Lab 4: Basic Measurements and I/O Impedances

1. Introduction

In this lab, you will learn to use Oscilloscopes for the purposes of viewing data signals. You will also investigate the impedances of common measurement devices and the impedances of output devices.

1.1 Lab Objectives

- Learn Oscilloscope Operation
- Learn to use a multi-meter
- Investigate the effects of input and output impedances

1.2 Project Objectives

- Begin Prototyping your solution

1.3 Lab Hardware

- Oscilloscope
- Digital multi-meter
- Function Generator

1.4 Project hardware

- Each team will receive
  - Arduino Uno
  - Arduino Mega
  - Toolbox (optional)
- Teams should purchase parts from TA as needed using their team budget

2. Laboratory Concepts

2.1 Measuring Root-Mean-Square (RMS) Values

In this section, you will learn how to calculate and measure RMS voltages for periodic signals using the instruments in the laboratory. For a signal *v(t)* of period T:

- V_{rms} – Root mean square voltage

$$V_{rms} = \sqrt{\tfrac{1}{T}\int_0^T v^2(t)dt} \tag{1}$$

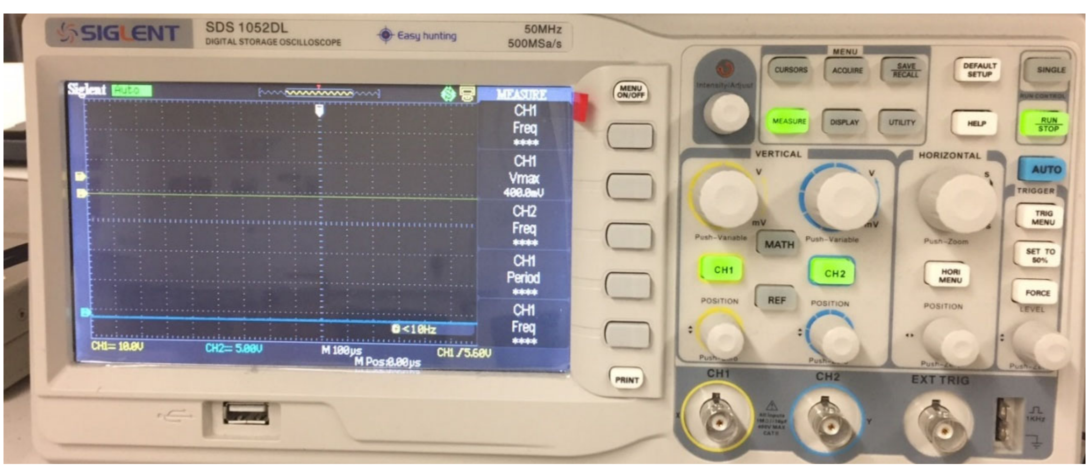
- V_{ravg} – Rectified average

$$V_{ravg} = \tfrac{1}{T}\int_0^T |v(t)|dt \tag{2}$$

From the analysis above, you can see that, for a given peak-to-peak voltage, $V_{p\text{-}p}$, the real RMS value depends on the DC component, V_0, and the shape of the signal (e.g. sine wave, square wave, triangular wave). The measured value will depend on what kind of instruments you have. Some DMMs measure true RMS for any waveform, while others just measure the rectified average and use a fixed conversion factor (assuming a sinusoidal waveform) to convert from V_{ravg} to V_{rms}. This will give true RMS for a sinusoidal waveform, but not for other types of waveforms. Your job is to evaluate the laboratory instruments regarding the measurement of the RMS value.

2.2 Oscilloscope Operation

The oscilloscope is probably the most ubiquitous tool used in the laboratory. Its basic function is to measure two voltages simultaneously and display them as a function of time on a screen. Older oscilloscopes are large and bulky, displaying the voltages on a cathode ray tube (CRT) screen. These come in both the analog and digital variety. Newer 'scopes with liquid crystal display (LCD) screens (either monochrome or color) can be quite small (about the size of a toaster) and are typically digital. Digital scopes capture the waveforms of interest in their internal memory and display them from that memory. Thus, a trace displayed on the screen is a set of samples displayed as a function of time. The oscilloscope used in this lab is shown in the following figure.



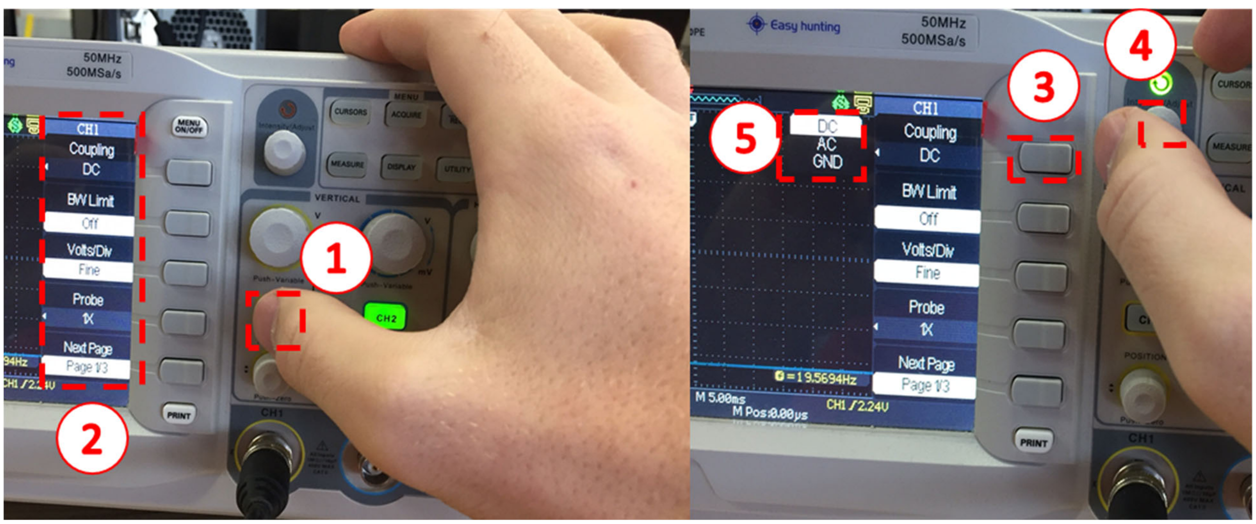
The most common configuration is to generate a horizontal (x direction) motion of the trace as a linear function of time. The magnitude of a voltage signal is shown as the vertical (y direction) displacement of the spot on the screen. Most oscilloscopes can display two such traces as a function of time, each representing a different input voltage signal. These two inputs are defined to be Channel 1 and Channel 2.

AC and DC Coupling

AC and DC coupling are two different modes that the oscilloscope uses to measure signals. In AC mode the DC offset is removed from the signal when displaying and measuring the signal. In DC coupling the DC offset is unaltered. An additional mode is GND. This is used to set where the GND reference is displayed on the screen.

To set the coupling mode used the steps outlined below and in the figure.

1. Press the channel button (CH1 or CH2)
2. A channel menu will show up on the right-hand side of the screen.
3. Press the menu button next to the coupling tab.
4. Turn the intensity/menu knob to cycle through the options [DC, AC, GND].
5. Select the coupling method (DC shown in figure) in the coupling submenu. Press the intensity/menu knob (#4) to complete the selection.

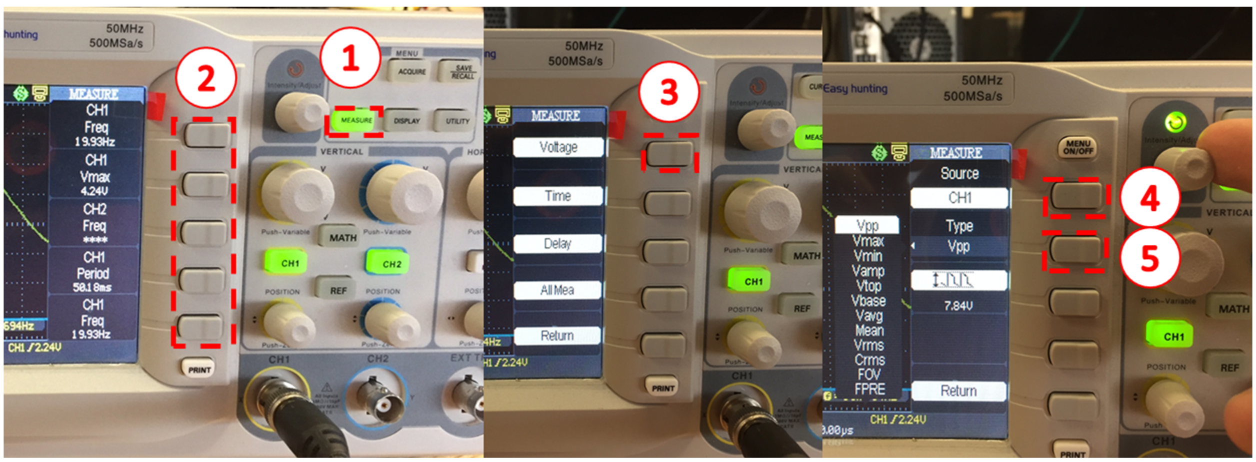


Oscilloscope Measurements

The oscilloscopes can display 5 different measurements at a time. These measurements can be different voltage and time-based measurements.

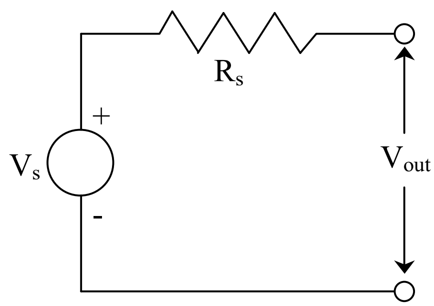
You can change these measurements by following the outlined below in the figure.

1. Press the measurement button to display the Measurement menu
2. Press one of the menu buttons to change what is displayed in the menu at that spot
3. Press one of the menu buttons to pick what type of measurement you want
4. Press the Source menu button to choose either CH1 or CH2
5. Press the Type menu button to open a sub menu of different measurement types. In this lab you will be using the Vpp ($V_{p\text{-}p}$), MEAN (V_0), and Vrms (V_{rms}). Use the menu nob to scroll through and choose the measurement type.

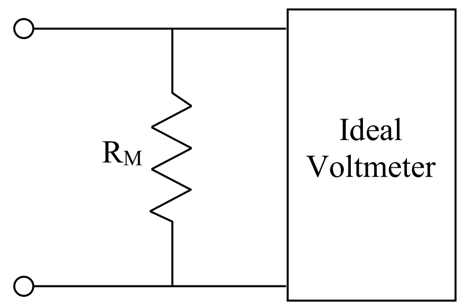


2.3 Instrument Input and Output Resistance Characteristics

In textbook problems, we often assume that voltage sources act ideally. However, in practice, voltage sources (such as the function generator), exhibit non-ideal behavior. A functional generator has a finite “output impedance” (or resistance) and is more properly modeled as a Thevenin source, as shown in part (a) of the figure below with an ideal voltage source (V_s) and a resistor (R_s). Depending on what load is connected to the source and how much current is drawn, the actual voltage V_{out} can be significantly less than V_s. Similarly, all voltage measuring instruments (such as DMMs, Scopes, and A/Ds) have a finite “input resistance” that causes them to draw current from the circuits to which they are connected. Thus, we can model a real voltmeter as an ideal voltmeter with a parallel resistor (R_M), as shown in part (b) of the figure below. Ideally, the input resistance (R_M) of the ideal voltmeter should be large enough that it does not draw enough current to affect the voltage you are measuring.



(a) Source model



(b) Voltmeter model

3. Pre-Lab Exercises

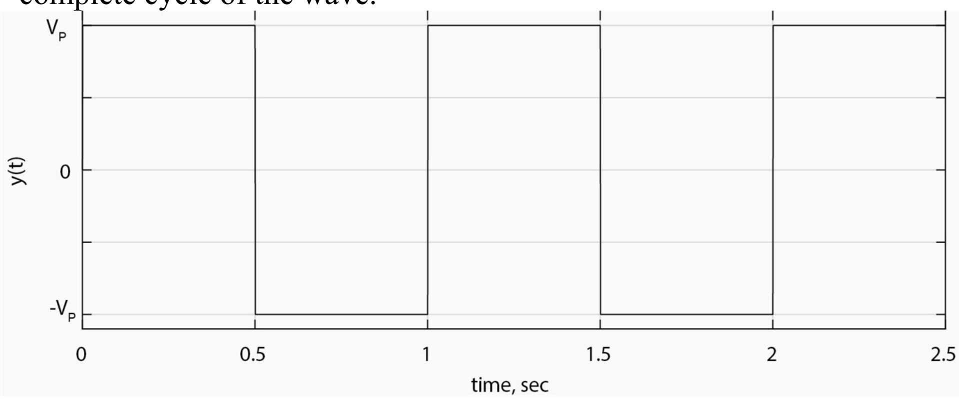
1. For the following sinusoidal signal where f is the frequency in Hz, V_p is the voltage of the sinusoidal part of the signal, and V_0 is the DC offset voltage:

$$v(t) = V_0 + V_p \sin(2\pi\ ft)$$

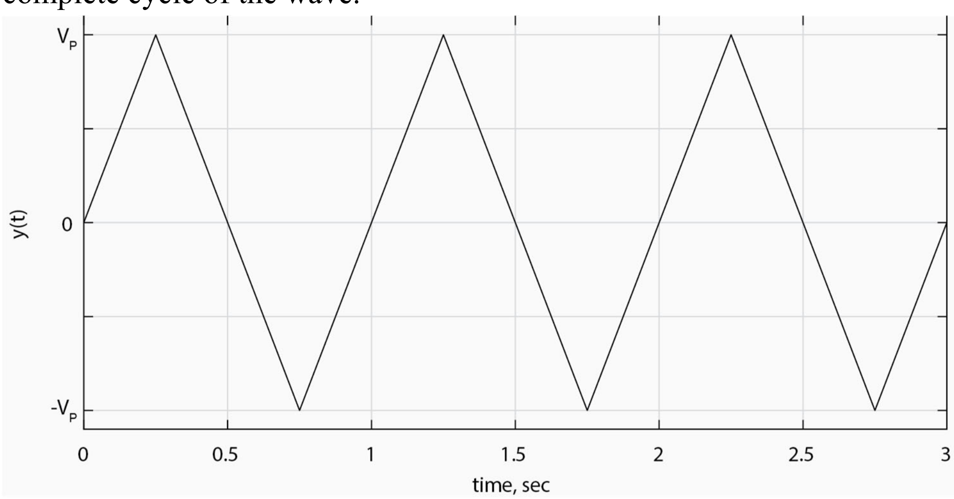
   a. Show that $V_{rms} = \sqrt{V_0^2 + V_p^2 / 2}$
   Hints: $\sin^2(x) = [1-\cos(x)]/2$, and the integral of sin(x) or cos(x) over one period is zero.

   b. Determine the ratio V_{rms}/V_p for $V_0 = 0$ (no DC component)

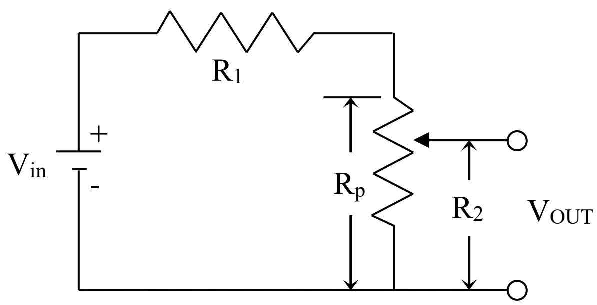
2. Derive the ratio of V_{rms}/V_p by taking the integral using equation 1 for the square wave signal shown below. Hint: you'll need to evaluate the integral piece-wise over one complete cycle of the wave.



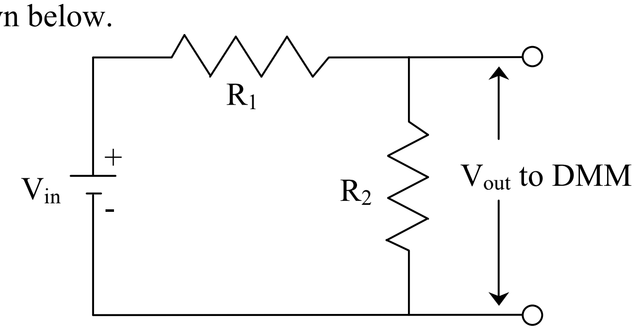
3. Derive the ratio V_{rms}/V_p by taking the integral using equation 1 for the triangle wave signal shown below. Hint: you'll need to evaluate the integral piece-wise over one complete cycle of the wave.



4. Derive the equation for V_{out} for the following circuit diagram, using Kirchhoff circuit laws. R_p is the resistance across the entire potentiometer whereas R_2 is the variable resistance between the current potentiometer position (wiper) and the ground side of the potentiometer.



5. Assume a Digital Multimeter is measuring the circuit below. Model the DMM as an ideal voltmeter in parallel with an internal resistance R_M as discussed previously. Analyze the system to show that the voltage measured V_M is a function of resistances and the input voltage as shown below.



$$V_M = \frac{R_2 R_M}{R_1 R_2 + R_M (R_1 + R_2)} V_{in}$$

4. Lab Exercises

4.1 Laboratory Instrument Evaluation

4.1.1 Setup the Function Generator (FG) and oscilloscope

- Set the FG to a frequency of 2 kHz sine wave.
- Connect the output of the FG to CH1 and CH2 to the oscilloscope using a BNC-tee.
- Set CH1 to DC coupling and CH2 to AC coupling
- Set oscilloscope measurements for CH1 to $V_{p\text{-}p}$ and V_{rms}.
- Set oscilloscope measurements for CH2 to $V_{p\text{-}p}$ and V_{rms}.
- Adjust the amplitude to be 8 Volts peak-to-peak with no DC offset.

4.1.2 Make measurements

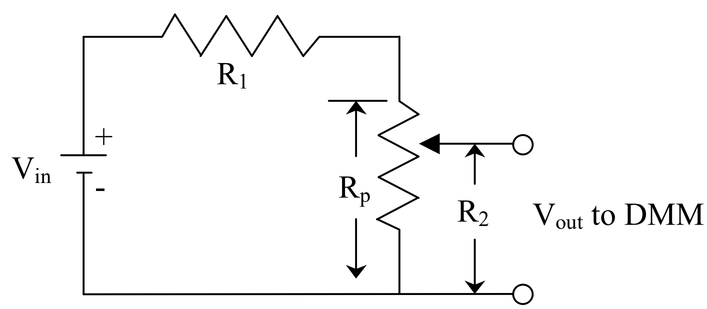
- Measure V_0 (the DC offset), $V_{p\text{-}p}$, and V_{rms} using the oscilloscope. Record the values in **table 4.1.2** below. We recommended that you make an excel spread sheet.
- Measure the Voltage using the DMM in both AC and DC mode. Record the data in the same table.
- Repeat the last two steps with a square wave; a triangular wave; and a sine wave again, this time with a 3V DC offset (see table).
- Verify the offset, V_0, by changing CH1 and CH2 to measure the MEAN on sine w/ DC offset signal.
- In the Calc. column calculate the expected V_{rms} using V_0 and $V_{p\text{-}p}$. (Hint: Prelab)
- You will discuss these readings in the Post-lab.

Have a TA check your progress

4.2 Voltage Divider Measurements

To understand the effects of input and output resistance on measurements, we first must understand a "voltage divider" circuit. In this exercise, you will build the circuit and verify the equation below. A voltage divider is a simple circuit with two series resistors that splits the total voltage drop over the pair of resistors.

$$V_{out} = \frac{R_2}{R_1 + R_p} V_{in}$$



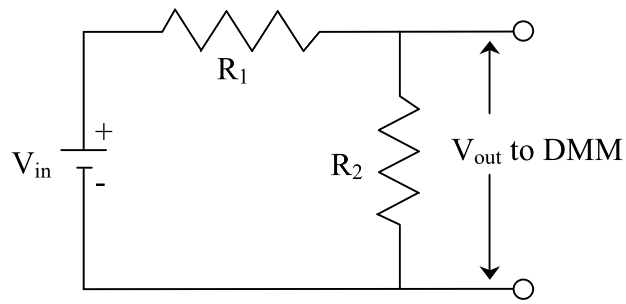
4.2.1 Construct the circuit shown above on a breadboard.

- Use a 5V source, a 100 kΩ resistor, R_1, and a 100 kΩ potentiometer, R_p.
- The potentiometer (a.k.a. "pot") is a three-terminal resistive element with an adjustable screw.
- Across one of the end terminals and the screw-adjustable terminal, indicated by an arrow in the figure, resistance, R_2, is continuously varied from zero to the maximum indicated value, R_p.
- With a DMM, Measure R_1, R_2, and R_p with the power supply off and disconnected from your circuit.
- With a DMM, Measure V_{in} and V_{out} for four different settings of the pot. Make sure that you cover the entire range. Record data in table 4.2.1 which is provided in Section 4.5.
- Calculate and record the theoretical V_{out} and the percent difference in the data table.
- Discuss with your TA whether the measured and calculated output voltage agree.

Have a TA check your progress

4.3 Input Resistance of a Digital Multimeter

4.3.1 Create the circuit in the following figure using identical resistors R1 and R2. V_{in} should be 5 V.



4.3.2 Measure V_{in} and V_{out} when $R_1 = R_2 = 2$ kΩ, 20 kΩ, 200 kΩ, 1 MΩ, 2 MΩ, and 4 MΩ. Be sure to measure the exact values of R_1 and R_2. Record data in the table provided in Section 4.5, which is provided as a single page document to keep. Do not write on the lab handout.

4.3.3 You will estimate the value of the DMM internal resistance in the Post Lab using the data in the table.

Have a TA check your progress

4.4 Output Impedance of Function Generator

4.4.1 Your function generator should have the output impedance labeled on it. See if you can come up with a way to verify it. (Hint: look at the Thevenin source model. This can be seen as the circuit in section 2.3. The idea here is that we are trying to verify R_s, the output impedance of the FG. Since we *don't know* R_s, we also don't know V_s. You might want to take a pair of measurements.) Talk to your TA if you are having problems deciding what to do. Conduct your experiment and write down your method. You will provide your method (in your own words and equations) and results in the post-lab.

Have a TA check your progress

Clean up your workstation and have your TA check you off for cleanup.

4.5 Student Work

Name(s): ________________________________ Lab Section: ____________________

Data table for 4.1.2:

	Scope						**DMM**		**Calc.**
	V_0		**V_{p-p}**		**V_{rms}**		**V_0**	**V_{rms}**	**V_{rms}**
	DC(1)	AC(2)	DC(1)	AC(2)	DC(1)	AC(2)	DC	AC	
Sine	0	0							
Square	0	0							
Triangular	0	0							
Sine w/ DC offset (V_0)									

Data table for 4.2.1

Set	R_1 (Ω)	R_p (Ω)	R_2 (Ω)	V_{in} (V)	V_{out} (V)		% diff.
					(measured)	(calc.)	
1							
2	same	same		same			
3	same	same		same			
4	same	same		same			

Data table for 4.3.2

Set	R_1 (Ω)	R_2 (Ω)	V_{in} (V)	V_{out} (V)	$\left[\frac{R_2}{R_1 + R_2}\right]V_{in}$ (V)	% diff.
1						
2			same			
3			same			
4			same			
5			same			
6			same			

Methods and Data from 4.4.1:

5. Post Lab Exercises

1. From table 4.1.2.
   a. In AC mode/coupling: Does the DMM measure the true RMS voltage for any signal with or without an offset? Does the Oscilloscope measure the true RMS voltage for any signal with or without an offset? Justify your answer.

   b. In DC mode/coupling do the DMM and Oscilloscope measure the same DC component (offset, V_0) of the signal? Justify your answer.

2. In this problem, you will estimate the DMM internal resistance. In the Prelab you derived the following relationship for the voltage measured by the DMM assuming an ideal voltmeter.
   a. What is the limit on the equation below when $R_M >> R_1R_2/(R_1+R_2)$? What does this mean in teams of using a voltmeter properly?

$$V_M = \frac{R_2 R_M}{R_1 R_2 + R_M (R_1 + R_2)} V_{in}$$

   b. From the data in table 4.3.2 and the equation above (not the result from 2.a), determine the DMM's internal resistance.

3. Describe your method and result of estimating the output impedance of the function generator (from Lab Exercise 4.4).

6. Project Milestone 4

In preparation for PM 6, begin prototyping your solution. Each team should prototype their mechanisms, mobile platform, and wireless transmitter. While building your transmitter, you should also begin setting up wireless communication. You should be making progress towards each of these categories. During Lab 5 you will present your current progress and prototypes. Your presentation will be a 5 to 10-minute PowerPoint presentation. As a team assignment, one team member will submit the presentation on Canvas on behalf of the team. Include your team number in the filename.

Have at least one slide on each of the following:

- Summarize each team member's contributions for this week.
- Summary of your robot and transmitter design
  - Include CAD model from PM 3
  - Updated CAD with any changes made from PM 3
- Summarize progress/changes for each mechanism prototype. Include images of current prototype(s).
- Summarize progress/changes for the mobile platform prototype. Include images of current prototype(s).
- Summarize progress/changes for the communication strategy.
- Your goals toward completing PM 6