EE4C10 Analog Circuit Design Fundamentals

Homework Assignment I

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Problem 1

For $I_D = 40\mu A$:

$$\begin{aligned} I_D &= \frac{1.8V - V_D}{R} \\ V_D &= 1.8V - I_D R \\ \underline{V_D} &= 1.0V \end{aligned}$$

Saturation region:

$$\begin{aligned} V_{GS} = 1.0V &> V_{TH} \\ V_{GS} - V_{TH} = 0.4V &< V_{DS} \end{aligned}$$

1. $\lambda = 0V^{-1}$

$$\begin{aligned} I_D &= \frac{\mu_n C_{OX}}{2} \frac{W}{L} (V_{GS} - V_{TH})^2 \\ L &= \frac{\mu_n C_{OX}}{2} \frac{W}{I_D} (V_{GS} - V_{TH})^2 \\ \underline{L} &= 0.39\mu m \end{aligned}$$

2. $\lambda = 0.06V^{-1}$

$$\begin{aligned} I_D &= \frac{\mu_n C_{OX}}{2} \frac{W}{L} (V_{GS} - V_{TH})^2 (1 + \lambda V_{DS}) \\ L &= \frac{\mu_n C_{OX}}{2} \frac{W}{I_D} (V_{GS} - V_{TH})^2 (1 + \lambda V_{DS}) \\ \underline{L} &= 0.41\mu m \end{aligned}$$

Problem 2

1. Bulk of the transistors are connected to the source, $V_B = V_S$

$$\begin{aligned} V_{TH} &= V_{TH0} + \gamma(\sqrt{2\varphi_F + V_{BS}} - \sqrt{|2\varphi_F|}) \\ V_{TH} &= V_{TH0} = 0.33V \end{aligned}$$

(a) Transistor M_1

$$V_{SG} = 2.5V - 1.7V = 0.8V$$

$$\begin{aligned} I_D &= \frac{\mu_p C_{OX}}{2}\frac{W}{L}(V_{SG} - V_{TH})^2 \\ W &= \frac{2LI_D}{\mu_p C_{OX}}\frac{1}{(V_{SG} - V_{TH})^2} \\ W_1 &= 2.72\mu m \end{aligned}$$

(b) Transistor M_2

$$V_{SG} = 1.7V - 1V = 0.7V$$

$$\begin{aligned} W &= \frac{2LI_D}{\mu_p C_{OX}}\frac{1}{(V_{SG} - V_{TH})^2} \\ W_2 &= 4.38\mu m \end{aligned}$$

(c) Transistor M_3

$$V_{SG} = 1V$$

$$\begin{aligned} W &= \frac{2LI_D}{\mu_p C_{OX}}\frac{1}{(V_{SG} - V_{TH})^2} \\ W_3 &= 1.37\mu m \end{aligned}$$

2. Bulk terminals are attached to the V_{DD}, $V_B = V_{DD}$.

(a) Transistor M_1

$$V_{BS} = 2.5V - 2.5V = 0V$$

$$\begin{aligned} V_{TH} &= V_{TH0} + \gamma(\sqrt{2\varphi_F + V_{BS}} - \sqrt{|2\varphi_F|}) \\ V_{TH} &= V_{TH0} = 0.33V \end{aligned}$$

$$\begin{aligned} W &= \frac{2LI_D}{\mu_p C_{OX}}\frac{1}{(V_{SG} - V_{TH})^2} \\ W_1 &= 2.72\mu m \end{aligned}$$

(b) Transistor M_2

$$V_{BS} = 2.5V - 1.7V = 0.8V$$

$$\begin{aligned} V_{TH} &= V_{TH0} + \gamma(\sqrt{2\varphi_F + V_{BS}} - \sqrt{|2\varphi_F|}) \\ V_{TH} &= V_{TH0} = 0.43V \end{aligned}$$

$$\begin{aligned} W &= \frac{2LI_D}{\mu_p C_{OX}}\frac{1}{(V_{SG} - V_{TH})^2} \\ W_2 &= 8.23\mu m \end{aligned}$$

(c) Transistor M_3

$$V_{BS} = 2.5V - 1.0V = 1.5V$$

$$\begin{aligned} V_{TH} &= V_{TH0} + \gamma(\sqrt{2\varphi_F + V_{BS}} - \sqrt{|2\varphi_F|}) \\ V_{TH} &= V_{TH0} = 0.49V \end{aligned}$$

$$\begin{aligned} W &= \frac{2LI_D}{\mu_p C_{OX}}\frac{1}{(V_{SG} - V_{TH})^2} \\ W_3 &= 2.31\mu m \end{aligned}$$

Problem 3

1. Testbench and I_D-V_{GS} characteristics of NMOS and PMOS
   (a) NMOS
      i. Testbench

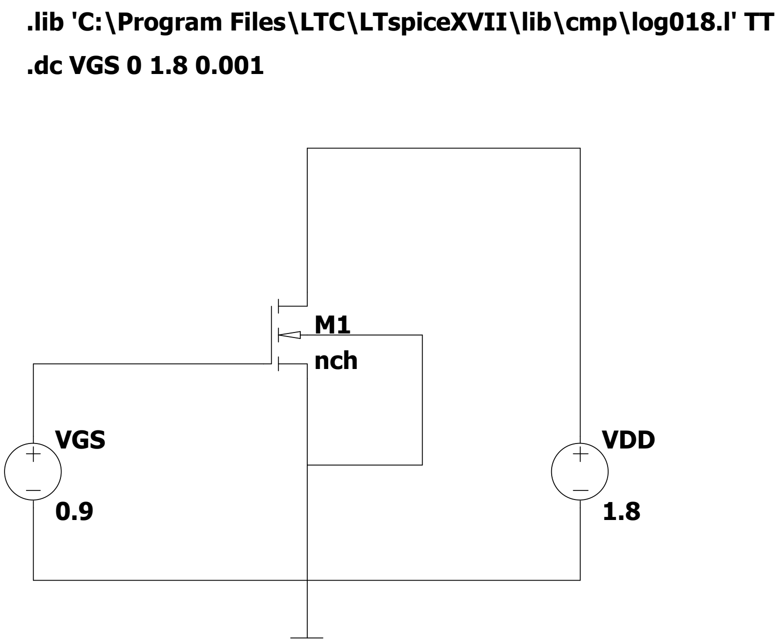

Figure 1: NMOS Testbench

      ii. I_D-V_{GS}

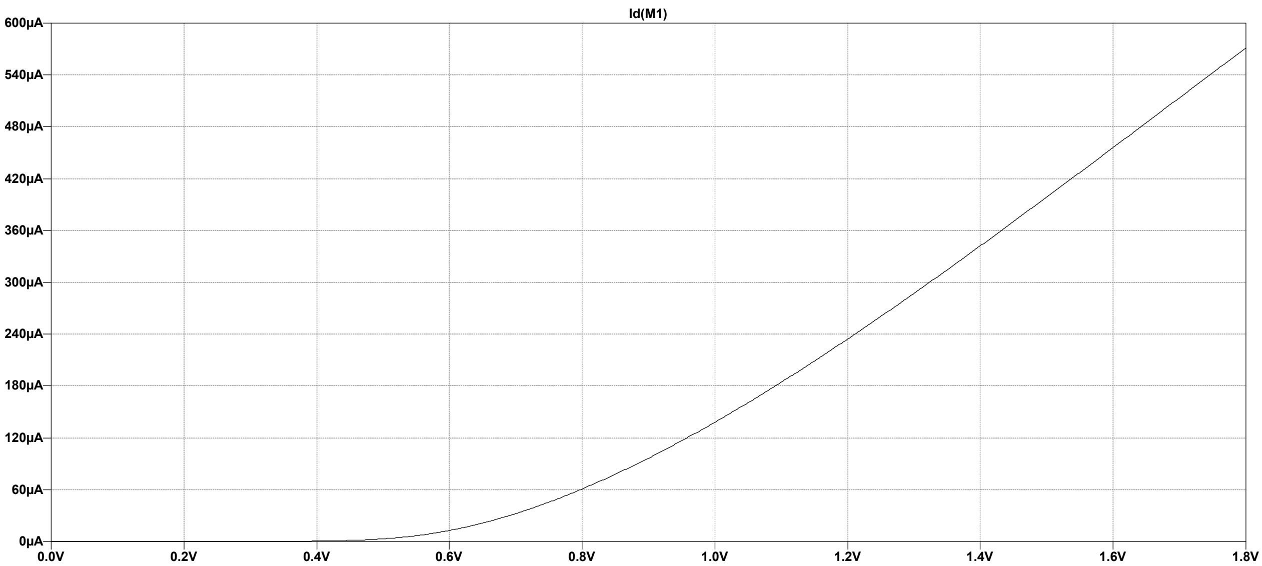

Figure 2: NMOS I_D-V_{GS}

   (b) PMOS
      i. Testbench
      ii. I_D-V_{GS}

2. $\mu_{n(p)}C_{OX}$ and $V_{THn(p)}$

Assuming that channel length modulation is negligible, V_{THn} for NMOS can be derived from the following relation:

$$\begin{aligned} I_D &= \frac{\mu_n C_{ox}}{2}\frac{W}{L}(V_{GS}-V_{THn})^2 \\ \frac{2I_D}{\mu_n C_{ox}}\frac{L}{W} &= (V_{GS}-V_{THn})^2 \\ \sqrt{\frac{2I_D}{\mu_n C_{ox}}\frac{L}{W}} &= V_{GS}-V_{THn} \end{aligned} \tag{1}$$

V_{THn} is the x-axis intercept when the saturation region is extrapolated. In the case of PMOS, the relation becomes:

$$\sqrt{\frac{2I_S}{\mu_p C_{ox}}\frac{L}{W}} = V_{SG}-V_{THp} \tag{2}$$

For deriving $\mu_n C_{OX}$, since $V_{THn(p)}$ is constant at specific temperatures. Differentiating both sides with respect to $V_{GS(SG)}$ will give:

$$\begin{aligned} \frac{d}{dV_{GS}}\sqrt{\frac{2I_D}{\mu_n C_{ox}}\frac{L}{W}} &= \frac{d}{dV_{GS}}(V_{GS}-V_{THn}) \\ \frac{1}{2}\frac{dI_D}{dV_{GS}}\sqrt{\frac{2}{I_D\mu_n C_{ox}}\frac{L}{W}} &= 1 \\ \sqrt{\mu_n C_{ox}} &= \frac{1}{2}\frac{dI_D}{dV_{GS}}\sqrt{\frac{2}{I_D}\frac{L}{W}} \\ \mu_n C_{ox} &= \frac{1}{2}\frac{L}{W}\frac{1}{I_D}(\frac{dI_D}{dV_{GS}})^2 \\ \mu_n C_{ox} &= \frac{1}{6I_D}(\frac{dI_D}{dV_{GS}})^2 \end{aligned}$$

In the case for PMOS, the relation becomes:

$$\mu_p C_{ox} = \frac{1}{6I_S}(\frac{dI_S}{dV_{SG}})^2$$

(a) NMOS

i. $\mu_n C_{OX} = 306\mu AV^{-2}$

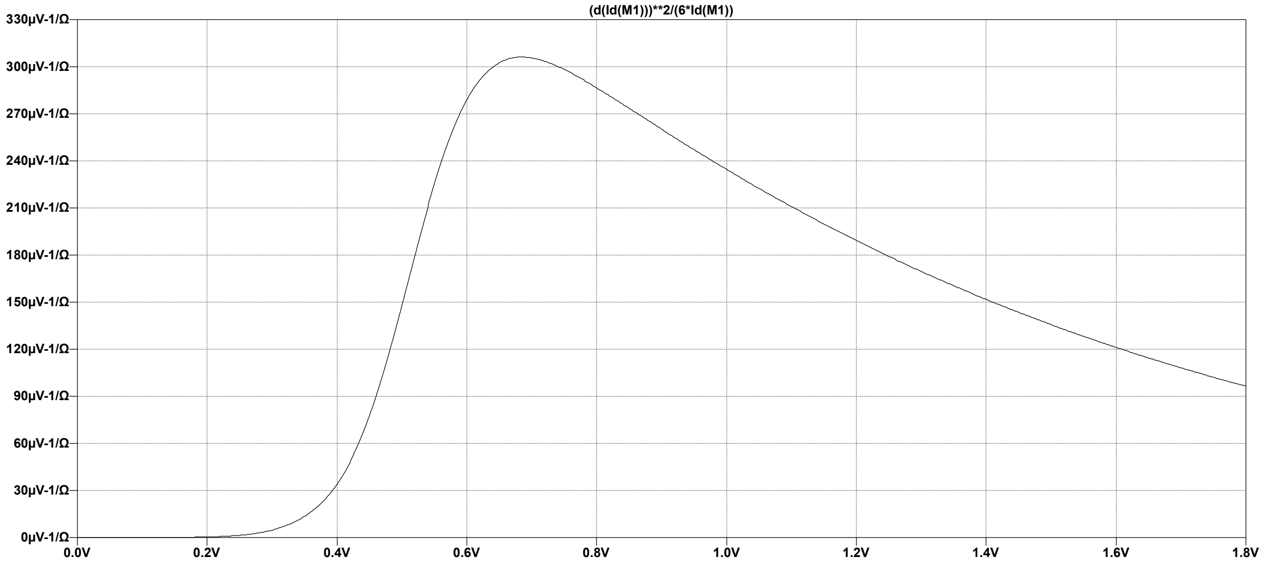

Figure 3: NMOS $\mu_n C_{OX}$-V_{GS}

ii. $V_{THn} = 0.44V$

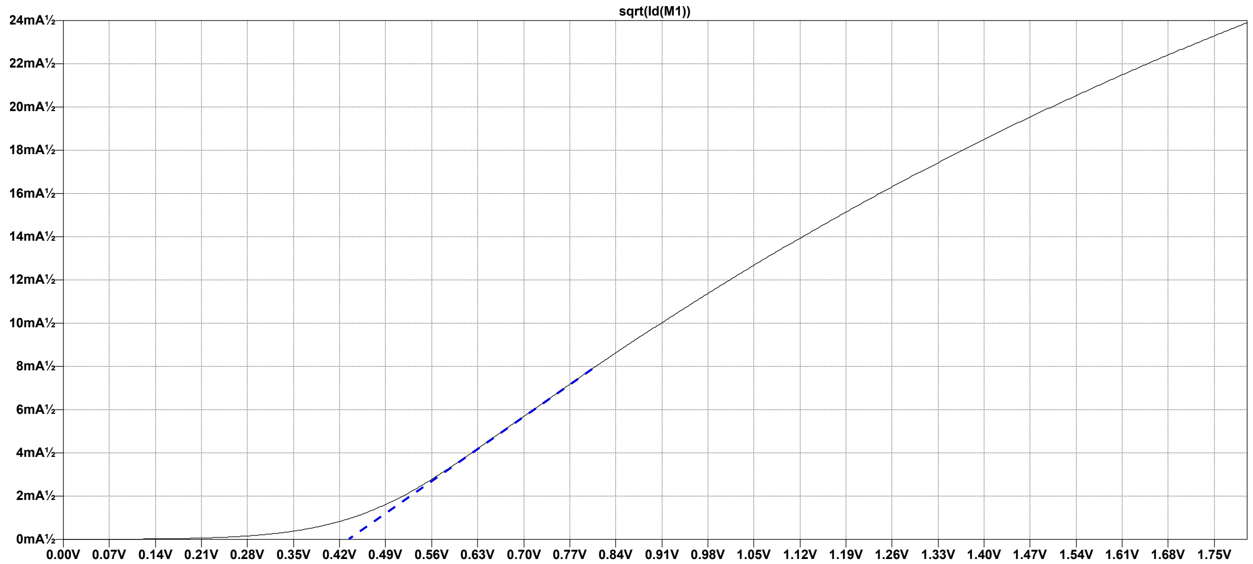

Figure 4: NMOS $\sqrt{I_D} - V_{GS}$

(b) PMOS
  i. $\mu_p C_{OX}$
  ii. V_{THp}

Problem 4

Problem 5

Problem 6

Problem 7