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:

- **Rensselaer IOBoard Rev D** (with Mobile Studio Desktop)
- **Oscilloscope** (Rensselaer IOBoard)
- **Function Generator** (Rensselaer IOBoard)
- Protoboard
- Resistors, Capacitors, Diodes, Zener Diodes, 9V batteries, op-amp
- 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 and ideal diode turns on, it is a short circuit and, therefore, the voltage across the ideal diode when it is on is always zero.
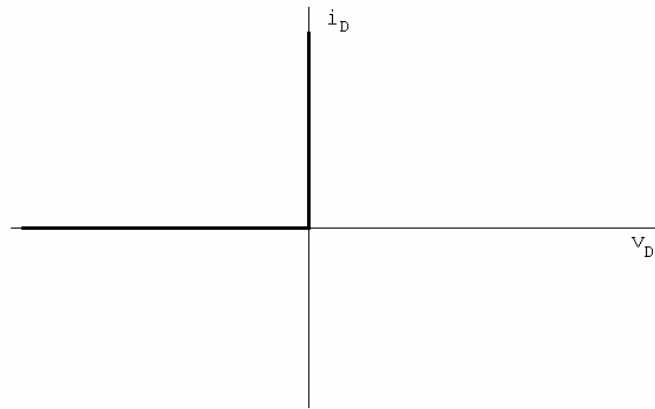
Figure A-2

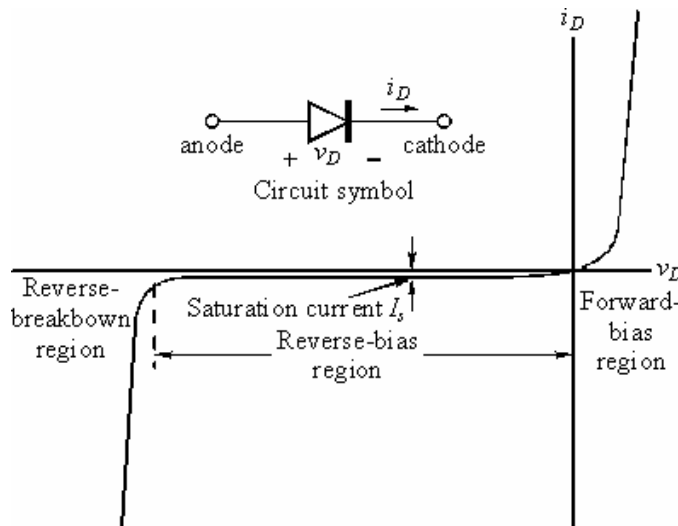*I-V Curve of a Diode:* Figure A-3 shows typical characteristics of a real diode.

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. The resistor of interest is labeled Ra2 in the figure below. PSpice allows you to plot currents, but the IOBoard doesn't. So we will add a 1kΩ "current sensing resistor," Ra1. The current through Ra1 is equal to the voltage across Ra1/1000. The IOBoard can be used to measure the voltage across the "current sensing resistor."

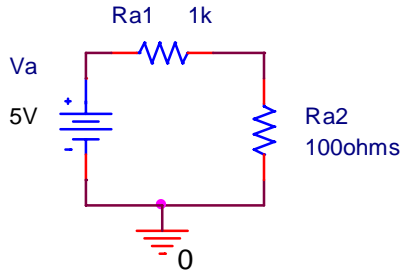- Wire the circuit shown in figure A-4 in PSpice.

Figure A-4

- Run a simulation and create the i-v characteristic curve
    o Set up a DC sweep from -6 to +6 volts in increments of 0.1 volt. (When you set up the DC sweep analysis, be sure that you name your source. It is "Va" in this diagram but it maybe V1 in your schematic.) *You do not need to add any probes.*
    o Run the simulation.
    o Select "Add Trace" to plot the current through resistor Ra2, I(Ra2). Recall that you must choose this current from the list you see when you use "Trace" and then "Add."
    o Change the x-axis of your plot as follows:
        ▪ In the Plot menu
            • Select "Axis Settings"
            • Then click on the X-axis Tab.
            • Click on the "Axis Variable" button at the bottom.
            • Enter V(Ra2:1)-V(Ra2:2) as the new X axis variable. This sets your x-axis to the voltage across the resistor Ra2.
                o If the plot has a negative slop, change the X axis variable to be V(Ra2:2)-V(Ra2:1). The resistor is just mounted with node 1 down.
            • The plot produced will show the I-V characteristic for resistor R1a2.Your PROBE plot should look something like figure A-5:
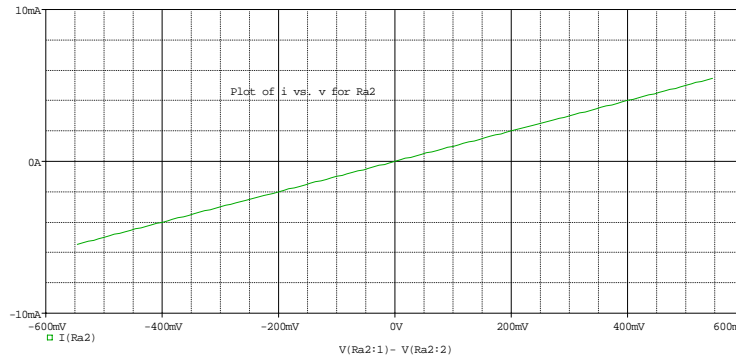

Figure A-5

- o Now add a trace to the PROBE, (V(Ra1:1)-V(Ra1:2))/1000
  - § You should note that the new trace falls on top of the old trace. The voltage across Ra1 and be used to determine the current through Ra1. The current through Ra1 equals the current though Ra2.
  - § Just to make things visible, double click on (V(Ra1:1)-V(Ra1:2))/1000 and edit the trace to be: (V(Ra1:1)-V(Ra1:2))/1000 – 0.001

Ra1 can be used as a current sensing resistor. The IOBoard can't measure current but it can measure the voltage across the Ra1 and use that to determine the current. Even though PSpice can measure current, we will use a current sensing resistor.

I-V Characteristic Curve of a Diode
Now we will plot the current through a diode vs. the voltage across the diode.

- Modify your PSpice schematic by replacing Ra2 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. In this diagram, Ra1 has been replaced with R1. This was done just for convenience.
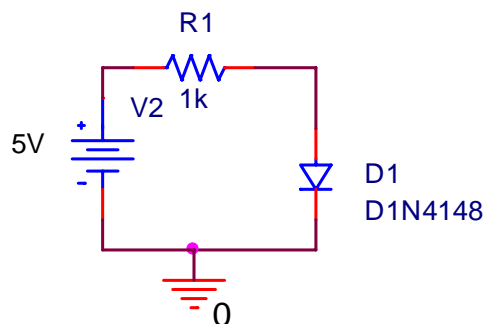

Figure A-6

- Run a simulation and create the i-v characteristic curve
  - o Rerun the DC sweep simulation, again from -6 to +6V.
  - o Select "Add Trace" to plot the current through resistor, (V(R1:1)-V(R1:2))/1000.
  - o Change the x-axis of your plot as follows (same as with resistor):
    - § Select "Axis 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.
  - o 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
  - o Expand the part of the plot with interesting results.
    - § Click on the plot menu
      - • Click on Axis Settings
        - o Click on X Axis
          - § Choose Data Range as User Define
          - § Set the range to interesting values, such as 0V to 1V
        - o Click on Y Axis
          - § Choose Data Range to User Define
          - § Set the range to interesting values, such as 0 to 5mV
          - § Note that by using R1 as a current sensor, the plot reads as mV but you know it represents mA

- ▪ *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.*
  - o *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 Mobile Studio to take a data sample from the circuit itself. Then, you can use Excel or MatLab 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. The IOBoard can't create a large enough output voltage by itself, so you need to build a gain of 10 op-amp circuit. Use either the uA741 or the LF351 op-amp for this circuit. Don't use the MAX473, it doesn't run at 9V. Use two 9V batteries to power the op-amp.
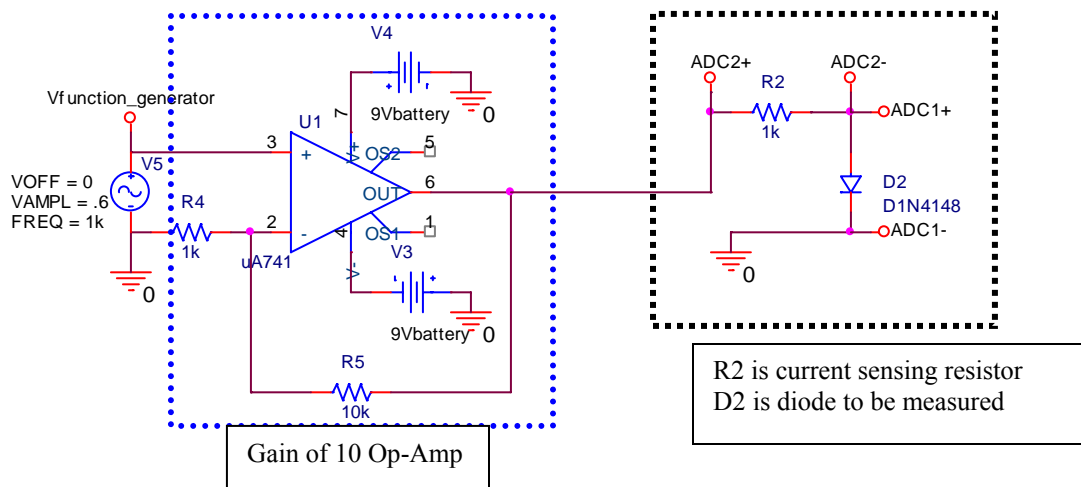

Figure A-7

- 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.
- *V5 isn't real, rather connect Func Gen 1 Output and Ground to these points.*
- *Use ADC2 to sense the current. Be careful to get this right. Remove the jumper between ADC2- and GND, if you have one. Make sure that you are using the 1st, 3rd, 4th and 6th of connector J10 of the IOBoard to connect to the labeled points on this circuit. See the figure of the IOBoard.*
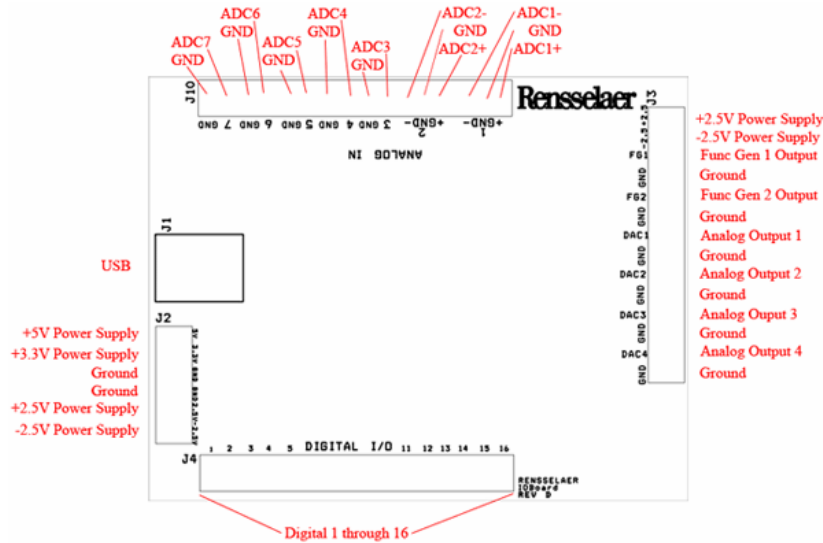
Figure 7-A

- Set Function Generator 1 to a1kHz, triangle wave, 1.2Vp-p
- Observe the diode voltage on channel 1 of the Oscilloscope, (ADC1)
- Observe the diode current on channel 2 of the Oscilloscope, (ADC2)
  o Remember that channel 2 is the current with a scale factor or 1000A/V , (1000A/V = 1mA/V)
- Set the oscilloscope up to display a couple of cycles of the signal, for example set the time base to 250uS/div
  o To smooth the data, first make sure that the trigger is working very well and the trace repeats itself
    ▪ Click on Display Options (located at the top of the scope.) Click on Averaging – try 16
- Save the data to a file once you have a clean plot on the screen
- Start Matlab and Import the data file
  o In Matlab, plot the diode current vs. the diode voltage. You only want to display the useful data, so for example there isn't a need to plot negative voltages because the current is zero.
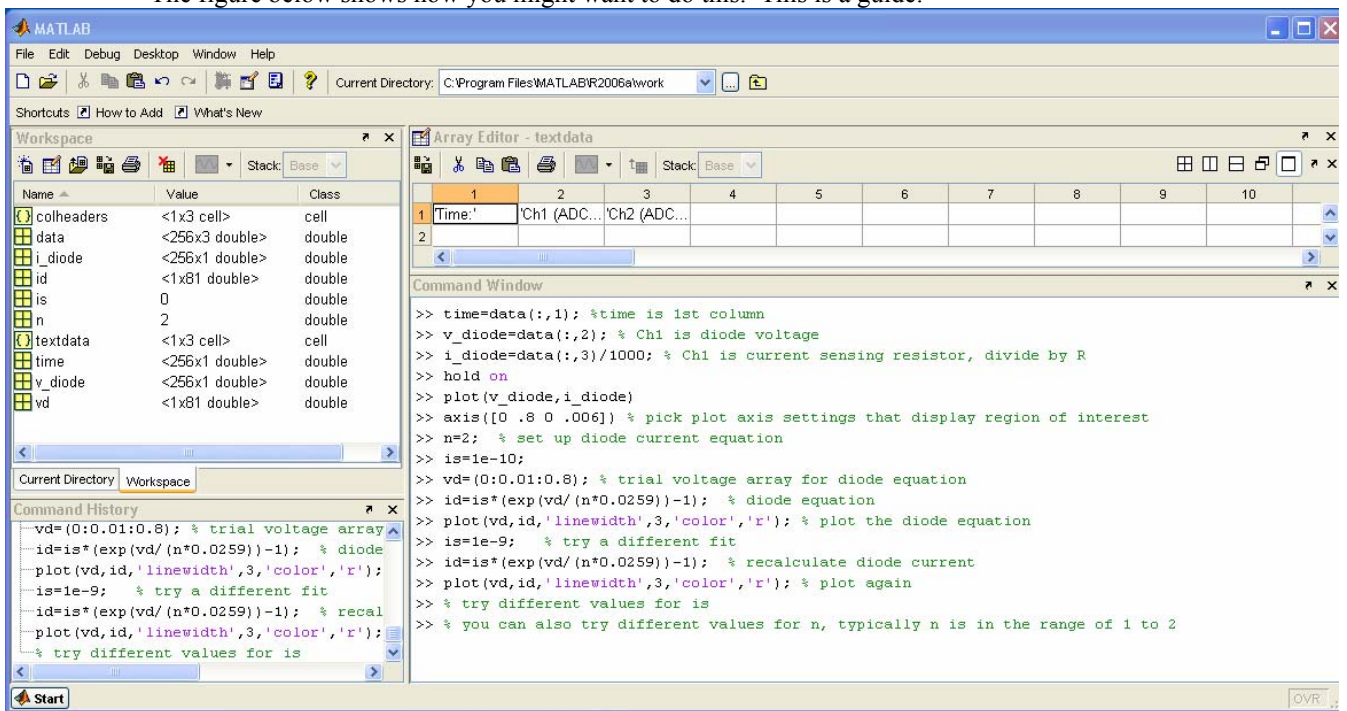   ▪ The figure below shows how you might want to do this. This is a guide.

Figure 8-A

- Add a plot of the diode current equation to the figure.

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

  o Start with n=2, guess a value for I_s, plug in several values for v_D, and plot the points.
  o Use 25.9mV for V_T.
  o Vary the value of I_s until you get a reasonable fit.
- The figure below is the result of the Matlab example on the output from the code on the previous page. You should be able to get a better fit. Consider using the grid command in Matlab.
- If time permits, vary the value of n also. For real diodes, n is in the range of 1 to 2.
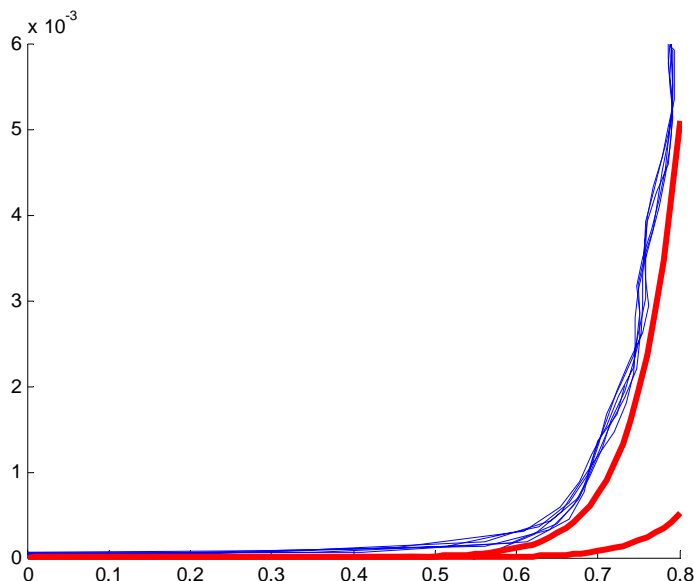

Figure 9-A Diode current vs. diode voltage. Thin lines are plot of experimental data, thick lines are two attempts to fit the diode equation. One curve is for n=2 and I_s=1e-10, the other curve is for n=2 and I_s=1e-9.

- **Include a copy of this plot in your write-up. List the final n and I_s**
- **Keep the gain of 10 op-amp circuit on your protoboard. You will need it again.**

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 also 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 will build a Half-wave rectifier circuit. Build the circuit in figure B-1. Be sure to **use a 10kΩ resistor for this circuit.** The op-amp circuit isn't changed. ADC1 senses the input signal to the half-wave rectifier circuit. ADC2 is connected to the output of the rectifier circuit. DC couple both channels.
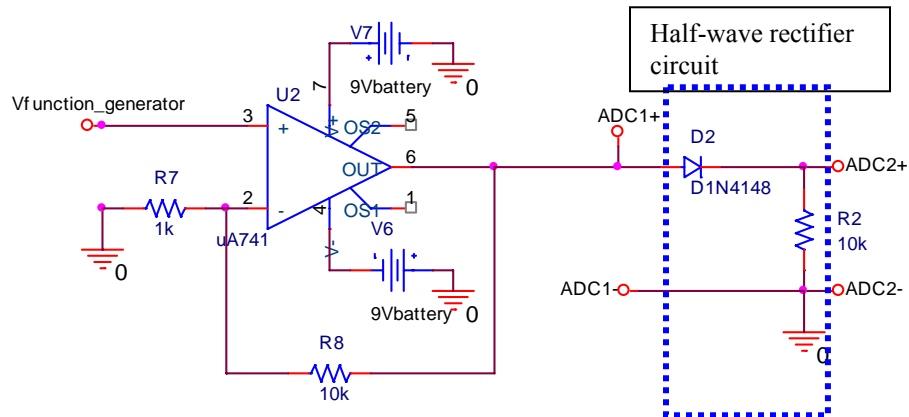

Figure B-1

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.

Experiment:
- Set the function generator on the IOBoard to a triangle wave at 1kHz with a 1.2Vp-p amplitude.
- **Print a plot of the oscilloscope channels 1 and 2. Include this in the report. The plot can be a picture from the Mobile Studio software, an Excel plot or a Matlab plot. Your choice. Label the traces.**

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.
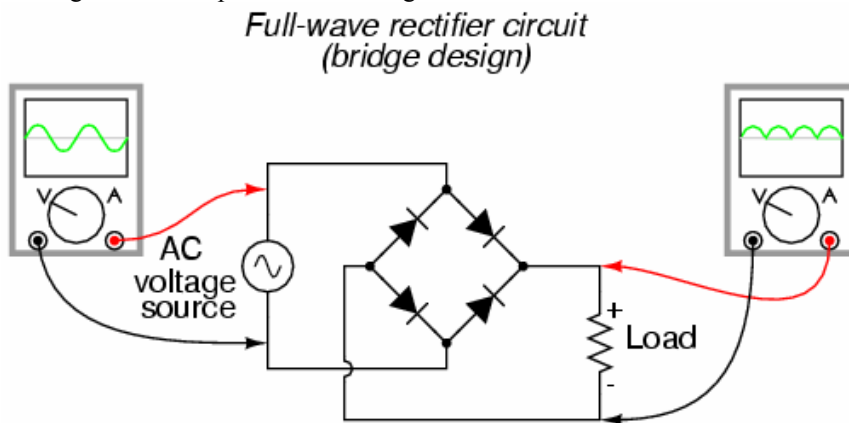

image from www.allaboutcircuits.com
Figure B-2

In a full wave rectifier one pair of diodes allows current in one direction to flow through the load resistor when the AC source has a positive voltage. The other pair of diodes is arranged such that when the AC source is negative, the current flows through the load *in the same direction.* This keeps the positive ½ 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.

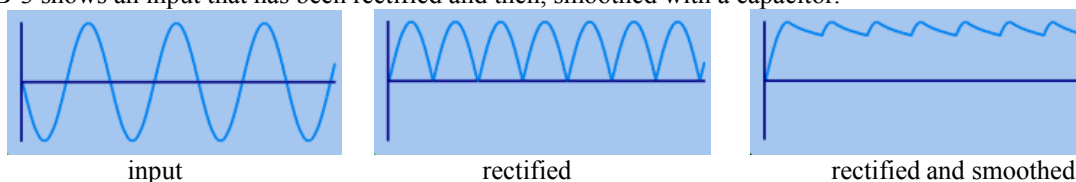| input | rectified | rectified and smoothed |

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.
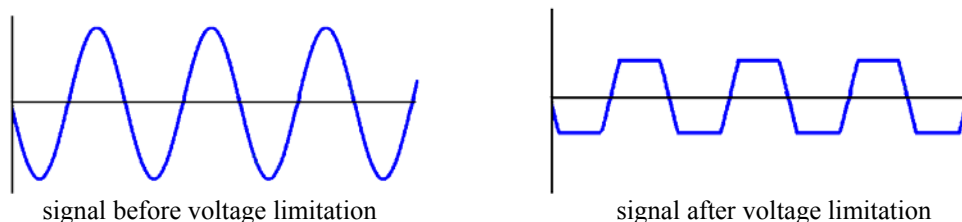

signal before voltage limitation   signal after voltage limitation

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.

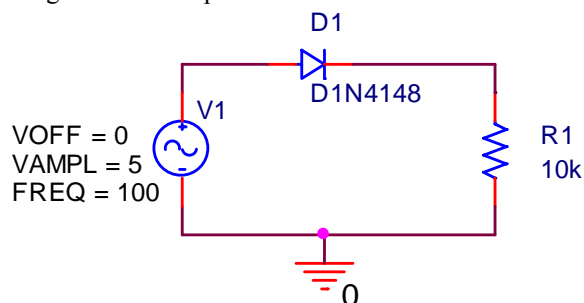- Create the circuit shown in figure B-5 in PSpice:

Figure B-5

- o Use VSIN for the source. Use the following parameters for VSIN: VAMPL = 5 (10V peak to peak), VOFF = 0, and FREQ = 100Hz

- Run the simulation
    - o   Perform a transient analysis for 50ms in increments of 10us.
    - o   Obtain a graph of the input and output voltages, V_{in} (V2) and V_{out} (voltage across R1), vs time.
    - o   Include this plot in your report.

- Add a capacitor across the resistor as shown in figure B-6 below:
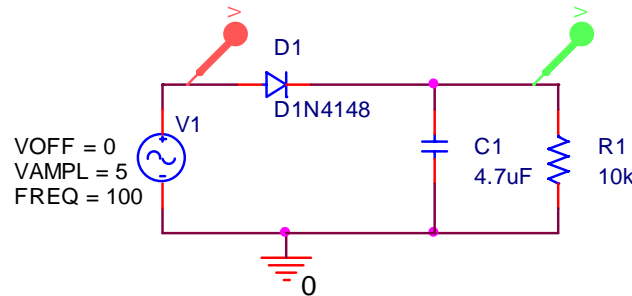

Figure B-6

- o   Modify your PSpice circuit by adding capacitor C1 in parallel with R1.
- o   Perform a transient analysis as you did in the previous part.
- o   Obtain a graph of the input and output voltages vs time.
- o   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
    - o   Modify the frequency of the source to 1k Hz and run the simulation for 2ms.
    - o   Generate a plot of the V_{in} and V_{out}.
    - o   Note the time at which the output voltage reaches around 4V.
    - o   Keeping the time and step size the same, modify the frequency of the source to 10kHz and rerun the simulation. Run the simulation for 500uS with a maximum step size of 1uS.
    - o   Note the time at which the output reaches around 4V.
    - o   What is happening as the frequency increases?
    - o   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. Note: you may find it useful to use averaging of your traces. It is in the Display options menu.

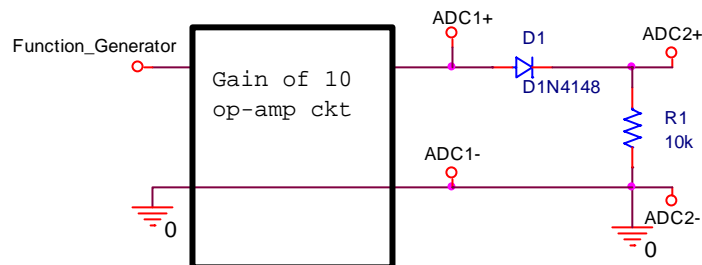- Return to the circuit in figure B-1, redrawn below

Figure B-7

- ▪   Use the function generator to supply an input sinusoidal signal of 100Hz, 1.0 volts peak to peak, this will supply a 10Vp-p signal to the rectifier circuit.
- 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 Mobile Studio or plot the data using either Excel or Matlab, (your choice.)
- Include this plot with your report. This is very similar to one of the previous plots except now the signal is a 100Hz sine wave.

- Repeat the procedure above with a 47uF capacitor in parallel with the resistor R, as shown in figure B-8.
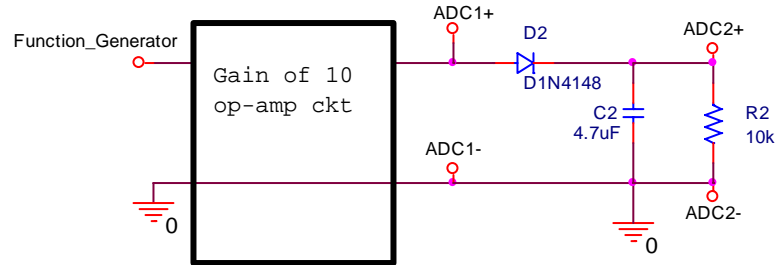

Figure B-8

o Note that the sine voltage from the generator will become distorted when you add the large capacitor.
o Record the input and output signals (ADC1 and ADC2) with Mobile Studio and include it in your report. Again you choose to use a picture or plot the data using Excel or Matlab.
o Measure the output voltage at approximately 5 points during one cycle.
   - The data points can be selected from the Excel or Matlab data files
   - Or the cursors can be used in Mobile Studio
      - Get at good trace of Vout, (ADC2) on the scope
      - Stop the scope
      - Click the Zoom icon (binoculars)
      - On the bottom plot, hold the shift key and click and hold the left mouse to select the region to expand.
      - Enable the Cursors, (window – cursor, in cursor window click enable)
         o Select the cursor in the upper window and move it into the expanded area
         o Use the cursor to read 5 voltages and times, including the minimum and maximum voltages, and 3 other points.
      - Right click in the bottom window to reset the zoom is necessary.
o Add the experimentally measured points to the plot generated with PSpice. This can be done by hand.
o 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. Try a larger capacitor, such as a 100uF capacitor.

PSpice simulation of voltage limitation
Now we can use PSpice to build a limiter using a pair of diodes.
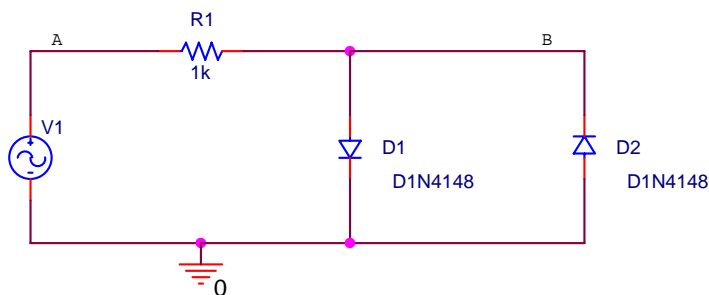
- Draw the circuit shown in figure B-9.

Figure B-9

- o   Use VSIN for the source (VAMPL = 5, FREQ = 100Hz, everything else = 0).
- o   Perform a transient analysis in increments of 50us for 250ms.
- o   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.
- o   <u>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.)</u>
- o   Change the amplitude of the sinusoidal input, Vin, to 2 volt. Repeat the transient analysis.
- o   <u>Print this plot also and include it in your report.</u>

Hardware implementation of limiter
Now build the limiter on your protoboard. Note: you may find it useful to use averaging of your traces. It is in the Display options menu.
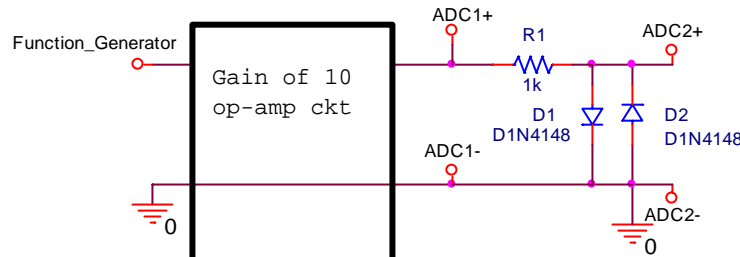

Figure B-10

- o   Wire the limiter circuit shown above
  - ▪   Use the function generator to supply a 100Hz, 1V, sinusoidal input. The gain of 10 op-amp will then provide a 10Vp-p signal.
  - ▪   Observe V_{out} (ADC2) and V_{in} (ADC1) with the oscilloscope.
  - ▪   <u>Take a Mobile Studio picture of this circuit or save and plot the data in Excel or Matlab. Include it in your report.</u>
  - ▪   <u>Record at least 5 experimental voltages and add to your PSpice output. The data point may be hand written on the PSpice plot.</u>

- •   What is the effect of altering the amplitude of your circuit?
  - •   Repeat the measurements with a 100Hz, 0.4V sinusoidal input.
  - •   <u>Take a Mobile Studio picture of this circuit with 0.4V amplitude and include it in your report.</u>

- •   Alter the circuit to limit voltage in only one direction
  - o   Return the amplitude of the function generator to 1.V
  - o   Remove one of the diodes from your limiter and observe the output.
  - o   What part of the signal is being limited?
  - o   <u>Take a picture of this output or plot it and include it in your report.</u>
  - o   Now reverse the polarity of the remaining diode in the circuit. (Turn it around).
  - o   What part of the signal is being limited now?

Summary

Diodes can be used as 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
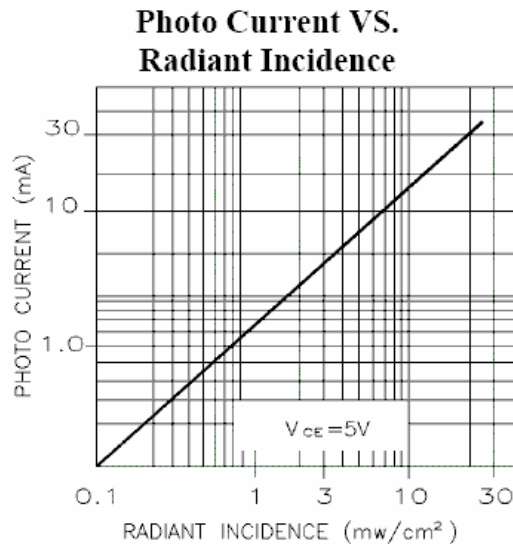
Experiment

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.

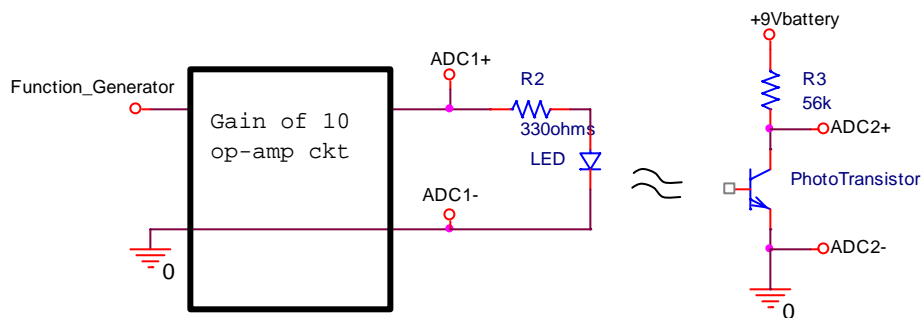- Wire the circuit in figure C-2 on your protoboard.

Figure C-2

- o The phototransistor looks like a clear diode. It is a transistor but the base doesn't have an external lead. Light supplies the base current.
- o There is a flat side on the phototransistor. The lead next to the flat goes to ground.
- o Note that resistor R3 is 56kΩ and resistor R2 is only 330Ω.
- o 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.
- o Adjust the function generator to produce a square wave with a frequency of 100Hz. Set the amplitude of the function generator to 1Vp-p, this will result in a 10Vp-p signal out of the amplifier circuit.

- Observe the output of your circuit.
  - o Connect the source voltage to one channel of your scope. Connect the output (the voltage across the phototransistor) to the other channel of your scope.
  - o If the output signal doesn't show a significant square wave then try:
    - ▪ Make sure the phototransistor is correctly installed, simply reverse the phototransistor and see if the signal increases.
    - ▪ Make sure that the tip of the LED points toward the tip of the phototransistor.

Take your data.
  - o Save a picture of the output when the circuit is working well.
  - o Include this plot in your report.
  - o After obtaining a clear signal with this optical link, block the light by placing a piece of paper, your finger, or something similar between the transmitter and receiver. Do you observe anything on the 'scope?
  - o Change the frequency of the square wave to 500Hz and 2kHz. Does the output look like the input?

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. A phototransistor is very much like a photodiode, but it also has the gain of at transistor. We use the phototransistor for this reason.

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.
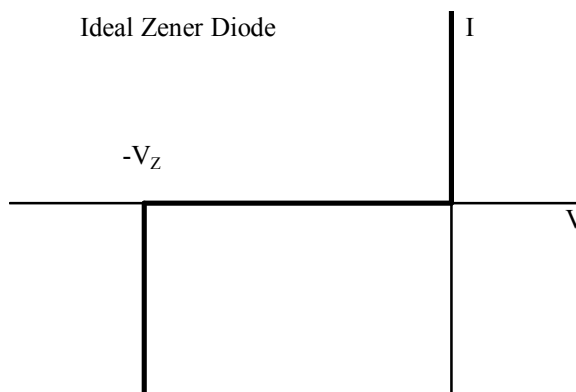
Figure D-2

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.
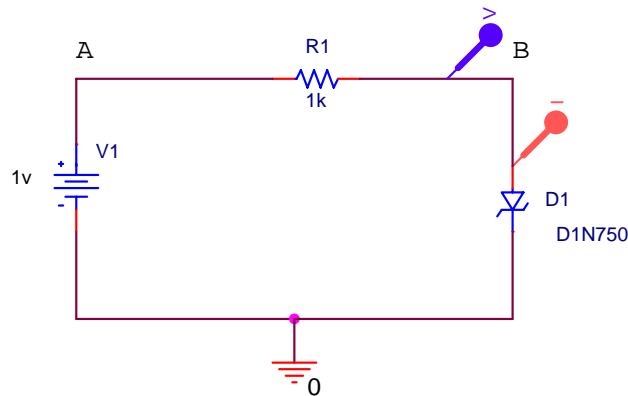

Figure D-3

*   Run a simulation and create the i-v characteristic curve
    o   Perform a DC sweep analysis of voltage source V1 from -20 to +20 volts in increments of 0.1 volts.
    o   Select "Add Trace" to plot current through diode D1, I(D1), or use the marker shown.
    o   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.
    o   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.
    o   Print this plot and include it in your experiment.

*   Determine the knee current
    o   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.)
    o   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.
    o   What is the maximum current (or knee current) for which the reverse bias voltage is within 0.1 volts of -V_Z?
    o   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. This is the same circuit as figure A-7 with the 1n4148 replaced with the 1n715
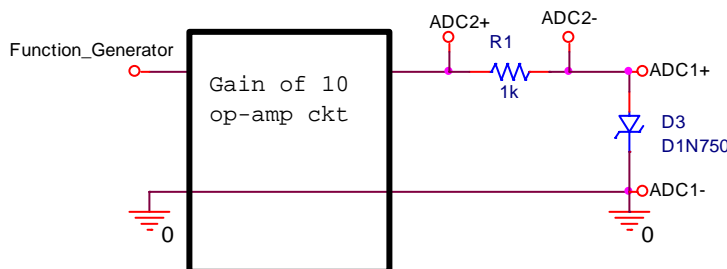
Figure D-4

- Measure the current vs. voltage characteristics of the 1n750 zener diode.
    - o Set Function Generator 1 to a1kHz, triangle wave, 1.2Vp-p
    - o Observe the diode voltage on channel 1 of the Oscilloscope, (ADC1)
    - o Observe the diode current on channel 2 of the Oscilloscope, (ADC2)
        - ▪ Remember that channel 2 is the current with a scale factor or 1000A/V , (1000A/V = 1mA/V)
    - o Set the oscilloscope up to display a couple of cycles of the signal, for example set the time base to 250uS/div
    - o To smooth the data, first make sure that the trigger is working very well and the trace repeats itself
        - ▪ Click on Display Options (located at the top of the scope.) Click on Averaging – try 16
    - o Save the data to a file once you have a clean plot on the screen
    - o Start Matlab and Import the data file
    - o See figure 8-A for help to plot the data in Matlab.
    - o Include the experimental plot of i vs. v in your report.

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 of a diode, the PSpice Plot with 5 points marked (3 pt)
2) Matlab plot of diode current vs. voltage from data taken using Mobile Studio 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? (curve on the Matlab plot) (4 pts)
2) Why do you know that the current through the diode is $V_{out}/R2$? (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 (32 points)

Include the following plots:
1) Picture or plot of Mobile Studio data for the circuit in figure B-1, the half-wave rectifier. This figure has a triangle wave input signal. (2 pt)
2) PSpice plot of half-wave rectifier circuit, figure B-5. (2pt)
3) PSpice plot of rectifier with smoothing with 5 experimentally obtained points marked (4 pt)
4) PSpice plot of rectifier (output only) at 10kHz. (2 pt)
5) Mobile Studio plot of rectifier (with no smoothing capacitor, sinusoidal waveform) (2 pt)
6) Mobile Studio plot of rectifier (with smoothing capacitor) (2 pt)
7) PSpice plot of voltage limiter at 10V (with 5 experimental points marked) (2 pt)
8) PSpice plot of voltage limiter at 4Vp-p (2V amplitude) (2 pt)
9) Mobile Studio plot of limiter circuit with 10Vp-p input, (it is 10Vp-p after the gain of 10 op-amp circuit.) (2 pt)
10) Mobile Studio plot of limiter circuit with 4Vp-p input amplitude (1 pt)
11) Mobile Studio plot of limiter with only one diode (1 pt)

Answer the following questions:
1) 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 10Vp-p input signal? (2 pt)
7) Why is this circuit called a limiter? (2 pt)

Part C (10 points)

Include following plot:
   1.   Mobile Studio plot of the input and output for the optical link. (5 pts)

Answer following questions/comments:
   1.   What are the minimum and maximum voltages of the output waveform under the best signal conditions? (2 pt)
   2.   Describe what happens to the output waveform at the higher frequencies. (1 pts)
   3.   Comment on two of the following: 1)the effect of misalignment of the LED and transistor 2) the effect of the room lights, 3) signal level through paper, skin, or other object. (2pts)

Part D (14 points)

Include the following plots:
1) PSpice Zener diode characteristic curve with vertical line and knee current marked. (5 pt)
2) Plot of Zener diode i vs. v from the experiment. (5pt)

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. (23 pt)
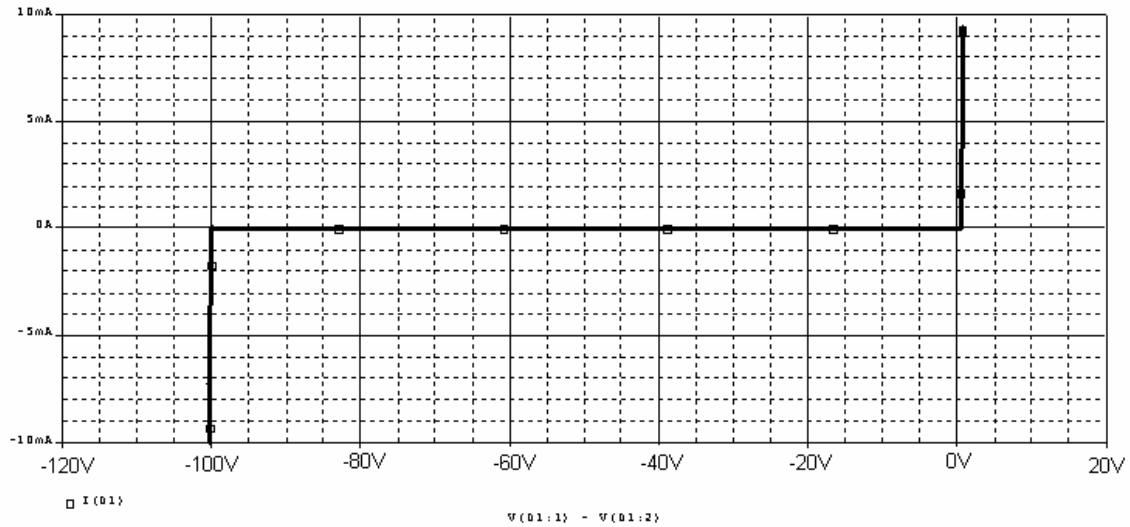
Summary (8 points)

1. Summarize the applications of diodes, include comments on diodes as rectifiers, limiters, LEDs and as photodetectors (remember we used a phototransistor which basically a photodiode with the gain of a transistor.) (6 pts)
2. 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.