ECE 111 Lab Manual

Fall 2015

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Contents

Chapter 0

Preface

0.1 How to Use This Manual

During this course, various tasks will be performed like the assembly of electronic devices and circuit analysis. These tasks are divided into individual lab documents. What is learned in these labs will be relevant and useful in later (related) courses and in your future career.

0.2 Important Symbols

During this lab and other TekBots labs, you will encounter the following symbols. So, review or acquaint yourself with these symbols, as they are widely used in this lab manual.

This symbol indicates an **important note** that should be remembered/memorized. Paying attention to notes like these will make tasks easier and more efficient.

This symbol designates **caution**, and the information in this caution-table should be read thoroughly, and adhered to, before moving ahead. If the caution warning is ignored, the task may appear impossible and/or lead to damaged TekBot and systems.

This symbol represents something that helps you make your task easier by reminding you to perform a particular task before the next step. These **reminder** symbols are not normally critical things to complete, but can make things easier.

The **innovation** symbol will give information to enrich your experience. These sections will give more insight into the what, why, and how the task being done. Use these to learn more, or to get ideas for cool innovations.

The entire lab is divided into various sections, in order to break up the tasks. Typically, each section will have the Section Overview as the introductory paragraphs and information detailing the tasks in the Procedure paragraphs. Towards the end, there are Study Questions (which will be your homework from this lab), and/or Challenges.

0.3 Lab Structure

Section Overview	The section overview briefly describes what will be learned in the section, and what will be done.
Procedure	The procedure portion of each section contains all of the tasks to be completed and relates to the corresponding lecture. Keeping this in mind will help to better understand the lecture as well as the lab material.
Study Questions	The study questions give more practice and insight into what has been learned in lab and lecture. Study questions will be due the week after the lab is finished.
Challenges	The challenge sections of labs are for extra credit. Performing the tasks in the challenge sections will improve understanding of what is being learned and will result in some cool TekBots and innovations.

0.4 Lab Safety

Safety is always important when working with electricity and electronics. This includes both the safety for you as well as safety for the circuit components you are working with. Concerns such as high voltage or currents can affect the human body, while static safety and proper component use can affect the life of your circuits.

0.4.1 Personal Safety

When working with high voltages and currents, it is important you remember that you can be hurt if your body becomes the ‘circuit’, since the human body is a conductor of electricity. This issue has long been combated by using the ‘one hand rule.’ Whenever you are working with a potentially dangerous circuit, turn it off, but if it cannot be turned off, use only one hand when working on it. This will prevent a circuit from going through your heart, which could be potentially fatal.

0.4.2 Component Safety

Many electrical components are likely to be damaged by static electricity. Static charge can build up to many thousands of volts, but with little energy. This cannot harm humans, but it can easily damage electronic components. To ensure static-safe handling, the best practice is to wear an anti-static strap and connect it to an earth ground such as a computer case or a water pipe. If you do not have an anti-static wristband, you can instead touch a ground every few minutes to discharge your static build up.

Chapter 1

Welcome to ECE!

1.1 Section Overview

Welcome to the ECE 111 lab manual! For many students, this may be their first exposure to soldering (pronounced saw-der-ing) and assembling an electrical system. Therefore, this manual has been written with the assumption that the assembler has very little knowledge of these skills.

1.2 Objectives

- Lab etiquette
- Resources
- Soldering
- Using the resistor value tables

1.3 Materials

- Teensy
- USB to mini cable
- Tool Kit
- Soldering iron tip and barrel nut
- Solder

1.4 Lab Etiquette

Proper etiquette in the labs is important when working with other students and Teaching Assistants (TAs). Engineers work with many different types of people and need to be able to do so proficiently. Another part of proper lab etiquette is cleanliness in the lab. Engineers work in a variety of spaces; some can work in spaces that are exclusively theirs but many work in shared spaces. When sharing work spaces, respect others that must use that space by keeping it clean and removing messes when finished.

1.4.1 Students

To get the fullest experience out of lab, students are expected to:

- **Prepare for each lab.**
  Students should read each section in the lab manual before going to lab. This ensures all the required tools are prepared and any questions for the TAs are ready.
- **Ask questions.**
  Students should talk to their peers and the TAs when questions arise. Other people will have different perspectives on an issue.
- **Respect their peers.**
  Everybody comes from a different background and has a different level of knowledge but everybody deserves the same level of respect.

1.4.2 Teaching Assistants (TAs)

Teaching Assistants are expected to:

- **Ensure the lab is prepared.**
  TAs make sure the room the lab is located in and the provided materials are prepped for the students during their assigned lab sections.
- **Fairly assess student performance.**
  TAs should outline their requirements for full credit on prelabs and study questions at the beginning of the term and grade to this standard for the term.
- **Help students think through problems in lab.**
  TAs will not give instant answers to problems encountered. They are available to guide students towards the correct answer.

1.4.3 Workspace

A messy workspace can be a safety hazard and create a chaotic environment. It is much easier to lose a small component when there are other items cluttering the table top. It is also important to keep a workspace clean because there are other classes that use the same room for their labs. Respect the lab and the other people that are working in the lab.

1.5 Resources

There are many sources of information available for students in need of help. There is a hierarchy that students should follow to ask questions before going straight to the instructor. Resources located higher in the hierarchy will be high quality but also more scarce. When a student has a question they should start on the first level to ask questions and progress from there.

1. **Yourself**
   Students who encounter problems should first examine the issue and attempt to solve the problem on their own.
2. **Peers**
   A student's peers should be the second resource utilized when a question arises. Asking peers helps the student with the question and it reinforces the concept to the person asked when they explain it. A student has many peers so the total amount of time available with peers is much more than any other resource.
3. **Teaching Assistants**
   Teaching Assistants (TAs) have gone through this material before and are confident with the content, making them a valuable source of information. They have recent experience as a student in the course and can offer insight regarding the course.
4. **Instructor**
   Going to the instructor or professor with a question should happen when other students and the TAs couldn't help. There is only a limited amount of time that an instructor is available for students to ask questions. However, instructors will know the most about a topic and how it pertains to the course.

1.6 Academic Dishonesty

The following is taken from the Oregon University System, Oregon State University Student Conduct Code[1]. Refer to the link for additional information.

1. Academic or Scholarly Dishonesty is defined as an act of deception in which a Student seeks to claim credit for the work or effort of another person, or uses unauthorized materials or fabricated information in any academic work or research, either through the Student's own efforts or the efforts of another.
2. It includes:
   (a) CHEATING – use or attempted use of unauthorized materials, information or study aids, or an act of deceit by which a Student attempts to misrepresent mastery of academic effort or information. This includes but is not limited to unauthorized copying or collaboration on a test or assignment, using prhibited materials and texts, any misuse of an electronic device, or using any deceptive means to gain academic credit.
   (b) FABRICATION – falsification or invention of any information including but not limited to falsifying reseasrch, inventing or exaggerating data, or listing incorrect or fictitious references.
   (c) ASSISTING – helping another commit an act of academic dishonesty. This includes but is not limited to paying or bribing someone to acquire a test or assignment, changing someone's grades or academic records, taking a test/doing an assignment for someone else by any means, including misuse of an electronic device. It is a violation of Oregon state law to create and offer to sell part or all of an educational assignment to another person (ORS 165.114)
   (d) TAMPERING – altering or interfering with evaluation instruments or documents.
   (e) PLAGERISM – representing the words or ideas of another person or presenting someone else's words, ideas, artistry or data as one's own, or using one's own previously submitted work. Plagerism includes but is not limited to copying another person's work (including unpublished material) without appropriate referencing, presenting someone else's opinions and theories as one's own, or working jointly on a project and then submitting it as one's own work.
3. Academic Dishonesty cases are handled initially by the academic units, following the process outlined in the University's Academic Dishonesty Report Form, and will also be referred to SCCS for action under these rules.

[1] http://arcweb.sos.state.or.us/pages/rules/oars_500/oar_576/576_015.html

1.7 Preparation

Proper preparation allows for a smoother and more efficient lab time. Follow these steps before starting each lab.

1. **Start with a clean work space.**
   Electronic components are very small and if dropped, could be easily lost in desk clutter. Therefore, put away papers, keyboards, mice, clothing, etc.

2. **Keep electronic parts neatly organized.**
   Often times, parts come neatly packaged and ready for use. Do not dump all of these parts together, such as in a box. Instead, if parts come separated, try to keep them that way. To stay organized, rather than spreading components out across the desk, use a small container. Some people use ice cube trays, kitchen bowls, art supply boxes, or other containers for convenient organization of parts.

3. **Care for tools.**
   The quality of electronics assembly is based on personal experience and tools used for assembly. Hence, try to keep tools in the best condition possible. When using cutting tools, try not to cut things that the tools are not typically used for.

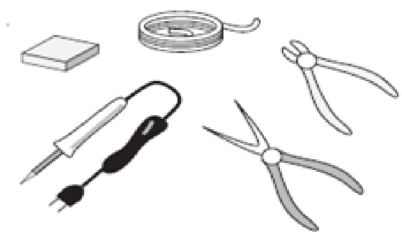
4. **Gather all supplies.**
   When working on a project, there is nothing more annoying than not having the parts needed, and having to stop working to go find them. Prevent this frustration by double-checking all supplies before starting. This includes manuals, tools, components, pens, and paper.

1.8 How to Solder

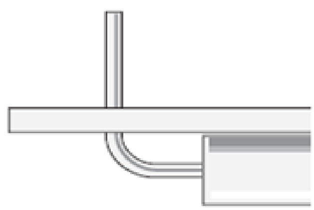
Never touch a component or the tip of the soldering iron while soldering! Return soldering iron to its stand when not in use. In step 5, cover the lead that is being cut to prevent it from flying away.

A variety of different soldering tutorials are available online to help with this process. More soldering hints can be found on the TekBots webpage.

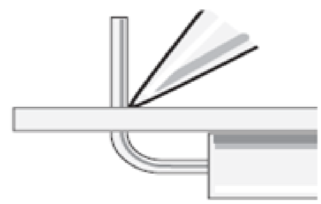
1. Plug in the iron and moisten sponge with water.



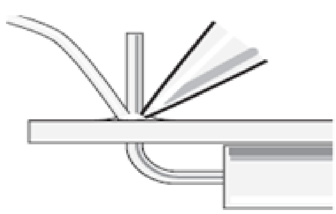
2. Bend the component's lead to fit the holes on the board, observing special orientation before inserting component.



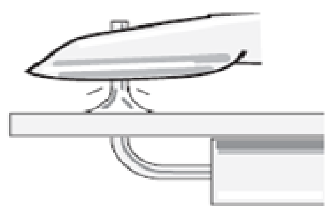
3. Clean the iron tip by wiping it across a wet sponge. Then tin the iron's tip using a small amount of solder. Heat the joint by placing the iron's tip at the component's base.



4. After a moment of heating, apply solder to the joint, remove the solder, then iron but hold the component in place until cooled. Make sure to store the iron in the stand *without wiping off the tip.*



5. Trim excess leads with wire cutters. Make sure to hold on or cover excess lead while cutting.



1.9 Preparing the Teensy

Some soldering is necessary to prepare the Teensy for this lab. Male header needs to be soldered into the small holes along the two long sides and one short side of the Teensy board. Aquire two 12 pin long strips of male header and one 5 pin long strip; one long strip is needed for both long sides of the board and the other is needed for the shorter side. Reference Figure 1.1 for an image on how the Teensy should look.

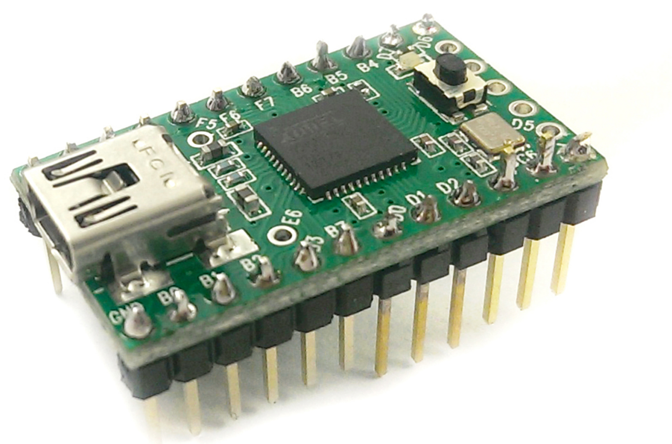


Figure 1.1: Teensy with male header.

1. Prepare to solder with the instructions from the previous section.
2. Take one 12 pin piece of male header and put the short side through the holes so the plastic part is on the underside of the board as shown in the picture.
3. Solder each pin to the board using the instructions from the previous section.
4. Repeat for the other sides of the board.

> When soldering the first piece of male header to the Teensy, it may be beneficial to find something small to put under the other edge of the board to keep the header and the PCB perpendicular.

1.10 Resistor Values

A resistor is a component that limits electrical current. Current creates a voltage drop across the two terminals of the resistor. Most resistors use a pattern of colored strips to indicate the resistance value. The diagram below shows how to read the resistor values.

Resistor Color Code Chart

Color	1st Color Band	2nd Color Band	3rd Color band (Multiplier)	Tolerance
Black	0	0	10^0	
Brown	1	1	10^1	± 1%
Red	2	2	10^2	± 2%
Orange	3	3	10^3	± 3%
Yellow	4	4	10^4	± 4%
Green	5	5	10^5	± .5%
Blue	6	6	10^6	± .25%
Violet	7	7	10^7	± .1%
Gray	8	8	10^8	
White	9	9	10^9	
Gold			10^{-1}	± 5%
Silver			10^{-2}	± 10%
None				± 20%

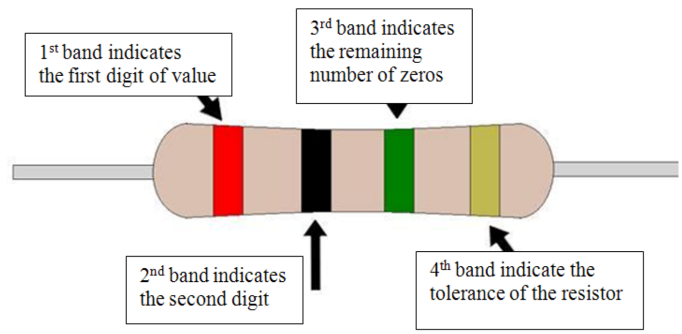


Figure 1.2: Resistor Color Code

From Figure 1.2, the color is Red, Black, Green, and Gold **Red** = 2, **Black** = 0, **Green** = 5 (zeros), **Gold** = $\pm$ 5% The resistor value is in between $2,000,000 \times (1 - 0.05) = 1.9M\Omega$ and $2,000,000 \times (1 + 0.05) = 2.1M\Omega$

1.10.1 Making Measurements

Use the resistor in the ECE 111 kit. This exercise uses the Digital Multimeter (DMM) to measure resistance. For instructions on how to use a DMM, reference lab 2 under section 2.5.

- Fill-in the band colors:

  ________ ________ ________ ________

- Fill-in values of the colors:

  ________ ________ ________ ________

- Calculated Resistance:

  ____

- Measure Resistance using DMM:

  ____

Are the values within the specified tolerance?

TA Signature: ____________________
(Lab Work Readable/Board is Prepared)

1.11 Study Questions

Type answers to the study questions below. Please keep answers clear and concise. Turn in the questions at the beginning of lab next week. You will be required to type all study questions for the future labs as well.

1. Soldering can be used for making one-of-a-kind things (prototyping) but there are many other ways of prototyping too. Find two other 'ways' of prototyping electronics circuits.

1.12 Challenge

Measure the resistance of the resistor shown in Figure 1.3. Note: These resistors can be obtained from your TA.

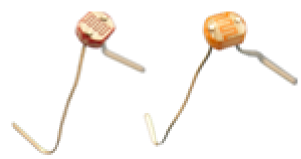


Figure 1.3: Special Resistor

Is there anything special about this type of resistor? Type a description and turn it in with the study questions.

Chapter 2

Materials and Devices

2.1 Introduction

Materials and Devices is concerned with how semiconductor devices, such as transistors, diodes, and sensors work and how they are built. Introductory courses cover the physics and properties of electronic materials: semiconductors, metals and insulators, and how these materials are combined to form electronic devices. Higher level courses specialize in particular areas such as optoelectronics, semiconductor processing, magnetics, or sensors. In the undergraduate semiconductor fabrication laboratory, students learn to use semiconductor processing equipment in the clean room to fabricate and test their own diodes and transistors.

2.2 Section Overview

A resistor is a two-terminal component which resists current flow in a circuit. The resistor depends on the resistivity of the material, length and cross-sectional area. Resistance has a unit of Ohms(Ω). See Figure 2.1.

$$Resistance = Resistivity \times (\frac{Length}{CrossSectionalArea}) \qquad R = \rho\frac{L}{A}$$

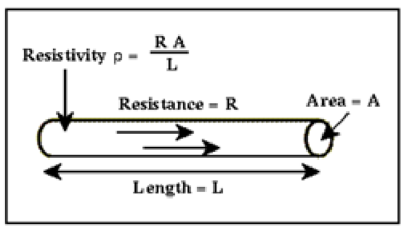


Figure 2.1: Finding Resistivity

2.3 Objectives

- Resistance Basics
- Use the digital multimeter
- Graph data
- Potentiometers

2.4 Materials

- Digital Multimeter
- Conductive Paper
- Teensy2.0
- Female-female prototyping wires

2.5 The Digital Multimeter

Digital multimeter (DMM) is a useful measurement tool. There are three settings in a typical DMM; Voltmeter measures potential difference (voltage), Ohmmeter measures resistance, and Ammeter measures current.

2.5.1 Using a Digital Multimeter

Setting up a dial switch: Choose an appropriate switch position for the measurement. Refer to Figure 2.2 for a description of each switch position. Make sure to set the dial switch before measuring, doing something like trying to measure voltage when the dial is set to current can possibly blow the fuse in your DMM.

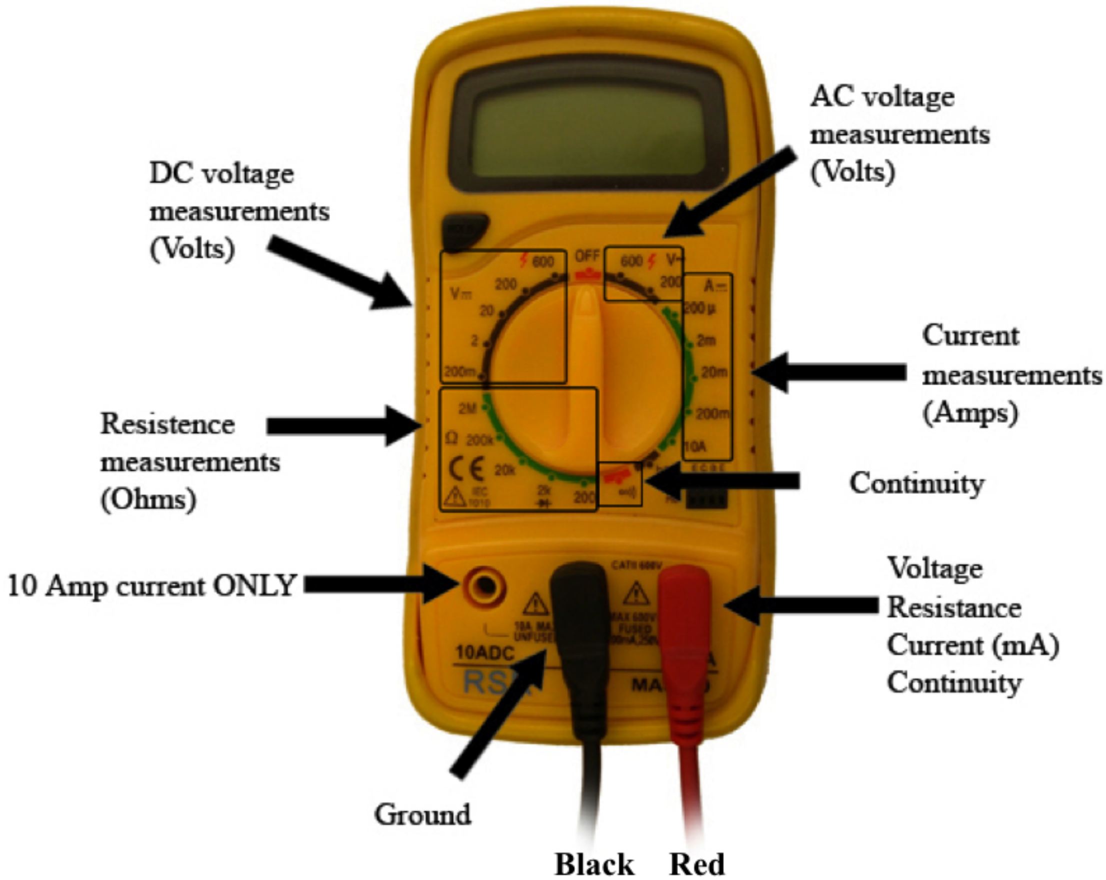


Figure 2.2: DMM Showing the Meter Switches

2.5.2 Using a DMM to measure Voltage and Current

1. To measure potential difference (voltage), the voltmeter is connected in parallel with the component. In Figure 2.3, the voltmeter is connected in parallel with a resistor.

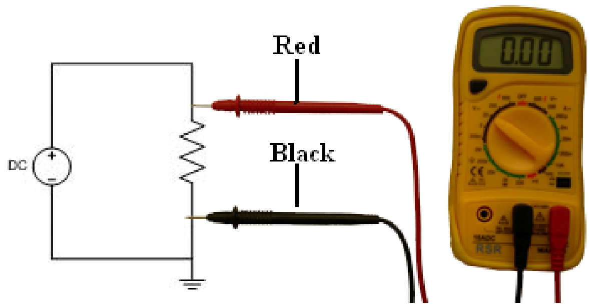


Figure 2.3: Measuring Voltage

2. To measure current, the circuit must be broken to allow the ammeter to be connected in series in the circuit. The ammeter becomes part of the circuit's connection. See Figure 2.4

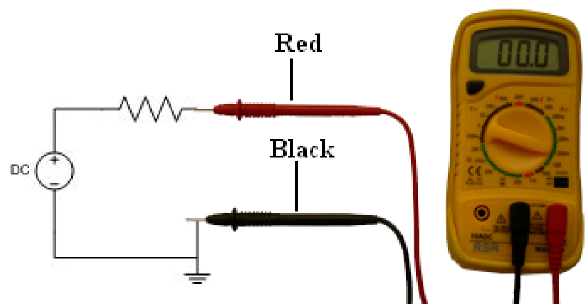


Figure 2.4: Measuring Current

3. To measure resistance, the component being measured must be removed or the power source must be disconnected, and place the ohmmeter in parallel with the component. See Figure 2.5

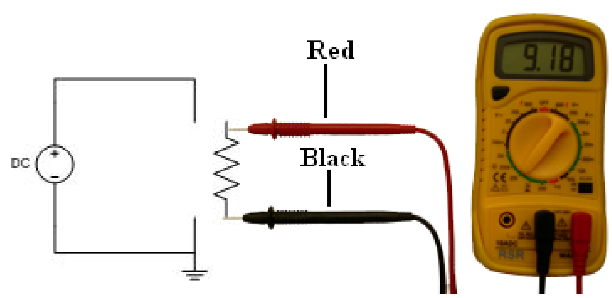


Figure 2.5: Measuring Resistance

2.5.3 Measuring Resistance

An ohmmeter is one of the useful functions in the digital multimeter (DMM). Since the ohmmeter uses its internal battery to conduct the resistance test, there must not be any power sources connected to the circuit. To test for resistance follow the procedures below:

1. Set the DMM to the Resistance or Ohms measurement setting, which is the region marked with "Ω", "R" or "Ohms". Figure 2.6 highlights the Ohmmeter region for an RSR MAS830 DMM. Note that your DMM might be different than the one in the picture.
2. Connect the black probe to the jack marked "COM", "GND", or "-"
3. Connect the red probe to the jacked marked "VΩmA" as shown in Figure 2.6 *(marked "Ω", "R" or "Ohms")*.
4. Put the leads from the DMM on each side of the component being measured as shown in Figure 2.7. If the DMM screen displays "1. ", this indicates that the range setting should be higher or the resistance is more than the maximum which can be measured on the range setting. For example, the Ohmmeter's rotary switch is at the "2k" mark. It should be changed to "20k" for a proper reading. If the DMM screen displays ".000", this indicates that the range setting should be lower. For example, the Ohmmeter's rotary switch is at the "200k" mark. It should be changed to "20k" for a proper reading. Continue adjusting the range setting as necessary.

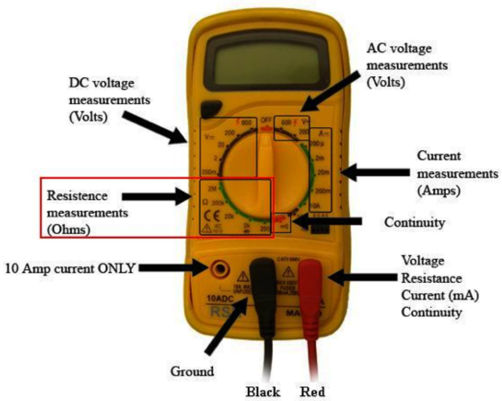


Figure 2.6: Digital Multimeter

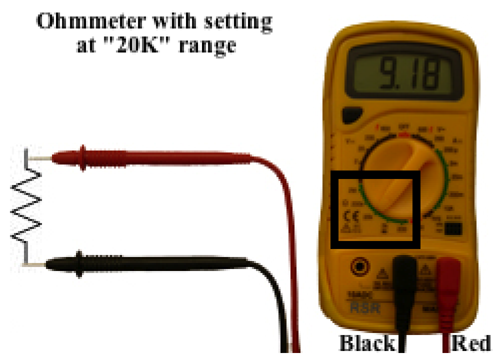


Figure 2.7: Using Digital Multimeter

5. For reading the value, each range of the Ohmmeter has a letter indicating the prefix for the unit. For example, the range setting of "20k" indicates that the unit is in Kilo Ω. Figure 2.7 shows that the Ohmmeter is set at "20k" range, the reading on the screen is "9.18." This means the resistance should be roughly 9.18KΩ.
6. Be sure hands are not making contact with the tip of the probes because a body appears as another resistor in parallel with the one being measured.

2.6 Procedures

In this section, different lengths and widths of conductive paper will be used to explore the resistance equation. Using scissors, cut the piece of paper provided as shown. Set the strip marked ”Keep for Lab 3” aside, as it is needed for the next lab, where a variable resistor is used to make a mini piano circuit.

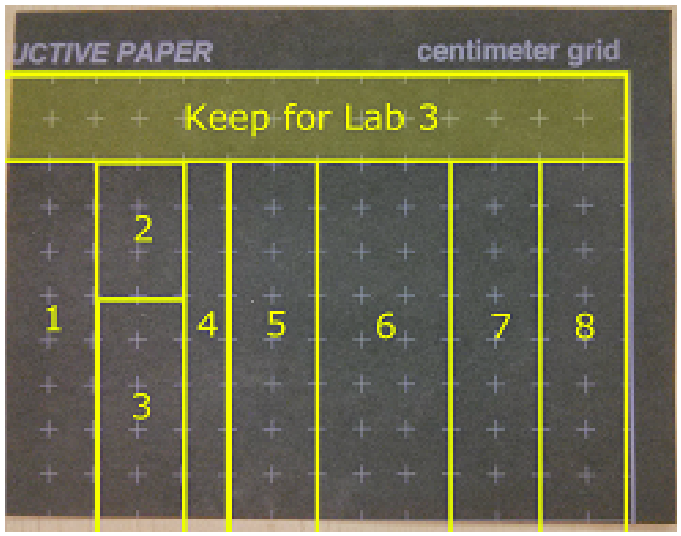


Figure 2.8: Cut the paper as shown.

2.6.1 Length

Explore the relationship between resistance and length by using strips numbered 1, 2, and 3. In this test, resistivity and cross sectional area are constant and length is varied. Measure the resistance of each of these strips using a DMM.

$R = \rho \frac{L}{A}$

Strip 1 Resistance = Ω

Strip 2 Resistance = Ω

Strip 3 Resistance = Ω

2.6.2 Width

Explore the relationship between resistance and cross sectional area by using strips numbered 4, 5, and 6. Resistivity, length, and thickness are constant. The width portion of cross sectional area is varied. Measure the resistance using the digital multimeter. *(Hint: Set the rotary switch to “200k”)*

$R = \rho \frac{L}{W \times T}$

Strip 4 Resistance = Ω

Strip 5 Resistance = Ω

Strip 6 Resistance = Ω

2.6.3 Thickness

Using strips 1, 5, or 7, explore the relationship between cross sectional area and resistance. Measure the resistance by using a digital multimeter. Use the resistance equation to calculate the approximate thickness of the paper. Assume the resistivity constant $\rho = 2.68\ \Omega m$. Convert all measurements to SI units before doing calculations.

$R = \rho \frac{L}{W \times T}$

Resistance = Ω

Thickness =

2.7 Variable Resistor

In this section a variable resistor, also known as a potentiometer will be created using a strip of conductive paper. The potentiometer could be used as a variable resistor in the circuit or as a voltage divider. For this lab, the potentiometer will be used as a voltage divider. Common applications that use a potentiometer are a light dimmer switch, a power supply, and speaker volume.

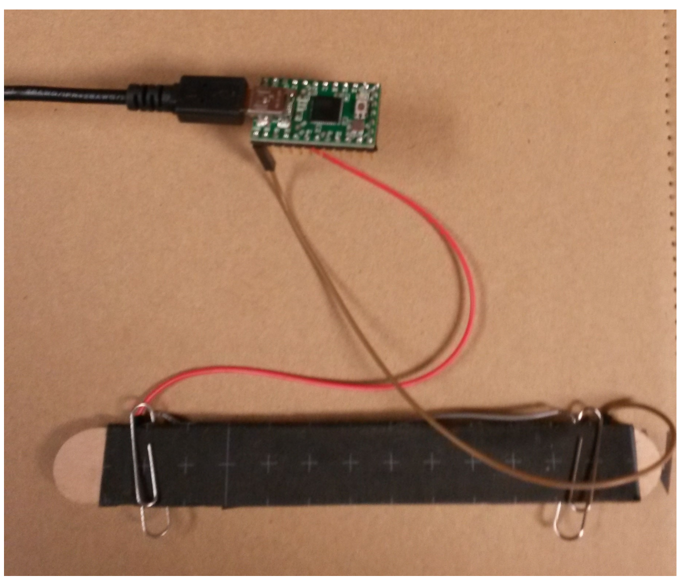


Figure 2.9: Conductive Paper Voltage Divider

1. Stick one paper clip each into the ends of two prototyping wires from the ECE 111 kit (look at figure 2.10 for a reference). Attach the other end of the wires into the VCC and GND pins on the teensy (make sure to plug the teensy into a power source).

Figure 2.10: Paperclip Connection

2. Attach one paper clip to one edge of the conductive paper and the other paper clip on the opposite edge.

   There is now 5V across the conductive paper.

3. Use a digital multimeter to measure the voltage at each grid line by putting the black lead of a DMM at GND and pressing the red lead against the paper at each grid line (each grid line is $1cm$ apart).

4. Record the measurements in Figure 2.11 and graph the data using Figure 2.12.

Measuring Point	Distance From Reference Point (cm)	Voltage (V)
A		
B		
C		
D		
E		
F		

Figure 2.11: Variable Resistor Table

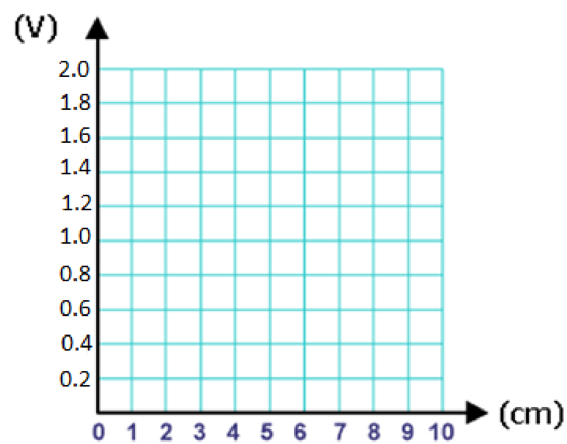


Figure 2.12: Voltage vs. Distance

TA Signature: ______________________

(Lab Work Complete)

2.8 Study Questions

Please type out your answers to the following questions. They will be turned in at the beginning of next lab.

1. List 3 ways the resistance of a resistor can be decreased. *(Hint: use the equation for resistance)*
2. List several products that are engineered using materials and devices concepts. Also, explain how they are related to materials and devices.
3. Find an OSU professor in the materials and devices track and describe one of their current research projects.

2.9 Challenge

Create a conductive paper potentiometer that can vary the intensity of an LED when connected in a circuit. For full points, demonstrate the working circuit and draft a schematic of the working circuit.

Chapter 3

Signals and Systems

3.1 Introduction

Signals, including audio (speech, acoustics, music), image (video, multimedia, medical scans) and remote sensing data, are phenomena that vary with time, space, or other parameters. Systems can be regarded as devices that manipulate signals. The disciplines of signal and image processing are concerned with the analysis and synthesis of signals and their interaction with systems. In communications, the objective is to transfer information (signals) from one or many sources to one or many destinations, which requires the design of transmission schemes (e.g., modulation and coding), receivers, and filters.

The Systems, Signals, and Communications area of interest covers the fundamentals of analog and digital signals and systems, the mathematical tools for the analysis of determinate and random signals, and applications to digital signal processing, digital image processing, and digital/analog communications.

3.2 Section Overview

This lab uses the Teensy in a simple circuit that acts like a piano. Using a variable resistor as input, an attached speaker will produce at least an octave of distinct musical notes. Later in the lab, application programming (programming for a computer) is used to interface with the embedded programming (programming for a device with hardware, like the Teensy2.0) to create a song composer program.

3.3 Objectives

- Learn to use a schematic to correctly build a circuit
- Download the ECE111 code
- Program the Teensy

3.4 Materials

- Teensy
- USB to Mini USB Cable
- ECE111 Kit
  - 0.1uF Capacitor
  - Speaker
  - Prototyping Wires
- Tool Kit

3.5 Building the Circuit

In the previous lab, a potentiometer was created out of conductive paper. In this lab, another potentiometer will be made out of conductive paper, but this time attached to a popsicle stick so that it will be more robust. This potentiometer will be used as a voltage divider to send an analog voltage to the Teensy. The Teensy will then interpret the analog voltage as a specific pitch and play the pitch using a small speaker as shown in Figure 3.1.

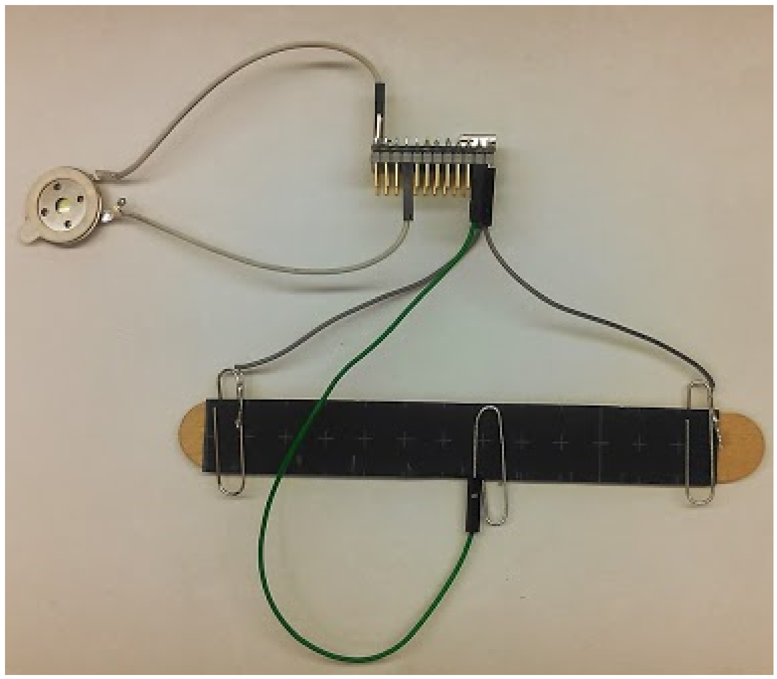


Figure 3.1: Completed Project Example

Figure 3.2 is a schematic for the piano circuit that is being built. A schematic is a diagram which shows every component and connection in a circuit. The schematic in Figure 3.2 shows how to correctly connect the potentiometer, speaker, capacitor, and Teensy.

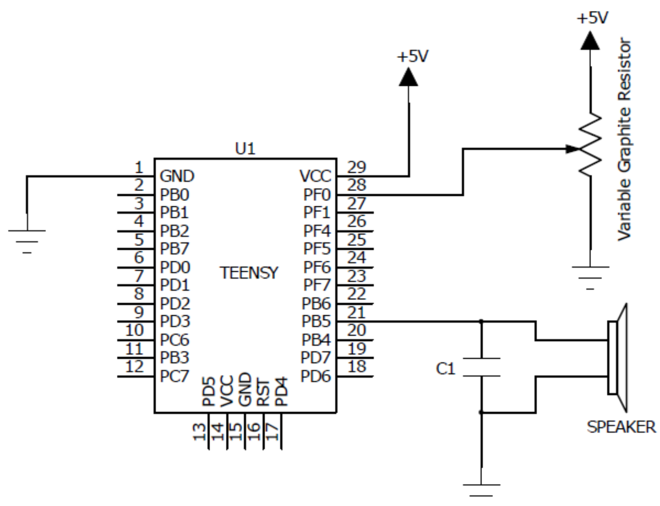


Figure 3.2: Simple Piano Schematic

Using paper clips to make a connection
The same paper clip method from lab 2 will be used here to make the potentiometer. A third prototyping wire attached with a paper clip will be needed to complete the potentiometer this time. Finish building the circuit according to the schematic (the component marked C1 is a capacitor and is provided by your TA. You must solder its two ends to the two ends of the speaker, orientation does not matter). In the end, you will have built a miniature piano!

3.6 Download the Source Code

The code for each lab for ECE 111 is located on the TekBots website[1] as a .zip file . Follow these instructions to download the code.

1. Navigate to the ECE 111 page on the TekBots website.
2. Download ”ECE 111 Programs” located under **Important Documents**
3. Save the .zip file in the desired location.
4. Extract the contents of the .zip file into the Z:\drive.

> Saving files on the Z:\drive allows for them to be accessed from any engineering computer. To access the Z:\drive from a personal computer, refer to `http://engineering.oregonstate.edu/computing/fileaccess/`

[1] http://eecs.oregonstate.edu/education/courses/ece111/

3.7 Program the Teensy

Download Drivers
Communication between a computer and the Teensy requires USB Drivers. Download the drivers on the lab website. The link is located under *Software Used*.
Download Loader
To program the Teensy, a loader application is necessary. This loader takes a .hex file (one of the files in the .zip that was downloaded) and loads it onto the Teensy. The .hex file contains the compiled code and is used to tell the microcontroller how to interface with the hardware correctly. The Teensy Loader Application is an executable that will need to be downloaded.

1. Go to `http://www.pjrc.com/teensy/loader.html`
2. Select the appropriate operating system and save the loader on a local drive.

   The Teensy Loader Program will not initially run from the network Z:\drive because of security permissions enforced by the University. It must be saved onto your computer's local drive or the Z:\bin\directory. If Z:\bin\does not exist, it can be generated on TEACH. The bin directory has special permissions that allows .exe files to be executed.
3. Run the loader. Figure 3.3 will appear on the screen.

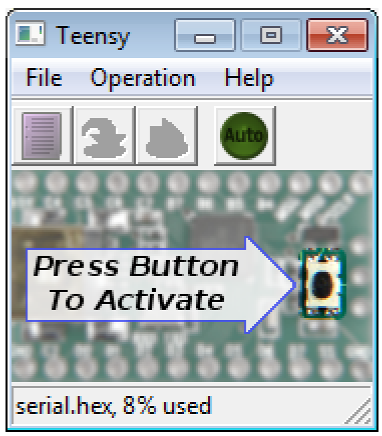


Figure 3.3: The Teensy Loader

Load HEX file onto Teensy
Follow these steps to load the .hex file onto the Teensy:

1. Open teensy.exe.
2. Plug the mini side of the USB to mini cable into the Teensy.
3. Plug the other side of the same cable into the computer.
4. Press the hardware reset button on the Teensy as indicated by the picture on the Teensy Loader Application.
5. Click the *Open HEX File* button in the Loader App. 
6. Navigate to the location where the lab code was saved.

   .\ECE111Files\HexFiles\Lab3.hex

7. Select the .hex file for the current lab and press *Open*.
8. Click the *Program* button in the Loader App. 
9. Click the *Reboot* button in the Loader App.

The code for this lab has succesfully been loaded onto the Teensy if a message says ”Download Complete” on the Loader App. If built correctly, pitches will play through the speaker when the paperclip is dragged across the conductive paper strip.

3.8 Application

In this section, Python software interfaces with the C firmware on the Teensy2.0 to create an embedded system. A GUI built with Python is used to compose a song that the Teensy will play on its speaker.

1. Run composer_qt.py located in the .*Lab3**PythonGUI*\\ folder

   The GUI in Figure 3.4 should appear. If nothing happens, the various python components may not have been installed correctly; refer to the *Python Install Guide* located on the lab website for help.
2. To add notes, select the desired length and pitch and click ”Add”.
3. Optionally use the slider to change the tempo of the song.
4. Select a COM port from the drop down menu to enable the ”Play” button. Select the Port that the Teensy is connected to.

   The port that the Teensy is located on can be quickly identified by unplugging the Teensy, clicking ”Scan” to refresh the port list, plugging the Teensy back in, and clicking ”Scan” once more to refresh the port list. Which ever COM port appeared after refreshing the list is the port the Teensy is on.

Use the ”Remove” button to delete the selected, individual note and the ”Clear” button as necessary while composing a song. For full lab credit, use the composer to create a recognizable song. Figure 3.5 shows the GUI with some notes entered in the queue and ready to output to the Teensy.

Figure 3.4: Composer GUI when first opened.

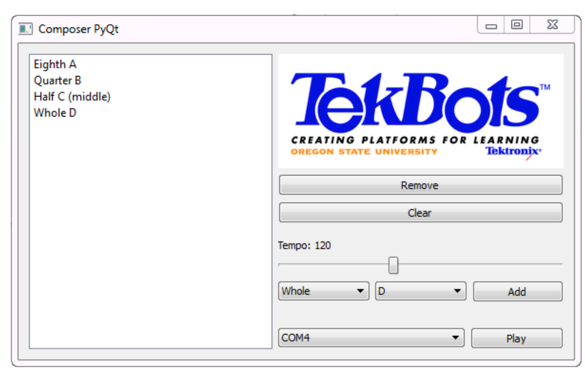


Figure 3.5: Composer GUI after adding notes to the queue.

TA Signature: ______________________________

(Circuit Complete and Working with GUI)

3.9 Study Questions

1. What are some of the applications of signals and systems in everyday life? (Think of anything that has a transmitter and receiver.) Name at least two.
2. Name two potential uses for a Python GUI application in other classes.
3. How does the capacitor affect the sound generated from the piano? Why does it do this?

3.10 Challenge

Improve the Python GUI used in this lab. There are suggested items at the beginning of Python file but other improvements are acceptable as well. Come up with a creative idea. The amount of extra credit awarded for this challenge is dependent on the difficulty of the improvement and the effort put in; a harder improvement will earn more points than a simple improvement.

Chapter 4

Energy Systems

4.1 Introduction

Energy Systems encompasses the disciplines of power electronics, electric machines and drives, power systems, and renewable energy. These disciplines must work together to generate, deliver, and condition power. Energy Systems covers everything between power generation and the end user, including: power electronic converters (e.g. power supplies), electric motors and generators (e.g. wind, wave, and other renewable energy generators), motor drives (e.g. hybrid and electric vehicles), and transmission systems (e.g. transformers and transmission lines).

4.2 Section Overview

This lab introduces DC (direct current) motors and their potential as an energy source. Later in the lab, the Teensy is implemented in a simple circuit that controls the speed of a motor. Using a variable resistor as input, an attached motor will change its speed in proportion to the change in resistance.

4.3 Objectives

- Generate energy using motors
- Use a Light Emitting Diode (LED) in a circuit
- Review schematics and programming the Teensy

4.4 Materials

- Teensy
- USB to Mini Cable
- ECE111 kit
  - L293 Motor Driver IC
  - LED
  - DC Motor
  - Small Rectangular Protoboard with hole in the corner
- Tool Kit

4.5 Using a Motor as a Generator

An electric motor is a machine that converts electrical current into mechanical motion. A good example is an electric lawn mower motor that converts the electricity provided by the battery into the mechanical motion of the turning blades. However, in many cases the process is reversed so that the motor is a generator that converts the mechanical motion into electricity. Two common examples of this are water dams and wind turbines. It can be demonstrated easily by connecting two motors together according to the schematic in Figure 4.1.

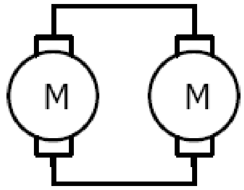


Figure 4.1: Schematic of a Motor as a Generator for Another Motor

With a partner, connect two motors together. Turn one motor and observe the reaction of the other. When one motor is turned, the mechanical motion is converted to electrical current which is transferred through the wire to the other motor which converts it back into a mechanical motion. Try turning one of the motors quickly and observing how the other motor responds.

4.6 Using a Motor to Model a Turbine

In the energy systems field, a turbine is a large engine that transfers energy from natural sources (wind, water, steam, etc.) into a form of energy that we can use to make electricity. To demonstrate how this works, use the motor provided in the ECE 111 kit to power an LED. In this case, the natural source of energy is going to be you! Work with a partner and connect the motor to an LED and resistor as shown in Figure 4.2. The resistor is necessary because LEDs can only handle a certain amount of current before they break. The resistor r "resists" the current to keep the LED safe. Always have a current-limiting resistor when working with LEDs. The long lead in an LED is positive.

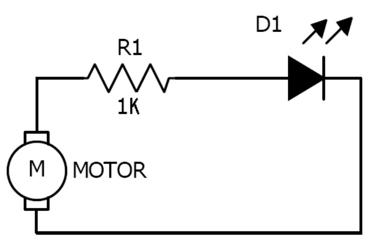


Figure 4.2: Schematic of a Motor as a Turbine

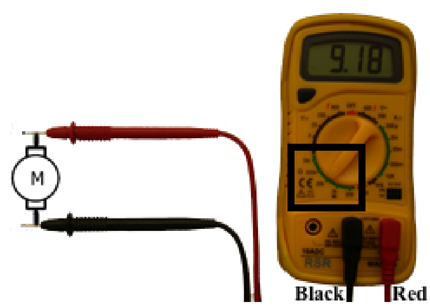


Figure 4.3: Connecting the DMM to the Motor

Once the motor is connected, turn the motor quickly while watching the LED. The LED should light up. Now measure the voltage generated by the motor by connecting a digital multimeter in parallel to the motor as shown in Figure 4.3. One person should measure the voltage generated by the motor while the other person turns the motor.

Find the minimum voltage necessary to turn the LED by turning the motor.

Minimum voltage necessary to power the LED ____________________V

Now try spinning the motor as fast as you can to see how much voltage you can generate. Record this value.

Maximum voltage generated ____________________V

4.7 Controlling Motor Speed with a Potentiometer

In the last lab a conductive paper potentiometer along with the Teensy was used to play different frequencies through a speaker. Using a similar concept in this lab, a normal 100kΩ potentiometer and the Teensy will be used to control the direction (forward/reverse) and speed of a motor. To help control the motor we need to use a motor driver (L293) that has been specifically designed to handle DC motors (google its datasheet to find what number corresponds to each pin).

Program the Teensy using the same process as last week, using Lab4.hex Then connect the motor controller, potentiometer, and the Teensy according to the schematic in Figure 4.4. *Use the small protoboard with one hole drilled for the L293.*

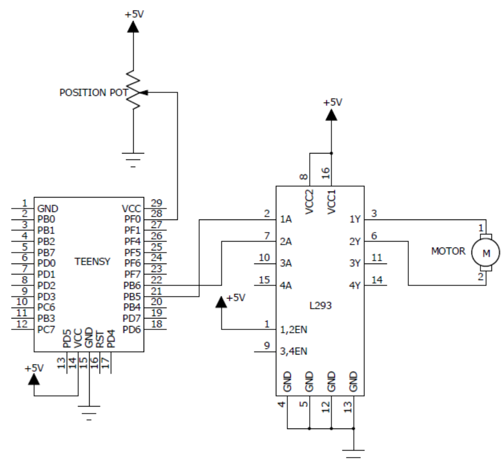


Figure 4.4: Schematic of Potentiometer Controlled Motor

The Schematic above isn't clear as to wihch lead of the motor and potentiometer should go where. Please reference the following top view of the potentiometer and motor so you know where to connect what.

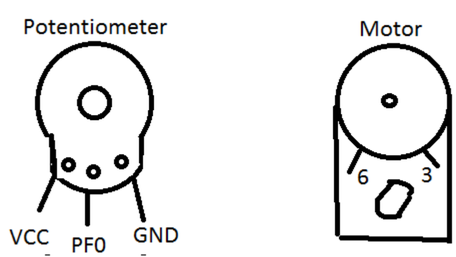


Figure 4.5: top view of potentiometer and motor

We recommend that you plan out where you're going to make connections to your L293 board by shading in the areas that will have solder blocks in Figure 4.6 (The red blocks are where your motor controller pins are).

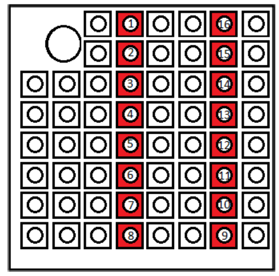


Figure 4.6: Back of protoboard with L293

Using a digital multimeter, measure the voltage at pin PF0 (where the potentiometer is connected to the Teensy) with the motor at a few different settings. Record the results below.

Voltage while Motor is in highest speed forward ______________________________V

Voltage while Motor is in highest speed reverse ______________________________V

Voltage while Motor is stopped ______________________________V

4.8 Controlling Motor Speed with a GUI

In this section, the speed of the motor will be controlled with a Python GUI instead of the potentiometer. For full lab credit, demonstrate the project working with the GUI and with the potentiometer.

TA Signature: ______________________________
(Lab Work Complete and Circuit Works with both Potentiometer and Python GUI)

4.9 Study Questions

1. Explain why when you use a motor as a generator it appears that not all of the mechanical energy is transferred from one motor to the other. *(Hint: research motor efficiency)*
2. What is the difference between a brushed DC motor and a brushless DC motor?
3. Research and list three potential careers that use concepts learned in this lab.

4.10 Challenge

When working with circuits such as these, it's useful to have something that indicates the current state. For this challenge, attach four LEDs to your Teensy in pins PF4-PF7 along with current limiting resistors (Ask your TA about how strong the resistors need to be). There is a part in this week's code that uses those four pins to create a speedometer. As the speed of the motor increases, more lights turn on. Besides connecting the LEDs, you will need to provide documentation for the speedometer. For each of the four LEDs, indicate the motor speed and voltage at which it turns on.

(Hint: The speed can be determined by counting the number of revolutions per minute, or rpm. Speed is equal to the circumference of the wheel hub multiplied by the rpm.)

Chapter 5

Robotics and Control

5.1 Introduction

The Robotics & Control field focuses on electro-mechanical control systems and their application to industry, military, aerospace, and research. Robotics & Control brings many engineering disciplines together requiring knowledge pertaining to electronics, mechanics, and software.

5.2 Section Overview

This lab modifies the DC motor control circuit built in the previous lab to create a servo motor. The Teensy is implemented in a simple circuit that uses a feedback potentiometer and a position potentiometer to control the position of the motor.

5.3 Objectives

- Modify a DC Motor into a servo motor
- Learn about feedback and control systems
- Learn control systems terminology

5.4 Materials

- Teensy
- USB to mini cable
- ECE111 Kit
  - Small white potentiometer
  - Plastic tubing
  - Square Protoboard with two holes
- Tool Kit

5.5 Making the Servo

Servos are made up of an electric motor mechanically linked to a potentiometer for feedback. In order to control them, specific code is needed. This code is provided for you on the ECE 111 page on the TekBots website. In the circuit being built in this section, a position potentiometer enables the user to define what position they want the motor to move to. The Teensy takes the user input, and powers the motor until it reaches the defined position.

For the Teensy to know when the motor has reached the correct position, a feedback potentiometer is used. It is attached to the shaft of the motor, so that the potentiometer turns with the motor. While the Teensy is powering the motor, it is also checking the feedback value. When the feedback matches the user input, the Teensy knows to stop the motor, because the defined position has been reached.

Using the motor control circuit built in the previous lab, follow the schematic in Figure 5.1 to make the necessary additions to create a servo.

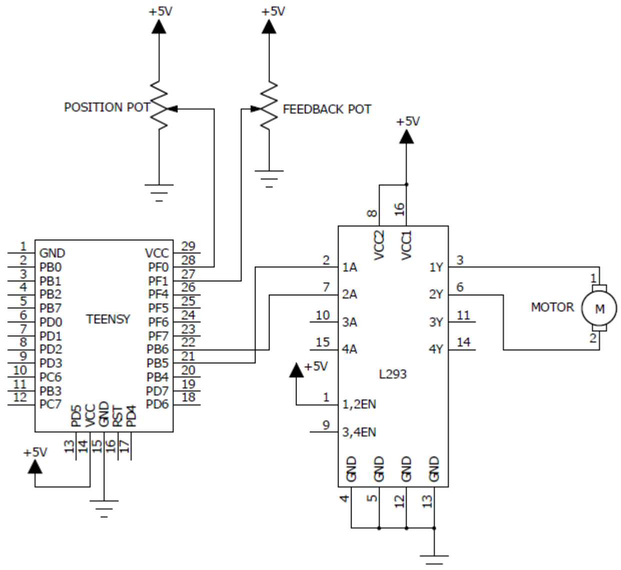


Figure 5.1: Schematic of a Motor as a Servo

A smaller white potentiometer needs to be added to the hub of the motor, as shown in Figure 5.2. Following are the instructions for attaching a feedback potentiometer to the motor.

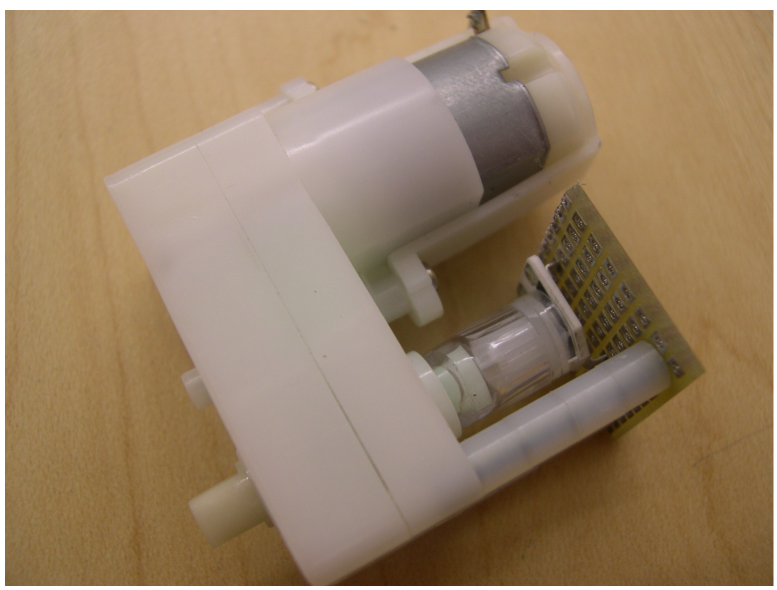


Figure 5.2: A motor with the attached feedback potentiometer.

1. Push the piece of plastic tubing around the inner shaft of the motor *(the green shaft next to the motor body)*.
2. Push the potentiometer into the the open end of the plastic tubing.
3. Mount the potentiometer on the protoboard so the drilled holes line up with the mounting holes on the motor and the potentiometer is in line with the motor shaft.
4. Place the bolts through the protoboard.

5. Add four spacers to each bolt.
6. Tighten the bolts into the motor, but make sure they are not too tight *(otherwise the potentiometer might not be able to move)*.

> The plastic tubing may need to be cut for it to fit without putting too much pressure between the motor and the board with the feedback potentiometer. Shorten the tubing if necessary.

7. Solder the potentiometer onto the protoboard.
8. Connect the lonely leg of the potentiometer to PF1 on the Teensy.
9. The other two legs will connect to VCC and GND of the Teensy as shown in 5.3.

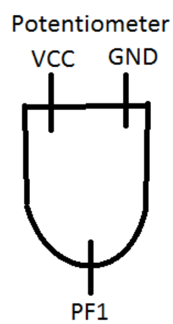


Figure 5.3: Smaller white potentiometer bottom view.

5.6 Controlling the Servo with a GUI

In this section, the position of the motor will be controlled with a Python GUI instead of a potentiometer. For full lab credit, demonstrate the project working with the GUI and with the potentiometer.

5.7 Control Systems

There are a wide variety of control systems. Since many systems require continuous feedback, closed loop control systems are very popular. It is this type of system being implemented on the servo circuit. A closed loop system uses the concept of feedback to control the output of a system. Feedback is when an output signal loops back and affects the input to a system.

For the implementation of a closed loop system in our circuit, see Figure 5.4. The control method being implemented in code on the Teensy is called PID (proportional-integral-derivative) control. PID control is widely used in industrial processes, and attempts to correct the error between the current state and desired state of a system.

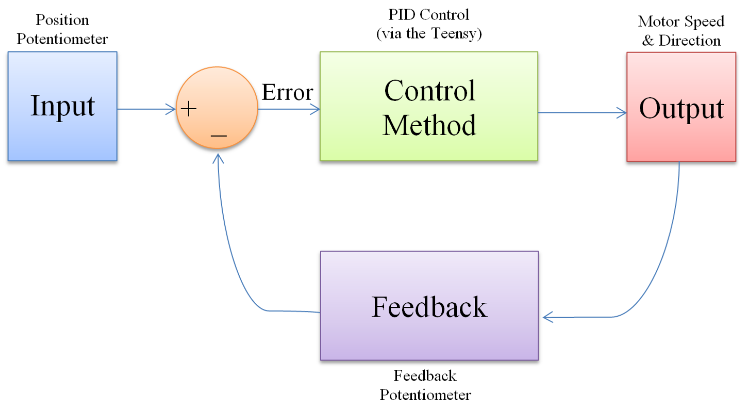


Figure 5.4: Block Diagram of a Typical Closed Loop System

5.7.1 Terminology

The control system design process begins by defining the output performance requirements. This performance is often measured by determining a set point and then comparing it to the output. The output waveform is measured using specific characteristics. These terms are defined below.

1. **Setpoint** - The desired output set via user input (in the form of a potentiometer in this case).
2. **Rising Time** - The time the system takes to go from 10-90% of the steady-state, or final value.
3. **Overshoot** - The amount that the actual output overshoots the final value (the point we want to reach).
4. **Settling Time** - The time required for the output to settle within a certain percentage of the final value.
5. **Steady-State Error** - The final difference between the actual output and the setpoint.

Using the terms defined above, label the graph in Figure 5.5. The graph shows the response of a typical PID closed loop system.

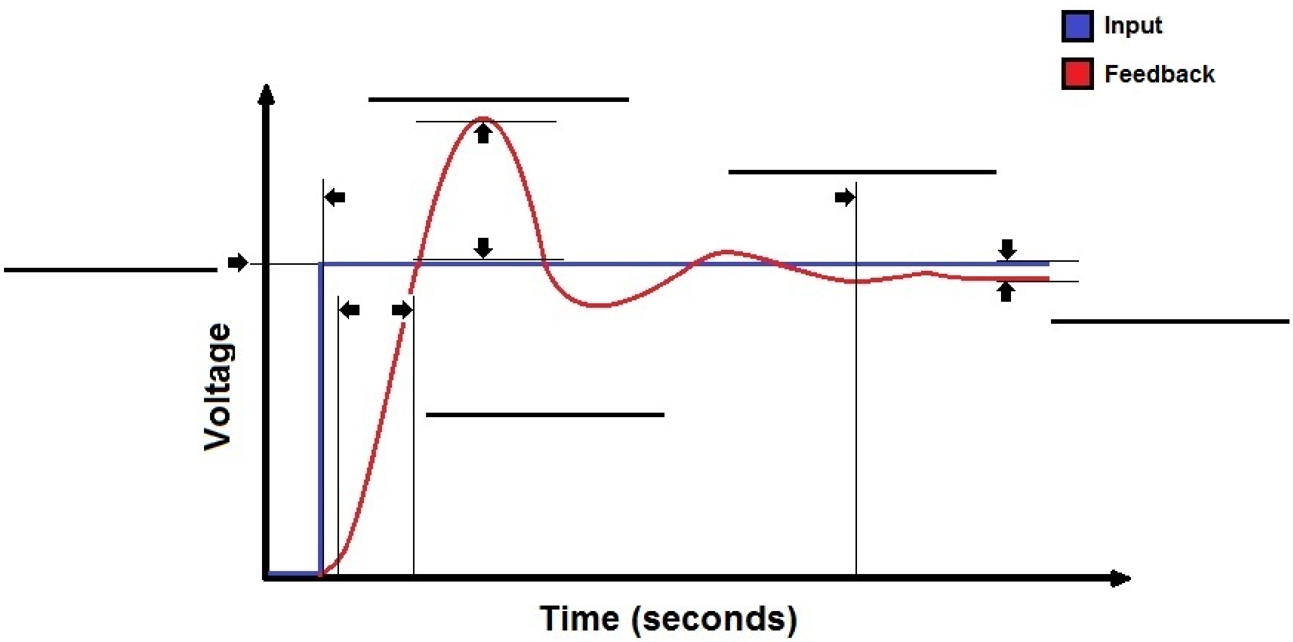


Figure 5.5: Graph of Closed Loop System Response

TA Signature: ______________________

(Lab Work Complete and Circuit Works)

5.8 Study Questions

1. What does the "P" in PID control stand for? How does it work?
2. What does the "I" in PID control stand for? How does it work?
3. What does the "D" in PID control stand for? How does it work?
4. List 3 examples of specific systems in which PID control is implemented.

5.9 Challenge

Improve the Python GUI used in this lab. There are suggested items at the beginning of Python file but other improvements are acceptable as well. Come up with a creative idea. The amount of extra credit awarded for this challenge is dependent on the difficulty of the improvement and the effort put in; a harder improvement will earn more points than a simple improvement.

Chapter 6

Sustainability and Renewable Energy

6.1 Introduction

The Sustainability and Renewable Energy field addresses global technological challenges balancing societal needs with environmental and economic tradeoffs. Topics addressed include energy conservation through more efficient electronic systems, intelligent energy management through smart grid approaches, and renewable technologies including solar PV, wind, and wave for energy generation and distribution. Students pursuing the Sustainability and Renewable Energy are of interest will engage in leadership development and demonstrate their leadership through community service related to sustainability. It is recommended that the leadership service take place as part of an international experience.

6.2 Section Overview

A number of activities have been done in lab that deal with the various electrical and computer engineering tracks here at OSU. However, many problems you'll deal with in the future will involve multiple electrical engineering disciplines. This lab involves using photovoltaic cells (sometimes known as solar cells), which encompasses two of the areas of interest that were covered before: Materials and Devices and Energy Systems. Ideas from these two areas are combined to use a green form of energy and relate to the new Sustainability and Renewable Energy area pf interest.

The completion of this project will result in a solar cell positioning system. The Teensy will rotate a motor with a solar cell attached to it. The voltage of the solar cell will be read using the ADC (Analog-to-Digital Converter) in the Teensy, and storing that data. Then, the motor will rotate back to the point where the voltage from the solar cell was highest (where it is converting the most energy).

6.3 Objectives

- Solar Energy and the integration into electronics
- Analyze efficiency tradeoffs

6.4 Materials

- Teensy
- USB to mini cable
- Protractor
- ECE 111 Kit
  - Photovoltaic cell
  - Rectangular piece of protoboard with single drill hole
  - Cut motor adaptor
  - 1" screw and nut
- Tool Kit

6.5 How Light is Affected by the Angle

The amount of light and heat energy received at a point on the globe is directly affected by the angle the sun's rays strike the earth. This angle is affected by location, time of day, and season because the Earth is constantly orbiting around the sun and revolving upon its tilted axis. As shown in Figure 6.1, the reason that the poles are colder and have greater fluctuating day lengths than the rest of the earth is because the sunlight is spread over a greater area in those regions, and because the light also has to go through twice as much atmosphere, further dissipating the rays and reflecting more of the energy back into space.

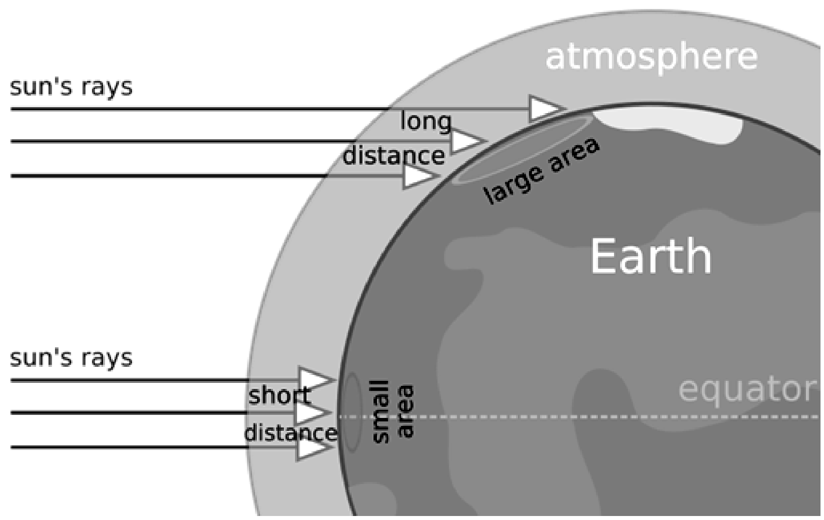


Figure 6.1: Sun's Rays hitting the Earth

6.6 Photovoltaic Cells

A photovoltaic (PV) cell is a device that converts light directly into electricity. Many photovoltaic cells are made of silcon, which is a type of semiconductor. The energy from the light knocks electrons loose, allowing them to flow freely. This flow of electrons is a current, and by placing metal contacts on the top and bottom of the PV cell, we can draw that current off to use externally. For example, the current can power a calculator. Understanding PV cells is important, because alternative energy is a rapidly expanding field of engineering.

6.7 Modeling Concepts

The concept of the sun's rays hitting the earth at different angles can be simplified and modeled in lab using a photovoltaic cell and directed light source as shown below in Figure 6.2, and mathematics can support it. This is important, because while everything must start as a concept, for it to be accepted and proven, engineers rely heavily upon mathematics and physics to support their ideas.

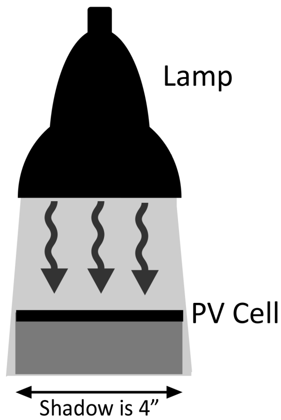


Figure 6.2: Flat PV Cell

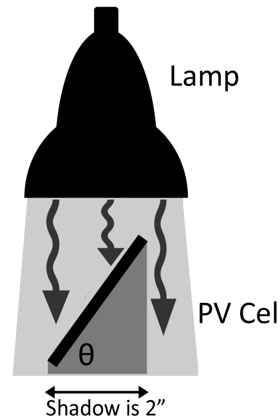


Figure 6.3: Angled PV Cell

6.7.1 Mathematical Support

$$Shadowwidth = SolarCellWidth \times cos(\theta)$$

Basic trigonometry shows us that the cosine of a 60^o angle is 0.5, whereas the cosine of 90^o is 0. Therefore, with a lamp beam of approximately 4 inch width directly hitting a 4 inch wide PV cell as shown in Figure 6.2, there will be maximum voltage output, because the most light is hitting it. The PV cell is at a 0^o angle with the ground, and therefore the cosine is 1. In Figure 6.3, the PV cell is at a 60^o angle with the ground, and therefore the cosine is 0.5, meaning that only half the amount of light is hitting the PV cell, and therefore the voltage output will be less as well.

6.7.2 Experimental Support

Now that there is mathematical support of the concept, there needs to be observational support as well through experimentation. A protractor is helpful but not required. Measure the voltages produced by the PV cell at no less than 7 different points between 0^o and 90^o. 0^o being what is shown in Figure 6.2. Graph these points on Figure 6.4 and analyze the resulting line.

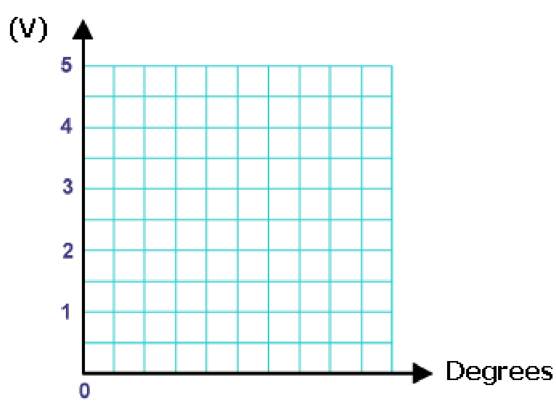


Figure 6.4: Voltage Output vs. Degrees

Distance between Lamp and PV Cell (at 0^o): ______________________________

6.8 Characterization

To characterize the solar cell there are a few tests that need to be completed. The open circuit voltage and short circuit current will be found in these tests.

1. Using the DMM, hook up each of the leads to the points on the solar cell. Turn the DMM knob to the “20 volt” setting. Place the solar cell by the window and then in a darker area. Record each individual voltage below.

   Sunlight Voltage____________________**V** **Dark Voltage**____________________**V**

2. Following the same procedure as above except now turn the DMM knob to the ”2mA” setting. Record both results below.

   Sunlight Current____________________**A** **Dark Current**____________________**A**

6.9 Assembly of Tracking Device

In this part of the lab, the goal is to create a light tracker using the servo motor circuit built in a previous lab in conjunction with a photovoltaic cell. The PV cell will need to attach to the servo so that the PV cell can still rotate approximately 180 degrees when placed below one of the lab lamps. After the PV cell is attached to the motor, program the Teensy. This code will turn the circuit into a light tracker. Basically, the PV cell will periodically scan the surrounding light area by rotating and recording the voltages at each point. Then, it will go to the point at which the voltage was highest and stay there until the solar cell isn’t receiving enough light. This way, the device will always find the strongest light source and can be the most efficient in its energy conversion.

To assemble the solar tracking device, a GM-8 motor along with a cut motor adaptor will be required. The code has been provided on the ECE 111 page on the TekBots website under the lab. What to attach to GND on the solar panel is marked with a sharpie. The schematic is in Figure 6.5 *(Hint: We will be using the same motor driver as in the Energy Systems Lab).*

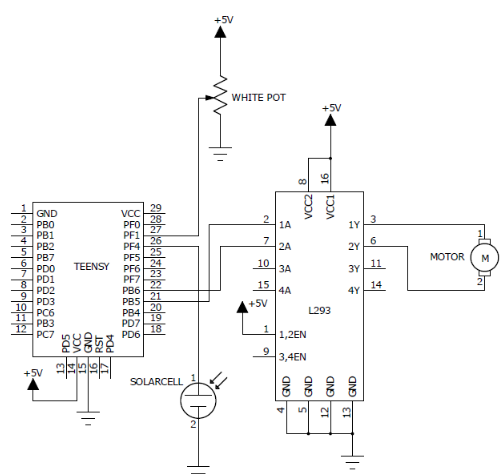


Figure 6.5: Schematic of Light Tracking Device

Mounting the Photovoltaic Cell to the motor

1. Place the 1 inch bolt through the hole on the protoboard.

2. Set the protoboard and bolt against the hub of the motor so the protoboard is resting on the side of the circle that has been cut flat and the bolt is resting in the slot on the face of the hub.
3. Put the nut on the end of the bolt and slowly tighten the bolt while holding the nut with a pair of pliers. *(Hint: This might work better with two people.)*
4. Make sure you tighten the bolt just enough to make a snug connection, but not so much that the bolt isn't flat against the hub.
5. The protoboard mounted to the hub is shown in Figure 6.6.
6. Mount the solar cell onto the protoboard with hot glue. Make sure not to cover up the mounting bolt on the protoboard.
7. Wait for the glue to dry before running the motor or moving the system around.

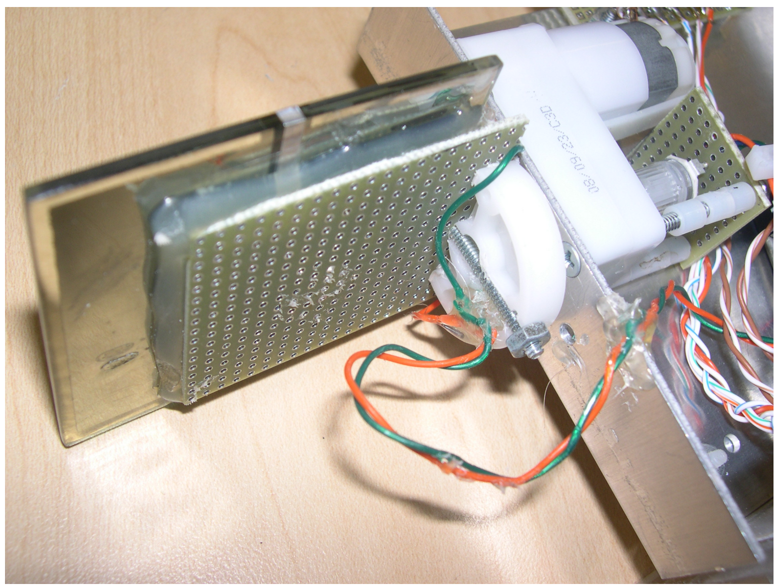


Figure 6.6: Completed Solar Servo

6.10 Controlling Solar Tracker with a GUI

In this section, the solar tracking data will be viewed with a Python GUI. As the tracker cycles through its range, the servo position and light intensity can be viewed in the Python window. Use steps similar to lab 3 to program the Teensy with Lab6GUI.hex and open the GUI. For full lab credit, demonstrate the project working with the GUI.

TA Signature: ____________________________
(Lab Work Complete and Circuit Works)

6.11 Study Questions

1. Name at least 3 applications that would benefit from solar cells or solar power in everyday life.
2. Explain in your own words why the voltages generated during lab created that kind of curve when graphed. Theoretically, it should be close in shape to a bell curve. What are some potential reasons why the graph isn't perfectly smooth?
3. Transparent electronics is something that has been developed here at OSU. One use they are being developed for is the creation of clear solar panels that can be used as windows. Using what you have learned from this lab about photovoltaic cells and light angles, discuss the pros and cons of using this new technology on skylights versus windows on the sides of buildings. Which one would be more efficient at energy conversion and why?

