Lab 3: The Junction Diode

1 Purpose

In this lab you will study the operation of a junction diode, and design/analyze several diode circuits and applications.

2 Introduction

The diode is the first semiconductor device that you will become familiar with, in this course. Its operation is relatively simple compared to other semiconductor devices and as a result, it is a good introduction for students beginning to study semiconductor devices.

Before doing this lab, please review the material on diodes and the applications that are covered in the class and read Chapters #3 & #4 of Microelectronic Circuits, Sedra & Smith, 6th edition, 2010.

2.1 Characterization and Modelling of Diodes

The relationship between the current through (I_D) and voltage across a diode (V_D) is nonlinear in nature and is accurately given by the diode equation. The diode equation predicts fairly accurately the operation of the diode in forward and reverse bias. It is given by:

$$I_D = I_s(e^{\frac{V_D}{nv_T}} - 1)$$

where I_S is the saturation current and V_T is the thermal voltage. Diode equation is **nonlinear** in nature and computationally expensive to evaluate. However, when working in a practical design environment, highly accurate models may not be the requirement, rather how fast we can evaluate these models and how easily these models can be embedded in circuit simulators may be of importance. In other words, often we may be required to have an approximate model for quick analysis purposes.

In this experiment we will study and compare the accuracy of different types of diode models. For most applications, any one of the simpler models listed below can be used.

2.1.1 Ideal diode Model (Zero Voltage Drop Model)

Here we assume that the diode conducts when the applied voltage is above zero volts (short circuit) and is an open circuit for below 0 volts as shown below.

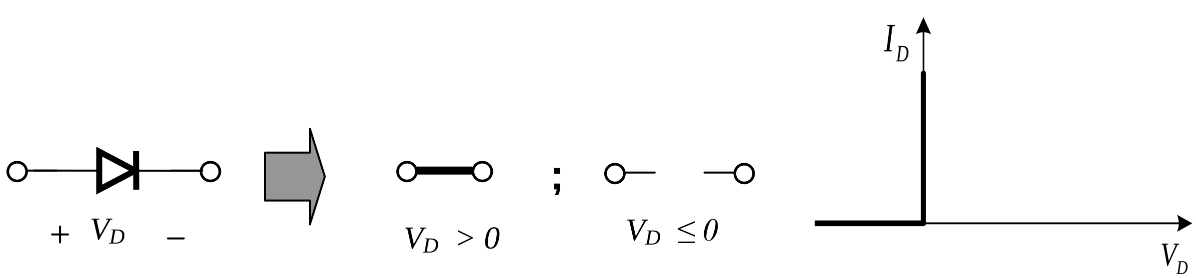

Fig. 1. Ideal Diode Model and the Corresponding Characteristics

This model is not very often used because it is too simplistic. However, a practical diode doesn't conduct until a forward voltage of approximately 0.7V is applied. This is not captured in the above model.

2.1.2 Constant Voltage Drop Model (Battery Model)

This is same as the previous model except the diode is assumed to conduct at 0.7V instead of 0V, which is the typical turn-on voltage for a silicon based p-n junction.

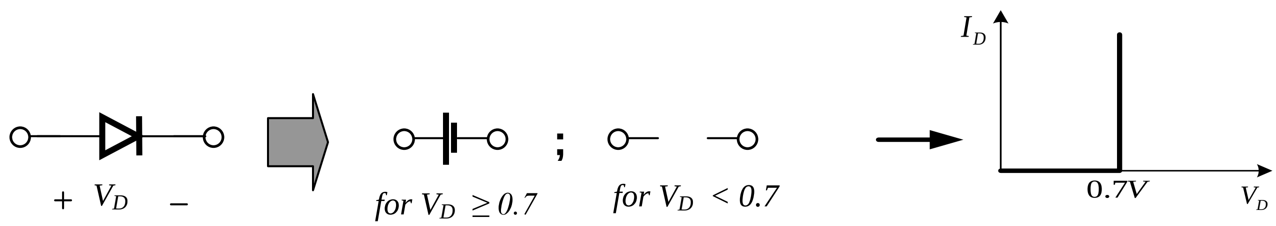

Fig. 2. Constant Voltage Drop Model and the Corresponding Characteristics

The constant voltage model is quite useful when trying to obtain approximate waveforms of circuits with diodes as switches or for quickly visualizing how a circuit consisting of diodes functions.

2.1.3 Constant Voltage Drop + Resistor Model (Battery + Resistor Model)

This model consists of not only a constant voltage drop, but also a resistor which represents the linear approximation of the diode characteristics after it starts conducting in forward bias mode.

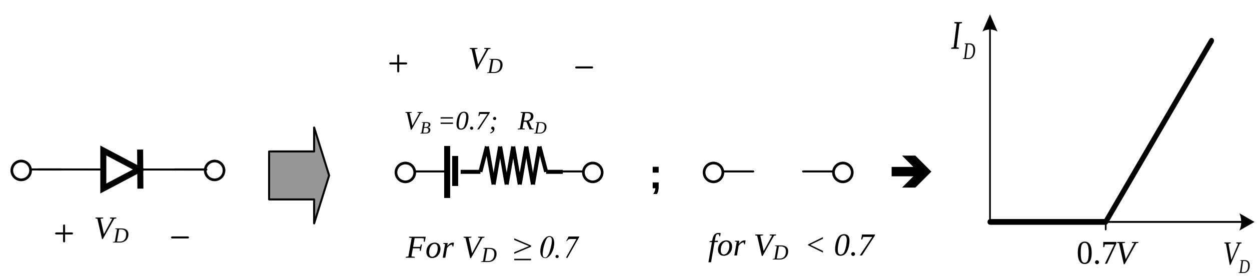

Fig. 3. Constant Voltage Drop + Resistance Model and Characteristics

As can be seen, this model provides relatively better approximation while being simple and linear in nature. This model is often used in circuit analysis to represent diodes where more accuracy is required than provided by other models in 2.1.1 & 2.1.2

2.2 Diode Applications

You will experiment with several useful applications of diode in this lab. They include rectifier, light emitting diode (LED), voltage regulator, clipping and clamping applications.

LEDs: A growing application for semiconductor junction diodes is in lighting applications. Direct-band-gap semiconductors generally emit in a narrow band of wavelengths and can efficiently convert current to light output. Incandescent bulbs generate significant output at infrared wavelengths and therefore suffer from lower efficiency. Note that silicon has an indirect band-gap and is not well suited to making light emitting devices. Recent advances in manufacturing high power, highly reliable white and blue diode sources has led to a rapid increase in the availability of consumer products using light emitting diodes (LED's). For higher brightness LED's are operated in a pulsed mode, however they are often operated from AC or DC sources. *A LED can be treated as a diode for circuit analysis, but the voltage drop will NOT be the same as for a silicon diode.*

For more information on diode applications, refer to class notes and the diode chapters in the text book.

2.3 Lab Organization

In this lab, you will explore the battery+resistance model for the diode. In the pre-lab, you will assume a voltage and resistance and make calculations based on that. In the lab, you will measure voltage and current values and calculate actual resistance values for the diode. The final part of the lab deals with rectifier and clipper applications for the diode.

3 Pre-lab Preparation:

3.1 For the circuit in Fig. 4, assume a load resistance R_L =270Ω, and a source resistance R_S =50Ω. Assuming a "*battery (0.7v) + resistance (20 Ohms) model"* for the diode (see Fig. 3 & section 2.1.3) complete the entries of Table-1 for input voltages between -5V and +5V in 1V steps. Plot the diode I-V characteristics (I_D v/s V_D) and also V_L *v/s* I_L, using the data points from this Table.

TABLE 1.

V_L	V_D	$I_L = I_D$

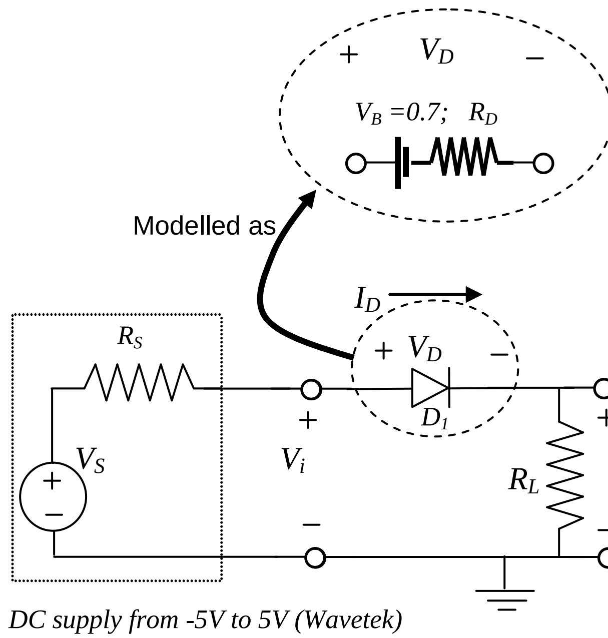

Fig. 4. Diode circuit with source and load

3.2 The current through the LED in the circuit shown in Fig. 5, should be kept below 10 mA. Choose an appropriate value for R_L (Choose R_S =50Ω; and LED forward bias drop of 1.5V).

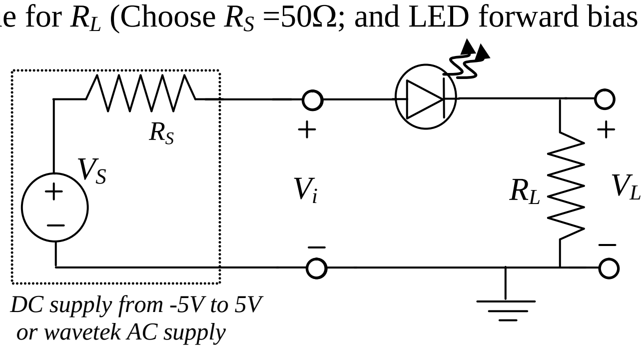

Fig. 5. LED circuit with source and load

3.3 Explain briefly the operation of a bridge rectifier circuit. In Fig. 6, output of the transformer is sinusoidal AC with10.6V (rms) amplitdue and acts as an input to the bridge rectifier circuit. Sketch the output waveform of the bridge rectifier circuit (V_L), assuming the *battery (0.7v) model* for the silicon diodes.

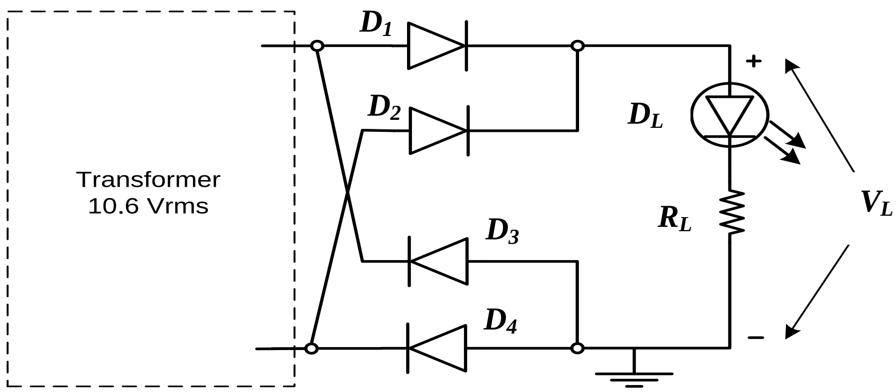

Fig. 6. Bridge Rectifier (full-wave rectifier) Circuit

3.4 Assuming a Zener voltage of 12V for the Zener diode (ignore zener resistance) and forward bias drop of 0.7V, sketch the shape of the output waveform for the circuit in Fig. 7.

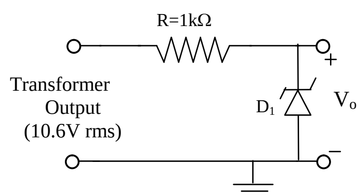

Fig. 7. Zener Diode Circuit

3.5 It is required to design a DC adapter circuit. Apart from the circuit blocks in Fig. 6 & Fig. 7, what other blocks do you think are necessary to achieve this. Make a sketch of the possible circuit configuration for this purpose and explain each block briefly.

3.6 Assuming the *battery (0.7v) model* for diodes, sketch the shape of the output waveform for circuits in Fig. 8, for a sinusoidal AC input with10.6V (rms) amplitdue (which is the output of the transformer). Also draw the transfer characteristics for each of the circuits. Clearly mark the amplitude levels.

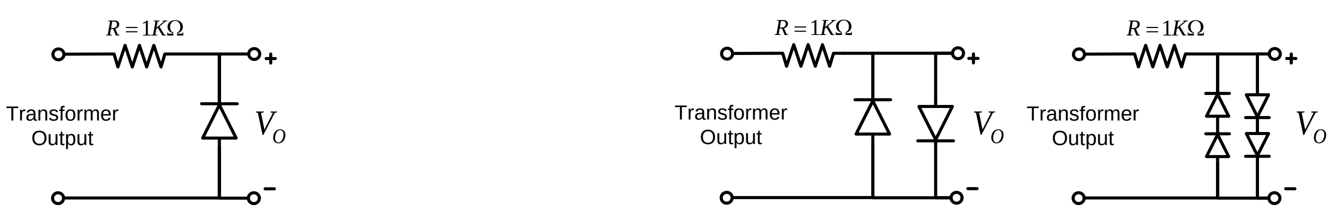

Fig. 8. Limiter Circuits

4 Experiment

Equipment:	Oscilloscope:	Tektronix TDS3012
	Transformer:	110 V:10.6V
	Function Generator:	Wavetek 182 A
	DC Power Supply:	DOE FG515
	Multimeter:	Wavetek DM15XL
Parts:	270 Ω and calculated resistors, Light emitting diode of any color, 4 x 1N4006 or similar diodes, 12V Zener diode	

4.1 Diode Characteristics & Simplified Models

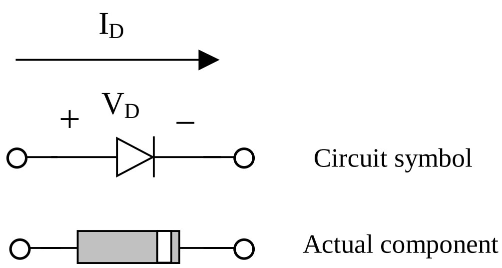

Fig. 9. Diode: Symbol & Direction Flow

4.1.1 Build the circuit as shown in Fig. 4, with D1 chosen as diode 1N4006 and R_L = 270 Ω. Note from Fig. 9, on how to indentify the p and n terminals of a diode.

4.1.2 Turn on the Wavetek function generator. Make sure all the function buttons are out, which will give a variable DC output controlled by the DC offset knob. Check the voltage with the Multimeter, and set it to –5V (use the HI output on the generator).

4.1.3 Connect the Wavetek generator to port 1, as shown in Fig. 4. Vary the source voltage V_S from -5V to 5V in 1V steps and using the multimeter, measure the voltages V_D and V_L. Make a table similar to the one shown in Table-1 and enter measured values for V_L, V_D and calculated values for load current $I_L=V_L/R_L$, and effective diode resistance $R_D=V_D/I_D$. (off course you'll need to make the table larger!)

4.1.4 Plot the diode I-V characteristics of the diode (I_D v/s V_D), using the data points from Table 1 and compare it with your pre-lab results from Table 1.

4.2 Applications: LED light source

A LED can be treated as a diode for circuit analysis, but the voltage drop will NOT be the same as for a silicon diode.

4.2.1 Connect the circuit as shown in Fig. 5, where D1 is your LED and R_L =270 Ω.

4.2.2 Use the Wavetek generator as a variable DC source, and estimate the forward bias voltage drop for your LED (V_{DO}).

4.2.3 Switch the generator to the AC sinusoidal source (turn off the DC offset!). Set the amplitude to 5V and the frequency to about 5 Hz. Use the oscilloscope to view the voltage V_L (you may have some trouble triggering at the low frequency, and you'll need a large time scale). Sketch $V_L(t)$ in your lab book. Record your observations about the behaviour of the LED.

4.2.4 Reduce the amplitude of the AC signal to about 400-500 mV. Increase the DC offset until the DC current through the diode is 5mA. Comment on the behaviour of the LED. Find the AC resistance ($r_d = v_{ac}/i_{ac}$) for the diode.

4.3 Bridge (Full Wave) Rectifier

The circuit in Fig.5 turned the diode on for only half the period of the AC signal, and acted as a half wave rectifier. We can make a circuit which runs the device for the full period using the bridge rectifier (full wave), which can increase the power supplied to the lamp.

4.3.1 Construct the circuit shown in Fig. 6. Choose a value close to the value calculated in 3.2 that will keep the diode current below 10 mA.

4.3.2 Observe and sketch the output voltage waveform $V_L(t)$ (**DO NOT try to display 10.6 volts AC along with output (if you do so you may be shorting D4 in Fig. 6)**.

4.3.3 Measure the average dc voltage output.

4.4 Limiter Circuits

Limiter circuits are used to limit the output levels of general waveforms. They are also some times referred as clippers (some part of the output waveform is clipped).

4.4.1 Construct the circuits shown in Fig. 7 and Fig. 8.

4.4.2 Observe and sketch the output voltage waveforms. It is most convenient and accurate to use the constant voltage drop model for your sketches.

4.4.3 Comment on the results.