Mechatronics Lab 2: Magnetic Levitation

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PART 1: Detector, Emitter and Current Driver Circuits

Step 1. Collect the following items from the components box:

Qty	Part	Qty	Part
1	1k ohm potentiometer	1	0.1 ohm resistor
1	200k ohm potentiometer	1	OPA547T op-amp and heat sink
3	1k ohm resistor	1	LM741 op-amp
1	15k ohm resistor	2	~ 100uF polar/electrolytic capacitors
1	47k ohm resistor	-	Various colors of hookup wire

Note that you will be expected to return the op-amps and potentiometers at the conclusion of this lab.

While building the following circuits, please make sure you keep your breadboards clean and uncluttered. Do not use unnecessarily long wires. Use color coding for wire connections, which will help you debug the circuit later. In general, use Black for ground, Red for high voltage (+15V), orange/yellow for low voltage (-15V), etc.

Step 2. The Emitter Circuit (one half of the ball position sensor)

The emitter for your position sensor is a Lite-On infrared LED. The LED will be driven by a constant voltage from your power supply. This LED is already installed on the Mag-Lev stand provided to you.

For now, set the 1K pot to 50 Ohms using a multimeter. Implement the circuit in Fig.1 on your breadboard. **CAUTION**: Make sure that you are connecting the “Anode” terminal of the photo-emitter to high voltage side. The cathode and anode terminals are labeled on your Mag-Lev stand.

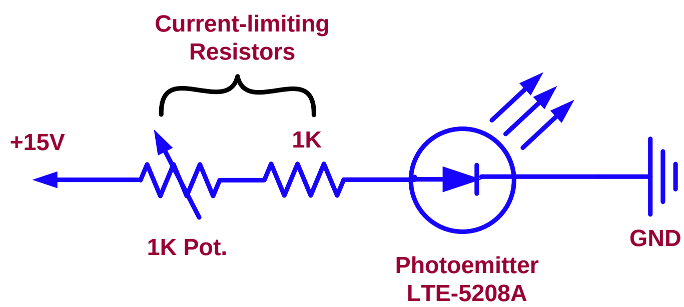


Figure 1: Photo-Emitter Circuit

Step 3. The Detector Circuit (second half of the ball position sensor)

To detect the infrared output of the LED, you will use a Lite-On phototransistor. We use a buffer op-amp configuration to avoid circuit loading effects caused by the Analog Input (AI) terminal on the NI data acquisition (DAQ) device. Once again, note that the Lite-On phototransistor is already installed on the provided Mag-Lev stand. Use the LM741 data-sheet for the correct pin connections. **CAUTION**: Make sure that you are connecting the "Collector" terminal of the photo-detector to high voltage. The collector and emitter terminals are labeled on your Mag-Lev stand.

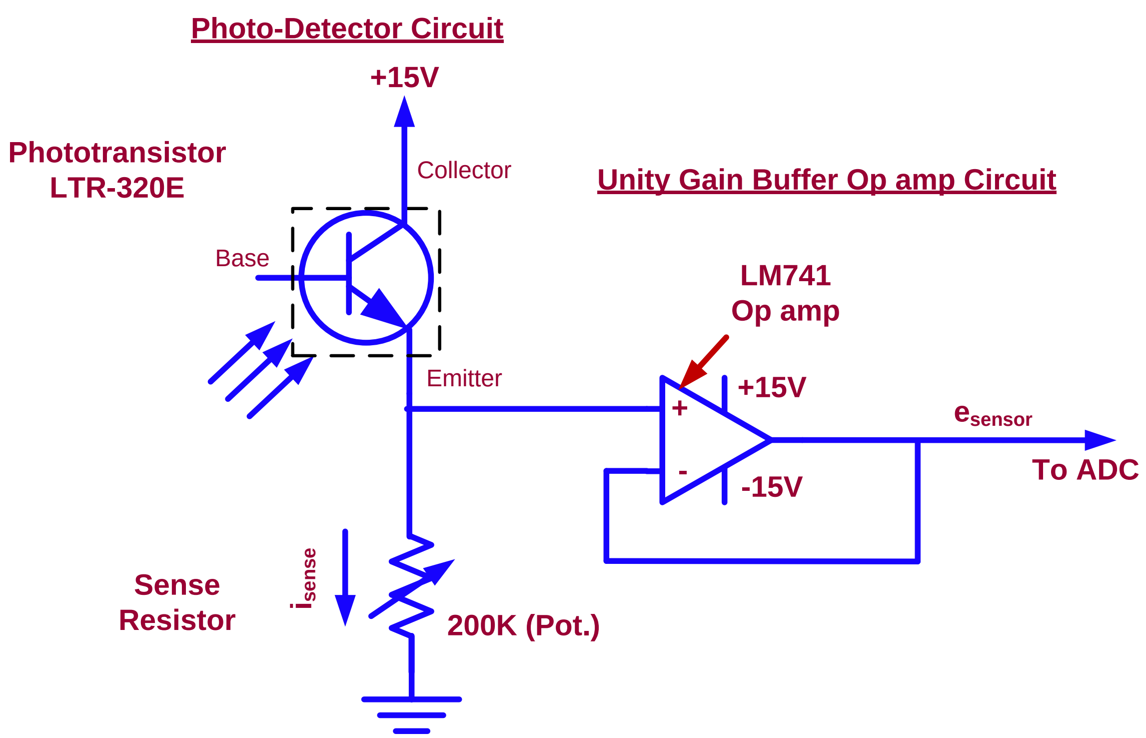


Figure 2: Photo-detector and Buffering Op Amp Configuration

Step 4: The Voltage-to-Current Amplifier / Current Driver / Actuator Driver

To drive the electromagnet, you will use a high-current power op-amp**,** OPA547T, configured as a voltage-to-current amplifier. Create the circuit as shown below and consult the OPA547T datasheet for the correct pin connections.

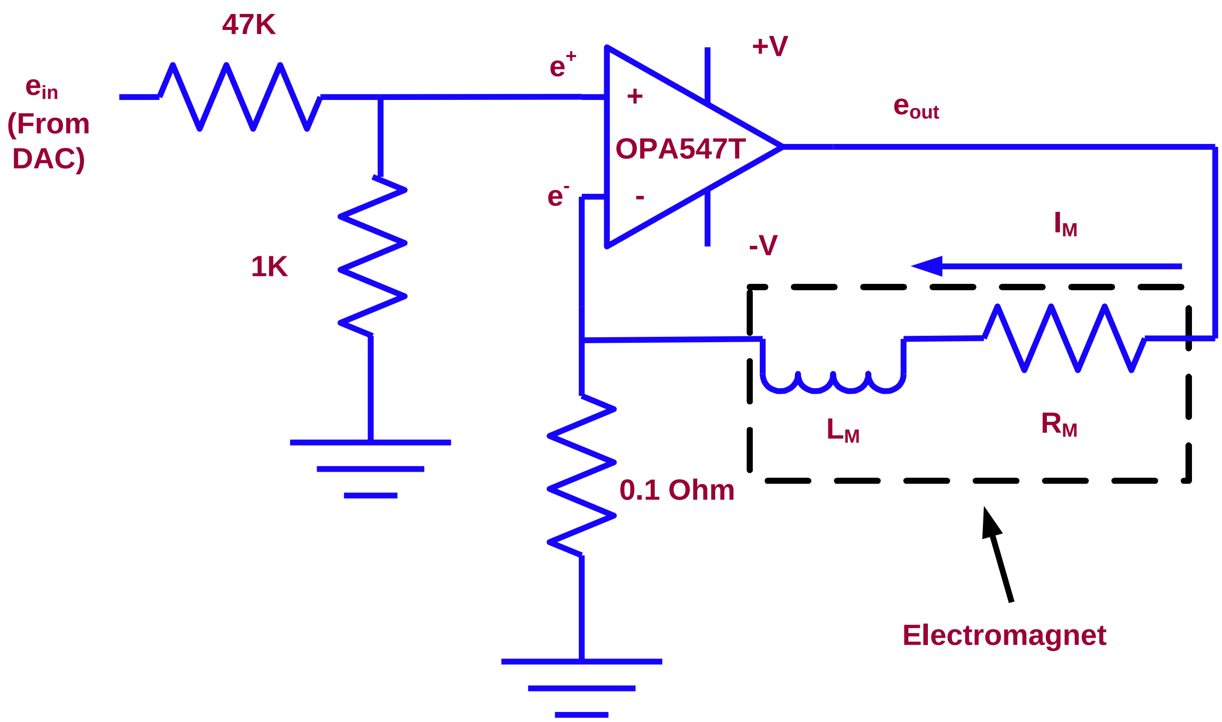


Figure 3: Voltage-Current Driver Configuration

Make sure to set a current-limit on the op-amp to prevent damage using the circuit shown below. Again, look at the datasheet for the pin numbers. Set $R_{CURRENTLIMIT}$ = 15KΩ.

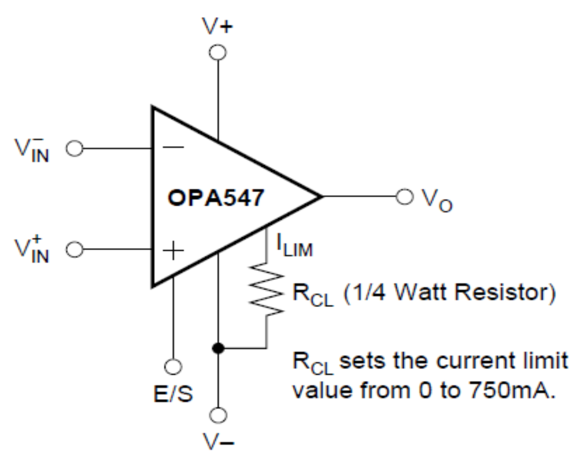


Figure 4: Current-limit on Op-Amp

CAUTION: Make sure that you install the heat sink to the power op-amp OPA547T with the screws and nuts provided. An improper installation of the heat sink will cause the op-amp to over-heat, potentially leading to component failure.

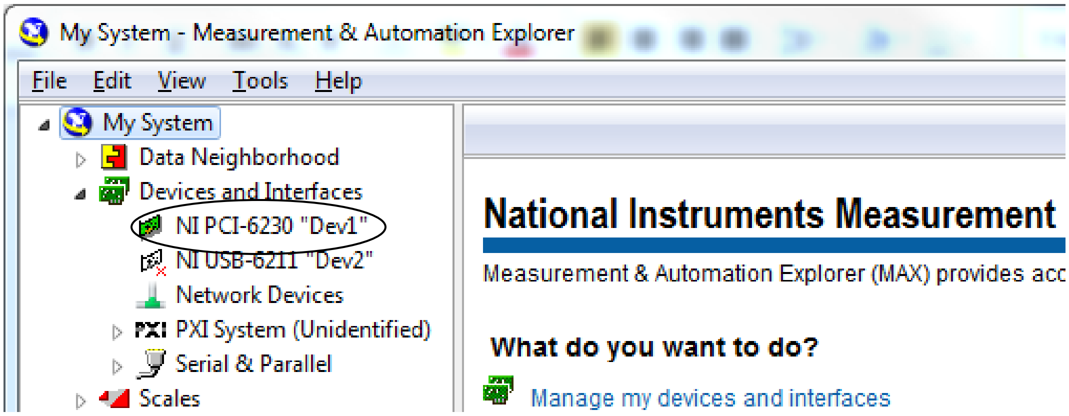
Step 5. Power Filtering Capacitors

Connect one polar / electrolytic capacitor between the +15 and Ground line and the other capacitor between the -15V and Ground lines on your breadboard, to filter out the high frequency noise in the power supply. CAUTION: A polar / electrolytic capacitor has polarity, in the sense that there is only one correct way of connecting it between two voltage levels. Look for a minus sign on the side of the capacitor, which corresponds to the low voltage side. If the capacitor legs have not been clipped, then generally the shorter leg corresponds to the lower voltage side. Note that when connecting between Ground and -15V, the former is high voltage and the latter is low voltage.

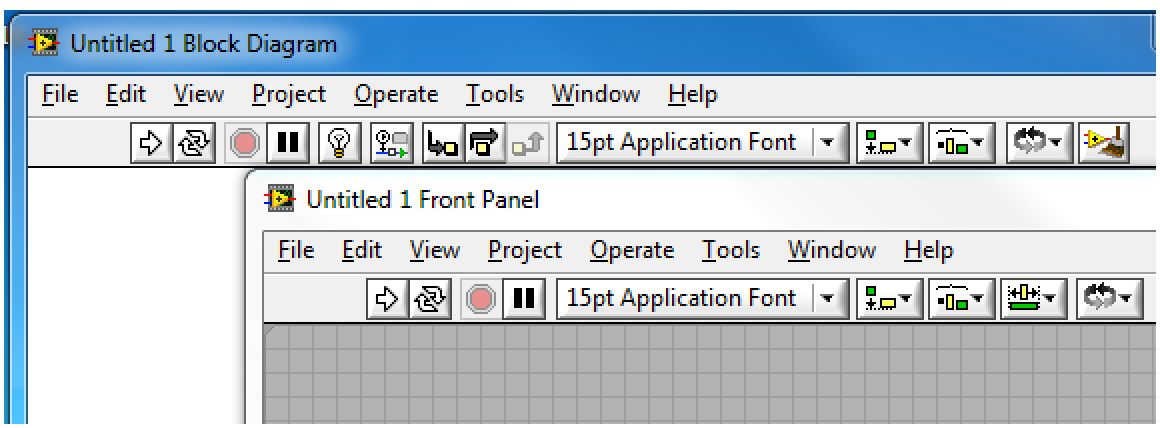
NOTE: Do not switch on the power supply yet. Build your LabView VI and connect the physical system to the data acquisition device (DAQ) by following the instructions provided in the next section. Once done, have your circuit and all connections reviewed by one of the GSIs or instructor, after which you can turn on the power supply.

PART 2: LabView Control System

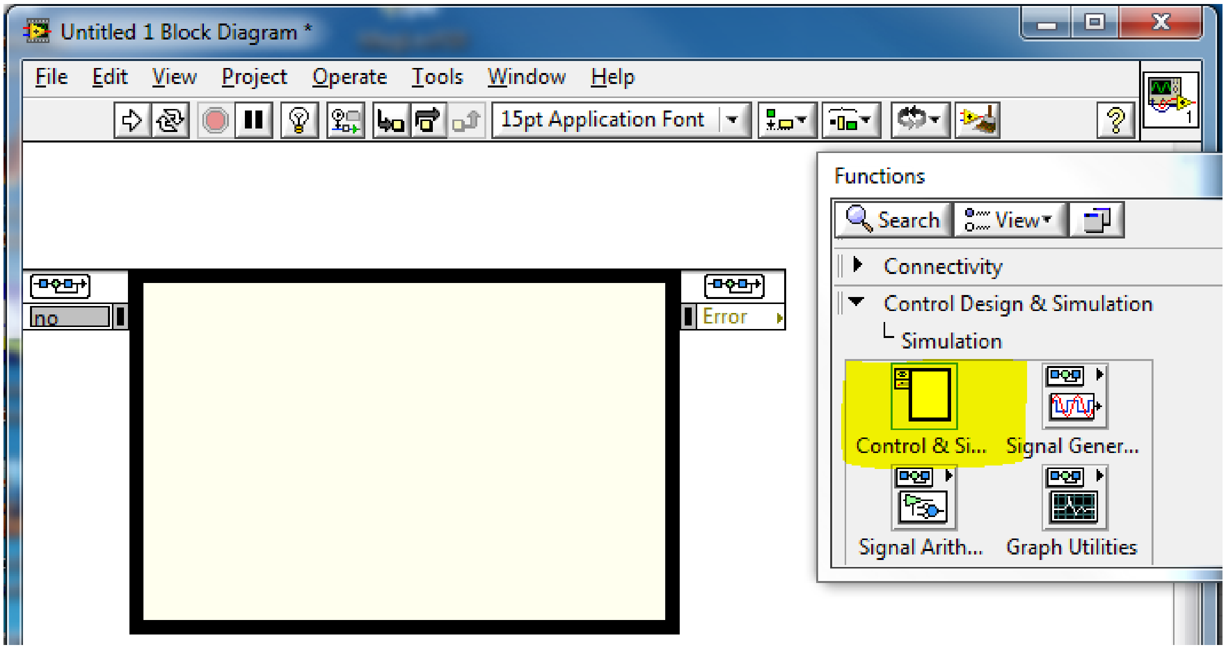
Before you start building the VI, make sure that LabView acknowledges the data acquisition (DAQ) device installed in your computer. This can be done by opening Measurement and Automation Explorer (MAX) by going to "All programs" => "National Instruments". You can also find MAX on your Desktop (blue colored icon). Once MAX is open, go to "My system"=>"Devices and Interfaces". You should see NI PCI-6230 here with a green pointer on the side as shown in the figure below. "Green" implies that the DAQ device has been recognized by the NI software on your computer. Also, you can right click on your device (NI PCI-6230) and select "Self Test" to ensure that the DAQ device is working as intended. Finally, you can also right click on your device (NI PCI-6230) and select "Pinout Diagram", which will open a picture of the pin connections on your break-out board. You can keep this window open for future reference.



Step 1. Open LabView and create a new VI.



Step 2. Switch to the Block Diagram window, and insert a Simulation Loop, located at Control Design & Simulation>Simulation>Control & Simulation Loop.


Untitled 1 Block Diagram *
File Edit View Project Operate Tools Window Help
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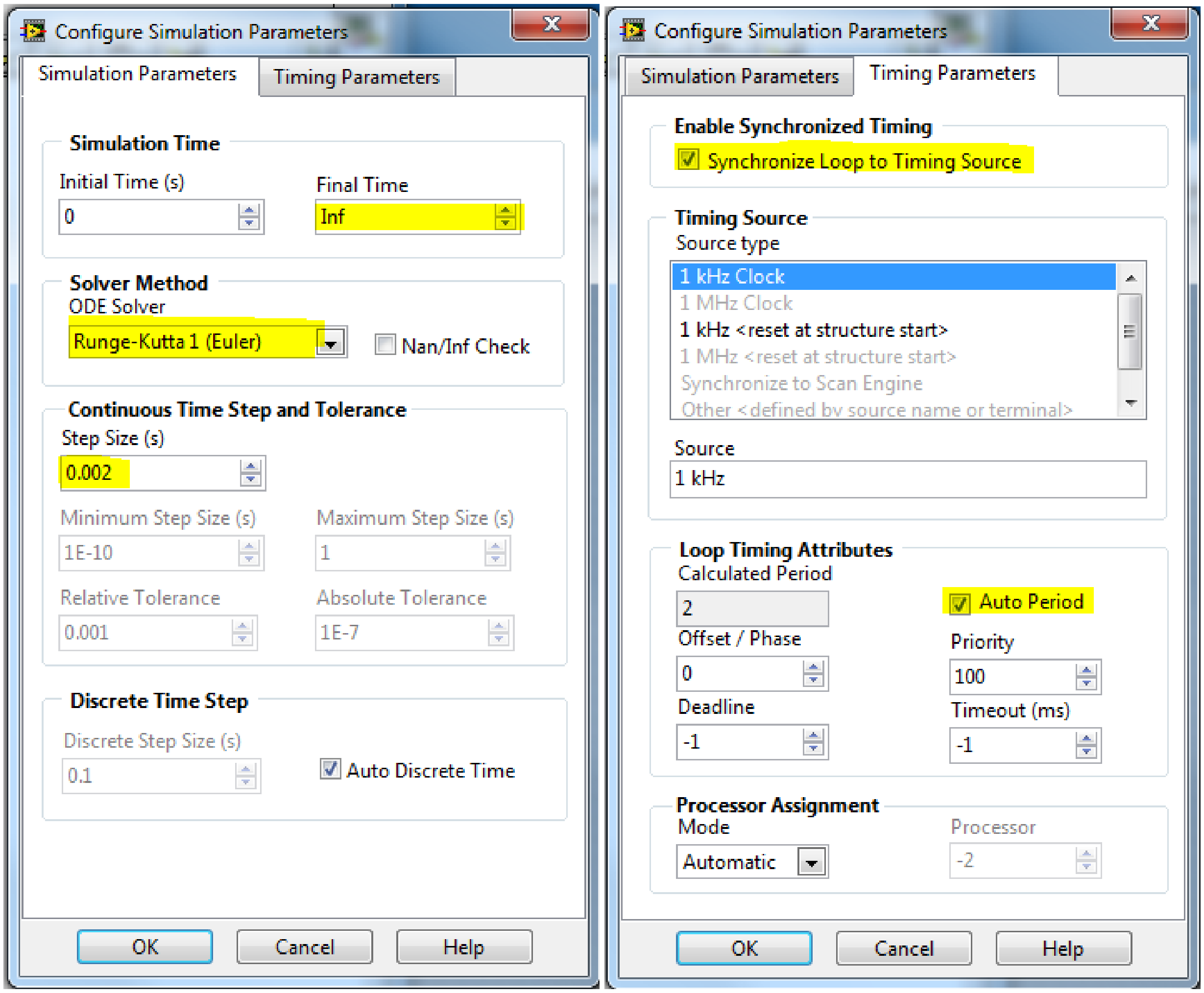
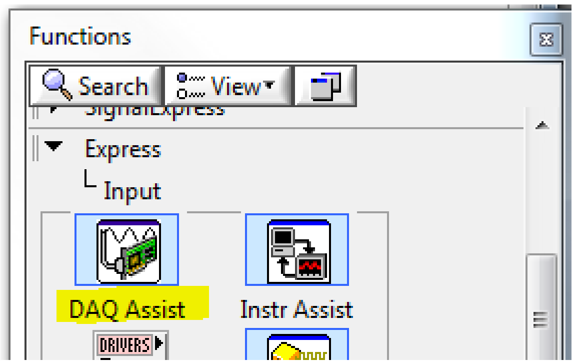
Step 3. Right click the thick black border of the loop and select Configure Simulation Parameters.

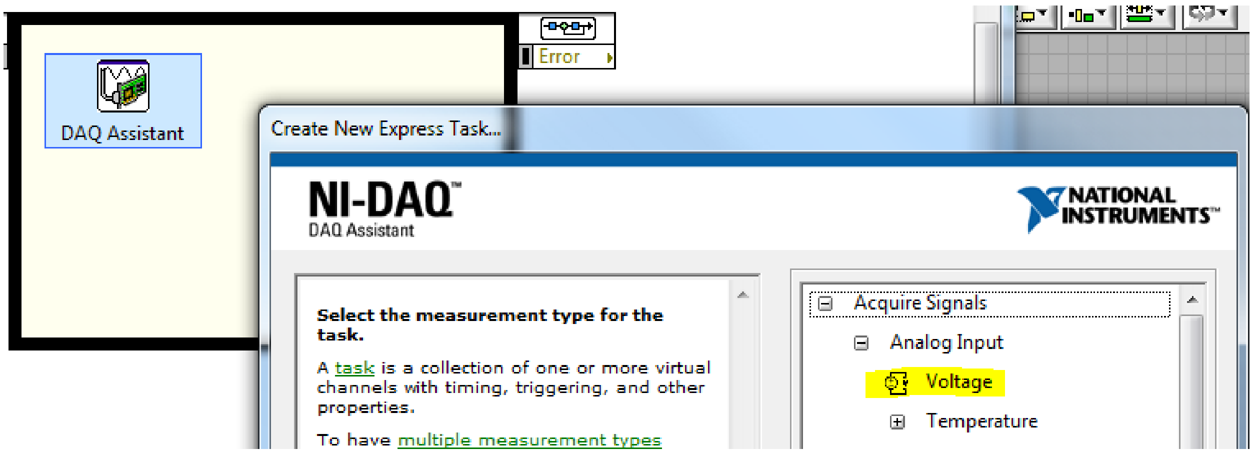


In the Simulation Parameters Tab, set Final Time to “Inf”, ODE Solver to “Runge-Kutta 1 (Euler), and Step Size (s) to “0.002”. Later on you can vary this Simulation Step Size and observe its effect on the closed-loop system performance. In the Timing Parameters tab, check the “Synchronize Loop to Timing Source” box, and select “Auto Period.”

Step 4. Now that you have created a loop, you need to acquire data from your phototransistor. Insert a DAQ Assistant block via Express>Input>DAQ Assistant onto your block diagram inside of the simulation loop

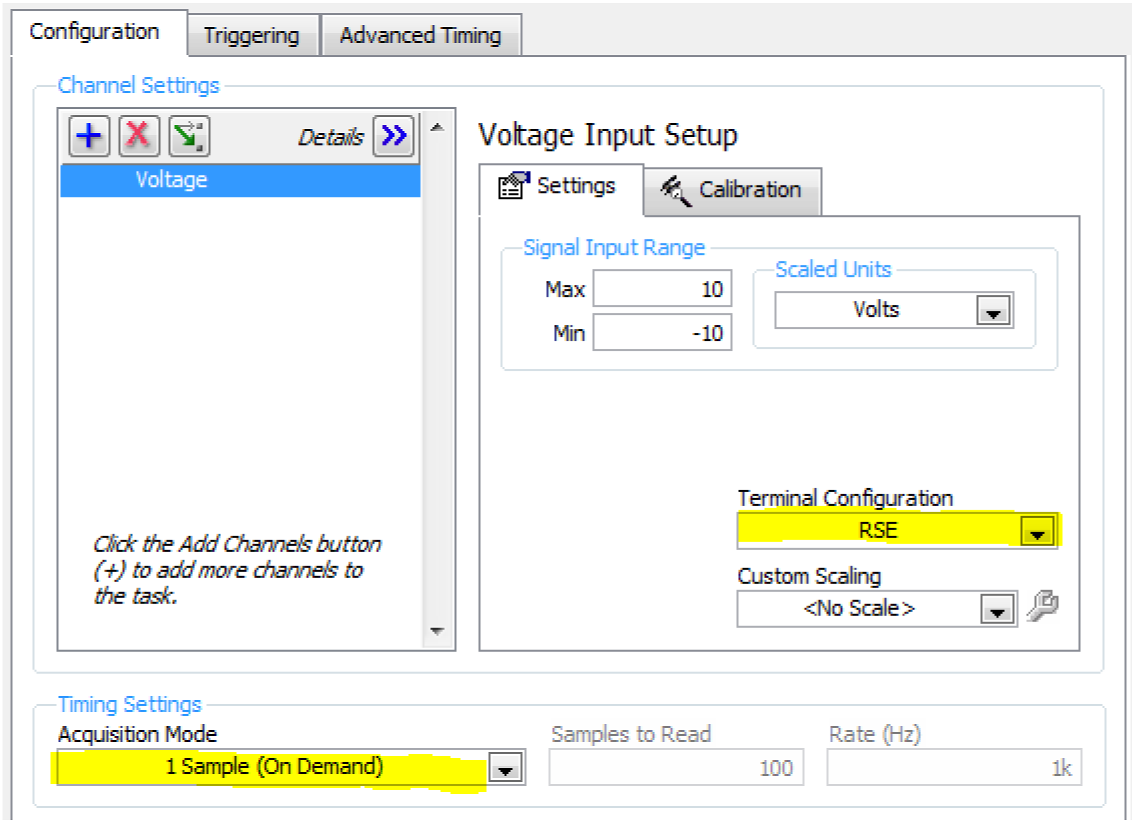


When the DAQ Assistant launches, select Acquire Signals>Analog Input>Voltage

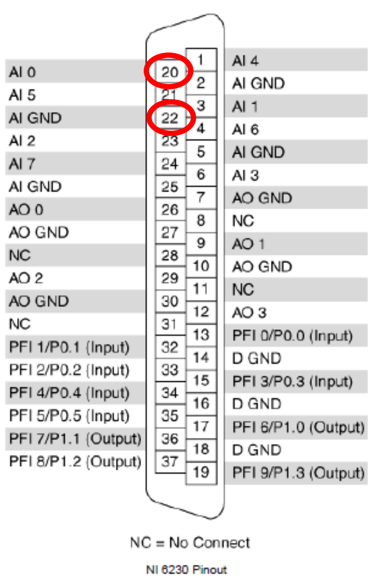


If you have already connected your circuit (i.e. sensor output) to the DAQ via the green colored breakout board on your desk, select the channel that you picked for your analog input (e.g. AI0, AI1, etc.). If you have not already connected your sensor to the DAQ, then choose any channel at this point. Just make sure that the channel selected at this stage in the DAQ Assistant block corresponds to the actual channel used for connecting the sensor.

In the Configuration Tab of the Express Task, select a “1 Sample (On Demand)” Acquisition Mode, and the “RSE” Terminal Configuration. “RSE” stands for “Referenced Single Ended”.

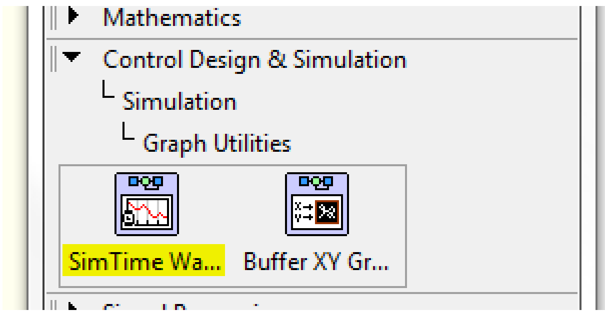


If you are unsure of how to connect your signal and ground from your phototransistor circuit to ai0, refer either to the DAQ datasheet or to the Connection Diagram tab in the DAQ assistant. (For example, in the case of ai0, you should connect your signal to screw terminal 20 and ground to screw terminal 22) Click OK to finish your DAQ Assistant setup.



If you recall the settings in Lab 1, you might notice that the pin assignment for the voltage input channel there was different from the setting in Lab 2. There, you chose the “Differential” option in the “Terminal Configuration” settings box in Lab 1, and as a result you used pin 1 and pin 20 for making your input connections, as you might remember from Lab 1. In general, both the “RSE” and “Differential” options have certain pros and cons. Can you figure out what these might be? (This is not part of the homework assignment, just for your own practical knowledge).

Step 5. Insert a SimTime Waveform Graph from Control Design & Simulation>Simulation>Graph Utilities.



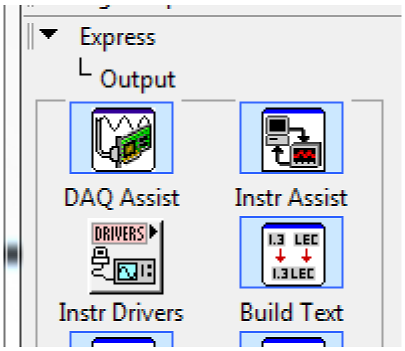
Now you can wire the “data” output of the DAQ Assistant to the input of the Simulation Time Waveform block connected to the Waveform Chart block.

Switch to the Front Panel window and locate the Waveform Chart. At this point you can set the various properties for the Waveform Chart.

a. Right click on the Waveform Chart and click on “Chart History Length”. Since you have set the loop rate of the simulation loop to be 500 Hz, if you set the chart history length to 5000, you should be able to see 10 seconds of data on your plot.
b. Right click on the Waveform Chart and select “X Scale”->”Autoscale”.
c. Right click on the Waveform Chart and select “Y Scale”->”Autoscale”.
d. To get access to the Zoom In \ Zoom Out buttons, right click on the Waveform Chart and select “Visible Items”->”Graph Palate”.
e. In order to access/change other more detailed Waveform Chart properties, you can right click on Waveform Chart and select “Properties”.

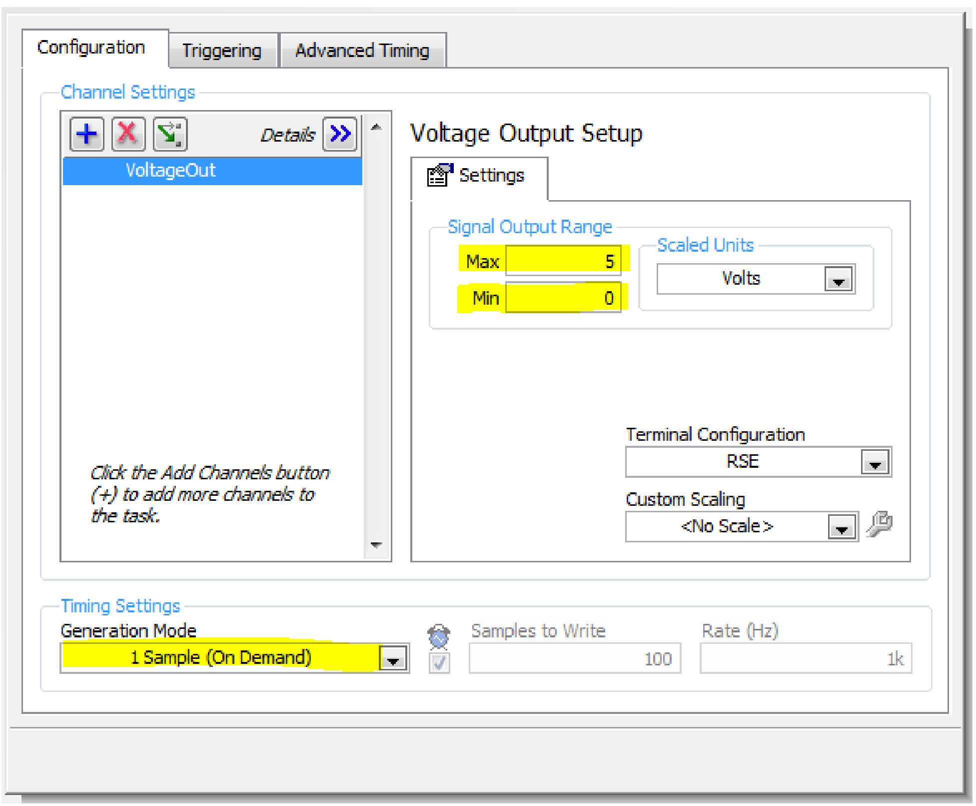
Step 6. Analog Out / Command to the Voltage-to-Current Amplifier

Add another DAQ Assistant block, via Express>Output>DAQ Assistant



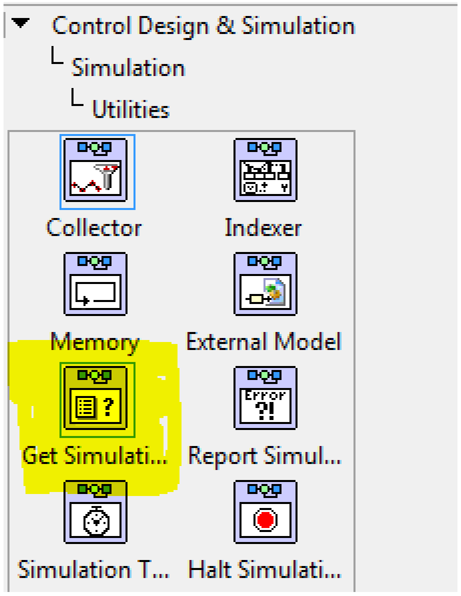
Select the “1 Sample (On Demand)” generation mode and min and max outputs of 0 and 5 volts.

Make sure to connect your OPA547T input and ground to the corresponding screw terminals for the DAQ output channel that you select.

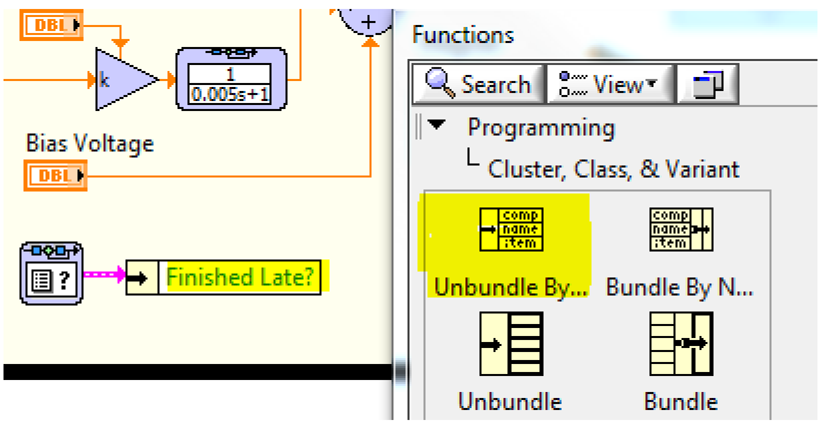


Step 8. Checking ODE Solver

We want to make sure that the ODE solver is keeping up with the loop rate. To do this, add a Get Simulation Status block from CD&S>Simulation>Utilities.

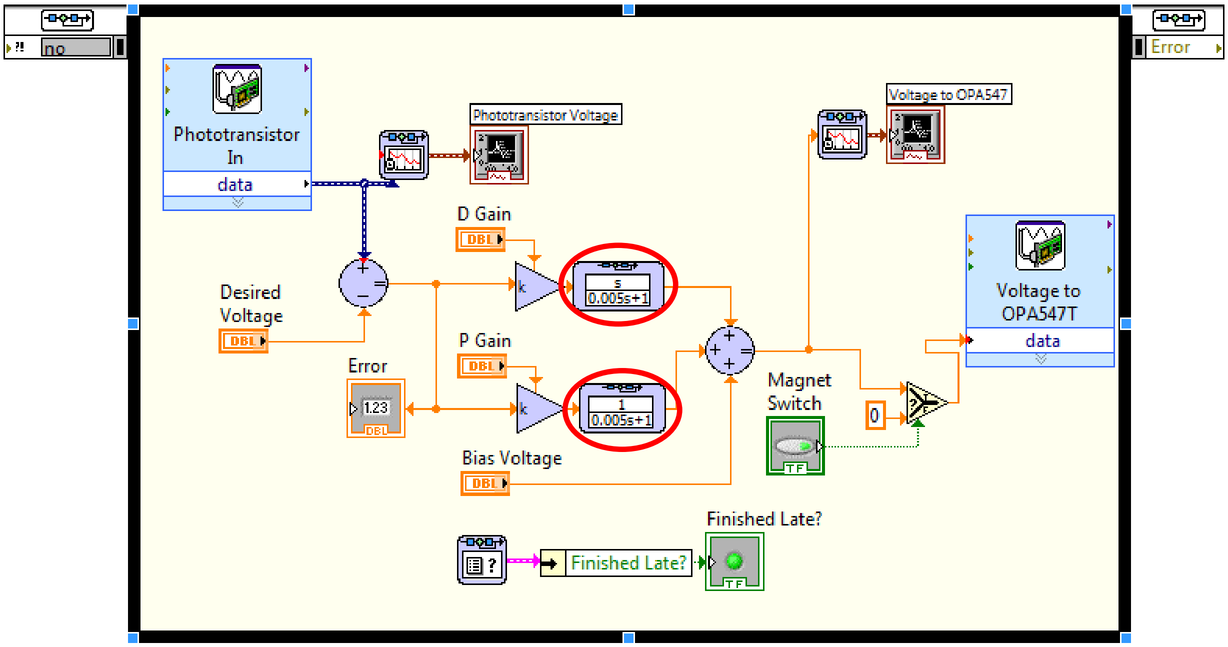


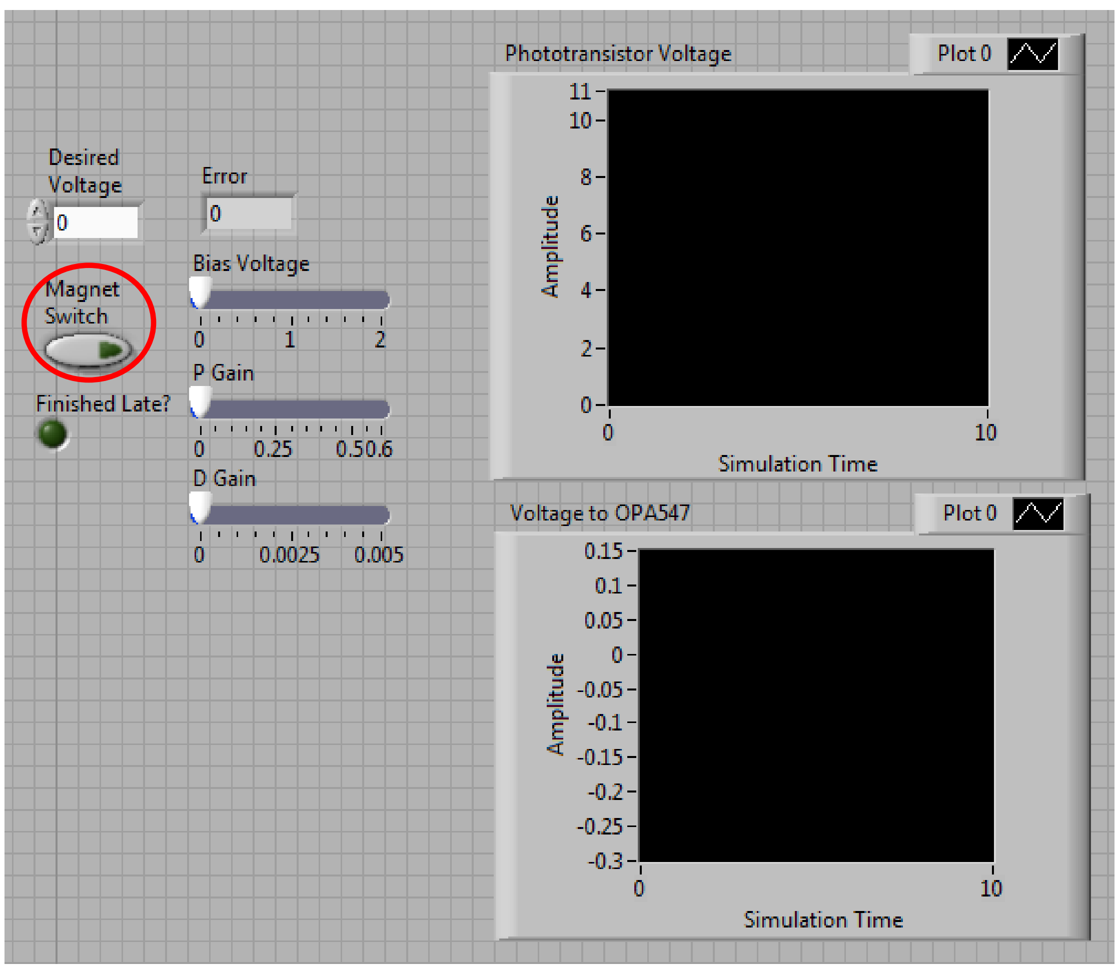
Wire the output of the Get Simulation Status block to an "Unbundle by Name" block.



Right click the bundle and select the Boolean output "Finished Late?". Add a Boolean indicator to the front panel to warn you if the ODE solver ever finishes late.

Step 9. Now that you have your input and output configured, create the rest of the VI to implement the feedback controller that you have designed based on the discussion in the lecture. You may use the following screen-shot of a completed VI for reference.


no
Error
Phototransistor In
data
Phototransistor Voltage
Voltage to OPA547
D Gain
DBL
Desired Voltage
P Gain
Error
1.23
Magnet Switch
Bias Voltage
Voltage to OPA547T
Finished Late?


Desired Voltage
Error
Bias Voltage
Magnet Switch
P Gain
Finished Late?
D Gain
Phototransistor Voltage
Plot 0
Amplitude
Simulation Time
Voltage to OPA547

Step 10. On/Off Switch

Note the Magnet switch included in the above VI, which serves as an On/Off button. It is helpful to insert such a switch and a set of associated logical blocks that will allow you set the output of your control loop to either 0 or the calculated value, even as the VI is running. Insert a Select block from the Programming>Comparison function window and wire the control signal output to the true terminal. Create a constant 0 wired to the false terminal, and create a Boolean control button connected to the Boolean terminal of the select block.

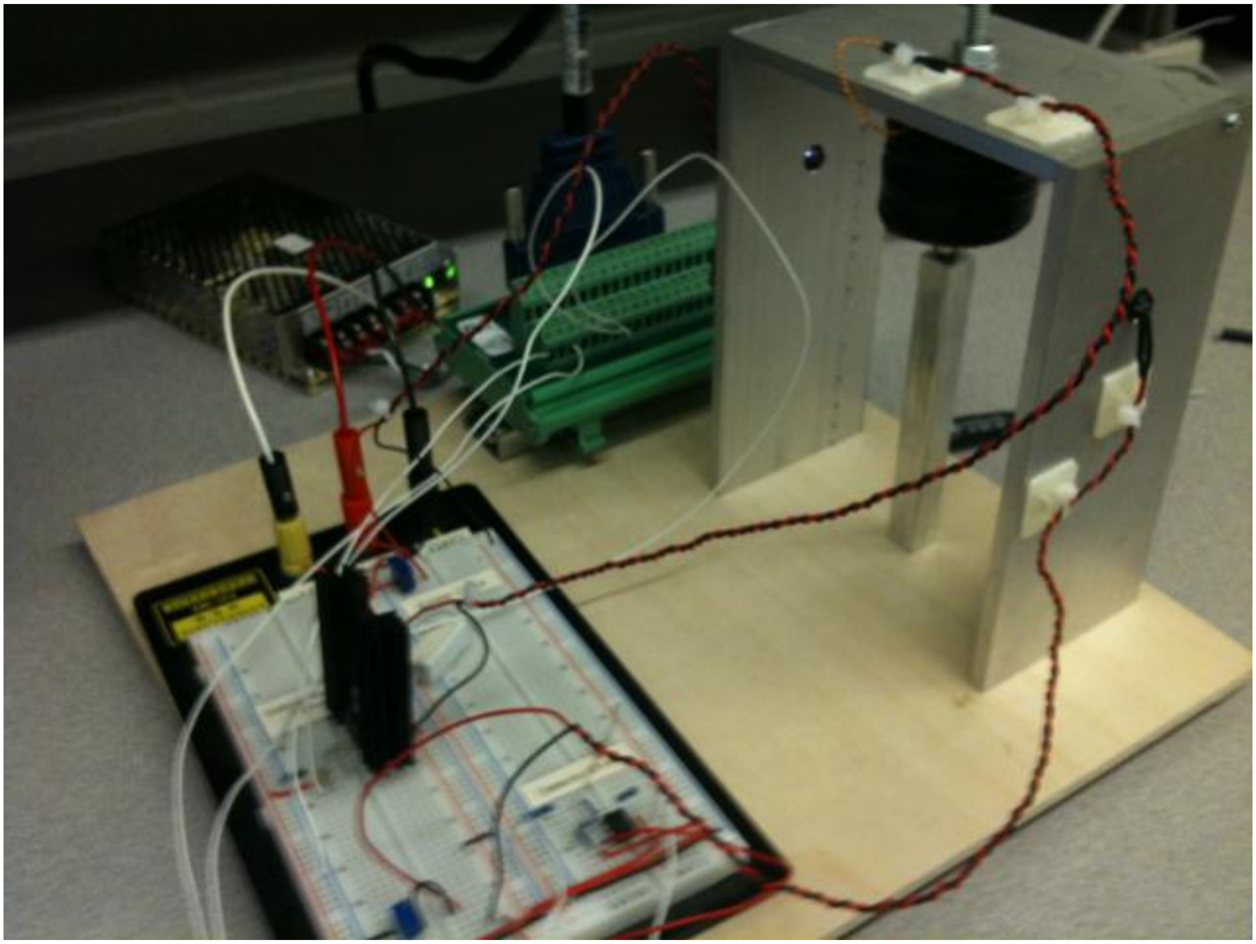
Also, you will notice a couple of “transfer functions” used in the above VI. You can find this block by clicking in the blank space inside the block diagram and then choosing:

Control, design and simulation> Simulation> Continuous linear systems>Transfer function

You will have to configure this Transfer Function block to meet your desired functionality.

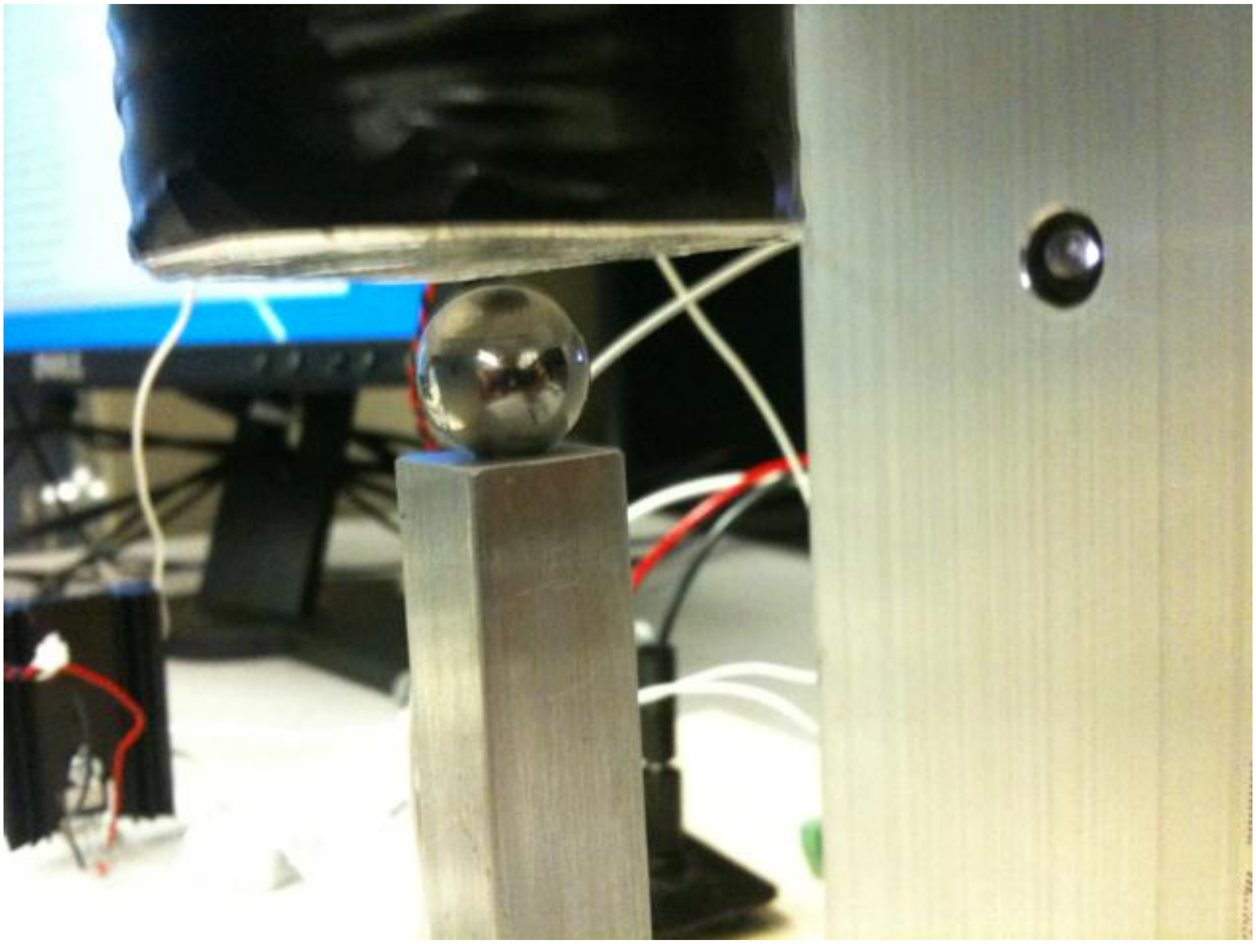
PART 3: Running the MagLev System

Now we're ready to test the whole system. It should look similar to the setup shown below. Once you have your circuits and connections reviewed by one of the GSIs or instructor, you can turn ON the power supply.



Step 1. Make sure that the ON/OFF switch on your VI is still in the OFF position. Start the VI.

Check the ball position signal (i.e. sensor output). If required, adjust the potentiometers in the emitter and detector circuits so that the position signal remains between 0V (LED completely blocked) to 10V (LED completely unblocked).



Step 2. Determine the Bias Voltage

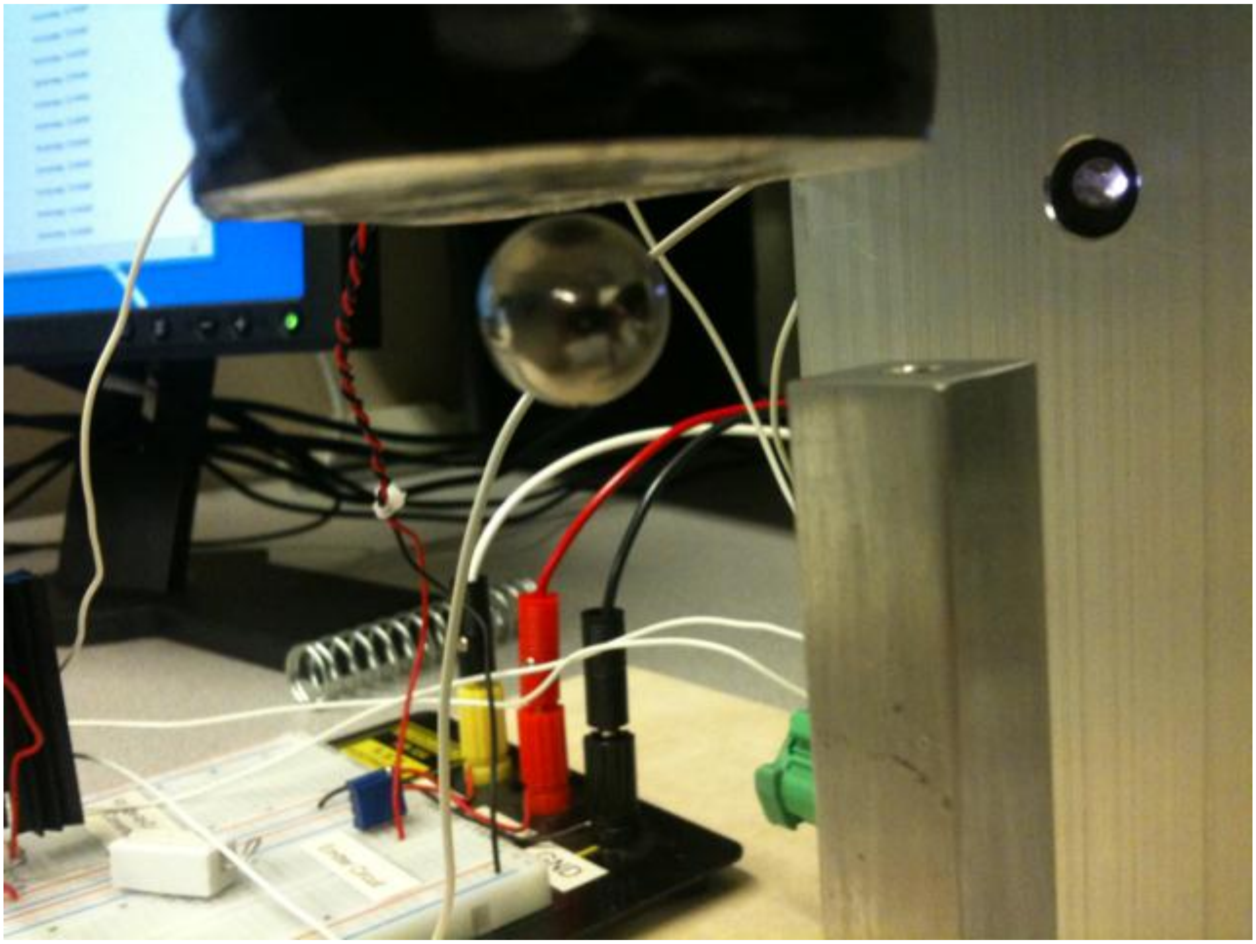
Double check your circuit and turn on the electromagnet from the front panel. Think about the easiest way in which you can determine the bias voltage. You should first try to understand what is bias voltage and why is it used in the controller. You can use the square cross-section Aluminum stands provided with each system, for this purpose.

Step 3. Select your reference voltage.

This corresponds to the position where you want to levitate the ball.

Step 4. Set the controller gains.

Hint: Start with the gains that you selected during your controller design and simulation. Since these gains were based on an approximate model, you might have to tune the gains of your controller, along with the bias and the reference voltage to make your system work.



There are several steps in this lab that you will have to figure out for yourself. This is part of the lab exercise. Please keep posting your questions on the Forums if you run into issues that you are not able to easily resolve.