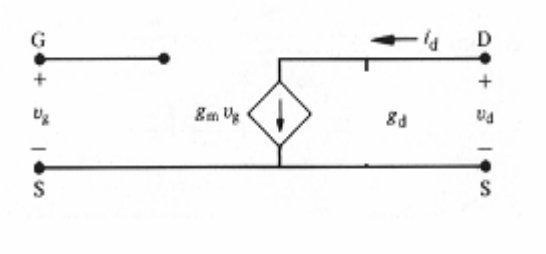
   a. The resistance between the drain and source in the linear region of operation for small values of V_D (i.e., $V_D = 0$).
   $C_{ox} = \varepsilon_{ox} / x_{ox} = 6.67 \times 10^{-8}$ F/cm^2
   $g_D = (Z \mu C_{ox}/L) \times (V_G - V_T - V_D)$
   $= 15 \times 10^{-4} \times 1000 \times 6.67 \times 10^{-8} \times (4 - 2) / 10^{-4} = 2 \times 10^{-3}\ \Omega^{-1}$
   ➔ The resistance is 500 Ω

   b. The drain to source current when the device is in saturation.
   $I_{Dsat} = Z \mu C_{ox} / 2L (V_G - V_T) = 2$ mA

   c. The drain voltage that should be applied for the device to be in saturation.
   The drain voltage for saturation is 2 V.
   $V_{Dsat} = V_G - V_T = 4$ V $- 2$ V $= 2$ V

   d. Transconductance and drain-to-source conductance under saturation.
   $g_m = Z \mu C_{ox} / L (V_G - V_T) = 2 \times 10^{-3}$ A / V
   $g_d = 0$

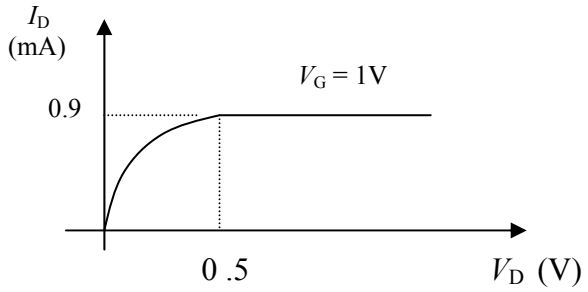
   e. Draw the equivalent circuit under saturation.



   Under saturation the drain conductance is zero, hence draw the circuit without g_d.

   f. Calculate the cut-off frequency.
   $f_t = g_m / (2\pi C_{gs}) = 31.8$ GHz. (C_{gs} here is the gate-to-source capacitance).

2. The figure below shows the drain current (I_D) versus drain voltage (V_D) of a silicon MOS transistor as a function of gate voltage (V_G). The gate capacitance (C_{ox}) of the device is 1×10^{-12} F.



a. Is this an **n-channel** or p-channel device?
$V_{Dsat} = V_G - V_T$
0.5 V = 1 V – V_T
So, V_T = 0.5 V as the threshold voltage is positive, we have an n-channel MOSFET

b. Is this an enhancement or depletion mode device?
This is enhancement mode because at 0V there is no channel. We need to apply a positive voltage of 0.5 V for the channel to appear.

For a gate voltage, V_G = 3 V:

c. What is the drain voltage for saturation?
V_{Dsat} = 3 V – 0.5 V = 2.5 V

d. What is the drain current in saturation?
$I_{Dsat} = [\, Z\, \mu\, C_{ox} / (2L)\,] (V_G - V_T)^2$
When V_G = 1 V, I_{Dsat} = 0.9 mA; for V_G = 3 V, I_{Dsat} = 22.5 mA.

e. What is the small-signal trans-conductance in saturation?
Transconductance g_m = 0.72 mA/V

***Note*:**
Enhancement mode device is OFF when $V_G = 0$
Depletion mode device is ON when $V_G = 0$

For an NMOS: If V_T is positive, enhancement mode
If V_T is negative, depletion mode

For a PMOS: If V_T is positive, depletion mode
If V_T is negative, enhancement mode