Module 3: Piezoelectric Materials

Engineering Disciplines: Materials Science and Engineering, Macromolecular Engineering, Electrical Engineering

For the Module 3 Part I Lab Report, each team will submit:

- 1 .m file containing code for Labs 1 & 2
- 1 CSV file generated in Lab 2, Part 1
- 1 PDF file containing typed answers to the discussion questions for Labs 1 & 2, the Module 3 Design Worksheet completed through part D, and your Project Planning and Management Task List

Prepare and submit these files in accordance with the ENGR 130 Style Guide and Assignment Submission Guide.

Lab 1: Measuring Signals with the Oscilloscope

Overview

An oscilloscope is used to analyze electrical signals by plotting them on a screen. The oscilloscope measures voltage as a function of time and can be used to analyze moving electromagnetic waves as well as short bursts of electric energy.

In today's lab, you will analyze signals and generate waveforms with the Arduino and show them on the oscilloscope. This will come in handy in the next lab when you measure the electrical activity of piezoelectric materials. One important feature of a repeating signal is the frequency, or the number of signals that occur per unit of time. When a signal is plotted, the frequency can be measured as the inverse of the period, or length of one wave, in seconds. Frequency is reported as 1/sec or hertz.

Materials

- Arduino Uno
- LED
- 330-Ω resistor
- Jumper wires
- Breadboard
- Oscilloscope probe

Procedure

1. *Project planning and management*
    a. Complete the [Module 3 Project Planning and Management Task List](), following the instructions in the [Module 3 Project Planning and Management]() document. You will continue to edit your task list this week and submit your task list, current as of the submission date, as part of your Part I (Labs 1 & 2) Report.

2. *Measure your first signal and check probe*

a. Look at the left half of Figure 1 and use it to identify the different parts of the oscilloscope probe, so that the directions that follow will be easier to understand. Turn the oscilloscope on and plug in the BNC end of the probe to channel 1 (CH1). The BNC connection twists and locks into place.

Figure 1: Different parts of the oscilloscope probe (left) and location of demo signal (right)

b. Press the “Default Setup” button. This will reset the oscilloscope in case a previous user altered the scope’s settings.

c. Attach your mini-grabber probe to the demo signal and alligator clip to the ground terminals on the oscilloscope as shown in Figure 1. We will use the demo signal to check that our probe and oscilloscope are working properly.

d. You should see a signal on the screen. Press the “Auto” button (next to the “horizontal” knobs) to automatically isolate your signal. It should be a mostly square wave. Press the “Run/Stop” button to freeze and unfreeze what you see on screen. Be aware that this is a snapshot and will not respond to changes in the signal. Note: The Auto button works <u>if and only if</u> it is a constant signal. It will not work for dynamic signals.

e. If the peaks of the square wave do not appear flat, the probe is not calibrated. Let a TA know, and they will guide you through the calibration process.

f. Dial the knobs to change the V/div and s/div on the screen and notice how the image on the screen changes. An example screen with the location of these settings is shown in Figure 2, and some handy buttons and knobs are depicted in Figure 3.

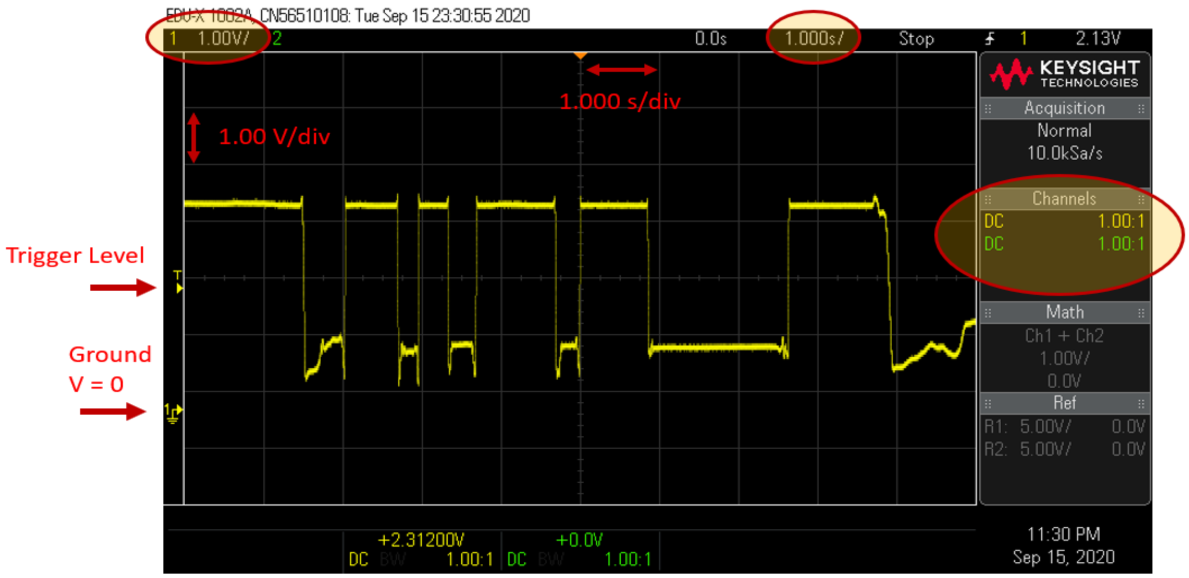

Figure 2: The top left shows the current V/div settings at 1 V for each division. The upper right shows time/div. Each square on the screen is 1 V tall and 1 s wide. The T with an arrow signifies the trigger level. The ground is shown by the other symbol on the left of the screen.

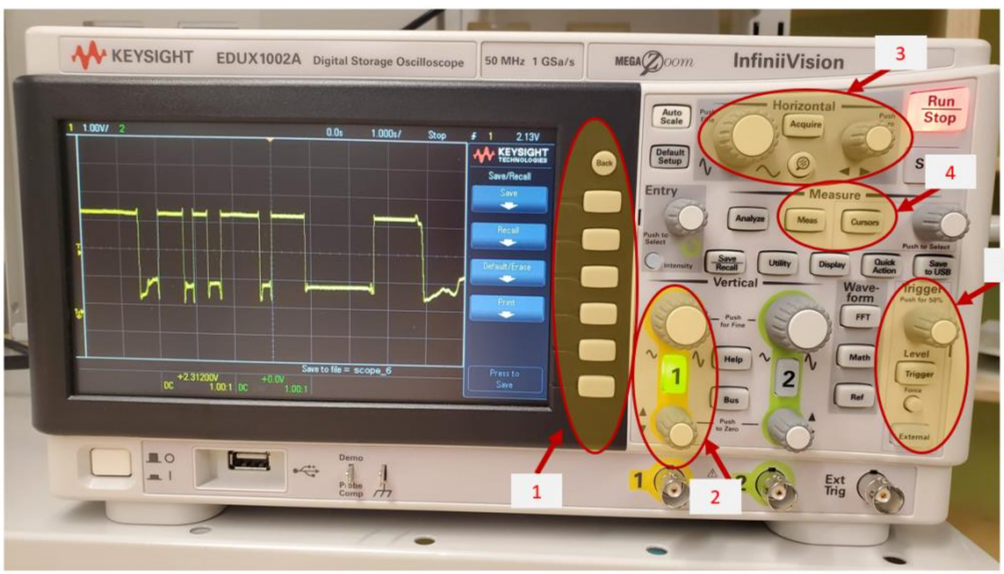

Figure 3: (1) Keys to select menu options on the screen (2) Vertical settings. Press the 1 for channel settings like attenuation. The big knob adjusts the V/div and the small knob adjusts the offset (moves the ground location up and down.) (3) Adjusts the timescale. (4) The “Meas” and “Cursors” buttons help get a more detailed look at signals through many menu options. The knob to the right to moves cursors. (5) The trigger level can be adjusted by turning the knob. Attempt to put it in the middle of the rising edge of your signal.

g. The oscilloscope probe has two attenuation settings (1x and 10x). 10x attenuation makes the signal 10x "shorter" in the vertical direction. This makes it easier to fit on the screen but can hide low-voltage signals. During calibration, the attenuation setting on the probe must match the setting on the oscilloscope. Press the probe settings button in Figure 3 and check to see if it matches the switch on your probe.

h. Press the button next to where "Probe" is displayed on the screen. Find "Probe Check" and press the button next to it. Follow the instructions to run a probe check to ensure that the probe is properly calibrated.

i. Use the measure ("Meas") button to measure the peak-to-peak amplitude, which is the difference between the highest value and lowest value of the signal, and frequency of the demo signal.

3. *Arduino signal analysis*

a. Recall the first circuit that you made to blink an LED in Module 2 (Figure 4). Construct this circuit again and place the oscilloscope mini grabber probe on the positive LED wire and the alligator clip on the negative resistor wire.

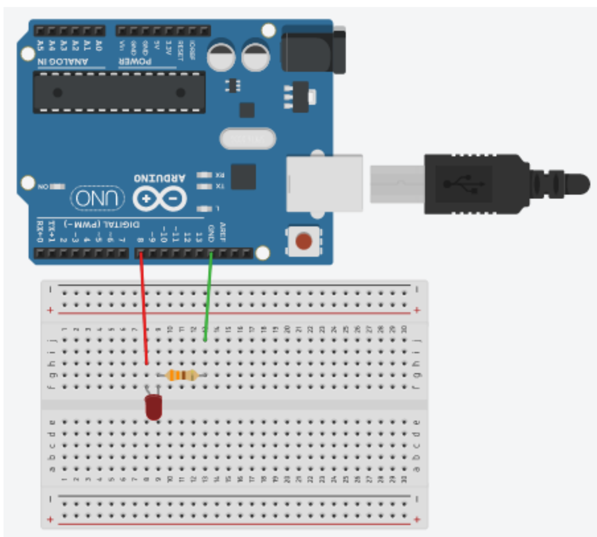

Figure 4: LED circuit diagram

b. Write code that blinks the LED for 30 seconds at a frequency of 1 Hz. Use the measure button to measure the frequency and amplitude of the signal.

Questions

1. What is the peak-to-peak amplitude of the demo signal from Part 2? What is the frequency of the demo signal?

2. What is the peak-to-peak amplitude of the 1 Hz signal from Part 3? What is the frequency of the 1 Hz signal?

END OF LAB 1

Lab 2: Piezoelectric Film

Overview

Today you will begin working with piezoelectric film to create signals by applying an impulse to the film and collecting the signals with the Arduino. Since the Arduino can only collect signals between 0 and 5 V, you will first need to determine the piezo signal range and determine if you need to alter (or attenuate) it to within 0-5 volts.

Materials

- Oscilloscope
- Oscilloscope probe
- PVDF piezoelectric film
- Breadboard and jumper cables
- USB thumb drive

Procedure

1. Test your film

a. Turn on your oscilloscope and wait for it to boot. Insert a USB thumb drive into the oscilloscope USB port. You should see a message stating “USB device installed” (it may take up to 15 seconds). If you do not see the message, pull out the USB thumb drive, power off the oscilloscope, and try again.

b. You should ensure that your probe is calibrated by running the probe check on the oscilloscope before you use it. Also, make sure the switch is in the 10x attenuation position. Plug the piezo film directly into the oscilloscope with the mini grabber on the red wire and the alligator clip on the black wire.

c. Practice flicking the film to see what happens on the oscilloscope. DO NOT bend or crimp the piezo film.

d. Use “Single” mode to see one electrical impulse of the piezo film. Try different time scales and trigger levels. Consult the figures from Lab 1, if you need a refresher on where the controls are. The trigger level is the value at which you want the oscilloscope to recognize a change in the signal as something potentially significant to capture on the screen.

e. Once you have a good signal displayed on the screen, do not adjust the vertical or horizontal scales in any way. Save the data as a CSV file. To do this, plug a USB drive into the oscilloscope and press the “Save/Recall” button. Press the button next to where “Save” is shown on the display. You can change the format by using the selection buttons and the “Entry” knob. You will submit this CSV file as part of your lab report.

f. Try testing your film in different ways besides flicking. Try running it across the table or gently bending it (do **NOT** fold it) or tapping it or anything else. Think about how you might use a film like this in real-world applications.

2. *Process CSV data*

a. Import the CSV into MATLAB using the `readmatrix()` function and view the resulting matrix. You should have a two-column matrix with times in the first column and voltages in the second.
   i. Some of your time values will likely be negative. This is okay but be aware of it.
   ii. You may have some rows containing `NaN` (which means “Not a Number”) values at the top and/or bottom of each column. You will need to exclude these rows from your analysis. There are methods exclude `NaN` values automatically, but for the purposes of this lab you may remove these rows manually or hard-code specific vector values into your code.

b. Plot the following on one set of axes:
   i. Your captured signal voltage vs. time as a solid black line.
   ii. A blue circle at the x-y location of the maximum measured voltage.
   iii. A red square at the x-y location of the minimum measured voltage.
   iv. A magenta horizontal dashed line extending across the entire figure that shows the mean measured voltage.
   v. Include a legend on your figure so that the meaning of each line and symbol is explained. Also include a meaningful title and axis labels.

c. Save your figure window as a PNG file to be included in your module report.

3. *Research and plan your knock sensing device*

Read through the details for Lab 4, download the Module 3 design worksheet, and complete Parts A-D. You will turn in your design worksheet, completed through Part D, as part of your Module 3, Part I Lab Report. Materials that will be available for this challenge are on one of the classroom carts and you may look to see what is there.

Questions

1. Include the PNG image of the figure from Part 2.

2. Does the mean voltage you calculated and plotted seem to agree with your figure? How can you tell?

3. How does the piezoelectric film respond to other manipulations? What other applications of piezoelectric films can you think of based on these results?

END OF LAB 2

Lab 3: Detecting Knocks

For the Module 3 Part II Lab Report, each team will submit:

- 1 .m file containing your completed code for entire module (including Labs 1 & 2)
- 1 PDF file containing typed answers to the discussion questions for Labs 3 & 4, the completed Design Worksheet, your completed PowerPoint slide that you displayed in Lab 4, and your final Project Planning and Management Task List

Prepare and submit these files in accordance with the ENGR 130 Style Guide and Assignment Submission Guide.

Overview

Piezoelectrics have applications in the production and detection of sounds, nanotechnology, electronic ignitions, and precision optics motors. Products are getting faster, more efficient, and smaller. Electronic devices are interactive and wearable. Piezoelectric materials embedded as sensors are enabling devices to be connected by the Internet of Things (IoT), a network of devices which collect, send, and act on data they acquire. There are also possible applications in renewable energy, generating power from everyday vibrations. Materials scientists and engineers are working to discover new, more efficient, piezoelectric materials.

In today's lab, you will analyze the signal generated by the piezo when someone knocks on it. This will form the basis of the product you will design, prototype, and share in Lab 4.

Materials

- Arduino Uno
- PVDF piezo film
- Breadboard
- Jumper cables
- Oscilloscope
- Oscilloscope probe
- Zener diode
- 10-kΩ resistor

Procedure

1. *Measure the film with the Zener diode circuit & oscilloscope*

a. Build the circuit shown in Figure 1.

i. Note that the piezo and the Zener diode have polarity and therefore will not work correctly if they are inserted in the wrong direction. Inserting them in the wrong direction will not break anything on the oscilloscope, so feel free to experiment now. However, when we use the Arduino to measure signals in Part 2, incorrect orientation **could** damage the Arduino.

ii. The purpose of the Zener diode is to make the signal compatible with the Arduino board. The Zener diode limits negative voltage received by the Arduino, which may cause damage.

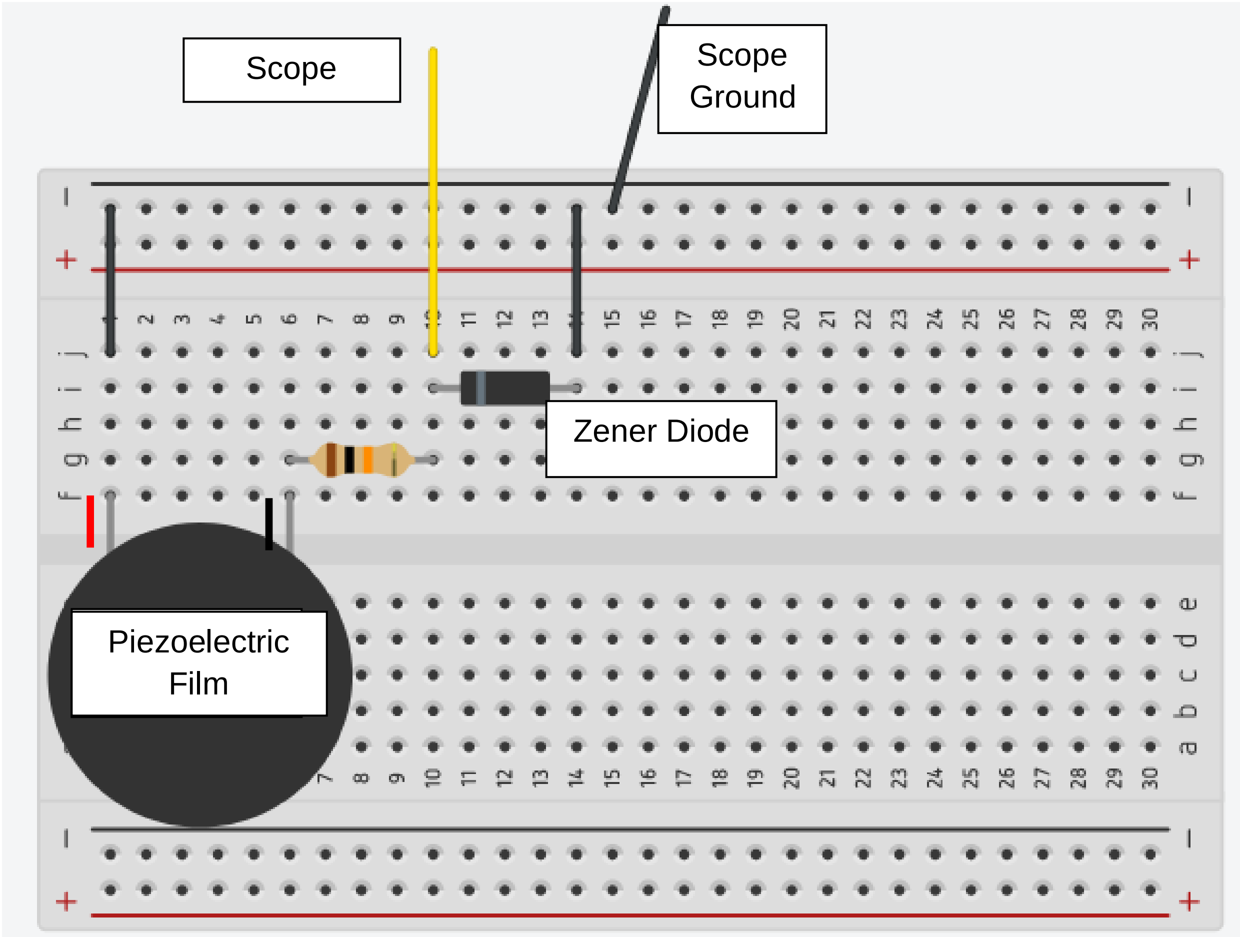

Figure 1: Zener diode breadboard diagram

STOP: You must have a TA check the circuit before you continue.

b. Generate and measure signals using the piezo film. Measure the voltages and make sure that the voltages are between -0.5 and 5 V.

2. Connect piezo film to Arduino

a. Keep the piezo film connected to the oscilloscope and add connections to an Arduino analog pin (one of the ones beginning with A) and to the Arduino ground pin so you can see the signal on the oscilloscope while collecting data with the Arduino (Figure 2). Remember the Arduino cannot accept negative voltages, so the orientation of the connections matter.

3. Write a knock sensor script in MATLAB

a. Write a script that will sample the voltage signal from the piezo film at 4 Hz for 10 seconds. Store the readings in an array named `voltages`.

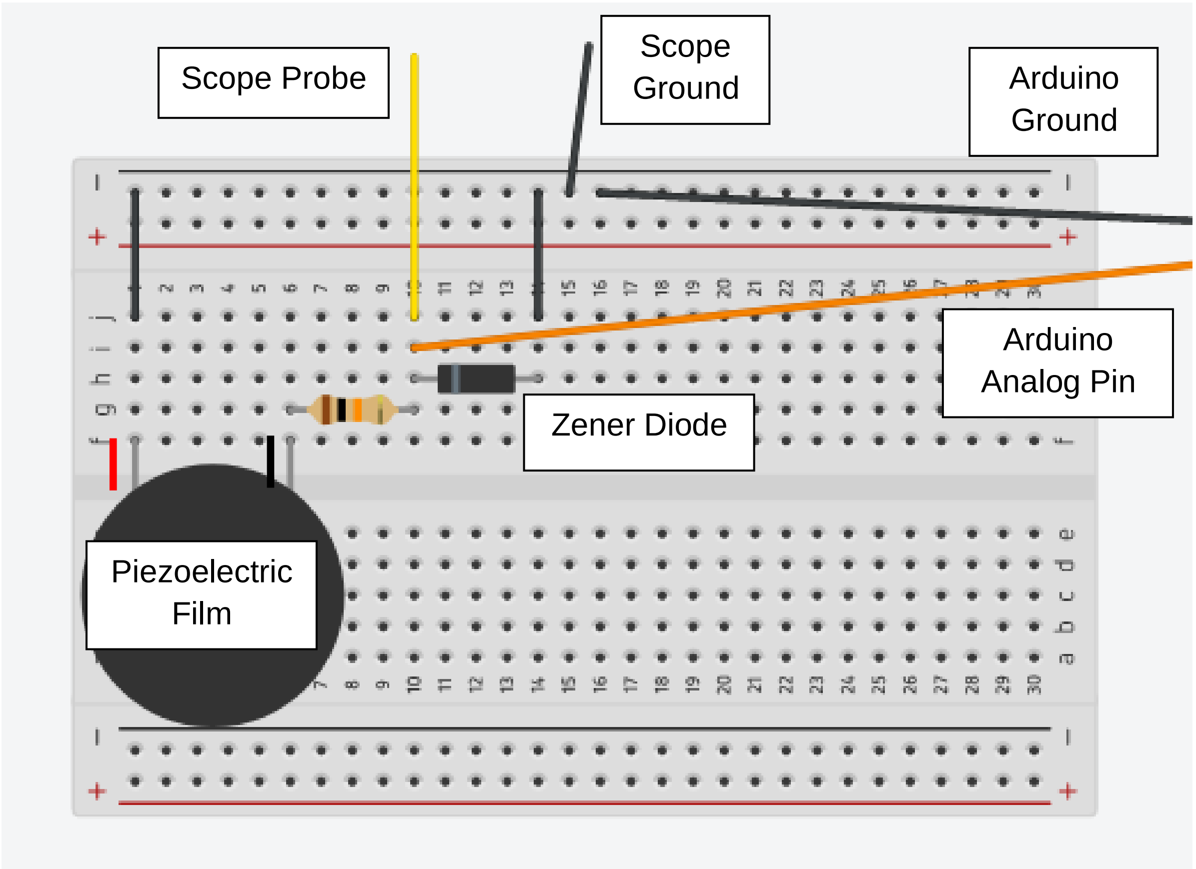

Figure 2: Zener diode breadboard diagram with Arduino

b. Create a new figure and plot voltage vs. time with the first sample at t = 0. Label and title your plot.

c. Set a voltage threshold that will signal a knock. Store this threshold in variable `thresh`. Plot all points above the threshold on the same plot as above with a red circle marker. Add a dashed horizontal line to the plot at the threshold value.

d. Write an algorithm on a lab whiteboard to count the number of knocks in the voltages vector. To write your algorithm, draw a sample signal and think about what criteria your brain is using to count knocks. You will turn in your algorithm as an answer to a question below.

e. Write the MATLAB code that you planned in the previous step. Display this number to the command window with the statement "`The number of knocks recorded is <x>`", where `<x>` is the number of knocks. Make sure your code works for any signal acquired from the piezo film as well as any threshold, even if the signal contains zero knocks. (Note: When knocking on your sensor, knock slowly and firmly. The number of knocks detected may be less than the actual number due to the sampling rate, i.e., you could knock in between Voltage readings.

4. Prepare for Lab 4's Design Challenge

You should arrive in class for Lab 4 with plan for what you will build and how to build it. Complete your Module 3 design worksheet through Part F. Plan what each of you will do for Lab 4’s design challenge. Update your task list, as necessary. You may view materials available for this challenge on one of the classroom tables.

Questions

1. Based on your experiments, what do you think is the optimal threshold value for a door knock sensor? Why? How is your threshold justified by the data that you collected?

2. What engineering applications might benefit from a knock sensor, i.e., how could you use the sensor in your own life?

3. Look around your environment. Where are piezoelectric materials currently in use?

4. Submit your algorithm from Part 3d.

5. Explain how you detected knocks in Part 3. Are there any situations that are not accounted for by your code? These are called “corner” or “edge” cases and can be difficult to identify in programming. Carefully reflecting on your coded solution can help you realize when your code won’t work as expected.

END OF LAB 3

Lab 4: Creating a Knock Sensing Device

Overview

Today you will use the knock sensor that you have developed as a component in the prototype design of a new product. You will first create the prototype. Then you will demonstrate your product design as classmates circle the lab in small groups. You will also have a turn to circulate and see other teams' designs.

The Challenge

A company that creates equipment for secret agents has learned of the knock-detecting work going on in this class. They want to see your creative ideas for incorporating a knock sensor into gadgets in their next product line. Today your team will design a device and prototype it.

Details

You will complete your Module 3 Design worksheet and submit your final worksheet with your Part II Lab Report. You have 55 minutes to develop a prototype of your device. During this time, you will also prepare a PowerPoint slide to project on the screen at your team's table when it is time to share your device. The slide should indicate your team number, the name of your device, and a one-sentence description of the device's purpose. You will also submit this slide as part of your Lab Report. Here is a template for the slide, but you are not required to use this exact template.

Constraints: You may only use one piezoelectric film and one Arduino. You may also use any other components that are on the equipment table. Here are descriptions of the components and brief tutorials on how they can be used.

After you complete your design, there will be a 20-minute design showcase, where all teams will share their products with other members of the class. For the first 10 minutes of it, half of your team will walk around to see the designs of the other teams while the other half stays to show off your product. After 10 minutes, you will switch.

The last 5 minutes of class are for circuit disassembly and returning electrical components to the equipment cart. Your breadboard, Arduino, and piezoelectric film should be left at your worktable at the end of class.

Project Planning and Management

Complete your final Module 3 Project Planning and Management Task List. You will turn in a pdf of your final task list with your Part II (Labs 3 & 4) Lab Report.

END OF LAB 4