EXPERIMENT 5 : *DIODES AND RECTIFICATION*

Component List

- Resistors, one of each
    - 2   10Ω 10W
    - 1   1kΩ
    - 1   10kΩ
- 4   1N4004 (I_{max} = 1A, PIV = 400V) Diodes

- Center tap transformer (35.6V_{pp}, 12.6 V_{RMS})
- 100 µF Electrolytic Capacitor
- 5, 10, 50, and 1000µF Caps.

Introduction

Until now, we have focused on passive elements, i.e., elements through which current is linearly proportional to voltage. We will now begin our study of non-linear devices with the diode.

The ideal diode has the following characteristics:

- In the <u>forward</u> bias direction, the diode acts like a wire, passing current with no voltage drop across the diode.
- In the <u>reverse</u> bias direction, the diode acts like an open circuit, passing no current for any amount of reverse bias.

Figure 1 is a typical plot of an ideal device showing current versus voltage in both forward and reverse biased directions. Real diodes only approximate this behavior and look more like Fig. 2.
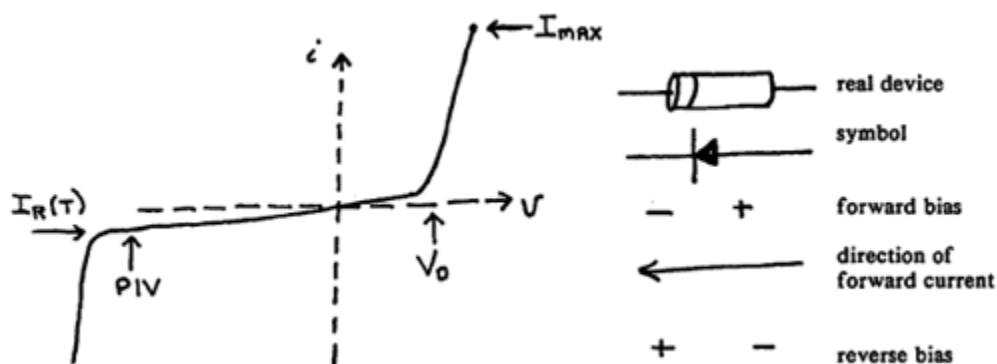

Figure 5.1 Ideal diode

Figure 5.2 Semiconductor PN junction diode characteristic and symbol

We are interested in the solid state PN junction diode which has the following type of characteristics. The diode's symbol is an arrow with a bar, the arrow indicates the direction in which <u>positive</u> forward current flows. Figure 2 shows the positive forward bias needed to make the diode conduct, V_D, and the peak inverse voltage rating of the diode, PIV, beyond which the diode also conducts. Note that exceeding PIV is destructive (non-reversible breakdown) to many diodes. The small reverse current, $I_R(T)$ is typically 10 pA for a silicon diode at room temperature and rapidly increases with increasing temperature.

For example, at high temperatures (~ 200°C) the junction no longer acts like a diode and passes in both directions. The diode's temperatures will rise as current flows through the diode. Excessive temperature rise can be controlled either by limiting the power the device dissipates for current in the forward direction or by employing a heat sink. The first approach implies a maximum current, Imax, for the diode in the forward direction.

The real diode we will use is a 1N4004 (400 V PIV, I_{max} = 1 A) and the white line at one end indicates the direction in which positive forward current flows.
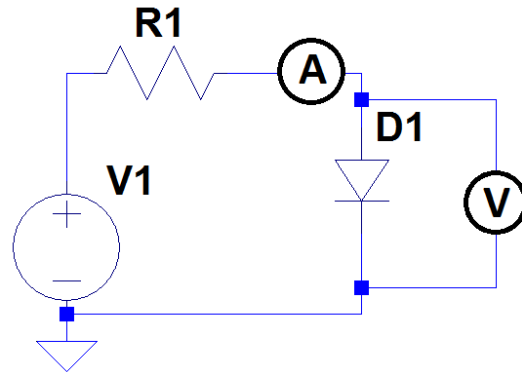
Figure 5.3 Circuit to measure the forward bias part of a diode's characteristic curve. Flip the diode for reverse bias operation.

Part I: Diode Characteristics

1. Set up the following circuit with the voltmeter, on the 4 VDC scale. Use the protoboard to mount the diode. The 10Ω 10W resistor limits the current, regardless of what the diode does.
2. Slowly increase the power supply voltage from zero. Record on the data sheet representative values of voltage *across the diode* versus current *through the diode*. Do not exceed 1000 mA.
3. Power down.
4. Graph I vs V and estimate V_D. From your graph fit a line to the data at very small currents and a second line for the data points at high currents. Use these to estimate the effective resistance of the diode before it becomes conductive (R_{off}) and after (R_{on}).
5. Now add to the circuit to a 10 Ω resistor in parallel with the diode. Use two ammeters to measure the current through: the diode and through the new 10 Ω resistor. Use your knowledge of how resistors add in parallel to estimate the effective resistance of the diode before and after it becomes conductive from this data. For simplicity evaluate the diode resistance at the point when its current is 1mA and when it is 100 mA.

Question: How do your results from the parallel current divider circuit compare to what you found from the series arrangement?

Part II: Half Wave Rectifier

Power generators usually produce AC voltages since they are most convenient for power transmission. On the other hand many devices require DC voltages. Rectifiers produce DC from AC (which usually has no DC component) by redirecting the AC current flow in such a way as to produce a DC component, then to filter out the remaining AC component. The diode in Figure 5.4 is a rectifier as you will verify.

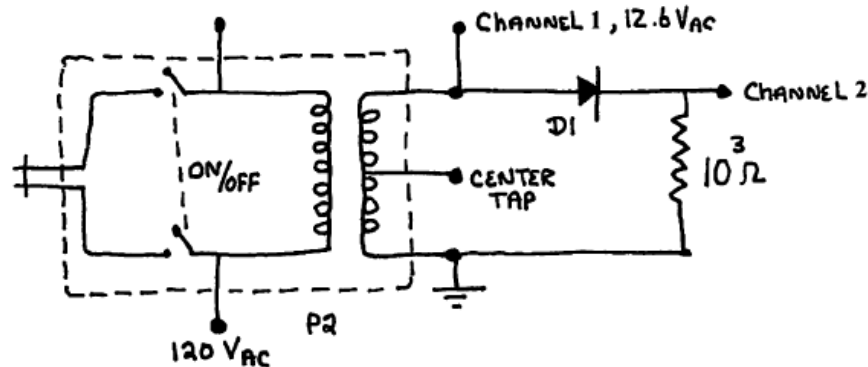1. Construct the following circuit. Switch your oscilloscope to DC coupling.

Figure 5.4 Center Tap Half Wave Rectifier

The transformer converts 60 Hz 120 V RMS line voltage in the primary to 12.6 V RMS across the secondary. The secondary has a center tap which can split the secondary into two 6.3 V RMS parts. The secondary is isolated from the primary. By grounding the bottom of the secondary (see Fig. 5.4), point 1 will be positive during a half cycle, then negative in the following half cycle.

2. Use your scope to observe the voltage at point 1.
3. Now observe the voltage across the resistor at point 2. Make sure that the scope is DC coupled. (See what happens when the scope is AC coupled.) Draw the waveform at the 2 output.
4. This is an example of a half wave rectifier. Reverse the direction of the diode and draw the waveform at the 2 output.

Both configurations are called half-wave rectifiers; i.e., for one polarity the diode conducts and the input signal appears across the resistor, while for the opposite polarity the diode does not conduct and the input appears across the diode.

This half-wave rectified signal can be filtered to produce a DC voltage voltage but it is only half as strong as it could be if it used the full wave.

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Part III: Full Wave Rectifier

Here are two example of full-wave rectifiers. Figure 5.5 shows a center-tap full-wave bridge rectifier. For half a cycle the top loop is forward biased, the D_1, diode conducts. In the next half cycle the bottom loop is forward biased, the D_2 diode conducts. Either way the current passes through the resistor in the same direction as the load receives both half cycles with the same polarity. Note also that the rectified voltage across the resistor is the center tap peak voltage which is equal to one-half the peak secondary voltage.

1. Construct the circuit in Fig. 5.5 using the secondary's center tap. DC couple your oscilloscope.
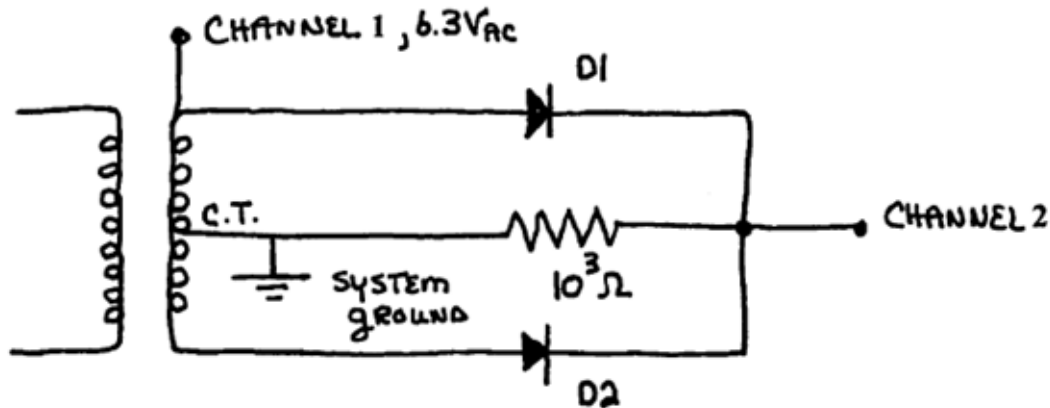2. Draw the resultant waveform across the resistor.

Figure 5.5 Center tap full wave bridge rectifier

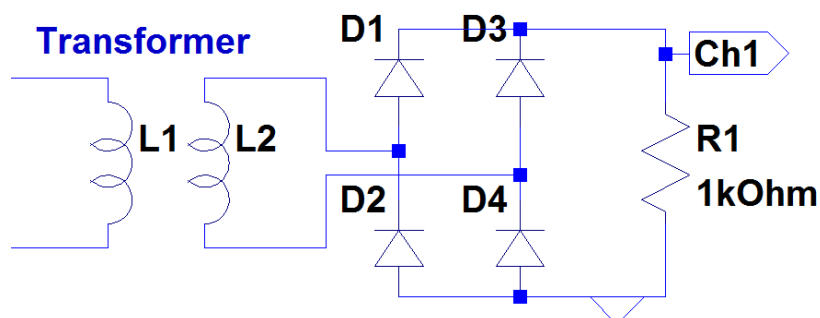3. We can rectify the full secondary voltage with a bridge rectifier as shown in Fig. 5.6.

Figure 5.6 Full-wave bridge rectifier. This yields a higher output voltage than the center-tap full-wave bridge rectifier.

Note from the figure that opposite pairs of diodes steer the current through the resistor during alternate half cycles, pushed through (D_1, D_4) then pulled through (D_2, D_3). Either way the current only flows in one direction through the resistor. Finally, the rectified voltage is the full voltage of the secondary.

4. Make a sketch of the waveform and then leave this setup as is for the moment.

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IV. The RC Filter

Now that we have a rectified signal, we would like to convert it into a DC signal with as little AC ripple as possible. A simple technique for low current cases is the capacitance filter. Consider the effect of placing a 100 µF capacitor across the load resistor, initially uncharged.
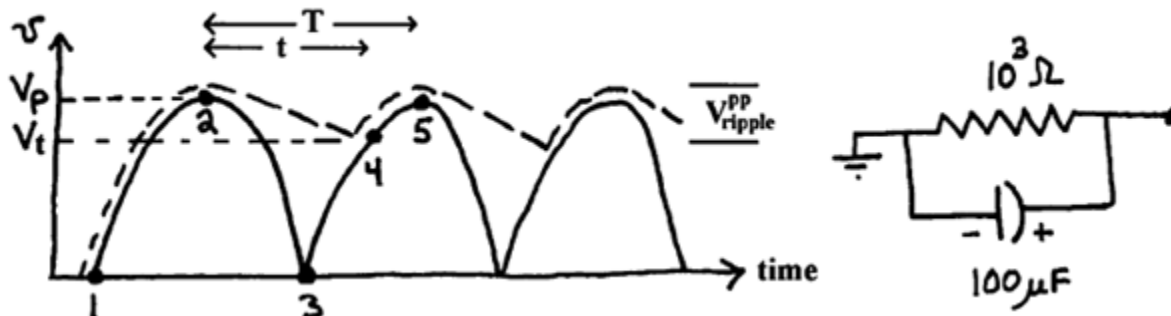

Figure 5.7 Effect of an RC filter on a full wave rectifier

On the very first half cycle as the secondary voltage rises from point 1 to 2 (solid line), diodes D_2 and D_4 are forward biased and conduct, current flows through the resistor, and the capacitor is charged up to V_P. As the secondary voltage falls towards point 3, the capacitor cannot discharge its positive charge through diode D_2 or D, since they are reverse biased; thus, the voltage at point A does not follow the secondary. (A similar argument follows for the negative charge and diodes D, and D_4.) However, the capacitor can discharge through

$$v(t) = v_p e^{-t/\tau} \tag{1}$$

where the time constant in this case is $\tau = RC = 1k\Omega\ 100\mu F = 100ms$. At the same time, the period of the full wave rectified signal is half that of line voltage, $T = \frac{1}{2f} = \frac{1}{120Hz} = 8.5\ ms$. Thus, the RC time constant is much longer than the period of the full wave rectified signal, i.e. $T \ll \tau$. Since $t \sim T$, we can make the approximation that

$$v(t) \cong v_p \left(1 - \frac{t}{\tau}\right) \quad or \quad V_T \cong v_p \left(1 - \frac{T}{\tau}\right) \tag{2}$$

over a half cycle. The capacitor discharges linearly until the secondary voltage reverses itself and climbs to point 4 at which point diodes D_1 and D_3 conduct and recharge the capacitor back up to V_P at point 5. Then the whole process repeats itself (dotted line).

The AC peak-to-peak ripple voltage is just

$$V_{ripple}^{pp} = V_p - V_T = \frac{V_p\ T}{\tau} \tag{3}$$

Since the desired output is simply a DC voltage you can specify how imperfect your real output is by comparing the size of the ripple voltage to the average voltage.

$$\frac{V_{ripple}^{pp}}{V_{DC}} \tag{4}$$

1. Determine the ratio in Eq. 4 experimentally for R = 1kΩ and 10kΩ. When you connect the 100µF capacitor to the full wave bridge, be sure to observe the proper polarity. To measure a small AC ripple riding on a large DC background, switch to AC coupling on your oscilloscope. With the DC component blocked you can increase the gain of the oscilloscope to measure the peak-to-peak ripple voltage.

2. Replace the capacitor by either a decade capacitor box or another electrolytic capacitor as needed so that we can now vary the time constant of the RC filter. Using R=1kΩ adjust the capacitor to 4 µF, 8 µF, 50 µF, and 1000 µF. For each value calculate the time constant τ = RC. Measure V_P and V_T for each value of the capacitor. Sketch a graph of the wave form that you see in each case being sure to label all relevant values for the voltages.

Question: Explain why the waveforms look like they do in each of the four cases you explored in the last part of the experiment.

Note that the DC voltage and the ripple factor depend on the load. How they change with load is a measure of the regulation of the power supply. We will find latter that there are ways of improving the regulation of DC power supplies.

Prelab Questions:

1. How many diodes does it take to build a half-wave rectifier?
2. How many diodes does it take to build a full-wave bridge rectifier?

NAMES_____

Part 1:

V$_D$ (Volts)	I$_D$ (mA)
-5	
-4	
-3	
-2	
-1	
0	
.1	
.2	
.3	
.4	
.5	
.6	
	50
	100
	200
	300
	400
	600
	800

Estimate of resistance

	From graph	From parallel circuit
R$_{off}$		
R$_{on}$		

Part II: Half-wave rectifier sketches

Part III: Full-wave rectifier sketch

Part IV the RC fliter

	$R_1 = 1k\Omega$	$R_1 = 10k\Omega$
V_{DC}		
V_{ripple}^{pp}		
ratio		