

**EE3 INTRODUCTION TO ELECTRICAL ENGINEERING**

# **LABORATORY MANUAL**



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### *Acknowledgements*

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Previous students of EE3 gave us many suggestions that we have attempted to include in the re-design of this important “Introduction to Electrical Engineering.”

Finally, I thank the Elenco Corporation for the generous use of their copyrighted materials.

-Prof Oscar Stafsudd, 2012

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-Dr. Michael Briggs, 2015

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-Dr. Michael Briggs, 2019

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-Dr. Michael Briggs, 2020

## Week 4: RSLK Setup and Introduction

### Week 4 Prelab

1. **Introduction:** This lab introduces you to the RSLK, the Texas Instruments Robot System Learning Kit. You will be looking it over and performing some simple but revealing tasks to familiarize you to the system and give you a head start on the project.

#### 2. Arduino Installation:

You will use a software product called Arduino. Arduino development environment works with the TI MSP432 microcontroller. The MSP432 LaunchPad is a development kit including the MSP432. It is mounted to the RSLK that you will be using for the project. Download and install the required Arduino IDE software before the lab. You will be submitting to Bruin Learn the proof of your installation. The latest software version of Arduino can be found online at:

<https://www.arduino.cc/en/software> (Scroll down to Legacy 1.8.19)

**FOR WINDOWS USERS:** You will probably need to install a [driver \(64-bit\) from this site](#).

Also, you may experience one of two symptoms that result from the same problem:

- None of your com ports resolves an error at compile/build time. When you go to Device Manager, the XDS110 device is not shown, or is shown with a yellow triangle “caution” icon covering it.
- An error message when building your code that includes the term “XDS110”.

The XDS110 is the JTAG Emulator and is an essential part of the LaunchPad board. The fix is to use Google to find “XDS110 CMSIS-DAP” (without the quotes). There may be several hits from this search. Be sure to use the Texas Instruments site (software-dl.ti.com).

**FOR MAC USERS:** You may see an error during the build that says it cannot find Python 2.7. The newest version of Python is incompatible with our system. You will need to uninstall your version of Python and install [version 2.7.18 macOS 64-bit installer](#). URL: <https://www.python.org/downloads/release/python-2718/>

**FOR WINDOWS, LINUX, AND MAC USERS:** DO NOT USE Arduino 2.0. It has not been validated for use with the following LaunchPad driver package. Use instead Arduino version 1.8.19.

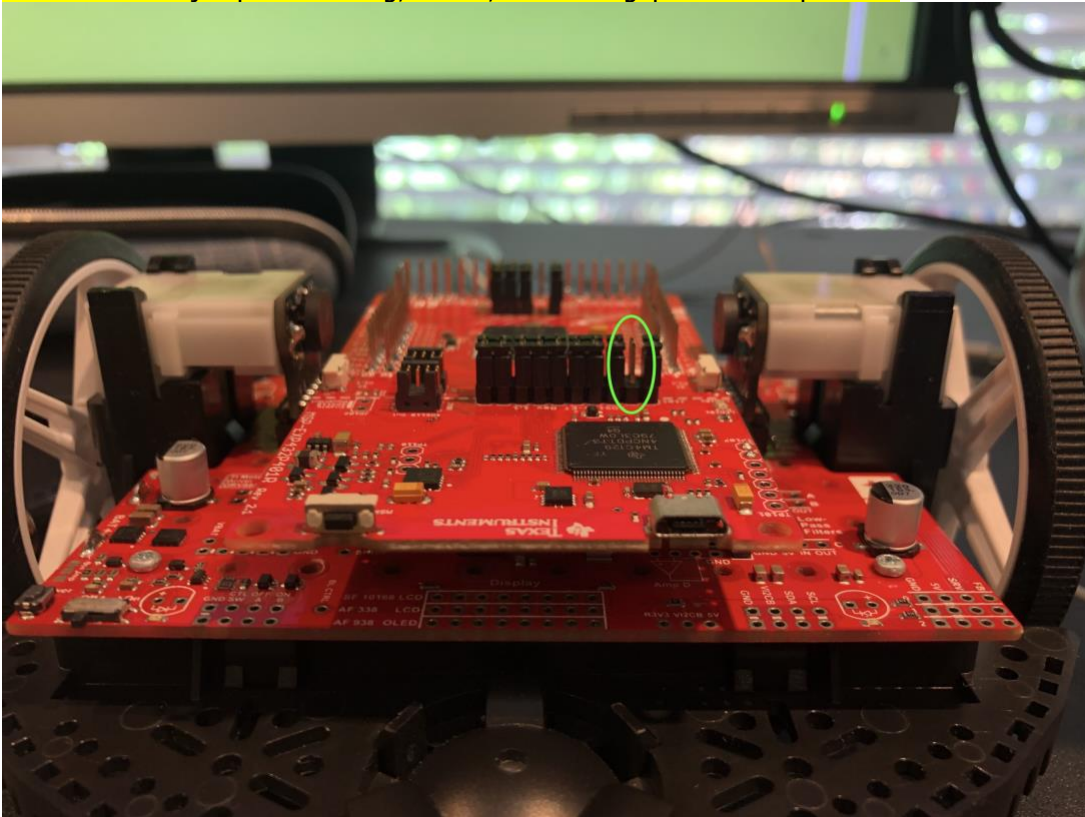
You will need to update the drivers to include the MSP432 LaunchPad. This update will take about **15 minutes**. **Do this before coming to lab!** Here is how to do that: (reference: <https://www.hackster.io/measley2/robotics-system-workshop-arduino-programming-on-ti-rslk-max-d33faa>). Scroll down to “Lab 0 – Prework” and follow steps 2-4, repeated below:

- (1) Add the URL [http://s3.amazonaws.com/energiaUS/packages/package\\_energia\\_index.json](http://s3.amazonaws.com/energiaUS/packages/package_energia_index.json) to your File > Preferences > Additional Board Manager URLs. Also check the box for show line numbers if you like that and adjust your font size if you would like it bigger.
  - (2) Go to Tools > Boards > Boards Manager and scroll to the bottom of the list with Energia MSP432 and install 5.29.1. Note: this step takes a few minutes, leave time for the install between 10-20 minutes.
  - (3) After the install completes, you need to select the board and COM port in Arduino IDE. Go to Tool > Boards and now you should see the "Energia MSP432 Red Boards" > "Red LaunchPad MSP432P401R EMT" and make sure this is selected.
3. Take a screen shot of your installation and submit it to the proper Pre-Lab slot on your section assignment in Bruin Learn.
4. In lab section this week, you will use the Arduino IDE to upload your first sketches (i.e., programs) to the RSLK. Read through them to get an idea of what you'll be doing.

## **End of Week 4 Prelab**

#### Week 4 Section – First Project Day Instructions

1. Start with no batteries in RSLK.
2. Launch Arduino.
3. Tools | Board | Boards Manager, scroll down to Energia MSP432 EMT RED boards. Check version #; should be 5.29.1 and have "INSTALLED" next to the version number.
4. insert USB cable, check for green LED.
5. Remove USB cable.
6. Push the slide switch on the rear edge of the Chassis Board to OFF. It will stay in that position for the remainder of the course.
7. (VERY IMPORTANT: **YOU WILL \*KILL YOUR CAR\* IF THE FOLLOWING JUMPER IS \*NOT\* REMOVED!**) Be sure the 5 V jumper is missing; that is, there is a gap at the 5 V position.



The gap may be shrouded under a piece of tape. Check to be sure that a gap exists at the 5 V position. If there is no tape, ask your TA to help you find the 5 V position.

8. Insert batteries.
9. Push the POWER pushbutton switch. Both the green and a blue LED should light up.
10. Push the POWER pushbutton switch again. Both LEDs should turn off.
11. insert USB cable.
12. In the Arduino IDE, go to File | Examples | 01.Basics | Blink
13. Click on right-facing arrow in upper left corner of window.
14. Blinky should compile and load successfully, red LED should start blinking.
15. In lines containing the `delay()` function, change the numbers in the arguments. NOTE: if Blink does not compile and shows an error message stating that `LED_BUILTIN` is not recognized, consult the [LaunchPad with MSP432P401R Pin Map](#) (scroll down in web page). Look for the "RED LED" entry in the table close to the lower left corner of the circuit board picture. Replace `LED_BUILTIN` with the corresponding pin number.

16. Click on right-facing arrow in upper left corner of window.
17. The red LED should blink at a different rate.
18. Make sure the Off-On slide switch in the lower left corner of the Chassis Board is in the "Off" position.
19. Push the Power **pushbutton switch** in the lower left corner of the Chassis Board. Check for both blue and green LEDs.
20. Download Basic Code .ino file from Bruin Learn, Week 4. (Can be opened with Notepad or TextEdit) Store in some appropriate place.
21. In Arduino IDE, File | New; Delete existing code; Paste Basic Code into the sketch.
22. Pick up the RSLK so the wheels are **off the tabletop**. Click on the right-pointing arrow. After compile and download, one wheel should turn, one yellow LED on right front of Chassis Board should flash.
23. Power down the Chassis Board by pushing the Power button again.
24. Download the MSP432 Pin CHART on Bruin Learn, Week 4.
25. Note the pin numbers for direction, non-sleep (nslp), and PWM (in the blue rectangles; ALSO NOTE there are two pin numbers for nslp, one each for right and left wheel).
26. Modify the Basic Code to make the RSLK do a doughnut (spin like a top). **To do this, the wheels must spin in opposite directions.**
27. Download ECE3.zip from Bruin Learn, Week 4. Do NOT unzip the zip file.
28. Arduino IDE | Sketch | Include Library | Add .ZIP Library ... navigate to ECE3.zip and select.
29. Sketch | Include Library; ECE3 Library should appear on pulldown list
30. Navigate to (on the MAC and Windows)  
~/Documents/Arduino/libraries/ECE3/examples/IR\_Sensor\_Example; double-click IR\_Sensor\_Example.ino. This opens IR\_Sensor\_Example in the Arduino IDE.
31. Navigate to (on the MAC and Windows) ~/Documents/Arduino/libraries/ECE3/src/ECE3.cpp. (For Windows, the ECE3 software is stored in Documents | Arduino | Libraries.) Open ECE3.cpp with a text editor.
32. After `QTRSensors IR` (**IF NOT ALREADY 13 & 12**), paste  
`#define P5_0 13`  
`#define P5_2 12`
33. Save
34. Power up the Chassis Board.
35. Compile and download to the RSLK.
36. Tools | Serial Monitor should show 8 columns of numbers from ~500 to ~2000, depending on amount of reflection from surface. **If you place the car on a white sheet of paper, all 8 columns should be in the 500-800 range. If you pick up the car and hold it over the floor at desktop height, all 8 columns should read ~2500.**

## RSLK Inspection

You will be led on a walk-around of the RSLK in order to familiarize you with its components and their locations. The components and procedures to be covered in this section are:

- The MSP432 LaunchPad
- Wheels and motors
- Speed sensors
- Path sensors
- Battery compartment and battery insertion
- Four programmable LEDs
- Power on and off procedure
- Connecting to your laptop

## Introduction to Energia

Energia is an Arduino-like development environment that enables one to create control and monitoring programs and download them to the LaunchPad. You will first execute the “Hello World” for a real time embedded microcontroller: blinking an LED. Then you will learn about:

- The Pin Chart
- The motor control commands
- The path sensing commands
- Serial print and plot

### The Pin Chart

Below is the pin chart for the MSP432 microcontroller. When you wish to control a pin, or read the value of a pin, in your Energia code, use the pin numbers in the “Energia pin #” columns.

- Motor control pins:
  - Pins 29 & 30 control the rotation directions.
  - Pins 39 & 40 control the motor speeds.
  - Pins 11 & 31 turn the motors on and off (nSLP stands for “not Sleep”).
- Chassis Board LED Control Pins (41, 51, 57, 58)
- Chassis Board Bump Switch Pins (6, 8, 24, 25, 27, 28)

Main headers J1-J4:													
		Energia pin #	J1 1	J3 21	Energia pin #			Energia pin #	J4 40	J2 20	Energia pin #		
CC2650/CC3100	1	3.3V	5V	21	CC2650/CC3100	PWML, Left Motor PWM	40	P2.7	GND	20	CC2650/CC3100		
CC2650	2	P6.0	GND	22	CC2650/CC3100	PWML, Right Motor PWM	39	P2.6	P2.5	19	CC2650/CC3100		
CC2650/CC3100	3	P3.2	P6.1	23	Center IR Distance / OPT3101	PWM Arm Height Servo	38	P2.4	P3.0	18	CC3100, SPI_CS, GPIO		
CC2650/CC3100	4	P4.3	P4.0	24	Bump 0 [3]	CC3100, UART1_CTS	37	P5.6	P5.7	17	available GPIO? / OPT3101 RST?		
nHIB	5	P4.1	P4.2	25	Bump 1 [3]	CC3100, UART1_RTS	36	P6.6	1RST	16	CC2650/CC3100		
Bump 2 [3]	6	P4.3	P4.4	26	TEsaScope input	CC2650	35	P6.7	P1.6	15	CC3100 SPI MOSI		
CC3100, SPI_CLK	7	P1.5	P4.5	27	Bump 3 [3]	CC3100, NWP_LOG_TX	34	P2.3	P1.7	14	CC3100 SPI MISO		
Bump 4 [3]	8	P4.6	P4.7	28	Bump 5 [3]	CC3100, WLAN_LOG_TX	33	P5.1	P5.0	13	ERB (3.3V) [1]		
UCB1SCL [4]	9	P6.5	P5.4	29	DIR_L	PWM Arm Tilt Servo	32	P3.5	P5.2	12	ELB (3.3V)[1]		
UCB1SDA [4]	10	P6.4	P5.5	30	DIR_R	nSPLP [2] / nSPLR [2]	31	P3.7	P3.6	11	PWM Gripper Servo		

Notes:

[1] This is encoder output. Sever VPU=VREG jumper and connect VPU to 3.3V

[2] This disables a motor driver. 0 to sleep/stop. Sever VCCMD=VREG jumper and connect VCCMD to 3.3V. Consider severing nSPLP=nSPLR jumper.

[3] Use Port 4 for edge-triggered interrupts

[4] Primary I2C channel supported by Energia

Bump 0 is right side of robot, Bump 5 is left side

CTRL on the motor board is a power switch. A high pulse (>1V) turns on the switch; a low pulse turns off the switch and power to the microcontroller. Leave this pin floating (an input) for normal operation.

Yellow highlights changes from previous pin assignments

Red highlights changes from version 4

Grey is changes from version 5

Orange needs to verify with Jan if routing possible to combine nSPLP to free up an additional PWM pin

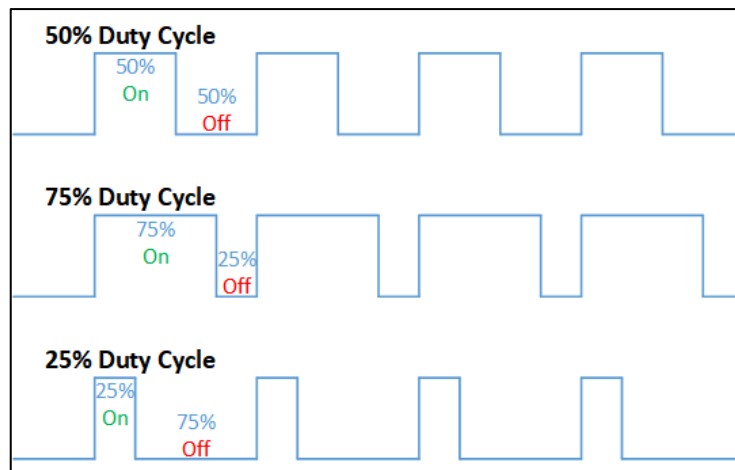
[illegible]



## PWM Based DC Motor Control

The RSLK uses a circuit called an H-bridge to control the direction of each of its two DC motors. View the **Lab 4 Appendix** for a detailed explanation. As said in that discussion, the H-Bridge can only dictate the direction the motor turns and whether it is on or off. To control the speed of a DC motor, the RSLK must also drive the H-bridge using a pulse-width modulated (PWM) signal.

A PWM signal has two states: high and low. The signal is also periodic, having the properties of period (measured in seconds) and duty cycle (a percentage from 0% to 100% inclusive). The duty cycle dictates for how much of a period the signal is high ((period \* duty cycle) seconds) while for the rest of the period, the signal will be set low ((period \* (1 - duty cycle)) seconds). Below we illustrate possible duty cycles:



[https://en.wikipedia.org/wiki/Pulse-width\\_modulation](https://en.wikipedia.org/wiki/Pulse-width_modulation)

PWM signals are useful in cases where the average value of signal matters more than the instantaneous value. This is because you can easily vary a PWM signal's average value by adjusting the duty cycle. For example, one application of PWM is a dimmable LED. With a short enough period, the eye cannot distinguish when a PWM signal is on or off so a person only perceives the average intensity of the light. Therefore, a short duty cycle makes the LED appear dim and a long duty cycle makes the LED appear bright.

### PWM – Duty Cycle

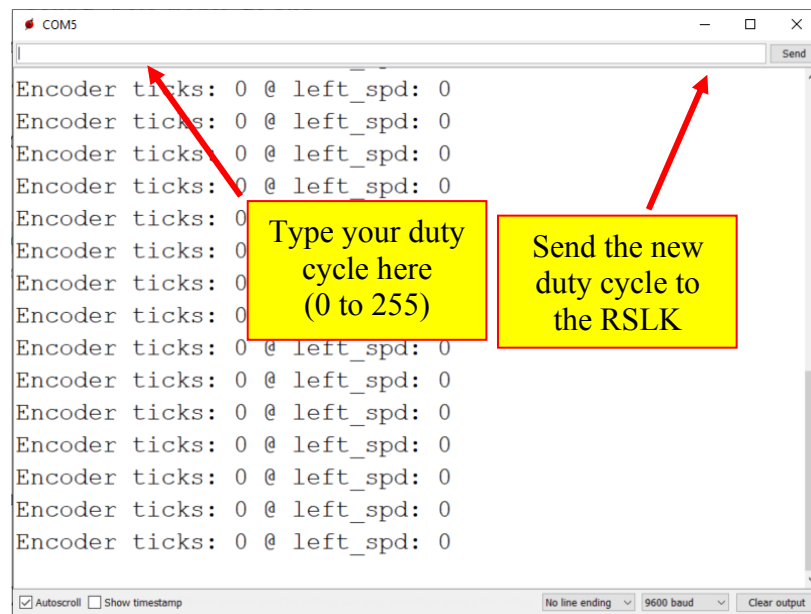
In this exercise, you will apply a PWM signal at varying duty cycles to the left DC motor. You will see how duty cycle changes the speed of the DC motor while also learning how to use the `analogWrite` function to create a PWM signal. You will be using this function in your own sketches.

The `analogWrite(pin, value)` function has two parameters: pin number (**pin**) and duty cycle (**value**). Use pin number to select the motor you would like to apply the PWM signal to (pins PWMR and PWML in

the chart above). Duty cycle accepts an integer from 0 to 255 where 0 implies a 0% duty cycle and 255 implies a 100% duty cycle.

Follow these steps to complete the exercise:

1. Download the sketch `pwm_dutycycle.ino` from BruinLearn. Launch Energia and open the sketch.
2. Read through the code to get an understanding of what it does. Ensure you understand how we used the encoder to calculate speed.
3. Hold the car in your hand or place it on a box so it does not move unexpectedly.
4. Plug in your car and open the **Serial Monitor** (in the top bar click Tools > Serial Monitor). **Set the Serial Monitor baud rate to 9600.**
5. Upload the sketch to your Launchpad. You should see “Encoder ticks: 0 @ left\_spd: 0” being printed out continuously on the Serial Monitor.
6. Turn on your car (press the push button labeled “Power”).
7. In the Serial Monitor, use the text box at the top to specify a duty cycle from 0 to 255 and click “Send”. This will update the `left_spd` variable, turning the left DC motor. Use the following image:



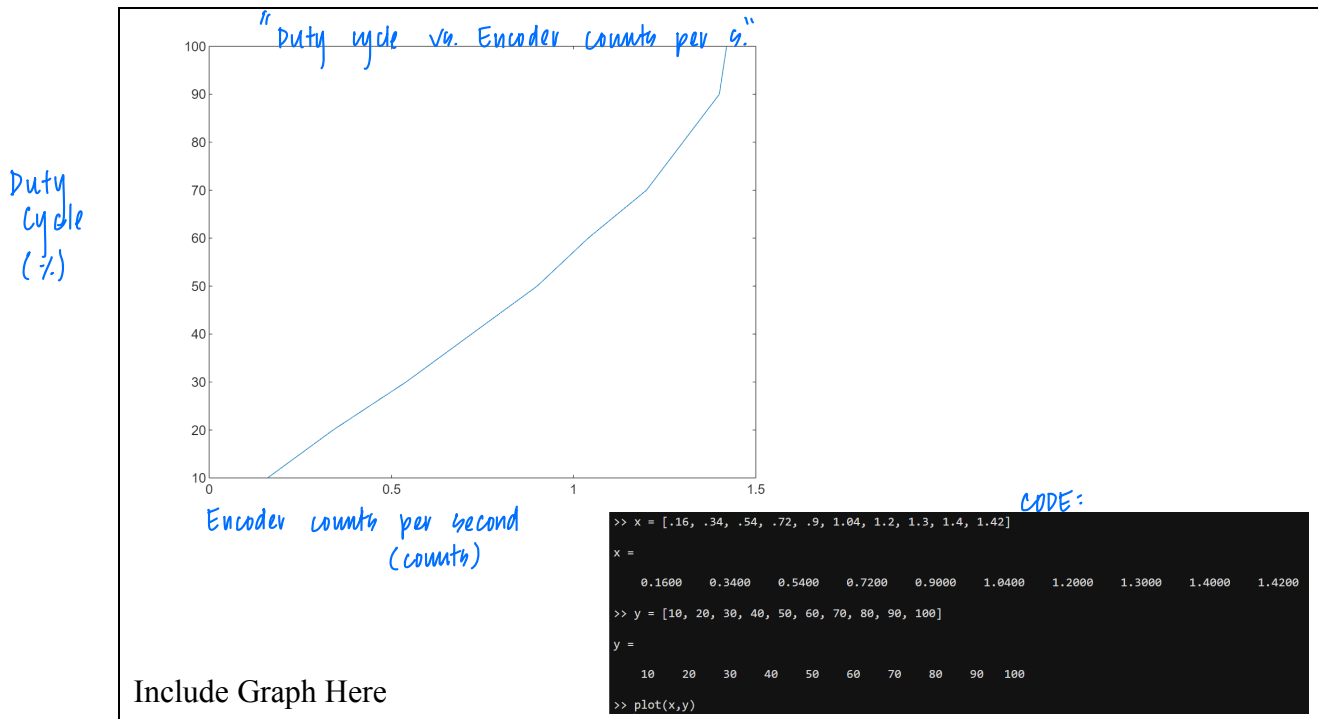
Serial Monitor Window  
(Note: your COM port may be different)

8. For each duty cycle listed below, calculate the correct **value** argument for the `analogWrite(pin, value)` function and apply the PWM signal to the left DC motor. Record the encoder counts per bin for each duty cycle:

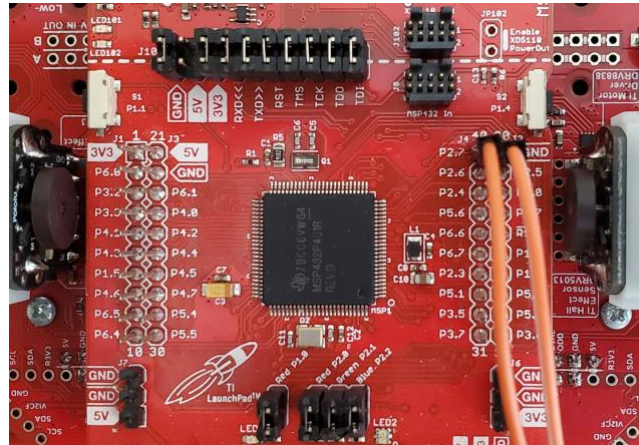
# WORK SHEET HERE:

Duty Cycle %	analogWrite value (0 to 255)	Encoder Counts Per Bin	Bin Length: <u>0.0</u> s (from code)
10	<u>26</u>	<u>9</u>	→ <u>.16</u>
20	<u>51</u>	<u>17</u>	→ <u>.34</u>
30	<u>77</u>	<u>27</u>	→ <u>.54</u>
40	<u>102</u>	<u>36</u>	→ <u>.72</u>
50	<u>128</u>	<u>45</u>	→ <u>.9</u>
60	<u>153</u>	<u>52</u>	→ <u>1.04</u>
70	<u>179</u>	<u>60</u>	→ <u>1.2</u>
80	<u>204</u>	<u>69</u>	→ <u>1.3</u>
90	<u>230</u>	<u>78</u>	→ <u>1.4</u>
100	<u>255</u>	<u>87</u>	→ <u>1.42</u>

Plot your data in your favorite plotting app with Duty Cycle on the y-axis and Encoder Counts **per Second** on the x-axis:

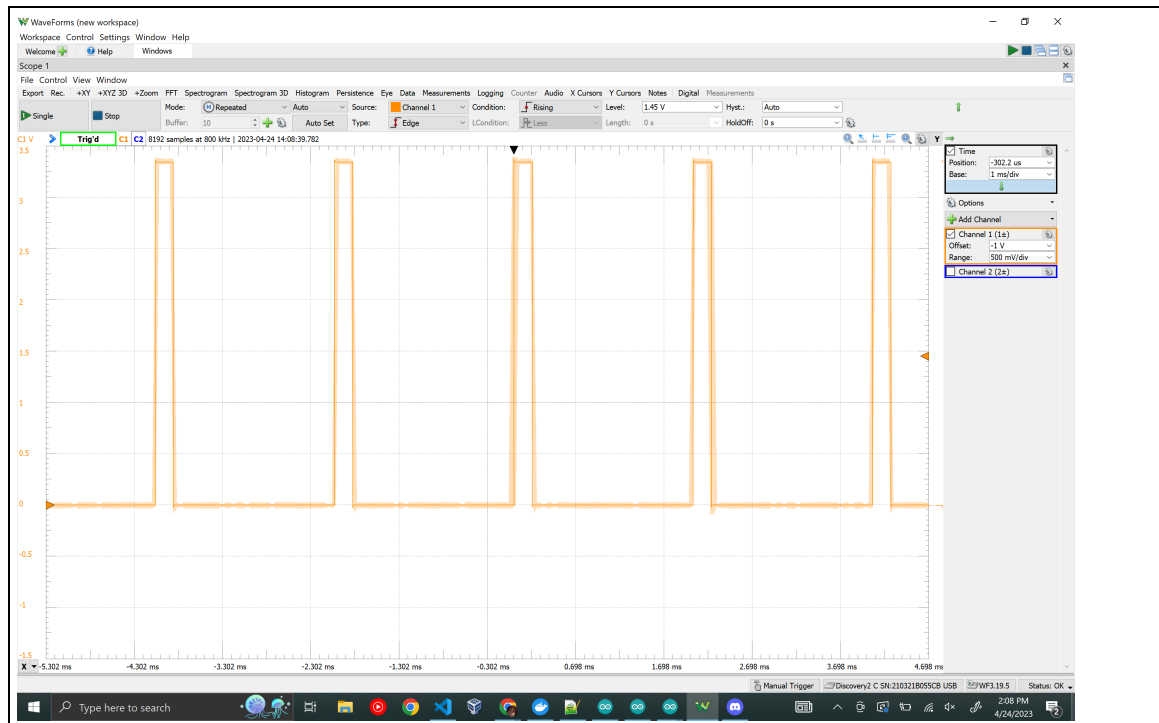


9. Using the skills you've built from previous labs, we can probe the PWM signal the RSLK applies to the left DC motor. Using your AD2, connect Channel 1 to probe the pin PWML. To do this, using the chart above, you must attach 1+ to pin P2.7 and 1– to GND. Notice that you can attach the AD2 directly to the Launchpad (no breadboard necessary). Use the image below for guidance:



AD2 Channel 1 Connected to P2.7 and GND

With the left DC motor running (at a duty cycle of your choice (other than 0% and 100%)), use your AD2's Scope application to view the PWM waveform. Include a screenshot of the waveform here (you must set the time base and amplitude appropriately):



Answer the following questions to verify your oscilloscope view is correct:

Duty Cycle Setting: 10 % (20 left, upd)

Measured Signal On-Time (per period): 207.2 ns = .2072ms

Measured Signal Off-Time (per period): 1.990 ms

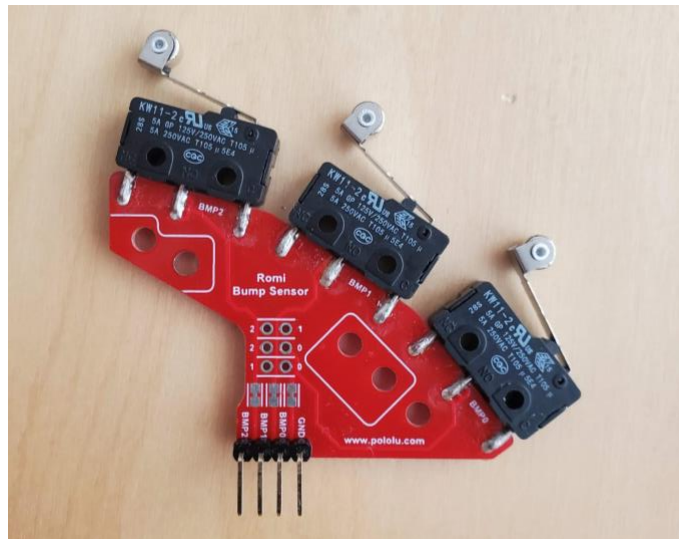
Measured Duty Cycle: 10.14 %

ratio it's  
on. →

### PWM - Period (OPTIONAL)

On the RSLK, we use PWM to vary the speed of the DC motors. In this section, we will demonstrate the role of **period** in a PWM signal when running a motor.

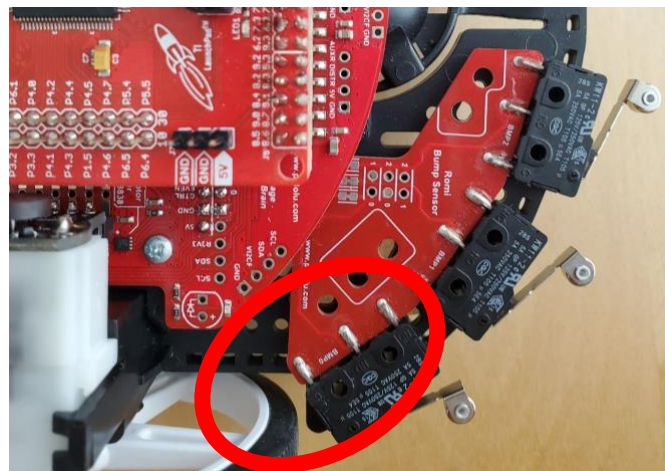
1. Download the sketch pwm\_period.ino from BruinLearn. Launch Energia and open the sketch.
2. Read through the code to get an understanding of what it does. Some of the techniques used here (such as using `micros()` rather than `delay()` for time delays) may become useful to you later on.
3. Make sure you have the bumper attachment connected to your car. Look at the following images to ensure this is done correctly:



Bumper Attachment



RSLK Front View (Bumper Installation Location Circled)



Complete Bumper Installation (Bumper 0 (BMP0) Circled)

4. Hold the car in your hand or place it on a box so it does not move unexpectedly.
5. Plug in your car and open the **Serial Plotter** (in the top bar click Tools > Serial Plotter). **Set the Serial Plotter baud rate to 19200.**
6. Upload the sketch to your Launchpad. You should see the Serial Plotter printing the PWM signal.
7. Turn on your car and you should now see a second curve tracing the left motor speed. The following image shows what you should see:



Serial Plotter Output After Turning the Car On  
(Note: your COM port may be different)

8. Press BMP0 to vary the period. You will hear a high frequency warbling sound from the motor for the smaller period. This is because the pulse rate is 10 pulses per second, and the motors can partially follow the pulses at that rate. Compare this pulse rate to then end of the previous exercise, where you measured the PWM pin pulse rate when using analogWrite.

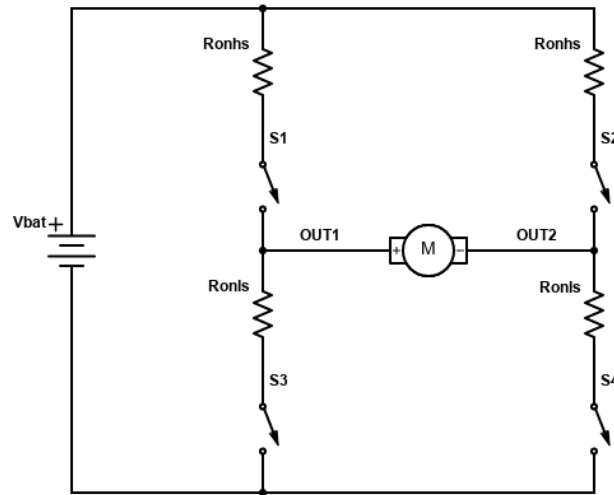
#### Questions:

1. If we look at this motor control scheme as a system, we'd say that the input is the PWM signal and the output (also called the response) is wheel speed. From this perspective, what kind of filter could you characterize this system as: low pass, high pass, band pass, or band stop? Explain you answer.

The pwm\_period.ino sketch seen here is only for demonstration. As said earlier, when you create your own sketches for the RSLK, you will use the analogWrite(pin, value) function to create a PWM signal.

## Lab 4 Appendix – H-Bridge Motor Control

The RSLK uses two DC motors to drive the left and right wheels. In order to control each DC motor, a basic circuit called the H-bridge is used. Below is a *simplified*<sup>11</sup> schematic of this circuit to help understand its working principles:



Simplified H-Bridge Schematic

In practice, H-bridge circuits use four MOSFETs (metal-oxide-semiconductor field-effect transistors) to control a DC motor. In this diagram, we use four SPST switches (S1, S2, S3, S4) in series with resistors (Ronhs, Ronls) in place of these transistors to show a simplified view of how these MOSFETs would behave in-circuit. Note that Ronhs and Ronls have very small values (on the RSLK,  $R_{onhs} + R_{onls} = 230\text{ m}\Omega$ ).

Terms:

- M – The DC motor.
- Ronhs – On-resistance of the high side MOSFETs.
- Ronls – On-resistance of the low side MOSFETs.

Operating Principle:

The purpose of the H-bridge is to give the ability to turn a DC motor in two directions rather than one. To do this, the circuit must be able to send current through the motor in two different directions. In

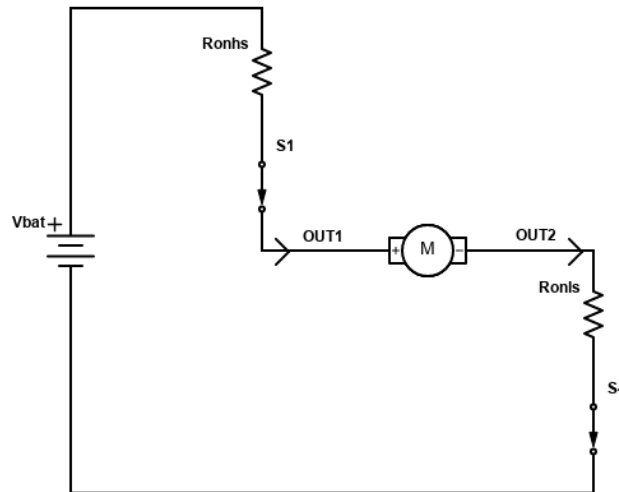
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<sup>11</sup> Among other things, this circuit is missing *essential* voltage spike protections.



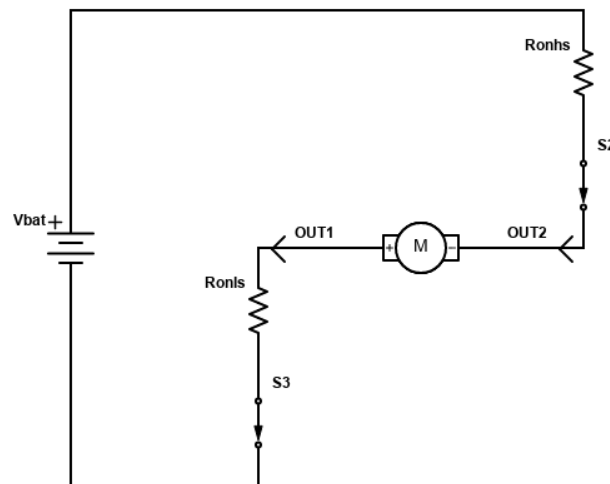
the schematic, this is done by individually pulling OUT1 and OUT2 either high (to Vbat) or low (to GND).

In this way, the circuit turns the motor forward by **closing switches S1 and S4** and **opening switches S2 and S3** to drive OUT1 high and OUT2 low:



Driving the DC Motor Forward

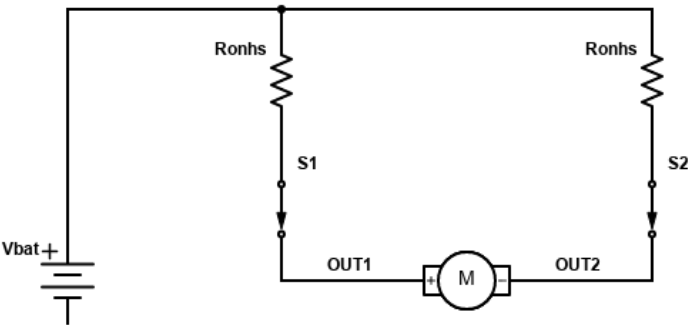
The circuit turns the motor backward by **opening switches S1 and S4** and **closing switches S2 and S3** to drive OUT1 low and OUT2 high:



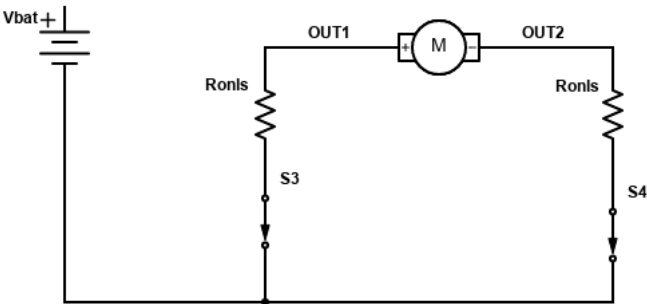
Driving the DC Motor Backward

Finally, an H-bridge can brake the DC motor by pulling OUT1 and OUT2 to the **same** potential. This can be realized in two ways. One is to **close switches S1 and S2** and **open switches S3 and S4** to drive

OUT1 and OUT2 high. The other is to **open switches S1 and S2** and **close switches S3 and S4** to drive OUT1 and OUT2 low:



Braking by Driving OUT1 and OUT2 High



Braking by Driving OUT1 and OUT2 Low

Driving the RSLK’s DC Motors:

On the RSLK, each DC motor has its own H-bridge housed in an IC (integrated circuits) on the Chassis Board. These ICs have additional logic that simplifies how you interface with the H-bridge to three 3.3 V input signals: nSLEEP, PH (phase), and EN (enable) (meaning you only indirectly control the MOSFETs corresponding to switches S1, S2, S3, and S4). The table<sup>12</sup> below shows how these input signals drive the outputs OUT1 and OUT2:

nSLEEP	PH	EN	OUT1	OUT2	Motor State
0	X	X	Z	Z	COASTING
1	X	0	LOW	LOW	BRAKING
1	1	1	LOW	HIGH	BACKWARD

<sup>12</sup> This table is from the H-bridge IC’s datasheet ([DRV8838](#))

1	0	1	HIGH	LOW	FORWARD
---	---	---	------	-----	---------

Terms:

- X – This signal state has no effect on the output (often called a “don’t care”)
- Z – The signal is disconnected from both Vbat and GND (aka high impedance)

This discussion boils down to the following. To run a motor in the forward direction you will drive its corresponding nSLEEP high, PH low, and EN high. To run a motor in the reverse direction, you will drive its corresponding nSLEEP high, PH high, and EN high. When referencing the chart at the beginning of Lab 4, the left motor IC’s pins are labeled:

Left Motor H-Bridge IC Input Name	Energia Pin Chart Name
nSLEEP	nSLPL
PH	DIR L
EN	PWML

***Week 4 Lab End***

