EXPERIMENT #3

Linear Voltage Regulators

Goals:

To introduce the concepts of a linear voltage regulator and their use to maintain a regulated voltage output. Data collected during this laboratory experiment will be compared to the datasheet for the parts used.

References:

Microelectronics-Circuit Analysis and Design, D. A. Neamen, McGraw-Hill, 4th Edition, 2007, ISBN: 978-0-07-252362-1.

Equipment:

Triple Power supply
TL081-TL084 family of operational amplifiers
2N2222A NPN transistor
Capacitors available in the laboratory
Resistors available in the laboratory
Multimeter
7805 and 7812 linear three terminal regulators

Pre-laboratory:

Read this laboratory experiment carefully to become familiar with the background and the procedural steps in this experiment. Carefully read each section and become familiar with the equations for each circuit.

Using the simulation package of your choice in which you are the most familiar with: Mulitsim, Workbench or LTSpice IV simulate the linear regulator of Figure 2.

a. Pick R1 and R2 such that Vout is 3 volts. The minimum values for R1 and R2 should be 1000 ohms.
b. Set RL = 100 ohms and Vin = 6 volts. Measure with the simulator Vout.
c. Measure IL and Iin. Calculate Pin, Pout and Preg.
d. Calculate the Efficiency = Pout / Pin · 100%.
e. Vary RL from 50 to 10k ohms and measure Vout and IL.
f. Plot Vout versus IL
g. Setting RL to 1k ohms vary Vin from 0 to 6 volts.
h. Plot Vout versus Vin
i. What is the dropout voltage for this regulator.
j. Lookup the data sheet for the 7805 and 7812 (LM340) voltage regulators

k. Find the typical output voltages.
l. Find the dropout voltage and calculate the minimum allowed input voltage Vin for the 7805 and 7812 voltage regulators.
m. Find the peak output current.
n. Find the maximum allowed power dissipation of the regulator at room temperature and with no heatsink (assume a TO220 case).
o. Find the load regulation.
p. Find the thermal resistance of the voltage regulator.

Discussion:

Consider the following circuit given in Figure 1. With R1 equal to 100 ohms Vout is equal to 10.9 volts. If R1 is changed to 10 ohms, then Vout is equal to 6 volts. Vout depends on the load resistor R1. In other words, the output voltage decreases as the load current (the current through R1) increases. In many applications it is desirable to have a constant voltage source that is independent of load current. For example, the +Vcc and -Vcc input to a typical op-amp circuit should remain constant independent of the op-amp current.

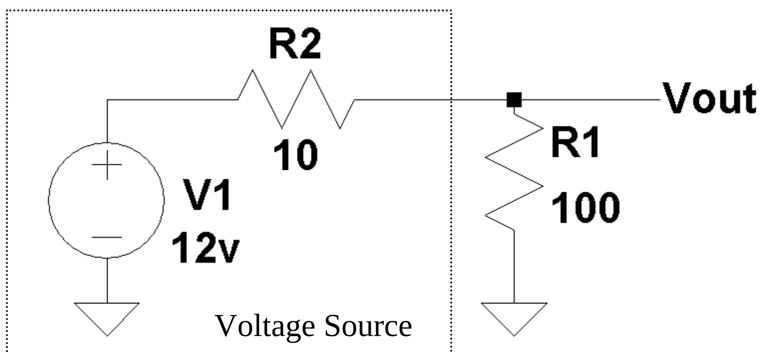

Figure 1: An example of a 12-volt voltage source with an internal resistance of 10 ohms.

A circuit that maintains a constant output voltage is called a regulator. There are two types of voltage regulators that are available. Those that work at a DC or constant operation point (known as linear regulators) and those that are based. upon varying a duty cycle of a pulse (known as a switching regulator). This laboratory experiment will focus on linear regulators. Switching regulators will be discussed in a later laboratory experiment.

Figure 2 gives the circuit diagram for a linear regulator. This regulator uses a 2N2222 transistor and an op-amp to perform the output regulation. It is based upon the requirement that the op-amp will try to adjust its output so as to keep its inputs, V^+ and V^-, equal. The voltage at the V^+ terminal is

$$V^+ = Vcc\,\frac{R4}{R3 + R4} \qquad (1)$$

Assuming +Vcc =15v and -Vcc = -15v, then V^+ = 1.485 volts. The op-amp will adjusts its output voltage so that V^- terminal is the same as V^+. Since the output from the regulator Vout is equal to voltage output of the opamp -Vbe, the output of the regulator also changes. Given that the V^- terminal is related to Vout as

$$V^- = \text{Vout}\,\frac{R2}{R1 + R2} \tag{2}$$

then setting $V^+ = V^-$ gives

$$V^- = \text{Vout}\,\frac{R2}{R1 + R2} = \text{Vcc}\,\frac{R4}{R3 + R4} \tag{3}$$

Solving for Vout

$$\text{Vout} = \text{Vcc}\,\frac{R1 + R2}{R2}\,\frac{R4}{R3 + R4} \tag{4}$$

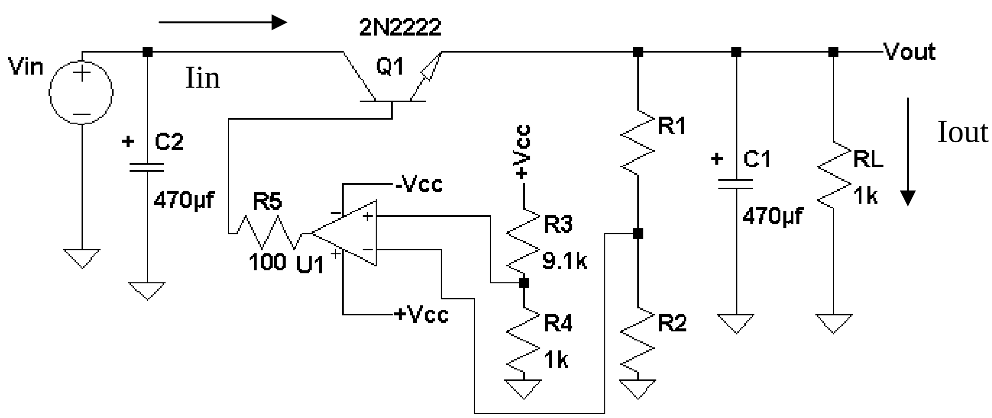

Figure 2: An example of a linear regulator.

For +Vcc = 15 volts, R3 = 9.1K, and R4 = 1k Vout becomes

$$\text{Vout} = 1.485\text{v}\,\frac{R1 + R2}{R2} \tag{5}$$

From Equation (5) Vout does not depend on the load current, as was the case for the circuit given in Figure 1.

Here's how the regulator in Figure 2 maintains a constant voltage at Vout. Assume Vout drops below its regulated voltage given by Equation (4) or (5). Then the V^- terminal voltage will be less then the V^+. Since the voltage output of the op-amp is Aod ($V^+ - V^-$), the voltage output from the op-amp will increase in the positive direction ($V^+ > V^-$). This increasing voltage will raise the voltage on the base of the transistor. Since Vbe is a constant (about .7 volts), Vout will increase. Vout increases until $V^+ = V^-$. Now consider that Vout increases in voltage beyond regulated voltage given in Equation (4). For this case V^+ will be less than V^-. Since the voltage output of the op-amp is Aod ($V^+ - V^-$), the voltage output from the op-amp will tend to decrease in value. This lowers the voltage on the base of the transistor, which lowers the transistor's emitter voltage and lowers Vout.

As a final note, R5 is used to limit the current out of the op-amp and capacitors C1 and C2 are bypass capacitors used to maintain low AC impedance path to ground from Vin and Vout. These capacitors are used to eliminate any AC signals from appearing on Vin and Vout so the output of the regulator is a constant DC value.

The regulator of Figure 2 is a simple regulator with no short circuit or thermal protection. The linear regulator of Figure 2 is available in a three terminal part with both thermal and short circuit protection. Figure 3 gives the circuit diagram for this regulator. One set of linear regulators that are commonly used is the 78XX three terminal linear regulator family, where XX gives the output voltage of the regulator. Both the input and output voltages of these regulators are positive. For example, a 7805 voltage regulator produces an output voltage +5 volts. For negative output voltages, the 79XX regulators are available.

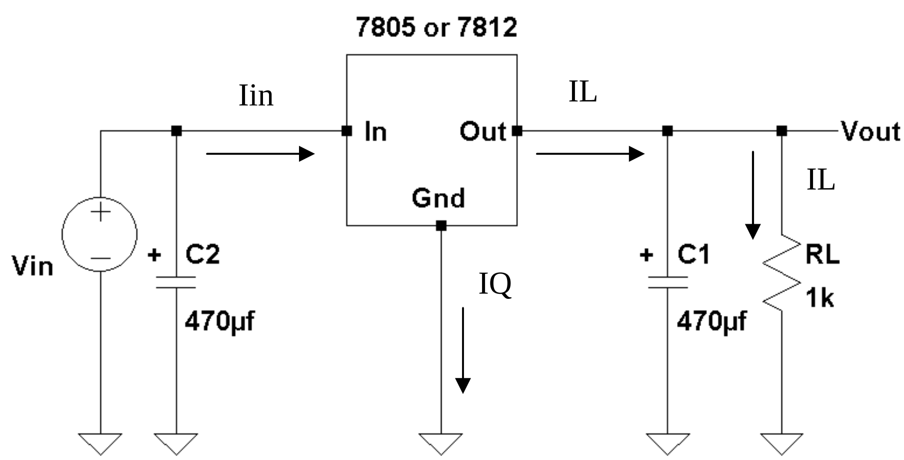

Figure 3: An example of a three terminal linear voltage regulator.

There are several parameters that are important when dealing with a linear regulator:

$$Iin = IL + IQ \tag{6}$$

IQ is the regulator quiescent current and typically is milliamps. If the load current is much larger than IQ then Iin $\approx$ IL and IQ can be ignored in the following equations.

$$\text{Pin} = \text{Vin} \cdot \text{Iin} = \text{Vin} \cdot (\text{IL} + \text{IQ}) \tag{7}$$

$$\text{Pout} = \text{Vout} \cdot \text{IL} \tag{8}$$

$$\text{Preg} = \text{Pin} - \text{Pout} = (\text{Vin} - \text{Vout})\,\text{IL} + \text{IQ Vin} \tag{9}$$

Where Pin is the input power, Pout is the output power, and Preg is the power dissipated in the regulator. The efficiency of a voltage regulator defines the percentage of power that is delivered to the load and is given by

$$\text{Efficiency} = \frac{\text{Pout}}{\text{Pin}}\,100\% \quad . \tag{10}$$

The main objective of a voltage regulator is to maintain a constant voltage over various load currents. One parameter of importance is the load regulation parameter. This parameter gives the change in Vout as the regulator's output current, IL, is varied from a minimum to a maximum current. From Equation (9), the power dissipated in the regulator is proportional to the voltage across the regulator. To minimize the power dissipated in the regulator, the goal is to use as minimum a voltage across it as possible. Another parameter of importance is the minimum allowable voltage across the regulator for the regulator to maintain a constant output voltage. In other words the regulator is still in regulation. This minimum voltage across the regulator is known as the dropout voltage Vdo.

As with any electronic parts, there are maximum ratings that must be adhered to, such as the maximum input voltage, the maximum allowable load current, the maximum power dissipation allowed and the maximum operating temperature. Finally, since these parts are short circuit protected, the maximum short circuit current is also given. As long as the maximum power dissipation and maximum operating temperature are not exceeded the part will operate indefinitely with its output shorted to ground.

There are several items that will destroy one of these three-terminal regulators even if these parts are correctly installed in the circuit diagram of Figure 3 and the maximum rating are adhere to. The first is applying the wrong polarity voltage at the input. The second is having Vout be greater than Vin. This can occur if C1 > C2 and the energy storage in the output is greater than the energy storage in the input. This commonly occurs during power off if C1 > C2. The input to regulator will discharge toward zero volts faster than the output. Figure 4 shows a solution to protecting the regulator should Vout become greater than Vin. Under normal use, Vin > Vout, and the diode is reversed biased. Should Vout become greater than Vin, the diode is forward biased preventing any current flowing into the regulators from its output.

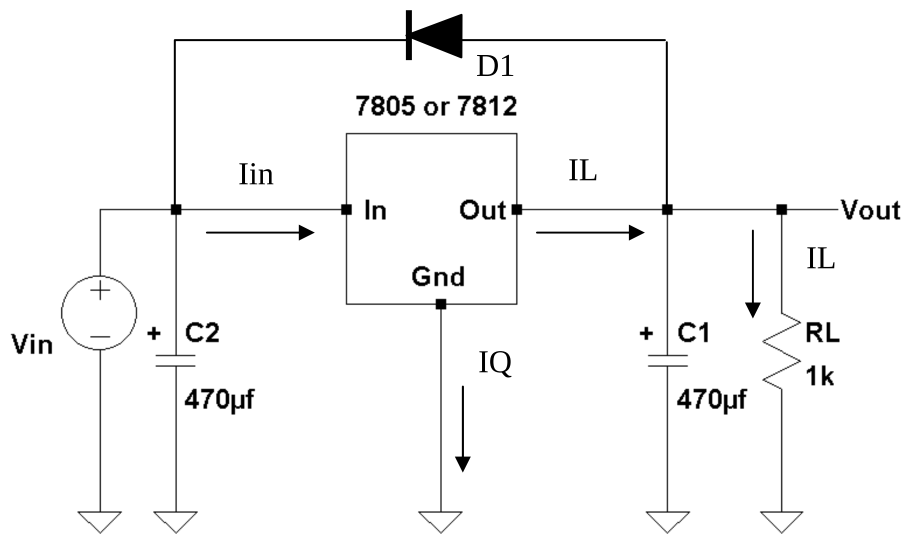

Figure 4: An example of a linear voltage regulator with protection.

The three terminal regulators can also be made to be adjustable so any desired regulated output voltage can be obtained. The only requirement is that the minimum voltage is that of the part itself. For example, a 7805 regulator can be made adjustable, but its minimum output voltage is 5 volts. Figure 5 gives the circuit required to make a three-terminal linear regulator adjustable. For this discussion, assume the regulator output voltage is Vreg (the voltage between the output and the ground pins of the regulator). Then IR1 is then given by

$$IR1 = \frac{Vreg}{R1} \quad . \tag{11}$$

and the voltage across R2 (VR2) is

$$VR2 = R2\,(IQ + IR1) = R2\left(IQ + \frac{Vreg}{R1}\right) \quad . \tag{12}$$

The output voltage from the regulator Vout is the sum of VR1 + VR2. But VR1 is equal to Vreg

$$Vout = R2\left(IQ + \frac{Vreg}{R1}\right) + Vreg \quad . \tag{13}$$

or

$$Vout = R2 \cdot IQ + Vreg\left(\frac{R2}{R1} + 1\right) \quad . \tag{14}$$

If the current IR1 >> IQ then the quiescent current IQ can be ignored in Equation (14) and Vout is given by

$$\text{Vout} = \text{Vreg}\left(\frac{\text{R2}}{\text{R1}} + 1\right)\ . \qquad (15)$$

Since for the 78XX regulators, IQ is about 6 milliamps. IR1 should be about at least 30 milliamps. The goal is not to make IR1 too large, as this will reduce the efficiency of the regulator circuit.

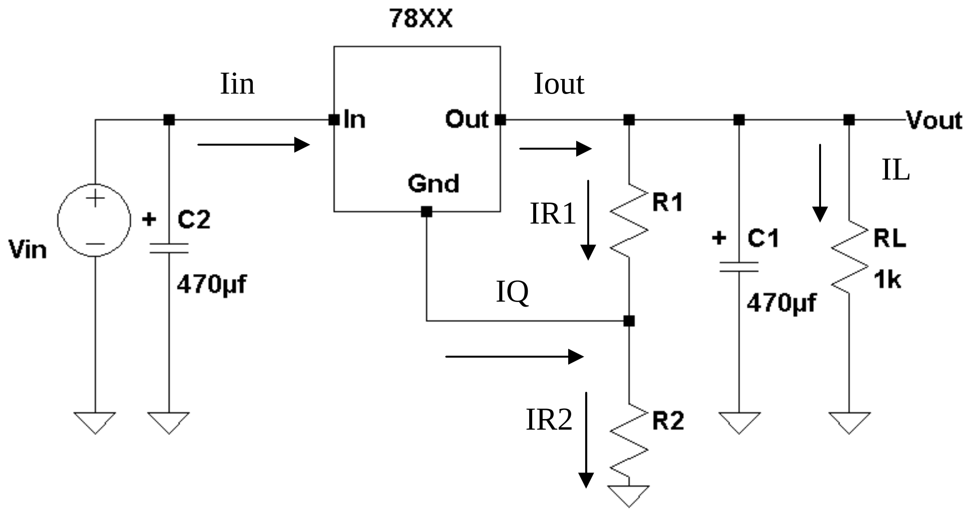

Figure 5: A circuit diagram to make linear voltage regulator adjustable.

Procedure:

General Setup:

1. Record the model and serial number of the scope, power supply, multimeter and function generator used in laboratory experiment.
2. Download the datasheet for the 78XX regulators. This will be needed to obtain the pin-out of the regulator. When comparing datasheet data values to experimental data use the typical values in the datasheet if given.
3. Obtain the pin-out for the 2N2222 transistor
4. Make sure that the power supply to the op-amp is correctly wired so as not to apply the incorrect polarity to the op-amp.
5. When measuring any values, make sure to measure all inputs as well as the output of the circuit. Do not rely on the values indicated on the instruments. Always measure all signal values.
6. Before turning any power on, double check the wiring to make sure that it is correct.
7. Measure all resistors that are used in the amplifier circuits using the multimeter and record these values.
8. Use all measured values to determine experimental results such as gain and current.
9. Comparing data means to calculate the percent difference between two values. For example, theoretical values versus measured values.
10. Comparing data graphically means to plot the data on the same plot to see how the data overlaps.

Discrete linear regulator:

1. Build the linear regulator of Figure 2.
2. Calculate the resistors R1 and R2 required to produce an output voltage of 3 volts for the circuit of Part 1. The minimum values for R1 and R2 should be 1000 ohms.
3. Set +Vcc = 15 volts and -Vcc to -15 volts.
4. Build this linear circuit (Part 1) using a 1000 ohm resistor for RL. Take note of the polarity of the two electrolytic capacitors. Double check your wiring.
5. Vary the input voltage Vin, between 0 and 6 volts and measure Vout, Iout and Iin.
6. Plot the output voltage Vout as a function of Vin.
7. What is the dropout voltage for this regulator?
8. Plot the output current Iout as a function of Vin.
9. Plot the input current Iin as a function of Vin.
10. Calculate Pin and Pout from steps 6, 7, 8 and 9.
11. For step 5, plot the output efficiency Pout / Pin as a function of Vin once the output voltage becomes constant.
12. Keeping Vin at 6 volts and varying the RL between 100 and 10000 ohms and measure Vout, Iout, and Iin as a function of Vin. Use 5 different load resistor values.
13. Calculate the load regulation.
14. For step 12, plot the output efficiency Pout / Pin as a function of RL.

78XX Three terminal linear regulator

1. Build this linear regulator circuit of Figure 3 using the 7805 regulator and a 1000 ohm resistor for RL. Take note of the polarity of the two electrolytic capacitors. Double check your wiring.
2. Vary the input voltage between 0 and 20 volts and measure Vout, Iout and Iin.
3. Plot Vout as a function of Vin.
4. What is the dropout voltage for this regulator and compare this measured value to the value given in the datasheet.
5. Plot Iout and Iin as a function of Vin in Step 2.
6. Compute Pin and Pout as a function Vin.
7. From step 6, plot the output efficiency Pout / Pin as a function of Vin once the output voltage becomes constant.
8. Keeping Vin at 15 volts and varying the RL between 100 and 10000 ohms, measure Vout, Iout and Iin as a function of RL. Use 5 different load resistor values.
9. Compute Pin and Pout as a function RL
10. For step 9, plot the output efficiency Pout / Pin as a function of RL.
11. Repeat steps 1 – 7 for the 7812 voltage regulator.

78XX A three terminal linear regulator as an adjustable regulator

1. Calculate the resistors R1 and R2 required to produce an output voltage of 7 volts for the linear regulator circuit of Figure 5. The minimum values for R1 and R2 should be 1000 ohms.

2. Build the linear regulator circuit of Figure 5 using a 7805 regulator and a 1000 ohm resistor for RL. Take note of the polarity of the two electrolytic capacitors. Double check your wiring.
3. Vary the input voltage between 0 volts and 15 volts and measure Vout, Iout and Iin.
4. Plot Vout as a function of Vin.
5. Determine the dropout voltage for this regulator and compare this measured value to the value given in the datasheet.
6. Plot Iout and Iin as a function of Vin in Step 3.
7. Compute Pin and Pout as a function Vin.
8. From step 7, plot the output efficiency Pout / Pin as a function of Vin once the output voltage becomes constant.

Report: Please follow the procedures in this laboratory manual for writing the report for this experiment. Include in your report:

1. The equipment used model and serial number.
2. Laboratory partners
3. Date and time data were taken.
4. The goal of the laboratory experiment.
5. The procedures.
6. The pre-laboratory results.
7. All calculations for each step.
8. All plots generated for each step.
9. All comparisons calculations.
10. For each data collection step in the procedure, there should be either data collected, a calculation performed or a waveform recorded. Please include these in the report.
11. Short summary discussing what is observed for each of the steps given in the laboratory experiment.
12. Also include what you learned.
13. Make sure to include the measured dropout voltages as well as the dropout voltages from the datasheet.
14. Discuss the efficiency of this linear regulator and why is efficiency an important parameter.
15. Where does the regulator power go to?
16. Is the curve linear for IL versus Vin?