

# **EXPERIMENT NUMBER 4**

## **Examining the Characteristics of Diodes**

### **Preface:**

- **Preliminary** exercises are to be done and submitted individually and turned in **at the beginning of class**
- Laboratory hardware exercises are to be done in groups
- The **Lab Report** is the **Lab Notebook**, and it can be written by any one member of the group
- The student-group **MUST** have the data and answers acquired during the lab and entered in the **Lab Notebook** verified by the TA before they leave the class
- Failure to show the **Lab Notebook** to the TA, will result in no score for **Lab Report** for the entire group
- **Tech Memo** to be done in Word Doc according to the format uploaded on CANVAS and submitted by individual students at the **beginning of the next class**
- Review the guidelines for plagiarism to be aware of acceptable laboratory and classroom practices.

Diodes are common nonlinear circuit components. Here we will experimentally investigate the current-voltage (I-V) characteristics of diodes and the use of diodes in rectifier and limiter circuits.

### **Objectives:**

- Obtain the I-V curves of a signal diode and a zener diode
- Compare the performance of different rectifier circuits

### **References:**

- EE 121 Handouts
- EE 151 and EE 153 text: Cunningham and Stuller, *Circuit Analysis*, 2nd Ed. (Houghton Mifflin Company, Boston, 1995).

### **Curve Tracer Setup Parameters**

#### ***Tektronix 577 Curve Tracer settings for 1N4002 and 1N4739:***

- 1.) *C connection to Diode Anode*
- 2.) *E connection to Diode Cathode*
- 3.) *Max Peak Volts to 25V and 0.6Watt*
- 4.) *Collector Supply Polarity to AC*
- 5.) *Collector Voltage Percentage to Max*
- 6.) *Horizontal Volts/Div to 2V for 1N4739, and 5V for 1N4002*
- 7.) *Display Buttons – Norm and Norm*
- 8.) *Emitter/Base Grounded to Emitter Short*
- 9.) *Vertical Current/Div to 20mA*

#### ***King Instruments Curve Tracer (KI-3020A) and Oscilloscope settings for Diode Measurement:***

### **OSCILLOSCOPE:**

*Save/Recall Button -> Default Setup*

*Menu/Zoom Button -> XY*

### **KI-3020A:**

*Horizontal -> X or Oscilloscope Channel 1*

*Vertical -> Y or Oscilloscope Channel 2*

*Polarity Knob -> Diode*

*V Knob -> 20V*

*H Length Knob fully Clock Wise*

*Connect Diode following diagram on tracer panel*

*Selector Switch to side using*

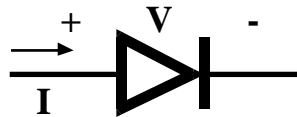
*Power ON*

*Adjust Oscilloscope V/div, Time/div, and Horizontal Position accordingly XY Origin denoted on the oscilloscope display at the left and top*

## **Background:**

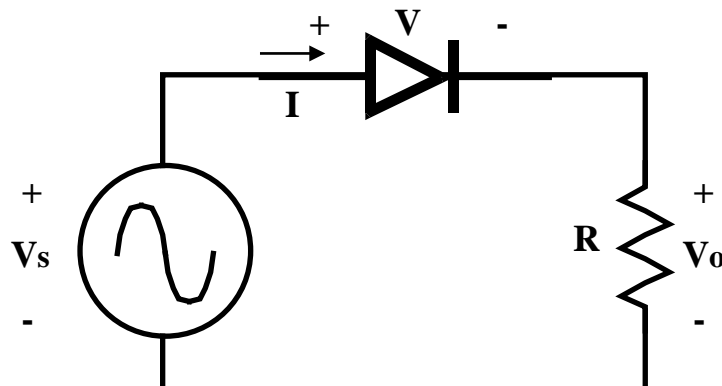
### **Diodes and Diode Circuits**

A diode is a two-terminal nonlinear device that performs differently under forward and reverse bias. Figure 1 shows a diode with typical current direction and voltage polarity. Its behavior approximates a short circuit for positive voltages and an open circuit for negative voltages. For forward bias (positive  $V$  and positive  $I$ ), the diode can conduct a large current with a relatively-small turn-on voltage. For reverse bias (negative  $V$  and negative  $I$ ), the diode supports a relatively-constant small current regardless of voltage. A large increase in diode current at a specific negative voltage is a result of breakdown effects. Diodes designed to operate with a specific, abrupt breakdown voltage may be known as zener diodes.

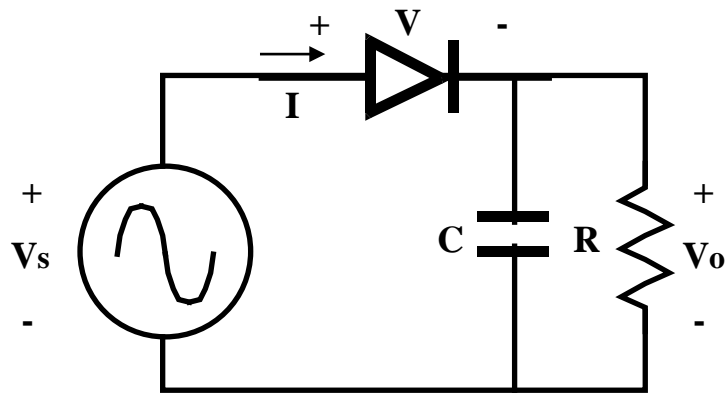


**Figure 1 - Diode**

A diode-based rectifier is shown in Figure 2. A half-wave rectifier will be setup in this experiment and it rectifies only the positive half of the wave. The addition of a capacitor as shown in Figure 3 improves the operation and converts AC waveforms to DC waveforms.

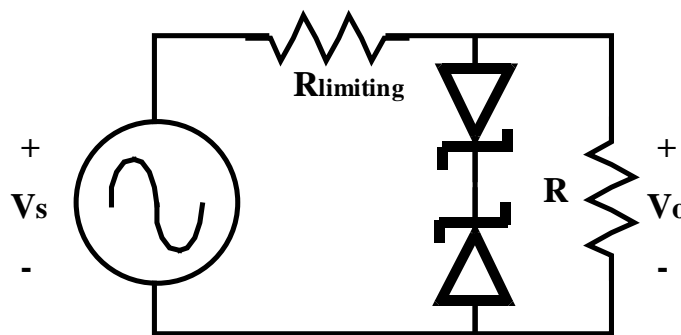


**Figure 2 – Half-Wave Rectifier**



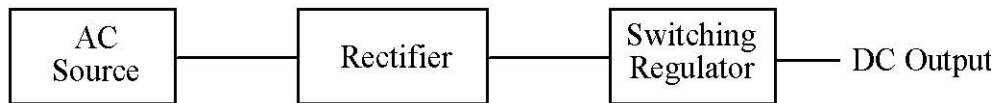
**Figure 3 – Half-Wave Rectifier with Capacitor**

Another use of diodes, especially zener diodes, is as a limiter. Figure 4 shows a case in which reverse-bias breakdown of zener diodes limit the voltage swing across the load resistor. A single zener diode would limit the swing in one direction only.

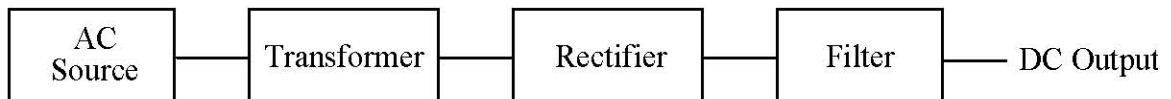


**Figure 4 – Diode Limiter with Zener Diodes**

Most electronics are run from a DC power supply. The 60-Hz AC power from a wall outlet is often converted to DC, such as 6 V or 9 V DC, using a rectifier built from diodes. The block diagrams for such “adaptors” are shown Figure 5. A goal of this experiment is to design and build a power source to supply 9.1 V DC to a load resistor which is nominally 2 k $\Omega$ . Our design will be of the "transformer-rectifier-filter" type.



**Figure 5 a – Block Diagram for AC-to-DC Converter**



**Figure 5 b – Block Diagram for AC-to-DC Converter with a Step-down Transformer**

## Transformers

The following discussion is oversimplified, but sufficient for the purposes of this laboratory. You will learn more about diodes and transformers in your electrical engineering courses.

A transformer is basically a ferrous (typically iron or steel) core with two or more coils of wire wound around it. The coils are linked by the magnetic flux through the core. One of the major uses of a transformer is to change the voltage level of an AC signal. A transformer can either step up (increase) or step down (decrease) an input voltage.

Consider a transformer with two coils (See Figure 6). One coil (the primary coil) consists of 500 turns of wire while the other coil (the secondary coil) consist of 50 turns. If we apply 120 V AC (all values are rms) to the primary coil of this transformer, we will measure 12 V across the secondary coil. (Note that the ratio of the secondary voltage to the primary voltage equals the ratio of the number of turns in the secondary to the number of turns in the primary.) If we now place a  $12\text{-}\Omega$  resistor across the secondary, a 1-A current ( $12\text{ V} / 12\ \Omega$ ) will flow through the secondary coil and through the resistor. If the transformer is ideal, it will consume no power, so that the power supplied by the secondary ( $12\text{ V} \cdot 1\text{ A} = 12\text{ W}$ ) will be the same as the power entering the primary. Since the voltage across the primary is 120 V, the primary current must be 0.1 A. Thus, in a transformer with an  $N:1$  turns ratio, the secondary voltage will be  $1/N$  times the primary voltage, but the secondary current will be  $N$  times the primary current. This is the step down process.

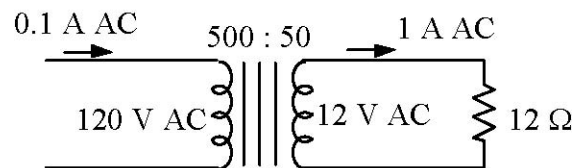


Figure 6 – Transformer

## Preliminary:

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

- Give an approximate sketch of the expected voltage waveform  $v_L(t)$  for the circuit shown in Figure 7. The source produces a sinusoidal waveform with a maximum voltage of 12.6 V. Assume that the diode has a turn-on voltage of 0.7 V and that the reverse saturation current is approximately zero.

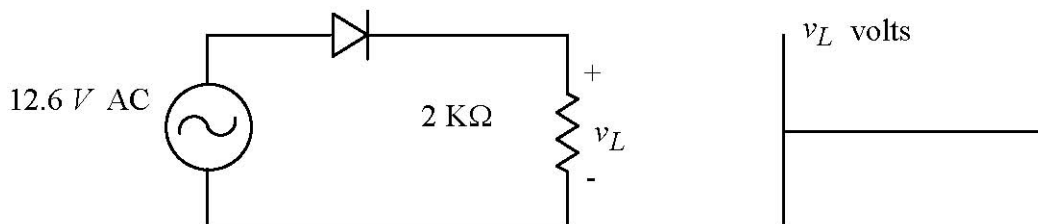
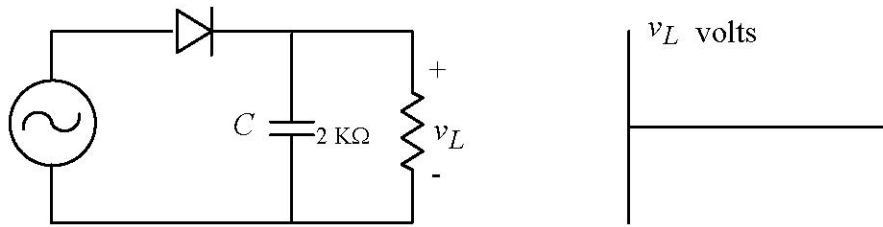


Figure 7 – Half-Wave Rectifier

- Now suppose a capacitor  $C$  is connected in parallel with the load as in Figure 8. Calculate a suitable value for  $C$  so that the RC time constant is about  $\sim 0.02$  seconds.

Give an approximate sketch of the expected  $v_L(t)$  waveform when  $C$  is added to the circuit. Qualitatively speaking, what is the role of a capacitor in this circuit?



**Figure 8 – Half-Wave Rectifier with Capacitor**

### Equipment:

Transformer  
Breadboard  
Oscilloscope  
Digital Multimeter (DMM)  
Curve Tracer  
1N4002 diode  
1N4739 zener diode  
Resistors

### Experimental Procedure:

(Record specifics in the Laboratory Notebook.)

**Note: Unplug the transformed when not in use.**

1. Use the curve tracer to determine the I-V curve of the 1N4002 diode. Plot or sketch the I-V curve showing the turn-on voltage explicitly.

*Q1: What is the approximate forward-bias turn-on voltage?*

2. Use the curve tracer to determine the I-V curve of the 1N4739 zener diode. Plot or sketch the I-V curve showing the turn-on voltage and the breakdown voltage explicitly.

*Q2: What are the approximate forward-bias and reverse-bias turn-on voltages?*

3. Plug the transformer into the wall and measure the voltage at the secondary side of the transformer using an oscilloscope. Save and record the waveform.

*Q3: Record the values for maximum voltage  $V_{max}$ , the minimum voltage  $V_{min}$ , the peak-to-peak voltage  $V_{pp}$ , and the average (DC) voltage  $V_{avg}$  (DC value).*

Note: You should notice that the DC value of the sine wave is almost zero.

4. Next, build the circuit shown in Figure 7 using the secondary voltage as the AC source and using a 1N4002 diode and a of 2-k $\Omega$  resistor. Measure the load voltage  $v_L(t)$  with an oscilloscope. Save and record the resulting waveform.

*Q4: Record the values for maximum voltage  $V_{max}$ , the minimum voltage  $V_{min}$ , the peak-to-peak voltage  $V_{pp}$ , and the average (DC) voltage  $V_{avg}$  (DC value).*

*Q5: Does the rectifier serve an acceptable DC source?*

Note: This half-wave rectifier rectifies only the positive half of the input sine wave.

5. Add a capacitor in parallel with the load as shown in Figure 8. Measure, save, and record the waveform for  $v_L(t)$ .

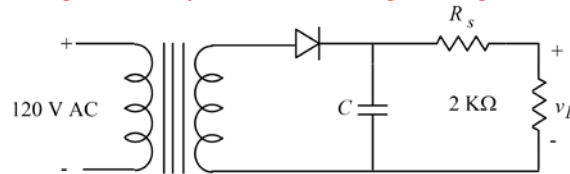
*Q6: Record the values for maximum voltage  $V_{max}$ , the minimum voltage  $V_{min}$ , the peak-to-peak voltage  $V_{pp}$ , and the average (DC) voltage  $V_{avg}$  (DC value).*

Note: The peak to peak voltage,  $V_{pp}$ , you observe is the AC signal riding over the DC signal and is called the ripple voltage.

6. Say you are required to build a DC power supply with an approximate DC output level of 9.1 V, at a load of 2 k $\Omega$ . The current setup obviously has a  $V_{avg}$  of more than 9.1 V. The excess voltage can be removed using a simple voltage divider circuit. Calculate the value of the resistor  $R_s$  (you might have to use a collection of resistors in series) as shown in Figure 9 required to obtain a 9.1 V output with a 2-k $\Omega$  load and add it to your circuit. Measure, save, and record the waveform for  $v_L(t)$ .

*Q7: Record the values of  $V_{pp}$  and  $V_{avg}$  (DC value).*

*Q8: Measure the average value of the load voltage using a DMM and record the value.*



**Figure 9 – Half-Wave Rectifier with Voltage Divider**

7. A good DC power supply should provide the desired set voltage at any reasonable load resistance. Observing the variation of load voltage with respect to a change in the load resistance provides a measure of performance of the DC power supply. Replace the load resistance by a decade resistance box initially set to 2 k $\Omega$ . Vary the load resistance from 100  $\Omega$  to 100 k $\Omega$  and note the load voltage (Take at least 8 readings).
8. Add a 9-V zener diode in parallel with the 2-k $\Omega$  load resistance in Figure 9 and repeat the measurements in step 7.

*Q9: Is the zener diode an effective limiter?*

### Technical Memorandum:

- Memorandum discussion:
  - (1) Describe, based on your observations, the I-V curves for the 1N4002 diode and the 1N4739 zener diode. Are the transitions for forward-bias turn-on and reverse-bias breakdown abrupt? How well do the theoretical diode equations and piecewise equivalent circuit models match the experimental behavior.
  - (2) Describe, based on your observations, the use of the various half-wave rectifier circuits to produce a DC waveform from an AC waveform. How did the peak-to-peak voltage change with the addition of the capacitor? (The varying signal around the average value is called a ripple voltage.) Does the rectifier serve an acceptable DC source (Q5)?
  - (3) Describe, based on your observations, the variation of output load voltage with load resistance. Is the zener diode an effective limiter (Q9)?
- Appendix 1: Record the sketch or plot of the I-V curve for the 1N4002 diode and the 1N4739 zener diode. State the approximate turn-on voltage for the 1N4002 diode and the approximate turn-on voltage and breakdown voltage for the 1N4739 zener diode (Q1 and Q2). Mark these voltages on the I-V curves.
- Appendix 2: Record the sketch of the oscilloscope waveform for (a) the transformer output in step 3, (b) the half-wave rectifier output in step 4, and (c) the half-wave rectifier with capacitor output in step 5. Tabulate the maximum voltage, the minimum voltage, and the average (DC) voltage associated with the waveforms in a, b, c (Q3, Q4, and Q6).
- Appendix 3: Show the calculation for the resistor  $R_s$  that is needed to create a voltage divider with a 9.1-V output across the 2-k $\Omega$  load resistor (step 6). Record the sketch or plot of the oscilloscope waveform for the resulting circuit and list the associated maximum voltage, the

minimum voltage, and the average (DC) voltage (*Q7*). List the DMM voltage measurement (*Q8*) and compare to the oscilloscope value (percent difference).

- Appendix 4: Tabulate the load voltage as the load resistance varies from 100  $\Omega$  to 100 k $\Omega$  (step 7) for at least eight resistance values to include 2 k $\Omega$ . Tabulate the load voltage for the circuit with a parallel zener diode as the load resistance varies from 100  $\Omega$  to 100 k $\Omega$  (step 8) with the same resistance values.