UNIVERSITY OF MIAMI
Department of Electrical and Computer Engineering
EEN 311

Name: ____________________
Section: ____________________
Date: ____________________

Experiment 2

THE ZENER DIODE AND IC VOLTAGE REGULATORS

PURPOSE: The purpose of this experiment is to demonstrate the characteristics of the zener diode and its use as a simple voltage regulator. Also, to demonstrate the operation of the three-terminal 7805 5-volt regulator IC and to measure its load and line regulation.

Background

ZENER DIODES

In general, if the reverse voltage across a diode is made sufficiently large, the diode breaks down and conducts large quantities of current. The diode will remain in operation until this current exceeds the maximum allowable current as dictated by the rated power dissipation of the device. Conventional diodes have large reverse breakdown voltages that are functions of the doping level of the semiconductor material from which they are fabricated. A *zener* diode is heavily doped to give it a low reverse breakdown voltage. The zener diode is designed to operate in its reverse breakdown region. In this region, the voltage across the junction remains practically constant and the current varies to accommodate the loading.

The current-voltage characteristic of a typical zener diode is shown in Fig. 2.1 along with its circuit symbol. The reverse breakdown voltage is labeled as $-V_Z$. The forward bias characteristics closely resemble that of a conventional diode studied in experiment 1. An ideal zener diode would maintain a constant voltage in the reverse region and would allow the current to vary without limit. Practical zener diodes, however, do not maintain a constant voltage and burn if the current exceeds the maximum allowable current $I_{Z,max}$. In general, the reverse voltage variation of zener diodes is small for a wide current variation and can be considered constant for all practical purposes.

VOLTAGE REGULATORS

An *ideal* voltage regulator maintains a constant voltage at the output regardless of how much the load changes or how much the input voltage changes. Practical voltage regulators, however, cannot maintain perfectly constant voltages at the output or deliver unlimited amounts of current to a varying load. One measure of the ability of a power supply to maintain a constant output voltage when the load is changed is its *output resistance,* R_o given by

$$R_o = \frac{\Delta V_o}{\Delta I_L} \text{ ohms}$$

Where ΔV_o is the change in output voltage that occurs when the load current changes by ΔI_L. Manufacturer's specifications for *load regulation* usually give a "typical" and a "maximum" value for ΔV_o corresponding to a specified value of ΔI_L. The output resistance of an ideal voltage regulator is zero and that of a practical regulator is in the order of milliohms.

The measure of how well a regulator is able to maintain a constant output voltage when the input voltage changes is called its *line regulation.* Line regulation is often specified as the change in output voltage, ΔV_o, that occurs for a specific change in input voltage, ΔV_{in}, when the load current is constant. Fig. 2.6 shows the V-I characteristics of practical current-limited voltage regulator. Note the rapid voltage cutoff that occurs when the load tries to draw more than rated current from the regulator.

In this experiment we will investigate two simple voltage regulator circuits. The first is a zener diode voltage regulator circuit as shown in Fig. 2.5; the second uses the 7805 series voltage regulator IC as shown in Fig. 2.7.

Fig. 2.5 shows a simple voltage regulator circuit that uses a zener diode. The zener diode is operated in its reverse breakdown region so the voltage drop across it will remain practically constant. In order for the circuit to operate properly, the circuit must be designed such that the current across the diode remains above $I_{Z,min}$ (see Fig. 2.1). The designer must always keep in mind the following factors:

I. The input voltage V_C (remember from experiment 1 that this voltage is unregulated and ripples around a nominal DC voltage) must always remain above a value that will successfully supply current above breakdown to the zener diode and supply load current to R_L.

II. The load R_L must not become too small and keep the zener diode from sinking the necessary current to keep it in the breakdown region (i.e., if R_L is shorted, no current will flow across the diode).

III. The power dissipation in the zener diode, $P_Z = V_Z I_Z$, must not exceed the maximum rated power dissipation, $P_{Z,max}$ (i.e., if R_L is open circuited, all the supply current flows through the zener diode).

The first two conditions require that V_C and R_L be large and the third condition requires that they be small. The series limiting resistance R in Fig. 2.5 must be carefully designed so that all conditions are met. The following inequalities bound the range of permissible values that R can take provided we know the supply and load variations as well as the zener diode specifications.

$$R \leq \frac{(V_C)_{\min} - V_Z}{(I_Z)_{\min} + V_Z/(R_L)_{\min}}$$

$$R \geq \frac{(V_C)_{\max} - V_Z}{(I_Z)_{\max} + V_Z/(R_L)_{\max}}$$

Where $(V_C)_{min}$ and $(V_C)_{max}$ are the minimum and maximum values of the unregulated input V_C,
$(I_Z)_{min}$ is the minimum reverse current required to keep the diode in breakdown,
$(I_Z)_{max}$ is the maximum reverse current that can be tolerated without exceeding the rated power dissipation of the diode, $(I_Z)_{max} \leq P_{Z,max}/V_Z$, and
$(R_L)_{min}$ and $(R_L)_{max}$ are the minimum and maximum values of the load resistance.

Fig. 2.7 shows the 7805 three-terminal integrated circuit voltage regulator. The device has three terminals. One is the unregulated input voltage, the second is the circuit ground, and the third is the regulated output voltage. The 7805 is a 5-V regulator, that is, the output will remain constant at 5 volts provided that the input voltage and the load remain within their permissible limits.

Preliminary Work

1. The voltage-current characteristic of a typical Zener diode is shown in Fig. 2.1. The maximum current, $I_{Z,max}$, that may flow through a Zener without damaging it is limited by the maximum allowable power dissipation, $P_{Z,max}$. The minimum Zener current, $I_{Z,min}$, that is required to keep the diode in its active region is usually given as $0.1I_{Z,max}$. If $P_{Z,max}$ = 1W for a given Zener diode with V_Z = 8.2V, find $I_{Z,max}$ and $I_{Z,min}$.

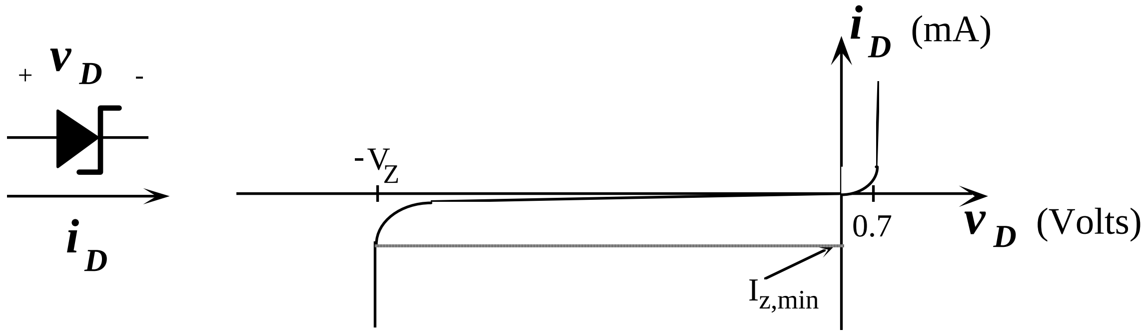


Figure 2.1 Voltage-Current Characteristics for a Typical Zener Diode

2. Find V_{out} in the following circuit if

   i) $V_{IN} < V_Z$, and
   ii) $V_{IN} > V_Z$.

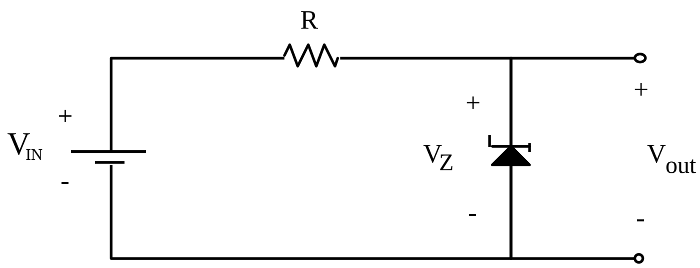


Figure 2.2 Simple Zener Diode Rectifying Circuit

3. Show that the maximum allowable load current, $I_{L,max}$, is bounded as $I_{L,max} \leq 0.9I_{Z,max}$ for the safe and proper operation of the following circuit (i.e., the zener remains in the active region and does not burn for load current values between $0 \leq I_L \leq I_{L,max}$.

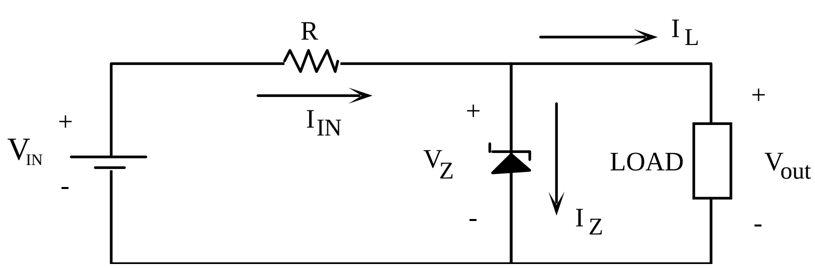


Figure 2.3 Zener Voltage Regulator Circuit with Load.

Experimental Procedure

I. Zener Diode Characteristics:

Vpp=40V, Vp=20v

N2/N1=turn ratio

Vpp=20V, Vp=10v

Set up the circuit shown in Fig. 2.4.

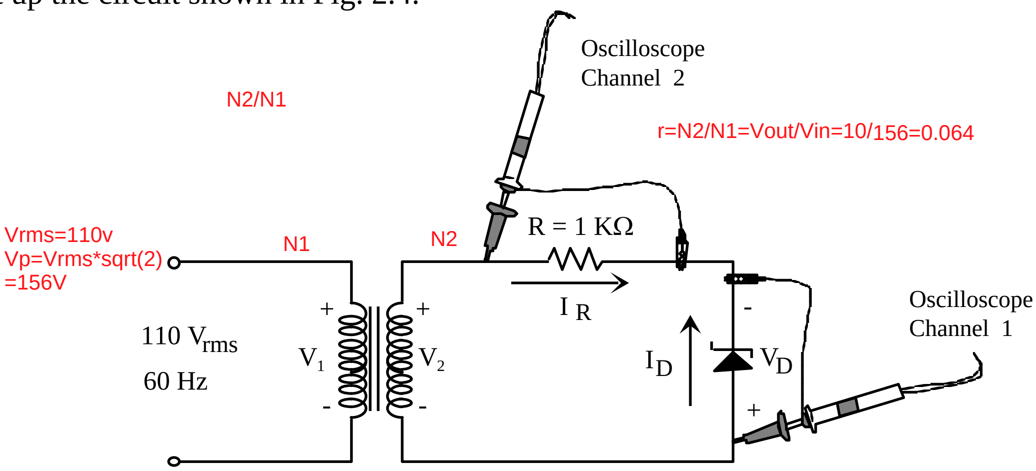


Figure 2.4 Simple Zener Diode Circuit

Apply a sinusoidal input signal of frequency 60 Hz using a transformer. Engage the "**X** vs **Y**" mode in the time scale knob of the oscilloscope. In this mode, channel 1 input signal provides horizontal deflection. Hence, the horizontal axis will represent the diode voltage V_D. Channel 2 input signal provides vertical deflection; therefore, the vertical axis will represent the voltage drop across the 1KΩ resistor, which is proportional to the resistor current.

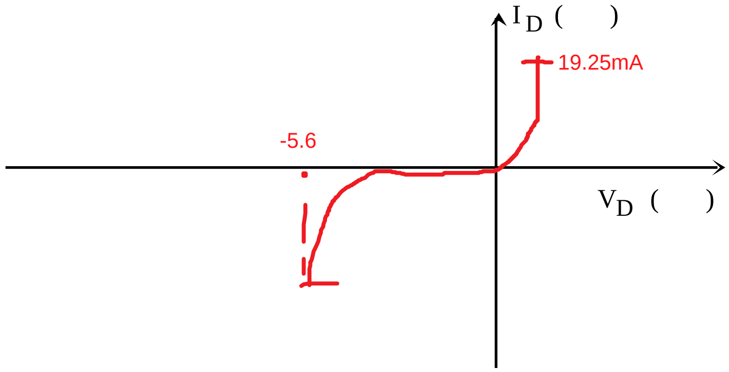
$$V_R = R\ I_R$$

$$I_R = \frac{V_R}{R}$$

$$I_R = \frac{V_R}{1000W} = V_R \text{ milliamps.}$$

Consequently, the vertical axis may be assumed to represent the resistor current in milliamps, which is also equal to the negative diode current (since the two currents are in opposite directions). Therefore the resulting pattern on the oscilloscope screen will be the V_D vs ($-I_D$) characteristics of the zener diode. To have the proper V_D vs I_D curve, you can invert the polarity of channel 2 input signal by engaging the "**CH 2 INV**" function of the oscilloscope.

Sketch the resulting pattern.



Zener Diode V-I characteristics

Mark the zener voltage on the graph and use this value for the next part.

II. <u>Zener Regulated Power Supply</u>:

Design the circuit of Fig. 2.5 for a ripple voltage V_r equal to 5% of the peak full-wave bridge rectifier output voltage and for load currents I_L between 0 and 1mA. Be careful to design R in accordance to the equations given in the supplemental notes. Recall from experiment 1 that the output voltage of the transformer is around 20 V_{peak} and that the voltage drop across the diode bridge is about $2V_D \approx 1.4$ V. Hence, the peak full-wave rectifier output voltage will be around 18.6 V and the ripple will be 0.93 V. The variation of V_C will then be between 17.67 and 18.6 volts. After designing for R, calculate C from the expression

Vp=20, Vp=40, Vc=17.67 and 18.6
Vr=Vcmax*0.05
Vdc=Vcmax-0.5Vr=20-0.5*20*0.05=19.5V

Vz=Vdc-2VD=19.5-1.4

$$V_r \approx \frac{V_{DC} - V_Z}{2 f_o R C}.$$

Where $V_{DC} = (V_C)_{max} - \frac{1}{2} V_r$. Make sure you choose a value of R that will result in a practical and available value of C since resistors are easier to find.

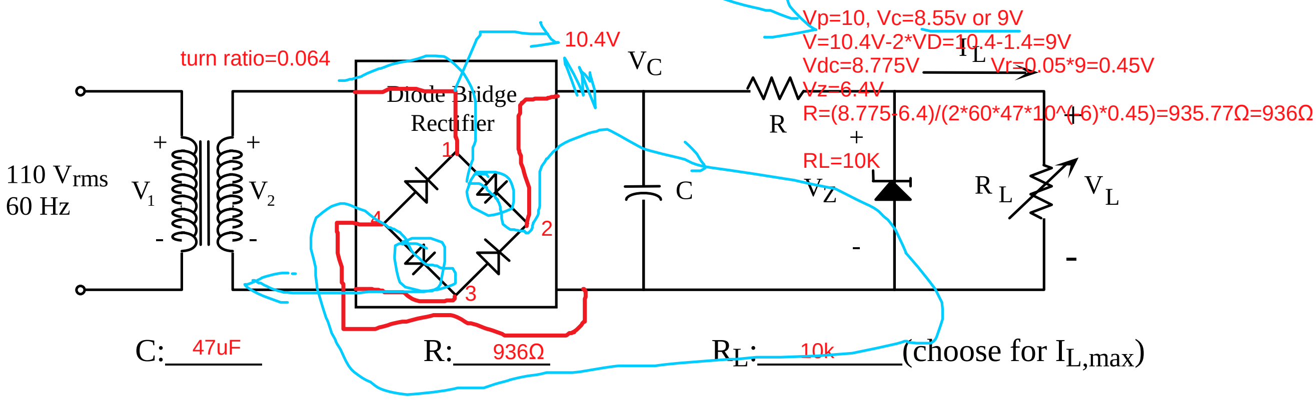
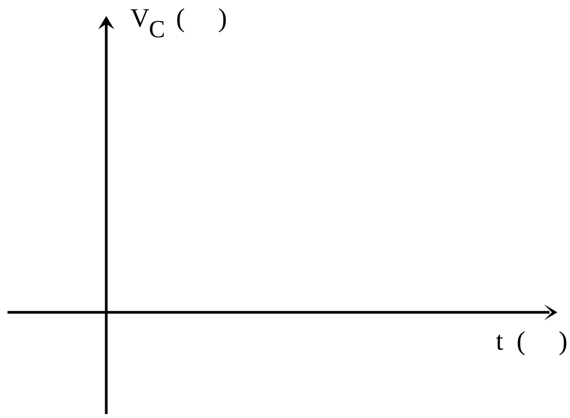
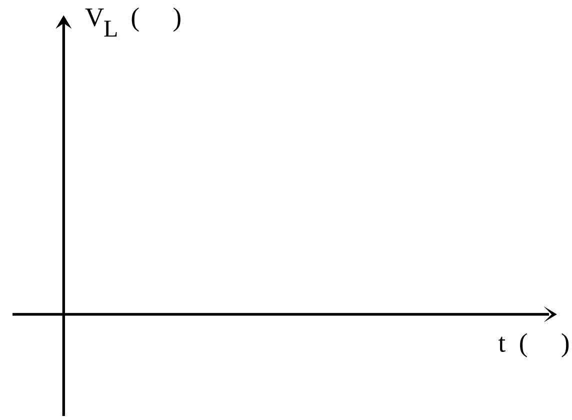


Figure 2.5 Zener Regulated Power Supply.

a) Set the oscilloscope to DC mode and sketch the waveform patterns of V_C and V_L. Show the ripple voltage V_r present in V_C **clearly.** Use the oscilloscope in DC mode.



Capacitor Voltage



Load Voltage

b) Slowly vary R_L, first by decreasing it to a value of 50 Ω, then increasing it up to ∞ (open circuit). Observe the effects carefully; they are to be discussed in the last part (see Discussion of the Results, question 5.

c) Remove the transformer, bridge rectifier, and capacitor in Fig. 2.5 and replace them with a DC voltage source so that it looks like the circuit in Fig. 2.3. To determine the line regulation, with R_L = 10 kΩ, set V_{IN} to 15 V. Measure the load voltage V_L. Repeat this procedure for each value of V_{IN} listed in Table 2.1.

V_{IN} (Volts)	**V_L (Volts)**
15	
16	
17	
18	
19	
20	

Table 2.1 Zener Regulator V_{IN} vs V_L Data.

d) To determine the output resistance of the regulator, with V_{IN} = 15 V and R_L = 20 KΩ, measure the load voltage V_L. Repeat this procedure for each value of R_L listed in Table 2.2.

R_L **(kΩ)**	V_L **(Volts)**	$I_L = \frac{V_L}{R_L}$	$I_{IN} = \frac{V_{INL} - V_L}{R}$	$I_Z = I_{IN} - I_L$	$P_Z = V_L I_Z$
20					
18					
16					
14					
12					
10					

Table 2.2 Zener Regulator Data for Variable Loading and Constant Input Voltage.

III. The 7805 Voltage Regulator IC:

Fig. 2.6 below shows a typical plot of load voltage versus load current for a current-limited regulator. Note that V_L drops rapidly as I_L approach its maximum permissible value.

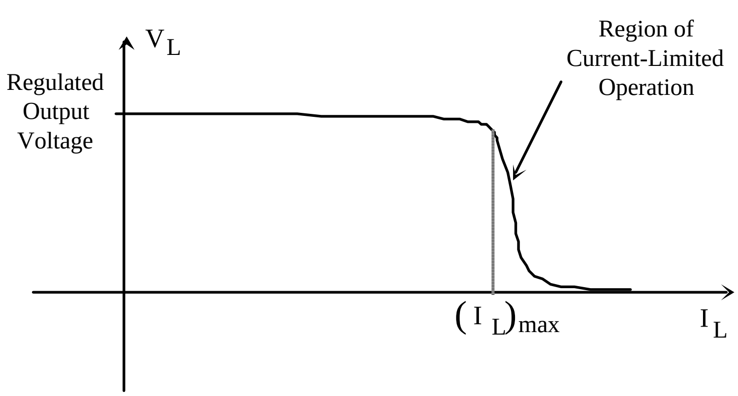


Figure 2.6 V-I Characteristics for a Typical Current-limited Voltage Regulator.

a) To demonstrate the 7805 three-terminal fixed-voltage regulator, connect the circuit shown in Fig. 2.7.

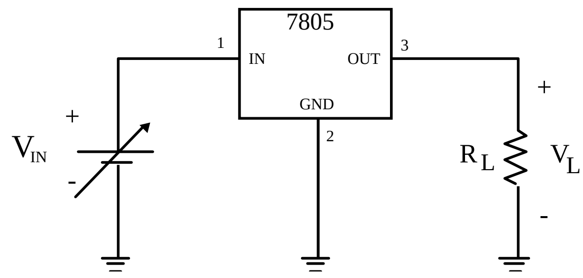


Figure 2.7 The 7805 Fixed-voltage Regulator Integrated Circuit.

b) To determine the load regulation of the 7805 voltage regulator, with V_{IN} = 10 V, measure the load voltage and current for the load resistances listed in Table 2.3. Repeat this procedure for each value of R_L listed in Table 2.3. Use a digital voltmeter accurate within a few millivolts dc for all voltage measurements.

R_L (Ω)	V_L (Volts)	I_L (Amps)
100		
47		
22		
10		

Table 2.3 Load Voltage and Current Variation with Load for 7805 Regulator.

c) To determine the line regulation, set R_L = 100 Ω (1 Watt) and adjust the input voltage V_{IN} to each voltage listed in Table 2.4. Measure the load voltage and current for each line voltage in Table 2.4. Use a digital voltmeter accurate within a few millivolts dc for all voltage measurements.

V_{IN} (Volts)	V_L (Volts)	I_L (amps)
10		
12		
15		
20		

Table 2.4 Load Voltage and Current Variation with Input Voltage for 7805 Regulator.

SPICE

Set R = 560 Ω in Fig. 2.3. Use the .DC command in *SPICE* to adjust the line voltage V_{IN}. To model the zener diode, use a diode with a BV (breakdown voltage) equal to the zener voltage. With R_L set to 1 kΩ, run SPICE to determine the minimum value of V_{IN} that will keep the zener diode in "regulation".

Discussion of the Results

1. Using the values obtained in Table 2.1, calculate the line regulation, $\Delta V_L/\Delta V_{IN}$, for the zener voltage regulator circuit of Fig. 2.5.

2. Using the values obtained in Table 2.2, calculate the output resistance, $\Delta V_L/\Delta I_L$, for the zener voltage regulator circuit of Fig. 2.5.

3. Using the values in Tables 2.3 and 2.4, determine the output resistance and line regulation of the 7805 three-terminal fixed-voltage regulator circuit of Fig. 2.7.

4. How does the zener regulator of Fig. 2.5 compare with the IC regulator circuit of Fig. 2.7 in term of output resistance and line regulation? Which is better?

5. Explain your observations for part II.b.

6. Write a conclusion.