

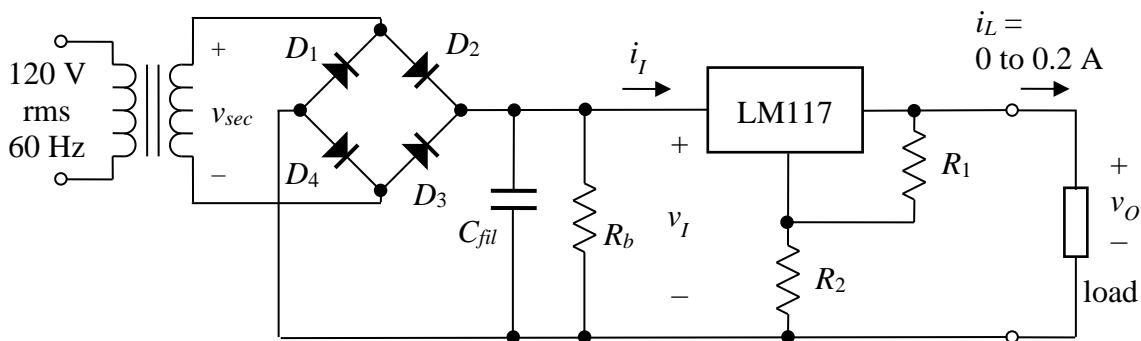
### Lab #4: Regulated DC Power Supply Using the LM117/317

#### Introduction

A simple DC power supply can be designed using only a transformer, a rectifier, and a filter capacitor. However, the average output voltage might not be stable because of line voltage fluctuations, and the output voltage ripple is significant unless a very large filter capacitor is used. Moreover, transformers are not available with a wide variety of secondary voltage options, especially in the very low voltages (e.g., 3.3 V, 1.8 V, or even lower) required by many modern electronic circuits. When a stable low voltage power supply with minimal ripple is required, the most common approach is to use a *voltage regulator* circuit. A wide variety of circuits are available for this task, ranging from zener diodes for very low-current applications to highly sophisticated integrated circuits and switching regulators. In this *Multisim* lab exercise, you will simulate a power supply based on a widely used integrated circuit regulator. Group assignments are listed at the end of this handout.

#### Theoretical Background

A widely used type of voltage regulator called a three-terminal regulator is a relatively sophisticated circuit fabricated on an integrated circuit chip. Three-terminal regulators were first introduced in 1969 and have been under almost constant development since then [1]. The name of the device family reflects its packaging and ease of use. As shown in Figure 1, a three-terminal regulator such as the LM117 can be connected between a power supply's filter capacitor and its load. The regulator has only an input terminal, an output terminal, and a common reference terminal. Some three-terminal regulators provide only a fixed output voltage, but the LM117 can produce an adjustable output voltage if a few external components are added. The LM117 is almost identical to the more commonly used LM317; the primary difference is that the LM117 is designed to operate over a much wider temperature range than the LM317.



**Figure 1.** A basic power supply that employs an LM117 three-terminal voltage regulator to maintain the output voltage  $v_O$  close to a desired value. The value of filter capacitor  $C_{fil}$  must be chosen to maintain the input voltage  $v_I$  of the regulator above a certain threshold for all expected values of the load current  $i_L$ . A value of  $240\ \Omega$  is recommended for  $R_1$  in the datasheet [2]. Resistor  $R_b$  is a bleeder resistor; its purpose is to discharge filter capacitor  $C_{fil}$  when power is turned off.

Three-terminal regulators are very easy to use, hence their popularity. As shown in Figure 1, they are simply inserted between the filter capacitor and the load along with a few external components. Resistors  $R_1$  and  $R_2$  are always required since their values set the desired output voltage. The datasheet recommends a value of  $240\ \Omega$  for  $R_1$ ; the value of  $R_2$  is then determined using a formula given in the datasheet [2]. Additional capacitors and diodes are recommended as well in certain situations, but they will not be considered here.

The selection of the value of  $C_{fil}$  requires a little thought. It must be large enough to maintain a sufficiently high input voltage  $v_I$  for the regulator but not excessively large. The voltage  $v_C$  across the capacitor, which is equal to the input voltage  $v_I$  of the regulator, will have a substantial ripple voltage just like it does in a basic power supply with no regulator. The capacitor is repeatedly charged and discharged as the transformer secondary voltage progresses through its sinusoidal cycle and the rectifier diodes turn on and off (off most of the time). The capacitor discharges into the regulator when the diodes are off. According to the datasheet, the minimum recommended difference between  $v_I$  and  $v_O$  is 3 V. This is called the *dropout voltage*. In practice, the difference should be maintained higher than the dropout voltage (maybe 4 to 5 V or even more for the LM117, depending on the available transformer secondary voltage) to provide an operational cushion. Thus, the minimum capacitor voltage must be many volts greater than the desired output voltage  $v_O$ . The maximum capacitor voltage is equal to the available peak secondary voltage minus two rectifier diode voltage drops. These two constraints together set the ripple voltage specification for  $v_C$ . That is one of the pieces of information needed to determine the minimum value of  $C_{fil}$ .

Another critical piece of information is the maximum current that flows out of the capacitor while it is discharging. That current is the current  $i_I$  that flows into the input terminal of the regulator. We can relate it to the load current  $i_L$  by remembering that KCL can be applied to entire regions of circuits, not just to circuit nodes. For the LM117 in Figure 1, application of KCL to the three terminals yields  $i_I = i_{ADJ} + i_L$ , where, as explained in Section 8.1 of the LM117/317 datasheet [2] available at the ECEG 350 Laboratory web page, current  $i_{ADJ}$  flows out of the reference terminal (the bottom terminal in Figure 1) and has a value of approximately  $50\ \mu\text{A}$ . If the load current is substantial (1 mA or more), then  $i_I \approx i_L$ . The formula used to determine the values of resistors  $R_1$  and  $R_2$  is also explained in Section 8.1. Additional practical information on the location of resistor  $R_1$  is given in Section 8.3.1. This information would be important if a physical version of the circuit were to be assembled.

## References

- [1] A. Bindra, "Three-Terminal Linear Regulator Evolution Continues Unabated," *IEEE Power Electronics Magazine*, DOI: 10.1109/MPEL.2014.2361596, Dec. 2014, pp. 12–15.
- [2] Texas Instruments, LM117, LM317-N Wide Temperature Three-Pin Adjustable Regulator datasheet, SNVS774Q, May 2004, rev. June 2020.

## Experimental Procedure

- Confirm that you have a functional installation of the *Multisim* circuit analysis software. If you are off campus, remember that the Bucknell VPN must be running for the software to operate properly. This is not an issue if you are using *Multisim Live* (the online version).

- Simulate in *Multisim* a basic power supply circuit with an LM117 three-terminal regulator like the one shown in Figure 1 that meets all of the specifications listed below.
  1. DC output voltage: approximately 9 V
  2. Maximum load current demand: 200 mA
  3. Rectifier diode type: 1N4001 or 1N4007 (datasheet available on ECEG 350 lab page)
  4. The bleeder resistance  $R_b$  should discharge the filter capacitor to 5% of its maximum voltage within 5 sec after the power supply is turned off but without loading down the rectifier significantly (i.e., its current should not add significantly to  $i_{max}$ ).
  5. The filter capacitor  $C_{fil}$  must be large enough for reliable operation at the maximum specified load current but not be excessively large. Keep in mind that the tolerance of electrolytic capacitors is typically 20–40% and that they are bulky and relatively expensive.
  6. The transformer's secondary voltage must be large enough to allow the voltage regulator to operate properly but not be unnecessarily large. Power transformers are relatively expensive. Assume that the available secondary voltages are 6 V rms (turns ratio of 20:1), 12 V rms (10:1), 18 V rms (6.67:1), and 24 V rms (5:1).
- Add *Multisim* oscilloscopes to monitor the time varying voltages across the filter capacitor and the load. Also add a multimeter to monitor the DC output voltage.
- Add an appropriate load to test whether the circuit is working correctly at full rated output current. The output voltage should have only a tiny amount of ripple (maybe 10–20 mV or less at full output current) with no large dips, and the filter capacitor ripple voltage should be close to the expected value according to your design. A successful test includes ensuring that the filter capacitor discharges within the specified period of time through the bleeder resistor. The latter should be possible to verify in *Multisim* using an oscilloscope. Note that simulated time might not be the same as real time. Capacitor discharge should be easier to observe and measure if you add an SPST on/off switch in series with the AC input voltage source.

The ripple on the output voltage might be so low that you will have to adjust the oscilloscope's vertical scale (in V/div) to a very small value. You will almost certainly have to move the 0 V level off of the screen to see the features of the output voltage waveform. Alternatively, you could consider switching the oscilloscope's input mode from DC to AC. Use the manual cursors to determine the peak output voltage and ripple voltage.

- With the load drawing the maximum specified current (~200 mA) from the power supply, use your observations of the capacitor voltage and output voltage waveforms to calculate the line regulation of the LM117 regulator. Compare the measured value to the specified value on the datasheet.
- Configure a set of SPDT or SPST switches and resistors at the output of the power supply so that you can easily select one of four equivalent load resistances. One resistance should draw the maximum rated current, and the others should draw 75%, 50%, and 25% of maximum. Using the multimeter, record the output voltage obtained for at each load current level. Record all of the displayed digits for each voltage. The measured voltages should trend slightly downward as the load current increases. Use the data to calculate the load regulation, and compare the calculated value to the specified value on the datasheet.

- As explained in Sec. 8.3.1 of the LM117/317 datasheet, the upper end of resistor  $R_1$  should have a very short and low-resistance connection to the output terminal of the regulator. If the resistance along that path is more than a few tenths of an ohm, the load regulation can be adversely affected at high output current levels. This effect (called stray resistance) was observed in ECEG 350L last year when the regulator circuits were assembled on plug-in protoboards. The stray resistance of the protoboard contacts led to poor circuit performance. Simulate a poor connection in your *Multisim* model by adding a resistance of  $0.5\ \Omega$  in series with the output terminal of the LM117 (like  $R_S$  in Fig. 16 of the datasheet). Record the DC output voltage for load currents equal to 25%, 50%, 75%, and 100% of the maximum specified value, and use the data to calculate the load regulation. Compare the value you obtain to the measured value you obtained earlier without the stray resistance  $R_S$  present, and compare it to the specified value given on the datasheet.
- Calculate the average power dissipation of the LM117 at the maximum specified output current of 200 mA.
- When you are satisfied with your results, schedule a meeting with the instructor to take place before the deadline posted on the Laboratory page at the course web site. All group members must be present. The purpose will be to explain elements of your design procedure and to discuss some of the implications of your measurements. Preparation instructions are given in the “Post-Lab Meeting” section below. Meetings will be scheduled in the order that requests are received. Meetings will not be rescheduled if the first one reveals circuit modeling problems, errors in the design or measurement procedures, or lack of preparation. Deadline extensions for illness or other extenuating circumstances will be considered on a case-by-case basis.
- Prepare documentation of your results with the following information. For full credit, the documentation must be neat, legible, and well organized. All or parts of it may be handwritten.
  1. Line regulation calculation at the maximum specified output current and comparison to line regulation specified in the datasheet.
  2. DC output voltage measurements at 25%, 50%, 75%, and 100% of the maximum rated load current.
  3. Load regulation calculation with  $R_S = 0$  and comparison to load regulation specified in the datasheet.
  4. Load regulation calculation with  $R_S = 0.5\ \Omega$  and comparison to load regulation specified in the datasheet.
  5. Average power dissipation of the LM117 at the maximum specified output current.
  6. Brief comments reflecting on the results and comparisons.
- Submit via e-mail the scanned and/or converted documentation in PDF format and your *Multisim* file with all switches, oscilloscopes, and multimeters in place by the deadlines posted on the Laboratory page of the course web site. Both files must use the naming convention “LName1\_LName2\_LName3\_Lab4\_fa20.pdf (or ms14),” where “LName1,” “LName2,” and “LName3” are the group members’ last names and the underscore ( ) characters are included. Submit one copy of each file for the group.

## Post-Lab Meeting

During the post-lab meeting, each group member will be asked to respond to one of the following prompts:

1. Explain how the value of the filter capacitor  $C_{fil}$  was determined.
2. Explain how the value of the bleeder resistor  $R_b$  was determined.
3. Explain how the load regulation was calculated (for either  $R_S = 0$  or  $R_S = 0.5 \Omega$ ) and how the corresponding specification in the datasheet was interpreted to allow comparison of the measured and specified values.

Each person will have a time limit of about **five minutes**. Your group may decide which member responds to each prompt. Each individual's response must make use of supporting visual aids (hand drawn is fine) that include a circuit diagram with component values clearly labeled, relevant equations, or any other supporting graphics as appropriate. All visual aids must be well organized, legible, and readily accessible to facilitate a lucid explanation.

Before or after the individual responses, there could be some general discussion of your design process and measurements, the performance characteristics of your circuit, or other related topics. If you made unusual design choices, you must be prepared to defend them.

This portion of your group's lab score will be based on the clarity and accuracy of your responses and the quality of your visual aids. It will be challenging to achieve a perfect score. A good demonstration must have excellent oral and visual components. The determination of your score will be guided by the rubric posted on the Laboratory web page at the course web site. You should review it carefully to help you prepare.

## Lab Scoring Criteria

Each group member will receive a score based on the following criteria quantized at the indicated levels. The first two criteria constitute a group base score; that is, each group member will receive the same score for those two criteria. The score for the third criterion will be assessed independently for each group member and will be determined by that individual's contribution to the post-lab meeting.

0, 10, 20, 30, 35, 40 pts	Functional <i>Multisim</i> model w/approp. component values (group)
0, 8, 15, 23, 30 pts	Documented measurements and calculations (group)
0, 8, 15, 23, 30 pts	Quality of response to prompt (indiv.)

If the documentation, *Multisim* file, and/or meeting are completed after their respective deadlines, a 10% score deduction will be applied for every 24 hours or portion thereof that the item is late (not including weekend days) unless extenuating circumstances apply. No credit will be given four or more days after the respective deadline.

## Group Assignments

The randomly generated groups for this lab exercise are listed below:

Roffer-Sago-Whalen

Luong-Sieck-Maduka

Nagle-Martinez-Gomez

Trejo-Medina-Mitchell

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