

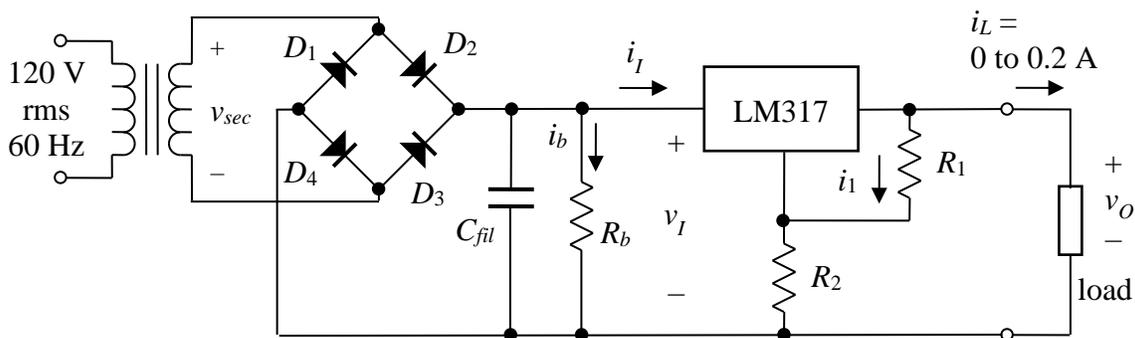
### Lab #3: Regulated DC Power Supply Using the LM317

#### 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 two-session lab exercise, you will design, assemble, and test a power supply based on a widely used integrated circuit regulator. Group assignments are listed at the end of this handout.

#### Theoretical Background

The three-terminal regulator is a relatively sophisticated integrated circuit that is widely used for producing steady DC voltages in modern electronic systems. 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. An example application is shown in Figure 1, which depicts a simple regulated power supply. The regulator is connected between the filter capacitor and the load. The device itself 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 LM317, which we will be applying in this lab exercise, can produce an adjustable output voltage if a few external components are added ( $R_1$  and  $R_2$  in Figure 1). A datasheet for the LM317 is available at the ECEG 350 Laboratory web page.



**Figure 1.** A basic power supply that employs an LM317 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  $120\ \Omega$  is recommended for  $R_1$  if the LM317 is used [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  $R_1$  [2], but for the LM317, it should be  $120\ \Omega$ . This guarantees that the output current will be at least 10 mA, which is required for proper operation. (See the minimum load current specification in Sec. 7.7 of the datasheet.) The value of  $R_2$  is determined using a formula given in the datasheet [2]. Additional capacitors and diodes are recommended as well in certain situations, but they should not be necessary for this circuit.

The selection of the value of  $C_{fil}$  requires a little thought. It must be large enough to maintain a sufficiently low ripple on the input voltage  $v_I$  of the regulator, but not so low a ripple that the capacitor is unnecessarily large. The voltage  $v_C$  across the capacitor is equal to the input voltage  $v_I$ . It will have a ripple just as in a basic power supply with no regulator because 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. Although it is not stated explicitly in the datasheet, it implicitly recommends a minimum difference between  $v_I$  and  $v_O$  of 3 V. This is called the *dropout voltage*. In practice, the difference could be even higher than this 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  $C_{fil}$ . All of this is discussed in more detail in the supplemental reading “Three-Terminal Linear Voltage Regulators,” which is available at the course Moodle site.

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 plus the current  $i_b$  that flows through the bleeder resistor, although it might be possible to assume that  $i_I \gg i_b$ . We can relate the input current  $i_I$  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 LM317 in Figure 1, application of KCL to the three terminals yields

$$i_I = i_{ADJ} + i_1 + i_L,$$

where, as explained in Section 8.1 of the LM117/317 datasheet [2], current  $i_{ADJ}$  flows out of the reference terminal (the bottom terminal in Figure 1) and has a typical value of approximately  $50\ \mu\text{A}$ , although it can be as high as  $100\ \mu\text{A}$ . If the load current is substantial (100 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.

## References

- [1] A. Bindra, “Three-Terminal Linear Regulator Evolution Continues Unabated,” *IEEE Power Electronics Magazine*, DOI: 10.1109/MPPEL.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.

## Preparation and Design Specifications

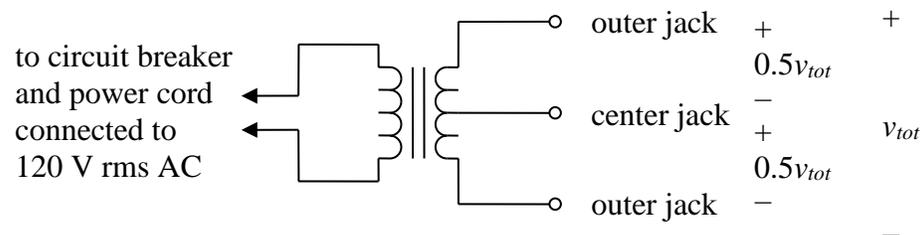
- During the first lab meeting, there will be an interactive demonstration of the characteristics of an unregulated power supply consisting of only a transformer, rectifier diodes, and a filter capacitor. This activity will cover the basic elements of power supply design up to but not including the regulator portion. Nevertheless, all of the guidelines covered in the demonstration will be applicable to the design of the regulated power supply. After the demonstration, you are strongly encouraged to read the “Design of Power Supplies with Linear Voltage Regulators” section of the supplemental reading “Three-Terminal Linear Voltage Regulators.” That section reviews some of the basics of unregulated power supply design and then moves on to summarize the design of regulator circuits.
- Before moving on, read the following important warnings. They will save you much time and possible frustration.

**Warning #1: Do not attempt to measure both of the voltages  $v_{sec}$  and  $v_O$  in Figure 1 with the oscilloscope at the same time. If you try to do this, the ground leads will create a short across diode  $D_4$  that will most likely lead to the destruction of diode  $D_1$ . You should trace the circuit connections in Figure 1 and understand how this can happen before proceeding.**

**Warning #2: Electrolytic capacitors are polarized. Failure to pay attention to their polarity could result in their spectacular destruction, an unpleasant smell for everyone nearby, and possible personal injury. The marking on an electrolytic capacitor’s package usually indicates its *negative* terminal. Look for a thick “-” sign, and interpret chevrons (angled lines) as arrows.**

- Design a power supply with an LM317 three-terminal regulator like the one shown in Figure 1 using one of the supplied transformer boxes. Consult the LM317 datasheet for details regarding the selection of external resistor and capacitor values. The power supply must meet the following specifications and guidelines:
  1. DC output voltage: approximately 9 V
  2. Maximum load current demand: 150 mA
  3. Current  $i_1$  through resistor  $R_1$  should be roughly 10 mA to meet the minimum load current specification of the LM317, which is necessary for it to operate properly.
  4. Average power dissipation of LM317: less than approx. 2.0 W at maximum load current (The goal is to avoid using a heatsink.)
  5. Rectifier diode type: 1N4001 or 1N4007 (data sheet available on lab page)
  6. Bleeder resistance  $R_b$ : should discharge the filter capacitor to 5% of its maximum voltage within 10 sec after the power supply is turned off but without loading down the rectifier significantly (i.e., its current should add as little as possible to  $i_{max}$ ).
  7. All diodes and resistors must be capable of dissipating the maximum expected time average power. This requirement includes any resistors used to simulate the load  $R_L$  for testing purposes. Make sure that any estimated values are reasonable for the worst cases expected. Apply a  $\times 2$  safety factor. You may combine resistors in series or parallel only for the purpose of meeting power dissipation requirements.

8. The filter capacitor  $C_{fil}$  must be large enough for reliable operation at maximum load current but not excessively large. You may combine capacitors in series and/or parallel only if single units with sufficient capacitance are not available. Keep in mind that the tolerance of electrolytic capacitors is typically 20–40% and that electrolytic capacitors are bulky and relatively expensive. An excessively complicated filter capacitor network will be viewed unfavorably!
9. For safety reasons, the transformer is enclosed in a box with a power cord and a circuit breaker. As shown in Figure 2, the three jacks on the box are connected to the secondary winding. The two outer jacks connect to the ends of the winding, and the center jack connects to a center tap. You will need to determine which pair of jacks to use by measuring the voltages between them and by considering the maximum and minimum filter capacitor voltages that you will need. Note that the output waveform of the transformer secondary might not be perfectly sinusoidal due to the presence of power line noise and/or harmonics in the local line voltage.



**Figure 2.** Connections to transformer inside its enclosure.

### Experimental Procedure

- After the design process for the regulated power supply has been completed, assemble it (except for the transformer, of course) on a breadboard.

As explained in Sec. 8.3.1 of the LM117/317 datasheet (you should read it), 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) is very likely to be present in your circuit because all of it will be assembled on a breadboard. The stray resistance of breadboard contacts can be quite high. There is not much that we can do about that, but we will observe the impact that it has on regulator circuit performance.

- Devise a way to test whether the circuit is working correctly at full rated output current. A successful test includes ensuring that none of the components overheats and that the filter capacitor discharges within the specified period of time through the bleeder resistor when the circuit is turned off. The equivalent load resistance should be infinite or a very large value for the bleeder resistor test. (Do you know why?) Under normal operation, 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.

- Display the capacitor voltage ( $v_I$ ) and output voltage ( $v_O$ ) waveforms simultaneously on the oscilloscope, and confirm that your power supply meets all specifications and design goals. Troubleshoot any problems. The ripple voltage might be so low that you will need to trigger the oscilloscope with the  $v_I$  waveform. You will probably have to switch to a sensitive vertical scale (small V/div setting) and move the 0 V level off of the screen to see the details of the output voltage waveform. Use the manual cursors to determine the peak output voltage and ripple voltage. Use the “BW Limit” feature to minimize the noise from WVBW.
- Capture an image of the oscilloscope screen simultaneously displaying the output voltage and capacitor voltage waveforms at full rated output current. Choose appropriate vertical and horizontal scale settings so that the key features of each waveform are clearly evident. Use the cursors to indicate important voltages and/or time instances.
- With the load drawing the maximum specified current (~150 mA) from the power supply, use your observations of the capacitor voltage and output voltage waveforms to calculate the line regulation of the LM317 regulator. Compare the measured value to the specified value on the datasheet. Record all of your observations and calculations; they will be presented during the post-lab meeting. Before attempting your measurements, it will be helpful to read the “Line Regulation” section and the “Measuring Load and Line Regulation” section of the supplemental reading “Three-Terminal Linear Voltage Regulators.”
- Measure and record the DC output voltage obtained when the supply provides 0%, 25%, 50%, 75%, and 100% of the maximum rated load current. You will need to modify your load to make these measurements. Make sure that any resistors that you use do not dissipate more power than they are rated to handle. You might wish to set up separate loads on your breadboard to allow for faster, easier, and repeatable switching between them for your tests and later demonstration. Use the bench-top voltmeter to obtain measurements with several digits of accuracy. You should find that the measured values trend slightly downward in value as the average load current increases. Use the data to calculate the load regulation, and compare the calculated value to the specified value on the datasheet. Record all of your observations and calculations; they will be presented during the post-lab meeting. For helpful guidance, read the “Load Regulation” section of the supplemental reading “Three-Terminal Linear Voltage Regulators.”
- When you are confident that the power supply is working properly, schedule a 30-minute post-lab meeting with me at a mutually agreed time before the deadline posted on the Laboratory page at the course web site. The following guidelines apply:
  - All group members must be present.
  - The meeting will take place in the Maker-E if Dana 307 is not available at the scheduled time.
  - Meetings will be scheduled in the order that requests are received.
  - Meetings will not be rescheduled if the first one reveals circuit problems, wiring failures, errors in the test procedure, or a lack of preparation.
  - Deadline extensions will generally be approved for confirmed illnesses or other extenuating circumstances.
  - Preparation instructions are given in the “Post-Lab Meeting” section below. **Read them carefully!** You will need to prepare a set of visual aids for the meeting.

- The visual aids that your group intends to use must be combined into a single PDF document and **e-mailed** to me before the post-lab meeting begins. Use a file name of the form

“LName1\_LName2\_LName3\_Lab3\_fa23.pdf,”

where “LName1,” “LName2,” and “LName3” are the group members’ last names. Include the underscore ( \_ ) characters. Add “LName4” if your group has four members. For example, if students Alvarez, Zhang, and Smith are lab partners, then their Lab #3 documentation would have the file name

Alvarez\_Zhang\_Smith\_Lab3\_fa23.pdf

**The file size must be less than 5 MB.** Keep a copy of your documentation if you wish to use it to prepare for the next exam or need it for future reference.

### Post-Lab Meeting

The group as a whole must address the first set of prompts listed below, and then each group member must respond to one of the individual prompts in the next set (a different prompt for each person) and possibly answer a few follow-up questions. Your group may decide how the prompts are assigned. Each person will have a time limit of **five minutes** for their individual responses.

**Special instructions regarding visual aids:** Each response must be supported by legible and well-organized diagrams, equations, and/or tabulated data that are readily accessible to facilitate a lucid explanation. At a minimum, your group should be able to refer to a legible circuit diagram with clearly labeled component values. Most visual aids may be prepared by hand, but they must be very neat and legible; however, all data tables **must** be prepared using software. For detailed instructions on preparing tables, read “Formatting Guidelines for Figures, Tables, and Captions” available at the Laboratory web page at the course web site. The quality, organization, and clarity of the visual aids will constitute a separate part of the overall lab score.

**Special instructions regarding demonstration planning:** Think through the various items that you will need to demonstrate, and organize your circuit layout and connections so that you can switch between demonstrations quickly. Any excessive delays between demonstrations will affect the overall group score.

The group prompts are:

1. Display an oscilloscope image of the output voltage waveform at full rated current at the rated voltage along with the capacitor voltage waveform. The ripple on both waveforms must be evident. The displayed waveforms should clearly indicate that the power supply is working properly.
2. Demonstrate that the filter capacitor voltage drops to under 5% of its maximum value within 10 sec under no-load ( $R_L \rightarrow \infty$ ) conditions after turning off the AC supply.
3. Explain how the filter capacitor’s value was determined.
4. Explain how you ensured that all of the load simulation resistors have sufficient power ratings.

The individual prompts are (data tables will be assigned group scores):

1. Explain how the value of the bleeder resistor  $R_b$  was determined. Also explain how its presence was accounted for (or why its effect was deemed insignificant) when the value of the filter capacitor was determined.
2. Demonstrate how the line regulation is determined from measurements, and explain how the corresponding specification in the datasheet was interpreted to allow comparison of it to the measured value. The line regulation data and results must be presented in a well-organized and properly formatted table. (The table quality will be assessed and scored at the group level.)
3. Demonstrate how the load regulation is determined from measurements, and explain how the corresponding specification in the datasheet was interpreted to allow comparison of it to the measured value. The load regulation data and results must be presented in a well-organized and properly formatted table. (The table quality will be assessed and scored at the group level.)
4. [Four-person group only:] Explain how you ensured that the maximum average power dissipation of the regulator IC did not exceed 2.0 W at full rated output current.

At the end of the demonstration, if there is time, your circuit will be used to supply power to a speaker/amplifier connected to a music source.

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

Each lab member's prompt response score will be based on the extent to which they understand the circuit's design and operation and on how effectively they use the available visual aids to support their response. A good demo must have excellent oral and visual components that are well integrated. It will be challenging to achieve a perfect prompt response score.

### Lab Scoring Criteria

Each group member will receive a score based on the following criteria quantized at the indicated point values. The first three criteria constitute a group base score; that is, each group member will receive the same score for those three criteria. The remaining criteria will be assessed independently, and the corresponding scores will be determined by that person's contribution to the post-lab meeting. The rubrics posted on the Laboratory page at the course web site will guide the determination of the various scores.

0, 10, 20, 30, 35, 40 pts	Functional circuit w/appropriate component values (group)
0, 2, 5, 8, 10 pts	Quality of load regulation data/results table (group)
0, 2, 5, 8, 10 pts	Quality of line regulation data/results table (group)
0, 8, 15, 23, 30 pts	Quality of response to prompt (indiv.)
0, 2, 5, 8, 10 pts	Effective use of supporting visual aids (indiv.)

If the meeting is completed after the deadline, a 10% score deduction will be applied for every 24 hours or portion thereof that it is late (not including weekend days) unless extenuating

circumstance apply. No credit for the two individual criteria will be given four or more days after the deadline; however, up to 60 pts will be assigned to each member of the group for the first three (group) criteria if at least one group member demonstrates a functional circuit within a week of the deadline.

### Group Assignments

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

Baganski-Miller-Piper  
Hackett-Samuels-Youn  
Bailey-Beaudette-Ren  
Powick-Sago-Zhang  
Beebe-Jiorle-Jeong  
Andrews-Freedenberg-Tuncel  
Ashnault-Flynn-Regec

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