

CHAPTER

6

Motor Driver

In this lab, we will construct the circuitry that your robot uses to drive its motors. However, before testing the motor circuit we will begin by making sure that you are able to operate two new pieces of laboratory equipment: the function generator and the oscilloscope.



Background

Fig. 6.1 shows the circuit diagram for one of the two identical motor driving circuits in the robot. Just as in the LED circuit, the input is digital and will be a high (5V) or a low (0V). For a high input, both transistors will be turned on. The voltage at the base of Tr5 will be two diode voltage drops (about 1.4V) above ground. Some of the current that goes through R28 will continue through R18. The rest of the current will go into the base of Tr5. We can estimate I_B of Tr5 as follows. The current through R18, by Ohms Law, is $1.4V / 4.7K\Omega = 0.3mA$. Assuming that the input voltage is +5V, then the current through R28, by Ohms Law, is $(5V - 1.4V) / 4.7K\Omega = 0.77mA$. Therefore, $I_{B5} = 0.77mA - 0.3mA = 0.47mA$. R21 will limit the current I_{C5} . When Tr5 saturates, $V_{CE5} = 0.2V$. Given that $V_{BE6} = 0.7V$,

$$I_{E5} = I_{B6} = (5V - 0.9V) / 100\Omega = 41mA$$

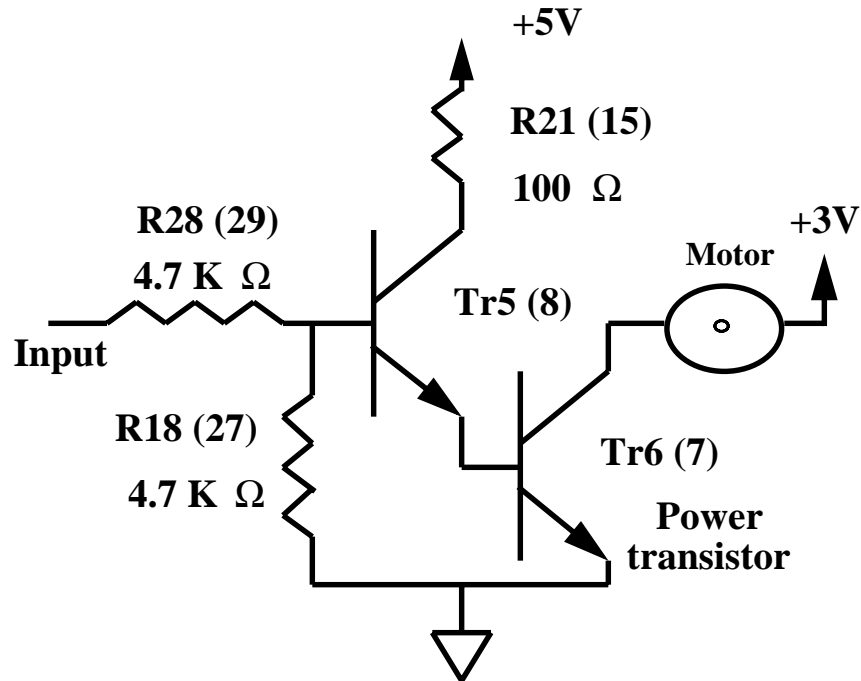


Figure 6.1 Motor driver circuit.

As long as $\beta > 41\text{mA} / 0.47\text{mA} = 87$, which is normally the case, then Tr5 will be in SATURATION.

Because motors need a fairly high current to operate properly, a second transistor, Tr6, is used to further amplify the current. Since the motor is such an energy drain, it would quickly exhaust the 9V battery used to power the control circuits. For this reason, two 1.5 V batteries are used exclusively for powering the motors. When you connect the batteries in series, they form a 3V power source. Tr6 can draw its collector current from the 3V batteries, leaving the 5V power supply undisturbed. This current will flow through the coils in the motor, making it spin.

As long as $I_{C6} < \beta I_{B6} = \beta 41\text{mA}$, which is several Amperes, Tr6 will also operate in saturation. Its collector current will be determined by the current that flows through the motor with roughly 2.8V across it. If you omit the motor, and simply connect the 3V source to the collector of Tr6, then you would probably destroy the transistor. Note, an advantage of using transistors in the saturated or switching mode is that even though they conduct large amounts of current, they do not dissipate much power -- remember that

power dissipated in a transistor is roughly $I_C \times V_{CE}$. In the saturated case V_{CE} is typically only 0.2V, so not much power is dissipated in the transistor.



Laboratory Equipment

In this laboratory exercise we will also explore the uses of the two additional pieces of laboratory equipment: the oscilloscope and the function generator.

Quite often in electrical circuits we are interested in seeing how the voltage at a circuit node evolves over time. This is the purpose of the **oscilloscope** (also nicknamed the "scope"). The oscilloscope has a screen with a grid on its face. Behind the screen there is an electron gun which sends a stream of electrons to a point on the screen, lighting the point up. If there is no input to the oscilloscope, then the point on the screen starts at the left, moves horizontally across the screen, and when it gets all the way to the right, it reappears on the left to start another run. The speed that the point moves with is varied by the time base knob on the front panel. The grid lines on the screen divide the screen horizontally and vertically into 10 divisions.

The Oscilloscope

As the point moves horizontally across the screen, the vertical deflection of the point is proportional to the input voltage on the amplifier channel being displayed. The gain can be set with the vertical volts/division knob. Effectively, as the point moves across the screen, a plot of voltage vs. time is displayed. When the time at which the point begins to cross the screen corresponds to a fixed time on a periodic waveform, then wave shape is plotted over and over again, resulting in a stable solid line on the screen. A good appreciation of how to use an oscilloscope will come with experience. You may need to ask your Lab TAs for help.

Fig. 6.2 shows a block diagram of a simple oscilloscope used to display voltage as a function of time. In essence, the oscilloscope draws a picture of voltage versus time. The input signal is amplified by the vertical amplifier with the gain selected by a knob on the front panel and controls the Y position (vertical axis) of the X-Y

display (a cathode ray tube). The X position (horizontal axis) is controlled by a linear ramp generator with a waveform as shown in Fig. 6.3. Zero volts corresponds to the left side of the screen and the maximum voltage corresponds to the right side. The rate at which the ramp increases determines the time scale of the plot that appears on the oscilloscope screen.

The ramp generator only starts a new ramp when it is triggered. The trigger signal is derived either from the vertical amplifier or from an external signal. Between sweeps the oscilloscope screen is blanked (meaning it is dark). Hence, there is no display unless the ramp generator (or time base) is triggered.

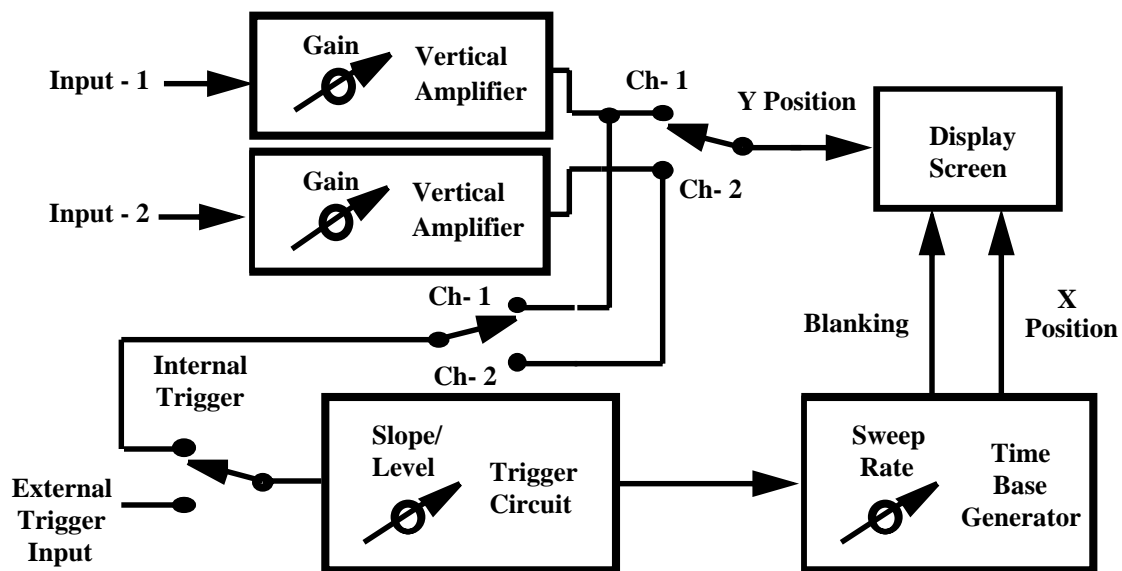


Figure 6.2 Oscilloscope Block Diagram

It is clear from the block diagram that the oscilloscope can display $V_{in}(t)$. However, a stable trace will only be obtained when the trigger circuit is operating properly; that is, when it always starts the time base at the "right" time. In the following, we will examine more closely the operation of the trigger circuit. The trigger circuit triggers the time base when the signal at its input satisfies conditions of both slope and amplitude. These are adjustable using the slope and level controls on the front of the scope. The sweep is

triggered when the input signal crosses the voltage selected by the level control in the direction selected by the slope control. Suppose the slope control is set to +. In Fig. 6.4, the sweep will start at t_1 (and again at t'_1) if the level control is set to level V_1 . On the screen, we will see the rising portion of the input signal first. If the trigger slope control is set to -, the sweep will start at t_2 . Note that if the trigger level is set too high or too low, the sweep will never start, and there will be no display.

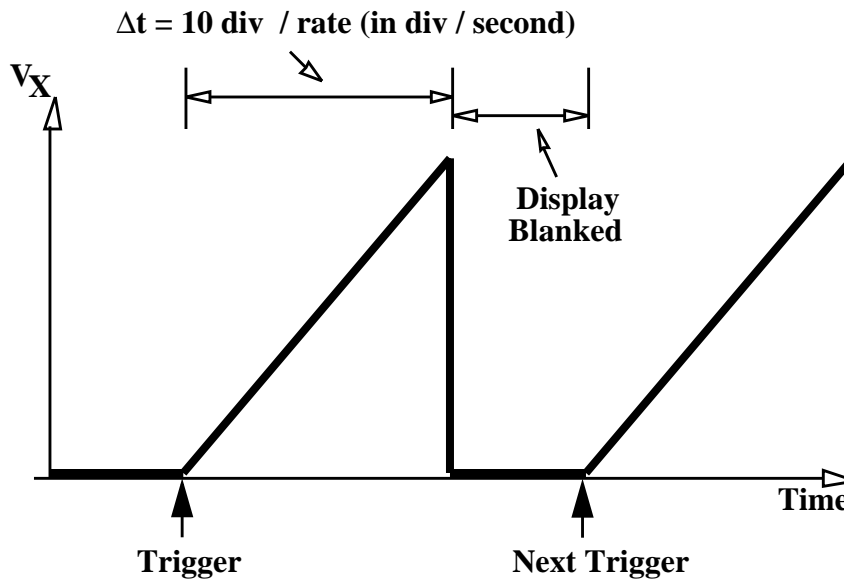


Figure 6.3 Timebase Generator Waveform

We are now in a position to explain the AUTO/NORM mode switch. Make sure you are using the level, slope and mode controls for time base A - they have an A next to them. When set to NORM, the operation of the trigger circuit is as described above. In the AUTO mode, the sweep is started after a certain time (several milliseconds) even if the trigger condition is not satisfied. A trace will then appear even if the trigger circuit is misadjusted. The AUTO mode is therefore very useful when setting up a measurement. In fact, **you should leave your scope in AUTO mode** unless instructed otherwise. Another important control is the trigger source switch. It typically has 3 positions: INT, LINE, and EXT. INT is the normal position you will use. In this position the signal on the vertical channel selected by the channel switch will be used for triggering. Also important is the external trigger input which is used for triggering if the trigger source switch is in the EXT posi-

tion. This allows us to use a trigger signal from a pulse generator or other external source to initiate the sweep. The advantage of this is that time relationships are preserved even when the probe is moved to another part of the circuit. The LINE position triggers the sweep at a 60 Hz rate derived from the power line.

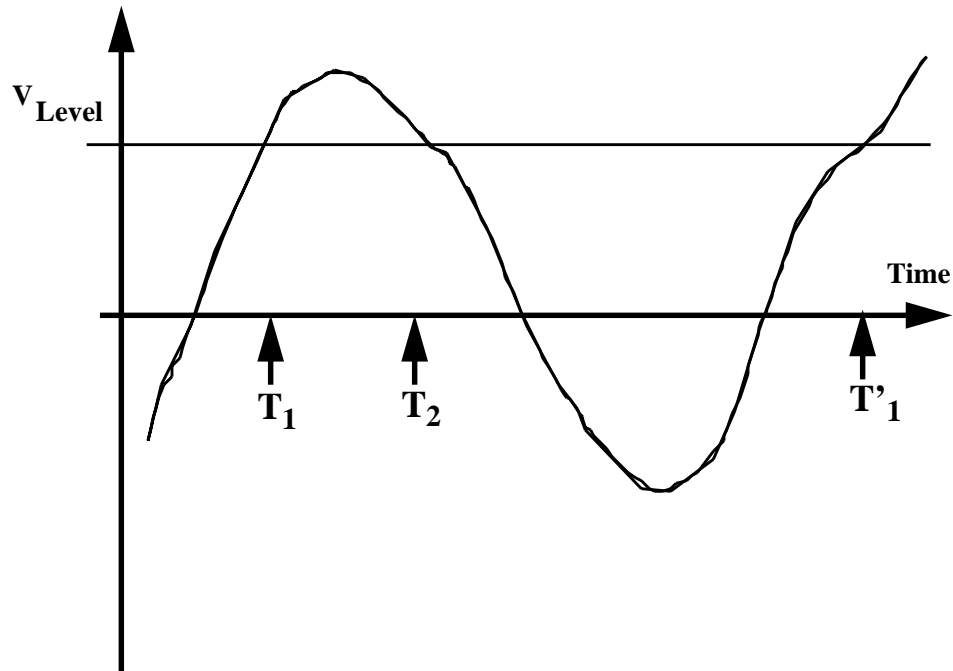


Figure 6.4 Input to the Trigger Circuit.

A few words about how the oscilloscope amplifies the voltage being displayed. The amplitude knob (one for each of the two channels) has one set of markings (0.2V/div, 0.5V/div, 1V/div, 2V/div, 5V/div, etc.) but two cursors, marked **x1** and **x10**. To read voltage, use the appropriate cursor for the probe you are using. In general, we will simply use a **BNC cable** to connect the signal to the scope. In this case you should **use the x1 markings** on the attenuator knob. For some circuits the large capacitance (approximately 60pF / foot) of the BNC cable will result in considerable loading of the circuit being measured. A 10:1 attenuating probe can be used to avoid this capacitive loading. The “10X” probe has an input resistance of 10M Ω in parallel with an input capacitance of 13pF. One important note about 10X probes, they are **very** fragile. To minimize circuit loading it is necessary to make the center conductor of the coax as small as possible, typically smaller than human hair. Treat them

gently. Sharp bends or the slightest stretching can ruin a 10X probe. When using a 10X probe you should read the cursor marked $\times 10$. The units are in volts per division, where one division is one box high on the oscilloscope face. An actual oscilloscope is somewhat more complicated than described above. However, the operation is nevertheless similar to that described above when only the basic operation is employed. The other time base is used for more advanced measurements and its use will be described in future courses. You should spend some time with your oscilloscope learning how to operate it, especially studying the use of the trigger controls to get the display you want. Test your knowledge of the scope by using it to look at the output of the function generator described in the next section.

Although the general capability of the digitizing oscilloscopes is similar to that of the analog oscilloscope described above, there are some important differences in how they work. However, it is not necessary to understand all of these differences before you are able to use either type of oscilloscope. To get a display on these oscilloscopes, connect a cable to the input labeled "CH 1," then push the button labeled "CH 1" above the input. The operating conditions for this channel will appear at the bottom of the screen. Push the "probe" button on the far right and toggle the display until "1" is highlighted. This means the ratio between the displayed voltage and the voltage applied is one. Next, set the vertical scale to 5 V/div by turning the left-most knob above the input. The scale is indicated near the upper right of the screen. Finally, set the time scale on the horizontal to 5 ms/div. The time-scale knob is further to the right of the vertical scale knob, and the time scale is also shown on the screen. With the cable connected to the function generator, push the disable button on the bottom left of the function generator to set its output to zero. Adjust the vertical position of the horizontal trace on the oscilloscope to the center of the screen using the knob just above the input. Push the disable button once again before applying a signal from the function generator.

Another instrument you have in the lab is a **function generator**. The function generator can be used to generate a DC signal, various time waveforms (a square wave, a sine wave, or a triangle wave), or both. The output has a variable amplitude setting and a variable frequency setting. A good way to learn about function generators and oscilloscopes is to use them together. Those of you using the Tektronix oscilloscopes will be using HP8111A pulse/function generators, while those using the HP digitizing oscilloscopes will be using HP8116A pulse/function generators.

Digitizing Oscilloscope

Pulse/Function Generator

The HP 8111A is a combined pulse/function generator which is designed for easy use. For normal operation, set the mode selection to normal, (press the top left button to cycle through the modes). In general, you should release (have them popped out) all six push-button near the output connections on the lower right hand side of the panel. The duty/width control should be pushed in. The settings of the function generator that you will normally adjust are frequency, amplitude, and the DC offset voltage. To set any of these, push the button over the appropriate control knob. Fine adjustments are made by adjusting the knob. For frequency, the range (power of 10) is selected with the range switch (a rocker switch to the right of the display panel). Coarse amplitude and offset are selected by the attenuation switches above the output. In general you will want these attenuators set to 0dB (released). -20dB attenuation means 1/10 and -40dB means 1/100. The value of the parameter being set is displayed on the digital display. The appropriate waveform (sine, triangle, square wave) is chosen with the function buttons (lower left hand side). **Do not** trust the voltage reading on the panel meter of the function generator - trust neither amplitude nor offset. Check it with the oscilloscope. Internally the function generator looks like an ideal voltage source, but it has a 50 Ω resistor in series with its output. The panel readings make the assumption that there is also a 50 Ω resistor as a load across the output of the function generator. Therefore the **voltage readings of the function generator will be almost 1/2 of the actual voltage** when it is driving a load impedance that is much greater than 50 Ω . In 18-100, you should always have a high impedance load, so your meter reading should always be about 1/2 of the actual voltage. However, it is a good habit to always verify the amplitude with the scope and the DC offset with the scope or with the DMM. Note: for all parameters except amplitude and offset the digital display gives an accurate indication of the actual output. The pulse generator mode is selected using the right most function button (directly over the toggle switch). The parameters to be set are frequency, width, amplitude, and offset. Illegal combinations of frequency and width will result in a flashing error signal. Do not confuse the output of the function generator with the trigger output. You should **always use the BNC connector at the lower right** of the front panel.

In this lab you will need to use the function generator to generate a DC voltage. To do this you need to make the following settings on your function generator.

For the HP8111A:

- Trigger = EXT (this is what keeps it from generating the selected waveform also)

- Function = Sinewave
- Amplitude Button pressed in (-20dB)
- Offset Button released
- Attenuation Button released
- Amplitude knob turned fully counter-clockwise (minimum amplitude)

Measure the DC output voltage with your meter and turn the "DC Offset" knob to vary it. **DO NOT** trust the offset voltage on the meter built into the function generator. Always use your DMM to measure the voltage when using the function generator as a DC source.

For the HP8116A:

- Mode: normal
- Function: All functions off
- Amplitude: 100 mV
- Offset: vary 0-5 V with rocker switches at upper right



Laboratory Exercises

1. Connect the output of your function generator to the input of channel 1 of the oscilloscope. Set up your function generator to generate a 5V peak-to-peak amplitude, 0V offset sinewave with a frequency of 2KHz. Remember to make sure that the function generator's mode control is set to "normal". Set the oscilloscope to 2V/division vertically, and 0.1ms/division on the time base. You should see about 2 cycles of a sinewave. You should have channel 1 set to DC. The trigger selection should be set to CH1, and INTERNAL. The trigger mode switch should be set to AUTO. Experiment with adjusting the trigger level in order to get a stable trace on the screen. Observe the change in the phase of the sinewave at the left edge of the display as you change the slope and level controls of the trigger. Vary the amplitude slowly on the function generator and watch how the screen changes. Also, vary the frequency slowly and see the screen change. Keeping the function generator

at a constant setting, vary the sweep rate (ms/div) of the oscilloscope, and the vertical gain (V/div). Watch how the screen changes as the scales change. Make sure you have a good feel for what you are doing before you move on. Ask the TA if you need some help.

2. Set up the function generator to generate a DC offset as described above. A DC signal should appear as a horizontal line on your oscilloscope. Remember that the output of the function generator may not correspond to its setting so USE YOUR OSCILLOSCOPE to measure the voltage. Use your scope to verify that the function generator's output is indeed independent of time. Adjust the function generator's output voltage.
3. Next, build the Motor circuit on the protoboard as shown in Fig. 6.1. Tr5 is a 2SC1815 and Tr6 is a 2SC2120 (pinout is shown in Fig. 6.5 and Fig. 6.6). If you mix these up, your motors will not run as well.
4. Before attaching one of the motors, measure its resistance using the DMM. Then, attach the leads from one of your motors as shown in Fig. 6.1.
5. Set the +6 volt section of the power supply to +3V and connect it to the motor. Set the +20 volt section of the power supply to +5V and connect it to R21. Connect the common of the power supply to the ground of your circuit (R18 and the emitter of Tr6). Use the function generator as described above to generate a DC input voltage. Adjust the function generator's output voltage using the DC offset knob. Vary the input voltage slowly between 0 and 5V. At what point does the motor begin to run.
6. Mount the motor driver circuit on the robot PC board, leaving the input lead of R28 free. Also attach the motor to the motor drive pins on the Robot PC board - see the Graymark Robot Instruction booklet. Set the +20V part of your power supply to +9V and attach it to the +9V pin next to R9 of the robot PC board. Attach the power supply common to the common pin of the robot PC board. Check that the output of your voltage regulator is still +5V. Adjust the +6V part of your power supply to +3V and attach it to the +3V pin on the robot PC board. Connect the function generator ground to robot PC board ground, and the signal lead of the function generator to the free end of R28. By setting the

DC offset of the function generator to 0V or +5V, turn the motor on and off. If there are any problems, identify them, fix them. If you have a problem ask your TA for help. When you are done, solder the free end of R28 into the robot PC Board.

7. Build the second motor circuit on the protoboard and verify that it works correctly. Then mount the second motor circuit on the robot PC board and verify that it still works.

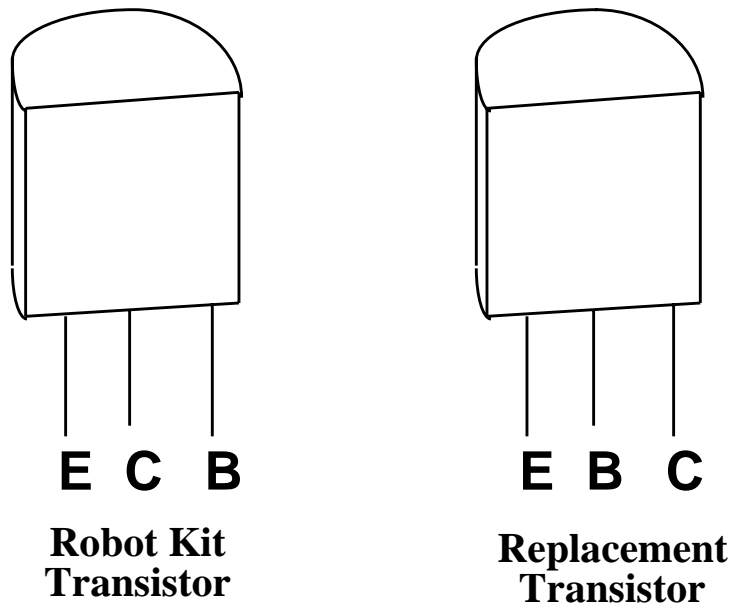


Figure 6.5 The physical appearance of the Bipolar transistor.

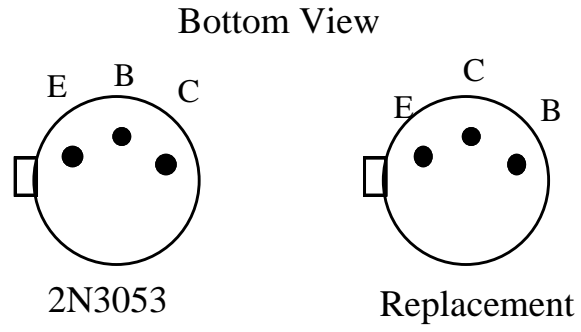


Figure 6.6 Pinout of Replacement Power Transistors.