CHAPTER 5

Voltage Regulator

In your robot, the energy is derived from batteries. Specifically, there are two sets of batteries wired up to act as voltage sources; a 9V battery, and two 1.5V batteries in series that act as a 3V source. Since different circuits in your robot require different voltage sources, it is not always possible to hook up the battery directly to power the circuits. The ICs in your robot circuit are designed to work with a constant 5V source. Therefore, it is important to convert the 9V source into a 5V source. Since a DC voltage (one that is fixed over time such as a battery) is being converted to another DC voltage, the circuit that does this is called a DC-to-DC converter or a voltage regulator. If we were to convert 110V AC (alternating current - like the power in a wall outlet) into a 5V DC source, the circuit would be an AC-DC converter.

Background

In this lab, you will build the voltage regulator circuit which converts the 9V batteries output into a constant 5V voltage source. The circuit has already been designed for you. Your task will be to build and test its operation. You will also do some experiments that will allow you to develop an understanding of how the circuit works.

The voltage regulator circuit consists of 5 different components; a 9V battery, a resistor, a diode, a transistor, and a capacitor. You may wish to review the description of the operation of these components in the Lab Guide. The circuit you will be building is shown in Fig. 5.1 . The pin out for the transistor is shown in Fig. 5.2 -

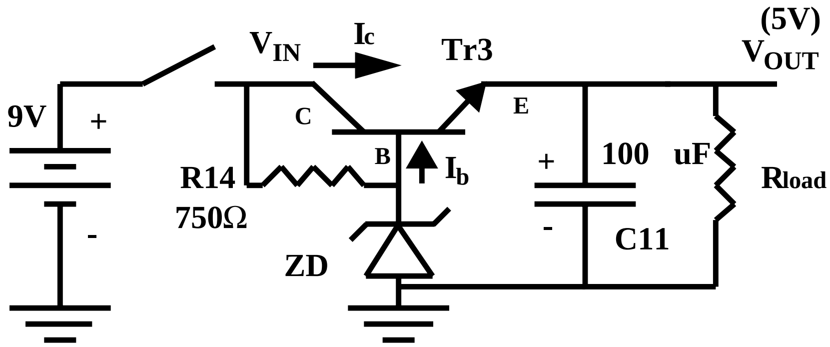

Figure 5.1 Power Supply Regulator.

please be very careful, interchanging the base and collector will result in immediate destruction of the transistor. If you are using the replacement transistor rather than the one that comes in the robot kit, its leads come out in a different order (shown on the left in Fig. 2). For more details on identifying the E, B, and C terminals of your transistors see the Lab Guide. Another potential problem is that the capacitor is electrolytic - which means that it can only stand to have voltages applied in one direction. If voltages are applied contrary to the sign of the label on the capacitor it will be destroyed. Note, this circuit is also shown in the Graymark Robot Assembly Manual in Figure T2 - but it may be WRONG. The Zener diode may be incorrectly connected with the arrow pointing toward ground. Follow the schematic shown above in Fig. 5.1 or in the schematic in Chapter 1 of this manual.

A brief description of the circuit operation is as follows. Before the 9V battery is attached, all points on the circuit are at 0V (ground). Let us first consider the operation of the circuit without the capacitor (C11). When the switch is closed, a voltage is applied to the Zener diode through R14. The value of R14 is chosen so that the Zener diode is in the reverse break-down region. Consequently, the voltage across the diode is held constant at 5.6 V. This 5.6 V also appears across the base-emitter junction of the transistor and the load resistor in series. Since this voltage is much greater than 0.7 V, the base-emitter diode is forward biased and current flows into the base of the transistor. The voltage across the resistor is therefore fixed at 5.6-0.7=4.9 V as long as the Zener diode is in the reverse breakdown region and the base-emitter diode is forward biased.

To see how this circuit is always able to hold the voltage across the load at approximately 5 V, let us consider the current flows in the circuit. The current flowing through R14 is split between the Zener

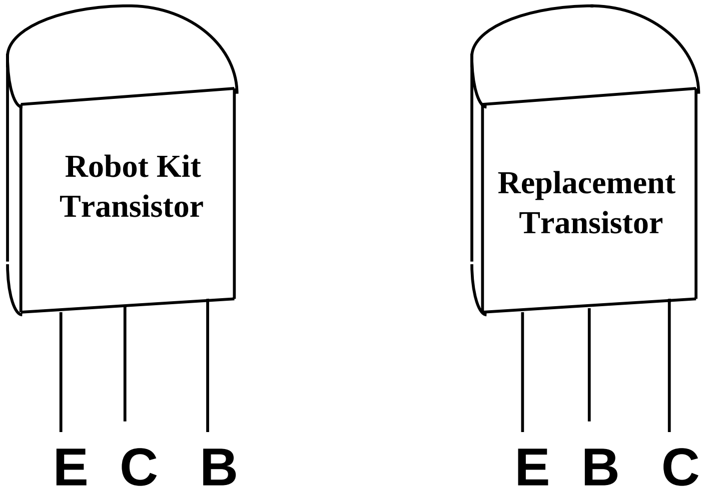

Figure 5.2 Transistor lead configurations.

diode and the base-emitter diode of the transistor. If we denote the current flowing into the base as I_B, a current equal to $ßI_B$ flows from the battery into the Collector. Since the transistor is connected to operate in the "Forward Active" region, a current equal to $(ß+1)I_B$ flows out of the emitter and through the load resistor. If the load resistor changes, the current through the Zener diode changes so that the base current and therefore the emitter current has the proper value to give the required 5 V across the load resistor.

The capacitor is a circuit element that stores electrical charge. It is used in this circuit to help keep the voltage regulator's output voltage constant over time. The rate of change of the voltage across a capacitor is proportional to the current flowing out of it divided by the capacitance. Therefore, the larger the capacitor, the smaller the changes in voltage at the output of the regulator over time for a fixed current drain.

Laboratory Exercises

1. First, build the circuit shown in Fig. 5.1 on your protoboard. See Chapter 1 and Chapter 3 for a description of the Zener diode. The transistor is TR3, a 2SC2120 (see

Fig. 5.2 for its terminal connections). See Fig. 5.1 to determine how the voltage regulator circuit should be wired together. Connect the voltage regulator output to a 4.7KΩ resistor (which will give you a load current of about 1mA) which acts as the load resistance, RLoad. For testing purposes, we are replacing the battery with the 0–+20V power supply. Connect the Common terminal to the bottom of the diode and C11. Make sure you set the +20V output of the power supply output voltage to 0V before you connect the +20V terminal of the power supply to the transistor collector and R14. Measure the output capacitor voltage, V_{OUT}, for varying values of power supply voltage, V_{IN}, starting at 0 volts and increasing the supply by 1 volt steps until it reaches 9 volts. As you increase the power supply voltage keep an eye on the ammeter on your power supply. If it moves noticeably, immediately turn the voltage back down and check your circuit.

2. One important characterization of a voltage regulator is how well it holds the output constant in the face of changing input voltage - this is called line regulation. Line regulation is characterized by the change in output voltage divided by the change in input voltage. That is,

$$A_{line} = \Delta V_{OUT} \ / \ \Delta V_{IN}$$

The line regulation error for the ideal voltage regulator is 0%. With a single 4.7KΩ resistor as a load for the voltage regulator output, and a power supply voltage of 9V, measure the output voltage. Change in the power supply voltage to 8V and then measure the output voltage. What is A_{line} for your voltage regulator?

3. Next, we will explore what is called the “load regulation” of your voltage regulator. Good load regulation means that the output voltage does not change much with changing load resistance. To characterize the load regulation of your regulator circuit, set the power supply voltage at 9V, and see how the output voltage varies as you draw current from (load down) the voltage regulator output. Measure the regulator output voltage with a 4.7KΩ resistance (which means a load current of about 1mA) and with a load resistance of two 4.7KΩ resistors in parallel (which means a load current of approxi-

mately 2mA). We formulate the voltage regulator's load regulation in terms of its incremental output resistance - the change in load voltage divided by the change in load current

$$R_{supply} = \Delta V_{OUT} / \Delta I_{OUT} = \Delta V_{OUT} / 1mA$$

Note, an ideal voltage source would have

$$R_{supply} = 0\Omega.$$

What is R_{supply} for your regulator?

4. After you have verified that the circuit functions properly, solder the voltage regulator circuit onto the robot PC board. Note, do not cut off the leads of the components flush with the board. You should leave enough wire protruding so that a clip lead can be attached for testing. Verify that the connections are correct by examining the underside of the board. Set the +20V part of your power supply to +9V and attach it to the +9 V pin of the robot PC board between R14 and the power switch SW1. Attach the power supply common to one of the GND pins of the robot PC board. Turn SW1 on and check to see that your voltage regulator still works by measuring the voltage of the output pin with respect to ground. If the output voltage is not 5V, identify the problem and fix it. If you cannot rectify the problem ask your TA for help.