Experiment 9 : Pulse Width Modulation

Name/NetID:

Teammate/NetID:

Section AB/BB:

0 1 2 3 4 5 6 7

8 9 A B C D E F

(circle one)

Laboratory Outline

In experiment 5 we learned how to control the speed of a DC motor using a variable resistor. This week, we will learn an alternative method of driving the motor that requires the use of the transistor we learned about last week. Rather than adjust a constant voltage to the motors, we will change the voltage applied to the motors using *pulse width modulation* (PWM). This method has some significant advantages over the constant voltage method.

Learning Objectives

- Use a PWM signal to drive the motor for IV characterization.
- Recognize the ability of PWM-based motor-drive circuits to be both power efficient as well as stall-avoiding.
- Build a flex-sensor-controlled PWM signal that can be used for motor-drive in the next lab.

Analysis of Motor Efficiency

Using the motor drive that we constructed earlier, we will implement a new method of motor speed control and compare it to DC methods. There are many parameters that can be used for this comparison and we will learn how to decide which parameters are relevant to us and which are not.

Methods of Generating PWM Signals

We will generate PWM signals using a new circuit. In the past, you used a simple oscillator circuit and a function generator. Neither of these methods provided a convenient way to control duty cycle if this were to be inserted into an autonomous vehicle. Today, we revisit the oscillator circuit and use the magic of diodes to alter its function in a way that we can understand. In the end, the bend of a flex sensor will become the controller of the PWM's duty cycle and enable the PWM generator to be used without the experimenter adjusting a knob!

Notes:

Driving Motors with PWM

Analyzing a PWM Signal

A problem encountered with the previous techniques of speed control is strongly related to the stall current of the motor. A lower DC voltage will eventually stall the motor, drawing a large current that drains the battery while failing to turn the motor. Pulse-Width Modulation (PWM) is a method by where the peak voltage is high enough to overcome the stall point on the IV curve and, theoretically, no current will be drawn from the battery when the voltage falls back to zero. Less energy is wasted in the speed-control mechanism. By controlling the Duty Cycle of a square-wave signal rather than the level of a DC voltage, the wheel should move continuously at a slow speed without stalling.

- ✓ Configure the function generator to produce a $0 - 5\ V$ square-wave signal with a frequency of $5\ kHz$.
- ✓ Don’t forget this will require a 2.5-V offset.
- ✓ Set a duty cycle of 80%.
- ✓ Set the function generator to High-Z (Press: Shift-Enter, >>>> [D: SYS MENU], ˅˅ [50 OHM], > [HIGH Z], Enter).
- ✓ Configure the oscilloscope to measure the frequency and duty cycle produced by the function generator.

Question 1: Use the oscilloscope’s Meas button to measure the (DC) ***rms*** voltage.

$V_{rms} =$ (experimental)

Question 2: Use the cursors on the oscilloscope to measure T_{on} and T_{period} of your square wave and compute the duty cycle. Record your data and computations here.

Notes:

Question 3: Mathematically compute the **rms** voltage and determine if the scope measurement agrees.

$$V_{rms} = \sqrt{\frac{\int_0^T v^2(t)dt}{\int_0^T dt}} = \qquad \text{(theoretical)}$$

(*Remember that you don't need calculus to compute this!*)

Question 4: Compute the %error of the **two** previous average voltage measurements using a theoretical value of a perfect 80% duty cycle signal as the theoretical reference below.

$$\%\, error = 100 * \frac{|experimental - theoretical|}{|theoretical|} =$$

Driving a Motor

The function generator cannot supply the higher current needed to drive the motor. Instead, we will employ the transistor circuit we studied earlier. If you haven't already, construct the motor drive circuit as shown and connect the function generator as the input.

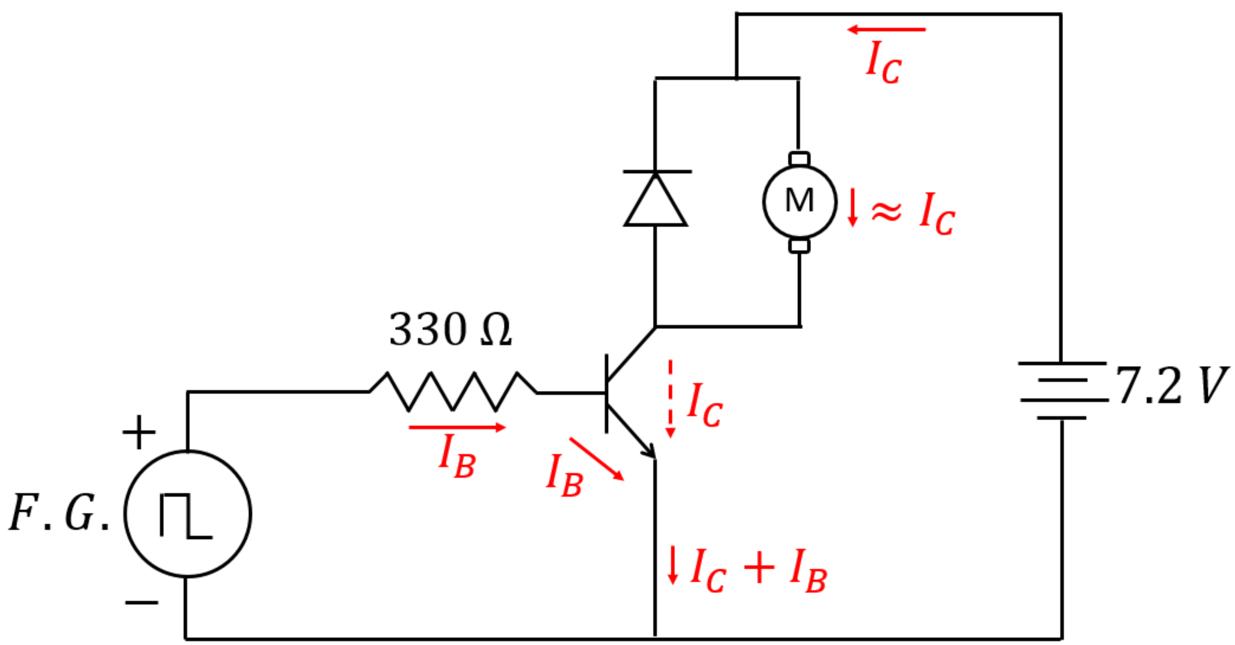
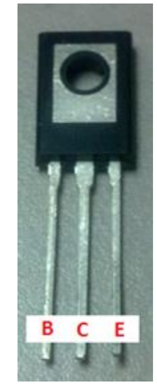


***Figure 1**: Circuit schematic of the motor drive circuit.*

Question 5: Use your oscilloscope to measure the voltage across the motor. Comment on what you see. Why do you think this signal might ***not*** look like a perfect square wave?

Notes:



Warning! The oscilloscope's "black" probe is connected to earth ground. Most of the Function generators in our lab are not connected to earth ground, but some may be. To avoid a possible short between the lower end of the motor and the – terminal of the function generator, you may need to use two probes on the oscilloscope. Place Ch1 across the battery and Ch2 across the Emitter/Collector terminals. You can then use a Math Function to view the difference between the two probes. The difference will be the voltage across the motor!

Notes:

Question 6: Use your oscilloscope to measure the average voltage across the motor when driven by the full range of duty cycles (starting from 20% to 80% in appropriately-sized steps). Be sure to use increasing V_{rms} to find the duty cycle necessary for turn-on if you can.

Duty Cycle (%)	V_{rms} (V)	$I_{rms}(mA)$*	Comments

*Table 1: I-V curve for motor with PWM signal while **Increasing Duty Cycle.***

**While V_{rms} will be measured by the scope, I_{rms} should be estimated using the motor IV data you collected last week as a lookup table.*

Notes:

Question 7: Decrease the duty cycle to find the stalling point if you can. Report the stalling duty cycle here.

Generating PWM with a Circuit

In previous experiments, we constructed an oscillator circuit using a resistor, capacitor and inverter as shown below. In this circuit, the frequency of oscillation is controlled by the time it takes for the capacitor to charge and discharge. Since the capacitor charges and discharges through the same resistor, the amount of time the oscillator spends at 5 V equals the amount of time it spends at 0 V, i.e. it has a 50% duty cycle. (Refer to Lab 6.)

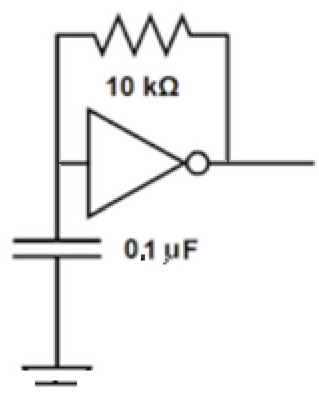


***Figure 2**: A simple oscillator circuit.*

Now let's make a couple of simple modifications to oscillator that allows us to control the duty cycle. Specifically, we'll modify the circuit so that the capacitor charges through one resistor and discharges through another. In addition, we've added an extra inverter at the output of the circuit so that we can integrate this oscillator into other circuits without its behavior being affected. Construct the modified oscillator circuit shown below. ($C = 0.1\ \mu F$, $R_1 = 10\ k\Omega$, $R_2 = 22\ k\Omega$)

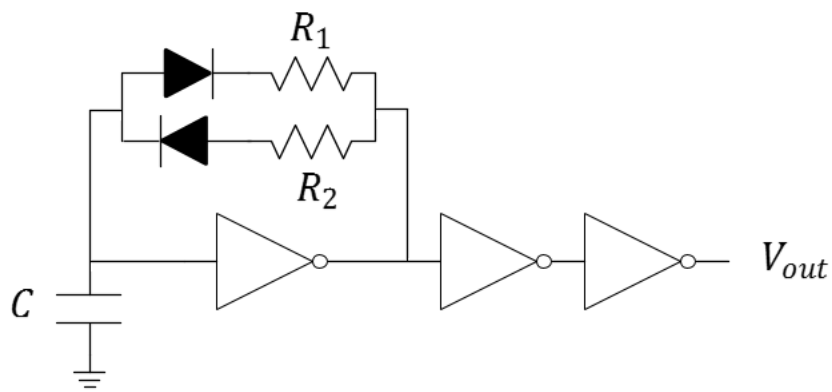


***Figure 3**: Circuit schematic of an oscillator with a selectable duty cycle. The two extra inverters serve to "buffer" the oscillator from the motor-drive circuit.*

Question 8: Measure the frequency and duty cycle of this oscillator.

Question 9: Apply the following formula to estimate the duty cycle of this oscillator.

$$DC = \frac{R_2}{R_1+R_2} =$$

Question 10: Suppose we replace R_1 with the flex sensor. What range of duty cycles do you expect this new circuit to produce? (You'll need to measure/recall the minimum and maximum resistance of the flex sensor.)

Notes:

Notes:

Question 11: Replace R_1 with the flex sensor and record the minimum and maximum duty cycle.

Putting it together

Connect your flex-sensor-controlled PWM circuit to the input of your motor drive circuit. If necessary, adjust the value of R_2 so that the motor slows as much as possible without stalling.

Question 12: Draw the circuit diagram for the full circuit (oscillator and motor-drive circuits combined) and include the values of any and all resistors.

Notes:

Conclusion

Question 13: Compare and contrast two methods of motor-speed control, PWM vs VDR.

Armed with what you've learned in lab all semester, you are just about ready to start building engineering designs. Next week, we'll use everything we've been learning to build an autonomous car.

What You Learned

After today's lab, you will be ready to embark on your own design challenges. Think about this for just a moment. You know how to collect data. You know how to use resistive sensors. You know how to read datasheets. After today, you'll know how to efficiently control motors to drive wheels. Next week, you'll compile all this knowledge to build your autonomous vehicle.

Explore More!

As time permits, please continue your experimentation using the Modules as recommended by your TAs. Recommended modules include ***Explore More!*** **Voltage Follower Buffer** and ***Explore More!*** **Voltage Comparator** and ***Explore More!*** **The Amplifier: Gain and Offset Control**.

Notes:

Lab Report Rubric

The following rubric will be provided at the end of each lab procedure. As a final step in preparing your lab report, you will use this rubric to analyze your own performance.

Section	**Criterion**	**Comments:**
Experimental Setup and/or Design Description	Circuit Schematics are drawn neatly, accurately, and properly labeled. Decisions regarding experimental setup and design are clearly explained.	
Measurements	Tables include units and proper precision. Any *new device* introduced should be characterized using measurements!	
Computations	Computations performed on raw data are *explicitly* described and follow rules for significant figures.	
Analysis	Graphs have title, labels, units, scale, legend; Lines for curve-fitting appear in the graph when needed and parameters like the intercepts and the slope are labeled.	
Modeling	A mathematical model for the curve-fit graph allows for more abstract references to the device's behavior. The expected behavior is explained in the context of the graph.	
Conclusion	Conclusions are drawn from your experimental results to support the reason(s) for completing the experiment. Closes the loop on the Introduction.	
General Formatting	Answers to questions clearly labeled. The overall appearance of the report is professional.	
Self-assessment	This table has been thoughtfully completed.	