EXPERIMENT NUMBER 6
Characterization and Use of Field Effect Transistors for Digital Applications

Preface:

- Preliminary exercises are to be done and submitted individually.
- Laboratory hardware exercises are to be done in groups.
- Work done in notebooks to be submitted individually.
- The laboratory notebooks to be submitted immediately following the laboratory.
- The laboratory notebooks must include all settings, steps and observations in the exercises. All statements must be in complete sentences and all tables and figures must have a caption.
- This laboratory requires technical memorandum to be submitted individually. The technical memorandums require a specific format, must include specific appendix tables, and must address the listed questions. Review the associated guidelines.
- Review the guidelines for plagiarism to be aware of acceptable laboratory and classroom practices.

MOSFETs are often used in digital logic circuits. This laboratory explores the characteristics of MOSFETs and their use in some simple digital circuits.

Objectives:

- To observe the I-V characteristics of a MOSFET.
- To determine the input capacitance of a MOSFET.
- To learn how to use a MOSFET as a switch.
- To understand the use of MOSFETs in digital applications

References:

- EE 121 Handouts
- Neamen, Donald A., Electronic Circuit Analysis and Design, 2nd ed., (McGraw-Hill, New York, New York, 2001), Chap 6 and 16.

Background:

To obtain an I-V curve, we will use a curve tracer. A curve tracer measures the current flowing through a device when the voltage across a pair of terminals is swept from a low- to high-value. In our case, the voltage V_{DS} will be swept, while the current through the drain of the FET is measured.

In digital designs, microprocessors can often sink current better than they can source it. Since a p-channel MOSFET turns on when the gate voltage is low and a microprocessor generates a better low than a high, p-channel FETs are often more desirable to control than n-channel FETs. Here we will explore the control of a simple P-channel MOSFET switch.

CMOS logic has become widely used in designing circuits, because the size of the circuit can be made very small compared to other types of logic. To show how CMOS logic works, we will look at the following CMOS inverter in Figure 1. Note that the resistors R_1 and R_2 are included to aid in understanding the MOSFET operation and are not included in practical circuits. Also, the LEDs are included to show current flow and are not part of practical circuits.

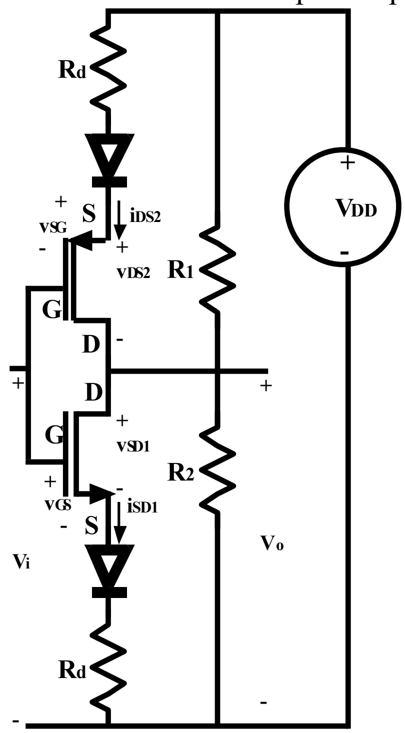

Figure 1 – MOSFET Inverter Circuit

A schematic of a switch is given in Figure 2 using an N-MOSFET transistor which turns an LED "on" when the input is 15 V and turns the LED "off" when the input is 0 V. The resistor R is used to limit the current following through the LED. Note that the resistance, $R_d = 1\ k\Omega$, needed to limit the current to about 15 mA is 1kΩ when using the following parameters:

- $V_{DD} = 15$ V
- $V_{D(ON)} = 2$ V

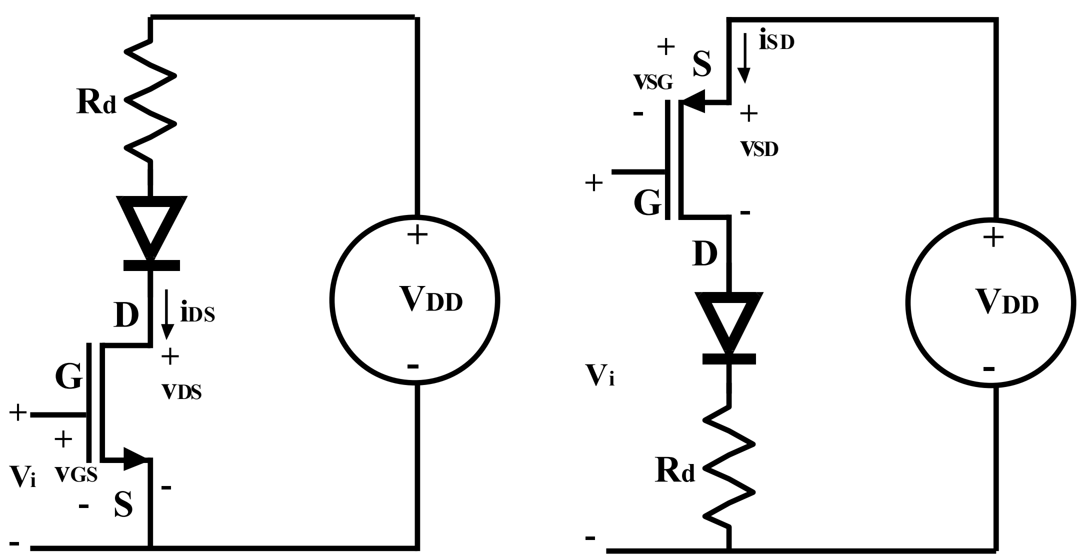

Figure 2 – N-MOSFET and P-MOSFET Switching Circuits

Preliminary:

(Work on separate paper and turn in at the beginning of the laboratory session.)

- Print the data sheets for a Fairchild IRF9630 (p-channel power MOSFET) and RFO14N05L (n-channel power MOSFET). Using these data sheets, identify the value of the threshold voltage, input impedance, and input capacitance.
- From the schematic for a CMOS inverter given in the Background, identify which FETs are on and the output voltage a) when the input is high and b) when the input is low.

Equipment:

- I-V Curve Tracer
- LCR Meter
- DC Power Supply
- Breadboard
- Oscilloscope

Experimental Procedure:

(Record specifics in the Laboratory Notebook.)

1. Using the curve tracer, obtain the I-V characteristics of the n-channel and p-channel MOSFETs. Consult with the Laboratory TA on connecting the MOSFETs. Plot or sketch the I-V curves.

   Q1: How does the I-V curves compare to the theoretical expectations?
2. Use an LCR meter to determine the gate-to-source input capacitance of each MOSFET by connecting the meter between the gate and source. Record these values and compare them to those given in the data sheets. Calculate the percent difference.
3. Build the N-MOSFET switch from the preliminary. Apply a 5 V input voltage using the DC Power Supply and not the Signal Generator, and then remove the input voltage (thus supplying first a high input voltage and then a low input voltage). Measure and record the output voltage for the input low and high conditions. Note that the voltage does not change after the high input voltage is removed. Charge is stored and must be drained by connecting the input to ground.

   Q2: Does the circuit operate as a switch? What input voltage turns on the LED?
4. Repeat step 3 using the p-channel MOSFET switch from the preliminary. Measure and record the output voltage for the input low and high conditions. Note the differences from the N-MOSFET configuration and operation.

   Q3: Does the circuit operate as a switch? What input voltage turns on the LED?
5. Build the CMOS inverter circuit from the preliminary with resistors R_d = 220 Ω, R_1 = 220 Ω, and R_2 = 220 Ω. Verify the circuit works by setting V_{DD} to 10V and changing v_i from 0 V (low) to 10 V (high) by manually connecting and disconnecting the source input. Measure and record the output voltage for the input low and high conditions. Use oscilloscope to compare output to the input.

   Q4: Does the circuit operate as an inverter?
6. The CMOS circuit can be used as a high-gain amplifier by removing resistors R_1 and R_2 from the inverter circuit. Using the oscilloscope, record the v_i and v_o curves vs. time on the same graph when v_i is a 1 V_{pp} sine wave oscillating at 1kHz and centered at 5 V.

   Q5: How is the output voltage related to the input voltage?
7. Generate a v_i vs. v_o curve using the oscilloscope in the x-y mode using v_i as in step 6. Make the y-axis v_i and the x-axis v_o. Plot or sketch the curve.

   Q6: At what input voltage does the output voltage begin to change state?

Technical Memorandum:

- Memorandum discussion:

(1) Describe, based on your observations, I-V curves of the Fairchild IRF9630 (p-channel power MOSFET) and RFO14N05L (n-channel power MOSFET). Does the curve match theoretical expectations? (Q1) Describe any differences.

(2) Describe, based on your observations, the use of the switch configuration using N-MOSFET and the P-MOSFET. Does the switch work as expected for each case? What voltage turns on the LEDs? (Q2 and Q3)

(3) Describe, based on your observations, the use of the inverter configuration using N-MOSFET and the P-MOSFET. Does the inverter work as expected? (Q4)

(4) How does the output voltage relate to the input voltage for the amplifier? (Q5) At what input voltage does the inverter output voltage begin to change state? (Q6)

- Appendix 1: Record the sketch or plot of the I-V curves of the Fairchild IRF9630 (p-channel power MOSFET) and RFO14N05L (n-channel power MOSFET).
- Appendix 2: Tabulate the input and output voltages for the two switch configurations. Tabulate the input and output voltages for the inverter and amplifier configurations. Record the sketch or plot of the v_i vs. v_o curve