Laboratory 5  
Regulated DC Power Supplies

OBJECTIVE

To design a regulated DC power supply using a zener shunt regulator. To learn to use a three terminal IC voltage regulator and compare its characteristics with that of the zener shunt regulator.

BACKGROUND

The zener shunt regulator

The schematic diagram of a zener shunt regulator is depicted in Fig. 5-1. The unregulated power supply input V_s to the shunt regulator is obtained from a diode bridge rectifier with filter capacitor. The zener diode employed in the circuit should have a breakdown voltage that is a few volts higher than the lowest value V_{s_{\text{min}}} of the input voltage V_s. The zener diode thus operates in the reverse breakdown region, and the voltage V_o across it (the load voltage) is held fairly constant despite the fairly large voltage swing of the input signal V_s. As indicated in Eq. 3-4 of lab 3, the zener diode can be modeled as a voltage source V_{Z_o} in series with a dynamic resistance r_z. Replacing the zener diode by this model, analysis of the circuit of Fig. 5-1 yields the following expression for the output voltage V_o of the regulator:

\[
V_o = V_{Z_o} \frac{R}{R + r_z} + V_s \frac{r_z}{R + r_z} - I_L (R \parallel r_z) \quad \text{Eq. 5-1}
\]

![Fig. 5-1: A zener shunt regulator](image)

The line regulation of a voltage regulator is the ratio of the output voltage ripple to the input voltage ripple. We have

\[
\text{Line regulation} = \frac{\Delta V_o}{\Delta V_s} = \frac{r_z}{R + r_z} \quad \text{Eq. 5-2}
\]

The load regulation of a voltage regulator is the ratio of the change in output voltage to the load current change that caused it. We have
Load regulation = $\frac{\Delta V_o}{\Delta I_L} = -(r_z || R)$  \hspace{1cm} \text{(Eq. 5-3)}$

The lower the line or load regulation, the better the voltage regulator. Note that increasing the value of the resistor $R$ lowers the line regulation. There is, however, a limit on how large $R$ can be. If $R$ is too large the zener diode can come out of the breakdown and the regulator will not work as intended. The value of $R$ should be such that the zener diode remains in breakdown even when the supply voltage is at its lowest i.e., when $V_s = V_{s_{\text{min}}}$. Let $I_{Z_{\text{min}}}$ be the minimum value of zener current $I_Z$ that will be tolerated. The value of $I_{Z_{\text{min}}}$ chosen should lie in the reverse breakdown region of the diode characteristic. Let $I_{L_{\text{max}}}$ be the highest possible load current $I_L$. To maintain the minimum zener current $I_{Z_{\text{min}}}$, we select $R$ as follows:

$$R = \frac{V_{s_{\text{min}}} - V_{Z_0} - I_{Z_{\text{min}}} r_z}{I_{Z_{\text{min}}} + I_{L_{\text{max}}}}$$ \hspace{1cm} \text{(Eq. 5-4)}$

Three terminal voltage regulators

The LM78XX is a series of three terminal IC voltage regulators that delivers positive output voltages. The XX denotes the output voltage — for example the LM7809 is a 9V regulator chip. These IC voltage regulators have internal current limiting and other safety features, and have characteristics that are far superior to zener shunt regulators. The three terminals of the regulator are the input, ground, and output terminals. A three terminal regulator can be substituted in place of the resistor $R$ and the zener diode in the circuit of Fig. 5-1. The input terminal of the regulator connects to the unregulated power supply, the output terminal to the load, and the ground terminal forms the common node.

PRELAB

1. Replace the zener diode in Fig. 5-1 by its circuit model and derive Eq. 5-1.
2. Eq. 5-4 specifies the value of the series resistor $R$. Explain how this equation is obtained.
3. Assume that the full-wave rectifier with capacitor filter that you designed last week is the input to a zener shunt regulator. Use the 1N4739 zener diode (available in your lab kit) for your shunt regulator. The regulator should supply 9.1V to a load that has a minimum resistance of 500Ω. Choose an appropriate value for the zener series resistor. Show all your design work and state any assumptions. Determine the theoretical values for the line regulation and load regulation of your regulator.
   \textbf{Note:} The following are the specifications of the 1N4739 zener diode (from its PSpice model): $V_z = 9.1 \, @ \, 28mA$, $Z_z = 21 \, @ \, 1mA$, $Z_z = 7.25 \, @ \, 5mA$, $Z_z = 2.7 \, @ \, 20mA$. Use the zener resistance value of 2.7Ω to calculate the value of $V_{Z_0}$ for the zener diode model.
4. Simulate your design using PSpice. Use a VSIN part as the input to the diode-bridge. Set the amplitude of the sinusoid to 21.21V (15V rms). Obtain waveforms of the capacitor voltage (at the input to the shunt regulator), and the load voltage. Compute
the ratio of load voltage ripple to the input ripple. Compare this with the theoretical line regulation of your regulator.

**Note:** You will find that the evaluation version of PSpice does not have a 1N4739 part. Models for parts not in the evaluation version can be found on the server under classes/spicelib. You can use notepad to view any of the .lib files in this directory. You will find the model for the 1N4739 in the file diode.lib.

To simulate a 1N4739, do the following: Place a dbreakz part on your schematic (zener diode breakout part). Select the part and click *Model* under the *Edit* menu. Click *Edit Instance Model*. Copy and paste the entire model description for the 1N4739 into the window that appears (replace the dbreakz description). Click on ok. Your dbreakz part should be transformed into a 1N4739, and you should be able to run your simulation. If there is a problem with the simulation, select the part and edit the instance model again. If there are any + signs in the model description, delete them. Click on ok. The simulation should work now.

**IN LAB**

1. Use the curve tracer to obtain a plot of the i-v characteristic of your 1N4739 zener diode in its normal operating region. Approximate the curve by a straight line (in the range of currents of interest for your voltage regulator). Use the straight line to determine the values of the parameters $V_{zo}$ and $r_z$ in the zener diode model. Compare these with the values used in the prelab.

2. Construct the zener shunt regulator designed in your prelab. Obtain a printout of the oscilloscope screen depicting the capacitor voltage (input to the shunt regulator). What is the input ripple voltage? Measure the ripple on the load voltage. Obtain a printout of the oscilloscope screen with a waveform in which the ripple on the load voltage is clearly visible. What is the line regulation of your shunt regulator? Compare with the theoretical value of line regulation.

3. Measure and record the average value of the voltage across the $500\Omega$ load. Remove the load resistance and measure the average value of the output voltage again. Use these measurements to determine the load regulation of your power supply. Compare against the theoretical load regulation value.

4. Disconnect power to your shunt regulator. Replace the zener shunt regulator (zener diode and series resistor) by the 7809 voltage regulator chip. Measure the line regulation and load regulation of the power supply based on the 7809 chip. Compare the performance of the 7809 based power supply with that of the zener shunt regulator.