EE 3101 ELECTRONICS I LABORATORY

EXPERIMENT 3 LAB MANUAL

THE SERIES-PASS VOLTAGE REGULATOR

OBJECTIVES

In this experiment you will

- Learn how series-pass voltage regulator circuits are designed.
- Gain experience in making power supply performance measurements.
- Learn how to take steps to improve the efficiency and reliability of the power supply using "worst-case" design techniques.
- Gain more experience working with real electronic circuits.

LAB NOTEBOOKS

The format of lab notebooks should be such that the information can be used to reproduce the lab, including what values were used in a circuit, why the values were used, how the values were determined, and any results and observations made. This lab manual will be used as a guide for what calculations need to be made, what values need to be recorded, and various other questions. The lab notebook does not need to repeat everything from the manual verbatim, but it does need to include enough information for a 3rd party to be able to use the notebook to obtain the same observations and answers. In the following numbered sections there are **bolded words and/or lines**. These bolded words and/or lines are statements and/or questions that the lab TA will be looking for an answer either in the lab preliminary, or lab notebook.

INTRODUCTION

When designing a regulated power supply, we usually would want to use an integrated circuit regulator whenever possible. These regulators are easy to use and often provide other capabilities such as current limiting, short-circuit protection and temperature compensation. However, you will often encounter a custom-designed regulator made with discrete components. This could be in an older piece of equipment, or merely due to the fact that a non-standard voltage, high current or unusual design specification is required.

For the purposes of this experiment, we will work with the full-wave rectifier circuit we studied in Experiment 2. We will design a series-pass regulator to provide approximately 9.1 VDC @ 400 mA. The desired circuit is shown in Figure 1. Since more load current is required, we will use two RL203 (2 Amp) diodes. The forward diode drop will be approximately the same as V_F was for the 1N4002 diode.

Referring to Figure 1, the circuit works as follows. Diode D3 has a Zener voltage that is nominally 9.1 volts, and the series diode D4 is used for two reasons:

- The voltage drop of the diode is approximately equal to the transistor base-emitter voltage drop. This makes the output voltage nearly equal to the Zener voltage.

- It serves as temperature compensation element. As the temperature of the circuit increases, both the diode voltage and the base-emitter voltage change in the same direction so that the output voltage remains about the same.*

* The temperature coefficient (TC) of a Zener varies with current and Zener voltage. For Zener voltages over 5 volts or so, and the right quiescent current, you can obtain a positive, negative or even zero TC.

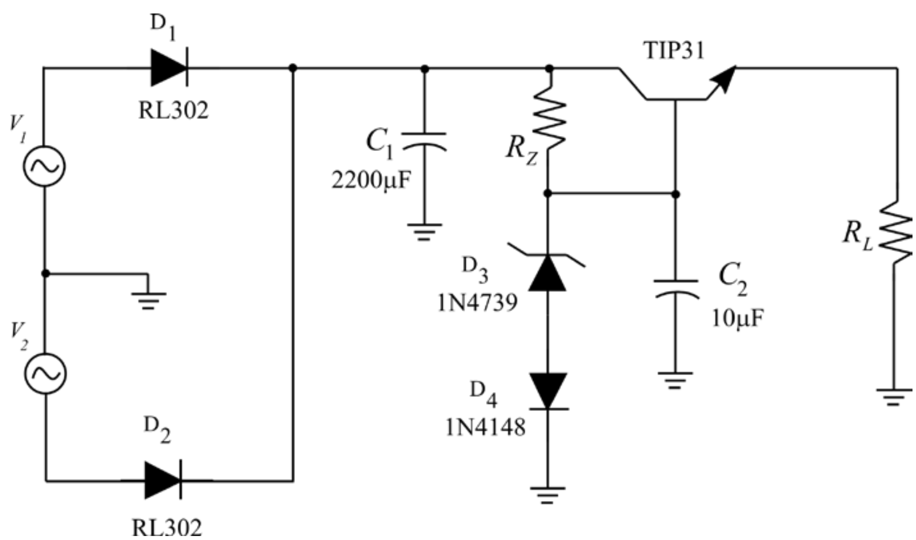

Figure 1: A 9.1 volt power supply with series-pass regulator.

Capacitor C_2 serves three purposes. First, it helps attenuate noise generated by the Zener diode D3. Second, it provides a "stiff" bypass for the base to improve transient response of the regulator. (Note that this also helps lower the small-signal output impedance of the regulator.) Third, and perhaps most important, it reduces the 120 Hz ripple that makes it past the Zener. In fact, it is not unusual for a good regulator to suppress power supply ripple by a factor of 50. The two voltage sources in Figure 1 represent the two sides of the center tapped transformer.

PRELIMINARY

1. From the design criteria presented in the introduction, **calculate the resistance** needed for the circuit to be operated at full load. **Calculate the power that the load resistanc**e will dissipate also.

2. Find a data sheet for the TIP31 series transistor, and in particular find β (or h_{FE}) for a TIP31A. Using the value of β, which should be the minimum or "worst-case" value, **calculate the maximum base current needed for the load condition of 400 mA**. This will essentially guarantee that any TIP31A used should meet specifications.

3. **Calculate the maximum permissible Zener current for the 1N4739 (1 Watt) device**.

4. Assuming the maximum base current is supplied, **calculate the value needed for R_Z that will allow at least 10% of $I_{z(max)}$ to flow through the Zener**. This will ensure that the Zener draws enough current to stay in regulation (i.e., over the "knee"), even when output current is maximum. R_Z can be determined by taking the voltage loop shown in Figure 2, and solving for R_Z.

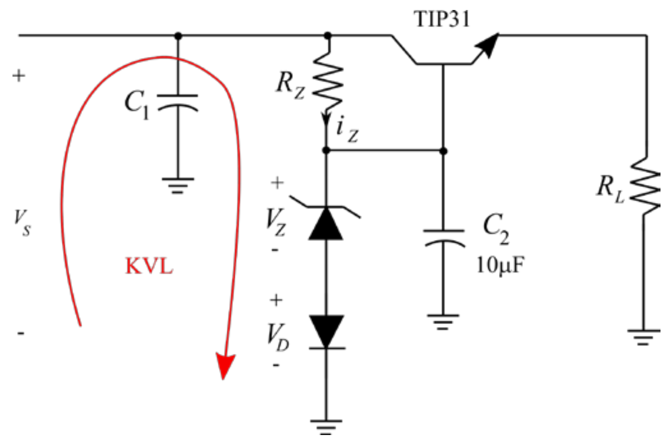

Figure 2: KVL loop to determine R_Z.

5. Choose the next <u>lower</u> standard value of resistor for R_Z. It is also wise to check the Zener current at the other extreme. That is when no load is connected to the power supply. The Zener must then carry all of the current coming through R_Z. To provide a safety margin, make sure that this current will never exceed 90% of $I_{z(max)}$. **Calculate the current i_z, for no load condition, and compare to the 90% of $I_{z(max)}$.**

EXPERIMENT

1. Construct the circuit of Figure 1 using parts in the laboratory.

2. Referring to the textbook equations you used last week, **calculate the ripple you expect to see across the filter capacitor.**

3. After checking your circuit connections, apply AC power to the circuit. **Measure the load voltage to confirm that the output is being regulated to approximately 9.1 VDC**. With the oscilloscope (AC coupling), **measure the peak-to-peak ripple at the output and at C_1**. Do this as accurately as possible. Compare the ripple present before and after the regulator.

Q1. Did the regulator reduce the ripple?

Q2. By what factor?

4. The "percent regulation" of a DC power supply is a measure of how much the output voltage changes between a no-load condition and full load. A basic power supply such as this one will not regulate properly unless some load current is being drawn. For our purpose, we will select a high-valued (1k) resistor to simulate a no-load condition.

   a. Remove the full load resistor and replace it with the 1kΩ (no-load) resistor and **measure the resulting output voltage**.

   b. **Calculate the percent regulation ζ of the power supply** as

$$\zeta = \frac{V_{no\ load\ output} - V_{full\ load\ output}}{V_{full\ load\ output}} \times 100\%$$

   c. **Calculate the percent ripple ρ at full load** from

$$\boldsymbol{\rho} = \frac{V_{full\ load\ peak-to-peak\ ripple\ voltage}}{V_{full\ load\ DC\ output\ voltage}} \times 100\%$$

Q3. Would you consider these good values? (Compare with the specifications of your laboratory power supply.)

Q4. What factors might be contributing to make these values higher than they should be?

Q5. How much power is being supplied at full load?

Q6. Approximately, how much power is being dissipated in the power transistor?

5. On the last page of this handout (Figure 4), there is a circuit that is a dual polarity output of 9.1 V.

Q7. What is the one specification on the transformer that you would need to change?

COMMENTARY

As the load current varies, the current through the Zener diode also varies. A large variation is not desirable, since the Zener has a finite incremental resistance that will cause a subsequent change in the terminal voltage of the Zener. This effect can be reduced by adding a second, higher-gain transistor as shown in Figure 3. This forms what is called a Darlington pair or a "beta multiplier." The gain of this two-transistor pair greatly reduces the required Zener current. In fact, a 500 mW Zener could probably be used.

It will also be noticed in Figure 3 that a second 1N4148 diode is added to the circuit. This compensates for the extra V_{BE} drop of the 2N3904 transistor. If you have time, you might try this circuit. Remember to recalculate R_Z.

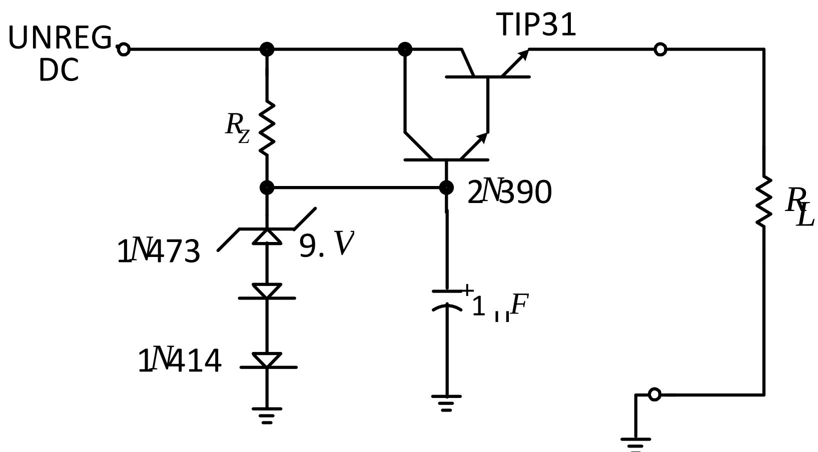

Figure 3: Series-Pass Regulator with a Darlington Pair.

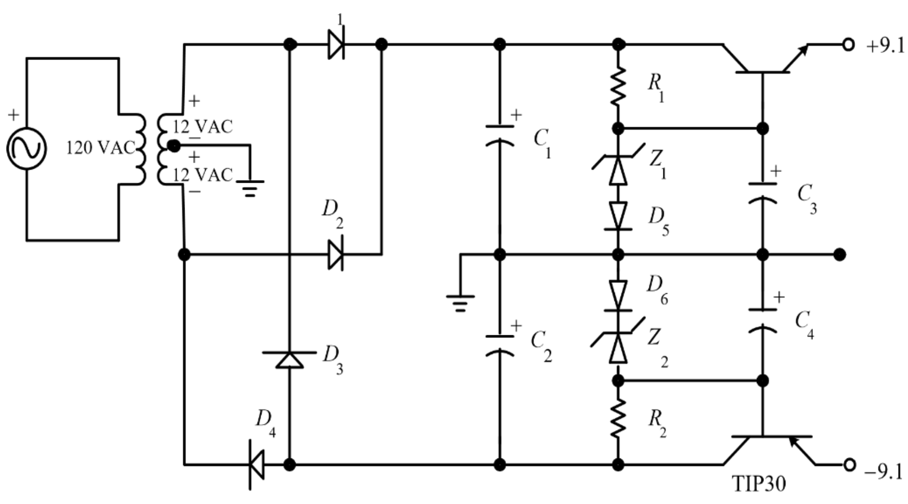

Figure 4: A Regulated Dual Power Supply.

[1] Cunningham, D. Stuller, J. 1991. Basic Circuit Analysis. Boston, Massachusetts. Houghton Mifflin Company.