1 Introduction

Most electronic systems require a nonvarying current and voltage ("dc") for their power source. If the power supplied by an electric utility is to be used, it is necessary to convert the utility’s alternating voltage (an “ac” quantity) to that required by the electronic system. Frequently the alternating voltage is transformed with an iron-core transformer to a potential appropriate for the electronic equipment. In this experiment, a full-wave bridge rectifier and a capacitor filter will be used to produce a nearly constant load voltage, $v_L$, as shown in Fig. 1. If it is assumed that the transformer secondary voltage, $v_{trans}$, is unaffected by the capacitor (this assumption is valid only for large values of load resistance), the load voltage, $v_L$, and diode current, $i$, result, as shown in Fig. 2.

![Figure 1: Full-wave rectifier using 4 diodes.](image1)

![Figure 2: Output (load) voltage as a function of time, indicating the charging interval, $t_c$, and discharging interval, $t_d$, of the capacitor (shown in Fig. 1).](image2)
The capacitor is alternately charged by the diode current (increasing its stored energy) and discharged by the load resistance, modeled with the equivalent circuit shown in Fig. 3. During the discharge interval (labeled $\tau_d$), the diode current, $i$, is zero; that is, none of the diodes are conducting since they are all reverse biased. The variation of the load voltage during this interval is readily determined since it corresponds to

$$v_{L_{\text{min}}} = v'_m \exp^{-\tau_d/(R_L C)}$$

To minimize the variation in the load voltage, the time constant of the circuit must be much larger than the discharge interval, $\tau_d$. For most applications, relatively large values of capacitance are required.

During the charging interval (labeled $\tau_c$), two diodes are conducting and the diode current, $i$, depends on both the capacitance and the load resistance.

$$i = C \frac{dv_L}{dt} + \frac{v_L}{R_L}$$

To obtain a “solution” for $v_L$ over an entire period, the individual solutions for the charging and discharging intervals must be joined together, taking into account both the voltage and the current. The transformer voltage, however, is an unknown. During the charging interval when the diodes are conducting, the diode current, and hence the transformer current, is large. As a result of the transformer’s inductance and resistance, its terminal voltage is reduced. Furthermore, a nonlinear effect, a saturation of the transformer’s core, generally occurs. As indicated in the preceding diagram, the maximum value of load voltage is somewhat less than the voltage that occurs without a capacitive filter. In addition, the current pulses tend to be somewhat longer than that which results for an undistorted transformer voltage.

An analytical determination of $v_L$ is generally not possible. As a result, a set of approximations are normally used to predict the behavior of the power supply load voltage. Of particular interest is the peak-to-peak variation (the ripple) in the load voltage. To calculate this quantity, it is assumed that the discharge interval of a full-wave rectifier circuit continues for one-half of a period ($\tau_d = T/2$). The peak-to-peak ripple voltage, $v_{\text{ripple}}$, shown in Fig. 4, may readily be calculated for these assumptions.

$$v_{\text{ripple}} = v'_m - v_{L_{\text{min}}} = v'_m \left(1 - \exp^{-T/(2R_L C)}\right)$$
If the time constant of the circuit, $R_LC$, is large compared to $T/2$, the exponential may be approximated by the first two terms of its Taylor series' expansion.

$$\exp^{-T/(2R_LC)} \approx 1 - T/(2R_LC) \quad \text{for } T/(2R_LC) \ll 1$$  \hspace{1cm} (4)

The fractional variation in the load voltage is therefore given by a relatively simple expression, Eq. 5:

$$\frac{v_{\text{ripple}}}{v_m^{'}} \approx \frac{T}{2R_LC} = \frac{1}{2fR_LC}$$  \hspace{1cm} (5)

The Hertizan frequency, $f$, is that of the power-line voltage. It should be noted that the approximate expression obtained for the ripple voltage tends to predict a somewhat greater voltage than that which actually occurs. Hence, if this expression is used when designing a power supply, it assures that the actual ripple voltage is less than that used for the calculations. The average value of load voltage (its “dc” value) falls between $v_{L\text{min}}$ and $v_m^{'}. The average voltage depends on the characteristics of the transformer and the voltage across the diodes when they are conducting.

2 Experimental Procedure

A transformer that has a secondary voltage of 24 V (rms value) and a current rating of one ampere is required. Either four individual power diodes or an integrated circuit bridge rectifier may be used. The individual diodes or the bridge rectifier should have a current rating of at least one ampere and a peak inverse voltage (PIV) of at least 50 volts. If individual diodes are used for the bridge circuit, it is imperative that they be connected correctly, otherwise two diodes will be destroyed when the supply is turned on. An electrolytic capacitor (500 mF) with a voltage rating of at least 50 volts is required. It is important that the
polarity markings of the capacitor correspond to the polarity of its terminal voltage. If the capacitor should happen to be connected to the circuit with its leads reversed, it will be destroyed (very likely accompanied by a noticeable “bang” and obnoxious odor). A “power” resistor capable of dissipating at least one watt is necessary for $R_L$. Since the leads of the components that are likely to be used are larger than those intended for use with an experimenter board, a suitable experimental “bread-board” designed for large leads or a prewired assembly is necessary for this experiment.

1. Assemble the circuit omitting the capacitor for this part of the experiment. Note that neither side of the transformer’s secondary winding is connected to the common ground connection of the circuit (that to which the ground lead of the oscilloscope is connected). Using an oscilloscope, observe and sketch $v_L$. Determine the peak value of the load voltage from the oscilloscope trace. If the circuit is working properly, the amplitude of adjacent peaks will be the same. Using a digital multimeter (AC range), determine voltage across the secondary winding of the transformer. A meter that does not have one of its inputs connected to a common ground, such as a hand-held, battery-powered instrument, is necessary. Using a multimeter, determine the average value of the load voltage, $v_L$. For this voltage measurement a DC range should be used.

2. Before proceeding, it should be established that the data of the previous part is reasonable. Using the ac reading of the digital multimeter, calculate the corresponding peak transformer voltage, $V_{trans}$. Compare this voltage with the peak value of $v_L$ obtained from the oscilloscope trace. For no instrument and reading errors, a difference of about 1.4 volts, a voltage corresponding to the forward voltage of two diodes, would be expected. If the difference is considerably greater than this, the circuit is not operating properly.

3. Connect the 500 mF capacitor to the circuit (being sure to observe its polarity markings). Using an oscilloscope, observe and sketch $v_L$. An accurate determination of the peak-to-peak value of the ripple voltage may be accomplished by using the AC input of the oscilloscope. For this condition, the average value of the load voltage is, in effect, subtracted from the actual voltage. The sensitivity setting of the oscilloscope may then be increased to produce a “magnified” display of the varying voltage component. A multimeter may be used to determine the average value of the load voltage.

4. The dependence of the average load voltage and the corresponding ripple voltage on the average load current is to be determined. A set of load resistors (five or more) with values of 30 to 500 ohms is needed. These resistors should have a power rating of at least 2 Watts. Since these resistors will become fairly hot when dissipating even a few watts of electrical power, care should be exercised in handling the resistors. Avoid exceeding the 2-Watt rating by ensuring that the DC voltage never exceeds roughly 8 volts by adjusting the variac voltage, as $P = V^2/R$, and $R$ is at least 30Ω. Using the procedure of section 2.3, determine, for each value of load resistance, the peak-to-peak ripple of the load voltage and its average value. The average load current is the average load voltage divided by the resistance.

5. In the previous part, the ripple load voltage ($v_{ripple}$) for small values of load resistance was greater than that generally acceptable for an electronic power supply. To reduce the ripple voltage, a larger capacitance is required. For the smallest value of load resistance used (a value of approximately 30 ohms), observe the effect of connecting a second 500 mF capacitance in parallel with that of the circuit (resulting in a value of 1000 mF for $C$). Determine the average and ripple voltage for this circuit. Increase the circuit capacitance to 2000 mF and again determine the average and ripple load voltage.

6. If a “current probe” is available for the oscilloscope, it may be used to determine the instantaneous diode current, $i$. Simultaneously observe the current and the ripple voltage for the load resistance
and capacitances of the previous part. Carefully sketch the resultant current noting both its peak amplitude and its duration.

7. Using a suitable instrument, obtain measured values for the resistances and capacitances used in this experiment.

8. Now connect the LM7805 voltage regulator as shown in Fig. 6. Use the 10 ohm, 10 Watt, resistor for $R_L$, monitor $v_L$ with an oscilloscope, and measure the ripple voltage as a function of the transformer secondary voltage, $v_{trans}$ from 8-9 volts-rms to 3.5 volts-rms. Be careful when making these measurements to monitor the temperature of the load resistor... it can get very warm.

3 Conclusion

In section 2.1 of the experimental procedure, the rectified voltage of a power supply with no filter was determined. Based on the peak value of $v_L$ (determined from the oscilloscope display) and the multimeter measurement of the transformer voltage, what was the voltage across the diodes when they were conducting? Using the peak value of $v_L$, calculate, assuming that it is a full-wave rectified voltage, the average value of $v_L$. Compare this value with that measured with the multimeter.

In sections 2.3 and 2.4 (capacitive filter) the dependence of the average and peak-to-peak ripple voltage on the load resistance, $R_L$, was determined. Plot the measured values of ripple and average load voltage as a function of the average load current (average voltage divided by $R_L$). Also plot a theoretical curve of ripple voltage (it may be assumed that $v'_m$ is equal to the average value of the load voltage). If the ripple voltage is large, the exponential relationship will need to be used in calculating its theoretical value.

In section 2.5 of the experimental procedure, the dependence of the ripple voltage on the filter capacitance (for a fixed value of $R_L$) was determined. Plot, as a function of capacitance, the experimentally determined ripple voltage an that predicted by the theoretical expressions.

The diode current was determined in section 2.6 with an oscilloscope current probe (if one was available). The average value of the diode current is equal to the average load current since the average value of the capacitor’s current is zero. Using the sketches of current, $i$, estimate the average currents by performing a graphical integration. Using an appropriate table, compare the average values of current with the measured values of the load current. The peak diode current is of importance when selecting a diode rectifier. List these values in the table.

Often the rms value rather than the peak-to-peak value of the ripple voltage of a power supply is specified. This is the voltage indicated by a “true rms voltmeter.” These type meters generally ignore the average value of their input voltage. An appropriate theoretical rms value of the ripple voltage may be obtained by assuming that it has a triangular waveform, as shown in Fig. 7:

$$2v_r = v_{\text{ripple}}.$$  (6)
Figure 7: Approximate theoretical rms value of the ripple voltage, assuming a triangular waveform.

For full-wave rectification, the period of this voltage is one half that of the sinusoidal transformer voltage. What is the rms value of the voltage expressed in terms of its peak amplitude, $v_r$? Obtain an expression for the ratio of this voltage and $v_m'$.

Concerning the use of the 7805 regulator, from your plot of ripple vs. AC input voltage, what can you conclude about the value of using such a regulator in the design of a power supply?