Lab 3: Field Effect Transistors

3.0 Objectives

By completing the research, design, and experimental requirements of this lab, the student should be able to:

a. Determine the iv-characteristics of a MOSFET
b. Extract MOSFET model parameters from iv measurements
c. Characterize and explain the behavior of a voltage divider bias circuit for a MOSFET
d. Characterize and explain the behavior of a CMOS inverter

3.1 Prelab

0. No prelab required

3.2 Components

Analog Discovery 2 module
Resistors: 100Ω, 1kΩ (2), 10kΩ (2), 100kΩ (2).
Transistors: CD4007

3.3 Task 1: IV-characteristics

The CD4007 has three pairs of transistors. One pair (Q3(N) and Q3(P)) is wired as an inverter. In the other two pairs, the N & P devices have a shared gate but not a shared drain so they may be tested separately.

A MOSFET is a 4-terminal device. If the bulk and source terminals are shorted it becomes a 3-terminal device. This is the configuration that we have focused on in this course.
In the CD4007, only Q1(N) and Q1(P) have their bulk and source terminals shorted. The other two pairs have separate bulk and source connections. Therefore, if you use the other pairs, care must be taken to connect the bulk terminals appropriately. For an NMOS device, this means connecting the bulk terminal to the most negative voltage in the circuit. For a PMOSFET, it means connecting the bulk terminal to the most positive voltage in the circuit. **Failure to observe these requirements will likely damage the MOSFETs**.

Q1(N) uses pin 7 for the source and body terminals, pin 8 for the drain, and pin 6 for the gate. Q1(P) has the same gate (pin 6). Pins 13 and 14 are drain and source respectively.

1. Build the circuit in Figure 3.1. Use R_G = 100kΩ and R_D = 100Ω. Use the CD4007 for your MOSFET. The CD4007 is a 14-pin chip that contains six different MOSFETs (3 nMOS and 3 pMOS). Search online for the datasheet for the CD4007 to identify the pins on the package. The circled numbers on Figure 3.1 correspond to using the Q1(N).

2. Start Waveforms and open the supplies tab. Set V- to -5V and enable it. Disable V+. Leave the Master Enable OFF.

In order to generate the family of curves of i_D vs. v_{DS} for different values of v_{GS}, we need to step the value of v_{GS} over a number of levels then, for each value of v_{GS}, continuously vary the value of v_{DS} over a defined range.

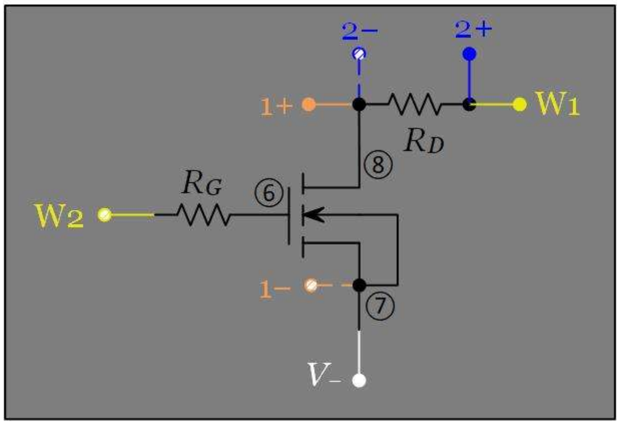

Figure 3.1. Measuring iv-characteristics of a MOSFET.

3. Open the wavegen tab. Under Channels, enable both W1 and W2.
4. For W2 choose Custom. Click New. A dialog window to define the new custom waveform will open, similar to Figure 3.2.
5. In the name field, enter “5 levels.” (You can name the waveform anything you want. Since we are creating a waveform that has five different voltage levels, this seems an appropriate name.)

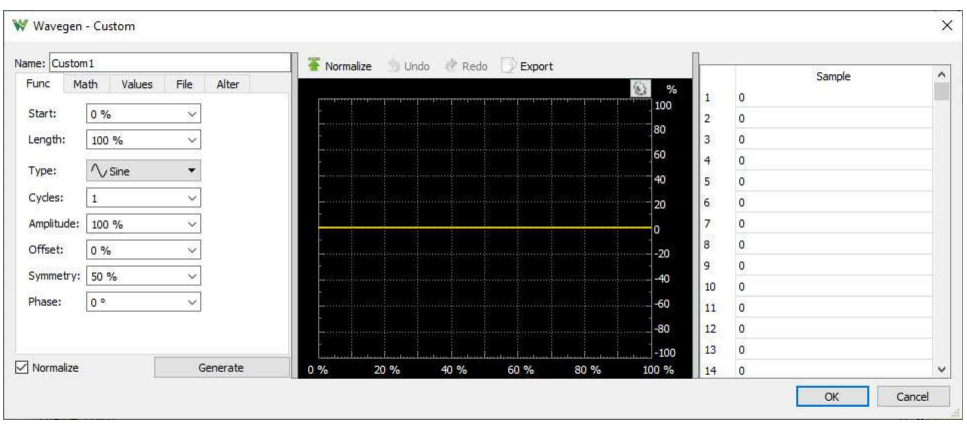

Figure 3.2. New custom waveform dialog.

6. Select the values tab. Change the values to be 0, 1, 2, 3, 4 and delete all the remaining values.
7. Click Generate. You should get a display similar to Figure 3.3. Note that the bottom level is defined as -100% of the waveform and the top step is defined as +100%. This means that when you define an offset and amplitude for your waveform the minimum level will be the offset minus the amplitude while the maximum level will be the offset plus the amplitude. Click OK.
8. Back on the main wavegen menu, the new waveform you defined is now selected as W2. Set the frequency to 20Hz, the offset to 0V, and the amplitude to 5V. You will see in the display that you are now generating a waveform that goes from -5V to +5V in four equal steps (generating a total of 5

Figure 3.3. A step waveform with five voltage levels.

levels). Because the frequency is 20Hz, the complete pattern will repeat every 50ms. This means that each step will be 10ms long.

9. Define W1 to be a 100Hz sine wave with a 5V amplitude.
10. From the selections at the top of the screen, change synchronization to “Auto synchronization.”
11. Before leaving this tab, make sure that the Enable box is checked for both sources.
12. Open the scope tab.
13. Create a new math channel and set its formula to C2/100 and its units to A.
14. Create an XY plot with C1 on the horizontal axis and M1 on the vertical axis. For C1, set the offset to be -5V and the range to be 1V/div. For M1, set the range to 2.5mA/div and the offset to -10mA.
15. Run the supplies, wavegen, and scope. Your XY plot now shows the iv-characteristics of an enhancement mode n-channel MOSFET.

This set of curves is sometimes referred to as the **output characteristics** of the MOSFET.

16. Stop the wavegen, supplies, and scope.
17. Move the 1+ wire to measure the voltage on the gate (pin 6).
18. On the wavegen tab, change W1 to a DC voltage with offset 5V.
19. Change W2 to a 100Hz sine wave with amplitude 5V.
20. Return to the scope tab and start the supplies then wavegen. Your XY plot is now a graph of V_{GS} vs. I_D.

This graph is called the **transfer characteristics** of the MOSFET.

21. Export the data to a csv document.
22. Stop the wavegen, supplies, and scope.
23. Open the data in the csv document using Excel or any other data analysis software.
24. Using a procedure similar to the one used in Lab 2 to extract the value of I_0 for a diode, use the square law behavior of I_D vs. V_{GS} to extract the parameters K and V_T for the MOSFET.

3.4 Task 2: IV-characteristics of a PMOSFET

25. Change the wiring on your circuit to obtain the circuit of Figure 3.4.
26. On the supplies tab, disable V-, enable V+, and set V+ to 5V.

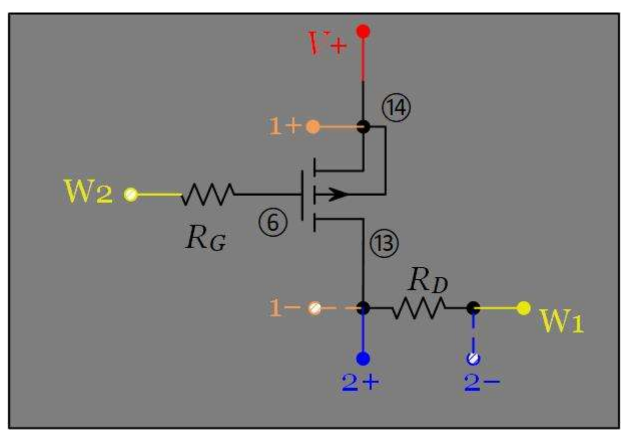

Figure 3.4. Measuring the iv-characteristics of a PMOSFET.

27. Repeat the procedures of steps 3-15 to get the output characteristics of the PMOS.
28. Adapt the procedures of steps 16-20 to get the transfer characteristics of the PMOS (you will need to make W1 -5V instead of +5V).
29. Stop the supplies. Stop and close wavegen and scope.

3.5 Task 3: Voltage divider bias circuit

30. Build the circuit in Figure 3.5. Use R_1 = 120kΩ, R_2 = 100kΩ, and R_3 = R_4 = 1kΩ. Use the CD4007 Q1(N) as your MOSFET (pins 6, 7, and 8 for gate, source, and drain, respectively). Use the V+ from the AD2 to set V_{DD} and set it to 5V. Use the V- to set -V_{SS} and set it to -5V.

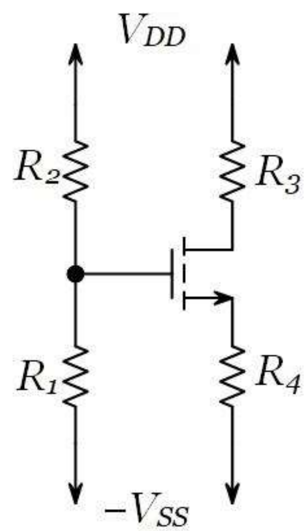

Figure 3.5. Using voltage divider bias with a MOSFET.

31. Run the supplies and use the voltmeter to measure V_G, V_D, and V_S.
32. From your measurements determine I_D.
33. Use the parameters you measured in Task 2 to analyze the circuit and determine the theoretical values expected. Compare with your measurements.
34. Stop the supplies.

3.6 Task 4: CMOS inverter

35. Build the circuit in Figure 3.6. Your NMOSFET should be the Q1(N) and your PMOSFET should be the Q1(P). Review Tasks 1 & 3 and the CD4007 datasheet to make sure that you are connecting the correct pins.
36. Use the V+ from the AD2 to set V_{DD} to 5V. Use the V- to set -V_{SS} to -5V.
37. Use W1 as v_i and connect C1 to measure it. Connect C2 to measure v_o.
38. Set W1 to be a 1kHz sinusoid with 5V amplitude.
39. Run the supplies and wavegen and examine the waveforms for v_i and v_o. Adjust the display settings to be able to see at least two full cycles.
40. Generate an XY plot with C1 on the horizontal axis and C2 on the vertical axis. This is called the voltage transfer characteristics (VTC) of the circuit. This circuit is what is known as a complementary MOS (CMOS) inverter.
41. Stop the supplies, wavegen, and scope.

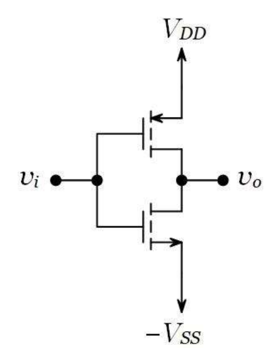

Figure 3.6. CMOS inverter.