

EXPERIMENT 5 : *THE DIODE*

Component List

- Resistors, one of each
 - 1 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

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

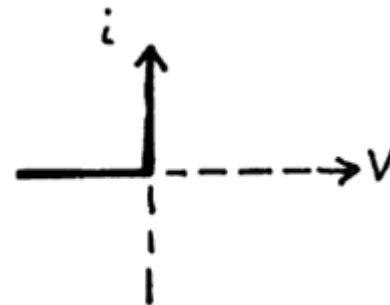


Figure 5.1 Ideal diode

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.

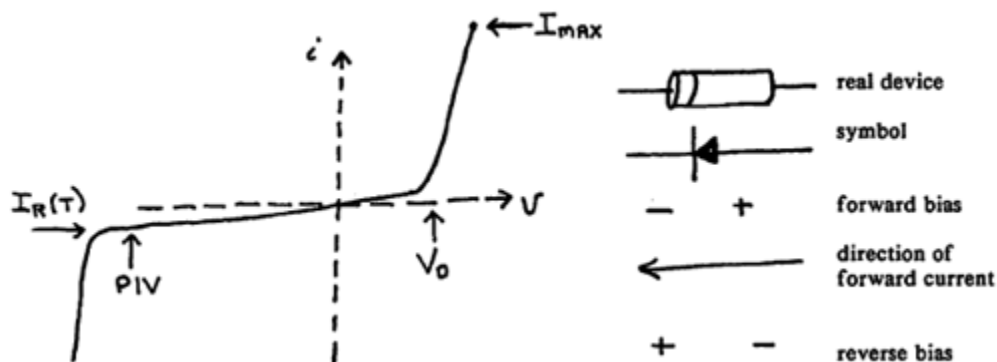


Figure 5.2 Semiconductor PN junction diode characteristic and symbol

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 positive 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 ($\sim 200^\circ\text{C}$) 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, I_{\max} , for the diode in the forward direction.

The real diode we will use is a 1N4004 (400 V PIV, $I_{\max} = 1 \text{ A}$) and the white line at one end indicates the direction in which positive forward current flows.

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 .

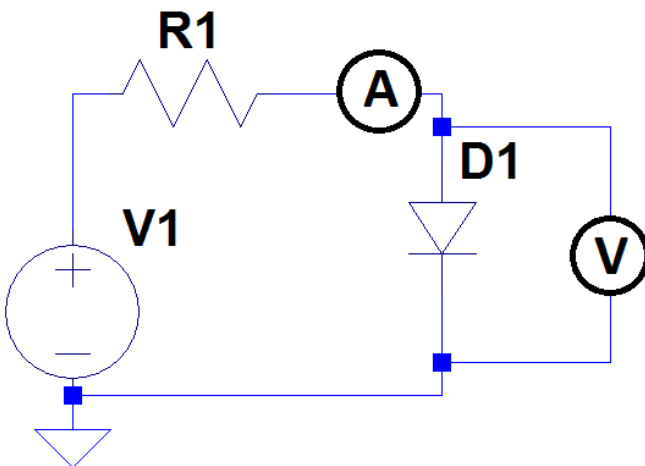


Figure 5.3 Circuit to measure the forward bias part of a diode's characteristic curve. Flip the diode for reverse bias operation.

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.

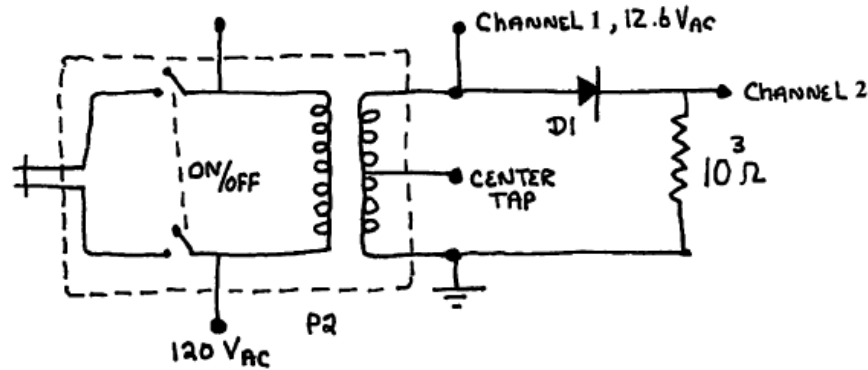


Figure 5.4 Center Tap Half Wave Rectifier

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 but it is only half as strong as it could be if it used the full wave.

Part III: Full Wave Rectifier

1. Construct the following circuit using the center tap of the secondary. DC couple your oscilloscope.
2. Draw the resultant waveform across the resistor.

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. In either case the current passes through the resistor in the same direction; thus, both half cycles are presented to the load 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.

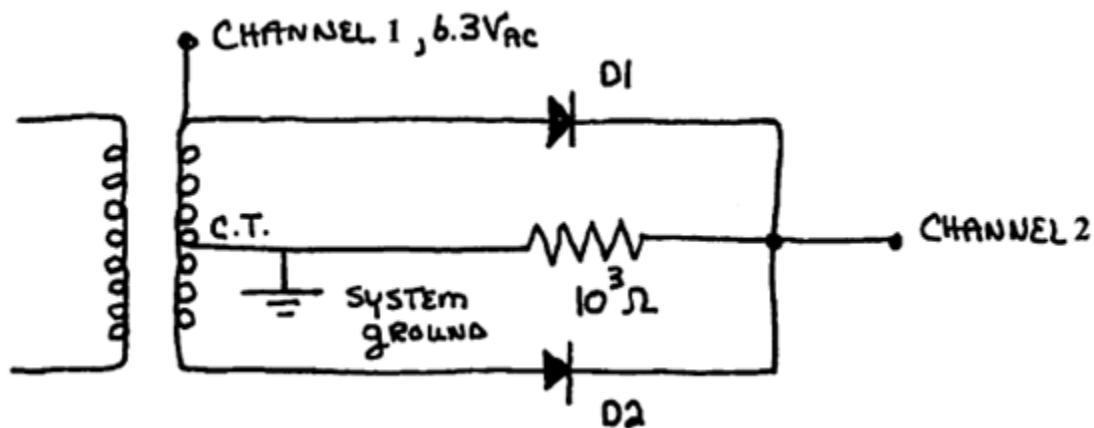


Figure 5.5 Center tap full wave bridge rectifier

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

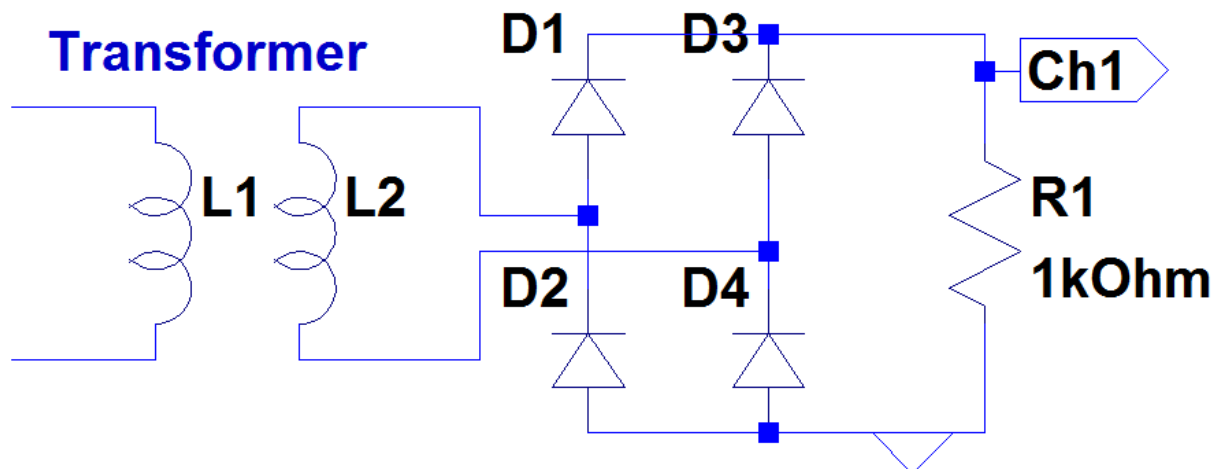


Figure 5.6 Full-wave bridge rectifier. This yields a higher output voltage than the center-tap full-wave bridge rectifier.

Note from the figure that opposite pairs of diodes steer the current through the resistor during alternate half cycles, pushed through (D₁, D₄) then pulled through (D₂, D₃). Either way the current only flows in one direction through the resistor. Finally, the rectified voltage is the full voltage of the secondary.

4. Leave this setup as is for the moment

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.

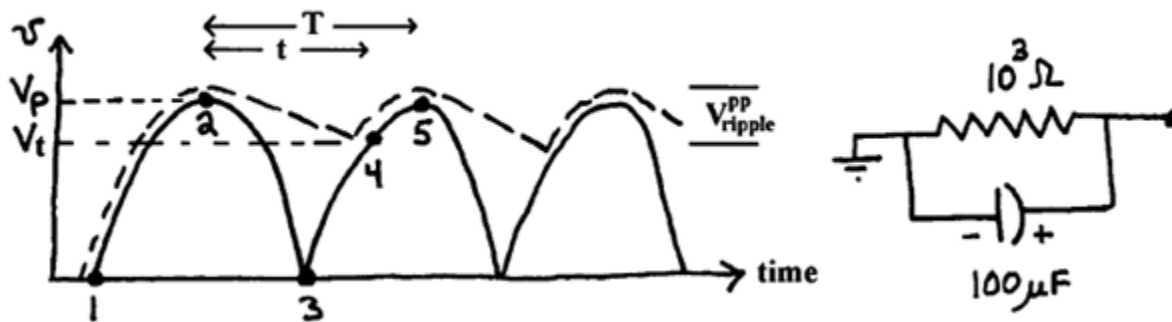


Figure 5.7 Effect of an RC filter on a full wave rectifier

On the very first half cycle as the secondary voltage rises from point 1 to 2 (solid line), diodes D₂ and D₄ 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 D₂ or D₄, 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 D₁ and D₃.) 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

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

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

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

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.

$$\frac{V_{ripple}^{pp}}{V_{DC}} \quad (4)$$

1. Determine the ratio in Eq. 4 experimentally for $R = 1k\Omega$ and $10k\Omega$. When you connect the $100\mu F$ 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.

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 later that there are ways of improving the regulation of DC power supplies.

Prelab Questions:

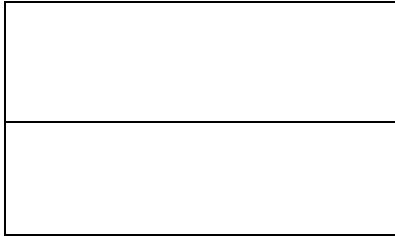
1. How many diodes does it take to build a half-wave rectifier?
2. How many diodes does it take to build a full-wave bridge rectifier?

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

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		