UNIVERSITY OF NORTH CAROLINA AT CHARLOTTE
Department of Electrical and Computer Engineering

EXPERIMENT 4 – DIODES AND BRIDGE RECTIFIERS

OBJECTIVES

The purpose of this experiment is to introduce diode rectifier circuits used in DC power supplies.

INTRODUCTION

Almost all electronic systems require at least one DC power supply that converts AC line voltage (most often 120VAC @ 60 Hz) to DC voltage (typically 5 to 20 VDC). To accomplish this, diodes are used to produce either positive or negative DC voltage from an alternating source in a process called rectification. The diode is, therefore, an essential element of every DC power supply.

The purity of DC voltage delivered by the power supply is largely determined by the requirements of its load (i.e., electronic system). Rectified AC naturally pulsates, and is usually smoothed by filtering to produce a steady DC value. Perfect filtering would produce a DC output having no AC variation at all. In practice, some unwanted AC voltage, called “ripple”, appears at the output along with the desired DC voltage. The ratio of AC ripple voltage to DC voltage at the power supply output is called “ripple factor”. Ripple factor is defined as either $\frac{V_{RMS}}{V_{DC}}$, or $\frac{V_{p-p}}{V_{DC}}$. The peak-to-peak definition is used here, primarily for ease of measurement.

Maximum allowable AC ripple factor and minimum DC current output are usually specified as part of a power supply’s design requirements. A DC power supply block diagram is shown in Figure 4-1.

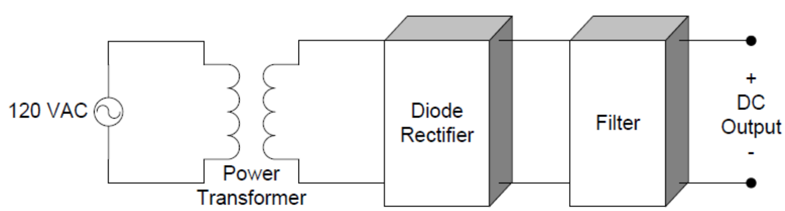
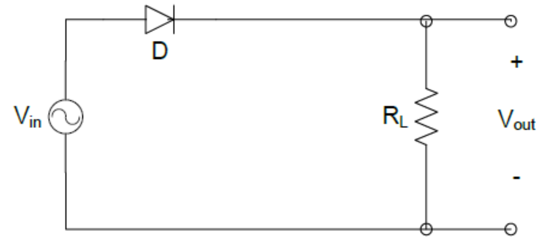


Figure 4-1 DC Power Supply Block Diagram

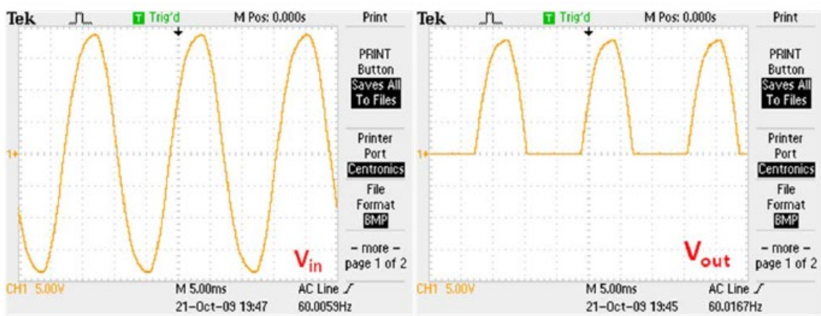
The AC input voltage is stepped down from 120 V to the appropriate level at the rectifier input by the power transformer. The rectifier converts the sinusoidal voltage to a pulsating, DC voltage, which is then filtered to produce a relatively low ripple DC voltage at the output. The type of filter selected depends on load current, ripple specifications, cost, size and other design requirements. To further reduce the ripple and stabilize the magnitude of the DC output voltage against variations caused by changing load, a voltage regulator is often employed as well.

When designing a power supply, two important parameters must be specified to assure that diodes are selected properly: 1) the maximum current capability, which is determined by the largest current that the diode is expected to conduct, and 2) the peak inverse voltage (PIV), which is determined by the largest reverse voltage that is expected to appear across it.

Rectifier circuits used in DC power supplies are classified as either half-wave or full-wave types. The half-wave rectifier shown in Figure 4-2 passes only the positive half-cycles of the sinusoid to the output, because the diode blocks current flow during the negative half cycles.



(a)

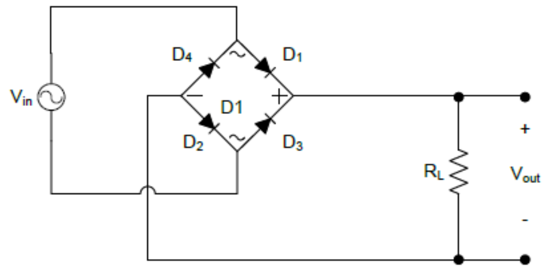


(b) (c)

Figure 4-2 (a) Half Wave Rectifier, (b) Input Waveform, (c) Output Waveform

The full-wave bridge rectifier circuit shown in Figure 4-3 inverts the negative half-cycles of the sinusoidal input voltage and passes both half-cycles of each alternation to the output. During the positive half-cycles of the input voltage, current in the full-wave bridge rectifier is conducted from the positive terminal of the source, through D1, through the load (resistor) connected to the output, and then through D2 to return to the source. During the negative half- cycles of the input voltage, current is conducted from the negative terminal of the source, through D3, through the load, and then through D4 and back to the source. Note that the load current's direction is the same for both positive and negative half-cycles.

If a simple capacitor filter is connected to the rectifier output as in Figure 4-4, the output voltage is smoothed and approaches its ideal DC value. The capacitor charges up while the diodes are conducting, and then discharges when the diodes are not conducting to maintain current flow through the load. When load current is small, ripple are low and the diodes conduct high current for a very short part of the cycle, transferring charge from the source to the capacitor by means of large current spikes.



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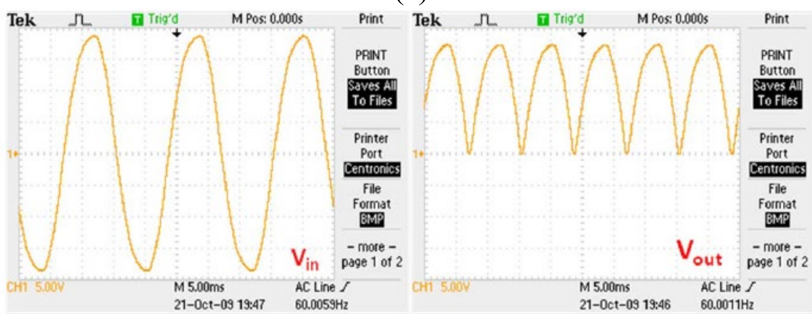
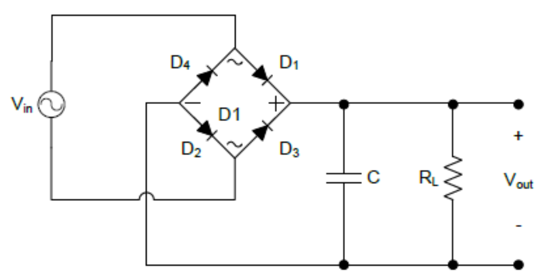


(b) (c)

Figure 4-3 (a) Full Wave Bridge Rectifier, (b) Input Waveform, (c) Output Waveform



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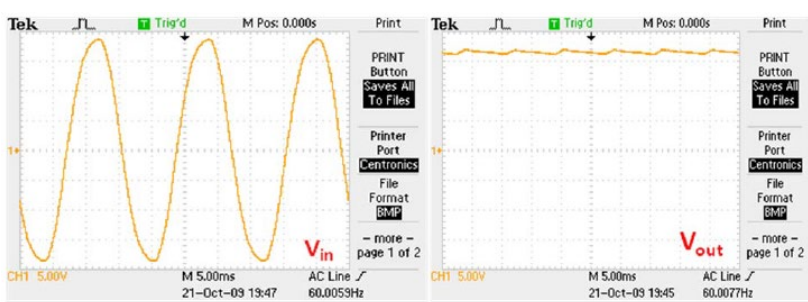
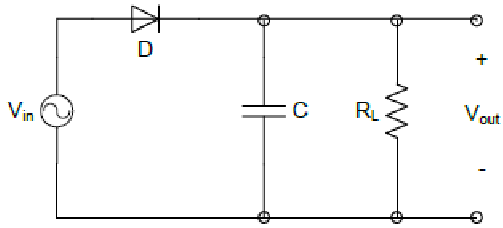


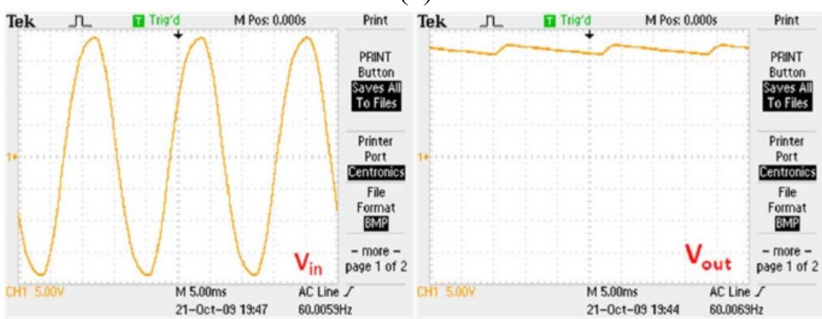
(b) (c)

Figure 4-4 (a) Filtered Full Wave Bridge Rectifier, (b) Input Waveform, (c) Output Waveform

A capacitor filter at the output of a half-wave rectifier (Figure 4-5) also results in smoothing of the output, but it is less effective than in the full-wave bridge because the voltage peaks are twice as far apart in time, necessitating a deeper discharge of the filter capacitor between intervals of diode conduction.



(a)



(b) (c)

Figure 4-5 (a) Filtered Half Wave Rectifier, (b) Input Waveform, (c) Output Waveform

Figure 4-6 is an expanded view of the output voltage ripple of Figure 4-5, captured using AC oscilloscope coupling.

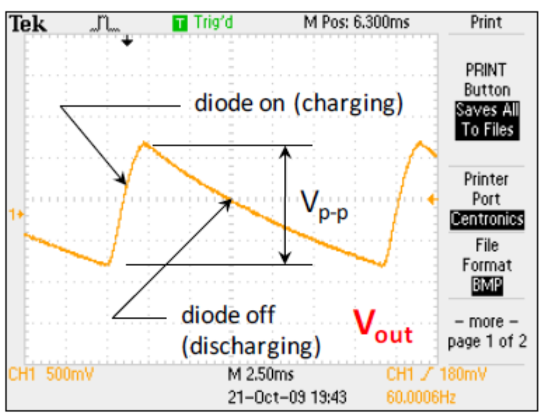


Figure 4-6 Filtered Half Wave Rectifier Ripple Voltage

Peak voltage at the output is given by$V_p = \sqrt{2}V_{inRMS} - V_D$, where V_D is the forward voltage drop across the conducting diode. The filter capacitor discharges with time constant R_LC between voltage peaks, which occur with period T. Peak-to-peak ripple voltage (V_r) for the filtered half-wave rectifier may, therefore, be approximated by $V_r = V_{p-p} = \frac{V_p}{R_LC}T = \frac{\sqrt{2}\,V_{inRMS}-V\_D}{f_rR_LC}$, where f_r is the ripple frequency.

PRELAB

1. For the full wave rectifier of Figure 4-4. If C = 330 µF, R_L = 3.3kΩ, V_{in}=5VRMS @60 Hz and each diode's forward voltage drop is 0.7 volts, calculate
   a. Ripple frequency, f_r
   b. Peak output voltage V_p (This is not the sinusoidal input voltage's peak.)
   c. Peak-to-peak ripple voltage, V_r
   d. Load current, I_L (A good approximation is obtained by neglecting ripple.)
   e. Average diode current, I_{Dav}
   f. Maximum diode current, I_{Dmax}
2. Repeat Question 1, but for a full-wave bridge rectifier when one of the diodes (D1 from Figure 4-4) is blown (open). This is equivalent to a half-wave rectifier but with two diodes in series. (It may be helpful to re-draw the circuit in order to visualize this.)

NOTE: During the experiment you will need a means of saving waveforms measured with the oscilloscope in order to perform the experiment and answer the post-lab questions.

PROCEDURE

Full Wave Bridge Rectifier

1. Obtain precise values of output filter components for use in post-lab calculations. Refer to Figure. 4-7.
   a. Measure and record precise values for R_L and R_s using a laboratory grade bench-top digital multi-meter. (**Use at least a ½ watt resistor for R_L and a 3 watt resistor for R_s.**)
   b. Measure *C* using a laboratory grade bench-top capacitance meter and record its value.
   c. The purpose of the 0.5 Ω "current sensing" resistor is to facilitate measurement of capacitor current ($I_C = \frac{V_1}{R_S}$)
2. Construct the full-wave bridge rectifier shown in Fig.4-7. Use 1N400X (e.g. 1N4002/1N4006) series diodes. (The last digit (X) indicates the diode's PIV rating. Find and review the data sheet for the selected diode to confirm that its PIV rating is adequate for this experiment.)
   a. Use the multifunction signal generator as an AC supply.
   b. Make certain that the diode and capacitor are installed with correct polarities.

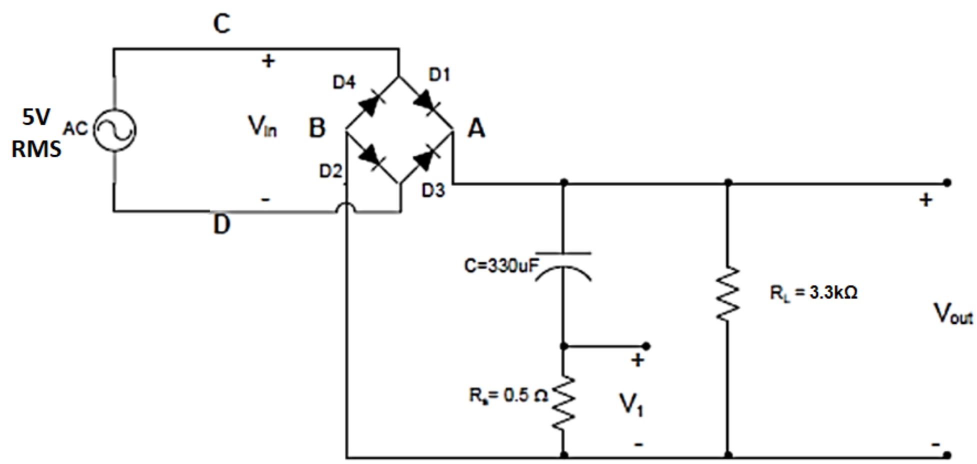


Figure 4-7 Filtered Full Wave Bridge Rectifier Circuit with Current Sensing Resistor

3. Measure Input Voltage and Output Voltage.
   a. Using the oscilloscope, measure V_{in} and V_{out}
   b. Record both peak-to-peak and RMS values for V_{in} and V_{out} (The RMS value of the input should be approximately 5 volts.). Take an oscilloscope image.
   c. Then remove the filter capacitor *C*.
   d. Observe the output voltage waveform and verify that it is correct for full-wave rectification. Take an oscilloscope image.
   e. Remove D2.
   f. Observe the output voltage waveform and verify that it is correct for half-wave rectification. Take an oscilloscope image.
   g. Measure and record the peak value of V_{out}. Determine the forward voltage drop per diode.
4. Measure Output and Ripple Voltages
   a. Replace D2 and *C* to return the circuit to the configuration of Figure 4-7.

b. Measure and record peak and average values for V_{out}.
c. Measure peak-to-peak ripple voltage. (Hint:This is accomplished more easily by selecting AC coupling mode on the oscilloscope and observing the AC component of V_{out} without the DC offset.)
d. Record the frequency of output voltage ripple. (Hint: ΔV; use peak-to-peak on oscilloscope)

5. Estimate Load Current
   a. From the output voltage waveform, measure and record: a) capacitor charge and discharge times, and b) slope ($\frac{\Delta V_{out}}{\Delta T}$) of the discharge portion of the waveform. See Figure 4-8.
   b. The capacitor discharge current (which is also the load current during discharge) is described mathematically as $I = C\frac{dV_{out}}{dt}$. This may be approximated by $\frac{\Delta V_{out}}{\Delta T}$
   c. Return the oscilloscope to DC coupling mode. Oscilloscope vertical position and triggering may have to be adjusted in order to view the waveform properly. Save this waveform (with DC offset).

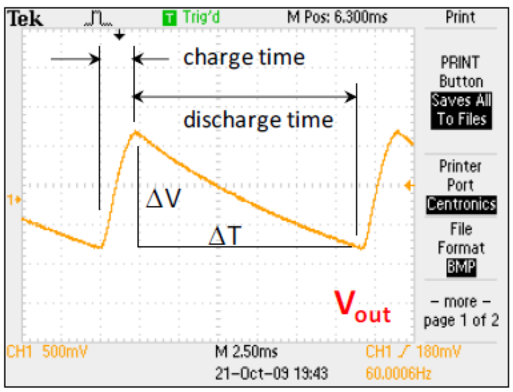


Figure 4-8 Filter Capacitor Parameters

6. Measure Capacitor Charge and Discharge Currents.
   a. Observe the voltage waveform across R_s, the 0.5Ω current sensing resistor. This waveform shows how the capacitor charges during the diode on-time and discharges to the load during the diode off-time. The purpose of the sensing resistor is to allow measurement of current with a voltage probe. The capacitor current waveform is identical to the voltage waveform, except for scaling. Save this waveform.
   b. Calculate and record the scaling factor. Save the voltage waveform (with the DC offset).
7. Measure the Load Current
   a. Connect the oscilloscope probe across R_L to display the load voltage waveform. Note that the load current waveform is identical to the load voltage waveform except for scaling determined by the load resistance ($I_L = \frac{V_{out}}{R_L}$). Save the load waveform (with the DC offset) and record the scaling factor.

POSTLAB

Post-Lab questions must be answered in each experiment's laboratory report.

1. Using the measured values for V_{in} ,R_L, R_S, C and diode forward voltage drop, repeat the pre-lab calculations for:
   a. Ripple frequency, f_r
   b. Peak output voltage V_p
   c. Peak-to-peak ripple voltage, $V_{p\text{-}p}$
   d. Load (resistor) current, I_L
   e. Diode average current, $I_{D(av)}$
   f. Diode maximum current, $I_{D(max)}$

Present and compare the calculated results alongside measured results in a table of values. Comment on the differences between calculated and measured results.

2. Use three different methods to determine load currents for both cases:
3. $I_{L(average)}=\frac{V_{out(average)}}{R_L}$
4. $I_L=\frac{\Delta V_{out}}{\Delta T}$ during capacitor discharge
5. $I_L=\frac{V_1}{R_S}$ at the mid-point of the capacitor discharge period.

Using measured values, apply the above methods to determine load current, I_L, and comment on the differing results. Explain why the "slope" method is the least accurate.

6. Using your recorded waveforms and scaling factors for the full-wave bridge rectifier circuit, first determine the load current waveform $i_L(t)$ and capacitor current waveform $i_c(t)$, and then apply Kirchoff's Current Law to find the diode current waveform $i_D(t)$. Include the three current waveforms in your report and comment on their relationships to each other.