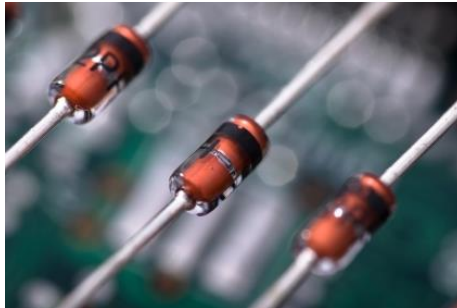


Class #8: Experiment Diodes Part I



Purpose: The objective of this experiment is to become familiar with the properties and uses of diodes. We used a 1N914 diode in two previous experiments, but now we would like to learn more generally how they behave. We will first consider the I-V characteristic curve, which is similar to most diodes we will use for low power signals and also power applications. 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.

Background: Before doing this experiment, students should be able to

- Analyze simple circuits consisting of combinations of resistors.
- Measure resistance using a Multimeter.
- Do a transient (time dependent) simulation of circuits using LTspice
- Build simple circuits consisting of combinations of resistors, inductors, capacitors, and op-amps on protoboards and measure input and output voltages vs. time.
- Review the background for the previous experiments.

Learning Outcomes: Students will be able to

- Generate I-V curves for resistors and diodes, both experimentally and with LTspice simulation
- Make differential voltage measurements using Analog Discovery and WaveForms.
- Do a DC sweep simulation of circuits using LTspice.
- Characterize the operation of diode rectifiers (half-wave and full-wave) both experimentally and using LTspice simulation.
- Add smoothing
- Build basic LED circuits

Equipment Required:

- **Analog Discovery** (with Waveforms Software)
- **Oscilloscope** (Analog Discovery)
- **Function Generator** (Analog Discovery)
- **Protoboard**
- Resistors, Capacitors, Diodes
- LTspice

Helpful links for this experiment can be found on the course website under Class #8.

Pre-Lab

Required Reading: Before beginning the lab, at least one team member must read over and be generally acquainted with this document and the other **required reading** materials.

Hand-Drawn Circuit Diagrams: Before beginning the lab, hand-drawn circuit diagrams must be prepared for all circuits either to be analyzed using PSpice or physically built and characterized using your Analog Discovery board.

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 - 0.8V for a standard silicon signal or power 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 of 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.

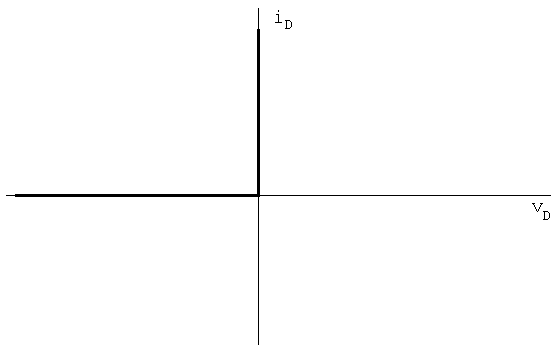


Figure A-2.

I-V curve of a diode: Figure A-3 shows typical characteristics of a real diode.

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 1V. The reverse-breakdown voltage might be about 100V, and the saturation current I_s may be of the order of 1nA. Power diodes may allow forward currents up to many amps at forward voltage drops of 0.6 to 1.5V or so, depending on the type of diode. The reverse-breakdown voltage of power diodes may range from as low as 50V up to 1000V or even much more.

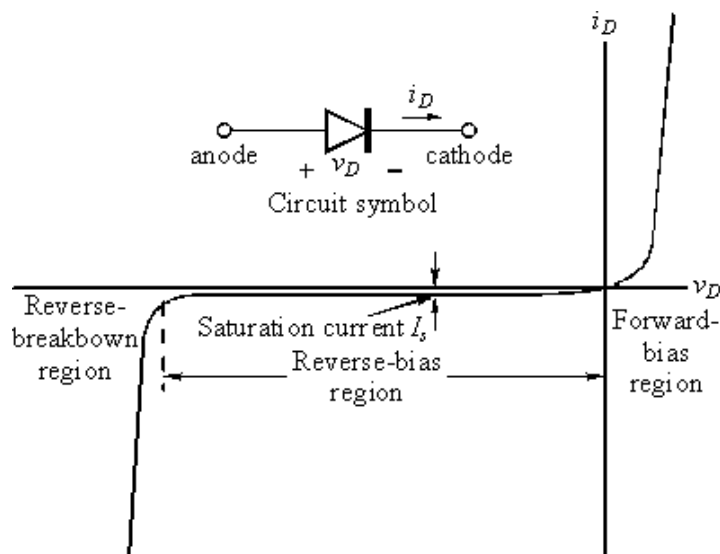


Figure A-3.

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 microamps, or nanoamps. V_T is the Thermal Voltage where $V_T = kT/q = 0.0259V$ at 300K and n is a somewhat arbitrary parameter that depends on how the diode is constructed 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 R2 in the figure below. LTspice allows us to plot currents, but Analog Discovery does not (at least not directly). So we will add a 1k Ω “current sensing resistor,” R1. The current through R1 is equal to the voltage across R1/1000. Analog Discovery can be used to measure the voltage across the “current sensing resistor.”

- Wire the circuit shown in Figure A-4 in LTspice.

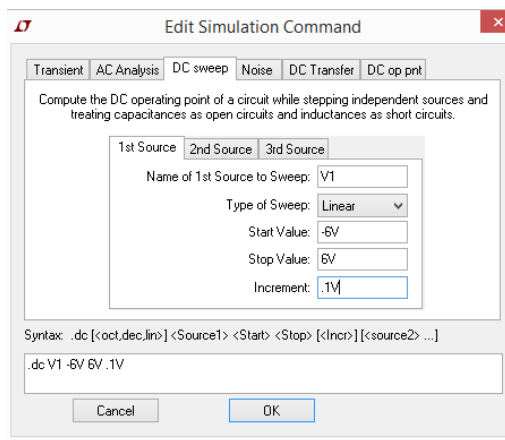
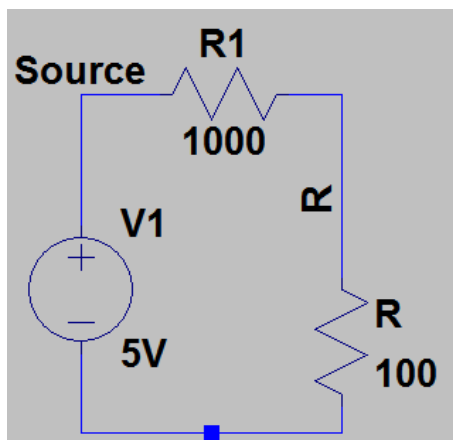


Figure A-4.

- Run a simulation and create the I-V characteristic curve
 - Set up a DC sweep from -6V to +6V in increments of 0.1V. (When you set up the DC sweep analysis, be sure that you name your source. It is “V1” in this diagram but it may be something else in your schematic.) The window for DC sweep analysis is also shown in Figure A-4
 - Run the simulation.
 - Use a current probe to display the current through R1. The plot produced will show something similar to the I-V characteristic curve for resistor R2. It should look something like Figure A-5:

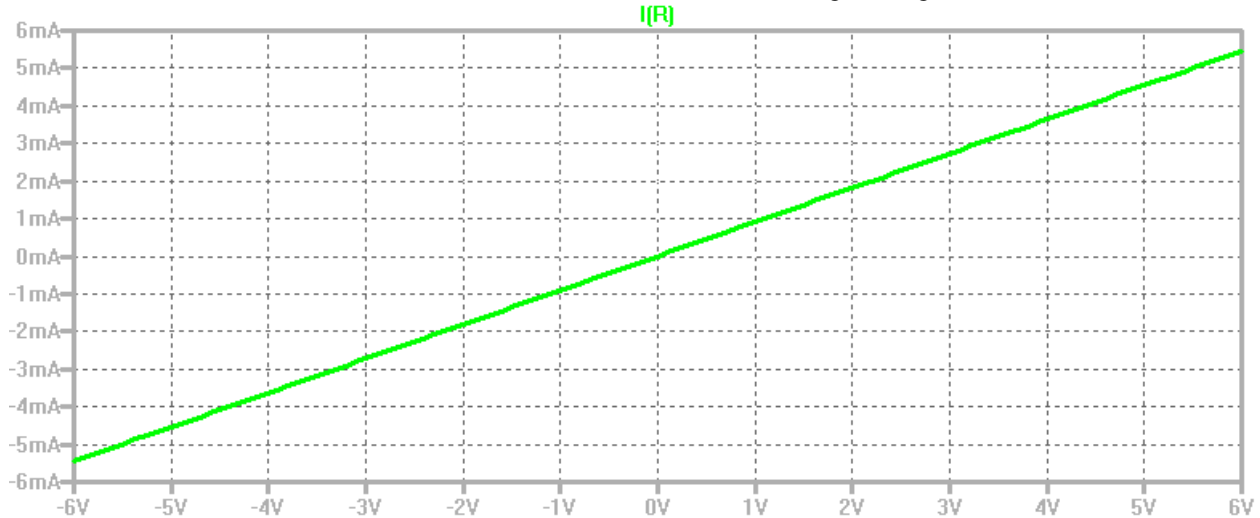


Figure A-5.

- The problem with the plot above is that the current through the resistor is shown vs the voltage from the source. We need to voltage across the resistor. Thus, we now need to change the axis variable in the plot. This is easy to do in LTspice, but the procedure is not obvious. To change the horizontal axis variable, left-click your mouse on the name of the current being displayed. Note that I named the resistor R so I can easily identify the current through the resistor. I also named the node just above it with the same letter R so I can easily identify the voltage across the resistor. You should now have the cursor activated. Drag the cursor down until you are located over the horizontal scale. The cursor symbol will be replaced by the ruler you see when you change the vertical scales. Left-click again and you will see the Horizontal Axis window, shown in Figure A-6. Change the Quantity Plotted to the voltage just above the diode. This will be the diode voltage, because the other end is grounded. For the circuit in Figure A-4, the quantity is V(R).

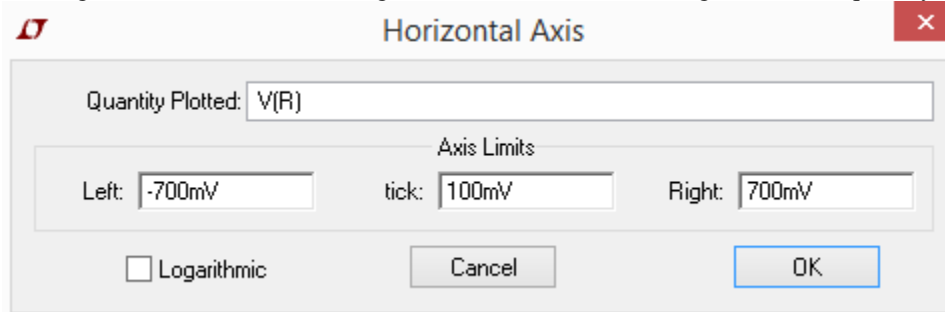


Figure A-6

The I-V plot should now be correct in that it is Resistor R current vs. Resistor R voltage. See Figure A-7.

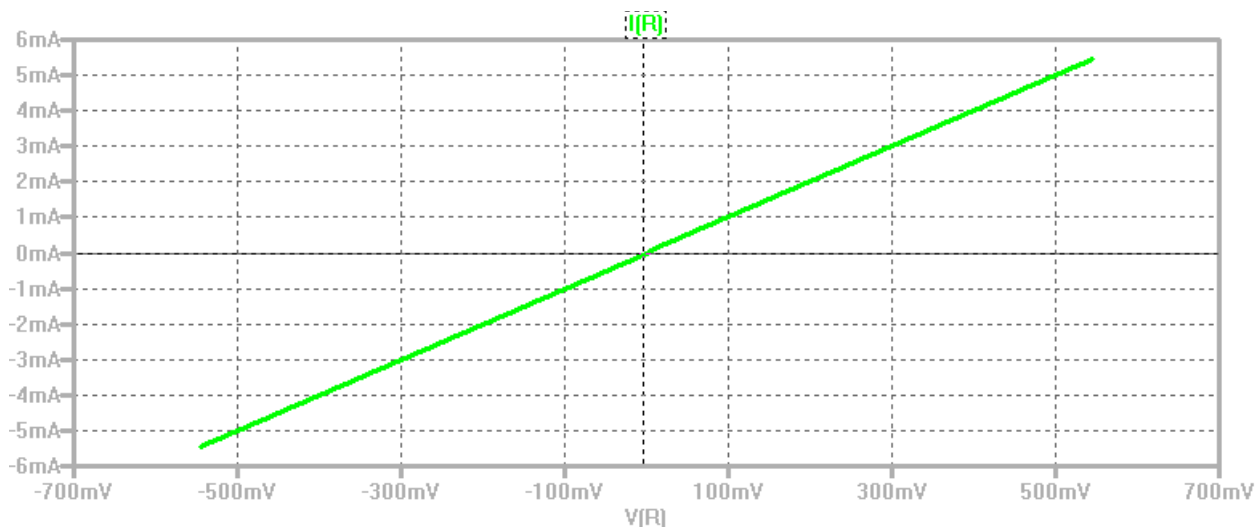


Figure A-7

- To prepare for measuring current with Analog Discovery, add a trace to the plot, $(V(\text{Source})-V(\text{R}))/1000$ {Again, the node names may be different. You should be plotting the voltage just above R1 minus the voltage just below R1 divided by the resistance of R1.}
 - You should note that the new trace falls on top of the old trace. The voltage across R1 can be used to determine the current through R1. The current through R1 equals the current through R2.

R1 can be used as a current sensing resistor. The Analog Discovery can't measure current directly but it can measure the voltage across the resistor R1 and use that value to determine the current. Even though LTspice 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 LTspice schematic by replacing R2 with D1, a 1N914 diode, as shown in Figure A-8. You will find this diode in the parts list, as we have seen in previous experiments.

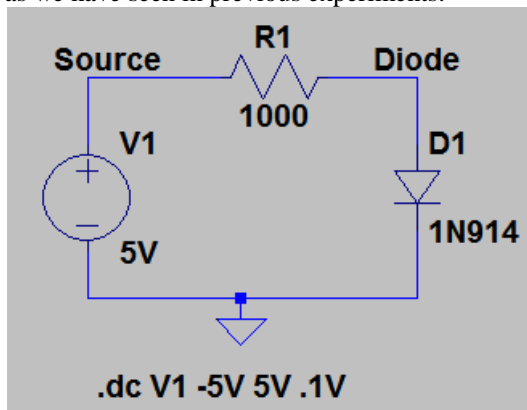


Figure A-8.

- Run a simulation and create the I-V characteristic curve.
 - Rerun the DC sweep simulation, again from -6 to +6V.
 - Use a current probe to display the current through R1.
 - Change the x-axis of your plot to the diode voltage $V(\text{Diode})$ following the directions above.
 - Add a trace to your plot of the current through the resistor, $(V(\text{Source})-V(\text{Diode}))/1000$. Again, this line should fall on top of the diode current $I(\text{D1})$. Also, your voltages and currents may have different names.

- 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
 - Fully annotate your plot. Use the cursor to find the reverse current at -4V and a few representative points for forward voltages (e.g. at currents of 1mA, 2mA, 3mA, 4mA).
 - **Copy your plot and include it in your report.**
1. Compare the points you have labeled with manufacturer data from the diode spec sheet. Instructor/TA:
-

I-V Curve of a Real Diode

In this part, we will build the simple diode circuit on your protoboard and use Analog Discovery to take a data sample from the circuit itself. Then, you will use a feature of Analog Discovery that will permit us to generate the I-V curve.

- Wire the circuit shown in Figure A-8 on your protoboard. The output of the Analog Discovery function generators is limited to $\pm 5V$, which is not quite enough to identify the features of all of the diodes we will be using. However, we will live with it for now and possibly return to our diode study when we can use amplifiers to extend the range of measurement.
 - Diodes look like very small resistors with only one stripe. The stripe corresponds to the straight line of the diode symbol at the cathode. Be sure you have the 1N914 diode.
 - When you wire the circuit, make sure your diode is placed so that the cathode faces toward ground as shown in the figure above.

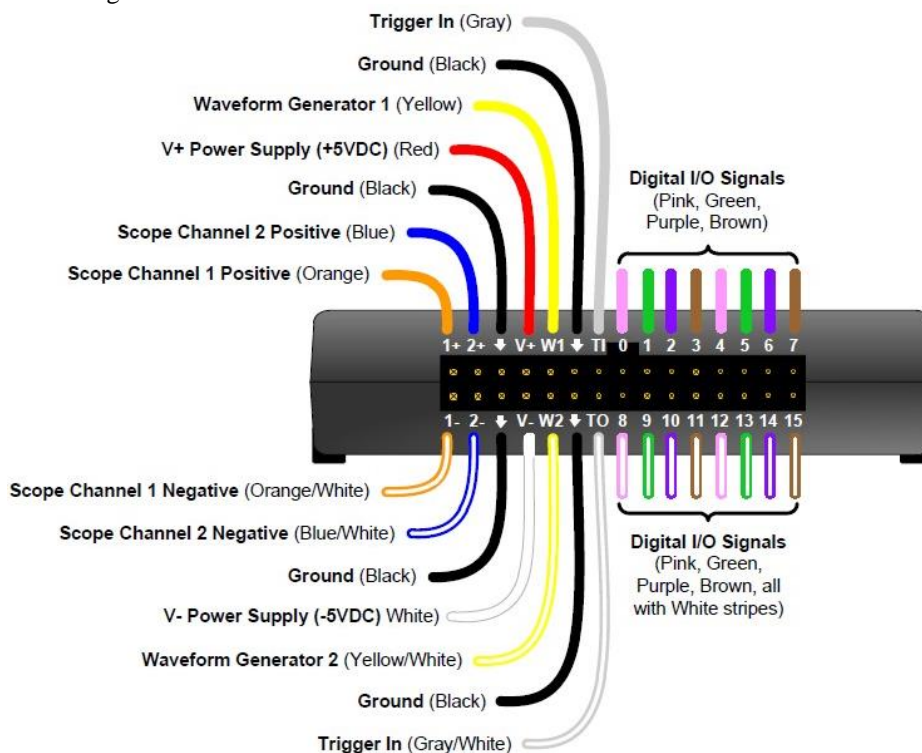


Figure A-9. Analog Discovery.

- Set Function Generator 1(W1) to a 1kHz, triangle wave, 5V amplitude.
- Observe the diode voltage on channel 1 of the Oscilloscope, (1+, 1-). Remember that the negative input (1-) for channel 1 should be connected to ground.
- Observe the diode current on channel 2 of the Oscilloscope, (2+, 2-). This is what is called a differential measurement with (2+) connected above the resistor and (2-) connected between the resistor and the diode.

Thus, channel 2 will measure the voltage across the resistor, not relative to ground. Remember that channel 2 is the current with a scale factor of 1mA/V because $R_2=1k\Omega$.

- Set the oscilloscope up to display about five cycles of the signal, for example set the time base to 500 μ s/div.
- Save a copy of the plot to your report and fully annotate it.

Now we will add a math channel to display the current.

- Add a custom channel and set it up to display Channel 2 divided by 1000 (which will be the current). When you do this you should see that the scale for this custom channel is still in Volts. We need to change that. The display scale window should look like Figure A-10. To change the units to Amps, open the drop-down menu just to the left of the X in the upper right. At the bottom of the next menu you will find a place to change the units to Amps. You will still be able to select the number of Amps per division in the range menu of Figure A-10. Set up the display to show 1mA/div as shown. Now you should be displaying the diode current in your plot.

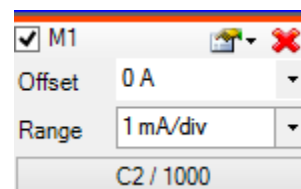


Figure A-10

Finally, we will display the I-V plot using another great Analog Discovery feature.

- Above the Run/Stop button, there is a button that allows us to Add XY. This will plot Channel 2 vs Channel 1. Again, that is not exactly what we want to do. Go ahead and select Add XY. A plot that looks like the I-V characteristic of the 1N914 diode should appear along with another menu that allows us to choose what we will plot. If the additional menu does not appear, you can open it with the menu button located in the upper right of the XY window. For the Y axis, choose the Math channel. Now you should have a really nice I-V plot.
- Save the data to a file once you have a clean plot on the screen. Also save the plot in your report and fully annotate it. Again, you should label a representative number of points on your plot. You can get the points using a cursor on the main time dependent plot displayed by Analog Discovery.

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 experiments.

Half-wave rectifier: You already built a half-wave rectifier in the very first circuit of Class #5. For this experiment, we will begin by rebuilding that circuit, with a few modifications. We will use a larger resistor (10k Ω) and a higher frequency triangular wave source (1kHz), as shown in Figure B-1.

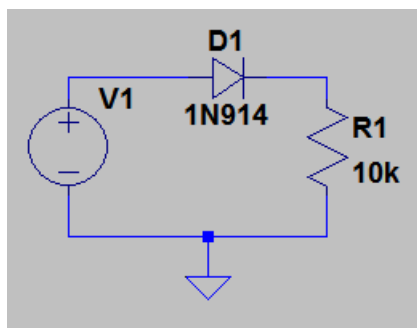


Figure B-1.

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 will not be DC, but the average of the signal is now positive.

Experiment:

- Set the function generator on Analog Discovery to a triangle wave at 1kHz with a 2V amplitude.
 - **Produce a plot of the oscilloscope channels 1 and 2. Include this in the report. Label the traces (i.e. Annotate your plot.).**
 - Add a $4.7\mu\text{F}$ capacitor in parallel with the $10\text{k}\Omega$ resistor. Remove and add it a few times to more easily observe how it affects the voltage across the resistor.
 - **Produce a plot of the oscilloscope channels 1 and 2. Include this in the report. Label the traces (i.e. Annotate your plot.).**
2. Describe the differences between the smoothed (with capacitor) and unsmoothed output.

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.

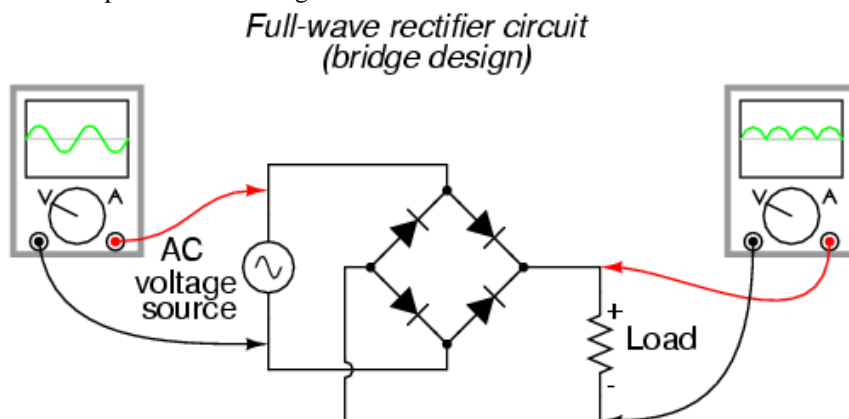


Image from www.allaboutcircuits.com

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 half 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.

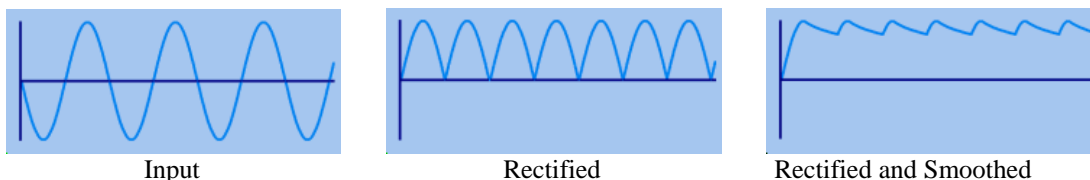


Figure B-3.

Experiment:

- Repeat the experiment above but first build the full-wave rectifier shown in Figure b-4. Note that this circuit is the reason why there are four 1N914 diodes in your kit.

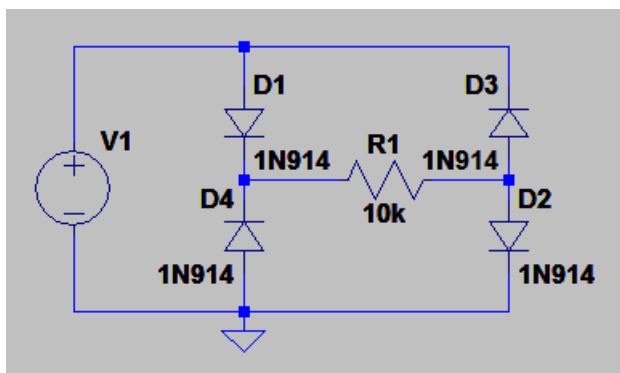


Figure B-4

- Produce plots of the oscilloscope channels 1 and 2 both with and without smoothing. Include these in the report. Label the traces (i.e. Annotate your plot.).** Instructor/TA _____
- Describe the differences between the full- and half-wave rectifier outputs, with and without smoothing.
 - Will the output with smoothing in both cases become smoother at higher or lower frequencies? You many want to try this to see before answering.