

Experiment 8  
Diodes

**Purpose:** This objective of this experiment is to become familiar with the properties and uses of diodes. We will first consider the I-V characteristic of a standard diode that we can use in the classroom. We will also see how the diode can work as a rectifier, which is an essential part of most DC sources that are driven by AC voltages. A serious problem with simple rectifiers is that the DC voltage they produce is dependent on the load. A common way to make the rectifier less sensitive to the load is to add some regulation. This we can do by utilizing the avalanching effect that occurs if we reverse voltage the diode too much. We will also see what kind of voltage limitation can be achieved with a forward biased diode. Such limitation of voltages is usually applied to protect circuit components.

Equipment Required:

- HP 34401A Digital Multimeter
- HP 33120A 15 MHz Function / Arbitrary Waveform Generator
- HP 54603B Oscilloscope
- HP E3631A Triple Output DC Power Supply
- Protoboard
- Resistors, Capacitors, Diodes, Zener Diodes
- HP Benchlink and OrCAD Capture and PSpice

Helpful links for this experiment can be found on the links page for this course:

<http://hibp.ecse.rpi.edu/~connor/education/EILinks.html#Exp8>

## Part A – The I-V Characteristic Curve

## Background

*Diodes:* An ideal diode is a device that allows current to flow in only one direction. The symbol of a diode, shown in figure A-1, looks like an arrow that points in the direction of current flow. The current flows through the diode from the anode to the cathode. The cathode is marked on a real diode by a band.



Figure A-1

A small positive voltage is required to turn a diode on. This voltage is used up turning the device on so the voltages at the two ends of the diode will differ. The voltage required to turn on a diode is typically around 0.6-0.8 volt for a standard silicon diode

*I-V Characteristic Curve:* In order to understand how a diode functions, it is useful to look at a plot of the voltage across the diode vs. the current through the diode. We call this type of curve and i-v characteristic curve. If we were to create an i-v curve of a resistor, where the current is directly proportional to the voltage ( $V=IR$ ), we would see a straight line with a constant slope or  $R^{-1}$ . When we plot the characteristic curve of an ideal diode (that switches on when the voltage across it goes above zero), we see zero current when  $v_D$  is negative and infinite current as soon as  $v_D$  tries to go positive. This is shown in figure A-2. Note that, when an ideal diode turns on, it is a short circuit and, therefore, the voltage across the ideal diode when it is on is always zero.

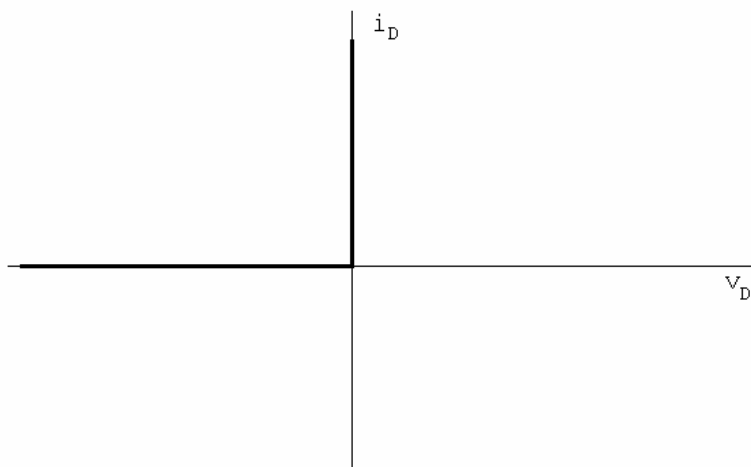


Figure A-2

*I-V Curve of a Diode:* Figure A-3 shows typical characteristics of a real diode.

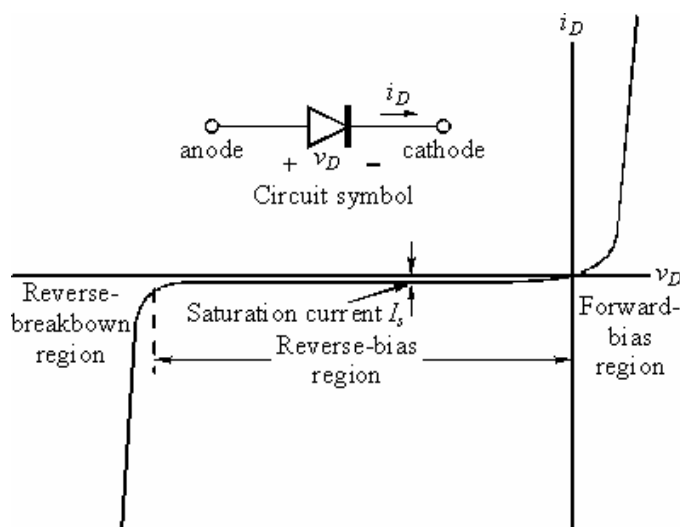


Figure A-3

Ideally, a diode is a device that allows current to flow in one direction only. In practice, diodes allow large amounts of forward current to flow when the positive voltage across them reaches a small threshold. They also have a small “saturation” current and a “breakdown” region in which a large amount of current will flow in the opposite direction when a large negative voltage is applied. In small signal diodes, the forward current will typically be up to a few tens of mA at a forward voltage of about 1 V. The reverse-breakdown voltage might be about 100 V, and the saturation current  $I_s$  may be of the order of 1 nA. Power diodes may allow forward currents up to many amps at forward voltage drops of 0.6 to 1.5 V or so, depending on the type of diode. The reverse-breakdown voltage of power diodes may range from as low as 50 V up to 1000 V or even much more.

*The Diode Equation:* The equation below gives a reasonably good representation of the  $i$ - $v$  characteristics of a diode.

$$i_D = I_s \left( e^{v_D/nV_T} - 1 \right)$$

$I_s$  is the saturation current, usually measured in micro, or nano amps.  $V_T$  is the Thermal Voltage [K in your book] where  $V_T = kT/q = 0.0259$  V at 300 K and  $n$  is a somewhat arbitrary parameter which depends on construction and usually lies between 1 and 2. Note that this equation characterizes the basic features of the diode  $i$ - $v$  curve, but leaves out some details like reverse breakdown, junction capacitance, etc.

## Experiment

### *I-V Characteristic Curve of a Resistor*

Now we will plot the voltage across a resistor vs. the current through the resistor.

- Wire the circuit shown in figure A-4 in PSpice.

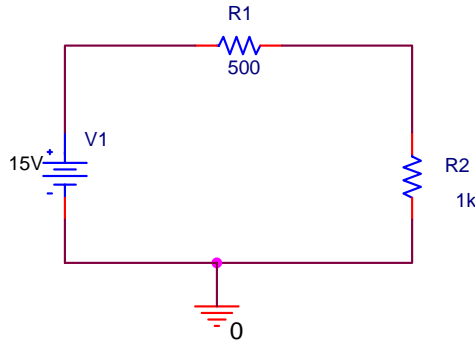


Figure A-4

- Run a simulation and create the  $i$ - $v$  characteristic curve
  - Set up a DC sweep from -15 to +15 volts in increments of 0.1 volt. (When you set up the DC sweep analysis, be sure that you name your source "V1.") *You do not need to add any probes.*
  - Run the simulation.
  - Select "Add Trace" to plot the current through resistor R1, I(R1). Recall that you must choose this current from the list you see when you use "Trace" and then "Add."
  - Change the x-axis of your plot as follows:
    - Right click on the plot and choose "Settings"
    - Then click on the X-axis Tab.
    - Click on the "Axis Variable" button at the bottom.
    - Enter V(R1:1)-V(R1:2) as the new X axis variable. This sets your x-axis to the voltage across the resistor R1, a value dependent upon the source voltage., which is sweeping from -15 to 15 volts.
    - The plot produced will show the I-V characteristic for resistor R1.
  - Your PROBE plot should look something like figure A-5:

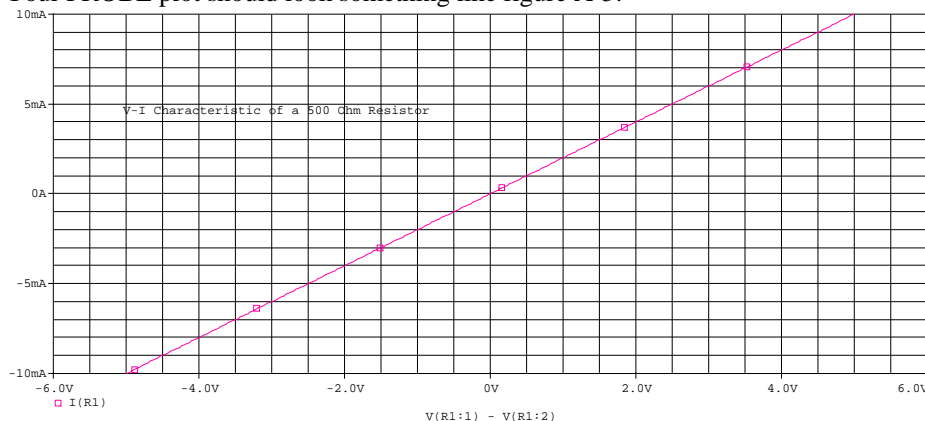


Figure A-5

*I-V Characteristic Curve of a Diode*

Now we will plot the voltage across a diode vs. the current through the diode.

- Modify your PSpice schematic by replacing R1 with D1, a D1N4148 diode, as shown in figure A-6. You will find this diode in the parts list. It is in the EVAL library.

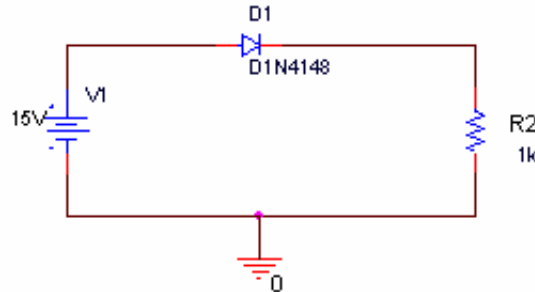


Figure A-6

- Run a simulation and create the i-v characteristic curve
  - Rerun the DC sweep simulation.
  - Select "Add Trace" to plot the current through resistor D1, I(D1).
  - Change the x-axis of your plot as follows (same as with resistor):
    - Right click on the plot and choose "Settings"
    - Then click on the X-axis Tab.
    - Click on the "Axis Variable" button at the bottom.
    - Enter V(D1:1)-V(D1:2) as the new X axis variable. This sets your x-axis to the voltage across the diode.
  - The plot produced will show the i-v characteristic curve for diode D1. It should look like the i-v curve for a real diode. If it looks upside down or backwards, change the sign of one or both of the parameters.
- Mark your plot
  - Using the cursors, mark at least 5 points off of this plot. You will be using these 5 points in Excel to help you plot the characteristic curve of the diode. Choose points that accurately represent the features of your curve.
  - Print your plot and include it in your report.

*I-V curve of a real diode*

In this part, we will build the simple diode circuit on your protoboard and use Agilent to take a data sample from the circuit itself. Then, you can use Excel to generate the i-v curve of the diode using the data from the diode itself.

- Wire the circuit shown in figure A-7 on your protoboard.

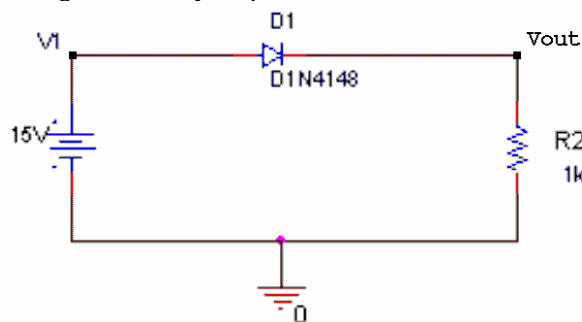


Figure A-7

- Diodes look like very small resistors with only one stripe. The stripe corresponds to the straight line of the diode symbol at the cathode. The D1N4148 diode should have a “48” written on it.
  - When you wire the circuit, make sure your diode is placed so that the cathode faces toward ground as shown in the figure above.
  - Do not place a DC voltage of 15 volts on the circuit, we will use the function generator to create a wave to represent the DC sweep.
- Create a DC sweep input signal.
    - Select the triangular waveform on the function generator, and connect it as the input voltage.
    - Select a slow repetition rate (frequency) of 100Hz, and a sweep from -10V to 10V.
    - Observe the signal on channel one of the scope to make sure it has the desired characteristics.
    - Adjust the scope so that you are observing at least one upward ramp of the input signal from -10V to 10V. This ramp represents our DC sweep. (Don’t show too many cycles or you will not get a good set of data.)
  - Measure the voltage across the diode
    - We cannot measure the voltage across the diode directly because the black lead of the scope must be grounded. We can however, measure the voltage on either side with respect to ground and then subtract them.
    - Place one channel of the scope at the input voltage (V<sub>1</sub>) and the other channel at V<sub>out</sub>.
    - Take a sample in Excel of the input and output voltages.
  - Match the diode equation to your data
    - Eliminate all points from your data except for one upward ramp of the input voltage. This represents a single DC sweep from -10V to +10V. [You can eliminate the data before and after simply by deleting the points from the excel file. Locate the point at which the voltage is about -10V and then find when it reaches +10V. You can eliminate all but the points in between these two values. If you have only a few points in this range, you may want to retake the data using more data points in Agilent or fewer cycles displayed on the scope.]
    - You can now use this data to plot the i-v characteristic of the diode. You need to plot the voltage across the diode against the current through the diode.
      - The voltage across the diode is equal to V<sub>1</sub>-V<sub>out</sub>. Create a row to take the difference between the two voltages.
      - Since the circuit is in series, the current through the diode is V<sub>out</sub>/R<sub>2</sub>.
      - This is a plot of your data from the circuit. You should plot this data as one series on a scatter plot. The x-axis of the data should be a column created by subtracting the two voltages (V<sub>1</sub>-V<sub>out</sub>). The y-axis should be a column found by dividing the output voltage (V<sub>out</sub>) by the value of the resistor in the circuit.
    - Now that you have a set of points corresponding to the behavior of the diode (*i<sub>D</sub>* and *v<sub>D</sub>*), you can use Excel and your PSpice plots to plot the behavior curve of the diode.

$$i_D = I_s \left( \exp \left( \frac{v_D}{nV_T} \right) - 1 \right)$$

- You need to add another series using the equation. Although you could use your experimental data points for *v<sub>D</sub>* (V<sub>1</sub>-V<sub>out</sub>), these probably will not give you enough points to get a good curve. Recall the process that you used to plot your data when you were finding the mass of the beam. You found an estimation for your constants, chose x values, and calculated y values. You can do the same here.
  - *Choosing values for v<sub>D</sub> to use in your calculations:* If you try to calculate the current for voltages all the way up to +10V, you will get current values so much bigger than the experimental data that you will not have any means of comparison. Try calculating points for voltages from 0V to 1V in increments of 0.01. (100 points)

- *Apply the equation:* You can now plug the values you chose for  $v_D$  into the diode equation. You can find an estimate for  $I_S$  from your PSpice data. Guess some value for  $n$  between 1 and 2.  $V_T$  is a constant:  $V_T = 0.0259$  V at 300 K
- *Plot the curve for the equation:* Add a second series to your plot with the values you chose for  $v_D$  on the x-axis and the calculated values for  $i_D$  on the y axis.
- *Limit the maximum calculated current:* Note the maximum current you get from the experimental data (the first series). After you have calculated the current using the diode equation, you probably will have to eliminate all points that exceed the experimental current by a significant amount in order to compare the two sets of data effectively.
- *Adjust the equation to get a good match.* Now you can adjust  $n$  and/or  $I_S$  until the curve gives a good match to the data points.
  - Use your PSpice plot of the diode characteristic curve to pick a good guess for  $I_S$ .
  - Guess values of  $n$  between 1 and 2 (and possibly modify  $I_S$  slightly) until the theoretical curve fits your data.
  - Include a copy of this plot in your write-up.

### Summary

A diode is a device that allows current to flow in only one direction. An ideal diode looks like a short when the current is flowing and an open circuit when the current is not flowing. A real diode has a small voltage across it when it is on, a small negative current through it when it is off, a region in which it switches from on to off, and a breakdown region where it stops blocking the current entirely. As long as the voltages we use do not reach the voltage of the breakdown region, the diode will work close to ideally.

## Part B – Diode Circuits: Rectifiers and Limiters

### Background

*rectifiers:* A rectifier is a circuit that converts an AC current to a DC current. At the very simplest level, a rectifier circuit is a circuit that takes an AC voltage and modifies it so that the output voltage has only one sign. It will eliminate either all positive voltage or all negative voltage. A true DC current requires a constant DC voltage. The rectifiers we can build with only regular diodes give a first approximation to this. We will continue to refine the rectifiers presented here in other parts of this experiment.

*half wave rectifier:* You have already built a half wave rectifier. If we had put a sign wave at the input to the circuit in figure A-7, you would have observed an output like the one shown in figure B-1.

### Half-wave rectifier circuit

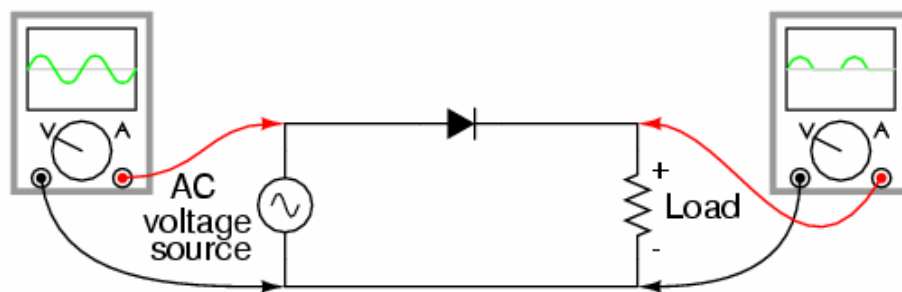


image from [www.allaboutcircuits.com](http://www.allaboutcircuits.com)

Figure B-1

The half wave rectifier uses the fact that the diode only allows current in one direction to eliminate the negative voltage of the input. Note that the current is not exactly DC, but the average of the signal is now positive and no longer zero volts.

*full wave rectifier:* We can use four diodes in a bridge configuration to create a rectifier that also uses the negative cycle of the signal. The output is shown in figure B-2.

Full-wave rectifier circuit  
(bridge design)

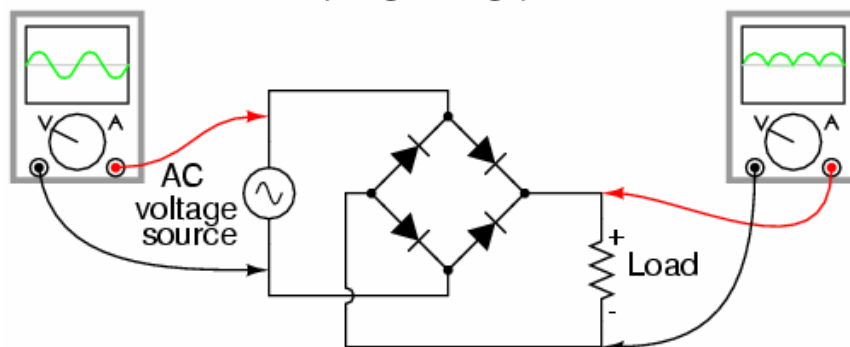


image from [www.allaboutcircuits.com](http://www.allaboutcircuits.com)

Figure B-2

In a full wave rectifier one pair of diodes allows current in one direction to flow through the load resistor. The other pair of diodes is arranged such that the current flows through the load *in the same direction*. This keeps the positive 1/2 of the input signal and inverts the negative half, resulting in the output shown. Note that the average voltage from this circuit is also positive, and (assuming the same input) its average voltage is greater than that of the half wave rectifier.

*smoothing capacitors:* You already know that an RC circuit has a characteristic charge and discharge rate. You should also be aware that larger capacitors charge and discharge more slowly than smaller ones. We can take advantage of the charge and discharge rates of capacitors in order to make the signal from our rectifier more like a DC voltage. As the signal in our rectifier increases, it charges the capacitor. As it decreases, the capacitor discharges. If the capacitor has a sufficiently long discharge rate, it will hold most of its charge until the next positive cycle of the input recharges it. This results in an output signal much closer to a true DC signal. Figure B-3 shows an input that has been rectified and then, smoothed with a capacitor.

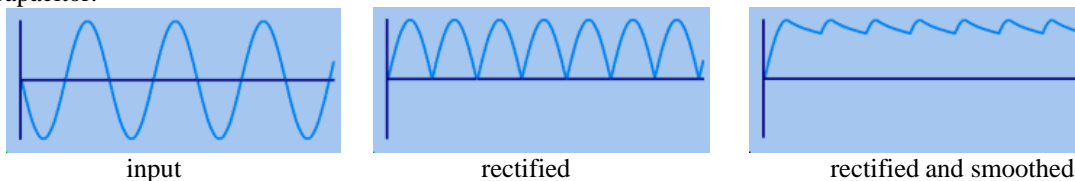


Figure B-3

*limiters:* The purpose of a voltage limiter is to prevent the voltage in a circuit from exceeding a certain level. These circuits are also called “*clippers*” because they clip the voltage signal off at a given level as shown in figure B-4. When you performed the triangular wave sweep of the 1N4148 diode, you should have observed that the voltage across the diode remained near 0.7 volts when it was on. We can take advantage of this effect to build a circuit that permits small voltages to pass without distortion, but clips any voltage outside the range of about -0.7 to 0.7 volts.

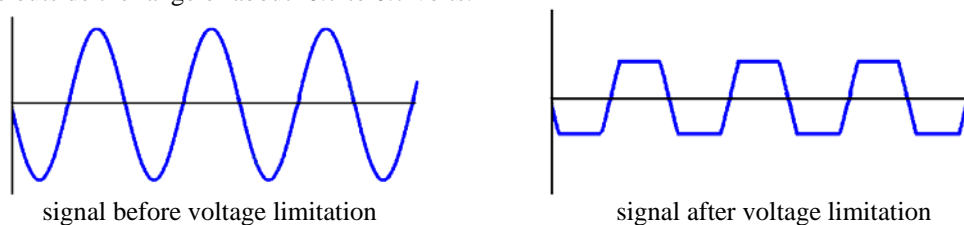


Figure B-4

**Experiment***PSpice Simulation of half wave rectifier with smoothing*

In this section, we will use a half wave rectifier to create a signal which maintains a fairly constant DC value by adding a smoothing capacitor.

- Create the circuit shown in figure B05 in PSpice:

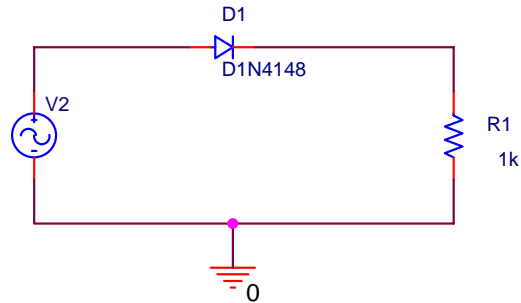


Figure B-5

- Use VSIN for the source. Use the following parameters for VSIN: VAMPL = 5 (10V peak to peak), VOFF = 0, and FREQ = 60Hz
- Run the simulation
  - Perform a transient analysis for 80ms in increments of 200us.
  - Obtain a graph of the input and output voltages,  $V_{in}$  (V2) and  $V_{out}$  (voltage across R), vs time.
  - Include this plot in your report.
- Add a capacitor across the resistor as shown in figure B-6 below:

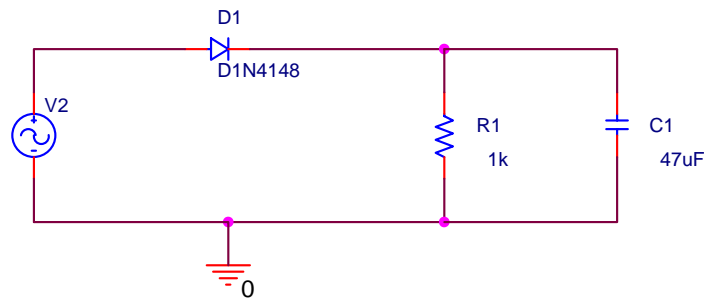


Figure B-6

- Modify your PSpice circuit by adding capacitor C1 in parallel with R1.
- Perform a transient analysis as you did in the previous part.
- Obtain a graph of the input and output voltages vs time.
- Include this plot in your report. (You will also be adding 5 experimental points to this plot based on the circuit you build in the next section.)
- Modify the frequency of the input source and observe the output
  - Modify the frequency of the source to 1k Hz, the time to 1ms, and the step size to 0.1 ms.
  - Generate a plot of the  $V_{in}$  and  $V_{out}$ .
  - Note the time at which the output voltage reaches around 4V.
  - Keeping the time and step size the same, modify the frequency of the source to 1Meg and rerun the simulation. (It may take a bit longer and the input trace will have many cycles.)



- Note the time at which the output reaches around 4V. (You will need to delete the other trace to see it.)
- What is happening as the frequency increases?
- Print a plot of the output from the second case only and include it in your report.

#### Hardware implementation of rectifier

Now wire the rectifier on your protoboard and observe the output with and without the capacitor.

- Assemble the rectifier circuit *without* the capacitor as shown in figure B-7.

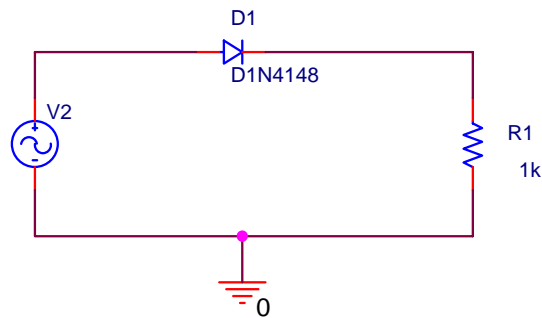


Figure B-7

- Use the function generator to supply an input sinusoidal signal of 60Hz, 10 volts peak to peak.
- Observe both the input and the output voltages with the scope.
  - Be sure that your 'scope is set to DC coupling.
  - Take a picture with Agilent.
  - Include this plot with your report.
- Repeat the procedure above with a 47 $\mu$ F capacitor in parallel with the resistor R, as shown in figure B-8.

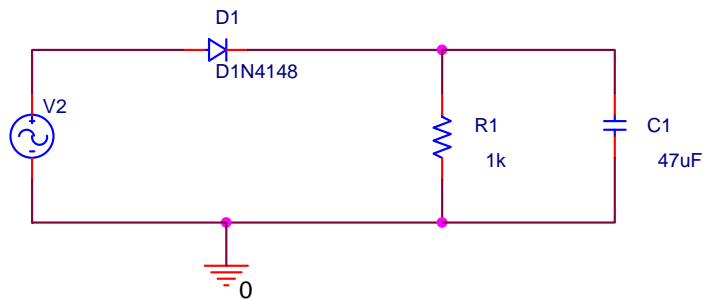


Figure B-8

- Note that the sine voltage from the generator will become distorted when you add the large capacitor. This is due to the finite, non-zero source impedance of the function generator (which we have been ignoring so far in this experiment) and the large variation in load seen during alternate halves of the cycle. In a more critical circuit, one might, for example, add a 50 ohm load (resistor) to the function generator. For our purposes here, we simply note the distortion.
- Take a picture of the input and output signals with Agilent and include it in your report.
- Measure the output voltage at approximately 5 points during one cycle.
- Add the experimentally measured points to the plot generated with PSpice.

- Vary the frequency of the function generator and observe both the input and output voltage of the rectifier with the capacitor. Try connecting and disconnecting the capacitor as you vary the frequency.

#### PSpice simulation of voltage limitation

Now we can use PSpice to build a limiter using a pair of diodes.

- Draw the circuit shown in figure B-9.

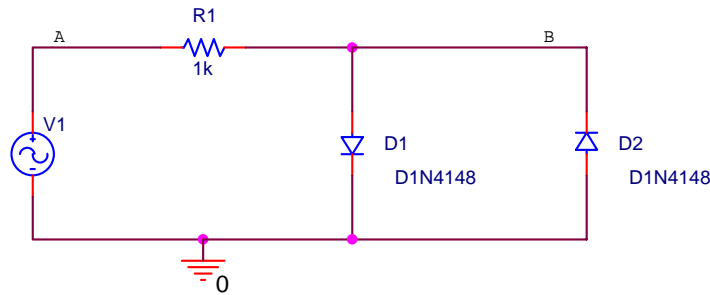


Figure B-9

- Use VSIN for the source (VAMPL = 10, FREQ = 1k, everything else = 0).
- Perform a transient analysis in increments of 50us up to 5ms.
- Plot the input (point A) and output (point B) voltages. The input is the voltage source while the output is taken across the diode pair, as shown.
- Print your plot and include it in your report. (You will also be adding 5 experimental points to this plot based on the circuit you build in the next section.)
- Change the amplitude of the sinusoidal input,  $V_{in}$ , to 0.1 volt. Repeat the transient analysis.
- Print this plot also and include it in your report (You will also be adding 5 experimental points to this plot based on the circuit you build in the next section.)

#### Hardware implementation of limiter

Now build the limiter on your protoboard.

- Wire the limiter circuit shown above
  - Use the function generator to supply a 1 kHz, 10V, sinusoidal input. Use the 'scope to set up the function generator amplitude.
  - Observe  $V_{out}$  (point B) and  $V_{in}$  (point A) with the oscilloscope.
  - Adjust the function generator output such that the signal you observe on the 'scope looks as much like the PSpice output as possible.
  - Take an Agilent picture of this circuit with 10V amplitude input and include it in your report.
  - Record at least 5 experimental voltages and add to your PSpice output.
- What is the effect of altering the amplitude of your circuit?
  - Repeat the measurements with a 1 kHz, 0.1V sinusoidal input.
  - Take an Agilent picture of this circuit with 0.1V amplitude and include it in your report.
  - Record at least 5 experimental voltages of the second signal and add to your PSpice output.
- Alter the circuit to limit voltage in only one direction
  - Return the amplitude of the voltage to 10V
  - Remove one of the diodes from your limiter and observe the output.
  - What part of the signal is being limited?
  - Take a picture of this output and include it in your report.
  - Now reverse the polarity of the remaining diode in the circuit. (Turn it around).
  - What part of the signal is being limited now?

**Summary**

Diodes can be used to create rectifiers, which convert an AC signal into a signal with an average non-zero DC voltage. The desired result of a rectifier is to create a DC signal from an AC signal. The signal from a simple rectifier circuit built with a diode can be improved by the addition of a smoothing capacitor. Diodes can also be used to limit voltage. This device is called a limiter. These can be used to limit voltage in one direction, or in both directions.

**Part C – LEDs, Photodiodes and Phototransistors****Background**

**LEDs:** An LED is a device that emits light when it is subjected to a voltage. Just like a regular diode, an LED will not turn on (and emit light) until a certain threshold voltage is reached. This threshold depends upon the color of the LED and the diode manufacturer. Red LEDs turn on when the voltage across them exceeds about 2.2V. With green LEDs, the voltage is about 1.6V. Note that, although diodes often have a plastic coating that matches the color of the light emitted, the light that comes from a diode is not white. It is light of the wavelength of the desired color. Ie. A red diode (even with a clear plastic covering) will put out light in the red region of the electromagnetic spectrum. The following equation can be used to decide what resistance to use with an LED, given its threshold voltage and the desired current through the diode. 20mA is a reasonable value to use for the current through the diode.

$$R = \frac{V_{in} - V_{LED}}{I_{LED}}$$

**Photodiodes:** A photodiode is a device that generates a current in the presence of light. As photons of light excite the PN junction inside the diode, a current is generated through the junction. The more light that shines on the photo-reactive surface, the more current flows through the device.

**Phototransistors:** A phototransistor is similar to a photodiode except that it takes advantage of the ability of the transistor to amplify current in the active region. The current it generates is still proportional to the amount of incident light, but it is amplified by the properties of the transistor. The graph in figure C-1 shows the linear relationship between incident light and current through a phototransistor similar to the one we will be using.

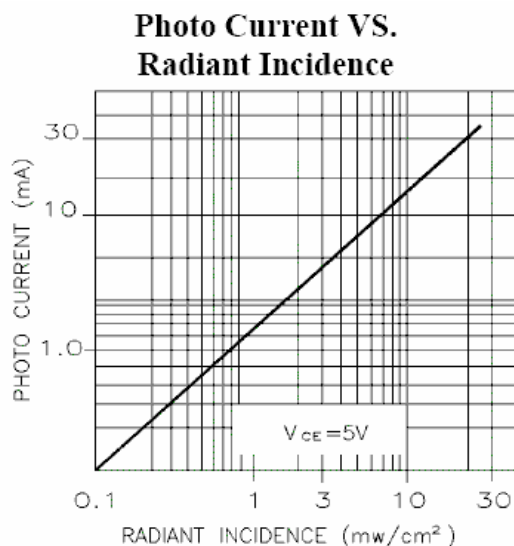


Figure C-1

**Experiment***Transmit a signal using light*

Here we will build two circuits. The first circuit will cause an LED to blink. A current will be created in the second circuit when the phototransistor detects the light from the blinking diode.

- Wire the circuit in figure C-2 on your protoboard.

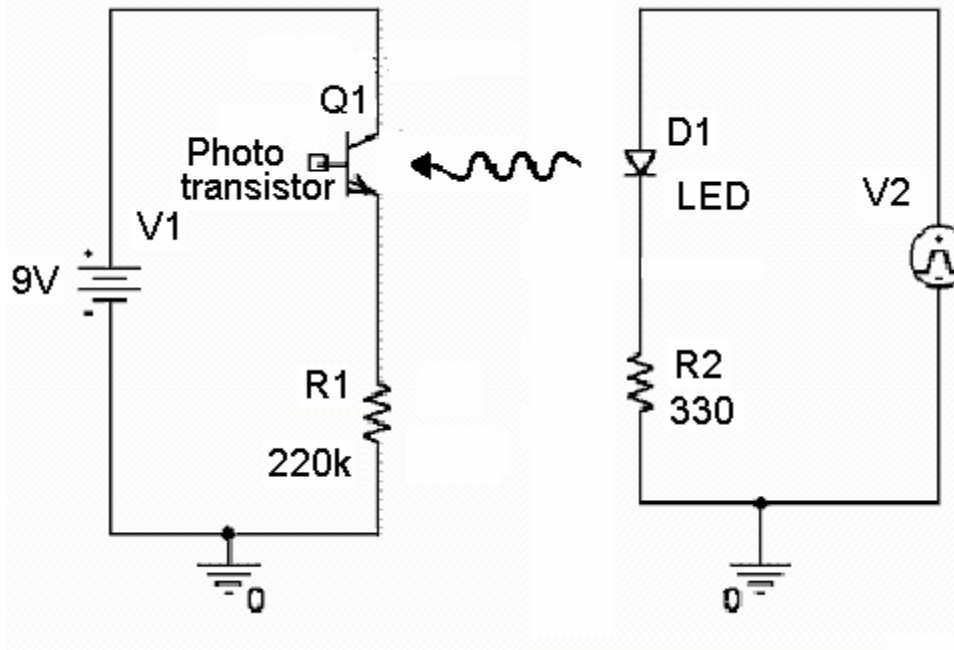


Figure C-2

- The phototransistor looks like a clear diode. It works in either polarity. The polarity you choose will depend upon the application you are using it for. Start by inserting the phototransistor so that the shorter leg points towards ground.
- Note that resistor R1 is 220K ohms and resistor R2 is only 330 ohms.
- When you wire your circuits, point the LED and the photodiode towards one another so that the rounded tips face each other. Recall that the light from the diode is most visible from the top. The photodiode takes in light primarily at the top as well. Having them face each other provides the maximum light transmission and also minimizes the secondary effects caused by other lights in the room.
- Adjust the function generator to produce a square wave with a frequency of 1 kHz.. Set the amplitude to an initial value of 100mV.
- Observe the output of your circuit.
  - Connect the source voltage (across R2) to one channel of your scope. Connect the output (the voltage across R1) to the other channel of your scope.
  - Raise the amplitude until you see a response in the detector circuit. Observe the coupling between these two components.
  - Now reverse the phototransistor.
  - Observe the output again. One polarity will show a good representation of the square wave signal. The other polarity will have higher amplitude, but the signal reconstruction will not be as accurate.

- WRITE DOWN which polarity of your phototransistor causes which result. Since this information depends upon the device in your kit, it may not be the same for every group. You will need this information for project 4.
- Place the diode in the orientation that produces the best reconstruction of a square wave.

Take your data.

- At 1kHz, find the minimum input wave amplitude that produces a signal in the phototransistor circuit. This is somewhat subjective.
- Raise the amplitude again until you can see a clear reconstruction of the input signal with little noise on it. Do not go too high in voltage, since you do not want to damage your LED. (Recall that digital circuits work with signals of up to 5 volts, so you can go at least that high.)
- Include this plot in your report.
- After obtaining a clear signal with this optical link, block the light by placing a piece of cardboard or something similar between the transmitter and receiver. Do you observe anything on the 'scope?
- Change the duty cycle of the square wave from 20% to 80%. Does the receiver do a good job of reproducing these signals?

### Summary

Photodetection is a very important use of diodes. LEDs and photodiodes can be used to emit and detect light in the visible spectrum and also in the infrared. These devices are used in remote control devices to transmit modulated signals of certain frequencies. They are also used to sense and/or display information in countless other applications. Can you name some?

## Part D – Zener Diodes

### Background

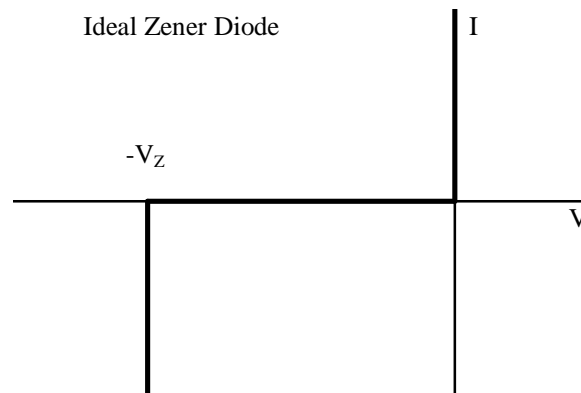
*The reverse breakdown region:* In a semiconductor diode, charge carriers (holes and electrons) are continually being thermally generated, which results in the small, voltage independent reverse saturation current when a diode is reverse biased. If the reverse voltage becomes too large, two phenomena occur to dramatically increase current. As the reverse bias voltage increases, so does the size of the depletion region (the insulating region between the holes and electrons). In this region, the charge carriers experience an electric field force which increases their energy. If this energy is large enough, the collision of a carrier with an ion will generate a new hole-electron pair. The electric field itself can also pull electrons from the ions once it becomes large enough. Both processes increase the number of charge carriers and thus increase the ability of the diode to carry current in the reverse direction.

*Zener diodes:* By appropriate doping, it is possible to design a Zener diode that breaks down at anywhere from a few volts to a few hundred volts. If you recall the figure above showing the I-V characteristic of a diode, you will see that, if a diode is sufficiently reverse biased, it will conduct in the reverse direction. Furthermore, the diode voltage will remain approximately constant over a wide range of currents. This property is known as breakdown; the negative of breakdown voltage is called the Zener voltage ( $V_Z$ ). Diodes that are designed to work in the breakdown state are usually known as Zener Diodes. Figure D-1 shows the symbol for a Zener diode.



Figure D-1

*Characteristic curve of a Zener diode* : The characteristic curve of a Zener diode is similar to that of a regular diode. The difference is that, whereas regular diodes will reach the breakdown region at voltages way beyond the operating range of your circuit, Zener diodes are designed to “break down” at (minus) the Zener voltage. You use this feature of the Zener diode as part of the design of your circuit. The characteristic curve for an ideal Zener diode is shown in figure D-2. In a real Zener diode, the forward bias region occurs at the same voltage as a regular diode, 0.7V. The reverse bias voltage of a Zener diode, is known as the Zener voltage. Although the breakdown region occurs at a negative voltage, the Zener voltage is always a positive number (the absolute value (or negation) of the actual breakdown voltage.) Zener diodes are rated by this Zener voltage. For example, a 10V Zener diode will reach breakdown at around -10V and a 5V Zener diode will reach breakdown at about -5V.

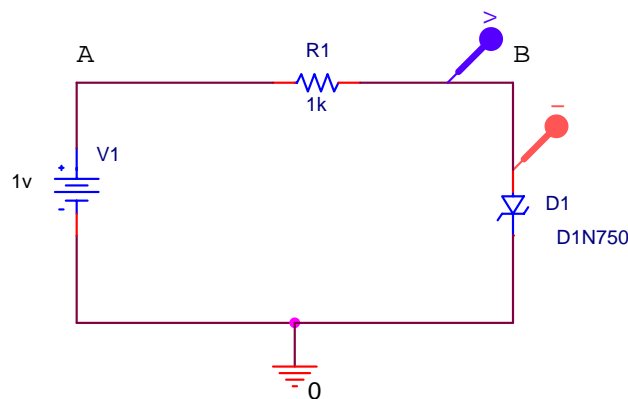


## Experiment

### *I-V Characteristic Curve of a Zener Diode*

Now we will plot the voltage across a Zener diode vs. the current through the Zener diode.

- Wire the circuit in figure D-3 in PSpice. The Zener diode is D1N750. It is in the "EVAL" PSpice library.



- Run a simulation and create the i-v characteristic curve
  - Perform a DC sweep analysis of voltage source V1 from -20 to +20 volts in increments of 0.1 volts.
  - Select "Add Trace" to plot current through diode D1, I(D1).
  - Change the x-axis of your plot as follows (same as with the regular diode):
    - In the "Plot" menu, choose "Axis Settings"
    - Then click on the X-axis Tab.
    - Click on the "Axis Variable" button at the bottom.

- Enter voltage at point B as the new X axis variable. (Example: V(R1:2)) (Note that the voltage at this point is the voltage across the diode.)
  - After you get the plot, remove all voltage markers, so that only I(D1) is displayed.
- The plot produced will show the i-v characteristic curve for diode D1. It should look like the i-v curve for a Zener diode.
- Print this plot and include it in your experiment.
- Determine the knee current
  - Look up the typical Zener voltage in the spec sheet for the 1N750A diode. (You can find a link to this spec sheet on the links page.)
  - Draw a vertical line in the reverse bias region on your output plot corresponding to the negation of the rated Zener voltage. Note that this diode will keep its reverse bias voltage quite close to  $-V_Z$  for a wide range of currents. The smallest current for which the bias voltage is about equal to  $-V_Z$  is called the knee current.
  - What is the maximum current (or knee current) for which the reverse bias voltage is within 0.1 volts of  $-V_Z$ ?
  - Mark the knee current on the plot.

#### Hardware Implementation

In the final part of this experiment, you will build a Zener diode voltage regulator on your protoboard. In this experiment, you will be measuring current. Current is always measured in series with a circuit.

- Assemble the circuit shown in figure D-4 on your protoboard. The Zener diode looks like the regular diode, except it should have “75” written on it. The DMM (which will be used to measure current in series) is shown in the circuit below. Also connect the scope as shown. You will need it to measure the voltage across the diode.

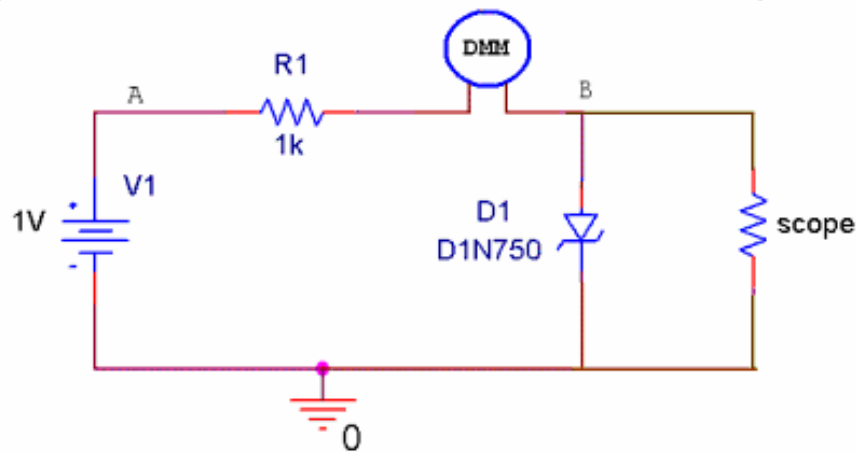


Figure D-4

- Measure the current using the DMM
  - To attach the DMM to the circuit, you must use the current inputs to the device. They are labeled with the letter “I”. The negative plug is the same as for voltage measurement, however, the positive plug for the current connection is below the negative plug (not above).
  - Set the DMM to measure DC current (DC I). (Use the shift button).
  - Adjust the *DC source voltage* (V1) until the current reads 1mA and record the voltage across the diode using the scope at point B. (You can get an exact DC value from the scope by using the Vave soft key). Now record the voltage across the diode for the remaining currents listed in the table on the next page:

Current	Voltage at B	Current	Voltage at B
1mA		-1mA	
3mA		-3mA	
5mA		-5mA	

- o Mark the six points on your PSpice output of the characteristic curve of the Zener diode.

### Summary

Zener diodes exploit the breakdown region of diodes to create a device that allows current to flow freely in one direction at a level above the Zener voltage. You can use a Zener diode to hold a voltage to the Zener voltage. An AC to DC converter of a desired voltage can be created by combining a Zener diode (rated at that voltage) with a rectifier and a smoothing capacitor.

### Report and Conclusions

The following should be included in your written report. Everything should be clearly labeled and easy to find. Partial credit will be deducted for poor labeling and unclear presentation.

#### Part A (16 points)

Include the following plots:

- 1) I-V Characteristic curve PSpice Plot with 5 points marked (3 pt)
- 2) Excel sample of characteristic curve taken using agilent software. This should include the data points and a line found using the diode characteristic equation. (5 pt)

Answer the following questions:

- 1) Use the data you took for the I-V characteristic of the 1N4148 diode to determine the mathematical representation of the I-V curve. What values did you find for  $I_S$  and  $n$ ? (4 pts)
- 2) Why do you know that the current through the diode is  $V_{out}/R_2$ ? (2 pt)
- 3) What differences, if any, did you notice between the I-V characteristic given by PSpice and the one you measured experimentally? (2 pt)

#### Part B (26 points)

Include the following plots:

- 1) PSpice plot of rectifier (1 pt)
- 2) PSpice plot of rectifier with smoothing with 5 experimentally obtained points marked (1 pt)
- 3) PSpice plot of rectifier (output only) at 1Meg Hz. (1 pt)
- 4) Agilent plot of rectifier (with no smoothing capacitor) (1 pt)
- 5) Agilent plot of rectifier (with smoothing capacitor) (1 pt)
- 6) PSpice plot of voltage limiter at 10V (with 5 experimental points marked) (1 pt)
- 7) PSpice plot of voltage limiter at 0.1V (with 5 experimental points marked) (1 pt)
- 8) Agilent plot of limiter circuit with 10V input amplitude (1 pt)
- 9) Agilent plot of limiter circuit with 0.1V input amplitude (1 pt)
- 10) Agilent plot of limiter with only one diode (1 pt)

Answer the following questions:

- 1) What is the function of a rectifier? (2 pt)
- 2) Explain why  $V_{out}$  changes when you add the capacitor to the rectifier in parallel with R. Explain why this circuit would be better for use as a DC source than the circuit without the capacitor. (3 pt)
- 3) Did the circuit with the capacitor work better (more like a DC source) at high or low frequencies? (1 pt)



- 4) Comment on the similarities and differences between the PSpice and experimental results for the rectifier. (2 pt)
- 5) At what values (positive and negative) does the limiter cut off the voltage of the 10V amplitude input signal? (2 pt)
- 6) Does the limiter cut off the voltage of the 0.1V amplitude input signal? Why or why not? (2 pt)
- 7) Why is this circuit called a limiter? When and why might a limiter circuit be useful? (2 pt)
- 8) Comment on the similarities and differences between the PSpice and experimental results for the limiter. (2 pt)

**Part C (10 points)**

Include following plot:

1. Plot of the input and output for the optical link. (4 pts)

Answer following questions:

1. What was the minimum amplitude square wave signal that you could detect with the phototransistor? (2 pt)
2. Describe the differences between the input signal and the output signal. How closely does the phototransistor reconstruct a square wave? Where are the discrepancies? Does it accurately reproduce the duty cycle? (4 pts)

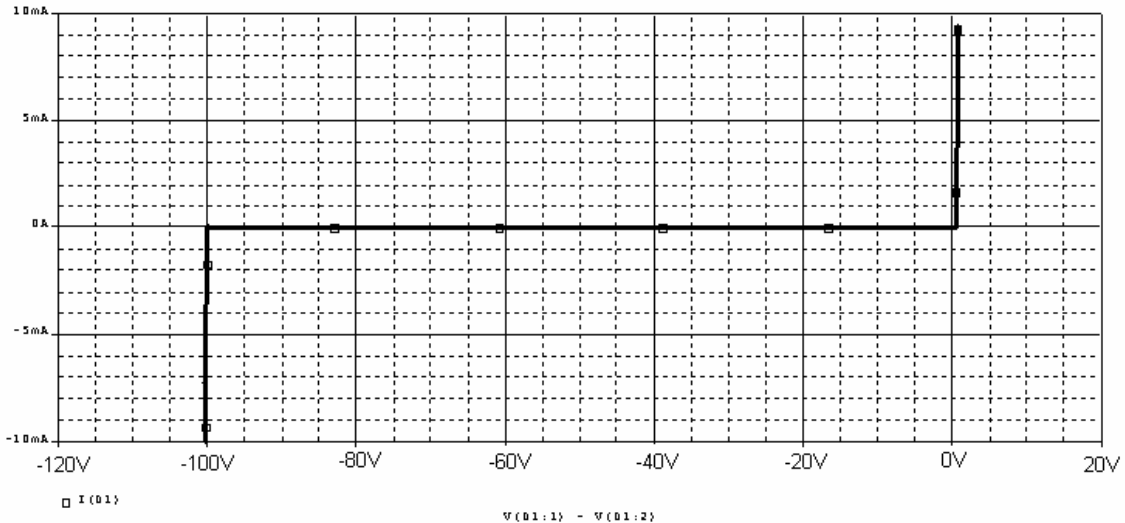
**Part D (16 points)**

Include the following plots:

- 1) Zener diode characteristic curve with vertical line, knee current marked and six points marked (6 pt)

Answer the following questions:

- 1) What are the Zener voltage and knee current for the diode you simulated? (2 pt)
- 2) Shown below is the I-V characteristic of the 1N4148 non-Zener diode we looked at in part A, but obtained over a much wider voltage range. Compare this plot with the one you obtained for the Zener diode. (3 pt)



- 3) We have seen that the voltage across the Zener diode will remain equal to the Zener voltage, as long as we provide enough voltage and current from the source. However, the circuit configuration we have studied does not include a load. A load resistor would be added in parallel to the Zener diode. Discuss how this circuit will perform for a load that is much smaller than 1k ohm (eg 50 ohms), equal to 1k ohm, and much larger than 1 k ohm (eg 1 megohm). That is, under what conditions will it produce the desired regulated voltage? Support your discussion with calculations, simulations, or experimental results. (5 pts)

**Summary (12 points)**

1. Summarize key points (8 pts)
2. Discuss mistakes and problems (2 pts)
3. List member responsibilities (2 pts)

**Total: 80 points for write up + 20 for attendance = 100 points**

**Attendance: 3 classes (20 points) 2 classes (10 points) 1 class (0 points) out of 20 possible points  
Minus 5 points for each late.  
No attendance at all = No grade for experiment.**