USAF Academy
Department of Electrical and Computer Engineering
ECE 321 – Electronics 1

Fall 2017

The Diode

Objective: To illustrate and reinforce the concepts of diode characteristics, operation, and both large and small signal modeling.

Authorized Resources: 1) ECE321 class handouts, 2) course texts, 3) lab and equipment manuals, and 4) simulation handouts.

Collaboration Policy: Cadets may collaborate regarding the theory relevant to this experiment and on the operation/use of software and hardware. <u>Cadets must design and develop their own experiments, take their own data and measurements, and perform their own analysis and conclusions</u>. Proper documentation is required per USAFA policy.

Due Date: Your completed Lab Notebook for this exercise is due IAW the syllabus.

Grading: This lab is a <u>significant</u> component of both your mid-term grade and overall lab grade for the course. See the syllabus for weightings.

Overview: In this lab, you will demonstrate the concepts of the junction diode, perform diode modeling, and investigate several diode circuits.

Start this lab (and all others) by reading over the ***entire*** lab before you do anything else. You ***must*** have a good idea of what you'll be doing before you start. Keep your lab notebook in the "**Traditional Experiment**" format. See the lab notebook handout to find out what should be included in this lab. Missing sections because of ignorance is not an excuse. Notebook details will also be given for each of the three parts to this lab.

Part A. Device Characterization. Experimentally determine the Shockley (also known as Boltzmann) Ideal Diode equation. You'll need to find the scale current I_s and the Ideality factor 'n' for a provided diode.

Part B. Small-signal Diode Modeling (Forward Bias and Zener). Perform small-signal analysis on a given diode circuit using the modeling methods and techniques discussed in class. Verify predictions through both simulation (use your I_s and 'n' from Part A) and hardware measurement.

Part C. Large Signal Modeling. Perform a large-signal analysis on a full-wave bridge rectifier circuit. What does a rectifier do? Use the constant voltage drop (CVD) model to predict its behavior. Compare results from all three methods: hand, simulation, and hardware.

Important: Each part requires a graded Prelab. You will turn this in at the **start** of each lesson for a grade. Be sure to keep a copy for your use in lab.

Part A. Device Characterization (Finding ‘n’ and I_s)

Use the methods discussed in class to determine ‘n’ and I_s for a real diode, 1N4002.

Your notebook should be done in the “**Traditional Experiment**” format because you already know everything except the actual data. Use Excel, Word, OneNote, and/or Matlab to perform and record your analysis.

You’ll need to use the data in your notebook and/or computer tables to complete the lab so make sure you keep sufficient data. Use tables and equations liberally – they are free.

Helpful Hints:

- When you apply voltage to your diode circuits and take a series of i-v data points for the ‘n’ and ‘I_S” determinations, don’t let the diode current get above about ¾ the maximum continuous forward current (I_F on the data sheet).
- Remember the I_D curve for a diode is exponential. Therefore, a small change in V_D can result in a huge change in I_D. For small values of the ideality factor, ‘n’ (1.11), a 20 mV change in V_D will roughly double I_D (assuming $V_T = 25.86$ mV).
- Consider putting a resistor in series with the diode to limit current and make adjustments to the diode voltage drop easier to control.
- Keep your current above 100 μA. As currents fall below that range, you are on, or getting near the horizontal part of the curve and might even consider the diode to be ‘OFF’.
- Take sufficient data to obtain accurate results. 15 sets of i-v pairs is a good number. More is easy and can’t hurt, but don’t go overboard.
- Remember loading of the DMM. This can be an issue at low currents if measuring V_D directly as R_D approaches the DMM resistance at low I_D. Consider measuring the voltage across a measured resistance that is much less than the DMM resistance.

Note: **Remember to turn in your Prelab and keep a copy for yourself.**

Part B. Small Signal Diode Modeling

Predict the behavior (line regulation) of both a series of forward biased diodes and a Zener diode used as voltage regulators. Predictions should be done by hand calculations and simulation. In your simulations use the actual measured I_s and 'n' from part A and the real/measured resistance values you will use in the physical circuit. You'll be looking to see how well the three methods (hand calculations, simulation, and hardware measurements) match.

Use the "**Traditional Experiment"** format of notebook.

The schematic of the diode/Zener circuits are shown below in Figure 1. Work things out for four different conditions (bias points).

- **Condition A:** The source has a 7 V 'large signal' DC offset and a 350 mV amplitude (700 mVpp) ac 'small signal' component.
- **Condition B:** The source has a 5 V 'large signal' DC offset and a 250 mV amplitude (500 mVpp) 'small signal' ac component.
- **Condition C:** The source has a 3 V 'large signal' DC offset and a 150 mV amplitude (300 mVpp) 'small signal' ac component.
- **Condition D:** The source has a 2 V 'large signal' DC offset and a 100 mV amplitude (200 mVpp) 'small signal' ac component.

Answer the following:

- How will the diodes act under the varying conditions?
    - At what point do the diodes cease to provide regulation as the diodes become an affective open, resulting in a simple voltage divider circuit r_d in parallel with $R_L = R_L$ as r_d approaches infinity?
    - What are the effective small signal r_d values in each situation (slopes of the i-v curve at the specific bias point)
    - Is an effective r_d value useful, does the small signal model (r_d) apply at each bias point?
- What is the line regulation for each circuit and bias point?
- Is the CVD model appropriate? Is V_D= 0.7 or V_D= -V_Z at all valued of supply voltage?
- Are any diodes in danger of burning up?

Note: **Remember to turn in your Prelab and keep a copy for yourself.**

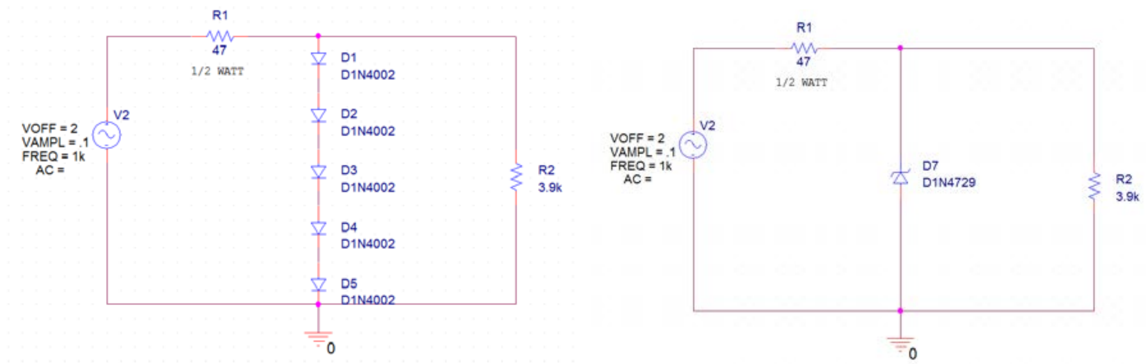

Figure 1. Circuit 1 – Diode Regulation, Circuit 2 – Zener Regulation

--You will use 5 1N4002 diodes (~0.7V * 5=3.5 V) in circuit 1 and 1 1N4729 3.6 V Zener diode in circuit 2. Both circuits use a ½ watt 47-Ω resistor and a ¼-watt 3.9 kΩ resistor. Do not use the normal resistors for the 47-Ω device because these circuits will exceed the normal ¼ watt power rating.

--For simulations, use the "DIODE" library and find the 4002 and 4729 devices. You should change the 'n' and I_s parameter for the 4002 to match those determined from Part A. You should not alter the 4729 Zener diode model.

Simulation Note: While it is possible to modify the version of a diode to show the measured 'n', I_s values, this is not typically done.

Also, when you use schematics and plots as part of you work, it's often a good idea to include at least some schematics and plots in your final analysis and conclusion. Make sure that these are well labeled and clear. One good idea is to put the schematic on the top of a page and its labeled waveform on the bottom half of the page. Microsoft Word is great for this. Indicate what each waveform is and how/where it was measured/obtained. Show where you placed probes on the circuit. Use sufficient waveform points so as to obtain a smooth graph. Include a circuit schematic with DC values. For procedural help, go to the course website.

Part C. Large Signal Modeling

Here, you'll be using a 10 V sinusoid attached to a bridge rectifier as shown below in Figure 2. As in Part B, your task will be to predict, simulate, and verify the operation of the circuit.

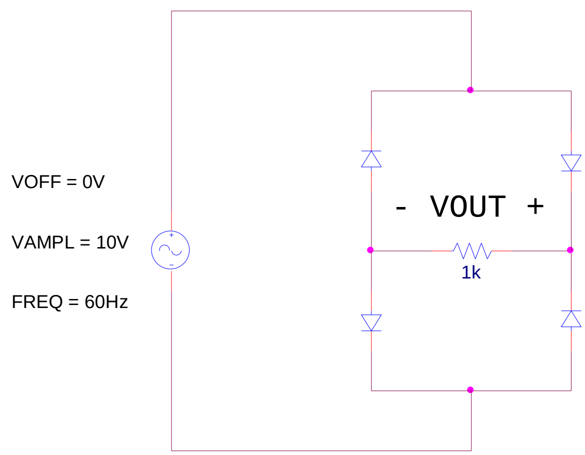

Figure 2. Bridge Rectifier Circuit

The chip you will use in lab can be any of these:

Collmer Semiconductor Silicon Bridge Rectifier: DF005M, DF04M or DF10M.

See the specific device data sheet for more specs.

Each bridge rectifier chip has FOUR diodes inside and four pins identified by the following symbols: **+, -, ~, ~** . You'll need to determine how they are configured. Hint: Use a DMM and your knowledge of how diodes work to determine how they are hooked up inside.

> **Note**: **Your bridge rectifier chip does not contain a resistor. It only contains 4 diodes. The resistor indicated in the circuit is your (external) load.**

Your notebook sections should include/consider things like:

Plots of expected waveforms
Equations
Large-signal model. (Is a small-signal model appropriate?)
Phase shift of output.
Current, Voltage
Power dissipated overall and by the various circuit elements and devices.

Simulation hints:

In place of an actual bridge rectifier model, just use 4 of the diodes you created in part B, so you have EASY access to all voltages and currents. Because it's a large signal, the actual diode used, within limitations, is not too important. Explain why.

Use +/- differential probes in simulation to find the voltage across the resistor. You will need to use TWO O-scope probes in lab to allow you to see the whole rectified signal. Simply subtract or add one to/from the other. ***Question: How can you measure the voltage between two points when one is NOT ground? See appendix A.***

Finishing the Rectification Process.

As discussed in class, it will take a capacitor in the correct location to smooth out your output signal. Determine an appropriately sized capacitor and the best location to create a DC-ish looking output signal. Continue to use the 1 kΩ load.

What is the ripple voltage of your output signal? Can you increase/decrease the ripple?

Note: **Remember to turn in your Prelab and keep a copy for yourself.**

Analysis and Conclusions

You completed various tasks in this lab starting with determining some parameters for a given diode and you learned some specific diode applications. Now it's time to put it all together in an analysis and conclusion. As you write your analysis and conclusion, consider:

--All parts of the lab.
--What did you learn?
--What would you do differently if you did the lab over?
--What were the sources of error (loading from DMM/O-scope, simulation errors, assumptions in the models)?
--How could you have avoided any errors you might have made?
--Were your predictions supported or not?
--Was there anything that you did not complete?
--Were there ***significant*** difficulties?
--Do you know the difference between ***large***-signal and ***small***-signal modeling?
--Could you use a diode in a circuit?

Deliverables:

--Notebook
--Typed Analysis and Conclusion section (NOT physically attached to the notebook)
--A copy of the grading rubric at the end of this handout.

Bonus Circuits:

Here are some additional circuits you can build just for fun. If you want to do any of these, just add a few pages in your notebook showing the circuit, operational waveforms, and a brief description.

- Peak detector
- Voltage doubler
- Any of the voltage limiting circuits

Appendix A: Differential Voltage Measurements

---In lab with the O-Scope

It is not possible to directly measure the voltage across two points if one of those two points is not the signal ground. This is because the scope's inputs are directly tied to case ground just like the function generator. In order to see the voltage generated between two points, you must obtain the voltage at each point on its own channel and then use the scope's mathematical functions to display the difference.

A. Connect Point A to Scope Channel 1, referenced to ground. Adjust Channel 1 setting (scale, time base and triggering) for a stable display.

B. Connect Point B to Scope Channel 2, referenced to ground. Adjust Channel 2 setting using the same vertical scale. You should not change the time base or triggering unless necessary to maintain triggering. If the time varying portion of Channel 2 is much greater than that of Channel 1, you might need to reduce the scale of both and might need to change the triggering source to Channel 2.

C. Find and press the +/- key, located between the Ch1 and Ch2 Keys. This activates the function menu keys below the screen face. Find and press "MENU" under the Function 1 section. Press the function key until you see '1-2". Return to the previous menu and set Function 1 to "On". The scope should now display Channel 1's signal MINUS Channel 2's signal.

D. You can now also turn off Channel 1 and 2 to make things easier to see. The signal is still present, just not displayed. You can adjust the vertical scale setting and offset of the difference trace by selecting the corresponding Function 1 menu key and adjusting its value with the "Entry" knob. Carefully note where the zero volt axis lies on your hardcopy output.

Make sure you have the correct multiplier set if you use the grey probes. It's the 10X setting, menu selection to the right.

---in simulation

Spice. Use the +- probe button. You will have to place TWO probes. When analysis is complete and waves are plotted, Spice will automatically subtract the - voltage from the + voltage to give the differential voltage. Multisim. Mathematically subtract one signal from the other.

<u>Grading Rubric</u>

(See Course Webpage for tips to getting better lab grades)

Notebook: Objectives	**_________ /10**
Notebook: Theory	**_________ /30**
Notebook: Procedures	**_________ /30**
Notebook: Simulations	**_________ /20**
<u>Prelab A</u>: Design, Simulation, and Test Plan	**_________ /30**
<u>Prelab B</u>: Design, Simulation, and Test Plan	**_________ /30**
<u>Prelab C</u>: Design, Simulation, and Test Plan	**_________ /30**
Notebook: Execution/Data Recording	**_________ /20**
Formal: Analysis & Conclusions	**_________ /80**
Formal: Written Communications (Grammar, Spelling, Organization, Sentence Structure)	**_________ /20**
Bonus Circuits: (30)	**_________**
Total Points Awarded:	**_________ /300**