American University of Beirut
Department of Electrical and Computer Engineering

EECE 310 – Electronics Fall 2007 – 2008

Homework 6

Problem 1.

a) The mobility of electrons in the channel of an NMOS device is 1100 $cm^2/V.sec$. Find the transconductance parameter k'_n for this MOSFET if its oxide thickness is 40 nm. The doping level in the channel is $N_A = 10^{16}$ cm^{-3}. The relative permittivity of the oxide (SiO_2) is 3.9, and that of Silicon is 11.7.

b) The threshold voltage V_{t0} for this NMOS transistor is 0.8 V. Find the required dimensions of the gate of the NMOS transistor (W and L) to get a drain current of 0.1 mA when the MOSFET is biased at (V_{GS} = 2.5 V, V_{DS} = 2.5 V, V_{BS} = 2 V). The minimum dimension is 0.25 μm.

c) The drain current of the NMOS transistor is I_{D1} at (V_{GS} = 2.5 V, V_{DS} = 2.5 V). When V_{DS} becomes 2 V, the current decreases by 10% to 0.9 I_{D1}. Find the channel length modulation parameter λ of this transistor.

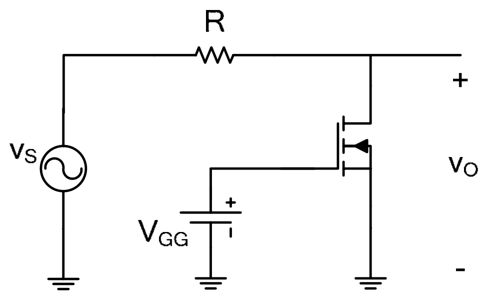
Problem 2.

The circuit shown below is a voltage-controlled attenuator. Assume V_{GG} = 2.5 V, R = 3.3 KΩ, and for the MOSFET: V_t = 0.8 V, $k'(W/L)$ = 0.12 mA/V^2.

a) For what range of output voltages does the MOSFET behave as a (voltage-controlled) resistor? Assume that the square term is negligible when it is less than 5% of the linear term in the MOSFET current equation.

b) Find the value of V_{OV} for the MOSFET and the value of its resistance r_{DS} when v_O satisfies the condition of part (a).

c) Plot the attenuation factor (v_o/v_s) as a function of V_{GG}.



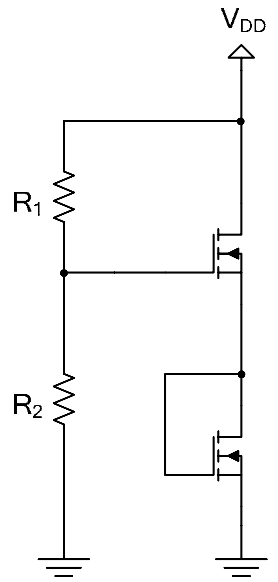
Problem 3.

Two identical enhancement MOSFETs with $k'_n(W/L)$ = 200 μA/V^2, V_t = 0.75 V, and λ = 0.12 V^{-1} are connected as shown below. The MOSFET drain current is 0.25 mA. Assume that V_{DD} = 5 V.

a) Find the value of V_{GS} for the lower MOSFET. In what region is this MOSFET operating?

b) Find the voltage at the gate of the upper MOSFET. In what region is this MOSFET operating?

c) Find the resistance R_1 when R_2 = 820 KΩ.



a) $K_n' = \mu_n C_{ox} = \mu_n \frac{\varepsilon_{ox}}{t_{ox}} = 1100 \times 10^{-4} \cdot \frac{3.9 \times 8.85 \times 10^{-12}}{40 \times 10^{-9}} = 94.9 \mu A/V^2$

b) $V_t = V_{to} + \gamma\left(\sqrt{2\phi_F + |V_{BS}|} - \sqrt{2\phi_F}\right)$

$\gamma = \frac{\sqrt{2q\varepsilon_s N_A}}{C_{ox}} = \frac{\sqrt{2 \times 1.6 \times 10^{-19} \times 11.7 \times 8.85 \times 10^{-12} \times 10^{16} \times 10^{6}}}{\frac{3.9 \times 8.85 \times 10^{-12}}{40 \times 10^{-9}}} = 0.667\ V^{1/2}$

$V_t = 0.8 + 0.667\left(\sqrt{0.6 + 2} - \sqrt{0.6}\right) = 1.36V$

- $V_{GS} = 2.5 > V_t \Rightarrow$ MOSFET is ON.
- $V_{GS} - V_t = 1.14$; $V_{DS} > V_{GS} - V_t \Rightarrow$ MOSFET is in saturation.
- $I_D = \frac{1}{2}\mu_n C_{ox} \frac{W}{L}(V_{GS} - V_t)^2 (1 + \lambda V_{DS}) = \frac{1}{2} K_n' \frac{W}{L}(V_{GS} - V_t)^2$

$\frac{W}{L} = \frac{2 I_D}{K_n' (V_{GS} - V_t)^2} = \frac{2 \times 0.1 \times 10^{-3}}{94.9 \times 10^{-6} (1.14)^2} = 1.62$

$W > L$ and minimum dimension is $0.25 \mu m$

so $L_{min} = 0.25 \mu m$ with $\frac{W}{L} = 1.62$.

$W_{min} = 0.405 \mu m$

c) $V_{DS2} = 2V > V_{GS} - V_t \Rightarrow$ the MOSFET is still in saturation.

$I_{D1} = \frac{1}{2} K_n' \frac{W}{L}(V_{GS} - V_t)^2 (1 + \lambda V_{DS1})$

$I_{D2} = \frac{1}{2} K_n' \frac{W}{L}(V_{GS} - V_t)^2 (1 + \lambda V_{DS2})$

$\frac{I_{D2}}{I_{D1}} = \frac{0.9 I_{D1}}{I_{D1}} = \frac{\frac{1}{2} K_n' \frac{W}{L}(V_{GS} - V_t)^2 (1 + \lambda V_{DS2})}{\frac{1}{2} K_n' \frac{W}{L}(V_{GS} - V_t)^2 (1 + \lambda V_{DS1})} = \frac{1 + 2\lambda}{1 + 2.5\lambda} = 0.9$

$\Rightarrow 1 + 2\lambda = 0.9 + 2.25\lambda \Rightarrow 0.25\lambda = 0.1 \Rightarrow \lambda = 0.4 V^{-1}$

$\lambda = 0.4 V^{-1}$

II

a) $V_{DS} = V_O$; $V_{GS} = V_{GG} = 2.5$

For MOSFET to act as a voltage controlled resistor, It must be in the linear region and for small values of V_{DS}

$\therefore V_{DS} < V_{GS} - V_t \Rightarrow V_{DS} < 2.5 - 0.8 \Rightarrow V_{DS} < 1.7V$

$I_D = \frac{1}{2} k_n' \frac{W}{L} \left(2(V_{GS} - V_t)V_{DS} - V_{DS}^2\right)$

If V_{DS} is small enough $\Rightarrow$ we can neglect V_{DS}^2 and $I_D = k_n' \frac{W}{L}(V_{GS} - V_t)V_{DS}$

squar term < 5% linear term.

$V_{DS}^2 < 0.05 \times 2(V_{GS} - V_t)V_{DS}$

$\Rightarrow V_{DS}^2 < 0.17 V_{DS} \Rightarrow V_{DS}(V_{DS} - 0.17) < 0.$

$\Rightarrow 0 < V_{DS} < 0.17 < 1.7V.$

$\therefore$ Range of V_o for the MOSFET to act as a resistor:

$0 < V_o < 0.17V$

b) $V_{OV} = V_{GS} - V_t = 1.7V$

$r_{DS} = \frac{V_{DS}}{I_D} = \frac{1}{k_n' \frac{W}{L} V_{OV}} = \frac{1}{0.204m} = 4.9\ K\Omega$

c). For $V_{GG} < V_t \Rightarrow V_{GG} < 0.8 \Rightarrow$ Mosfet is off

$\Rightarrow V_o = V_s \Rightarrow \frac{V_o}{V_s} = 1$

Note: In the saturation region, I_D becomes independent of $V_{DS} \Rightarrow V_s = RI_D + V_o$

$\Rightarrow \frac{V_o}{V_s}$ will be a function of V_s.

In the linear region where $V_{DS}^2 < 0.05 \times 2(V_{GS} - V_t)V_{DS}$

$\Rightarrow$ for: $0 < V_o < 0.1(V_{GG} - 0.8)$ The Mosfet acts as a resistor.

with $r_{DS} = \frac{1}{K_n \frac{W}{L} V_{OV}} = \frac{25K}{3(V_{GG} - 0.8)}$

By voltage division: $V_o = \frac{r_{DS}}{r_{DS}+R} V_s$

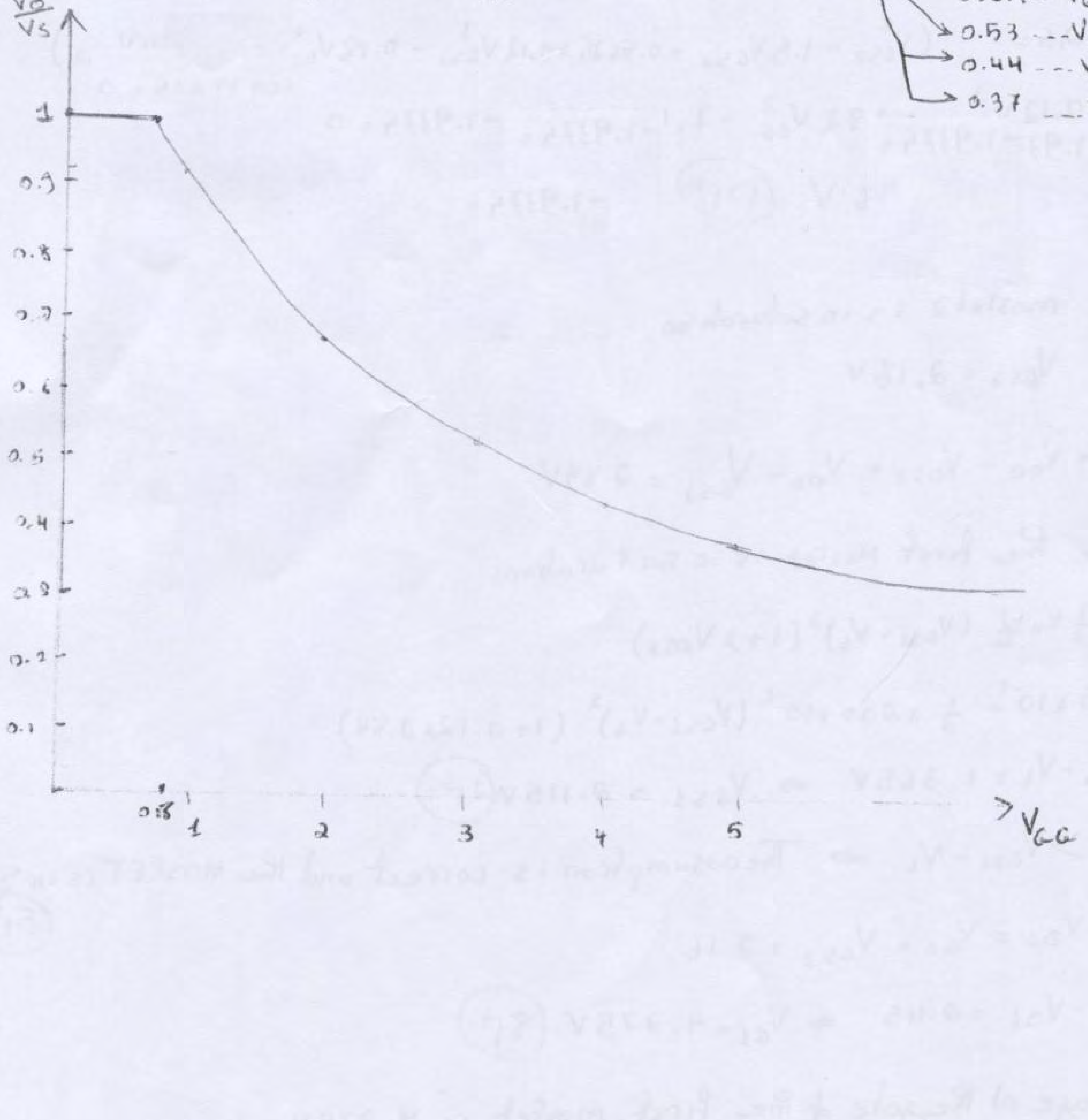
$\Rightarrow$ Attenuation factor $\frac{V_o}{V_s} = \frac{r_{DS}}{r_{DS}+R} = \frac{\frac{25}{3(V_{GG}-0.8)}}{\frac{25}{3(V_{GG}-0.8)}+3.3} = \frac{1}{1+\frac{9.9}{25}(V_{GG}-0.8)}$

$$\frac{V_o}{V_s} = \frac{1}{0.6832+0.396V_{GG}}$$

As long as $V_{GG} > 0.8$ and $0 < V_o < 0.1(V_{GG}-0.8)$

$$\frac{V_o}{V_s} = \frac{25}{17.08+9.9V_{GG}}$$

$\frac{V_o}{V_s}$:
- 1 — $V_{GG} = 0.8$
- 0.926 — $V_{GG} = 1$
- 0.677 — $V_{GG} = 2$
- 0.53 — $V_{GG} = 3$
- 0.44 — $V_{GG} = 4$
- 0.37 — $V_{GG} = 5$



III

a) $V_{DD} = V_{DS1} + V_{DS2}$; $I_{D1} = I_{D2} =$ mA since $I_G = 0$

$V_{D2} = V_{S1} = V_{G2}$

$\Rightarrow V_{DS2} = V_{GS2}$

$\Rightarrow V_{DS2} > V_{GS2} - V_t \Rightarrow$ Mosfet 2 is in saturation

$\Rightarrow I_{D2} = \frac{1}{2} K_n' \frac{W}{L} (V_{GS2} - V_t)^2 (1 + \lambda V_{DS2})$

$\Rightarrow 0.25 \times 10^{-3} = \frac{1}{2} \times 200 \times 10^{-6} (V_{GS2} - 0.75)^2 (1 + 0.12 V_{GS2})$

$\Rightarrow 2.5 = (V_{GS2}^2 - 1.5 V_{GS2} + 0.5625)(1 + 0.12 V_{GS2})$

$\Rightarrow 2.5 = (V_{GS2}^2 - 1.5 V_{GS2} + 0.5625 + 0.12 V_{GS2}^3 - 0.18 V_{GS}^2 + 0.0675 V_{GS2})$

$\Rightarrow 0.12 V_{GS2}^3 + 0.82 V_{GS}^2 - 1.4325 V_{GS} - 1.9375 = 0$

$\Rightarrow V_{GS2} = 2.16 V.$

∴ mosfet 2 is in saturation

$V_{GS2} = 2.16 V$

b) $V_{DS1} = V_{DD} - V_{DS2} = V_{DD} - V_{GS2} = 2.84 V$

Assume the first Mosfet is in saturation:

$\Rightarrow I_D = \frac{1}{2} K_n' \frac{W}{L} (V_{GS1} - V_t)^2 (1 + \lambda V_{DS1})$

$\Rightarrow 0.25 \times 10^{-3} = \frac{1}{2} \times 200 \times 10^{-6} (V_{GS1} - V_t)^2 (1 + 0.12 \times 2.84)$

$\Rightarrow V_{GS1} - V_t = 1.365 V \Rightarrow V_{GS1} = 2.115 V$

$V_{DS1} > V_{GS1} - V_t \Rightarrow$ The assumption is correct and the MOSFET is in Saturation

$V_{S1} = V_{D2} = V_{G2} = V_{GS2} = 2.16.$

$\Rightarrow V_{G1} - V_{S1} = 2.115 \Rightarrow V_{G1} = 4.275 V$

$\Rightarrow$ Voltage at the gate of the first mosfet is 4.275 V and it is in saturation

c) $V_{G2} = \frac{R_2}{R_1+R_2} V_{DD} = \frac{820}{R_1+820} \times 5$

$\Rightarrow R_1 + 820 = \frac{820 \times 5}{V_{G2}} \Rightarrow R_1 = 139\,K\Omega$