EE 255
ELECTRONICS I LABORATORY
EXPERIMENT 3
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.

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 @ 400mA. The desired circuit is shown in Fig. 1. Since more load current is required, we will use two 2A03G (2 Amp) diodes. The forward diode drop will be approximately the same as V_F was for the 1N4002 diode.

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

i) 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.

ii) 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.
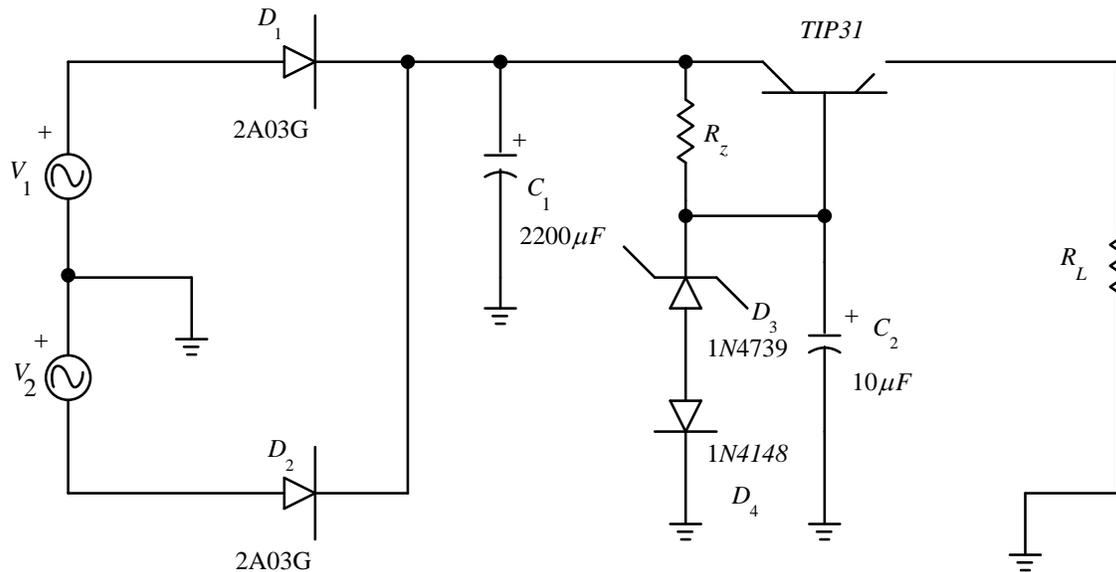
Fig. 1. A 9.1 volt power supply with series-pass regulator.

Capacitor C_2 serves three purposes. First, it helps attenuate noise generated by the Zener. Second, it provides a "stiff" bypass for the base to improve transient response of the regulator. (Note that this also helps lowers 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 Fig. 1 represent the two sides of the 24 VAC center-tapped transformer we have in the lab. Each voltage source will, hence, have a peak voltage of about 17 volts when delivering rated load current.

EXPERIMENT *(As in all experiments, do as many of the calculations before lab class as possible.)*

1. Begin constructing the circuit of Fig. 1 using parts in the laboratory. To simulate the 400 mA full load, use a power resistor that will draw at least this amount of current.

2. Refer to the TIP31 data sheet. We see that the DC current gain at the expected collector current is guaranteed to be at least 20. If we use this "worst-case" value to calculate the maximum base current needed, we essentially guarantee that any TIP31 used should meet specifications.

3. Now calculate the maximum permissible Zener current for the 1N4739 (1 Watt) device. With maximum base current 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. 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 . $I_{z(max)}$

4. Referring to the textbook equations you used last week, calculate the ripple you expect to see across the filter capacitor. For this calculation, you will need to calculate the DC current being drawn by the regulator under full load.

5. 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. Did the regulator reduce the ripple? By what factor?

6. 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 of the power supply as

   <u>(no-load output voltage) minus (full-load output voltage)</u> x 100%
                              full-load output voltage

   Calculate the percent ripple at full load from

   <u>full-load peak-to-peak ripple voltage</u> x 100%
                full-load DC output voltage

c. Would you consider these good values? (Compare with the
       specifications of your laboratory power supply.) What factors might
       be contributing to make these values higher than they should be?

7. How much power is being supplied at full load? Approximately, how much power is
    being dissipated in the power transistor?

8. If we were planning to mass-produce this circuit, it would be desirable to increase the
    efficiency by decreasing the power wasted in the series-pass transistor. One thing we
    could do is to allocate perhaps 3 volts across the pass transistor under full load and
    minimum expected input AC line voltage. We could then calculate the actual
    transformer turns ratio required such that the power supply would always meet
    specifications. Perform these calculations to determine the actual turns ratio needed.
    (Note: To compensate for the voltage drop across the rectifier diodes, use the worst-
    case forward voltage given in the 1N5401 data sheet. Assume that the lowest input
    voltage possible is 108 VAC.)

Note: On the last page of this handout (Fig. 3), you will see a circuit that provides both a
"+" and a "-" 9.1 volt supply. 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 Fig. 2. 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 Fig. 2 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
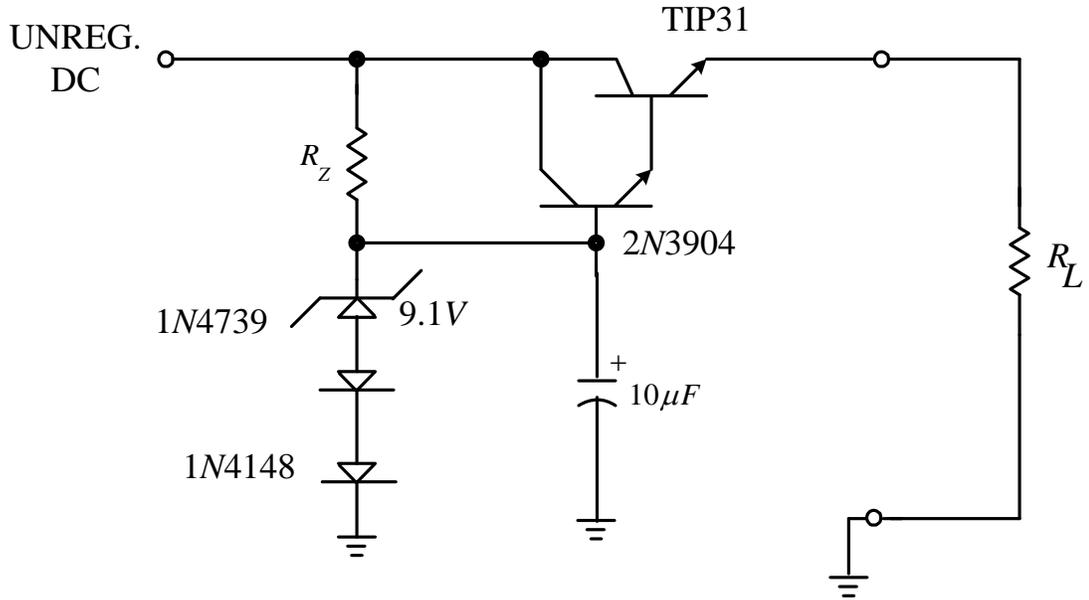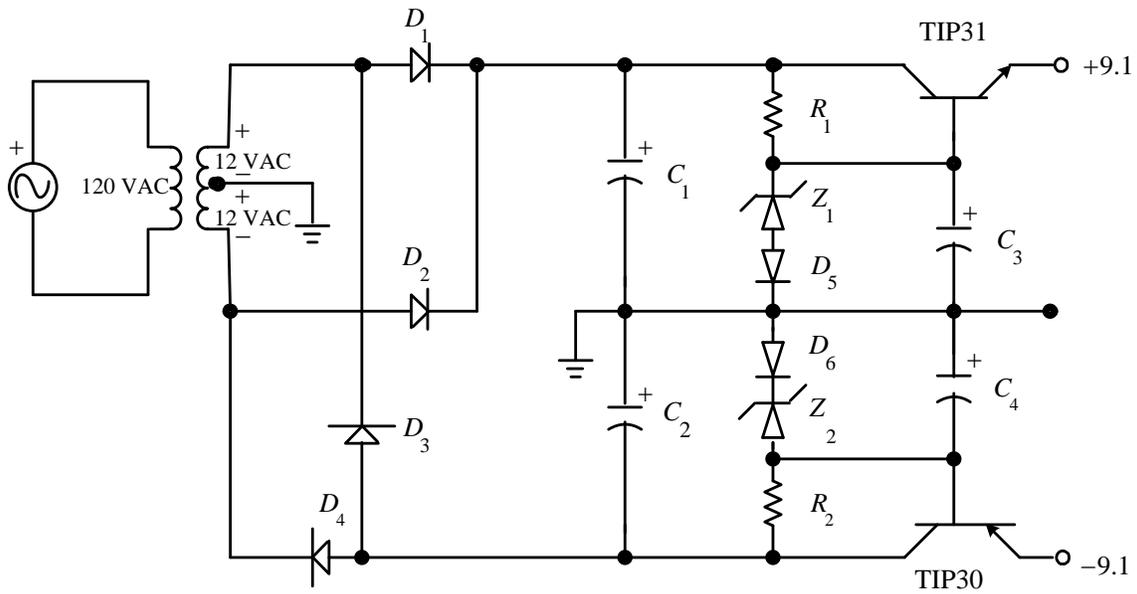might try this circuit. Remember to recalculate R_Z.

Fig. 2. Series-Pass Regulator with a Darlington Pair.

Fig. 3. A Regulated Dual Power Supply