Diodes: Experiment Guide

Components required for this lab:

1. **1N4148 diode (x 1)**
2. **1k resistor (x 1)**
3. **1M resistor (x 1)**
4. **22u capacitor (x 1)**
5. **10M resistor (x 1)**

I. Diodes Overview

Diodes are mostly used in practice for emitting light (as Light Emitting Diodes, 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" (or $v_{threshold}$) 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 1N4148 diode should have the same threshold voltage (around 0.6 volts) 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. Don't feel bad if you haven't studied pn junctions before; it is not required for this lab. The I-V graph for an ideal diode looks like:

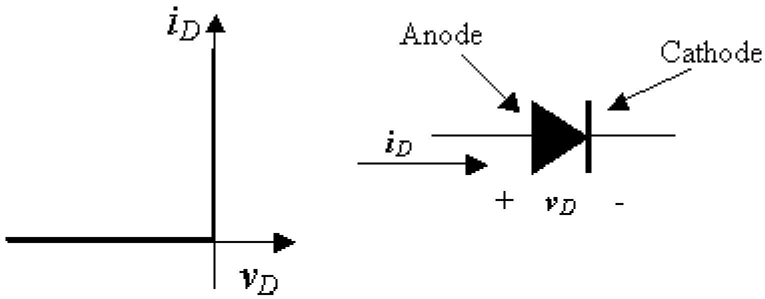

Figure 1. Ideal Diode I-V Curve and Symbol

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 have a low reverse threshold – you will deal with them later). We will see shortly that the behavior of diodes is actually somewhat like a switch, and so there are some easy ways to analyze circuits with diodes in them.

II. Diode I-V characteristics

The I-V graph for a non-ideal diode is shown in figure 2, along with an ideal approximation to accommodate the non-zero threshold voltage. The diode will be easier to understand if we compare the diode to another two terminal device we know (and love) the resistor.

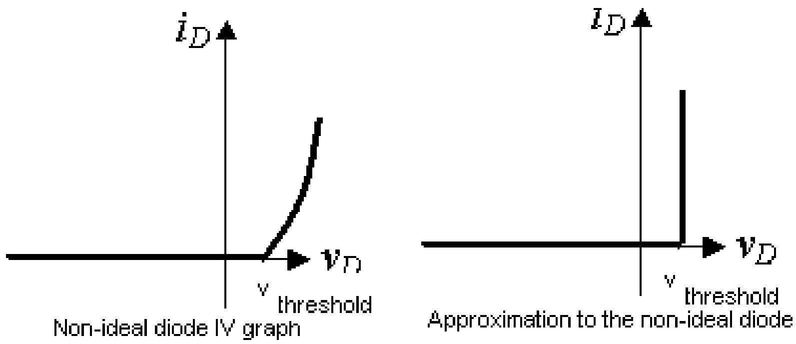

Figure 2. Non-Ideal Diode I-V Curve and an approximation to the non-ideal diode

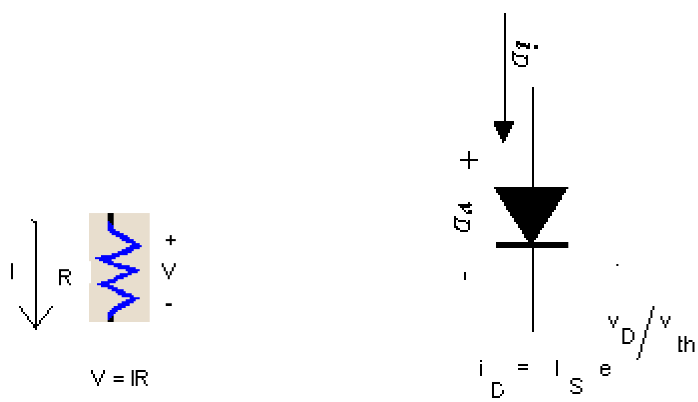

Figure 3. The resistor vs. the diode

From figure 3, we see that both diodes and resistors are two terminal devices. However, their I-V characteristics are very different. An equation that models the I-V characteristic of a non-ideal diode is shown below.

$$\begin{aligned} i_D &= I_S e^{\frac{v_D}{v_{th}}} \quad && \text{if } v_D \geq v_{threshold} \\ &= 0 && \text{if } v_D < v_{threshold} \end{aligned}$$

If v_D is greater than $v_{threshold}$, then the diode is said to be forward-biased or it is said to be in the forward-biased region. If not, the diode is said to be operating in reverse-bias. Also, in the equation above:

- I_S is a constant called the reverse bias saturation current and is approximately equal to 1×10^{-11} A
- V_{th} is a constant called the thermal voltage (**this is different from the threshold voltage**) and is approximately equal to 26 mV at room temperature.

So, what makes a diode hard to deal with? The diode equation above is very hard to solve in practice because it is non-linear. For instance, let us try and solve for the voltage across the resistor (Vload) in figure 4 if Vin = 3 V and R=1k:

$$Vload = i(1k)$$

The current through the resistor is the same as the current flowing through the diode. However, we first have to figure out if the diode is on (current is flowing through it) or off (no current flows through the diode). You can't readily tell since you don't know the voltage across the diode. If you did, you could compare it to the threshold voltage. Usually, you don't know the voltage across a diode. Thus, there are no hard and fast rules for determining whether a diode is on or off. A standard method is to use the ideal diode model first to figure out which diodes in a circuit are on and which are off. Then, if necessary, you solve for the exact value of the current through the diode. Let us assume the diode is on. Then, the current through the diode is:

$$i = I_S e^{\frac{v_D}{v_{th}}}$$

and v_D is 3 – Vload (KVL). Thus, we have to solve the following equation:

$$\frac{Vload}{1k} = (1x10^{-11}).e^{\frac{(3-Vload)}{26mV}}$$

The above equation is a recursive non-linear[1] equation. Mathematical techniques for solving the above equation are beyond the scope of this class. I solved the equation above using my calculator and obtained:

$$Vload \approx 2.497 \text{ volts}$$

Solving non-linear equations in general is very difficult. You can imagine what would happen if we have multiple diodes in our circuit. Hence, the ideal model shown in figures 1 and 2 is very helpful. You usually use the model in figure 1. The approximation in figure 2 is used if we need to take into account the threshold voltage. The circuit models for figures 1 and 2 are shown below. Make sure you understand them. If you have any questions, ask your TA before the lab starts.

[1] It is recursive because the unknown variable is on both sides of the equation. It is non-linear because the function in the equation is not a straight line.

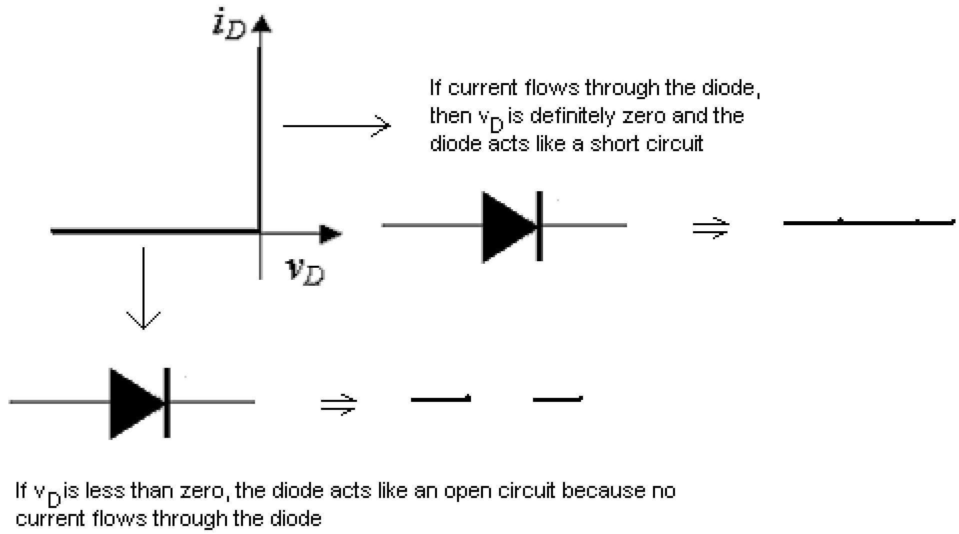

Figure 4. Ideal diode model without threshold voltage

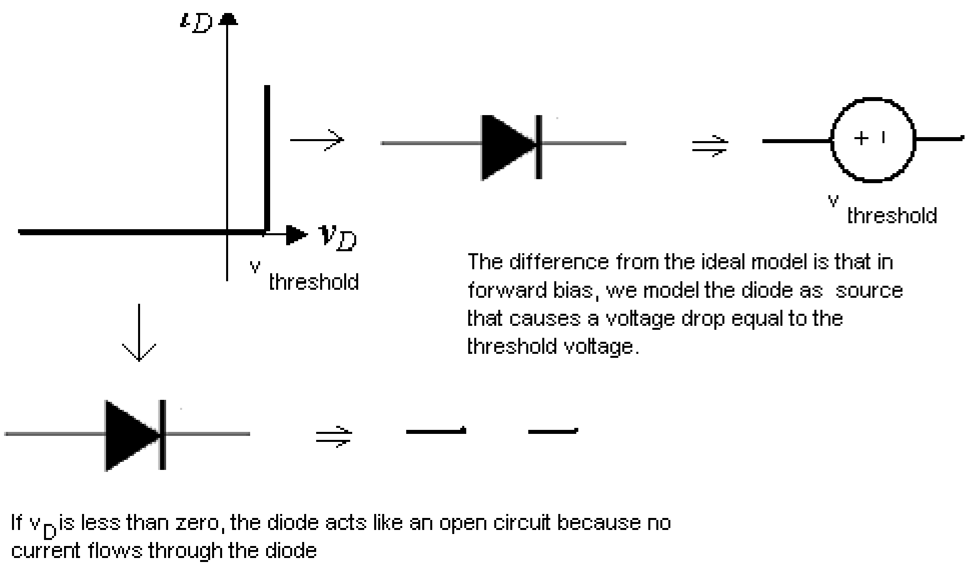

Figure 5. Ideal diode model with threshold voltage

One more property of the diode - looking at figures 4 and 5, if you think about the diode symbol as an arrow - you can infer that current can flow through the diode only in the direction of the arrow. Let us apply these two models and study the very practical diode circuit shown in figure 6 – the half-wave rectifier.

III. Half-Wave Rectifier

The half-wave rectifier is a circuit that allows only part of an input signal to pass[2]. 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 6 below).

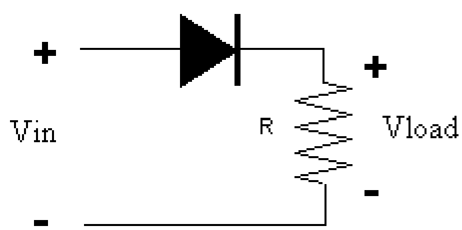

Figure 6. Half-Wave Rectifier Schematic

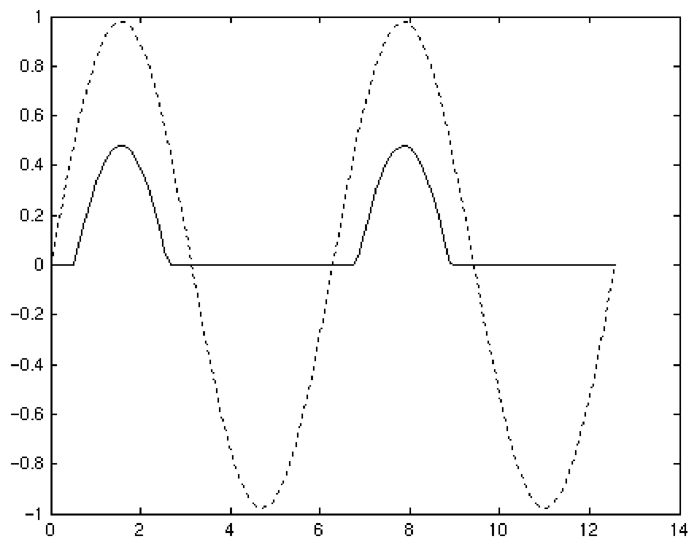

Figure 7. Half-Wave Rectifier, Voltage vs Time, Vload and Vin from figure 4 are plotted. The dotted line is the input sinusoid (Vin).

The output from the half-wave rectifier is shown in figure 7. We can see that if the Vin is greater than zero (corresponding to a positive half-cycle on the sinusoid), the diode is forward biased. Using the threshold voltage model from figure 5, we can redraw the circuit in figure 6 as:

[2] Rectifiers are circuits that convert AC to DC – you will learn how in the next section.

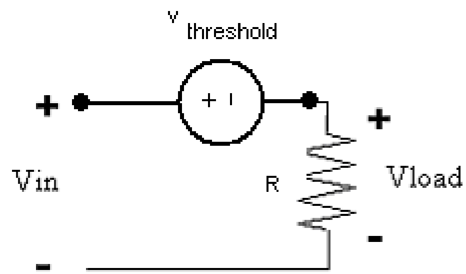

Figure 8. Half-Wave Rectifier with threshold voltage model when the diode is forward biased.

Hence, the effect of the diode is to drop a voltage of $v_{threshold}$ from the input. You can see this effect in figure 7, the peak Vload voltage is less than Vin by $v_{threshold}$. When the diode is reverse-biased, that is when the Vin is the negative half-cycle of the sine wave, the diode is off and hence it is modeled as an open circuit. Thus, the current flowing through the circuit is zero and Vload = 0. This explains what happens during the negative half-cycles of the sinusoid in figure 7.

IV. AC-to-DC converter

What is the use of the rectifier above? We can use it to convert AC voltage to DC voltage. In fact, most of the power supplies that plug into your wall outlet (like computers, blenders, microwave ovens etc.) do exactly this. A simple AC-to-DC (AC-DC) converter is shown below. Of course, the converters in computers and blenders are much more complex, but the fundamental circuit is still the same:

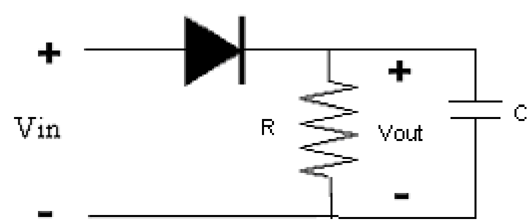

Figure 9. AC-DC converter

When the diode is forward biased, it just drops a $v_{threshold}$ from Vin. Hence, the capacitor charges and Vout increases. When the diode is reverse biased (during the negative half-cycle of the input sinusoid), the diode is open. Hence, the capacitor discharges through the resistor. The trick in the AC-DC converter is to have a very large time constant (RC value) as compared to the period of the input sinusoid. This ensures the capacitor does not loose any voltage before the next charging cycle.

V. Hands On

Part One: Half-Wave Rectifier

1. Build the half-wave rectifier circuit drawn in figure 6. Use a 60 Hz, 2 Vpp input signal with no offset (i.e. set the function generator to 0 offset and 1 Vpp). Let R=1k. **Note: You must be very careful with the function generator settings. If you have the output too high with a low resistance resistor (or if you have no resistance connected), you risk burning out the diode.** Show the completed circuit to your TA for check off.

2. a. Figure out how to use the multimeter to measure the threshold voltage of the diode.

   b. Measure the threshold voltage of the diode from the scope by measuring the voltage difference between the peak of the input signal and the peak of the output signal.

   c. Calculate the error between the multimeter value and your measured value. Explain to your TA how you are able to measure the threshold voltage of the diode from the scope.

Part Two: AC-DC converter

1. Build the AC-DC converter shown in figure 9. Use the same input[3] as Part One, use R=1M and use C=22uF. Calculate the time constant of the circuit. Have your TA checkoff your working circuit.

Part Three: EXTRA CREDIT (4 points)

1. Rebuild the half-rectifier, but use a 10M resistor for R. Look at the output waveform on the scope. You will see the negative end of the sinusoid is not completely clipped. Briefly explain why.

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[3] Of course, your wall outlet (that real AC-DC converters use) has a 120V output – we can't get that much volts out of our function generator and it is dangerous. Hence, we use 2 V.