

EE 462: Laboratory # 4
DC Power Supply Circuits Using Diodes

by
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(Lab 3 report due at beginning of the period) (Pre-lab4 and Lab-4 Datasheet due at the end of the period)

I. Instructional Objectives

- Design and construct circuits that transform sinusoidal (AC) voltages into constant (DC) voltages.
- Design and construct a voltage regulator based on the characteristics of the Zener diode.
- Evaluate the performance of simple rectifier and regulator circuits.

See Horenstein 4.3 and 4.4

II. Background

Electric power transmits best over long distances at high voltages. Since $P = I V$, a larger voltage implies a smaller current for the same transmitted power. And smaller currents allow for the use of smaller wires with less loss. The high voltages used for power transmission must be reduced to be compatible with the needs of most consumer and industrial equipment. This is done with transformers that only operate with AC (DC does not pass through a transformer). However, most electronic devices powered by a home outlet require DC (constant) voltages. Therefore, the device must have a power supply that converts AC voltages into a DC (constant) voltage.

The terminology "DC" is somewhat ambiguous. DC can mean the voltage or current always has the same polarity but changes with time (pulsating DC), or it can mean a constant value. In this lab assignment DC will refer to a constant voltage or current. Voltages or currents that maintain the same polarity, but change with time, have both a DC and AC component. The process of changing an AC signal to a signal with only positive values is called *rectification*, and circuits that perform this operation are called rectifier circuits. The rectifier circuit operates similar to the clipping circuits used in a previous lab. Figure 1 a) shows a half wave rectifier and Fig. 1 b) shows a full wave rectifier.

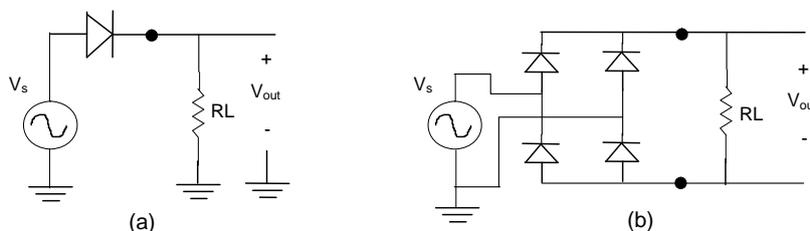


Fig. 1 a) Half wave rectifier. b) Full wave rectifier.

Although the output of a rectifier is always positive, it is generally not constant, often going from zero to a peak value. Thus, the output of the rectifier must be filtered to remove the AC component so as to pass only the DC (constant) component to the output. Since DC has a frequency of 0 Hz, a low-pass filter can be applied to attenuate or block the higher frequency signal components. The simplest low-pass filter is a capacitor. Figure 2 shows examples of passing rectified signals through a low-pass filter. Low-pass filtering a waveform is sometimes called smoothing because it *smoothes-out* fast or sharp voltage jumps. Real-time filter can not have a cut-off sharp enough to totally eliminate unwanted frequencies, so the actual output of the filter will always have some AC content, often called ripple (ripple voltage or ripple current). A rectifier combined with a filter forms a simple DC power supply.

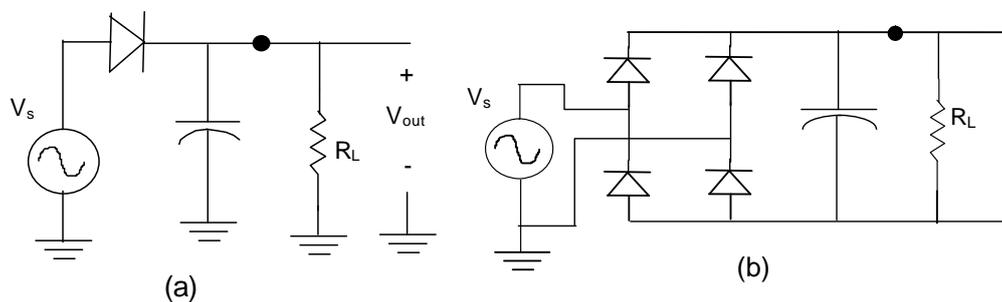


Fig. 2 a) Half wave rectifier with capacitor filter. B) Full wave rectifier with capacitor filter.

One performance measure of a DC power supply is the *percent output ripple* computed from the ratio of the (peak-to-peak) output voltage to the average (DC) output voltage. Output ripple can be expressed as r in the equation below:

$$r = \frac{V_{op-p}}{\langle V_o \rangle} \quad (1)$$

where V_{op-p} is the peak-to-peak output voltage and $\langle V_o \rangle$ is the mean of the output voltage, which is equivalent to the DC component. Multiply r by 100 for *percent output ripple*. A typical output signal is illustrated in Fig. 3. The best performance occurs when the percent ripple is zero (a battery produces ideal DC). This lab examines and compares the two rectifier schemes in Fig. 2, and demonstrates the contributions of the different stages to the final output.

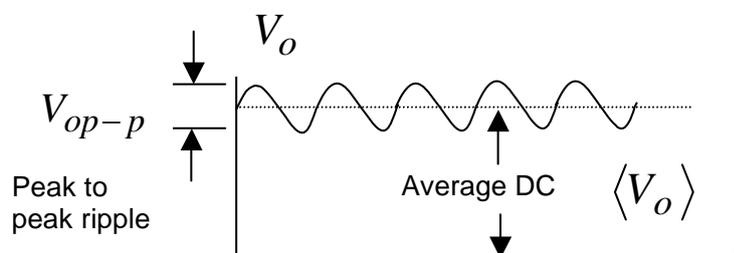


Fig. 3. Definition of percent ripple

A DC power supply provides constant DC voltage to a load, which can be modeled as a resistor. Ideally the constant DC output should be independent of the load and input voltage fluctuations. In an actual power supply, however, when a load is applied to the output (as in Figs. 1 and 2), the output voltage decreases due to increased current drawn and the increased internal voltage drops. A voltage regulator circuit is used to prevent/limit these output voltage changes. A Zener diode can be used to make a voltage regulator circuit (as shown in Fig. 4) by taking advantage of the Zener diode's reverse breakdown characteristic. Recall that once a Zener diode breaks down, its voltage remains essentially constant independent of its reverse current. The regulator's resistor, R_{reg} , limits the current through the Zener to reduce the power dissipated in the Zener. This is done, however, at the price of limiting the maximum load current that can be supplied with a regulated output voltage.

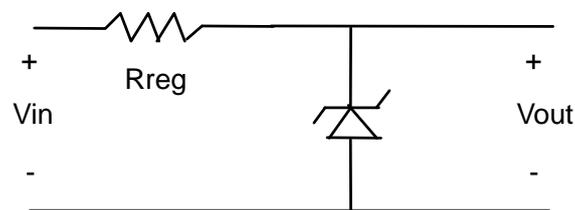


Fig. 4. Zener voltage regulator

An important characteristic of a voltage regulator is its percent regulation defined as the difference between the average no-load voltage (implies zero load current and thus infinite load resistance) and the average full-load voltage (the load draws its maximum (or rated) current and thus has its minimum (or rated) resistance) divided by the average full-load voltage. Regulation can be expressed in the equation below:

$$\text{Regulation} = \frac{\langle V_{oNL} \rangle - \langle V_{oFL} \rangle}{\langle V_{oFL} \rangle} \quad (2)$$

where $\langle V_{oNL} \rangle$ is the average output no-load voltage and $\langle V_{oFL} \rangle$ is the average output full-load voltage. *Percent regulation* is obtained by multiplying Regulation in Eq. 2 by 100. The best regulation performance is achieved with a 0 % regulation.

A typical DC power supply consists of 3 stages, which are a rectifier, a filter, and a voltage regulator. A power supply using this combination is shown in Fig. 5.

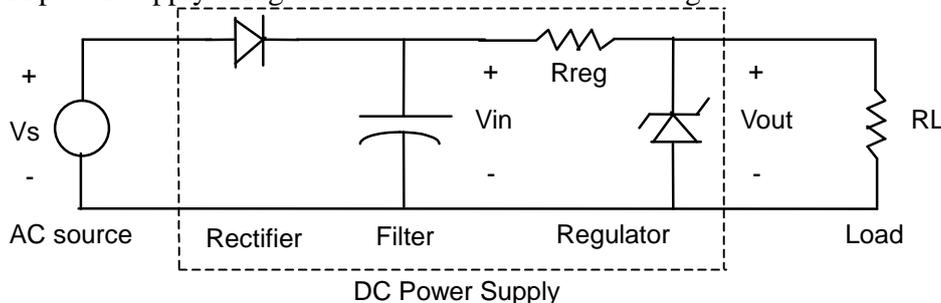


Fig. 5. Basic power supply consisting of a rectifier, filter, and regulator.

III. Pre-Laboratory Exercise

Rectification Waveforms:

1. For the half-wave and full-wave rectifiers in Fig. 1:
 - a) Determine the output voltage and the current through a load R_L . Write the results in symbolic, piecewise notation and sketch the voltage output waveforms for a single period of sinusoidal excitation.
 - b) Write a Matlab program to plot the voltage and current on the same graph and numerically compute the average power in the load. $R_L = 2.2\text{k}\Omega$, $\mathbf{vs(t)}$ is a sinusoidal, 6.4Vrms, 60Hz input voltage, and assume the diode ideal forward voltage is .7 V. (Use the MATLAB *syms* command or do numerical integration to find the power using equations derived in 1(a))

Filtering Rectified Waveforms:

2. For the filtered half-wave and full-wave rectifiers in Fig. 2, assume a 2.2k Ω load with a sinusoidal, 6.4Vrms, 60 Hz input voltage. Use suitable approximations to:
 - a) Determine a capacitor value so that the output ripple voltage is 0.5V P-P for the half-wave rectifier with a 2.2k Ω load.
 - b) Use the same capacitor value found in part (a), and determine the percent ripple for the full-wave rectifier.
 - c) Determine the percent ripple voltage for the half and full-wave rectifiers with no load ($R_L = \infty$).
 - d) If the calculated value of capacitance is not available in the lab, should a larger or smaller capacitor be used to ensure specifications will be satisfied? Explain your answer.
3. For the full-wave rectifier case, sketch a schematic showing how you will place your probes to measure the output voltage and briefly describe how you will measure this voltage. Grounding is the issue for this connection. So clearly indicate where the grounds of probes are placed and describe the oscilloscope scope settings for viewing the waveform of interest.

Regulation with Zener:

4. Consider a Zener voltage regulator circuit as seen in Figure 4. This circuit can be used to regulate the output of the filtered rectifier circuit to 5.1V (use a 5.1V Zener - 1N751A or equivalent).
 - a) Determine R_{reg} assuming the maximum power that the Zener will absorb at no load is 15mW.
 - b) Using the value found for R_{reg} in part (a), determine the maximum load (in Amps) that could be supplied while maintaining output voltage regulation. (Hint - draw Fig.4 - the current in will be equal to the maximum voltage in, $6.4*\sqrt{2}/R_{reg}$ because the load resistance will be nearly zero to draw maximum current; the difference between this current and the current absorbed by the Zener will be the maximum current)

SPICE Simulation and Analysis

5. Simulate your completed power supply designs (Figure 5 for the half-wave rectifier, and the full wave rectifier with regulation circuitry) using SPICE to verify it meets requirements. Use values for R_{reg} and filter capacitor found in 2(a) and 4(a) of the pre-lab, but **round these values to the nearest available values found in your parts kit.**
 - a) Print out the transient simulation output showing steady-state voltage ripple.
 - b) Determine the output ripple percentage.
 - c) Determine percent regulation.
 - d) Bring the B2 SPICE files to lab so you can run this program and set the circuit values to the actual components you used and compare to your experimental results.

IV. Laboratory Exercise

Half Wave Rectifier Power Supply

1. Construct the half wave rectifier circuit in Fig. 1a, using an input voltage to 6.4Vrms and 60Hz.
 - a) Record the output waveform
 - b) Add the filter capacitor of the same value used in the SPICE simulation of part 5 of the pre-lab. You will need to use a polar capacitor to get the value calculated in the pre-lab, so make sure you get the polarity correct. (Small value capacitors tend to be non-polar while large value capacitors tend to be polar. The long leg is positive, the short leg negative; connect the short leg to ground.) Record the output voltage waveform.
 - c) Measure the percentage ripple of this circuit for no-load and for a full-load equal to 2.2k Ω .
 - d) Add the voltage regulator of Fig. 4 to the circuit (should now look like the circuit in Fig. 5). Use the value of R_{reg} from the SPICE simulation in part 5 of the pre-lab. Record the output voltage waveform for a full load equal to 2.2 k Ω .
 - e) Make measurements and estimate the percentage ripple of this circuit for full-load and compute the percent regulation.

Discussion: How do your measured results compare to your pre-lab calculations?

Full-wave Rectifier Power Supply

2. Construct the full wave rectifier in Fig. 1b. Repeat procedures and measurement as you did for the half-wave rectifier in part 1. Be wary of grounding issues in your measurements! (Hint: You must use the math function on the oscilloscope in this case to get the correct voltage measurements.)

Commercial Power Supply

3. For the left most variable DC output channel of your lab power supply at an output voltage of 9V, measure the percentage ripple for a 2.2k Ω load and compute the percent regulation. Record your results and the waveforms used to obtain your measurements.

Discussion: How does the regulation of your power supply compare to the regulation of the laboratory power supply? Overall, compare the performances of the 2 power supplies.