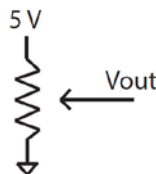


Lab 1: Simple pendulum

In this first lab, you will get experience making measurements with the Analog Discovery on a simple physical system. The lab will also involve the important step of calibration – converting the measured voltage for your system to a physical pendulum angle. This lab will also introduce you to using MATLAB as a plotting and analysis tool.

First you will need to download and install the [WaveForms 2015](#) software from the Digilent website. The software should only take a few minutes to download and install. Once you have installed the software, plug your Analog Discovery hardware into your computer's USB port and the hardware should now be recognized. You may need to wait a few moments and possibly reboot your computer. Open the waveforms software and your device should show up automatically. On the main screen, select "Scope" on the left to open the oscilloscope. Press the run button. Since nothing is connected to the device input you should see zero volts displayed on the graph.

Now get one of the metal plates with the bearing and potentiometer attached. A potentiometer is a variable resistor (we will discuss resistors in class next Monday). There are three header pins sticking out from the side of the small yellow circuit board. These pins will connect to the potentiometer to build the following circuit:

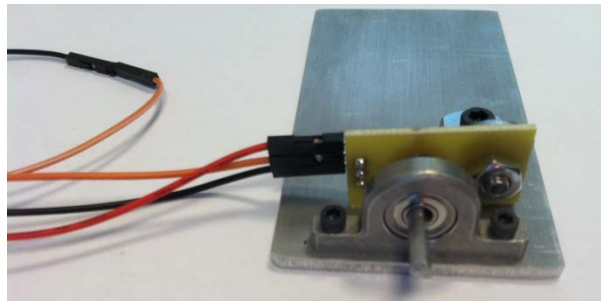


The potentiometer will act as two resistors in series. The total resistance across the potentiometer (measured from the 5 volt connection to ground) will always be 10,000 Ohms or 10K Ohms. The middle pin is connected between the two resistors in series which always sum to 10K. As you adjust the angle of the potentiometer, the balance between the resistors values change (due to the mechanical insides of the potentiometer). Since this is the first day of class, the previous paragraph likely made absolutely no sense to you. Hopefully after some reading and next Monday's lecture class, you will go back to read this paragraph and it will make sense.

Look at the labels on the set of wires coming from the Analog Discovery. We will not use the majority of these wires in this course. You will commonly use the two analog input channels to measure voltages – these are labeled as ± 1 and ± 2 . This notation means that channel one will measure the voltage **difference** between the plus and minus labeled wires (orange and orange/white for channel 1 and blue and blue/white for channel 2). You will use the ground wires which are black and labeled with a downward pointing arrow. In this lab, you also will need to use V+, which provides a positive 5 volts with respect to ground on the red wire. The

wires labeled 0 to 15 are digital lines that we will not use in this course. Hook the red wire to the “top” of the potentiometer and one of the black ground wires to the bottom.

Go to the main waveforms screen, select the “welcome” tab on the left. Select “Supplies”. Turn the power on the positive 5 volt supply. Now hook the measurement for channel 1 positive input to the middle pin of the potentiometer. Since channel one needs to measure a voltage difference you need to connect the negative input for channel one to one of the ground wires on the Analog Discovery. You can make the connection with an extra header pin. If you don’t connect the channel 1 negative input, you can get weird results since the voltage on this wire is floating. The basic setup is shown in the figure below.



While watching the Scope screen, move the axle of the device around by hand. If everything is working, you should see the voltage change as you adjust the angle. The voltage should vary between 0 and 5 volts. You will need to adjust the x and y axis settings. On the right of the Scope screen, turn off channel 2, adjust the time scale to be something like 1 second per division and the Channel 1 range to be 1 volt per division.

Once you think everything is working, attach the pendulum to the output shaft. Before doing so, rotate the shaft so the flat edge is facing up and then press the pendulum onto the shaft by hand. Use a bar clamp to hold the metal plate to your desk with the pendulum free to swing over the edge. Raise the angle and release the pendulum - you should see a signal which is proportional to the angle of the pendulum and over time should look like a damped sine wave. You may need to adjust the time scale per division on the Scope to see the pendulum come to rest.

Now you need to calibrate your pendulum. Note that the calibration will be sensitive to the initial angle of the shaft when you press on the pendulum – thus you will want to conduct all your experiments and record your data with the same physical setup. Decrease the time scale to something like 200 ms per division. Click on “view”, select “measurements”. Add a “defined measurement” of the average voltage for channel 1 (“average” is a vertical measurement). Take one of the protractors. Change the angle of the pendulum by hand and hold it stationary at a known angle. Record the voltage (use the value in the average display) as a function of angle – i.e. just write the numbers on a piece of paper. Take a measurement for every 20 degrees, obtaining data for angles plus and minus 80 degrees where zero degrees is defined as rest straight up and down (what direction is the positive angle is arbitrary). If you are ambitious you could collect more calibration data.

Now let’s record the pendulum dynamics. Increase the time scale per division such that you can collect a cycle of raising the pendulum, releasing it, and watching it come to rest. Collect one such run on the scope and

simply hit the “stop” button once the pendulum has stopped moving. Under file, click “export”. Select the source as “scope”. Keep all the comments, labels, and headers checked. Save the file as a .csv file and set the location for the file somewhere logical (i.e. make a directory on your computer for this course with sub-directories such as Lab1, Lab2, etc). Name the file something that makes sense when you go back to it.

Finally, let’s create our figures in MATLAB. Open MATLAB. Type your calibration data in as two vectors such as

- `Angle = [-80 -60 -40 -20 0 20 40 60 80]`
- `Vout = [x x x x x x x x x];`
- `plot(Vout,Angle, '*')`

These commands will generate a plot of measured voltage versus measured angle with stars at each data point. You of course need to type your numbers in instead of x. The resulting plot should be very linear. You can generate a calibration curve by hand using the form $\theta = a(V - V(\theta = 0))$ where $V(\theta = 0)$ is the measured voltage when the angle is zero. You can find the approximate slope of the line, a, by inspection of your plot. You can test your calibration curve by typing the commands

- `hold on`
- `V0 = x`
- `a = x`
- `plot(Vout, a*(Vout-V0))`

The command “hold on” keeps the previous plot active and puts the new plot on top of the old. Again, you need to replace x with actual numbers from your analysis. Please note that this is the first week and probably your first time working with MATLAB. If the above MATLAB commands made no sense, there is no need to panic at this point!

Now create the plot for your recorded pendulum dynamics. To import your experimental data from Waveforms into MATLAB there are a number of different ways. One simple way is to just click the “Import Data” button at the top of the MATLAB window. Find the file you saved and open it. The data should load into a spreadsheet properly and you can click “Import Selection”. The columns of data will be saved as variables in MATLAB with names given by the headers in Waveforms. The default variables are “Times”, “Channel1V”, and “Channel2V”. To check this naming, look in the “Workspace” window of MATLAB. You should see these data variables with size of 8000x1 – meaning 8000 rows and 1 column.

To make a plot try

- `plot(Times,Channel1V)`

To make a plot in terms of angle try

- `plot(Times, a*(Channel1V-V0))`

where you will need to have defined a and V_0 as before from your calibration. Once you have the plot, you can add axis labels and set the scale interactively through the plotting window. You can simply click arrow at the top of the figure window and then double click on the axis to edit the properties. You can also edit these things at the command line, such as

- `axis([0 20 -90 90])`
- `xlabel('time (seconds)')`
- `ylabel('angle (degrees)')`

You can save the figures through the pull down menus in many different file types.

Deliverables:

The most frequent question we are asked is “what do I turn in”. In general, we will provide some guidance in the lab writeup of what is required, but you will also need to learn to use your best judgment and not rely on us to tell you exactly what to do as the semester goes on. You DO NOT need to write a lengthy lab report. The lab report ONLY needs to include the results – (we know the basic experiment since we assigned it so there is no need to write an introduction or explanation of what you did). Just the results. Each week, we will provide some guidance about what you need to include. In general the lab report will include figures with short explanations of what each figure shows.

For this lab, you should include your calibration curve (angle versus V_{out}) and your measured dynamics in terms of angle versus time. The plots should be labeled with units, easy to read (make the fonts on the axis easy to read), and be annotated when appropriate. The Ninjas for the course will help you generate high quality figures as the year progresses. For this lab, since the data are so simple, you do not need to provide very much commentary on the results. You should always include a short but descriptive figure caption that explains what each figure in your lab report shows.