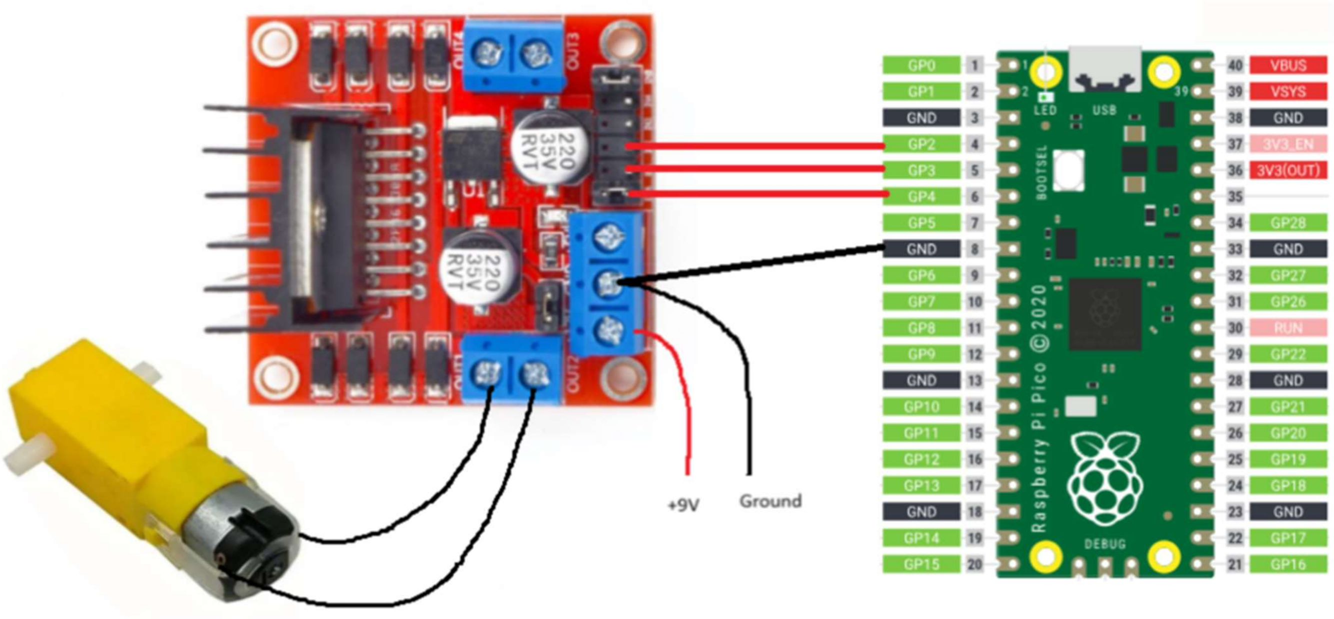
ME 3550 Mechatronic Components
Laboratory Experiments
Spring 2025

Dr. Robert L. Williams II
Mechanical Engineering, Ohio University

williar4@ohio.edu
people.ohio.edu/williams



Motor Control with Raspberry Pi Pico

These laboratory experiments were adapted from those designed by Dr. Jay Wilhelm, and subsequently modified by Kouree Chesser, ME OU.

ME 3550 Mechatronic Components
Laboratory Experiments
Table of Contents

Laboratory Experiment Reports Outline

Format

Lab reports are to be typed in 12 point Times New Roman font with 1.5 line spacing. Reports should include all of the sections below.

Objectives

The objectives section should be approximately one paragraph. This section should contain a thorough explanation of the benefits of performing the lab. Broad goals and steps to achieve expected outcomes should also be included.

Pre-Lab

Any preparation and/or deliverables outlined in each provided lab document should be included in this section. This section may include graphs, tables, diagrams, schematics and explanations, all in accordance with the provided lab documents.

Equipment and materials

Any equipment used should be recorded by type, make and model. A complete list of materials/parts should be included. Jumper wires/probes need not be included. An example list is given below.

- RIGOL DS1104 Digital Oscilloscope
- Agilent 33120A Waveform Generator
- IDL-800 Digital Lab Breadboard
- 1N4003 Diode
- 6.8uF, 68uF Capacitors

Methods

This section should include detailed descriptions of setup and steps performed to execute each experiment. The data measured and observed should not be located here, but rather in the results section. Setup diagrams and/or circuit diagrams should be included where applicable. Equipment settings should also be included in this section.

Results

The results section should include a detailed report of the data and observations collected for all experiments. Tables, graphs and figures should be used when applicable. This section is also the place to comment upon deviation between measured results and discuss possible sources of error. Finally, all questions prompted from the provided lab documents should be included here.

Conclusion

The conclusion section should include a brief summary of the experiments performed and their results. Students should also state what they learned or gained from the lab.

Lab 1. Lab Equipment

Purpose

The goal of this lab is to familiarize students with the equipment we will be using for the entirety of the course. This equipment will be used for all subsequent labs, so it is imperative to have a working knowledge of the setup and operation.

Pre-Lab

There are no deliverables for this week's pre-lab. Instead, students are expected to explore the basic principles of the four main pieces of equipment we will be using: oscilloscope, waveform generator, multimeter and benchtop power supply. The links below direct you to the YouTube channel. You need to access these through the EdPuzzle class and complete them through there. These are for additional reference.

How to Use a Power Supply
How to Use an Oscilloscope
Instrument Basics: Function Generator - Workbench Wednesdays
How to use a multimeter like a pro! The ultimate guide

Exercises

Reading and Measuring Resistance

Begin by using a multimeter to test the resistance of the following three resistors: 120Ω, 5.1KΩ, 220KΩ. Be sure to select the correct setting on the multimeter before testing your resistors (we are measuring resistance, so select the "Ω" option. Also, ensure that the red cable on the multimeter is plugged into the correct port to read resistance. Provide your findings from the lab in a table similar to what is provided below.

Band 1 Color	Band 2 Color	Band 3 Color	Band 4 Color	Band 5 Color	Nominal (expected) Resistance	Tolerance	Actual Resistance (measured with multimeter)	Is this within the expected range?

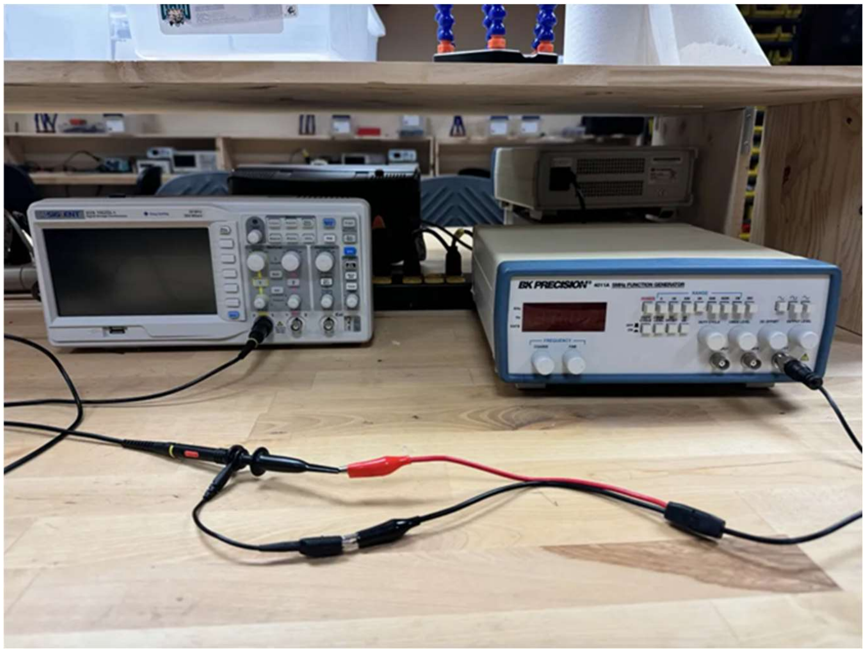
Measuring Voltage

Next, use the multimeter to measure four voltages of your choice on the power supply. Make sure you change your multimeter setting to measure voltage (V) rather than resistance from the last exercise. Provide your findings in a table similar to what is shown below when you create your lab report.

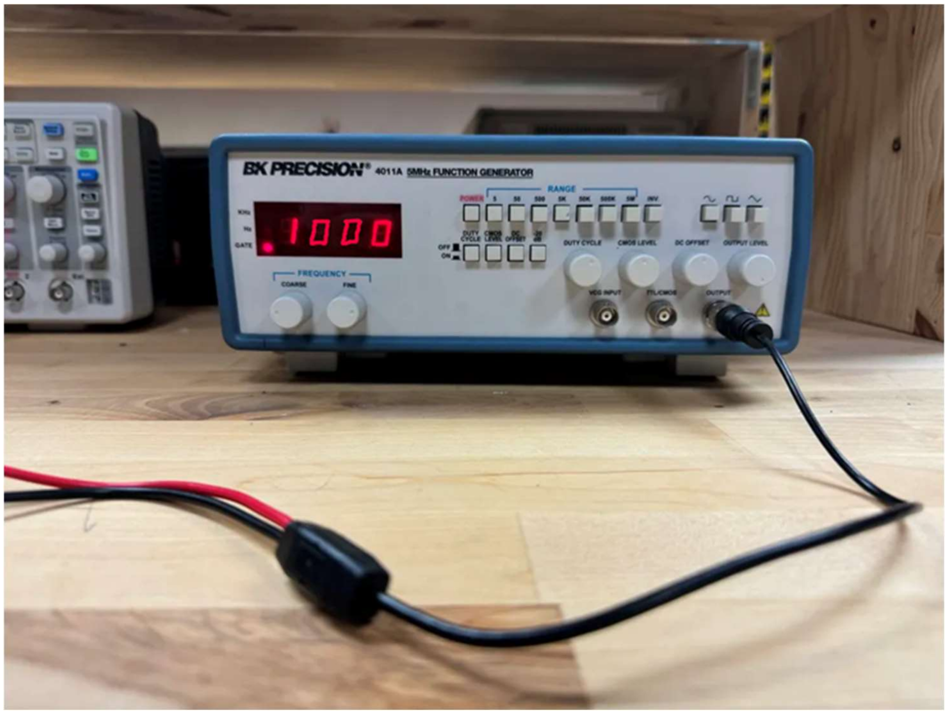
Expected Voltage (what the power supply says it is providing)	Measured voltage (what you measure with your multimeter)	Percent difference, if one exists.

Oscilloscope + Waveform Generator

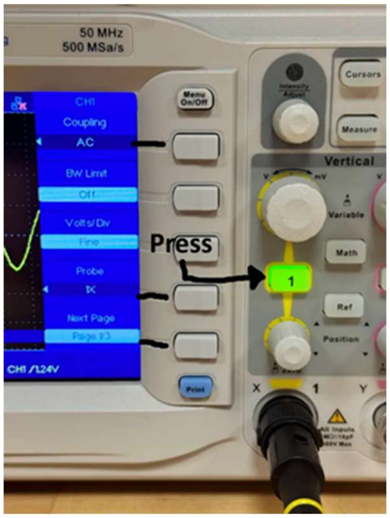
1. In the “Cables + Probes Kit” at your station, pull out one oscilloscope probe and one BNC-alligator clip. If you are not sure what those are, ask for guidance!
2. Plug in the oscilloscope probe to channel 1 and ensure channel 2 is off.
3. Plug the BNC end into the function generator output.
4. Connect the two probes together, as shown in the picture, to create a closed circuit.



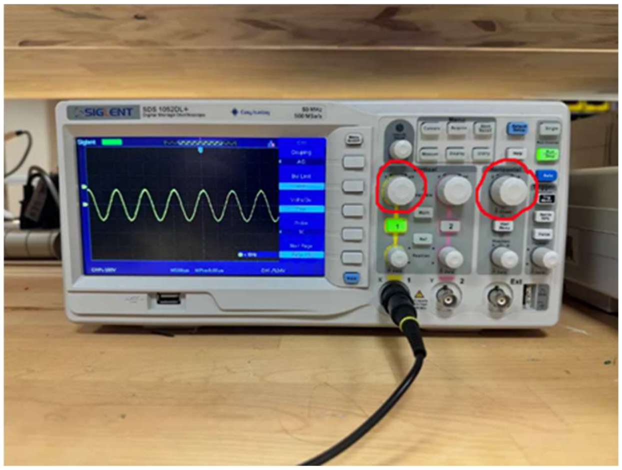
6. Turn on both pieces of equipment and set the function generator to a medium range (1 KHz is great for this, on BK Precision machines use the 5K option to set it).

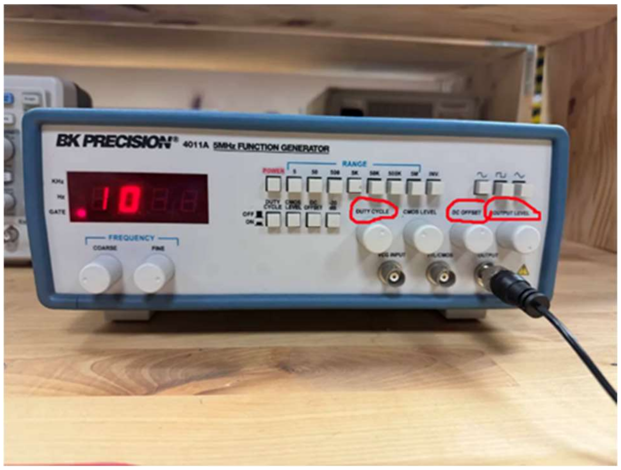


7. Under channel 1 settings on the oscilloscope (hit the 1 button to access it) set the coupling to AC, probe to 1X, and on the third page set unit to V.

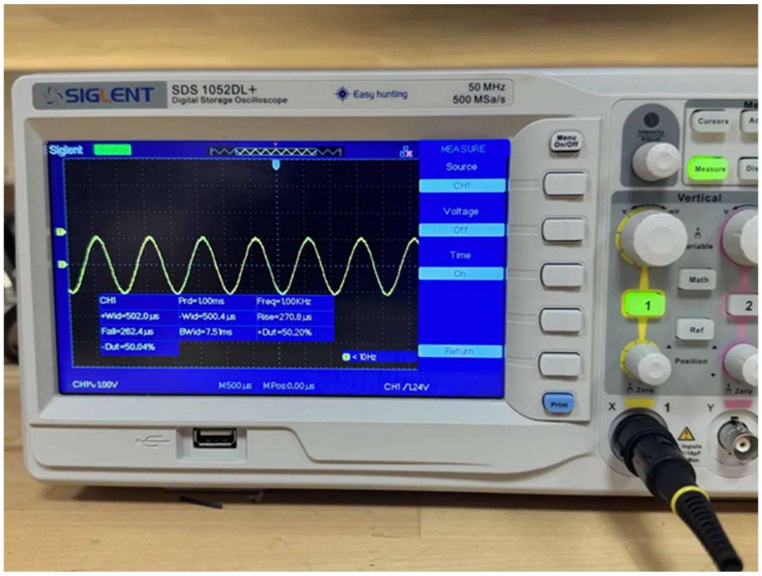


8. A wave should show up on the screen now so use the vertical channel dial, horizontal dial, and output level to get the waveform as clear as possible on the display. (Distortion can also come from the duty cycle and DC offset, so go until it looks like a normal sine wave).





9. Press the measure button and go to All Mea, make sure the source is correct and make sure time is on. Several measurements will show up, but the most important is frequency to determine if the oscilloscope is measuring properly. Any other data can be worked out to corroborate the main frequency data for precision. If your display is not in range, you can also try and press the "Auto" button.



10. Create a table to include in your lab report that includes the following information for each waveform listed below:
    - Frequency set on waveform generator.
    - Voltage set on waveform generator.
    - Frequency reading on oscilloscope.
    - Voltage reading on oscilloscope

11. Repeat the process for all wave types list below (sine, square, and triangle) and then repeat the process for a minimum (~100 Hz) and maximum (~1 MHz) frequency to check the function generators performance.

12. For each of the waveforms above, use the horizontal and vertical scaling knobs to bring the waveform into clear view. Save the observed waveforms either to a flash drive using the scope or take a picture using a cell phone. Also, record the horizontal and vertical scaling for each.

    - Sine wave 3V_{pp} 100Hz
    - Sine wave 3V_{pp} 10KHz
    - Square wave 5V_{pp} 1KHz
    - Triangle wave 1V_{pp} 100KHz

Finally, using an additional oscilloscope probe and two banana plugs with alligator clips, connect the output of the power supply to the input channel 2 of the scope. Configure any waveform of your choosing (under 5V_{pp}) on channel 1. Set the voltage of the supply to 3.7V and enable channel 2. Again, record observed waveforms and scope settings.

Results

Make sure to include all requested information from throughout the lab. Include all nominal, measured, and observed results in your report. Additionally, make sure to include all equipment settings and configurations. Configuration diagrams are not strictly necessary but will aid in demonstrating understanding. Having experienced some of the main functions of each piece of equipment, include an explanation of the functions and features used for each piece of equipment.

Lab 2. RC Circuits

Purpose

The goal of this lab is to allow students to practice the concepts learned in class with physical components. These concepts include equivalent resistance, capacitance, and DC response in RC circuits.

Pre-Lab

Calculate the equivalent resistances for two circuits shown for Part 1. Be prepared to share these with an instructor or TA at the beginning of lab. You should show all the work for this.

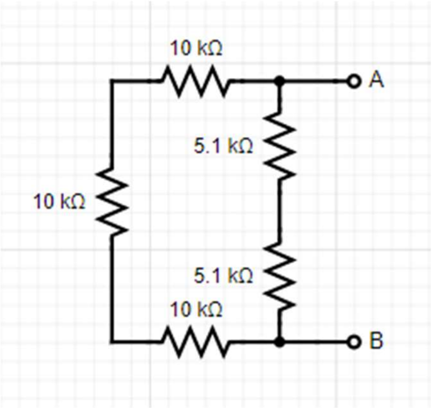
For part 2, calculate the amount of time it will take to charge the capacitor to 99% for each of the 3 scenarios. Also calculate the amount of time it will take to discharge the capacitor to 1% for each of the 3 scenarios. Be prepared to share these calculations and answers with an instructor or TA at the beginning of lab. You should show all the work for this.

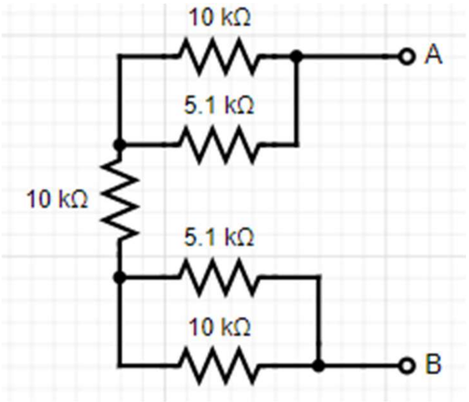
Finally, students should explore how to use solderless breadboards and the trigger function on the oscilloscope. The links below will aid in this process.

https://learn.sparkfun.com/tutorials/how-to-use-a-breadboard/all
https://www.youtube.com/watch?v=H0Czb2zBzsQ&t=119s

Part 1

Begin by calculating the equivalent resistances of the circuits below. Next, construct the circuits on a solderless breadboard. Measure the equivalent resistances of the circuits using a multimeter. Take note of the measured values.



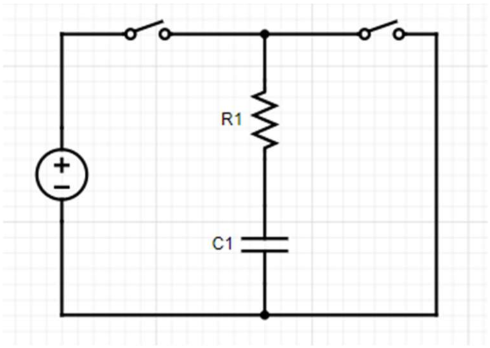


Part 2

This part will include 3 scenarios:

Scenario 1: R1 - 220KΩ C1 - 0.1μF
Scenario 2: R1 - 47KΩ C1 - 0.1μF
Scenario 3: R1 – 47KΩ C1 – 0.33 μF

1. Construct the circuit shown on a solderless breadboard using the values given above. For the DC source we will use our benchtop power supply set to 5V. Turn the power supply back off once the voltage is set.
2. After the circuit is built with the first resistor value, connect the oscilloscope probe across the capacitor. Make sure to discharge the capacitor before and after each trial. You can safely discharge these capacitors by using a jumper wire and "shorting" the capacitor; that is, connect both legs of the capacitor with the jumper wire. DO NOT DO THIS IN ALL SITUATIONS THOUGH! This can be very dangerous in larger capacitors, such as those that are on industrial equipment, home A/C units, etc.
3. On the oscilloscope, open the trigger menu and ensure you have the following settings:
    a. Type: Edge
    b. Source: Select the channel your oscilloscope probe is connected to.
    c. Slope: First option
    d. Mode: Single
4. Once the trigger is ready, turn on the power supply which should cause the oscilloscope to recognize a change in voltage and should cause it to stop recording in a very short amount of time.
5. Using your horizontal and vertical scaling knobs on the oscilloscope, zoom in to see the charging curve. Take a picture of this graph to add to your lab report.
6. Determine the horizontal and vertical scaling and record the time it took to charge the capacitor and the charged voltage.
7. Reconfigure the trigger on the scope then capture and measure the time it takes for the discharge curve. Turn off the power supply to allow the capacitor to discharge.
8. Repeat steps 5 and 6 to get your images, voltage, and time values for the discharge.
9. Repeat the exercise for the second and third scenarios.



Results

Include expected hand calculations for all parts of the lab. If hand calculations are neat and legible, they can be added to the lab report as figure, rather than having to type up all calculations into the Equation Editor.

Include all measured values and scope captures from part 2. Additionally, include a percentage error calculation between all expected and measured results. Discuss how the change in resistor or capacitor value affected the charge and discharge rate. How would changing the value of the capacitor up and down change the rate of charge/discharge. Finally, speculate sources of error.

In addition, compare your calculated values to what you observed, and data collected during the lab. Make sure to include all figures, voltage, times, and resistance values measured and observed throughout the lab to include them in your final report.

Lab 3. Diodes

Purpose

The goal of this lab is to get hands-on experience with the function of diodes. To do this, we will look at a few practical circuit applications of diodes.

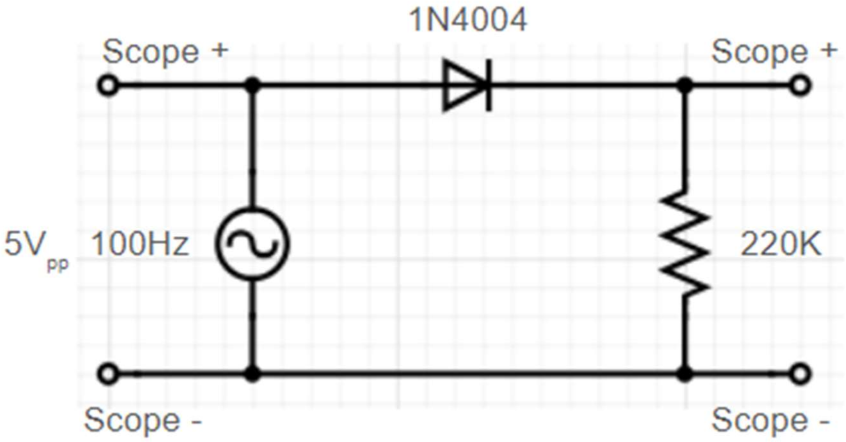
Pre-Lab

This week's pre-lab will involve constructing the circuits used in the lab ahead of time via the NI Multisim package. To begin, watch the Multisim basics video available via Blackboard. Next, construct the circuits presented below and perform the experiments in Multisim. Include screen grabs of the observed input and output waveforms from all experiments.

Lab

Part 1

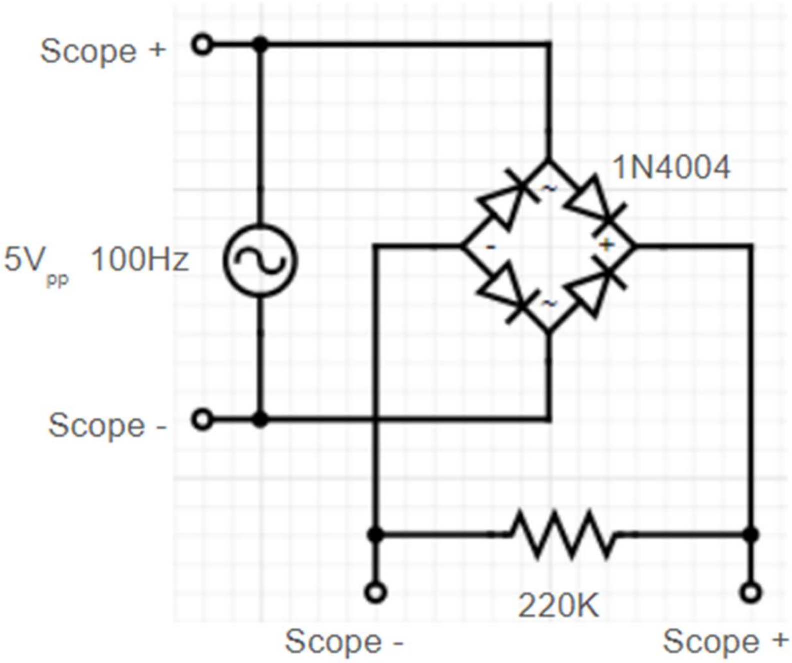
In the first part of this lab, we will experiment with a half-wave rectifier. Construct the circuit shown below using a diode, a resistor, a waveform generator, and the oscilloscope. The oscilloscope probes should be connected according to the diagram below with channel 1 connected to the AC source and channel 2 connected across the resistor.



Part 2

In part 2, we will experiment with a full-bridge rectifier. Again, construct the circuit below using the same components with the addition of three 1N4004 diodes. We have to connect the probes differently for this experiment. While the probe positioning is the same, we cannot have both channels connected at the same time. This is because the oscilloscope has common grounds between channels, **connecting both at the same time will short the waveform generator**. Instead, to keep the AC source floating, we need to follow these instructions:

1. Turn the waveform generator on and configure it
2. Connect oscilloscope channel 1 to the AC source
3. Record waveform
4. Disconnect oscilloscope channel 1
5. Connect oscilloscope channel 2 across the resistor
6. Record waveform



Results

Include all input and output waveforms observed from the pre-lab and lab. Did the Multisim results reflect the observed results of the physical circuits? Discuss the observed input/output waveform relationship between the two circuits. List some practical uses for the full-bridge rectifier.

Lab 4. H-Bridges

Use MOSFETs not relays!

Purpose

This lab aims to expose students to a practical application of the H-Bridge circuit. Our focus will be controlling these bridge circuits using microcontroller-compatible inputs. This exposure will be useful moving forward to ME4550. To do this, we will first look at the common L298N chip implementation of the bridge. We will then construct our own H-Bridge using relays as one might see in an industrial application. These circuits will be constructed on a perf-board and soldered so they can be saved for use in ME4550.

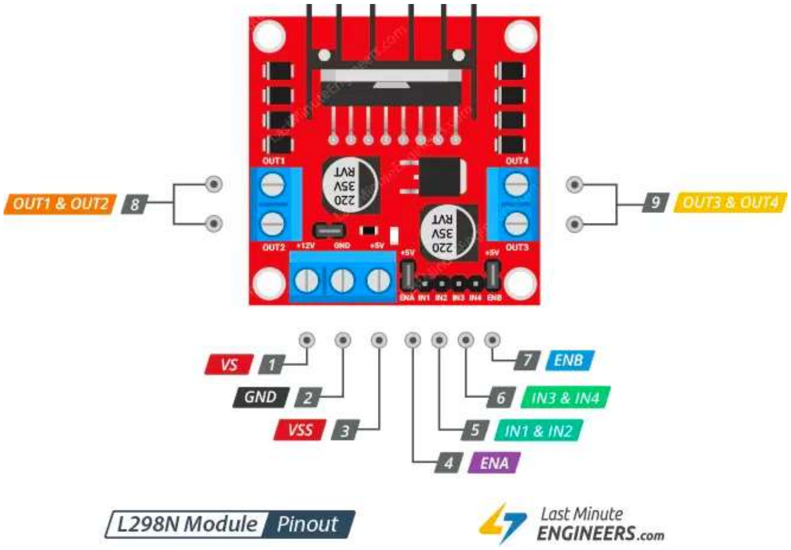
Pre-Lab

There are no deliverables for this lab. Instead, watch the soldering tips and tricks video below to ensure your success.

https://www.youtube.com/watch?v=VxMV6wGS3NY

Part 1

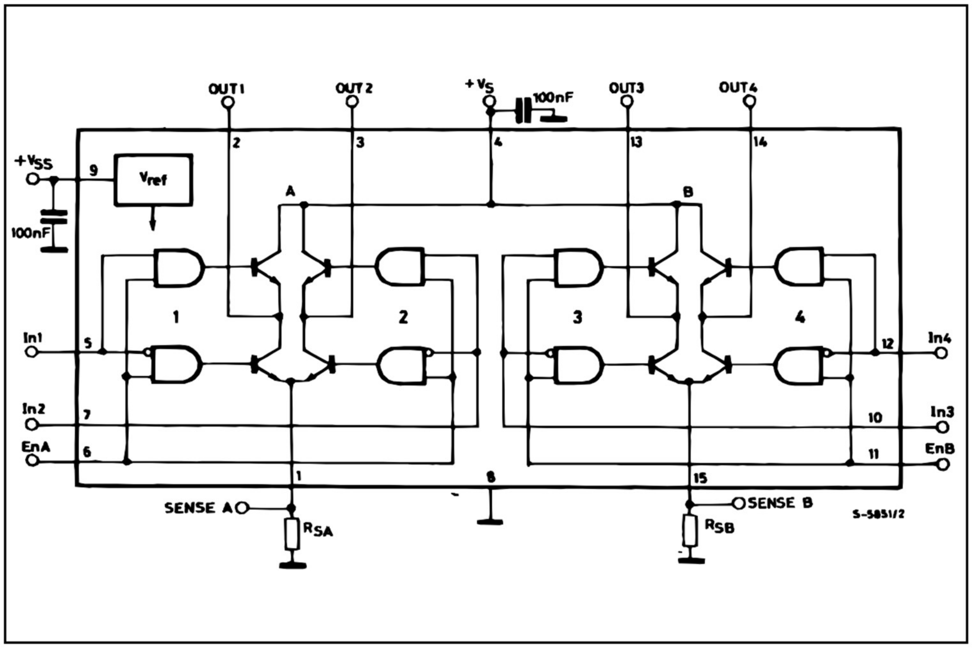
We will begin by exploring a common hobbyist breakout board based on the L298N dual-channel H-Bridge. This board is particularly useful as its inputs are logic level, meaning both H-bridges can be manipulated with a microcontroller or any other low current output. This board has three power inputs: GND, VS, and VSS. VS is the supply voltage that will be used for the H-Bridge to drive the outputs and VSS is the supply used for onboard logic.



Begin by connecting a DC motor to one of the outputs of the board. Next, connect a 9v battery to the GND and VS pins. Finally, set your power supply to 5v and connect it to the GND and VSS pins. To control the direction of the motor, alternate the application of 5v between the 2 corresponding input pins. Create a table in the following format:

IN1	**IN2**	**Current Direction**	**Motor Direction**
0	0		
1	0		
0	1		
1	1		

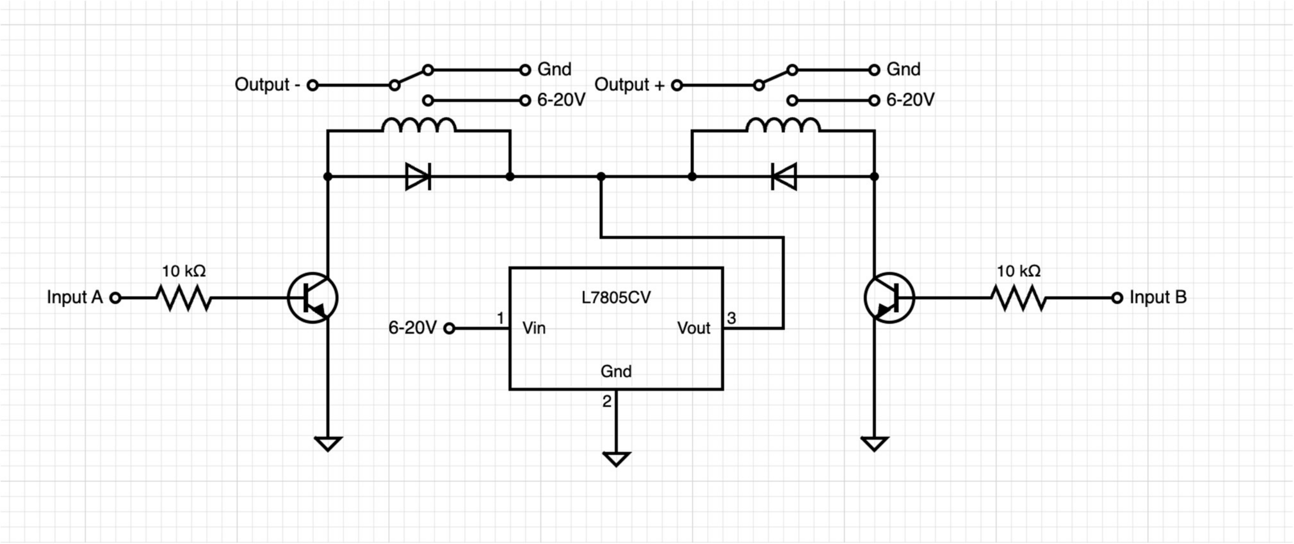
Use the oscilloscope on the motor output to view the change in the current direction.



The above schematic shows us what is contained inside the L298N chip. Notice that some AND gates have a NOT gate on their input. What purpose do the AND gates serve? The NOT gates?

Part 2

In this part, we will be constructing an H-Bridge using relays to drive a small DC motor. Begin by planning the best configuration of components on the perf-board to construct the circuit below. It helps to group components by node. Have a course instructor confirm your layout and plan before soldering. The 5v regulator is used to regulate a wide range of input voltages down to 5v for the actuation of the relays. The transistors are used to control the current to the relays which will surpass the amount available from a microcontroller. Once the circuit is finished, test it the same way as the L298N. Note that we no longer have a VSS input and the power supply should be set to 3.3v instead of 5v to reflect the voltage used by the Pi Picos.



1N4148 Diodes	Datasheet
2N3904 NPN Transistors	Datasheet
L7805CV 5V Regulator	Datasheet
JZC-11F-05VDC-1Z Relay	Datasheet

Use terminal blocks for input and output power
Use header pins for transistor inputs

Results

In addition to the normal lab guidelines, this lab report should include the following: tables from parts 1 and 2, a picture of the completed H-bridge, and answers to any prompted questions.

Lab 5. Micropython and Raspberry Pi Pico Basics

1. Go to: https://www.python.org/downloads/
2. Download Python for your operating system

Download the latest version for Windows

Looking for Python with a different OS? Python for Windows, Linux/UNIX, macOS, Other

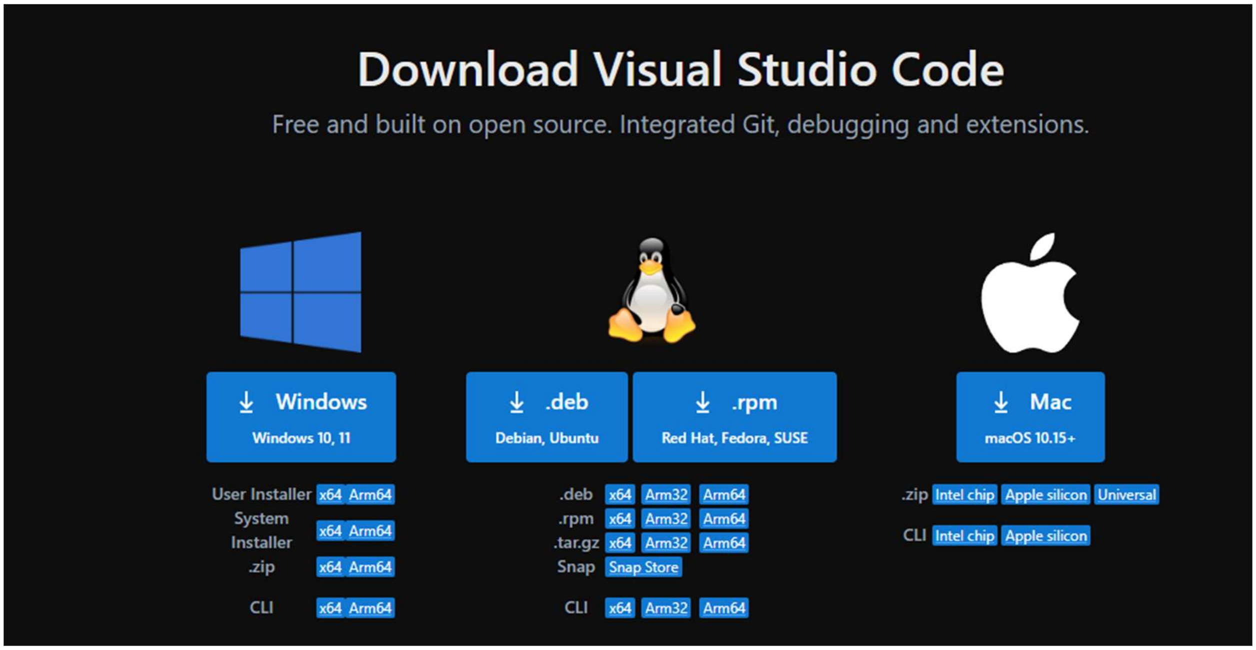
Want to help test development versions of Python 3.13? Prereleases, Docker images

3. **<u>VERY IMPORTANT!</u> Select add to PATH in the bottom of the screen – Windows ONLY**
4. Install Python

Visual Studio Code

1. Go to: https://code.visualstudio.com/download

2. Download VS code for your computer



Download Visual Studio Code

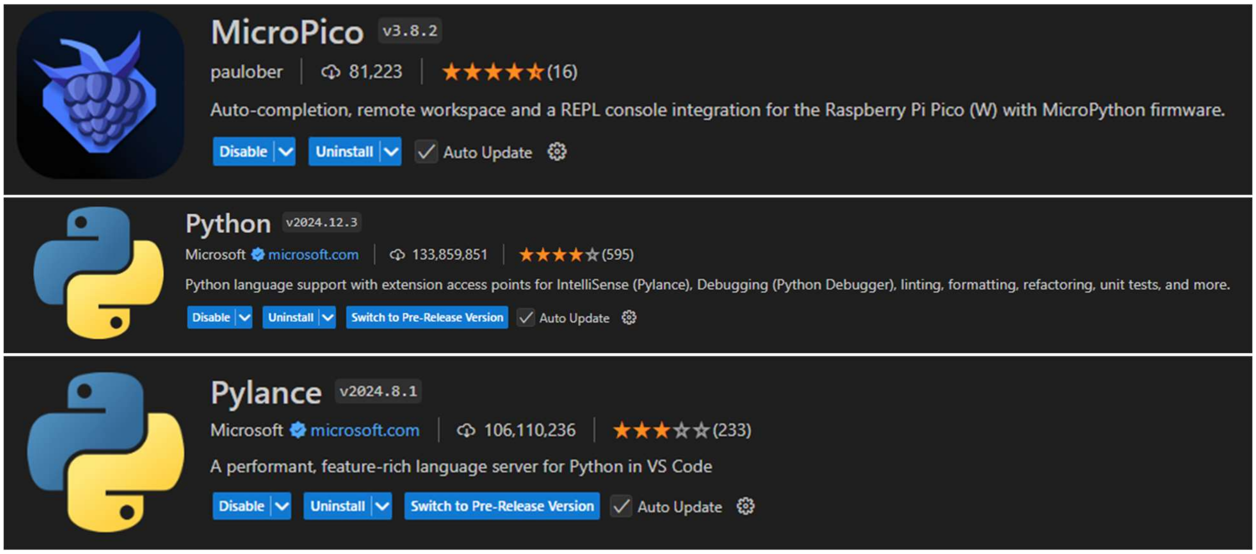
Free and built on open source. Integrated Git, debugging and extensions.

3. Install VS Code

4. Open VS Code

5. Go to Extensions page

6. Install the Python, Pylance, and MicroPico extensions. Pylance might install with the Python extension



MicroPico v3.8.2

paulober | 81,223 | ★★★★★(16)

Auto-completion, remote workspace and a REPL console integration for the Raspberry Pi Pico (W) with MicroPython firmware.

Python v2024.12.3

Microsoft microsoft.com | 133,859,851 | ★★★★☆(595)

Python language support with extension access points for IntelliSense (Pylance), Debugging (Python Debugger), linting, formatting, refactoring, unit tests, and more.

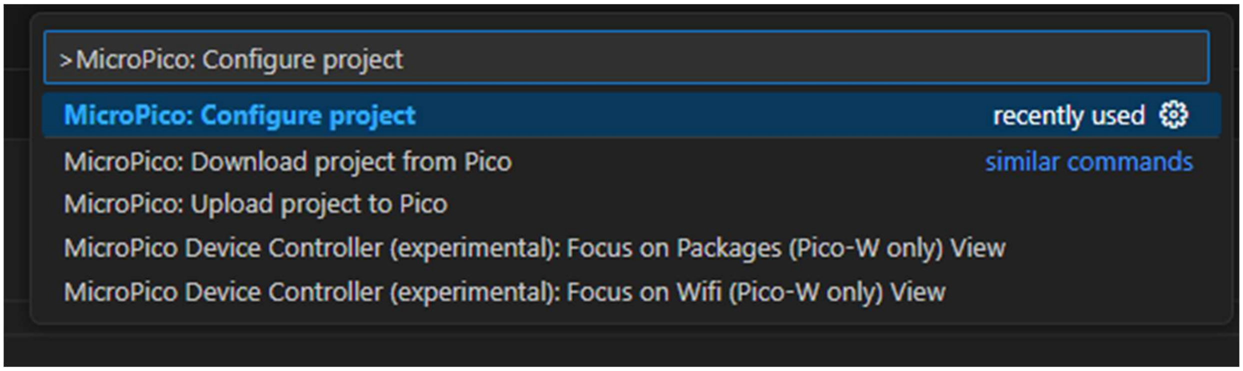
Pylance v2024.8.1

Microsoft microsoft.com | 106,110,236 | ★★★☆☆(233)

A performant, feature-rich language server for Python in VS Code

Setting Up Micropython Project:

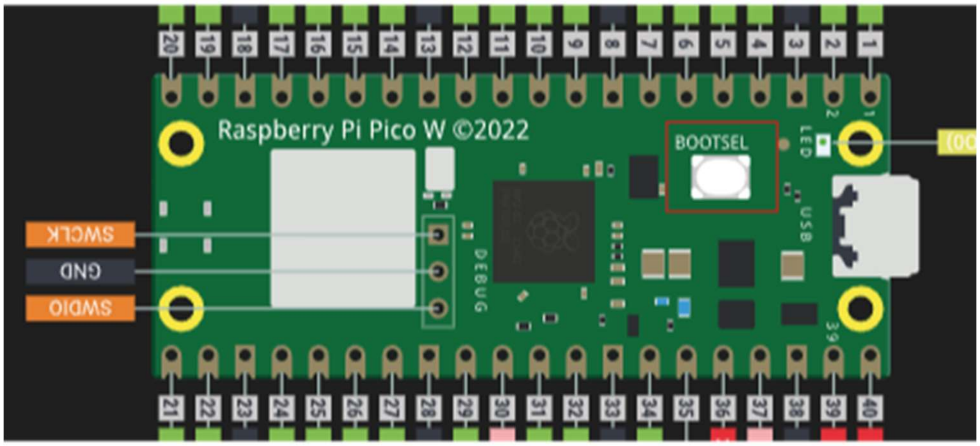
1. Open VS Code
2. Create Folder and add to workspace
3. In the top search bar in VS Code type: >MicroPico: Configure project



>MicroPico: Configure project

Installing Micropython to Pico and running files:

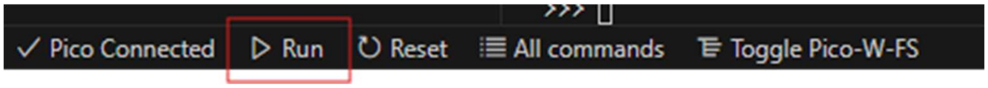
1. Download the Pico Firmware from Canvas
2. Unplug the Pico if plugged
3. Hold down the BOOTSEL button and plug in Pico while held down



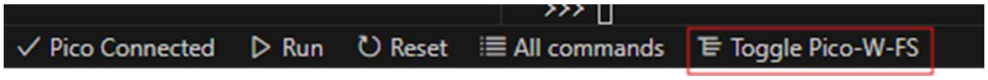
4. A file menu should pop up or in your computers file explorer titled RPI-RP2 similar to a USB drive
5. Drag the firmware file and the Pico should reboot itself, closing the file explorer window
6. You only need to install the firmware once

Running Files:

1. After you've written your file and configured your project, the bottom of VS Code should have a menu, select run and it will run the selected file from the computer



2. If you want to run the file directly on the Pico (this is sometimes required), click Toggle Pico-W-FS and a folder should appear in the workspace



3. Copy your file into the Pico (W) Remote Workspace folder and then you can run the file the same way as step 1
4. Any additional libraries not built-in to the firmware that will be needed for your program will need to be copied into the Pico's internal filesystems
5. If you wish to run the program without being connected to the computer, plug a 5V power source positive wire into the Vsys pin on the Pico and the negative wire into any ground, any voltage above 5V will probably blow up the Pico. After the Pico is powered rename your program to main.py and copy any necessary files into the Pico and it will run automatically.

Lab 6. Strain Gauge Load Cells

Purpose

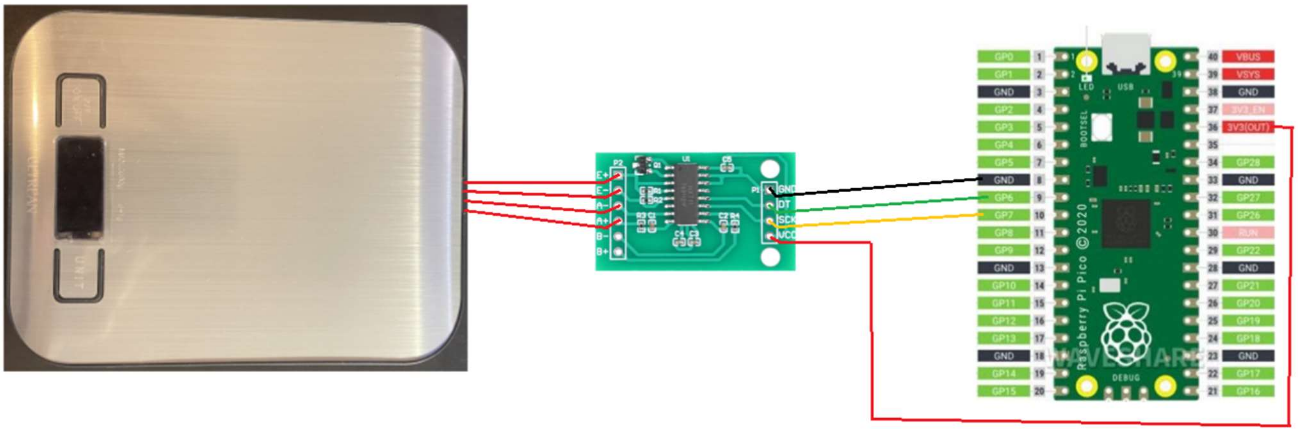
The goal of this lab is to familiarize students with a practical implementation of strain gauge load cells. This implementation demonstrates how individual strain gauges can be configured into a Wheatstone Bridge to form a load cell. Upon completion of this lab, students should be comfortable with the configuration of load cells and the concepts we use to read data from them. Additionally, an understanding of load cell calibration is expected.

Pre-Lab

A basic understanding of the HX711 library is necessary to perform this lab. Provide a description for all of the public function calls used in the provided code (scale.xxxx()). In addition, identify two functions not used in the code and explain their purpose. Make sure to install this library in your Arduino IDE as well. The library documentation can be found here: https://github.com/bogde/HX711

Lab

We will start by configuring the circuit shown below. In order to connect our own circuitry, our scales have been modified such that their main board is no longer connected to the strain gauges.



Part A

Once you have your circuit built, upload the provided code. When viewing the serial monitor, you should see values that change as you press on the scale, if not, consult a TA. At this point, the Arduino is reading a 24-bit integer representation of the small voltage being read from the Wheatstone bridge. There is no correlation between that value and weight yet. To build that relationship, we need to calibrate the scale. Using a weight of a known value, change the calibration variable until the scale reads the correct value. Once calibrated, weigh three items from around the room.

Part B

For this part of the experiment, be sure that the Pico is being powered by a laptop that is not plugged in to charge. First, connect the oscilloscope to the E+ and E- pins on the HX711. This allows us to see the excitation voltage used on the bridge. Next, move the probe to the A+ and A- pins, this allows us to see the voltage we are measuring with the HX711's ADC. This signal can be very noisy, so we will only concern ourselves with approximating the output voltage. Note the output voltage at 0 lbs, 10 lbs, and 20 lbs of weight.

Results

In addition to the pre-lab, students should provide data from the experiments in the format below. Could the excitation voltage and output voltage be measured at the same time using 2 channels from the oscilloscope? Why or why not? Why was it important that the laptop powering the Pico was not charging? Speculate why the output voltage was so noisy. What type of memory would a calibration value be stored in on a commercial scale?

Calibration Factor:

Item	Raw 24-bit Value	Weight (lbs)

Excitation Voltage (____units):

Weight (lbs)	Output Voltage (____units)	Raw 24-bit Value
0		
10		
20		

Lab 7. DC Motor Control

Purpose

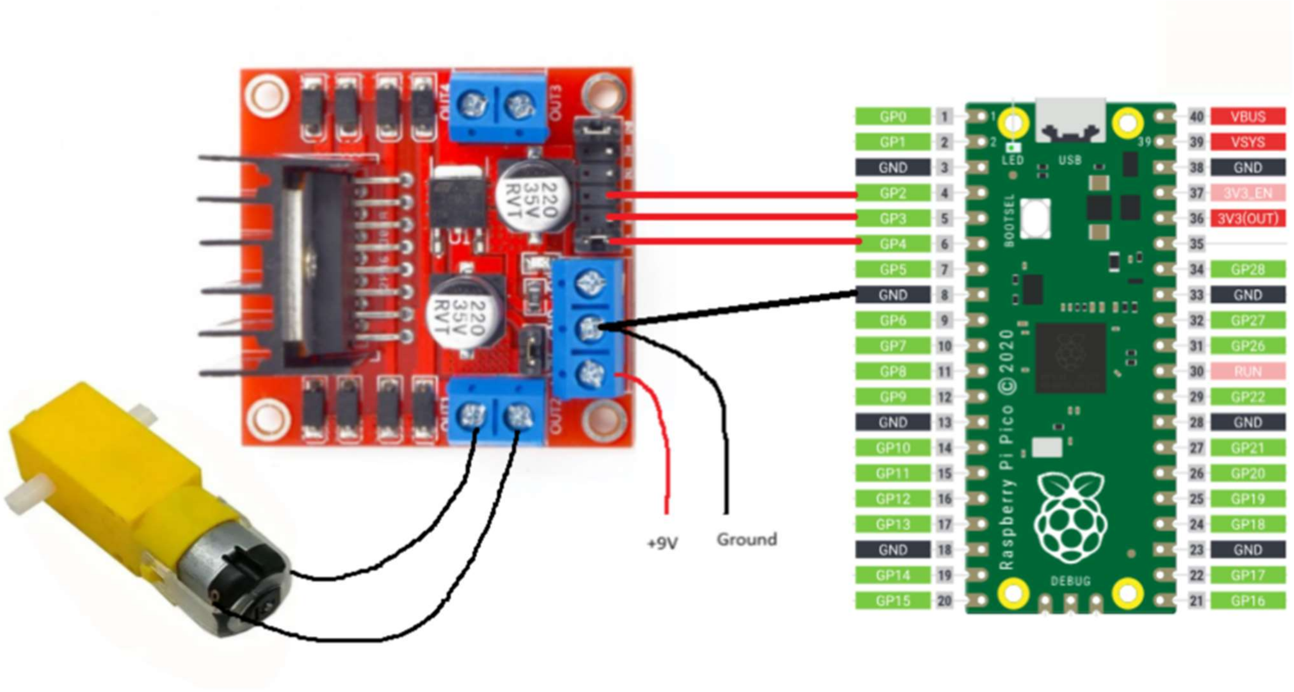
The objective of this lab is to learn how we can perform rudimentary motor control using a microcontroller and the L298 H-bridge boards. Having previously introduced bidirectional current control, we will introduce pulse width modulation to control motor output speed.

Pre-Lab

The provided code contains all the components needed to complete this lab. However, the comments still need to be completed. Please finish the code by adding a comment for every line describing its purpose. What is a function? What does each of our functions do? What will our expected PWM output look like? (sketch a waveform)

Lab

Begin by gathering a 9V battery and clip. Test the battery with a multimeter to ensure it is not dead (7.5-9v is a good battery voltage). Once you have your materials, construct the circuit according to the diagram below. **We also need to connect the oscilloscope across the two terminals on the motor.**



To begin the first experiment, uncomment `testA()` in the code then upload it to the Pico. Configure the oscilloscope such that the changing waveform can be on the screen. Take a picture or save a screen capture.

Once completed with the first part, re-comment **`testA()`** and uncomment **`testB()`** then reupload to the Pico. Configure the scope such that you can see at least 3 periods of the waveform. Again, capture the scope output.

Results

Alongside the questions for the prelab, please submit your newly commented code. Copy and paste 100% of the code contents into an appendix section at the end of your reports. Be sure to include oscilloscope captures from both experiments. Do your observations from experiment A match our expectations? Discuss what happens in our oscilloscope capture when the motor changes direction. For experiment B, discuss how your observed waveform differs from an ideal PWM signal. Speculate some reasons for this occurrence.