School of Engineering

ELC333-L1 **Spring 2020**

Lab 6

Advanced MOSFET Design

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1. Introduction (MF)

1.1 Objectives:

- Provide students with experience in the design of electronic circuitry, and the application of Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET).
- Students should also learn to calculate values of MOSFET

1.2 Importance:

Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) is mainly used for electronic circuitry, which this lab provides useful experiences in how to design. The MOSFET forms are the basic element in most modern electronic equipment. It is the most common transistor in electronics and the most widely used semiconductor device in the world. Studying MOSFET is critical in learning about modern electronic equipment

1.3 Theory and Background:

The Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) is a four-terminal device with source(S), gate (G), drain (D) and body (B) terminals. In this lab student would consider the 2N7002 MOSFET which yields a current-voltage relationship shown in figure 1:

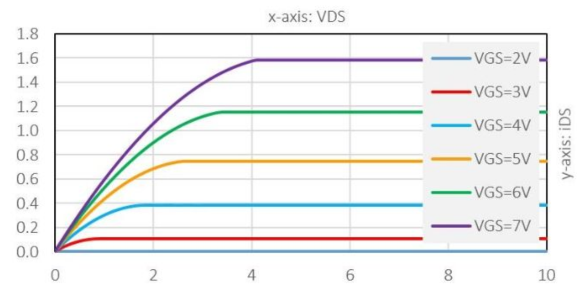

Figure 1. Drain-Source Current vs. Drain-Source Voltage for Fairchild 2N7002 MOSFET with Variable VGS

2. Materials and Devices: (MF)

- Computer with Pspice or LTSpice
- Instructor Provided Hardware Data

3. Procedure: (JB, AB, MF)

Consider the MOSFET-based circuit below with the following values/parameters:

- V_{DD}=+10V
- R_D=20Ω
- R_S=10Ω
- k_n=129mA/V^2
- V_S=+4V
- V_{GS}=+4.5V

Assume that the FET operates in the saturation region. Solve this circuit for values dictated below.

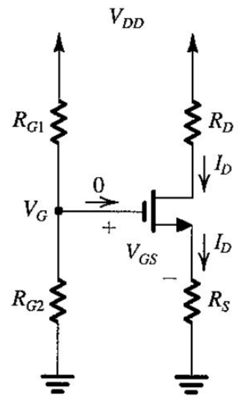

Figure 2: Main Schematic for Laboratory #6

By using these equations calculate follow the procedure

1. $i_D = \begin{cases} (\mu_n C_{ox}\frac{W}{L})(v_{0V} - \frac{1}{2}v_{DS})v_{DS} \\ \frac{1}{2}(\mu_n C_{ox}\frac{W}{L})v_{0V}^{\,2} \end{cases}$
2. $v_{0V} = v_{GS} - V_t$
3. $i_D = \frac{V_s}{R_s}$

3.1 Theoretical Task:

Step 1: Calculate the values of R_{G1} and R_{G2} from V_{DD} and V_G with the constraint that R_{G2}>1$k\Omega$. Clearly explain how you calculated this value, showing your process (aka. calculations).

Solving for

$V_G = V_{GS} + V_S = 4V + 4.5V = 8.5V$

Then using the voltage divider equation we can find $V_G/V_{DD} = R_{G2}/(R_{G2} + R_{G1})$ where $V_G/V_{DD} = 0.85$ and R_{G2} can have any arbitrary value over 2k Ω, so we can select a value of 1M Ω. Then solving for R_{G1},

$R_{G1} = 176k\Omega$

Step 2: Calculate the threshold voltage (V_t) for this FET, as dictated by schematics and parameters above. Clearly explain how you calculated this value, showing your process (aka. calculations).

Using Equation 3, $i_D = 4V/80\Omega\ =\ 50mA$

Using Equation 1,

$50mA = 1/2\ (129mA/V^2)V_{ov}^{\ 2}$

Then substituting into Equation 2,

$50mA = 1/2\ (129mA/V^2)(4.5 - V_t)^2$

Solving for V_t, the quadratic formula provides two results, 3.62V and 5.28V. V_t is smaller than V_G however, so $V_t = 3.62v$

Step 3: Calculate the value of v_{DS} for this case. Clearly explain how you calculated this value, showing your process (aka. calculations).

Solving for V_D

$i_D = (V_{DD} - V_D)/R_D$ => $V_D = V_{DD} - R_D i_D$

$V_D = 10 - 20 * 0.05 = 9v$

$V_{DS} = 9V - 4V = 5V$

Step 4: Confirm (using calculations) that the MOSFET is operating in the saturation region.

To confirm the MosFet is in the saturation region, $V_{DS} > V_{OV}$ where $V_{DS} = 5v$ and $V_{OV} = 0.88v$

So the MosFet is operating in the saturation region.

3.2 Simulation Task:

Step 5: Recreate the voltage-current relationship shown in Figure 1 via simulation. Create a similar graph from simulation results in Excel. Include this graph in your report.

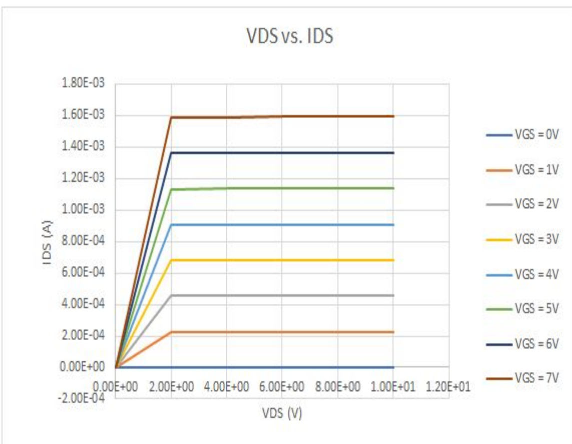

Figure 3: VDS vs. IDS graph for 2N7002 MOSFET

Step 6: Construct the circuit from Figure 2 in PSpice using the 2N7002 MOSFET and values you calculated above. Include a screenshot of your circuit in the report.

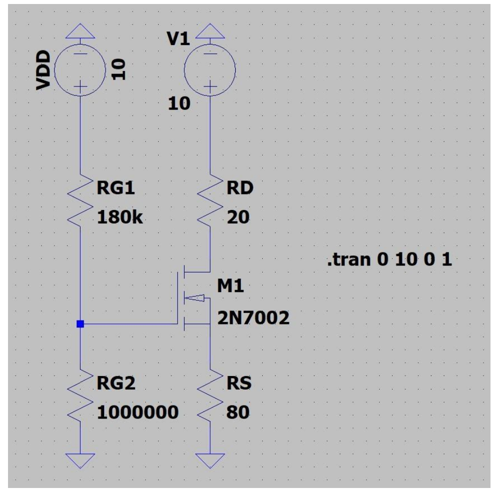

Figure 4: Replicated circuit from Figure 2 in LTSpice

Step 7: Simulate the circuit above with the theoretical parameters you calculated. Compare the values of i_D, V_D, and V_S yielded by the simulation to that given/calculated.

Parameter	Theoretical	Simulated
I_D	50 mA	73.6 mA
V_D	9 V	8.528 V
V_S	4 V	5.889 V
V_G	8.5 V	8.475 V

Table 1: Simulated vs. theoretical values

3.3 Hardware Results:

Step 8: Construct the circuit from Figure 2 in hardware using the 2N7002 MOSFET and values you calculated above. Include a picture of your circuit in the report.

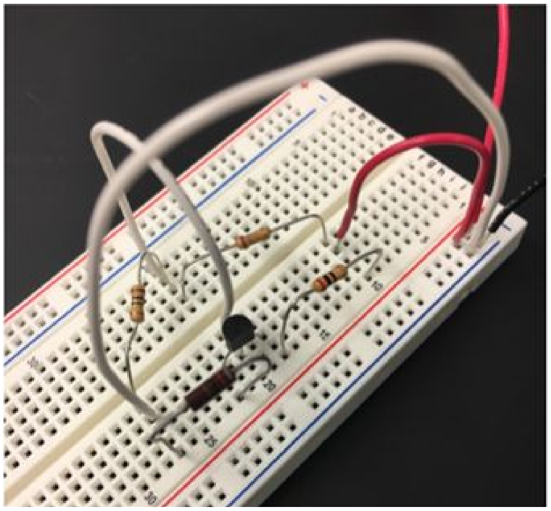

Figure 5: Circuit constructed on a breadboard

Step 9: Test and observe the circuit with the theoretical parameters you calculated. Compare the values of i_D, V_D, and V_S yielded by hardware to that given/calculated.

Parameter	Theoretical	Hardware
I_D	50 mA	75.6 mA
V_D	9 V	8.30 V
V_S	4 V	6.71 V
V_G	8.5 V	7.38 V

Table 2: Hardware vs. theoretical values

3.4 Comparison of Theoretical, Simulation, and Hardware Results:

Step 10: Create a table that compares the values of i_D, V_D, and V_S yielded by theory, simulation, and hardware. This table should also include the percentage error in these values, using theory as the ideal.

Parameter	Theoretical	Simulated	Simulated % Error	Hardware	Hardware % Error
I_D	50 mA	73.6 mA	47.2%	75.6 mA	51.2%
V_D	9 V	8.528 V	5.24%	8.30 V	8.43%
V_S	4 V	5.889 V	47.23%	6.71 V	67.8%
V_G	8.5 V	8.475 V	0.29%	7.38 V	13.2%
R_{G1}	180k Ω	180k Ω	0%	175k Ω	2.78%
R_{G2}	1M Ω	1M Ω	0%	998k Ω	0.2%
R_D	20 Ω	20 Ω	0%	20.1 Ω	0.5%
R_S	80 Ω	80 Ω	0%	85.9 Ω	7.38%

Table 3: All values compared with percent error

4. Conclusion: (MF, AB)

4.1 Background Research:

In order to complete the lab, students

would need to research their own background research and also know why the Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) is important. The students would need to research how to find the calculations for the MOSFET circuit and figure out LTSpice to recreate the circuit given to us. In the students' eyes,

The objective of the lab is using the MOSFET to get a better understanding of it and learn how to use it.

4.2 Procedure:

To complete this lab, students would

First need to calculate the theoretical task by calculating the values for the circuit. The next thing was to do the simulation task by using the values calculated and using LTSpice to recreate the circuit. Once the simulation task was done students would need to recreate the circuit by using hardware and test out the results. When both results are done students would compare the theoretical, simulated, and hardware results by creating a table which compares all three. Some problems that students may encounter is when doing the simulation the values may vary and you may need to figure out the values by yourself which may take a while to figure out. The most interesting step in the lab was trying to figure out the simulation since students may do a lot of test simulation which you could see how some values affect the simulations.

4.3 Analysis and Results:

Overall the lab did generate viable results. Hardware values had the highest percent errors in general, with the highest difference being 20.57% between the errors of V_S. This was not unexpected because the error in those values was most likely due to equipment error. The theoretical values were a little off from our simulated values, which was confusing as they are usually very similar in other labs. XX% errors were due to the simulated MOSFET and measured MOSFET component transfer curve differences. This is a typical problem in substituting components due to parts availability. The most interesting observation from the data was how the circuit required such large resistor values. This is because it was uncommon to use such large resistor values in the other labs.

4.4 Closing Ideas:

This experiment taught us even more about the function of MOSFETs in a circuit. This experiment will help us to excel in future classes because of this extra knowledge. It will also help us in the future because of the increased practice with LTSpice and Excel. Our most positive comment on this experiment was that it was relatively easy to operate on LTSpice with regards to actually building the circuit. Our most negative comment is that the instructions were confusing at times and left us trying to figure out how to get the correct values.

5. References:

- Microelectronics Circuits by Sedra and Smith; OxfordUniversity Press; Latest Edition
- LTSpice Wiki - MosFets ttp://ltwiki.org/LTspiceHelp/LTspiceHelp/M_MOSFET.htm