Lab 7: Diode Circuits

OBJECTIVES
- To reinforce the concepts behind diode circuit analysis
- Verification of diode theory and operation
- To understand certain diode applications, such as rectification and clipping

MATERIALS
- Your lab parts.
- Printouts (required) of the below documents:
  - Pre-lab analyses
  - Answers to pre-lab questions
  - Multisim screenshots e-mailed to course e-mail
- Graph paper.

INTRODUCTION

Device Theory and Operation
A solid state diode consists of a junction of either dissimilar semiconductors (pn junction diode) or a metal and a semiconductor (Schottky barrier diode). Regardless of the type, the circuit symbol for a diode is as shown in Fig. 1 (left) and the corresponding device in Fig. 1 (right).

If \( V \) is positive, the diode is **forward-biased** and the diode can conduct a significant positive current \( I \), even though \( V \) is a small voltage (typically 0.7 V for the most common [silicon] diodes). If \( V \) is negative, the diode is **reverse-biased**; the negative current produced by the reverse bias is so small that it is often considered to be zero. Thus, the usual function of a diode is to allow current to flow in the direction of the arrow (the forward direction) for positive \( V \)'s, but not allow any current to flow in the reverse direction for negative \( V \)'s.

![Diode Schematic Symbol](image)

Figure 1 – Diode schematic symbol (left) and physical representation (right)

Only a small forward bias (positive \( V \)) is required to cause a diode to conduct a significant current \( I \), and the less this voltage, the better. One model of an ideally diode has the following properties:
- This voltage drop for forward bias is zero volts.
- The diode can conduct any value of current \( I \) in the forward direction, with this value being determined not by the diode, but by other components in the circuit in which the diode is connected.
- The diode conducts zero amperes for a negative \( V \), regardless of the voltage magnitude.

In other words, an **ideal diode** is a **short circuit** for a voltage \( V \) that tends to be positive (but it cannot be more than 0 V) and an ideal diode is an **open circuit** for a negative \( V \). Thus, an ideal diode acts like a switch that is closed for current flow in the direction of the arrow in the diode circuit symbol, and open otherwise. Essentially, it is an electronically operated switch. This ideal approximation is satisfactory for analyzing many circuits that contain diodes, provided that the voltage levels are much greater than 0.7 V. Fig. 2 shows the \( I-V \) (current/voltage) characteristic for an ideal diode.
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Fig. 3 shows the $I$-$V$ characteristic of an actual, physical diode. The part of the curve in the first quadrant is the *forward characteristic*, and the part in the third quadrant is the *reverse characteristic*. The current $I_s$ is called the *reverse saturation current*. For a reverse voltage $V_B$, the diode “breaks down” and draws a large reverse current.

The diode forward characteristic is shown on an expanded scale in top right quadrant of Fig. 3. Notice the “turn-on” voltage $V_T$. For forward voltages less than $V_T$, a diode conducts very little current. In another diode model, in the normal forward operating range, the diode voltage is approximately by $V_T$ (independent of the current). For the common silicon diode, $V_T$ is approximately 0.7 V.

Usually, a stripe on the diode casing designates the cathode (‒) end. If there is any doubt, a DMM ohmmeter can be used to measure the diode resistance in both directions. A diode has a small resistance in the forward direction, which is for current flow from anode to cathode. It has almost an infinite resistance in the reverse direction, for current flow from cathode to anode.

**Measurement of Diode I-V Characteristics**
An oscilloscope display of the diode $I$-$V$ characteristic can be

![Figure 2 – Current/voltage characteristics of an ideal diode.](image)

![Figure 3 – Current/voltage (I-V) characteristics of a non-ideal diode.](image)

![Figure 4 – Circuit to obtain an I-V characteristics via oscilloscope display.](image)
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obtained using the circuit of Fig. 4 where the device is a diode. Actually, this circuit configuration can be used to displace the I-V characteristic of any two-terminal device. For this lab, however, we will use a two-wire current analyzer to obtain its I-V characteristics.

Diode Circuits
Diodes are used in many types of circuits. For example, they are used in rectifier circuits to convert ac to dc. Also, they are used in clipper circuits to select a certain part of a waveform that is either greater or less than some reference value.

The Half-Wave Rectifier
Consider the circuit of Figure 5. Assume that Vi represents a DC voltage source in series with the diode and the resistor. We monitor the voltage Vo across the resistor. If we consider the diode to be ideal (VT = 0) then current will flow in the diode only if Vi is positive, in which case the diode will act as a short circuit and Vo = Vi. For Vi < 0, the diode will be reverse biased, allowing no current flow and Vo will be zero.

If the diode is not ideal, then for the current to flow, Vi must be equal to or greater than VT. When the current flows in the diode, there is a voltage drop VT across it and the voltage across the resistor is given by Vo = Vi - VT. Again, for Vi < 0, V0 = 0.

Now reconsider the circuit of Figure 5, where we now have an AC voltage source v(t) of angular frequency \( \omega \) (period \( T = \frac{2\pi}{\omega} \)) and amplitude \( V_P \),

\[ v(t) = V_P \sin(\omega t) \ . \]

During the time \( 0 \leq t \leq T/2 \), \( v(t) \) is positive and the diode, if ideal, will act as a short circuit, resulting in \( v_o(t) = v(t) \). However, in the second half of the period, \( v(t) \) is negative and the diode will remain open during this time, resulting in \( v_0(t) = 0 \). If the diode is not ideal, then the diode current will remain zero during the time \( v(t) \) remains less than \( V_T \). However, when \( v(t) > V_T \), \( v_o(t) = v(t) - V_T \).

Diode Clipper Circuits
As the name implies, a diode “clipper” circuit will be one intended to remove, or “clip off,” part of the output waveform. These may be used singly (Fig. 6) to prevent reaching a certain value in the positive or negative portion of a waveform, or they can be used in pairs (Fig. 7) to perform double-ended limiting at two independent levels.
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Full-Wave Bridge Rectification
The diode bridge rectifier circuit is shown in Fig. 8. The operation can be understood by considering the polarity of the applied voltage $V_i$ at the top node $a$, with respect to the bottom node $b$. When this voltage is positive, diodes $D_1$ and $D_2$ are forward biased and therefore conduct, thereby causing the output voltage $V_o$ to be equal to the input voltage $V_i$. (For simplicity, the small voltage drops across the conducting diodes are neglected.) When, however, $V_i$ is negative, node $b$ is positive with respect to node $a$ and thus diodes $D_3$ and $D_4$ conduct, making $V_o = -V_i$. Since, however, $V_i$ is negative, $V_o$ is positive. Thus, $V_o$ is always positive and is equal to the magnitude of $V_i$. That is, $V_o = |V_i|$.

Suppose that the input voltage is $v_i = 10\sin\omega t$ V. Then, if $V_T = 0$, the input and output voltage waveforms will be as shown in Fig. 9 by the dotted curve. Actually, though, for a real bridge rectifier, the output waveform will be shifted down by $2V_T$ because of the diode voltage drops. This is shown by the solid curve in the bottom Fig. 9. Also, because of this shift, the output waveform will be zero for a short time between the rectified half cycles. This type of rectification is called full-wave rectification because both half cycles of a cycle of the input contribute to the output.
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PRE-LAB AND QUESTIONS

I-V Analysis
1. Simulate the I-V characteristics of the 1N4148 diode will be using in this lab. To do this, open Multisim and select the 1N4148 device from the “Place Diode” button. Next, select the IV-Analysis tool from the “Instruments” toolbar (the same toolbar where you find the DMM).
2. Wire the device and instrument as below in Fig. 10.
3. Simulate the circuit and double-click the IV-Analysis tool and set the parameters as seen in Fig. 11. Take a screenshot of your I-V characteristics.

![Figure 10](image1)

Figure 10 – Multisim schematic for pre-lab question 1.

![Figure 11](image2)

Figure 11 – IV Analysis settings.

Half-Wave Rectifier
4. Analytically, consider the circuit of Figure 5. Let $v_i(t) = 5.0 \sin(377t)$ V and $V_T = 0.7$ V. Sketch what you expect the waveform $v_0(t)$ to be and show the times when $v_0$ is zero. Does your answer depend on the value of the resistor?
5. Now simulate the output of the circuit of Fig. 5 using a 5-V peak, 1-kHz sinusoidal voltage for $v_i$. Connect an oscilloscope (in Multisim) to $V_o$ and adjust the time-scales and volts per division as necessary. Take a screenshot of this waveform and compare it to your sketch from 4.

Clippers
6. Consider the circuit shown in Fig. 6. Let $v_i(t) = 5.0 \sin(377t)$ and $V_r = 2.0 \text{V}$. Sketch what you expect the output waveform $v_0(t)$ to be and show the maximum and minimum values of the output voltage.
7. Simulate the clipping circuit shown in Fig. 6. Let $V_R = 2$ V and the input voltage $v_i$ be a 5-peak, 1 kHz sinusoidal voltage. Connect an oscilloscope (in Multisim) to $V_o$ and adjust the time-scales and volts/division as necessary. Take a screenshot of this waveform and compare it to your sketch from 6.
8. Reverse the direction of the diode in your simulation. Observe the output voltage $v_o$ waveform on your oscilloscope. How does this output voltage compare to that in step 7?
9. Consider the circuit shown in Fig. 7. Let $v_i(t) = 5.0 \sin(377t)$, $V_r1 = 3.0$ V, and $V_r2 = 2.0$ V. Take a screenshot the output waveform $v_0(t)$. What is generally different about this waveform compared to that of steps 7 and 8?
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Full-Wave Rectification

10. Simulate the circuit shown in Fig. 12. Apply a 5-V peak, 60-Hz sine wave and, using an oscilloscope, observe the voltage across the a,b terminals. Examine the waveform, including amplitude and time values. Take a screenshot of this waveform.

![Figure 12 – Schematic for Prelab 10](image)

11. Sketch the circuit that results in Figure 13 below. Build the circuit on your myDAQ breadboard and display the results assuming the threshold voltage of the diode is approximately 510mV. Show the circuit to your TA before the lab starts. (Hint: Refer to Figure 4).

![Figure 13 – Schematic for Prelab 11](image)
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LAB PROCEDURE AND QUESTIONS

ALL Experiments will be built on the ELVIS breadboard.

I-V Analysis
1. The Two-Wire Current-Voltage Analyzer panel is a stand-alone instrument that is a basic two-wire I-V curve tracer. It is capable of measuring four quadrant I-V signals within ±10V and ±10mA. The procedure for obtaining an I-V graph is as follows:
2. Select a diode and place it on the DMM readout of the ELVIS II across the DUT+ and DUT- terminals shown in Fig. 14. Connect the anode end of the device to DUT+ (row 29) and the cathode end to DUT- (row 30).
3. Set the current limits to ±10 mA and the voltage sweep range from 0V (start) to 1.2V (stop) with increments of 0.10V.
4. Run the tool.
5. Comment on how this characteristic plot compares to that of an ideal diode.

Half-Wave Rectifier
6. Construct the half-wave rectifier circuit shown in Fig. 5. Use a 5-V peak, 1-kHz sinusoidal voltage for $v_i$. Observe the output voltage $v_o$ on an oscilloscope and sketch it. Be sure that the AC-GND-DC switch (input coupling) for CH1 and CH2 are both set to DC to avoid shifting of the waveforms in a vertical direction. Can the diode turn-on voltage be estimated by looking at the output voltage waveform? If so, what is your estimate of it?

Clippers
7. Construct the clipping circuit shown in Fig. 6. Let $V_R = 2$ V and the input voltage $v_i$ be a 5-peak, 1-kHz sinusoidal voltage. Observe and sketch the output voltage $v_o$. This circuit transmits that part of the $v_i$ waveform that is more negative than $V_R + V_T$.
8. Reverse the direction of the diode in the circuit of Fig. 6. Then, observe and sketch the output voltage $v_o$. How does this output voltage compare to that in step 7?
9. Construct the circuit shown in Fig. 7. Let $v_i(t) = 5.0\sin(377t)$ V (frequency = 60 Hz), $V_{r1} = 3.0$ V, and $V_{r2} = 2.0$ V. Sketch the output waveform $v_0(t)$ and show the maximum and minimum values of the output voltage.

Full-Wave Rectification (NOT REQUIRED BECAUSE IT DOES NOT SEEM TO WORK)
10. Construct the circuit shown in Fig. 12. Be careful to connect the diodes so that they conduct in the directions indicated. The 2.2-kΩ resistor is included to limit the current to a safe value. Apply a 5-V peak, 60-Hz sine wave and, using an oscilloscope, observe the voltage across the $a,b$ terminals. Examine the waveform, including amplitude and time values. (Note: This worked fine with the ELVIS I system that we used previously, but does not seem to work with our ELVIS II or the myDAQs. If you can figure out why it does not work and MAKE IT WORK, please let me know.)