

# EE4C10 Analog Circuit Design Fundamentals

## Homework Assignment I

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## Contents

Problem 1	1
Problem 2	1
Problem 3	3
Problem 4	5
Problem 5	7
Problem 6	7
Problem 7	7

## Problem 1

For  $I_D = 40\mu A$ :

$$I_D = \frac{1.8V - V_D}{R}$$

$$V_D = 1.8V - I_D R$$

$$\underline{V_D} = 1.0V$$

Saturation region:

$$V_{GS} = 1.0V > V_{TH}$$

$$V_{GS} - V_{TH} = 0.4V < V_{DS}$$

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

$$I_D = \frac{\mu_n C_{OX}}{2} \frac{W}{L} (V_{GS} - V_{TH})^2$$

$$L = \frac{\mu_n C_{OX}}{2} \frac{W}{I_D} (V_{GS} - V_{TH})^2$$

$$\underline{L} = 0.39\mu m$$

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

$$I_D = \frac{\mu_n C_{OX}}{2} \frac{W}{L} (V_{GS} - V_{TH})^2 (1 + \lambda V_{DS})$$

$$L = \frac{\mu_n C_{OX}}{2} \frac{W}{I_D} (V_{GS} - V_{TH})^2 (1 + \lambda V_{DS})$$

$$\underline{L} = 0.41\mu m$$

## Problem 2

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

$$V_{TH} = V_{TH0} + \gamma(\sqrt{2\varphi_F + V_{BS}} - \sqrt{|2\varphi_F|})$$

$$V_{TH} = V_{TH0} = 0.33V$$

(a) Transistor M<sub>1</sub>

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

$$I_D = \frac{\mu_p C_{OX}}{2} \frac{W}{L} (V_{SG} - V_{TH})^2$$

$$W = \frac{2LI_D}{\mu_p C_{OX}} \frac{1}{(V_{SG} - V_{TH})^2}$$

$$W_1 = 2.72\mu m$$

(b) Transistor M<sub>2</sub>

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

$$W = \frac{2LI_D}{\mu_p C_{OX}} \frac{1}{(V_{SG} - V_{TH})^2}$$

$$W_2 = 4.38\mu m$$

(c) Transistor M<sub>3</sub>

$$V_{SG} = 1V$$

$$W = \frac{2LI_D}{\mu_p C_{OX}} \frac{1}{(V_{SG} - V_{TH})^2}$$

$$W_3 = 1.37\mu m$$

2. Bulk terminals are attached to the V<sub>DD</sub>, V<sub>B</sub> = V<sub>DD</sub>.

(a) Transistor M<sub>1</sub>

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

$$V_{TH} = V_{TH0} + \gamma(\sqrt{2\varphi_F + V_{BS}} - \sqrt{|2\varphi_F|})$$

$$V_{TH} = V_{TH0} = 0.33V$$

$$W = \frac{2LI_D}{\mu_p C_{OX}} \frac{1}{(V_{SG} - V_{TH})^2}$$

$$W_1 = 2.72\mu m$$

(b) Transistor M<sub>2</sub>

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

$$V_{TH} = V_{TH0} + \gamma(\sqrt{2\varphi_F + V_{BS}} - \sqrt{|2\varphi_F|})$$

$$V_{TH} = V_{TH0} = 0.43V$$

$$W = \frac{2LI_D}{\mu_p C_{OX}} \frac{1}{(V_{SG} - V_{TH})^2}$$

$$W_2 = 8.23\mu m$$

(c) Transistor M<sub>3</sub>

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

$$V_{TH} = V_{TH0} + \gamma(\sqrt{2\varphi_F + V_{BS}} - \sqrt{|2\varphi_F|})$$

$$V_{TH} = V_{TH0} = 0.49V$$

$$W = \frac{2LI_D}{\mu_p C_{OX}} \frac{1}{(V_{SG} - V_{TH})^2}$$

$$W_3 = 2.31\mu m$$

## Problem 3

### 1. Testbench and $I_D$ - $V_{GS}$ characteristics of NMOS and PMOS

#### (a) NMOS

##### i. Testbench

```
.lib 'C:\Program Files\LTC\LTspiceXVII\lib\cmp\log018.l' TT
.dc VGS 0 1.8 0.001
```

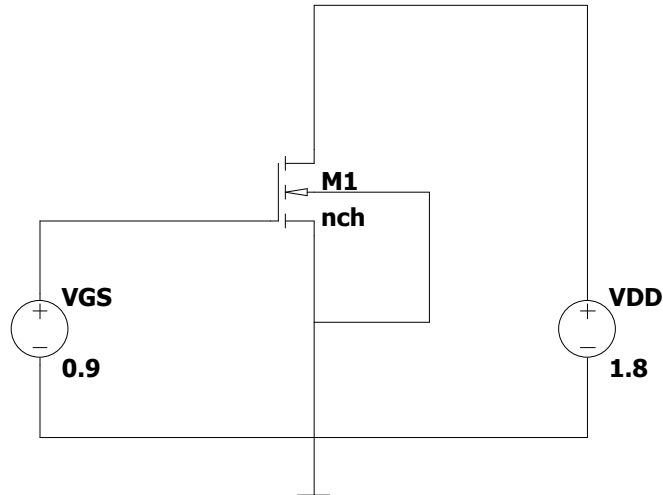


Figure 1: NMOS Testbench

##### ii. $I_D$ - $V_{GS}$

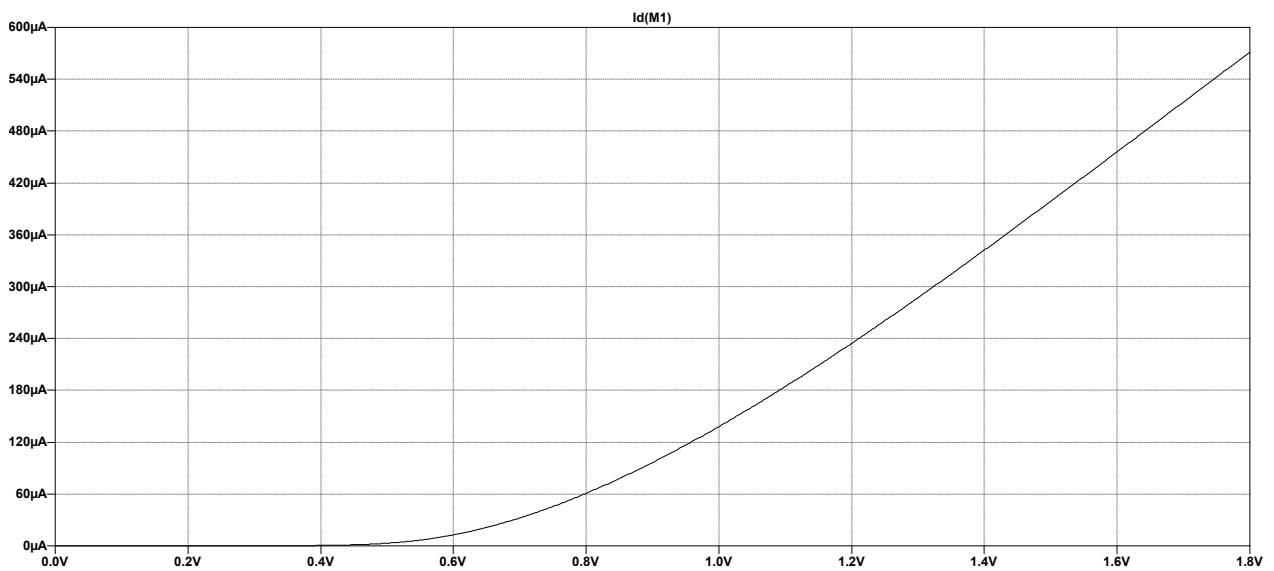


Figure 2: NMOS  $I_D$ - $V_{GS}$

#### (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:

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

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

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

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:

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

In the case for PMOS, the relation becomes:

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

(a) NMOS

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

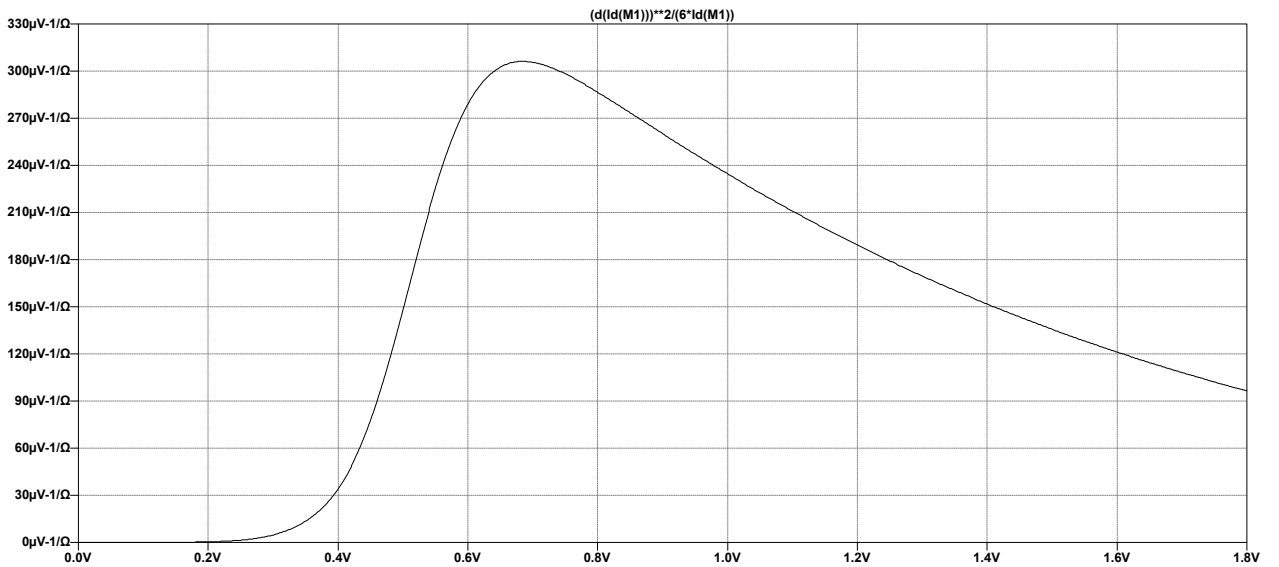


Figure 3: NMOS  $\mu_n C_{OX}$ - $V_{GS}$

ii.  $V_{THn} = 0.44V$

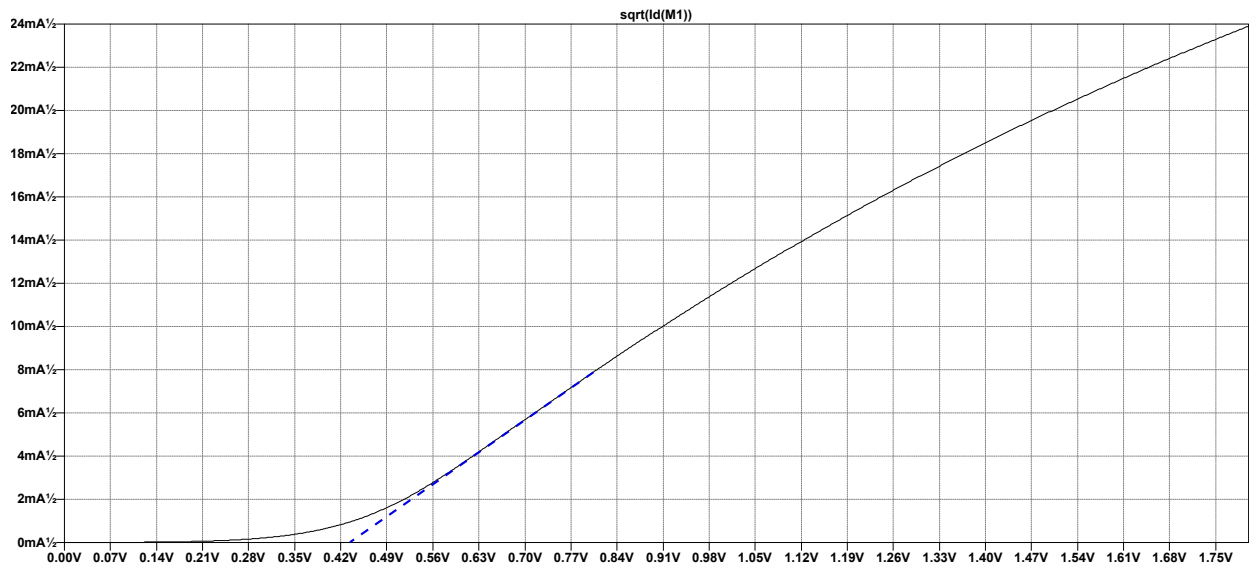


Figure 4: NMOS  $\sqrt{I_D} - V_{GS}$

(b) PMOS

- i.  $\mu_p C_{OX}$
- ii.  $V_{THp}$

## Problem 4

1. Testbench and  $I_D$ - $V_{DS}$  characteristics of NMOS and PMOS

(a) NMOS

- i. Testbench

```
.lib 'C:\Program Files\LTC\LTspiceXVII\lib\cmp\log018.l' TT  
.dc VDS 0 1.8 0.001
```

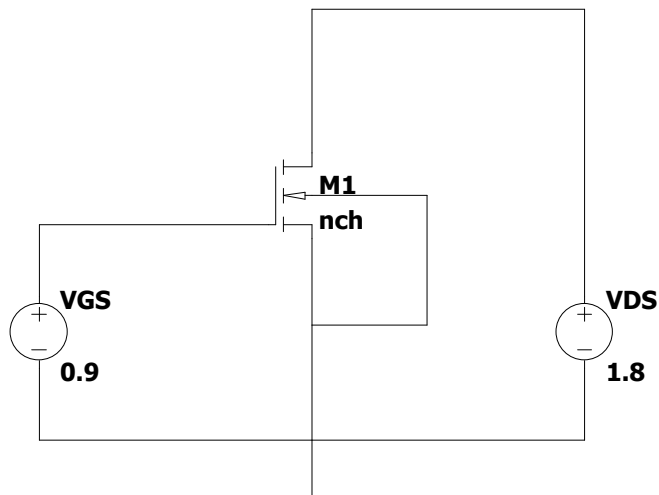


Figure 5: NMOS Testbench

- ii.  $I_D$ - $V_{DS}$  characteristics

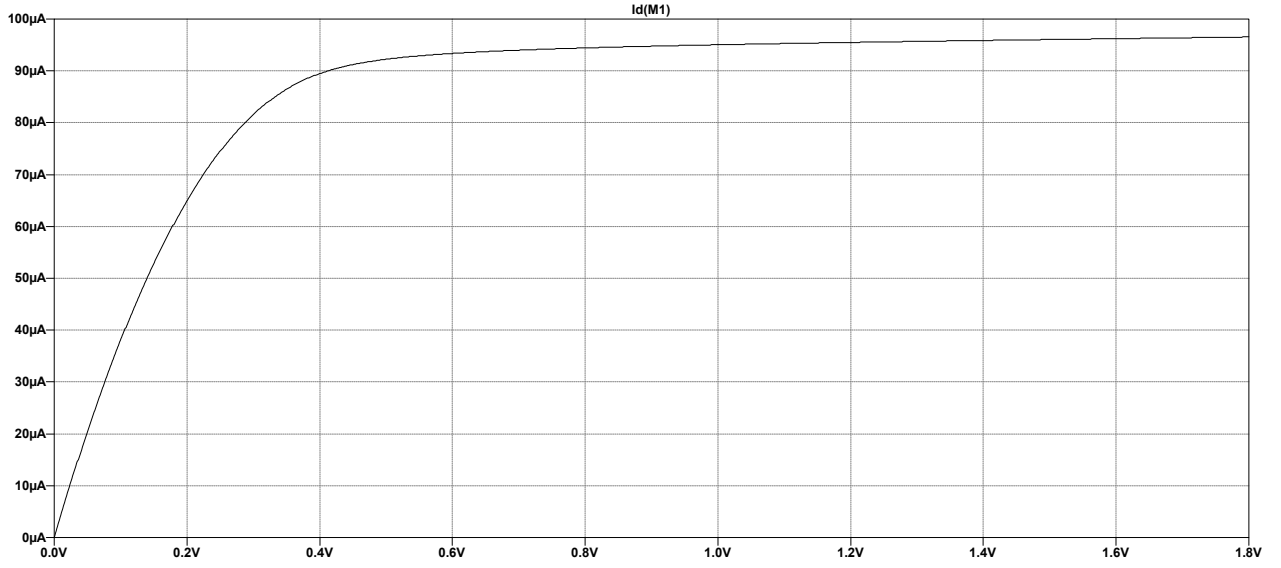


Figure 6: NMOS  $I_D$ - $V_{DS}$

(b) PMOS

- i. Testbench
- ii.  $I_D$ - $V_{DS}$  characteristics

2.  $\lambda_{n(p)}$

Drain current characteristics for NMOS under saturation conditions:

$$I_D = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{GS} - V_{TH})^2 (1 + \lambda_n V_{DS})$$

Differentiating both side with respect to  $V_{DS}$ .

$$\begin{aligned} \frac{dI_D}{dV_{DS}} &= \frac{d}{dV_{DS}} \left( \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{GS} - V_{TH})^2 (1 + \lambda_n V_{DS}) \right) \\ \frac{dI_D}{dV_{DS}} &= \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{GS} - V_{TH})^2 \lambda_n \end{aligned}$$

Assuming that the body-effect is small:

$$I_D \approx \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{GS} - V_{TH})^2$$

$$\begin{aligned} \frac{dI_D}{dV_{DS}} &\approx I_D \lambda_n \\ \lambda_n &\approx \frac{1}{I_D} \frac{dI_D}{dV_{DS}} \end{aligned}$$

In the case of PMOS:

$$\lambda_p \approx \frac{1}{I_S} \frac{dI_S}{dV_{SD}}$$

(a)  $\lambda_n = 0.18V^{-1}$

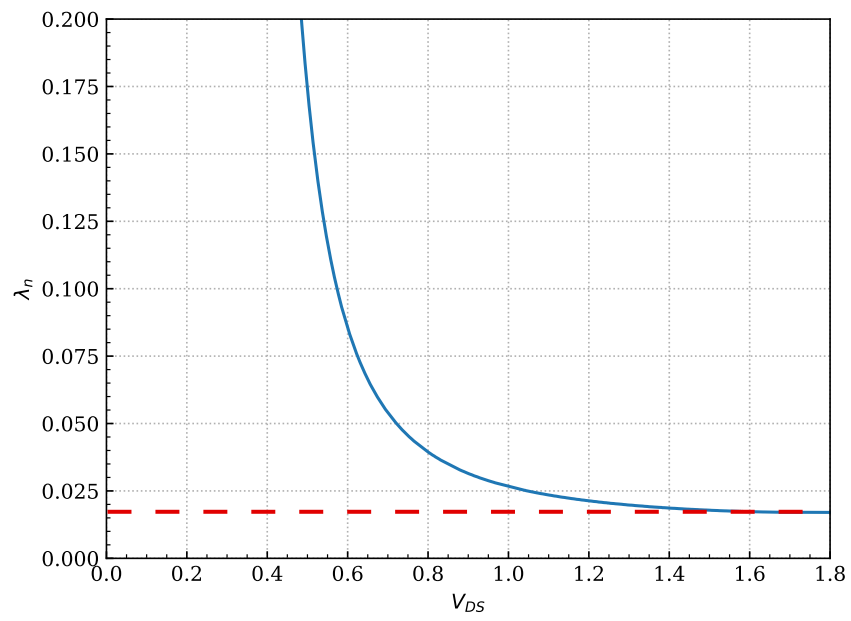


Figure 7: NMOS Testbench

(b)  $\lambda_p$

**Problem 5**

**Problem 6**

**Problem 7**