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Diodes and MOSFETs: Experiment Guide

I. Objective

The student will understand and experimentally verify some basic diode circuits and the current-vs-voltage (*I-V*) operating curves of the MOSFET.

II. Diode Overview

Diodes are mostly used in practice for emitting light (as LEDs) or controlling voltages in various circuits. The best way to think about diodes is to first understand what happens with an ideal diode and then to extend it to the practical case. An ideal diode has an infinite resistance when the voltage across it is less than its "threshold voltage" and zero resistance when the voltage is greater than the threshold. The threshold voltage is just a characteristic of each individual diode (i.e. every 1N914 diode should have the same threshold voltage whereas an LED may have a different threshold voltage). This threshold voltage concept comes from the fact that a diode is just a *pn* junction; the threshold voltage is defined by the concentration of donors and acceptors in the junction (Don't feel bad if you haven't studied *pn* junctions before; it is not crucial for this lab). So, we see that the I-V graph for an ideal diode should look like:

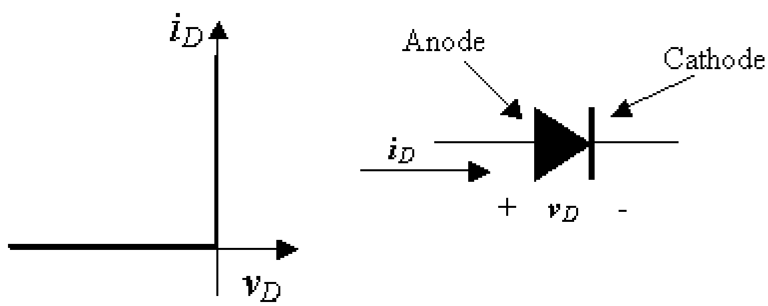

Figure 1 Ideal Diode IV Curve and Schematic

In the above graph, the threshold voltage (i.e. the voltage when the slope of the line changes from 0 to ∞) is at 0. This will not be the case for the real diodes we use in lab. For the diodes we will use in this lab, all threshold voltages will be positive (Zener diodes also have a low reverse threshold).

III. Diodes: Half-Wave Rectifier

The half-wave rectifier is a circuit that allows only part of a sinusoidal input signal to pass. The circuit is simply the combination of a single diode in series with a resistor, where the resistor is acting as a load (see figure 2).

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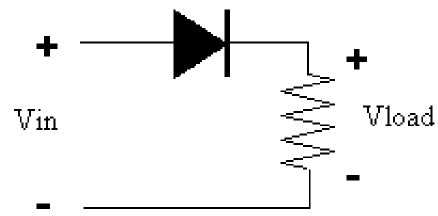

Figure 2 Half-Wave Rectifier Schematic

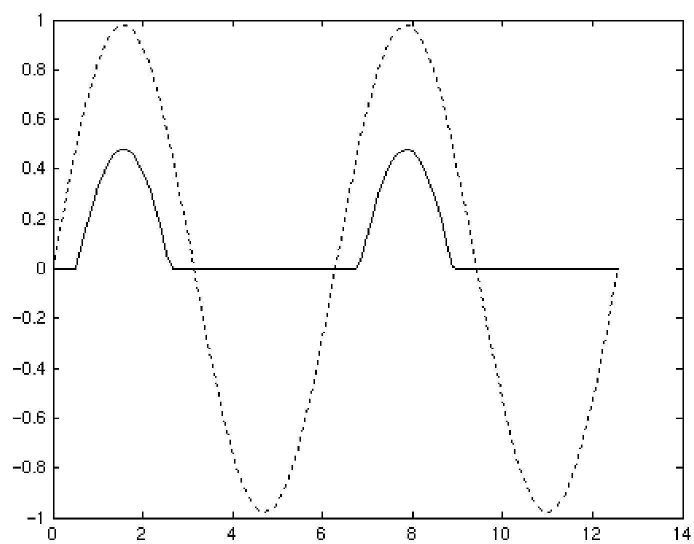

Figure 3 Half-Wave Rectifier, Voltage vs Time

We see from figure 2 that the output voltage across the load is just the input voltage minus the threshold voltage when the input voltage is greater than the threshold voltage (the threshold voltage here is embellished from what you would really see. Here, the threshold voltage is set to about 0.5 volts (can you see why?). We see that when the input voltage is not greater than the threshold voltage, we get zero voltage out. This makes sense if we look at figure 1, the plot of the ideal diode, again. We see that when the input voltage is less than the threshold voltage (and thus the voltage across the diode is less than the threshold voltage), we get zero current through the diode and so no current goes into the load (because, from the ideal diode plot, when the voltage is below the threshold, no current passes through a diode). We see if, on the other hand, we have an input voltage greater than the threshold voltage, essentially any current can pass through the diode (real diodes only approximate this vertical line). Basically, the diode will act as a switch. When the input voltage is below the threshold voltage, effectively no current will pass through the diode and so there will be no voltage across the resistor. If, however, the supplied voltage is greater than the threshold voltage, then we can think of the diode as being "on". When the diode is "on", the voltage drop across the diode will just be its threshold voltage and the current through it will be defined by the load (so, in our case, let's pretend we had a supplied voltage of five volts and a threshold voltage that we look up to be 2 Volts (which is just the voltage across the diode). Then, we know that there are 3 V across the resistor. If we know the resistance, then we know the current through the circuit). Thus, we can "rectify" half of the input signal on the output and we have built a half-wave rectifier.

IV. MOSFET Overview

A metal-oxide-semiconductor field-effect transistor (MOSFET) is a three-terminal device that can be used as a switch (*e.g.* in digital circuits) or as an amplifier (*e.g.* in analog circuits). The three terminals are referred to as the **Source**, **Gate**, and **Drain** terminals. The MOSFET also has a **Body** terminal, which is usually tied to the source terminal (so that V_{BS} = 0 volts) in discrete transistors. **Current flow between the source and drain terminals is controlled by the voltage V_{GS} applied between the gate and source terminals.** If the gate-to-source voltage V_{GS} is less than the threshold voltage value V_T (*e.g.* ~2 Volts, for the transistors which you will be using in this lab), no current can flow between the source and the drain – *i.e.* the transistor is OFF; if $V_{GS} > V_T$, then current can flow between the source and the drain – *i.e.* the transistor is ON. The circuit symbol for an n-channel enhancement-mode ($V_T > 0$ Volts) MOSFET is shown in Figure 1, along with the terminal current reference directions.

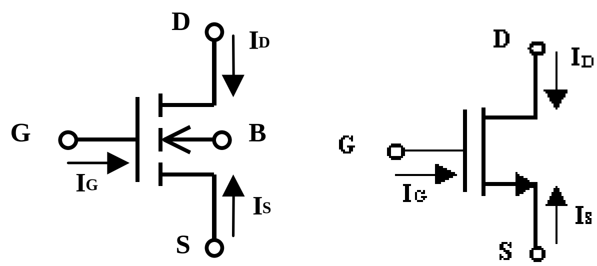

Figure 4 Circuit symbol for n-channel enhancement MOSFET

Note that each terminal current is defined to be positive flowing into the terminal. In the physical structure of the MOSFET, the gate terminal is electrically insulated from the source, body and drain terminals, so that no DC current can flow into the gate terminal:

$$I_G = 0 \qquad \text{(Eq. 1)}$$

In addition, if the transistor is operated properly, no DC current should flow between the body terminal and the source or drain terminals:

$$I_B = 0 \qquad \text{(Eq. 2)}$$

From Kirchhoff's Current Law, we know that the sum of all the terminal currents flowing into the MOSFET must be zero:

$$I_G + I_D + I_B + I_S = 0 \qquad \text{(Eq. 3)}$$

Substituting Eq. 1 and Eq. 2 into Eq. 3, we obtain

$$I_S = -I_D \qquad \text{(Eq. 4)}$$

Thus, **all of the current that flows into the drain terminal flows out of the source terminal**.

In the ON state, the current I_{DS} flowing from the drain to the source will depend on the potential difference V_{DS} between the drain and the source: I_{DS} increases with increasing drain-to-source voltage V_{DS} as long as the drain voltage is at least V_T below the gate voltage, *i.e.* as long as V_{GS}-V_T >

V_{DS}. When V_{DS} increases above V_{GS}-V_T, I_{DS} saturates at a constant value (*i.e.* it no longer increases with increasing V_{DS}.) Figure 5 shows the *I-V* operating curves for a typical n-channel enhancement-mode Field Effect Transistor (FET). As can be seen in the figure, for each value of V_{GS} there is a unique curve of I_{DS} vs. V_{DS}.

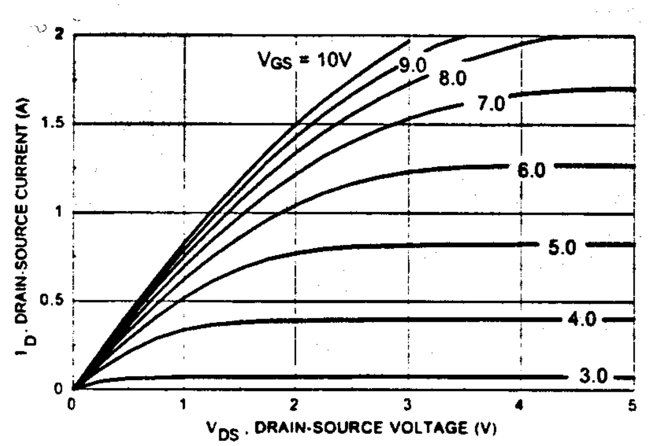

Figure 5 Current I_{DS} flowing through the drain to source of an n-channel MOSFET versus the voltage V_{DS} across drain to source, parameterized by the voltage V_{GS} applied across the gate to source.

V. Hands On

Part One: Half-Wave Rectifier

1. Build the half-wave rectifier circuit drawn in figure 2. Use a 1KHz, 5 Vpp input signal with no offset (i.e. the function generator should display 0 offset and 2.5 Vpp). Use a potentiometer (as a rheostat) as the load (so that you can vary the resistance and see what happens to the output). Use an LED for the diode. **Note: You must be very careful with the function generator settings. If you have the output too high with a low resistance rheostat (or if you don't have a rheostat connected), you risk burning out the LED.**

2. Measure the threshold voltage of the LED. To do this, either measure the distance (in Volts) between the input and output signal, or, find the time at which the output waveform begins to go high and measure the input voltage at that time (if you're unclear by this wording, ask your TA for clarification). Does this threshold change if you make the input Vpp smaller? What happens if you use a negative offset? If you make the input Vpp small (i.e. ~0.5 Vpp) and you increase the offset to 0.5 Volts, what do you see on the output? What happens if you lower the frequency of the function generator? What happens as you vary the resistance on the rheostat? Do different color LED's have different threshold voltages?

3. Replace the LED with a 1N4148 diode and measure the new threshold voltage. Is it different?

Part Two: Diode I-V Characteristics using LABVIEW

4. Open the file "DiodeIVGraph.vi" which can be found on the EECS40 website. Connect the circuit shown in Figure 6, using the 1N4148 diode and R=330Ω. Use the +6V DC power supply for Vin and one of the digital multimeters to measure the current through the circuit.

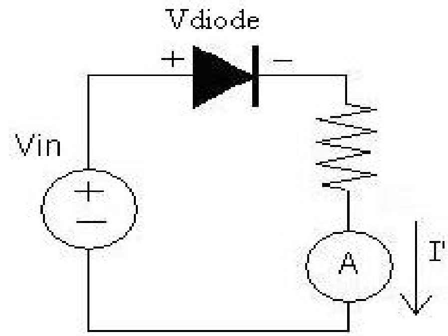

Figure 6 Circuit to measure load line of diode and resistor

5. Look at the block diagram of the DiodeIVGraph.vi program and make sure you understand what the program does. How does LABVIEW compute the voltage across the diode?

6. Run the LABVIEW program. You should sweep the power supply voltage from 0V to 5V. You should see the diode I-V characteristics displayed on the graph. Print out the graph and hand it in with your lab report.

7. Compute the saturation current I_o from the diode equation $I=I_o e^{qV/kT}$ based on your measured diode I-V characteristic. Use kT=25.83meV.

Part Three: MOSFET I-V Characteristics using LABVIEW

8. Open the file "MOSFETIVGraph.vi.". Using the BS170 MOSFET, connect the circuit shown in Figure 7. Use the +25V DC power supply for the gate-source voltage (V_{GS}) and the +6V DC power supply for the drain-source voltage (V_{DS}). Look at the MOSFETIVGraph.vi Block Diagram and briefly describe what this program does.

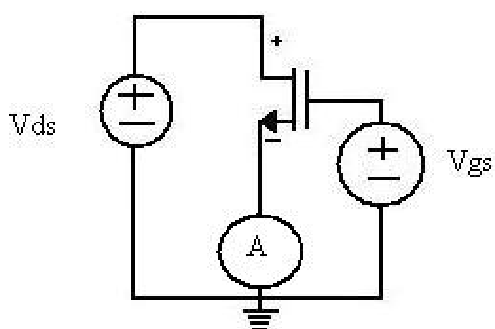

Figure 7: MOSFET circuit for LABVIEW program

9. Run the LABVIEW program. You should see a sweep of the MOSFET I-V characteristics. Print out the graph and hand it in with your lab report. Is this MOSFET a long channel or short channel device? (hint: Do you see evidence of velocity saturation?). Plot a graph of I_{DS} vs. (V_{GS}-V_t), assuming V_t=2V. How would you know if this MOSFET was a long or short channel device?