ECE 111 Lab Manual

Fall 2011

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Contents

Chapter 0

Preface

0.1 How to Use This Manual

During this course, various tasks will be performed from the assembly of electronic devices, and through the development process of ECE 111. These tasks are divided into individual lab documents that correspond to what is being taught in the ECE 111 lecture.

Everything learned in lecture is relevant and useful in later (related) courses and in your future career. As various tasks are performed in these labs, try to pay attention to how the lecture material relates to these tasks. Understanding how the lecture material is used and applied will greatly improve your understanding of the topics as well.

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 are intended to give more practice and insight into what has been learned in lab and lecture. Some of the study questions will be due in lab.
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 being 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

Assembly of Tiny26

1.1 Section Overview

Welcome to the Tiny26 assembly manual. For many of you, this may be your first time ever soldering or assembling an electrical system. Therefore, this manual has been written with the assumption that you, the assembler, have very little knowledge of these skills.

1.2 Objectives

In this section, the following items will be covered:

1. Soldering
2. Using the resistor value tables
3. Using a digital multimeter

1.3 Materials

1. Tiny26 Lite Microcontroller Kit (tiny26.1)
2. Tekbots Universal Programmer (usb_prog.2)
3. Tool Kit
4. Digital Multimeter
5. Soldering Iron

1.4 Preparation

1. **Start with a clean work space.**
   Often times, the electronic components you are working with are very small, and if dropped, they could be easily lost (among your usual desktop clutter). Therefore, put away papers, keyboards, mice, clothing, etc.
2. **Keep your parts neatly organized.**
   Often times, parts come neatly packaged and ready for use. Don't just dump all of these parts together, such as in a box. Instead, if parts come separated, try to keep them that way. When you do have parts out of their packages, you may want to have a small container to keep them in, rather than spreading them out across the desk. Some people use ice cube trays, kitchen bowls, or other containers for convenient organization of parts.
3. **Care for your tools.**
   The quality of your electronics assembly is based on your own experience, and on the tools you use for the assembly. Hence, try to keep your tools in the best condition possible. When using your cutting tools, try not to cut things that the tools are not typically used for. An important lab rule to remember is that you take care of your soldering iron properly. We will talk more about soldering irons later in this section.
4. **Make sure you have everything you will need.**
   When working with electronics, there is nothing more annoying than not having the parts you need, and/or having to stop what you are doing to go find them. You can help prevent this by double-checking that you have what you need before you start. This includes manuals, tools, components, pens, and paper.

1.5 Procedure

The procedural steps for this lab are designed to help you build the Tiny26 board efficiently. When you encounter any of the symbols, which were outlined in the preface of this manual, pause to read them thoroughly and implement the warnings/suggestions that come with that corresponding symbols table.

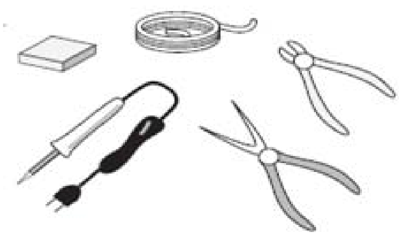
1.6 Purpose

Since this is possibly your first ever assembly of an electronic system, this guide will show you a step-by-step order of assembly. If you have multiple boards, you should assemble one, test it, and then assemble the next one. This prevents any mistakes you make from propagating. As we assemble the board, we will explain why we solder each part when we do, how it is oriented, and why it is placed in that position. Pay attention to these reasons, as in later courses, you will not be reminded of these concepts, and therefore you should retain most of these basic electronic concepts in this lab itself.

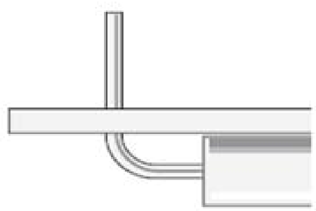
A good rule of thumb is to assemble circuits in an order that allows you to test it in pieces before the whole thing is assembled. If the circuit is very small, you may solder the whole thing before you test the first time, but in general you should assemble in sections.

1.7 How to Solder

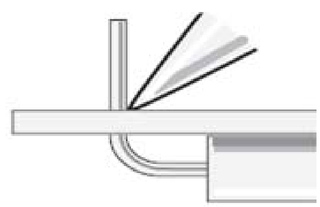
1. Plug in the iron and moisten sponge with water.



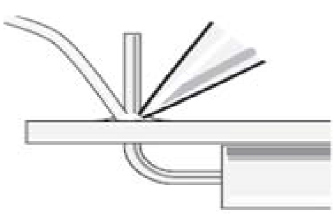
2. Bend the component's lead to fit the holes on the board, observing special orientation before inserting component.



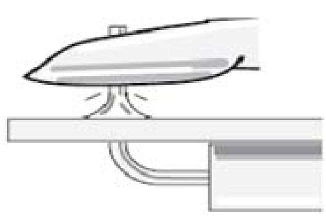
3. Clean the iron tip by wiping it across a wet sponge. Then tin the iron's tip using a small amount of solder. Heat the joint by placing the iron's tip at the component's base.



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.



Never touch component or the tip of soldering iron! Return soldering iron to its stand when not in use. In step 5 make sure you cover or hold the lead you are cutting to prevent it from flying away.

You can find a variety of different soldering tutorials online to help you with this process. More soldering hints can be found on the TekBots webpage.

The following need to be assembled on the Tiny26 Board

- Five Ceramic Disk Capacitors
- One 100K Ω resistor
- One Power Connector
- One Programming Connector
- Two Integrated Circuits
- One Battery Connector

1.8 Assembly of Tiny26

1.8.1 Step One: Adding Capacitors

For the assembly of this board, start first by placing the capacitors. The reasoning behind this is that the capacitors are not very tall and they are not static sensitive. This means that after they have been soldered in, they will not interfere with installation of other parts due to their height, and they will not be damaged by any static discharged by the soldering iron.

Static sensitive parts are components that can be easily damaged by static electricity if they come in contact with it. Semiconductors are especially prone to this type of damage, with the easiest ones to be damaged being integrated circuits. To avoid this type of damage, do not overly handle semiconductors while they are not soldered into a board or in static safe packaging.

Before assembling the board with the capacitors, you need to know how to identify the capacitors. Refer to Figure 1.1 and 1.2. You will notice that Figure 1.1 shows a Tiny26 printed circuit board before any assembly is done.

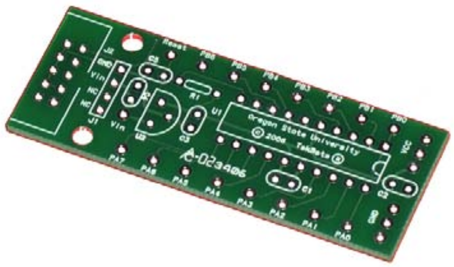


Figure 1.1: Top View of Bare Tiny26 Printed Circuit Board

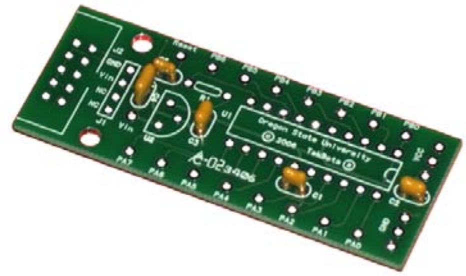


Figure 1.2: Tiny26 Circuit Board with Capacitors

In order to solder the capacitors, we need to know which capacitor goes where, and then solder them in place.

Identify the Position of the Capacitors

Refer to *Appendix A: Schematics* at the end of this document, to find out which capacitors go where.

To help you further identify their position, refer to Figure 1.3 to comprehend the meaning/code numbers on the side of the capacitors (look closely – they're very small).

.1uF → Code '104'
.33uF → Code '334'
1nF → Code '102'

Figure 1.3: Code Numbers and the Corresponding Capacitor

Once you know which capacitors go where, the next step is to solder them into place. Ceramic capacitors are 'non-polarized. This means that they can be inserted with either wire (lead) in either hole, and the capacitor will still work as expected. Other capacitors cannot do this, and we will learn about them in later courses. Figure 1.2 shows a view of the PCB, after the capacitors have been soldered into place.

1.8.2 Step 2: Adding Resistors

The next step is to install the resistors. This is again a part that is not very tall, and is not very sensitive to static energy; so, it can be soldered early in the construction phase. You only have one resistor in your kit, a 100K Ω. Resistors do not have a polarity, so you can insert it in any orientation you would like to. Insert the resistor in the place labeled 'R1' on the PCB. Figure 1.4 shows the Tiny26 PCB after the resistor is soldered into place.

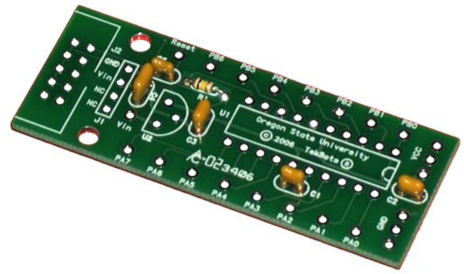


Figure 1.4: Tiny26 Circuit Board with Resistor

1.8.3 Step Three: Add Power and Programming Connectors

The next things to solder into place are the connectors J1 and J2. One of these is the power connector, while the other is the programming connector. Though these are taller parts, we need to solder them in before we put in the integrated circuits (to avoid damaging the circuits when we solder).

The connector used in J1 does not have a polarity, but J2 does. You will notice a small notch in the silkscreen border of J2. This should line up with the notch of the 2x5 male header piece that goes into J2.

Often, if a part is polarized, it will have some indication on the silkscreen (the white printing on the PCB) telling the assembler which way it should be inserted. These indications can vary, but a common one is a small plus or minus sign. In the case of integrated circuits, there will be a small dot or notch.

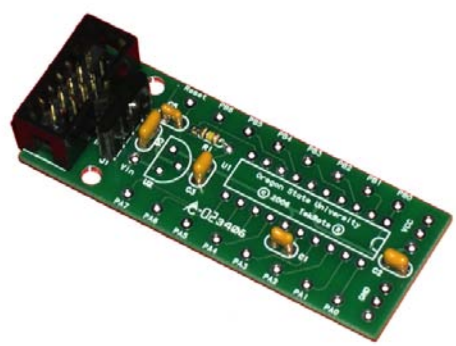


Figure 1.5: Tiny26 Circuit Board with Connectors Installed

1.8.4 Step Four: Add the Microcontroller Bay

The next component to solder into place is the U1 bay. The purpose of this bay is for easy removal of the microcontroller in case it becomes damaged. The bay is polarized, the small notch links to the orientation of the Tiny26 microcontroller. The small notch should match with the notch on the silkscreen.

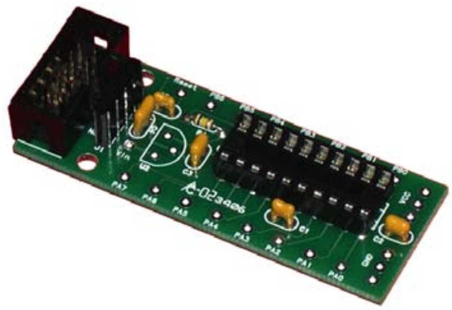


Figure 1.6: Tiny26 Circuit Board with IC Bay Installed

1.8.5 Step Five: Install Integrated Circuits

Before inserting the Tiny26 IC, complete the first two tests in the section named Testing. This will ensure that the correct voltage is being applied to the Tiny26. The 78L05 must be installed for the first two tests though.

The final step is to install the two integrated circuits for the board. Integrated circuits can come in a wide variety of different packages. The two circuits you have are a 20 pin through hole Dual Inline Package (20pin DIP) and a TO-92 3-pin package. You can start with either one, but pay attention to the polarity.

The DIP package will have either a small half circle or a dot, at one end of the chip. This denotes the end to the first pin of the circuit. For an example, look at Figure 1.7 and 1.8 to see the pin out of the Tiny26 chip, and the LM78L05 Voltage Regulator.

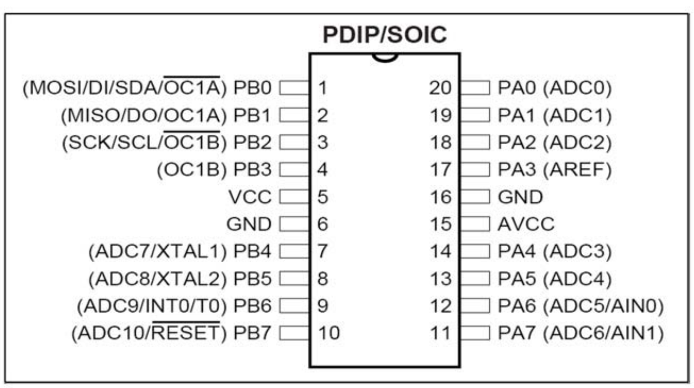


Figure 1.7: Pinouts of the Tiny26 Chip

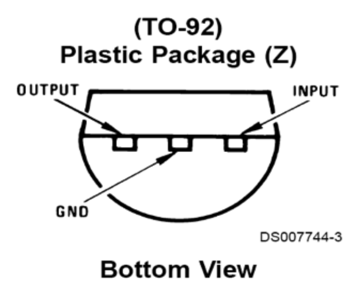


Figure 1.8: LM78L05 5V Regulator

When inserting the 78L05, you will notice that one end of the IC has a flat side. Make sure that the flat side of it lines up with the flat side of the silkscreen outline on the circuit board. Double-check the orientation of the chip before soldering in place.

Once the two integrated circuits have been installed, your board is complete. See the completed board in Figure 1.9 to compare your circuit with the one shown.

Some people like to install header's into the external connection pins, making for easier prototyping. This is not required, and is sometimes not desirable when the Tiny26 will be put into a permanent assembly.

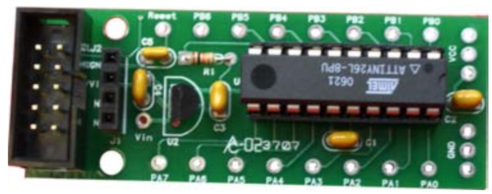


Figure 1.9: Completed Tiny26 Board

1.8.6 Step Six: Make a 9V Battery Connector

The Tiny26 board has an on-board power regulation that allows you to connect it to voltages from 6.7V DC (minimum input voltage required to maintain line regulation) through 35V DC (absolute maximum). It will convert the voltage into a regulated 5 volts as needed. This allows you to connect the board to the TekBots power system easily. If you do not have a TekBot system yet, a 9V battery clip is included for your use.

Before you make use of the 9V clip, you first need to connect a piece of 1x4 male header to the leads of the battery clip. The power connector on the Tiny26 is a TekBots standard connector. It is a 1x4 female header. Its pinout is shown in Figure 1.10.

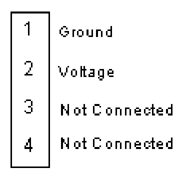


Figure 1.10: Pinout of Standard Tekbot Power Connnector

The reason that four pins are used is because if the power connector is plugged in backwards accidentally, nothing undesirable would happen. However, if only two pins were used, then the power and ground lines would be reversed, which becomes a bad situation.

Solder the battery clip leads, (as shown in Figure 1.11), to the 1x4 male header in the kit.

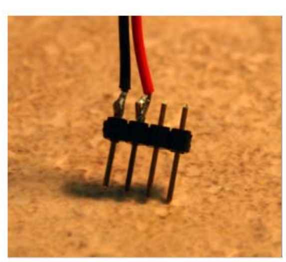


Figure 1.11: Male Header soldered to the 9V Battery Clip

Be sure the black wire is soldered to the outside pin, and the red wire to the one next to it.

This completes the physical assembly of the Tiny26 board. Next, you should move on to the section on testing after the digital multimeter section. If everything works at the end of the testing stage, you can assemble other Tiny26 kits with confidence.

1.9 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.

1.9.1 How to Use the Digital Multimeter

Setting up a dial switch: Choose an appropriate switch for measurement you want to make. See Figure 1.12

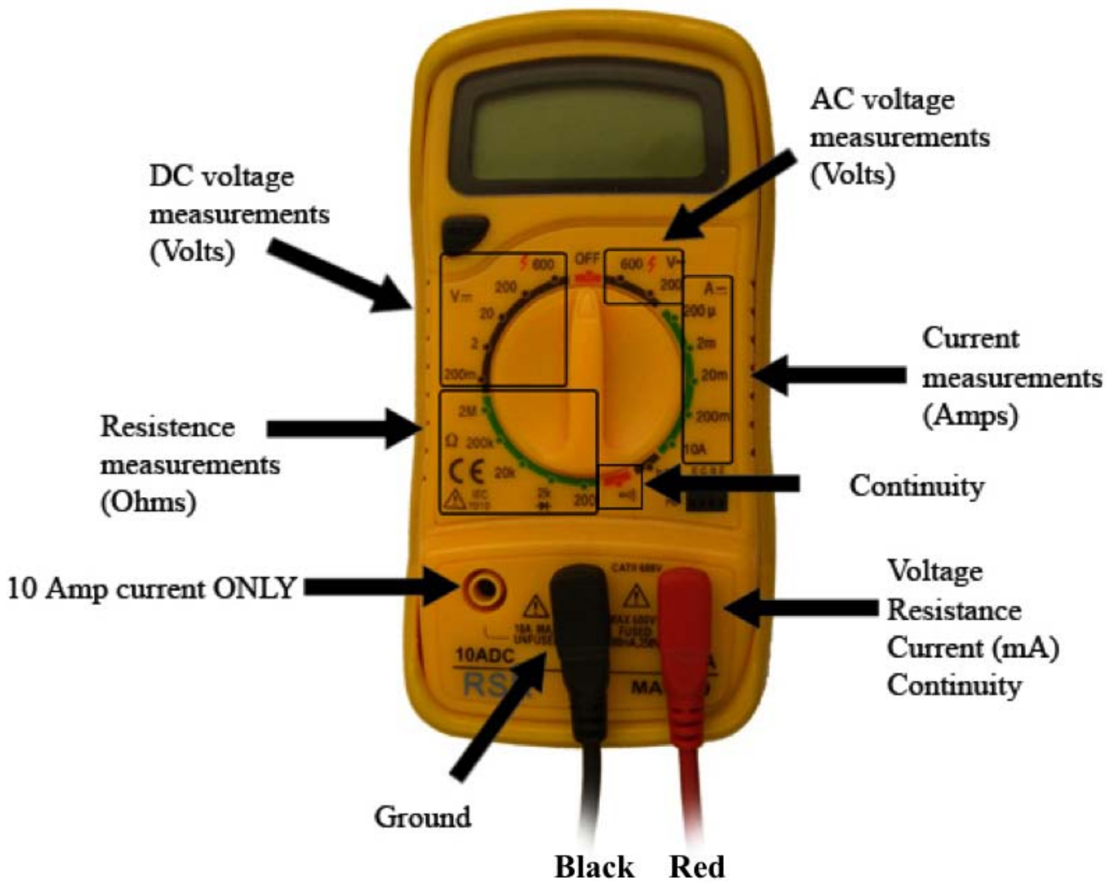


Figure 1.12: DMM Showing the Meter Switches

1.9.2 How to use DMM to measure Voltage and Current

1. To measure potential difference (voltage), the voltmeter is connected in parallel with the component. In Figure 1.13, the voltmeter is connected in parallel with a resistor.

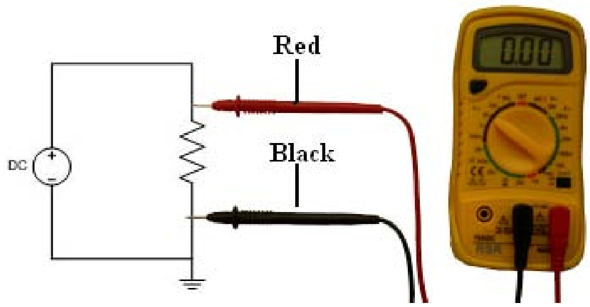


Figure 1.13: Measuring Voltage

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 1.14

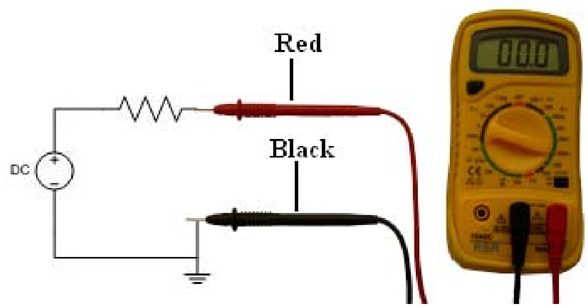


Figure 1.14: Measuring Current

3. To measure resistance, the component you are measuring must be removed or the power source must be disconnected, and place the ohmmeter in parallel with the component. See Figure 1.15

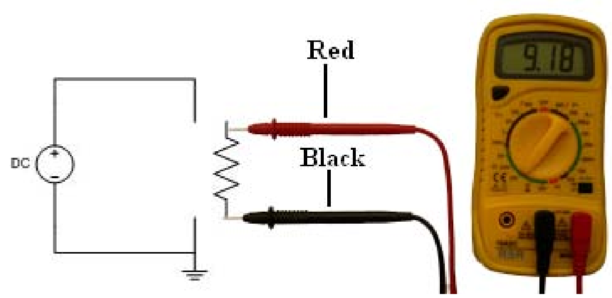


Figure 1.15: Measuring Resistance

1.10 Testing

To ensure that your Tiny26 circuit is working properly, several tests should be conducted. It is always important to test a circuit after building it to make sure it works properly to avoid damaging other parts or boards.

For tests 1 and 2, make sure the Tiny26 chip is *not* inserted into the microcontroller bay.

1. **Test the input voltage from the nine volt battery.**
   (Turn your multimeter to the 20 volt setting)

   There are three ways to test the voltage of the battery to make sure it is close to fully charged (9 volts).

   - Check the voltage straight from the battery by touching the black probe to the large battery terminal and the red probe to the small battery terminal and make sure it is around 9 volts.
   - Connect the battery clip to the battery and check from the red and black leads. Touch the black probe to the black wire, and the red probe to the red wire and measure the voltage making sure it is around 9 volts.
   - Connect the battery to the battery clip and then insert the four pins of the batter clip to J1 of the Tiny26 board (make sure the black wire is connected to the side of the header that says GND). Place the red probe on the small hole near J1 that says Vin next to it. Place the black probe on one of the three holes that are near the label GND on the opposite edge of the Tiny26 board and read the voltage making sure it is around 9 volts.

2. **Check the voltage output of the voltage regulator to make sure it is close to 5 volts.**
   (Turn your multimeter to the 20 volt setting)

   Plug the 9 volt battery into the battery clip and then insert the four pins from the clip into J1 on the Tiny26 board (make sure the black wire is connected to the side of the header that says GND). Place the red probe of the multimeter on one of the three holes near the label Vcc on the opposite edge of the Tiny26 board. Place the black probe on one of the three holes near the label GND (next to the Vcc holes) and measure the voltage.

3. **Make sure the Tiny26 is recognized by the computer.**

   - Plug the Tiny26 board into the Universal Programmer using the ribbon cable plugged into J2 on the Tiny26 board and J1 on the Universal Programmer. Plug the provided usb cord from the Universal Programmer to the computer.
   - Plug the 9 volt battery into the Tiny26 to provide power.
   - Open the Univeral GUI software on the lab computer:
     (a) Click Start $\rightarrow$ All Programs $\rightarrow$ TekBots Software $\rightarrow$ UniversialGUI $\rightarrow$ Universal GUI.
     (b) After the graphical user interface (GUI) opens up, select the AVR tab at the top.
     (c) Select ”osuisp2” as the Programmer.
     (d) Click the ”Identify” button to see if the computer recognizes the Tiny26 chip.
   - If the Output window at the bottom of the GUI reads ”Model = ATTINY26” or ”Model = ATTINY261” then it worked and the computer is recognizing the chip.
   - If it doesn’t identify the Tiny26, make sure you are powering the Tiny26 board and try again.
   - If it still isn’t working ask a TA to come look at it.

1.11 Resistor Values

A resistor is a component that limits electrical current. Current creates a voltage drop across two terminals. 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%

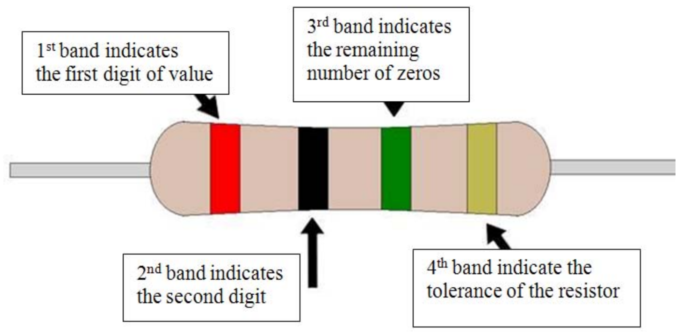


Figure 1.16: Resistor Color Code

From Figure 1.16, 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 $2,000,000 \times (1 + 0.05) = 2.1M\Omega$

1.12 Making Measurements

Use the resistor in the ECE 111 kit. This exercise is to get you familiar with using the DMM to measure resistance.

- Fill-in the band colors:

  ________ ________ ________ ________

- Fill-in values of the colors:

  ________ ________ ________ ________

- Calculated Resistance:

  ____

- Measure Resistance using DMM:

  ____

Are the values within the specified tolerance?

1.13 Study Questions

Lastly, turn in your answers to the study questions below. Please type your answers and keep clear clear and concise. Turn in the questions at the beginning o f the lab next week. You will be required to type all study questions for the future labs as well.

TA Signature: ____________________________
(Lab Work Readable/Board Works)

1. Looking at the LM78L05 Regulator datasheet found on the lab webpage. What is the maximum input voltage and the Peak Output Current (I_{PK})?

2. 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.

1.13.1 Challenge

Measure the resistance of resistor shown in Figure 1.17. Note: These resistors can be obtained from you TA.

Figure 1.17: Special Resistor

Is there anything special about this type of resistor?

Yes-Describe based on your measurements:

No-Describe based on your measurements:

TA Signature: ____________________________
(Answer is Correct)

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.

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

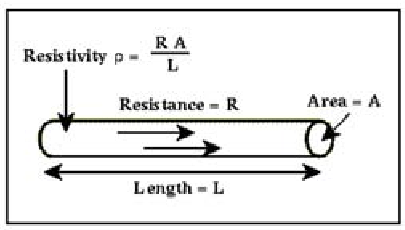


Figure 2.1: Finding Resistivity

2.3 Objectives

In this section, the following items will be covered:

1. The basics of resistance
2. Using the digital multimeter
3. Graphing data
4. Potentiometers

2.4 Materials

1. Digital Multimeter
2. Pencil
3. 9 volt battery and battery clip

2.5 How to Measure 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 your 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 2.2 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 2.2 *(marked ”Ω”, ”R” or ”Ohms”)*.
4. Put the leads from your DMM on each side of the component being measured as shown in Figure 2.3. If your DMM screen displays ”1. ”, this indicates that your range setting should be higher or the resistance is more than the maximum which can be measured on the range setting. For example, your Ohmmeter’s rotary switch is at ”2k” mark. You should change it to ”20k” for a proper reading. If your DMM screen displays ”.000”, this indicates that your range setting should be lower. For example, your Ohmmeter’s rotary switch is at ”200k” mark. You should change it to ”20k” for a proper reading. Continue adjusting your range setting as necessary.

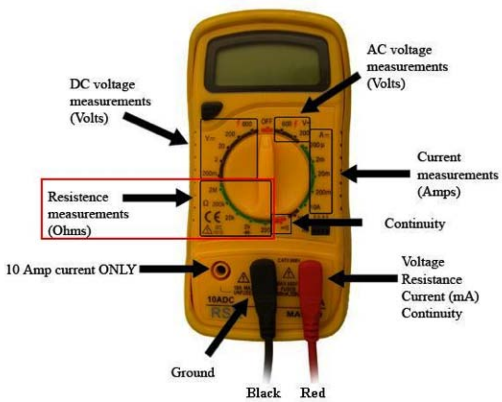


Figure 2.2: Digital Multimeter

Figure 2.3: 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 2.3 shows that the Ohmmeter is set at ”20k” range, the reading on the screen is ”9.18.” This means the resistance should be roughly 9.2KΩ.
6. Be sure your hands are not making contact with the tip of the probes because your body appears as another resistor in parallel with the one your are measuring.

2.6 Procedures

2.6.1 Length

Pencil lead, which is actually graphite and therefore conducts electricity, can be used as a resistor. Using a #2B pencil, fill in the boxes 2.4 to 2.6 to make resistors. Measure the resistance using the digital multimeter. Each individual box is 5 mm x 20 mm. *(Hint: Set your rotary switch to "200k")*

Figure 2.4: Length A

Resistance = Ω

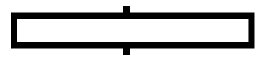


Figure 2.5: Length B

Resistance = Ω

Figure 2.6: Length C

Resistance = Ω

2.6.2 Area

Using #2B pencil, fill in the boxes 2.7 to 2.9 to make resistors. Measure the resistance using the digital multimeter. Each individual box is 5 mm x 40 mm. *(Hint: Set your rotary switch to "200k")*

Figure 2.7: Width D

Resistance = Ω

Figure 2.8: Width E

Resistance = Ω

Figure 2.9: Width F

Resistance = Ω

2.6.3 Thickness

Use a #2B pencil to fill in the boxes to make resistors. Be sure to fill each box *(Figure 2.10 and 2.11)* with different darkness. Measure the resistance by using a digital multimeter. Use the equation to calculate an approximation for the thickness of your resistor. Each box has an area of 10 mm x 40 mm. Assume the resistivity constant is $\rho = 8.5 \times 10^{-6} \Omega \bullet m$.

Figure 2.10: Dark Fill

Figure 2.11: Darker Fill

Resistance of Figure 2.10 = Ω Resistance of Figure 2.11 = Ω

Thickness of Figure 2.10 = (m)   Thickness of Figure 2.11 = (m)

2.7 Variable Resistor

In this section we will explore the applications of a variable resistor, also known as a potentiometer. The potentiometer could be used as a variable resistor in the circuit or as a voltage divider. Common applications that use the potentiometer are a light dimmer switch, speaker volume or power supply. To complete this section, follow the procedures below. Hint: Work in groups of 2-3.

1. Using a #2B pencil, fill in all of the boxes in Figure 2.13 below.

2. Strip both leads of a battery clip from your kit about $1/2$ an inch.

3. Spread wires of each lead for maximum contact as shown in Figure 2.12. Put the red wire to ”Reference Point” and the black wire to ”GND.”

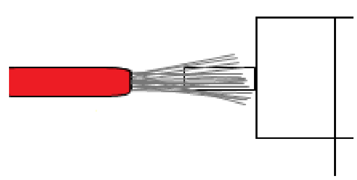


Figure 2.12: Maximum Wire Contact

4. Use your digital multimeter to measure the voltage at each labeled point (A-F) by putting the black lead of your DMM at GND point and moving the red lead of your DMM from left to right. Record your measurement in the table in Figure 2.14 and graph the data using Figure 2.15. The DMM setting needs to be at the Voltage region.

5. Repeat the procedures above for Figure 2.16, complete the table and graph for 2.17 and 2.18.

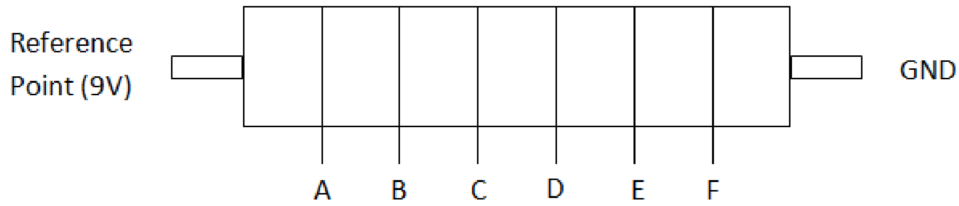


Figure 2.13: Variable Resistor

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

Figure 2.14: Variable Resistor Table

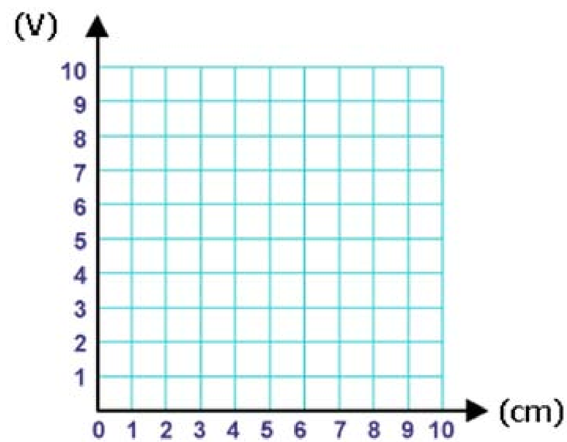


Figure 2.15: Voltage Vs. Distance

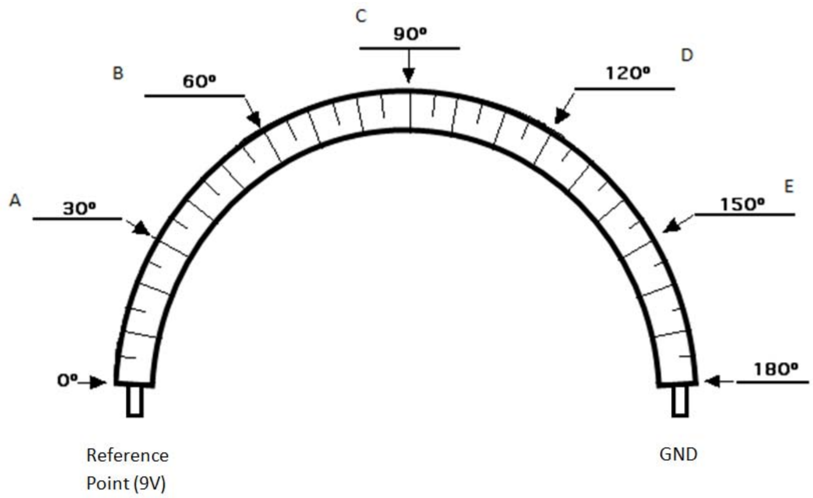


Figure 2.16: Voltage Protractor

Measuring Point	Degrees From Reference Point	Voltage (V)
A		
B		
C		
D		
E		

Figure 2.17: Variable Resistor Table

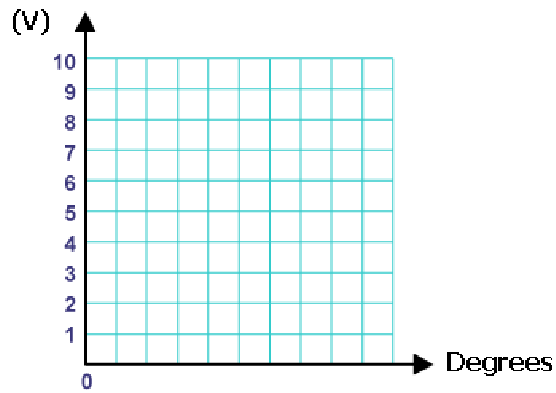


Figure 2.18: Voltage Vs. Degrees

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 you could decrease the resistance of a resistor. *(Hint: use the equation for resistance)*

2. If your voltage vs. distance graph is not linear, what could have caused this result?

3. List several products that are engineered using materials and devices concepts. Also explain how they are related to materials and devices.

4. Find an OSU professor in the materials and devices track and describe one of their current research projects.

2.8.1 Challenge

Create a variable resistor of graphite that could vary the intensity of an LED when connected in a circuit. For full points demonstrate the working circuit and make a schematic for what you build.

Chapter 3

Signals & 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 track 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 Tekbots programmer to program the Tiny26 microcontroller, which is then implemented 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 (8). Later in the lab, a few sample waveforms produced from the piano output are analyzed. The waveforms are caught using an essential electrical and computer engineering tool, the oscilloscope.

3.3 Objectives

In this section, the following items will be covered:

1. Downloading the ECE111 code repository
2. Programming the Tiny26 provided in the ECE111 kit
3. Learning to use a schematic to correctly build a circuit
4. Introduction to oscilloscopes, waveforms, and capacitors

3.4 Materials

1. TortoiseSVN software (Currently installed on lab computers)
2. TekBots Universal Programmer (usb_prog.2)
3. Tiny26 Microcontroller (tiny26.1)
4. Pencil
5. ECE111 Kit
6. Tool Kit

3.5 Downloading the Repository

A repository on Beaversource is used in ECE 111 to distribute the source code for for the labs[1]. To download this repository, we will use TortoiseSVN. The following instructions will download the repository onto your engineering student Z:\drive.

[1] http://beaversource.oregonstate.edu/projects/tiny26/browser/Classes/ECE111

1. Open a window to your Z:\drive on one of the lab computers.
2. Right click on blank space in the window.
3. Select SVN Checkout...
4. In the "URL of repository:" space, type the following website:

https://code.oregonstate.edu/svn/tiny26/Classes/ECE111

Tortoise SVN is case sensitive! Double check that the address is copied exactly as written.

5. Make sure the Checkout directory is correct (it should be Z:\ECE111 at this point). Click OK.
6. The Tortoise SVN Checkout window should pop up and show the download progress.
7. When the download is complete, click OK. You now have all the code necessary to complete this lab course!

3.6 Compiling the Code & Programming the Microcontroller

Remembering the correct command in AVR-gcc to compile the source code and the correct AVRdude command to program the machine code onto the microcontroller is tough. A tool called a makefile simplifies this process, and is included in each section in the repository. This makefile allows us to use the "make" command to compile the source code with AVR-gcc. The "make program" command compiles the source code, and also uses AVRdude to program the microcontroller with the Tekbots USB programmer. Lastly, a batch file, Programmer.bat, is used to easily call the makefile with a simple double-click. Here are directions for programming the microcontroller.There are two ways to do it (the first one is recommended).

3.6.1 Using a "batch" File

1. Open the ECE111 repository you just downloaded.
2. Go to "Lab 3 Signals Systems" → "code".
3. Plug the programmer into a USB port.
4. Use the rainbow cable to connect the programmer to the microcontroller.
5. Make sure the jumper on the programmer is on "USB Power," not "3.3V". This enables the programmer to power the microcontroller via USB.
6. Double-click on "Programmer.bat" This will open the command line window, and proceeds to compile the code and program it onto the microcontroller.
7. If the chip was programmed, the command line should display "Everything Compiled Fine!" and there will be no errors.

3.6.2 Using a "hex" File & the Universal GUI

1. Click Start → All Programs → TekBots Software → UniversialGUI → Universal GUI.
2. The Tekbots Universal Programmer v3.1 will pop up. Select the AVR tab at the top.
3. Select "osuisp2" as the Programmer.

4. Click ”Identify” to automatically select the Tiny26 as the Chip. It will show up as the ATTINY26.

> Make sure you’ve actually powered and connected the Tiny26 to the computer using the programmer. Otherwise, an error will pop up.

5. Check the Flash box, and click ”Browse”.
6. Navigate to and open the .hex file created by compiling. There should be one for every lab.
7. Click ”Write Flash”.
8. If the chip was programmed, the output window should display ”Operation Successful! Finished write to flash.”

3.7 Building the Circuit

In the previous lab you created a potentiometer out of pencil lead on a piece of paper. In this lab, you are going to make another potentiometer out of graphite from a pencil lead, but this time on a piece of protoboard, so that it will be more robust. You will use the potentiometer to play notes on a piano that is built using a Tiny26 and a small speaker as shown in Figure 3.1.

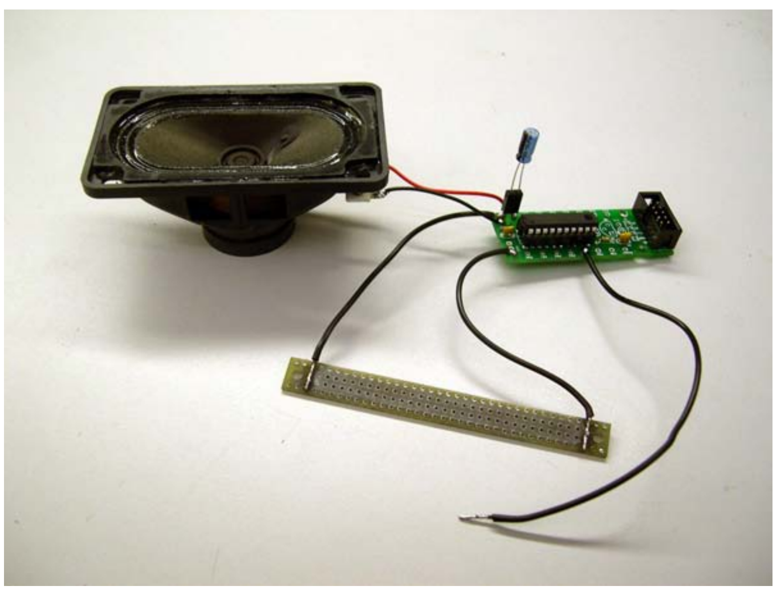


Figure 3.1: Example of Completed Project

Use pencil and make a wide band of graphite on the protoboard, similar to Figure 3.1. Since the protoboard in the kit is not cut to a small size, just use the edge of your board. Make sure that the block of graphite is filled in completely to ensure a good connection. Solder a wire to each side of the protoboard, as shown in Figure 3.2.

> As you make your potentiometer, periodically measure the resistance of it. The value decreases as you put more graphite on it (if the width and length stay the same). Keep going until the value reaches about 10kΩ. You may need to sharpen your pencil a few times to get to that point.

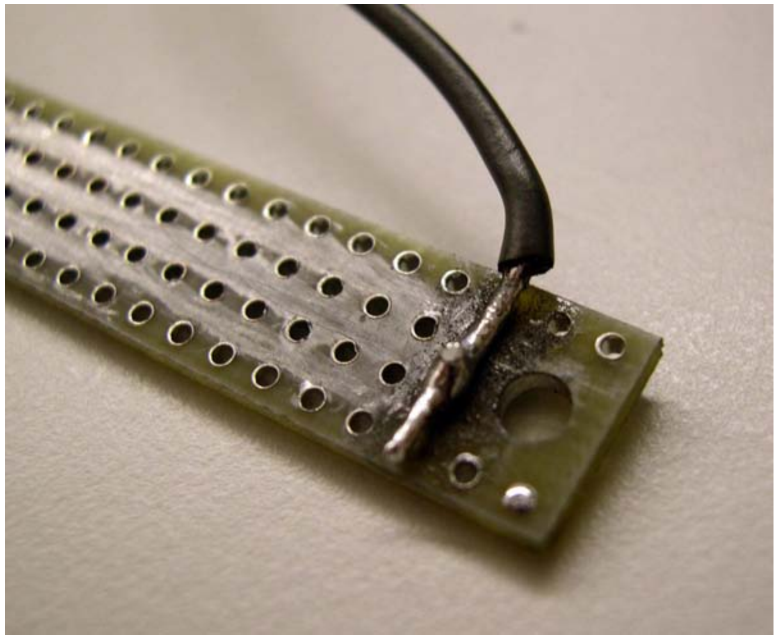


Figure 3.2: Properly connected protoboard

Figure 3.3 is a schematic for the piano circuit being built. A schematic is a diagram which shows every component and connection in a circuit. The schematic in Figure 3.3 shows how to correctly connect the potentiometer, speaker, capacitor, and Tiny26 board.

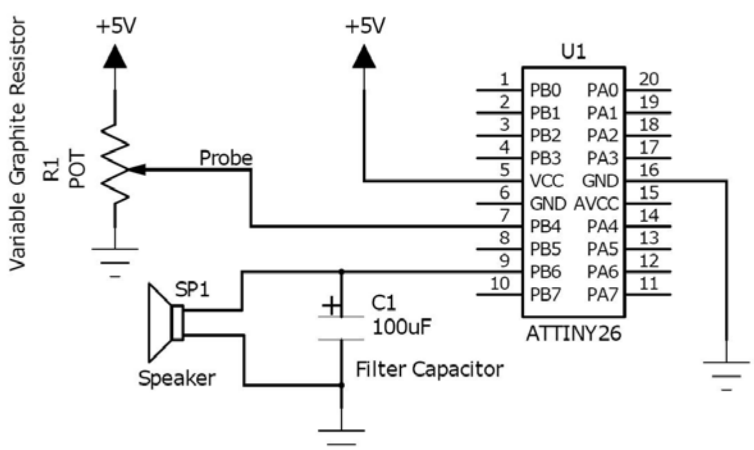


Figure 3.3: Schematic for building a simple piano

Finish building the circuit according to the schematic. Instead of soldering the 100 μF capacitor, use a piece of female header instead, so that it can be removed if desired as shown in Figure 3.4. In the end, you will have built a miniature piano!

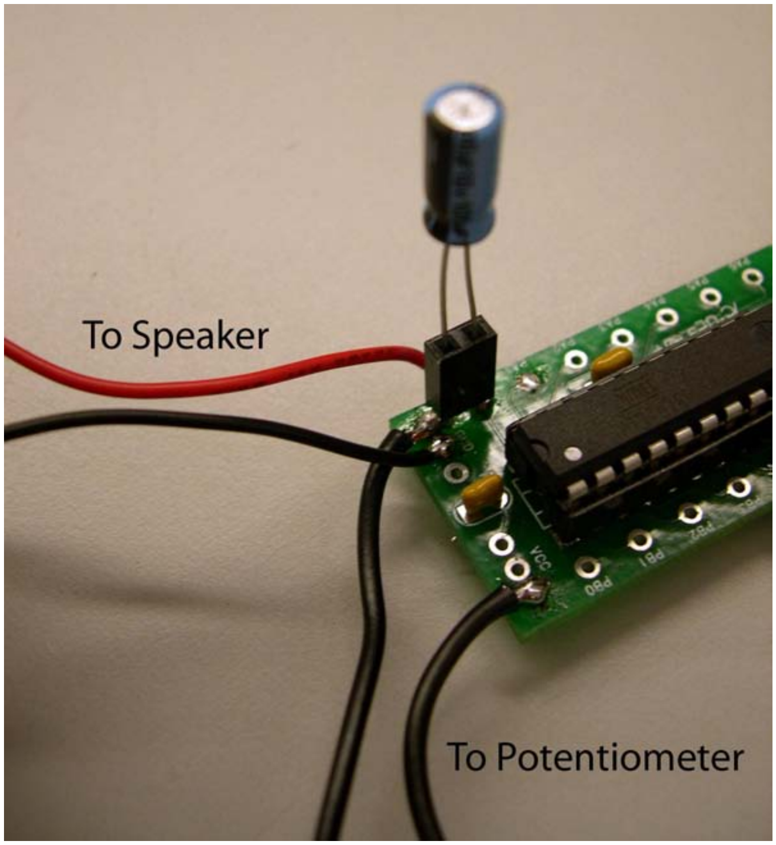


Figure 3.4: Use a piece of female header for the capacitor

3.8 Using the Oscilloscope

An oscilloscope is a device that displays a graph of how a voltage signal varies over time. The vertical axis represents voltage and the horizontal axis represents time. Using an oscilloscope, you can observe waveforms in order to determine things like the shape, amplitude, frequency and phase of a wave. It is often very useful to see a graphical representation of a waveform for troubleshooting and testing circuits with voltages which change over time.

A scope probe has two leads: the signal and the signal return. The signal return is placed at a reference voltage point in the circuit (usually ground). The other is placed at the point of interest in the circuit. The scope will display a high resolution graphical representation of the voltage at that point.

The sampling rate of an oscilloscope determines the maximum frequency signal the scope can measure. Fast scopes can sample signals in the GHz range, allowing you to measure changes in signals on the nanosecond scale. This fast sampling ability makes an oscilloscope more useful than simpler measurement devices such as digital multimeters which have a very slow update rate.

3.9 Analyzing Waveforms

In this part of the lab you are going to be analyzing waveforms recorded using an oscilloscope. From just the image created when the probe is touched to the potentiometer, you can determine a number of things. Ultimately, you will be able to calculate and conclude what note was played using the device you built. In order to analyze the waveforms generated from the musical notes played by the piano, there are a few key terms to understand first.

- **Period** - The time required for the signal to rise and fall through one complete cycle is called the period of the waveform. The symbol for period is T. Period is measured in units of seconds, abbreviated s.
- **Frequency** - The frequency of a periodic waveform is the number of cycles that occur in 1 second. The symbol for frequency is f. Frequency is measured in units of cycles per second, or Hertz, abbreviated Hz.
- **Amplitude** - Maximum displacement of a periodic wave from the zero or average position of a waveform (how tall the waveform is).

***Period** and **frequency** are mathematical reciprocals of one another. That is to say, if a wave has a period of 10 seconds, its frequency will be 0.1 Hz, or 1/10 of a cycle per second.*

By measuring the period of the wave on the horizontal axis of the oscilloscope screen and taking the reciprocal of that time value (in seconds), you can determine the frequency in Hertz. Once the frequency is known, the musical note being played on the piano can be identified.

3.10 Exercises

1. Figure 3.5 shows the voltage waveform across the speaker in the completed piano circuit, as measured by an oscilliscope. Look at Figure 3.5 to determine what the period is, calculate the frequency, and then look up the musical note. In order to find the musical note, reference Figure 3.9. You need to find the time scale in the image first, before you can determine the time it takes for one cycle. *Do not forget to put the units.*

   Figure 3.6 is the same exact note as Figure 3.5, except with a 100 μF capacitor acting as a low-pass filter. A low-pass filter only passes low frequency signals and reduces the amplitude of high frequency signals. That is why the shape of the waveform has changed so much from the unfiltered musical note. In a way, a capacitor acts like a battery. Although they work in completely different ways, capacitors and batteries both store electrical energy. As current flows into the capacitor, it charges. When current leaves the capacitor, it discharges. This causes the voltage highs and lows to be rounder in the waveform.

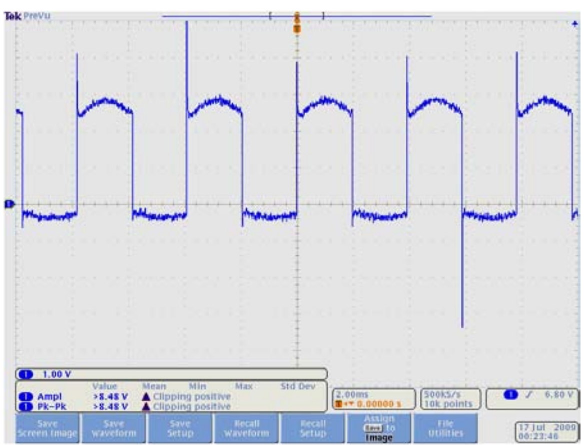


Figure 3.5: Waveform 1

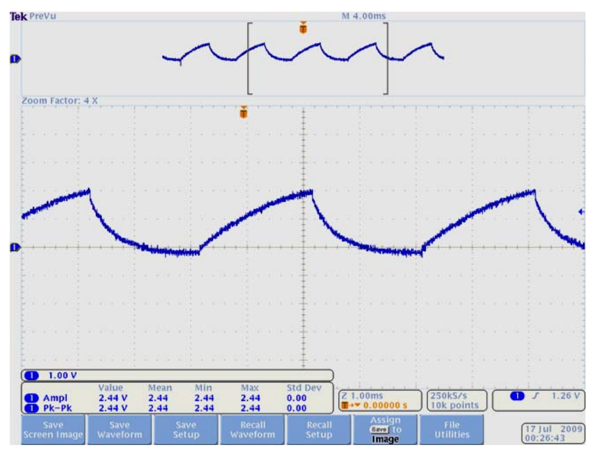


Figure 3.6: Waveform 1 with capacitor

   - Time Scale: ______________________
   - Period: ______________________
   - Frequency: ______________________
   - Musical Note: ______________________

2. Figure 3.7 is a waveform generated from a different note. Following the same steps as before, determine the time scale, period, frequency, and musical note.

   Figure 3.8 is the same exact note as the one previously, except this time with a 10 μF capacitor acting as the filter. There is not as dramatic of a change in the wave as last time, because the capacitor is smaller and therefore charges and discharges more quickly.

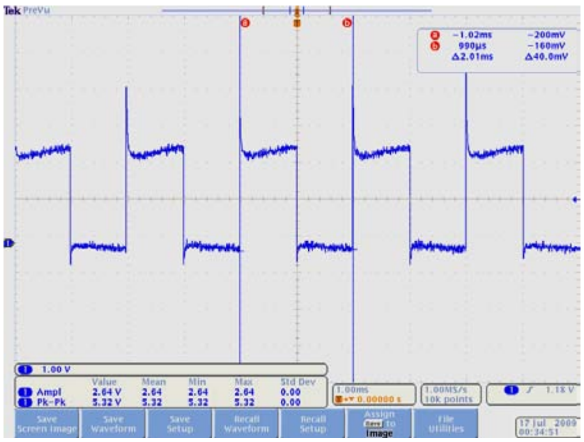


Figure 3.7: Waveform 2

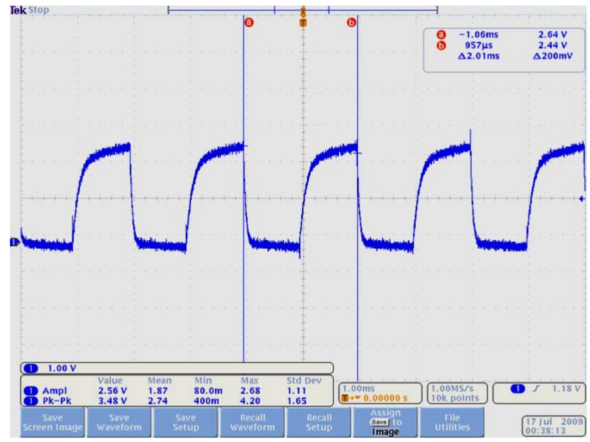


Figure 3.8: Waveform 2 with capacitor

- Time Scale: ____________________
- Period: ____________________
- Frequency: ____________________
- Musical Note: ____________________

3.11 Music Note Reference Chart

Note	Musical designation	Frequency (in hertz)
A	A_1	220.00
A sharp (or B flat)	$A^{\#}$ or B^{b}	233.08
B	B_1	246.94
C (middle)	C	261.63
C sharp (or D flat)	$C^{\#}$ or D^{b}	277.18
D	D	293.66
D sharp (or E flat)	$D^{\#}$ or E^{b}	311.13
E	E	329.63
F	F	349.23
F sharp (or G flat)	$F^{\#}$ or G^{b}	369.99
G	G	392.00
G sharp (or A flat)	$G^{\#}$ or A^{b}	415.30
A	A	440.00
A sharp (or B flat)	$A^{\#}$ or B^{b}	466.16
B	B	493.88
C	C^1	523.25

Figure 3.9: Music Note Reference Chart

3.12 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 of an oscilloscope in your classes.

3. How does the capacitor affect the sound generated from the piano? Why does it do this?

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 Tekbots programmer is used to program the Tiny26 microcontroller, which is them 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

In this section, the following items will be covered:

1. Generating energy using motors
2. Using an LED in a circuit
3. Reviewing schematics and programming the Tiny26

4.4 Materials

1. TekBots Universal Programmer (usb_prog.2)
2. Tiny26 Microcontroller (tiny26.1)
3. L293 Motor Driver IC
4. Light Emitting Diode (LED)
5. DC Motor
6. ECE111 kit
7. Tool Kit (especially the Digital Multimeter)

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. We can demonstrate this easily by connecting two motors together according to the schematic in Figure 4.1.

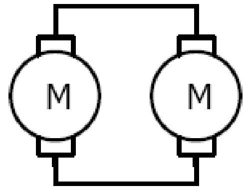


Figure 4.1: Schematic of a Motor as a Generator for Another Motor

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, you can use the motor provided in your kit to power an LED. In this case, the natural source of energy is going to be you! 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 ”resists” the current, to keep the LED safe. You always want to have a current-limiting resistor when working with LEDs.

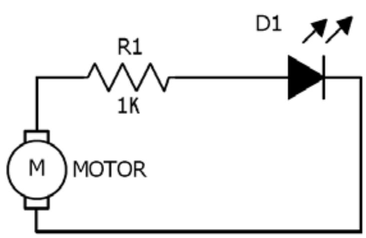


Figure 4.2: Schematic of a Motor as a Turbine

Figure 4.3: Connecting the DMM to the Motor

Once you have your motor connected, try turning the motor quickly while watching the LED. The LED should light up. Now try measuring the voltage generated by the motor by connecting your digital multimeter in parallel to the motor as shown in Figure 4.3. Do this activity in groups of two (someone to measure the motor and someone to turn 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 you used a graphite potentiometer along with the Tiny26 microcontroller to play different frequencies through a speaker. Using a similar concept in this lab, you will use a normal 100kΩ potentiometer and Tiny26 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.

Program the Tiny26 using the same process as last week, using the Energy Systems code. Then connect the motor controller and potentiometer to the Tiny26 according to the circuit in Figure 4.4.

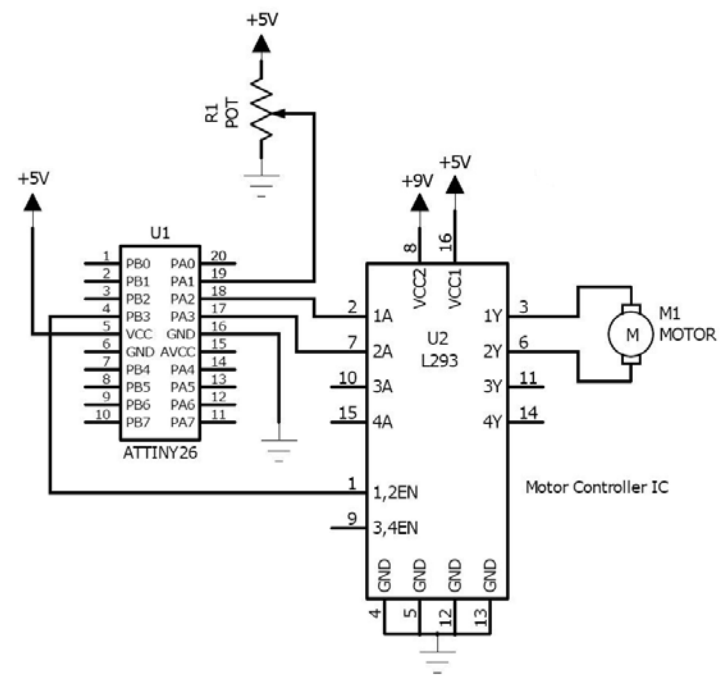


Figure 4.4: Schematic of Potentiometer Controlled Motor

Try playing around with the potentiometer and changing the direction/speed of the motor. Using your digital multimeter, measure the voltage at pin PA1 (where the potentiometer is connected to the tiny26) 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 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. What is a servo motor? *(Hint: a common type is an RC servo)*

4. Research and list three potential careers that could come as a result of the Energy Systems track here at Oregon State University.

4.9 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 Tiny26 board in pins PA4 to PA7 (don't forget the current limiting resistors!). 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 soldering on 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 & 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 Tekbots programmer is used to program the tiny26 microcontroller, which is then implemented in a simple circuit that uses a feedback potentiometer and a position potentiometer to control the position of the motor.

5.3 Objectives

In this section, the following items will be covered:

1. Modifying a DC Motor into a servo motor
2. Learning about feedback and control systems
3. Learning control systems terminology

5.4 Materials

1. TekBots Universal Programmer (usb_prog.2)
2. Tiny26 Microcontroller (tiny26.1)
3. Small white potentiometer
4. Plastic tubing
5. Protoboard
6. ECE111 Kit
7. 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 in the ECE111 repository. In the circuit being built today, a position potentiometer enables the user to define where they want the motor to move to. The Tiny26 microcontroller takes the user input, and powers the motor until it reaches the defined position.

For the Tiny26 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 as the motor turns, so does the potentiometer. While the Tiny26 is powering the motor, it is also checking the feedback value, so that when the feedback matches the user input it knows to stop the motor, because the defined position has been reached.

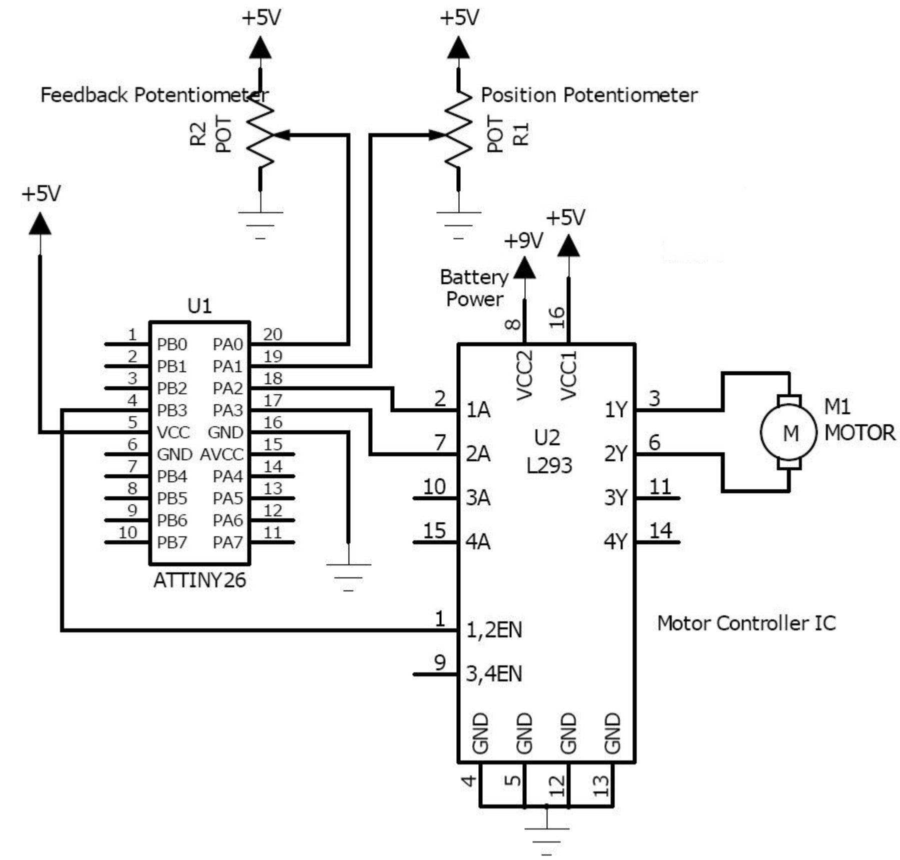


Figure 5.1: Schematic of a Motor as a Servo

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

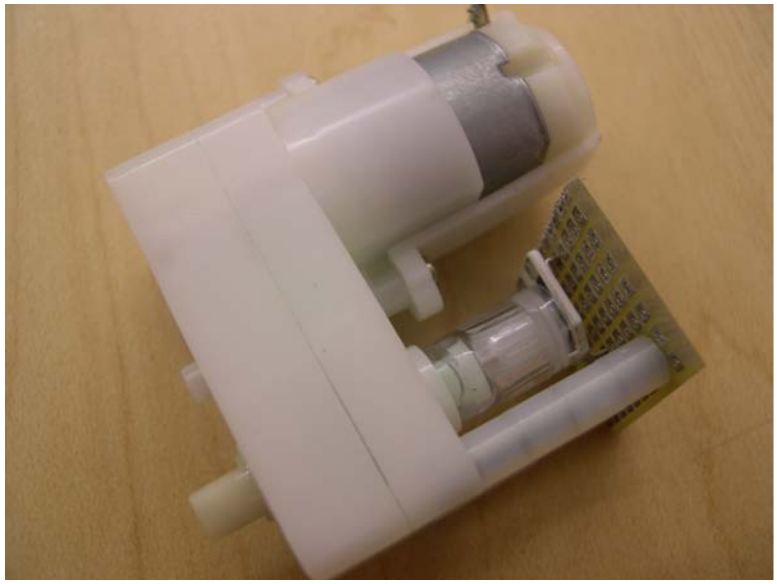


Figure 5.2: Attach a feedback potentiometer to the motor.

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 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).
7. Solder the potentiometer onto the protoboard.
8. Connect the lonely leg of the potentiometer to A0 on the Tiny26.
9. The other two legs will connect to VCC and GND of the Tiny26. Try one option. If you guessed right the motor will move to a certain position after programming, if the motor doesn't work right then switch VCC and GND of the feedback resistor.

5.6 Controlling the Servo

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 your 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 5.3. The control method being implemented in code on the Tiny26 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.

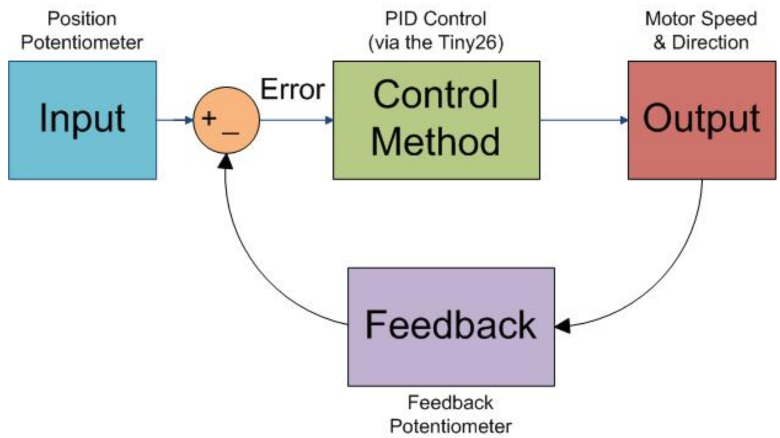


Figure 5.3: Block Diagram of a Typical Closed Loop System

5.6.1 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 our 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 5.4. The graph shows the response of a typical PID closed loop system.

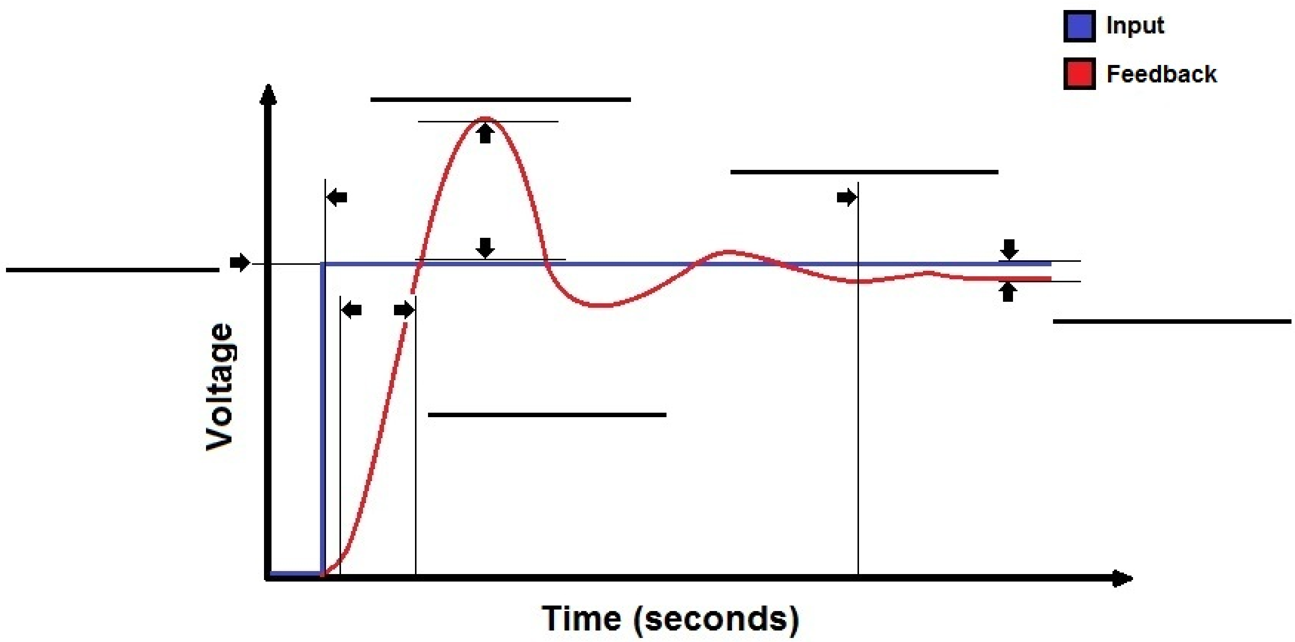


Figure 5.4: Graph of Closed Loop System Response

5.7 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.

5.8 Challenge

When working with systems and circuits such as these, it’s useful to have something that indicates the current status of the system. For this challenge, attach four LEDs to your Tiny26 board in pins PA4 to PA7 (don’t forget the current limiting resistors!). Then, write some code to add to the existing Robotics & Control lab code that displays where your motor is located at any given time.

Since you have four LEDS, you’ll need to determine the range of motion for the servo motor in degrees, and then divide that by four. When the motor is in a specific quadrant, the corresponding LED should light up. Along with a demonstration of the working circuit, to get full points you’ll need to provide documentation that shows the range of motion sections and which LED should light up.

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 track 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

In lab you have done a number of activities dealing 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 week's lab involves using photovoltaic cells (sometimes known as solar cells), which encompasses two of the tracks you have covered before: Materials & Devices and Energy Systems. Ideas from these two tracks are combined to use a green form of energy and relates to the new Sustainability and Renewable Energy track.

The completion of this project will result in an efficient Solar Cell Positioning unit. The Tiny26 will rotate a motor with a solar cell attached to it. We will be reading the voltage of the solar cell using the ADC (Analog-to-Digital Converter) in the Tiny26, 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

In this section, the following items will be covered:

1. The Engineering Method
2. Solar Energy and the integration into electronics
3. Analyzing efficiency tradeoffs

6.4 Materials

1. ECE 111 Kit
2. Photovoltaic cell
3. Tiny26 Microcontroller (tiny26.1)
4. Solar Tracker code from the ECE 111 Repository for the Tiny26

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.

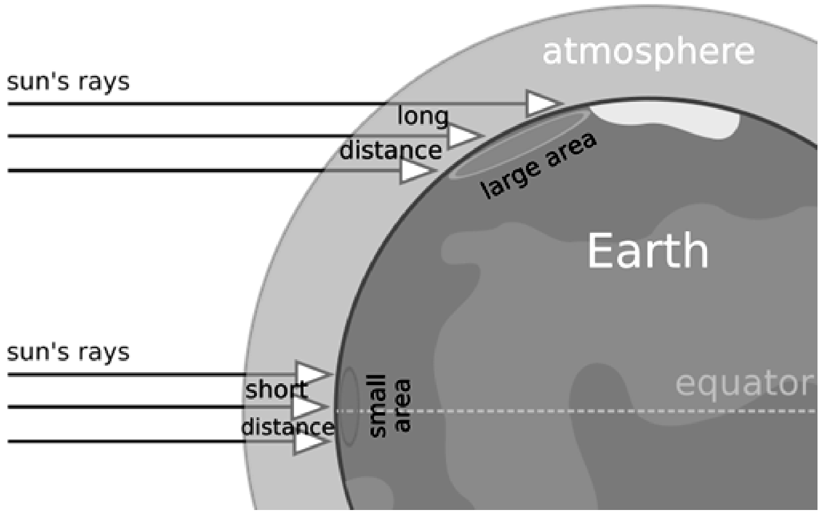


Figure 6.1: Sun's Rays hitting the Earth

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.

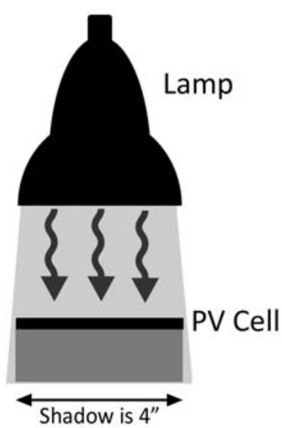


Figure 6.2: Flat PV Cell

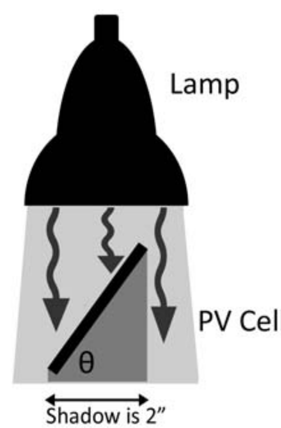


Figure 6.3: Angled PV Cell

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. For this, you will need some way of measuring angles (protractor). You need to measure the voltages produced by the PV cell at no less than 7 different points between 0^o and 90^o, zero being what is shown in Figure 6.2. Then graph these points on Figure 6.4 and analyze the resulting line.

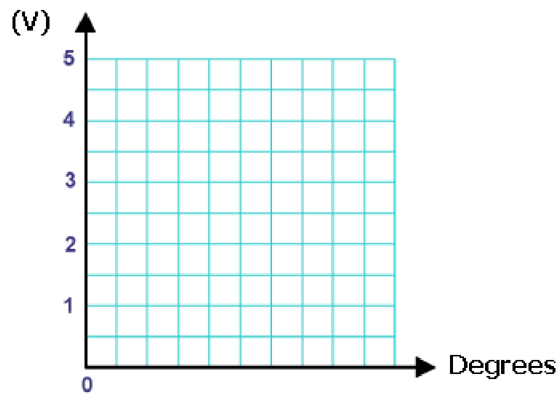


Figure 6.4: Voltage Output vs. Degrees

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. We will be finding the open circuit voltage and short circuit current.

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. Then 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 you built in a previous lab in conjunction with a photovoltaic cell. You need to attach the PV cell 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, you need to program the Tiny26. 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 motor adaptor will be required. The code has been provided in the code repository. The schematic is in Figure 6.5 *(Hint: We will be using the same motor driver as in the Energy Systems Lab).*

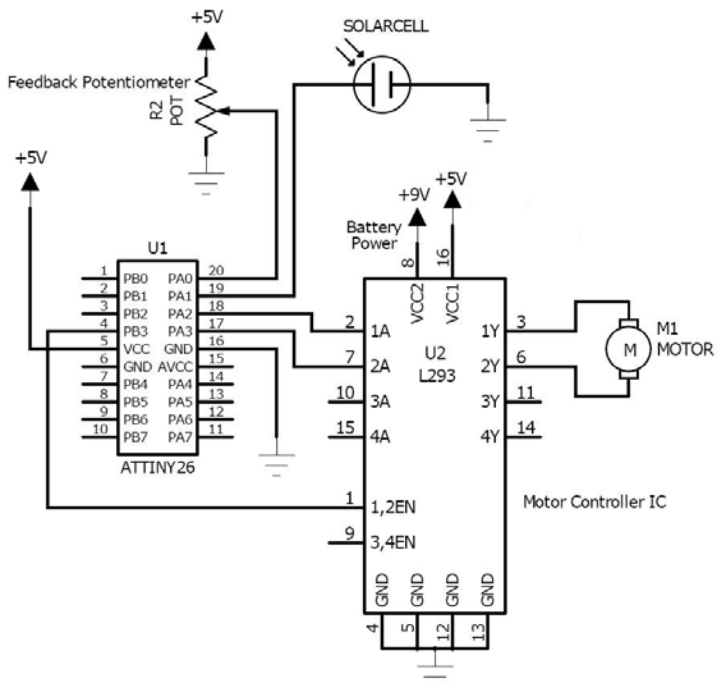


Figure 6.5: Schematic of Light Tracking Device

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. 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.

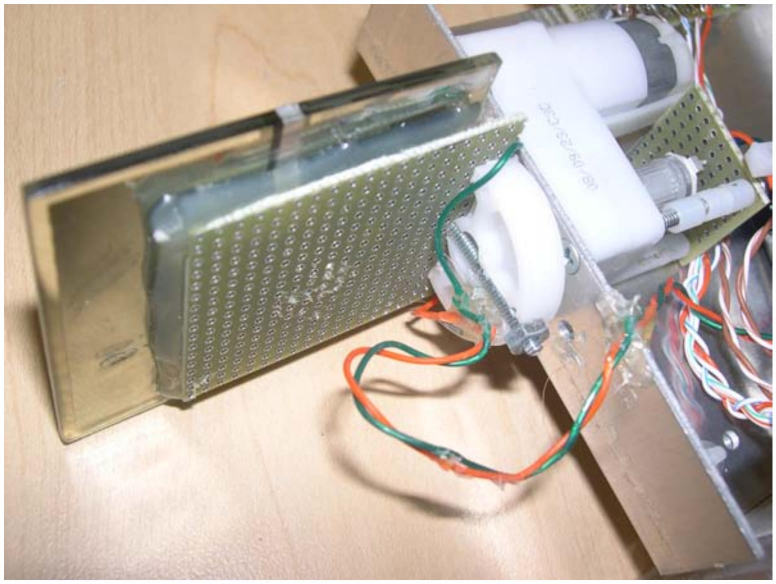


Figure 6.6: Completed Solar Servo

6.10 Study Questions

1. Name at least 3 places you've seen solar cells/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?

