

# **Magnetic Levitation System: Senior Project Report**

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Sponsor: Robert Weissbach

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## **Executive Summary**

This magnetic levitation system is designed to levitate a steel ball with an electromagnet that is suspended above it. The project is sponsored by Dr. Robert Weissbach, Chair of the Department of Engineering Technology at the Purdue School of Engineering Technology at IUPUI. This project was undertaken by undergraduate students Cody Martin and Zachary Snyder. The MagLev system was developed using the DMADV process.

To fulfill the purpose of the magnetic levitation system, we created a list of specifications based on customer requirements. Design decisions were then made to meet the customer requirements. We knew from the start that we would use a single electromagnet, along with a digital embedded microcontroller to program the control algorithm for the system. A DC power supply is also necessary to allow the system to run on 120VAC from a wall outlet. We discovered by trial and error that we would use an IR emitter and receiver as the sensor for our system. After months of work and study, we completed the entire hardware build of the project.

The MagLev system can be described as a closed-loop system. A closed loop system is necessary because of the natural instability of the magnetic levitation process. A sensor must be used to track the object, and a controller uses this sensor value to control the current through the electromagnet, which exerts an attractive force on the object. There are several different methods that could potentially work for controlling the MagLev system, but we have stuck with using Proportional, Derivate, and Integral (PID) control.

While our object has not successfully levitated the ferromagnetic object, the reference material proves that with correct calibration using similar systems is quite capable. It was successful in fulfilling the primary purpose, successfully enticing a prospective student.

## Version History

<b>Date</b>	<b>Version</b>	<b>Section Updated</b>	<b>Notes</b>
4-9-21	1.	N/A	Initial Version
5-2-21	2.	All	Version before repository submission

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## **Introduction**

The magnetic levitation system has a primary and secondary purpose. The primary purpose of the MagLev system is a demonstration showpiece for the Department of Engineering Technology at IUPUI. The system magnetically levitates small ferromagnetic objects using an electromagnet. We aim to create a MagLev system that has a sufficiently pleasing appearance that prospective students to the ET program would admire it. The secondary purpose of the MagLev system is to show the capability of IUPUI Engineering Technology students. By completing this system to the satisfaction of the sponsor. The MagLev system shows that students studying engineering technology at IUPUI can create an interesting device with a robust design.

## **Objective**

The magnetic levitation system will levitate a ferromagnetic object for many hours at a time. It will be an interesting showpiece that will attract the attention of prospective Engineering Technology students. The project will be complete by April 30, 2021. It will then be presented in front of students, faculty, and the IAB.

## **Scope**

- Levitate an object using a single electromagnet.
- A sensor will provide feedback on the position of the object being levitated.
- The enclosure will be portable.
- There will be a switch mounted to the enclosure to turn power on/off for the system.
- The electromagnet will not cause interference for nearby electrical devices.
- The system will be able to levitate the ball continuously until the power is switched off or the power cord is unplugged.

## **Out of Scope**

- Touch screen for user control.
- Multiple electromagnets used simultaneously.

## Marketing Requirements

1. Should visibly levitate an object.
2. The ball should remain in levitation when a thin material is passed over, under, behind it.
3. Should be easily portable by hand.
4. Should be powered from a 120VAC wall outlet without tripping a circuit breaker.
5. Should not interfere with other electronic devices.
6. Should be able to run continuously.
7. Should run quietly.
8. Should have an On/Off switch.
9. Must have circuit protection from a fuse or circuit breaker.
10. Frame grounded to prevent electric shock (if metallic).
11. Should be resistant to jarring.
12. Should be low cost.

## Specification Requirements

Customer Requirement	Specifications	Justification	Priority
1, 2, 5	The MLS will use an electromagnet capable of producing a magnetic field to lift a small ferromagnetic object.	This is the fundamental element for levitation.	1
3, 11	The enclosure will be sturdy, and all the components will be fastened securely to it. The envelope of the enclosure will not exceed 2x2 ft. The enclosure will not exceed 10lbs.	The MLS enclosure must be sturdy enough to resist jarring and small enough to be easily portable.	4
4	The MLS will use a DC power supply to convert the 120VAC from a wall outlet into the DC power needed to run the MLS.	The MLS must be able to run on 120VAC.	3
10, 9	The MLS will have overcurrent protection from a fuse or circuit breaker.	The overcurrent protection will prevent damage to circuit and provide a basic level of safety.	5
9	Any metallic parts of the enclosure will be grounded.	This will prevent possible electrical shock to the user and provide a basic level of safety.	6
8	The MLS will have an ON/OFF switch mounted on the enclosure.	This is how the user will turn the MLS on or off.	7
2, 6	The MLS will use a digital controller and a sensor to detect the position of the levitated object and control the current through the electromagnet.	This is the method used to maintain stability of the levitated object.	2
6	A method of cooling will be used within the enclosure.	The system should not be allowed to overheat while running for 9 hours.	8
7	The system should operate between 40-60 dB when consulting "Noise Comparisons."	The system should not be excessively noisy.	9

## High Level Design

The magnetic levitation system functions like this (Refer to Figure 1 for the signal flow):

- The IR receiver produces a different voltage depending on how much light the object blocks from the emitter.
- The IR receiver voltage is converted to a 16-bit value through the A/D converter.
- The A/D converter sends the 16-bit value to the digital controller through the I2C bus.
- The 16-bit value is input into the control algorithm which then outputs a PWM signal.
- The driver uses MOSFET to control the higher voltage of the electromagnet with the low voltage of the micro controller.
- The driver current flows through the electromagnet depending on the duty cycle of the PWM signal.
- The electromagnet exerts a force on the object which changes its position within sensor's field of view.
- The process repeats.

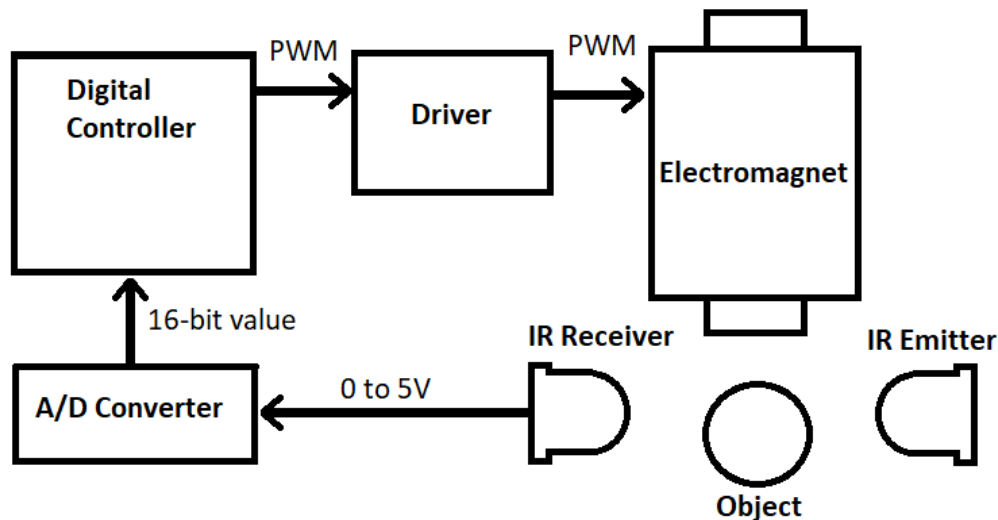


Figure 1: Block Diagram of the MagLev system and the signal flow.

## Design Choices and Reasoning

**Electromagnet:** The electromagnet produces a magnetic field to attract a ferromagnetic object. The amount of current through the electromagnet determines the strength of the magnetic field. The electromagnet is positioned with one of its poles directly above the levitated object. The levitated object will appear to “hang” while the magnetic force is about equal to the force of gravity on the levitated object.

**Reason:** This method of magnetic levitation was chosen because it is the most energy efficient method (Wong, 1986).

**Sensor:** A sensor detects the position of the ferromagnetic object and returns information to the digital embedded system. The sensor uses a separate emitter and receiver on opposite sides of the levitated object.

**Reason:** This sensor positioning was chosen because the customer requires that a thin sheet must be able to pass above and below the levitated object without interrupting levitation. This would cause any sensor placed above or below the levitated object to cease detecting the objects position, causing the object to fall.

**Digital Embedded System:** The digital embedded system interprets information from the sensor and adjusts the current through the electromagnet to keep the ball position stable.

**Reason:** A digital control method was chosen because it is not a common method to use in magnetic levitation. Magnetic levitation is typically achieved through an analog control method, which uses op-amp comparators. Using a digital method for control is thought to be more challenging for undergraduate projects.

**Software:** Using Python, the algorithm used by the system will allow the digital embedded system to interpret information from the sensor and control the current output to the electromagnet.

**Reason:** Python was chosen for the system due to the amount of community support and its versatility within Raspberry OS.

**DC Power Supply:** A DC power supply converts 120VAC into the VDC required by the system. This is necessary because all other components within the MLS will require DC power to operate.

**Reason:** The electromagnet needs DC power because AC power would produce alternating poles on the magnet and excessive heat from eddy currents. Also, the digital controller must have a DC power source to operate.

**Object:** The object needs to be ferromagnetic to be attracted to the magnetic field produced by the electromagnet. The object will be spherical in nature.

**Reason:** A ferromagnetic sphere is preferred because it takes out forces that are not easily corrected. Due to the electromagnet, the object will rotate. If an oddly shaped object were used, it could potentially through the system out of balance.

## Low Level Design

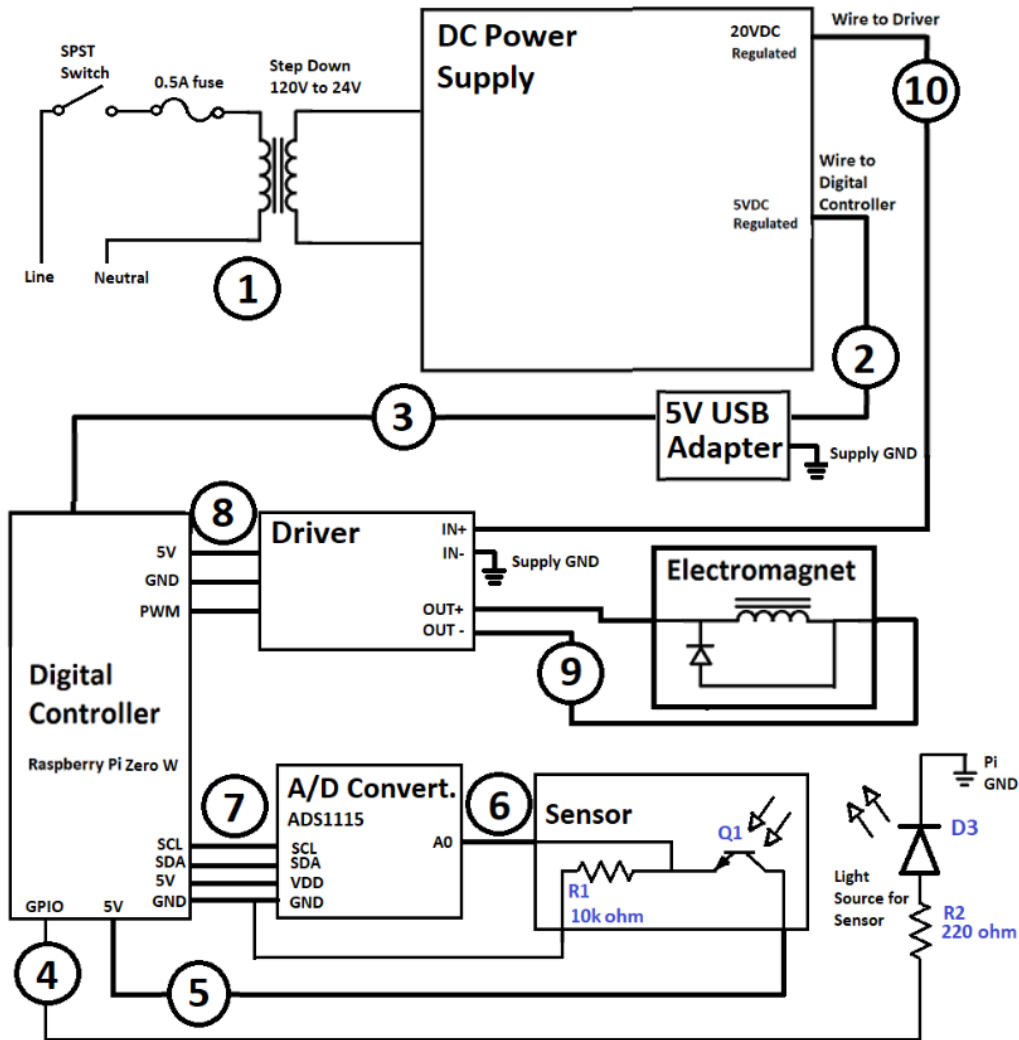


Figure 2: The complete maglev system and all wire connections.

### Numbered Wire Connections

The numbered connections shown in Figure 2 represent the following physical connections:

1. The AC side of the MagLev system. This includes a SPST switch in series with a fuse holder with a 0.5A slow-blow fuse. The switch is connected to the black “line” wire while the fuse is connected to one of the transformer’s primary wires. The other primary wire of the transformer is connected to neutral.
2. A positive and negative wire are connected from the 5VDC terminals of the DC power supply into the 5V USB adapter used to power the Raspberry Pi Zero W.

3. A USB to mini-USB cable connects power to the Raspberry Pi Zero W through the 5V USB adapter.
4. The IR emitter used as the light source for the sensor is connected to a GPIO pin on the Pi Zero W. A GPIO pin is used because it can be turned on or off if needed.
5. The IR receiver of the sensor is connected to +5V on the Pi Zero W.
6. The ADS1115 A/D converter has one of its analog input channels connected between the emitter of the IR receiver and a 10kohm resistor.
7. The ADS1115 A/D converter connected to the Pi Zero W through four wires: the SCL wire and SDA wire of the I2C bus, and the +5V and GND wires of the Pi Zero W.
8. The Pi Zero W outputs to the driver module through 3 wires: the PWM wire, and a +5V and GND wire.
9. The electromagnet is connected to the driver module through “OUT+” and “OUT-” terminals on the driver module. The cathode of the reverse biased flyback diode on the electromagnet must be connected to “OUT+”.
10. A positive and negative wire are connected from the 20VDC terminals of the power supply to the “IN+” and “IN-” terminals of driver module.

## **Test Procedures**

The purpose of this section is to describe the methods used to determine if the subsystems of the Magnetic Levitation System (MLS) comply with the requirement specifications previously determined for the MLS project. Test procedures will be described for each major subsystem to verify compliance with requirement specifications.

## **Test Supply List**

### **Tools:**

- Laptop or desktop PC
- USB cable (for connecting digital controller to PC)
- Infrared thermometer
- Oscilloscope
- Function generator
- Lab DC power supply
- Alligator clips and wires
- Ferromagnetic object

### **Subsystems to be Tested:**

- A/D converter
- Sensor
- MagLev system power supply
- Electromagnet
- Digital controller

## Test 1: DC Power Supply

Test Description	The DC power supply of the MLS will be tested to make sure it can deliver stable power to the electromagnet and the digital micro controller.	
Step	Actions	Expected Results
1.	Plug the AC power cord into wall outlet.	The fuse does not blow
2.	Turn the power switch to the ON position.	The fuse does not blow
3.	Use voltmeter and oscilloscope to measure output of step-down regulators.	Voltmeter reads 20 V and 5V from the regulators.
4.	Use a small ohm resistor with high power rating to put the outputs under high load.	Correct operation
5.	Connect an oscilloscope probe to the output of each regulator to measure their output ripple.	Power supply voltages will stay constant with $\leq 100$ mV ripple.
6.	Use an infrared thermometer to measure heat dissipation on regulators after several minutes.	Regulator temperature will remain below 140 degrees Celsius.

Test State: Completed Passed? Yes

Tested by: Cody Martin Date: 4-25-2021

Comments:

The MagLev system uses 0.861A when running at full load. 0.751A for the electromagnet at max power and 0.110A for the Raspberry Pi Zero W. The power supply seems to perform sufficiently for our system. The LM2676 voltage regulators never reach temperatures higher than 71°F All subsystems run at full load with no apparent problems regardless of the ripple on the power supply outputs. It helps that the USB adapter for the Pi is a boost regulator, which means that the Pi gets two stages of voltage regulation. Here are the full load ripple voltages according to the oscilloscope:

- 20VDC output = 400 mV peak-to-peak, 20.2V max, 19.8V min.
- 5VDC output = 200 mV peak-to-peak, 5V max, 4.8V min.

Figure 3 is an image the output waveforms measured with the oscilloscope set to AC coupling.

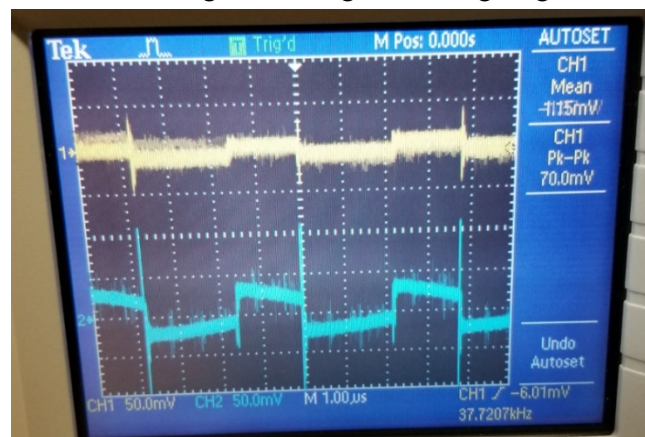


Figure 3: Waveforms of the 5V and 20V output of the power supply at full load. Channel 1 (yellow) is 5V, Channel 2(blue) is 20V.

## Test 2: Electromagnet

Test Description	Observe if the electromagnet will be able to produce enough force to attract the ferromagnetic object at a reasonable distance. Also test the heat dissipation on the electromagnet under the expected working amperage.	
Step	Actions	Expected Results
1.	Use alligator clips to connect terminals of electromagnet to positive and negative terminals of benchtop power supply.	Nothing yet.
2.	Power ON the lab power supply and adjust it to the 20V that would be used in the MLS.	Electromagnet should have no apparent reaction.
3.	Position the ferromagnetic object below the electromagnet and slowly lower it closer to the object.	At some point, the ferromagnetic object will be attracted to the electromagnet and stick to its steel core.
4.	Experiment by adjusting voltage and current output of the benchtop supply.	The characteristics of the electromagnet will be better understood.
5.	Adjust the lab power supply to output the current that is expected for operating the MagLev system and let the electromagnet sit for several hours.	The electromagnet will begin to heat up and reach a stable operating temperature between 60 and 100 °C.
6.	Use an infrared thermometer to check the temperature on the winding of the electromagnet.	The electromagnet will have an operating temperature safely below the maximum operating temperature of 155 °C (311°F).

Test State: Completed Passed? Yes

Test Run # 1

Tested by: MagLev Team

Comments:

The electromagnet has shown to be sufficient for our needs. It can 'grab' our 1.25in 50gram steel ball from .75in away. The electromagnet has 27 ohms of resistance across it when cold. At full load, the current through the electromagnet is 0.751A. The resistance gradually increases as the electromagnet runs and heats up, which causes current to drop; therefore, the force of the electromagnet to decrease. After running for 8 hours at full load, the temperature of the electromagnet reached 134°F. The 22ga wire is rated up to 311°F.

### Test 3: Driver

Test Description	Test if the current through the MOSFET can be controlled by a signal from the input of the optocoupler.	
Step	Actions	Expected Results
1.	Use a breadboard to set up the components of the driver circuit. Substitute the electromagnet for a resistor. Use Figure 14 as a guide.	Test circuit will be set the same as the design circuit, except with a resistor as a load.
2.	Use a square wave function generator set to 5V as the source for the input side of the optocoupler.	Simulates the PWM output of a digital controller.
3.	Use a benchtop DC power supply as the source for the output of the optocoupler and for the load resistor that is connected to the drain of the MOSFET. Set the DC power supply to 20 VDC.	MOSFET should conduct during each HIGH pulse of the function generator.
4.	Connect an oscilloscope probe between the load resistor and drain of the MOSFET and observe the results as the frequency of the function generator is increased.	We can infer how the driver circuit will react to the PWM output of the digital controller.

Test State: Completed Passed? Yes

Test Run # 1

Tested by: Zachary Snyder, Cody Martin

Comments:

The optocoupler/MOSFET driver module worked well for us. The optocoupler causes no significant delay. The test diagram ended up not being necessary. The driver was tested with the PWM input from the Pi Zero W (instead of a function generator), and the electromagnet was used as the load (instead of a high-power resistor).

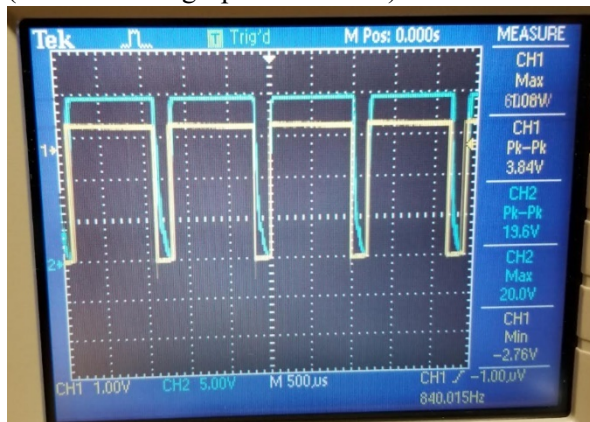


Figure 4: The PWM input from the Pi compared to the output from the driver. Channel 1(yellow) is the input of 3.3V PWM, channel 2(blue) is the output of 20V. The PWM frequency was set to 1kHz.

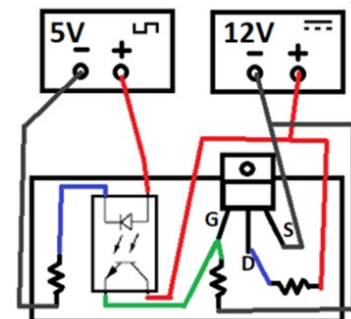


Figure 5: The wiring diagram for testing the driver circuit.

#### Test 4: Interface of Digital Controller, ADC, and Sensor

Test Description	Test if the digital controller, ADC, and sensor can receive and convert light level detected by the phototransistor.	
Step	Actions	Expected Results
1.	Using a breadboard, connect the IR receiver in series with a 10k ohm resistor.	This will create the necessary voltage divider.
2.	On the same breadboard, connect the cathode of the IR transmitter in series with a 100-ohm resistor.	The receiver will operate correctly.
3.	Connect the SCL, SDA, +5V, and GND pins between the ADC and digital controller.	This opens the communication between the ADC and the Raspberry Pi.
4.	Wire the ADC so that one of its analog inputs is connected between the IR receiver and the 10k ohm resistor.	The receiver will now be able to communicate with the Raspberry Pi.
5.	Power the digital controller through a typical AC/DC adapter.	The digital controller will indicate that it is powered.
6.	On the breadboard, connect +5V to the anode of the IR transmitter and the collector of the IR receiver.	The sensor and emitter are properly connected.
7.	Connect the unconnected ends of the 10k ohm and 330-ohm resistors to the GND of the digital controller.	The IR transmitter will turn on. The emitter will begin conducting.
8.	Connect the digital controller to a PC and open the serial monitor to see if it is reading information from the ADC.	The digital controller will read a 16-bit value from the ADC. The console displays the value that changes per the delay set in Python.
9.	Observe the values on the serial monitor while obstructing the light between the emitter and receiver. Wave hand/cup around. Turn on ambient light. Turn off ambient light.	With no obstruction, the maximum reading for the receiver is 4.096 V. The object shadow is the element that will alter the receiver reading.

Test State: Completed Passed? Yes

Test Run # 1

Tested by: Zachary Snyder, Cody Martin

Comments:

Interfacing of the device went smoothly. The readings of the sensor were as expected.

### Test 5: Complete System Operation

Test Description	The user will turn the power switch to the ON position. The system will start the digital embedded system and electromagnet. The IR sensor will detect the position of the object and indicate to the digital system how to change the PWM output to keep the ball floating.		
Step	Actions	Expected Results	Observed Results
1.	Power on machine	The system will power on. Using the power supply to provide power for Digital system and Electromagnet.	The machine powered on and did not sink the microcontroller.
2.	Introduce Object into system	The IR transistor will measure any change to the system based on the light that is sensed. A change in the sensor measurement will indicate to the digital system how much to adjust the PWM output to control the current through the electromagnet.	The sensor receives data and alters the PWM duty cycle based on this data. Calibration would allow the object to float.

Test State: Completed Passed? Yes

Test Run # 1

Tested by: Zachary Snyder, Cody Martin

Comments:

The complete system operates as expected. With correct calibration, the object should float.

## **Project Assessment**

### **System Components**

The primary function of the magnetic levitation system is to levitate an object in a way that would look like magic to a layperson. Although our maglev project isn't able to levitate an object yet, the physical parts of the system are whole.

First, the enclosure, while not the prettiest design of all time, manages to hold everything together in a reasonably sturdy and portable package. Weighing 12lbs, the enclosure is slightly over the design specification weight of 10lbs, but it remains within the 24"x24"x24" specification (it is 14"x14"x17.5"). Also, there is plenty of room inside the enclosure to comfortably fit all the components without having to cram them in.

Second, the electromagnet functions very well and is made of sturdy material. The grade 8 1" diameter steel bolt suspends very nicely from the top of the enclosure thanks to the convenient jam nuts that fit on the bolt's threading. By loosening or tightening the nut that suspends the electromagnet, the bolt threading allows some continuous adjustment of the electromagnet position. Also, the high number of turns and relatively low resistance of the electromagnet allows it to exert a strong force with only a fraction of an ampere of current.

Third, the power supply is sufficient for powering all the components of the system. Even at the maximum current of 0.861A, the 20V output only has 400mV Pk-Pk ripple; 2% of the maximum voltage. Likewise, the 5V output only has 200mV Pk-Pk ripple; 4% of the maximum voltage. The 5V output passes through a USB Adapter boost converter, giving the Raspberry Pi Zero W a second stage of voltage regulation. Also, there are no problems at all with components overheating; the only parts that get hot are the transformer and electromagnet and only if they are ran four many hours at full load (temperature does not exceed 134°F).

### **Problems with the Controller**

The final and most important component of the maglev system that still needs to be delivered is the controller. We tried several methods to make the digital controller. First, we tried something that resembles fuzzy logic. We had started to create this algorithm before we had even heard the term "fuzzy logic." It might have eventually worked, but it didn't seem worthwhile to continue with it when we knew of two other options. Our second attempt to develop the controller was through Phase-Lead compensation. Phase-Lead compensation proved to be a concept that was just too out of reach to be successful. Our third attempt was to make a PID controller; the method that our faculty advisor, Dr. Weissbach, had encouraged us to use from the very beginning of the design phase. When Dr. Weissbach first introduced us to the maglev project, we didn't really understand the gain logic and how it worked. It took months of studying to learn more about how that method worked. Even so, we couldn't quite figure out how to create a digital version of the controller using a high-level programming language like python.

During our search for a solution and any clues as to what direction to take, we found a hobby project that was quite like the MagLev system. We thought it seemed like a credible path to take, but the algorithm, written by an author named Simon Monk (2011), would need to change to suit our system. The Python code that is included in this report is adapted from code made for a different magnetic levitation project by Simon Monk. The code worked in a MagLev system that used an Arduino to program the controller, used a smaller magnet, with less voltage. Otherwise mirroring the design for our MagLev system. Our adaptation of Simon Monk's code is what is included in this report. It seems like the controller it is coming close to working, but needs more calibration.

### **Possible Improvements**

The most important next step is to continue debugging the digital controller until it is able to levitate the object; however, several other improvements would make the system easier to use, more robust, and/or prettier. First, we could modulate the sensor to make sure that no ambient IR light source could interfere with the sensor reading. Even while the IR receiver senses an object that is completely still, there is a fair amount of noise in the value it reads. It might be necessary to connect the IR emitter to a 555 astable multivibrator oscillating at a certain frequency. The IR receiver could then be connected to an active band-pass filter, which could attenuate anything outside of its band.

Second, we could add a method of continuous adjustment to the emitter/receiver positions. Right now, holes are drilled that allow discrete positioning of the sensor. If we instead used a sliding track, like used in some drawers, along with a screw to tighten the sensor into place, we could make fine adjustment to the sensor position.

Finally, we could find a way to bring down the cost of the system. This would be challenging given that the three pounds of copper in the electromagnet alone costs \$56.00, the transformer costs \$32.00, and the Pi Zero W costs \$24.00 (with the micro SD card). Now that we know the system doesn't need as much power as we had anticipated, we could get a smaller and cheaper 1.5A transformer. If we were successful developing the digital controller, we could also test the limits of how much speed and memory we really need to run the control algorithm. We could then buy the cheapest microcontroller possible that still meets our speed and memory needs.

### **Conclusion**

The magnetic levitation project is not complete. Although all of the physical subsystems are present and working, the code itself that would make up the maglev controller is not complete. As mentioned earlier, the code was shown to work for a similar magnetic levitation system, but the code had to be adapted from a different language and from a system with slightly different capabilities.

Although we were unable to get the system working before the final presentations, we did accomplish the objective of recruiting a student to the program. Working on the system in the work office did entice a student to switch his major from CIT to CPET.

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Banggood(b) (n.d.). *3V To 5V 1A USB Charger DC-DC Converter Step Up Boost Module* Retrieved from [https://usa.banggood.com/3Pcs-3V-To-5V-1A-USB-Charger-DC-DC-Converter-Step-Up-Boost-Module-For-Phone-MP3-MP4-p-946013.html?rmmds=myorder&cur\\_warehouse=CN](https://usa.banggood.com/3Pcs-3V-To-5V-1A-USB-Charger-DC-DC-Converter-Step-Up-Boost-Module-For-Phone-MP3-MP4-p-946013.html?rmmds=myorder&cur_warehouse=CN)

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Texas Instruments (June 2020). *LM2676 SIMPLE SWITCHER® High Efficiency 3-A Step-Down Voltage Regulator* [Datasheet]. Retrieved from [https://www.ti.com/lit/ds/symlink/lm2676.pdf?HQS=dismous-null-mousermode-dsf-pf-null-ww&ts=1611576966118&ref\\_url=https%253A%252F%252Fwww.mouser.com%252F](https://www.ti.com/lit/ds/symlink/lm2676.pdf?HQS=dismous-null-mousermode-dsf-pf-null-ww&ts=1611576966118&ref_url=https%253A%252F%252Fwww.mouser.com%252F)

Texas Instruments (October 2009). *Ultra-Small, Low-Power, 16-Bit Analog-to-Digital Converter with Internal Reference* [Datasheet]. Retrieved from <https://cdn-shop.adafruit.com/datasheets/ads1115.pdf>

# Appendixes

## Subsystem Descriptions

### DC Power Supply

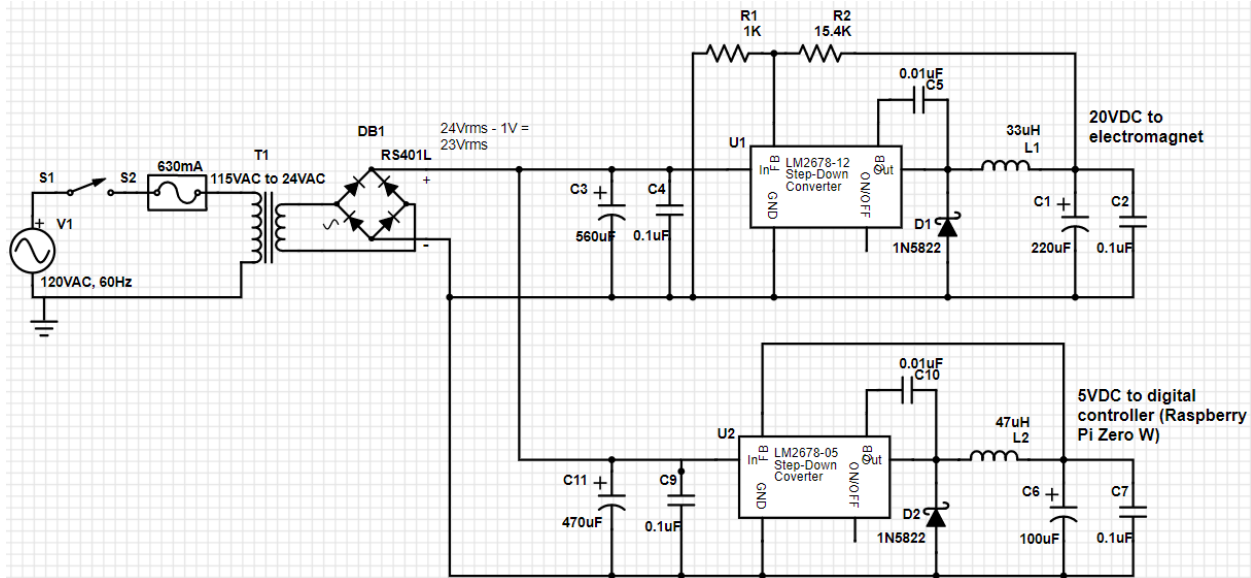


Figure 6: The schematic of the DC power supply which uses two LM2676 buck converters. One buck converter outputs 20V while the other buck converter outputs 5V. All the component measurements are correct in this schematic with exception that the LM2676-ADJ is mislabeled as a LM2676-12.

The power supply converts 120VACrms into 23Vrms unregulated DC through a transformer, full-wave rectifier ( $V_f = 1V$ ), and filtering capacitors. The 23V unregulated DC is regulated through two parallel LM2676 step-down voltage regulators. The design of the circuit was created with the help of the design recommendations in the LM2676 *Simple Switcher* datasheet (Texas Instruments, 2020). The LM2676-05 is set up to output 5VDC for powering the digital controller. The LM2676-ADJ is set up to output 20VDC for operating the electromagnet. The voltage output is determined the by voltage divider created by two feedback resistors. The calculation is:

$$V_{out} = V_{feedback} \left( 1 + \frac{R_2}{R_1} \right) \text{ where } R_1 = 1k \Omega \text{ and } V_{feedback} = 1.21V$$

$$\text{The real output} = 19.84V = 1.21V \left( 1 + \frac{15.4k\Omega}{1k\Omega} \right)$$

As the shown in the calculation, 19.84V is the real output because the limitation on precisely sized resistors available to make a perfect 20V output.

## Power Supply PCB

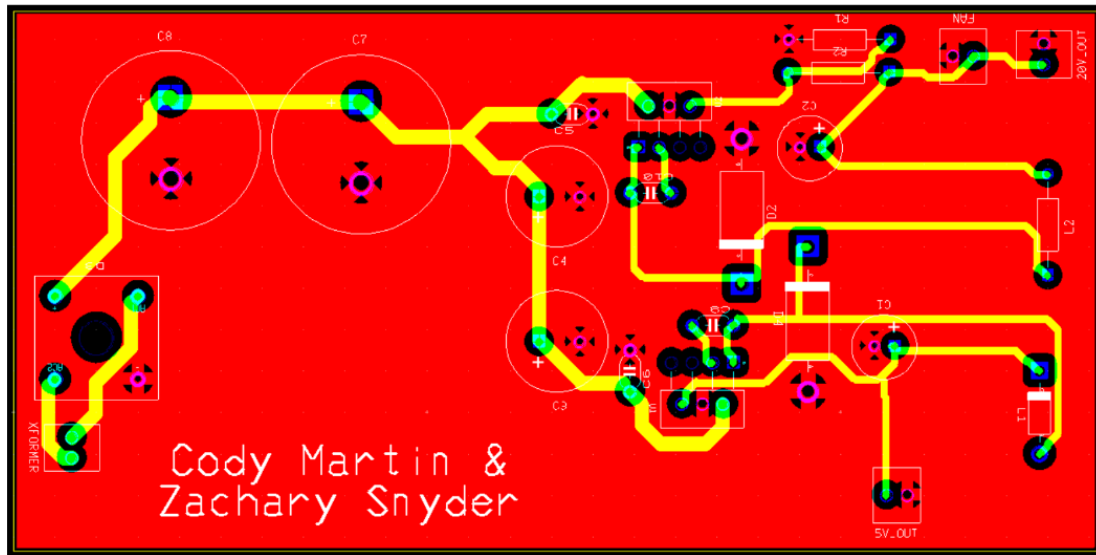


Figure 7: This the PCB for the switch mode power supply created using NI Multisim and NI Ultiboard.

## Electromagnet



Figure 8: Pictured on the left is the electromagnet mounted in the project enclosure. On the right is the diagram representation of the electromagnet.

The electromagnet is made of 3600 turns of 22gauge insulated copper wire wrapped around a steel core (Wong, 1986). A reverse biased flyback diode is parallel with the electromagnet.

## Driver

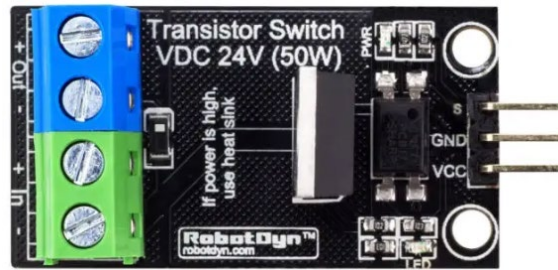


Figure 9: The driver circuit uses an optocoupler connected to a N-channel power MOSFET to control the high voltage of the electromagnet using the low voltage of the digital controller's PWM output. Source: Banggood(a), n.d.

The driver circuit is made of an IRLZ44N enhancement mode, N-channel MOSFET which is controlled by the digital controller through an opto-coupler. The PWM pin of the controller is connected to the input of the optocoupler which outputs the signal to the gate of the MOSFET. The drain is connected to the electromagnet. The source is connected to the 20V supply ground. The PWM output of the digital controller controls the drain to source channel thereby controlling the current through the electromagnet.

## Micro Controller



Figure 10: The digital controller will be programmed into a Raspberry Pi Zero W using Python. The Zero W is connected to the A to D converter using the SDA, SCL, +5V, and GND pins. Source: Raspberry Pi, n.d.

The digital controller is a Raspberry Pi Zero W. It communicates through 802.11 wireless LAN connection and a Bluetooth 4.1 connection. It has a 1GHz clock and 512MB of RAM. It receives power through a micro USB connection. The power input of the digital controller is connected to the 5V output of the power supply. To control the current through the electromagnet, one of the PWM digital output pins of the digital controller is connected the input of an opto-coupler which outputs to the gate of the driver MOSFET. The digital controller is connected to the A/D converter with four wires: SCL, SDA, +5V, and GND.

Both the SCL and SDA pins are connected between the two components which allows I2C communication. Through these two connections the digital controller receives information from the sensor. The digital controller provides power for the A/D converter from a 5V output pin and provides a ground connection from a GND pin.

## A/D Converter

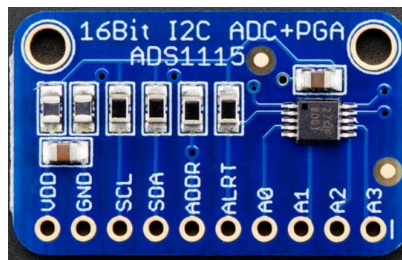


Figure 11: The A to D converter is an Adafruit ADS1115. It is a 16-bit ADC with four input channels. It communicates to the Raspberry Pi Zero W using I2C communication through the SCL and SDA pins. Source: Adafruit, n.d.

The A/D converter is an Adafruit ADS1115 16-bit (76 $\mu$ V quantization step) 4-channel converter. The ADS1115 receives the analog voltage detected from the sensor and returns a converted digital value to the digital controller through the I2C communication bus. The ADS1115 is connected to the digital controller through the SCL and SDA pins. The ADS1115 receives power through the 5V pin of the digital controller and is grounded through the GND pin of the digital controller.

## IR Sensor

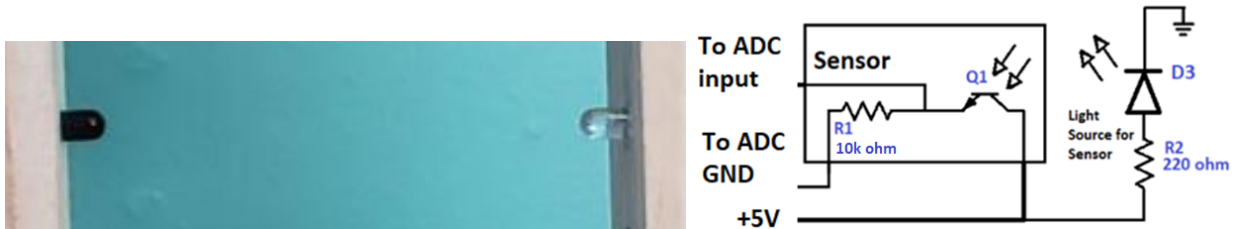


Figure 12: The IR transistor receiver and IR LED emitter that make up the sensor of the MagLev system. The physical sensor system as it is mounted in the enclosure is on the left. The schematic of the sensor system is on the right.

The sensor is made up of an IR transistor in series with a 10k ohm pull-down resistor. An analog input pin of the ASD1115 A/D converter is connected to the node between the IR transistor and 1k ohm resistor. The IR transistor allows more current to flow between the collector and emitter as its base is exposed to more light. As the light level reaching the IR transistor changes, the analog input of the ASD1115 will read a different voltage. An IR LED is positioned directly across from the IR transistor and the levitated object interferes with the light traveling from the IR LED to the IR transistor. This interference by the levitated object allows the system to keep track of the object's position. The IR transistor and 10k ohm resistor are connected to 5V from the digital controller. The IR LED providing light for the IR transistor is in series with a 100-ohm resistor connected to a GPIO pin from the digital controller.

## 5V USB Adapter

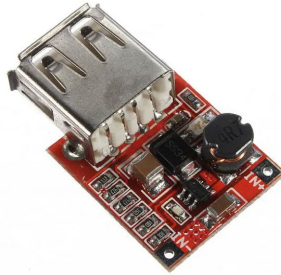


Figure 13: The 3V To 5V 1A USB Charger DC-DC Converter Step Up Boost Module. Source: Banggood(b), n.d

The USB adapter module makes it possible to use a USB to mini-USB cable to provide power for the Pi Zero W. It is a boost converter which accepts 2.5 to 6V input and output 5 to 12V. The module outputs 5V by default but can be adjusted to output 12V. With this module, the Pi Zero W has two stages of voltage regulation.

## System Enclosure



Figure 14: The enclosure for the system.

The system enclosure is reasonably sturdy and made almost entirely out of pine boards fastened together with wood screws. There are two box shaped sections that are topped with plexiglass to protect the electronic components inside. The base of the enclosure is a 14x14in square. The overall height of the enclosure is 17.5in. The enclosure weighs 12lbs.

## Enclosure Dimensions

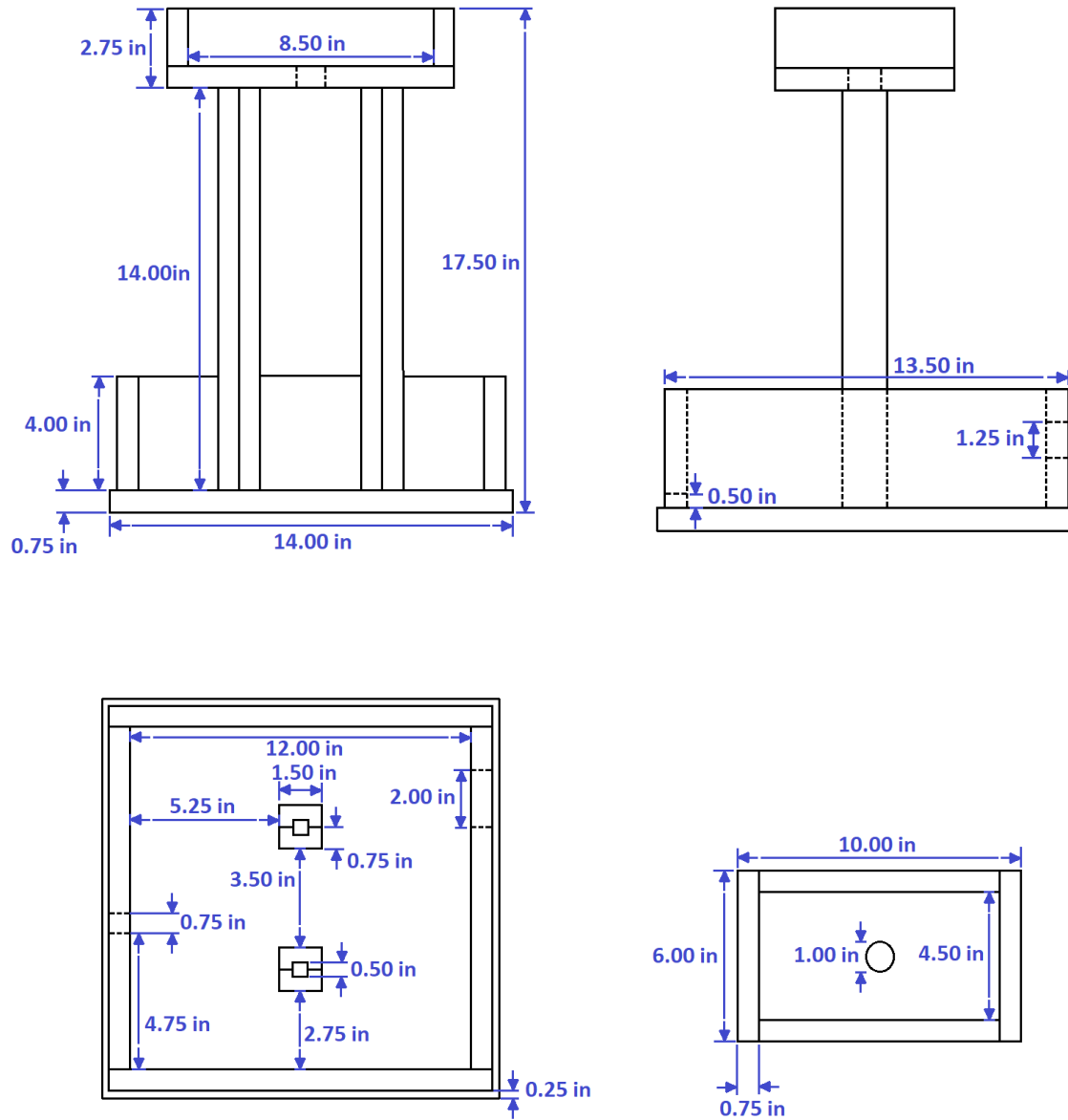


Figure 15: Dimensions of the Enclosure. Starting from the top left: front view, side view, overhead view of bottom box, overhead view of top box.

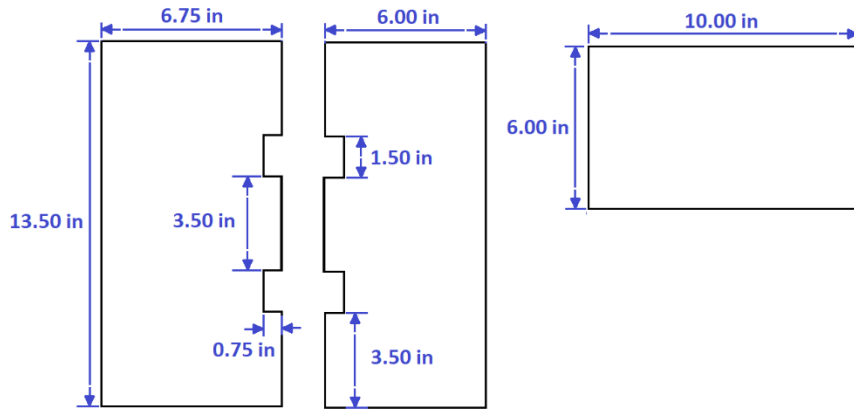


Figure 16: The plexi-glass sheets that cover the tops of the bottom and top boxes. The two sheets on the left cover the bottom box. The sheet on the right covers the top box.

Notes:

- All the boards used for the enclosure are 0.75in thick.
- The columns supporting the electromagnet are made by sandwiching two 1.50 x 0.75in boards together. There is a 0.25x0.50in channel cut into one side of each column piece which creates a 0.5x0.5in channel used to conceal the sensor wiring.
- All the wood pieces of the enclosure are fastened together with wood screws, the plexiglass sheets are fastened to the 0.75in rim of the top and bottom boxes using self-tapping machine screws.

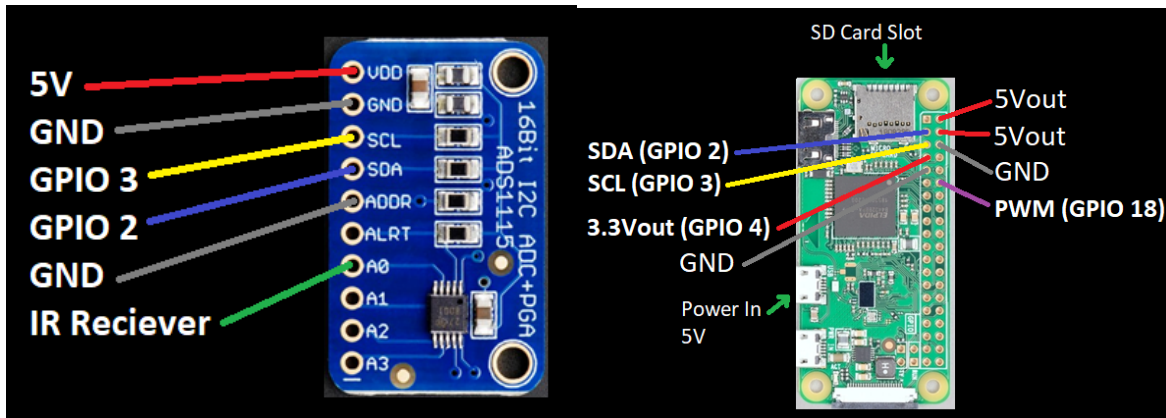


Figure 17: The ADC and Pi Zero W with their connections labeled.

Notes:

Figure 17 shows all the pin connections for the Pi and the ADC.

The user will have to provide the password and possibly the username when logging into the pi to edit code.

- Pi Username = “Pi”
- Pi Password = “Engineering!”

## Current Algorithm

```
# Best So Far
```

```
# Import Time Libraries for Delay (time.Sleep())
```

```
import time
```

```
import datetime
```

```
import math
```

```
# ADC Initialization
```

```
import board
```

```
import busio
```

```
i2c = busio.I2C(board.SCL, board.SDA)
```

```
import adafruit_ads1x15.ads1115 as ADS
```

```
from adafruit_ads1x15.analog_in import AnalogIn
```

```
ads = ADS.ADS1115(i2c)
```

```
chan = AnalogIn(ads, ADS.P0)
```

```
ads.gain = 2/3
```

```
# GPIO Initialization (PWM Module, IR LED)
```

```
import RPi.GPIO as IO
```

```
IO.setwarnings(False)
```

```
IO.setmode(IO.BCM) # Uses GPIO Header values
```

```
IO.setup(18, IO.OUT) # PWM Pin
```

```
p = IO.PWM(18, 1000) # Initialize PWM Variable(IO.Pin,Frequency(Hz))
```

```
p.start(0) # Sets Starting Duty Cycle
```

```
IO.setup(4, IO.OUT) # IR LED Pin
```

```
# Starting in an off state
```

```
#IO.output(18, IO.LOW)
```

```
#IO.output(4, IO.LOW)
```

```
# Starting Variables
```

```
MIN_MAP = 400
```

```
MAX_MAP = 1089
```

```
A = 9 # Ratio between MIN:MAX
```

```

B = float(input("Enter B Value:"))
C = 45      # Should be a constant
D = 0.005   # Delay in Seconds
maxPower = 95    # Duty Cycle (Full Percentage)

# Manipulated Variables
objectOldPosition = int()
ambientIRLight = int()
minpower = 45
objectPosition = int()
objectVelocity = int()
CompletedIterations = 0

# Calibration System

# Average Sensor Value (Removes some noisiness from sensor)
def IREmitter() :

    sensorArray = [chan.value, chan.value, chan.value, chan.value, chan.value]
    sensorAverage = (sensorArray[0] + sensorArray[1] + sensorArray[2] + sensorArray[3] + sensorArray[4])
/ 5
    return sensorAverage

# Calibration Function. (This was only occasionally needed so it is not called in this code)
def CalibrateFunction() :

    IO.output(4, IO.LOW)

    while True:

        for i in range(2) :
            time.sleep(i)
            print ()

        print ("Calibration Testing.")
        print ("\n")
        time.sleep(1)
        print ("Transistor Reading: IR LED LOW:\r")
        print (chan.value)

```

```
IO.output(4, IO.HIGH)
time.sleep(0.001)
print ("Transistor Reading: IR LED HIGH:\r")
print (chan.value)
IO.output(4, IO.LOW)
time.sleep(0.001)
print ("Test Completed\r")
```

```
count = 0
```

```
# While Loop Delay
while count < 6:
    count += 1
    p.ChangeDutyCycle(100)
    time.sleep(0.001)
    p.ChangeDutyCycle(0)
    time.sleep(0.003)
time.sleep(4)
```

```
#CalibrateFunction()
```

```
# End Calibration System
```

```
# Main Operations
```

```
# Ambient Function (read ambient light with the emitter off then later subtract from sensor reading)
```

```
def ReadAmbientLight() :
```

```
    IO.output(4, IO.LOW)
    time.sleep(0.001)
    AmbientValue = (chan.value)
    IO.output(4, IO.HIGH)
    return AmbientValue
```

```
#var = ReadAmbientLight()
#print ("Ambient Light {0}".format(var))
```

```
while True:
```

```
    CompletedIterations += 1 (keeps track of the number of loops)
```

```
    if CompletedIterations > 999 :
```

```
        ambientIRLight = ReadAmbientLight()
```

```
        CompletedIterations = 0
```

```
    # "chan.value" is the input from A/D converter
```

```
    RawSensorReading = (chan.value)
```

```
    RawSensorReading = (RawSensorReading - MIN_MAP) * (1024 - 95) / (MAX_MAP - MIN_MAP) + 95
```

```
    RawSensorReading = RawSensorReading
```

```
    objectPosition = RawSensorReading - ambientIRLight
```

```
    objectVelocity = objectPosition - objectOldPosition
```

```
    objectOldPosition = objectPosition
```

```
    power = objectPosition / A + objectVelocity * B + C
```

```
    # Tracking variables for debugging
```

```
    print ("Map: {0}".format(RawSensorReading))
```

```
    print ("Power: {0} Object Positon: {1} A: {2} Object Velocity: {3} B: {4} C: {5} ".format(power,  
objectPosition, A, objectVelocity, B, C))
```

```
    print ("\n")
```

```
    # Prevent power value from exceeding 100
```

```
    if power > maxPower :
```

```
        power = maxPower
```

```
    # Prevent power value from being below 0
```

```
    if power < minPower :
```

```
        power = minPower
```

```
    p.ChangeDutyCycle(power)
```

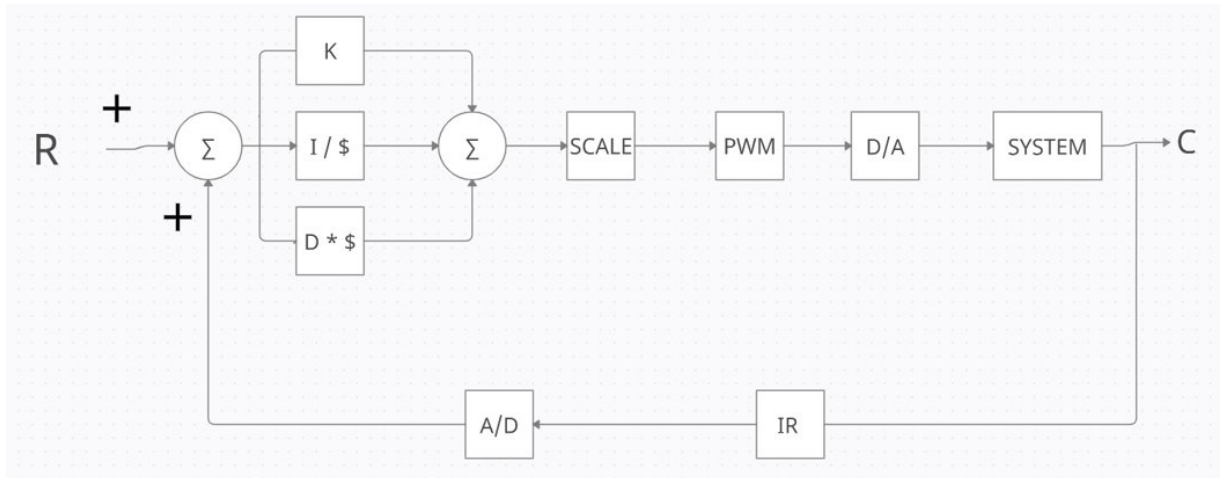
```
    # print ("Power: {0}".format(power))
```

```
    # Delay the loop by "D" seconds
```

```
    time.sleep(D)
```

## Current Algorithm Explanation

The model followed was written by Simon Monk (2011). The model follows the function of a PID controller, and the equation used by Simon Monk mirrors that of the PID model. The values can be adjusted to improve stability and cause the item to float. It is likely that the model would need calibration based on the environment to ensure correct device operations.



## Gantt Chart

**Notes:** We could have done a better decomposing the tasks into smaller parts and labeling them with the team member's name who would be responsible for the task. During phase II of the project, we were too aggressive with our timeline. We fell behind our timeline quickly.

8	✓	✦	▷ <b>Measure</b>	11 days	Fri 9/25/20	Fri 10/9/20
11	✓	✦	▷ <b>Analyze</b>	22 days	Fri 10/9/20	Mon 11/9/20
19	✓	✦	▷ <b>Design</b>	32 days	Mon 11/2/20	Tue 12/15/20
38		✦	◀ <b>Phase 2</b>	93 days	Mon 12/28/20	Wed 5/5/21
39	✓	✦	Purchase parts	30 days	Mon 12/28/20	Fri 2/5/21
40	✓	✦	◀ <b>Assemble subsystems</b>	35 days	Mon 12/28/20	Fri 2/12/21
41	✓	✦	▷ <b>Assemble Controller Related Subsystems</b>	20 days	Mon 12/28/20	Fri 1/22/21
44	✓	✦	▷ <b>Assemble Electromagnet</b>	4 days	Tue 1/19/21	Fri 1/22/21
48	✓	✦	▷ <b>Assemble Power Supply</b>	14 days	Tue 1/19/21	Fri 2/5/21
50	✓	✦	Assemble Driver	19 days	Tue 1/19/21	Fri 2/12/21
51	✓	✦	Begin designing enclosure	12 days	Sun 1/24/21	Mon 2/8/21
52	✓	✦	◀ <b>Begin Testing Subsystems</b>	65 days	Mon 12/28/20	Fri 3/26/21
53	✓	✦	▷ <b>Test 1: Interface controller</b>	20 days	Mon 12/28/20	Fri 1/22/21
55	✓	✦	▷ <b>Test 2: electromagnet</b>	6 days	Fri 1/22/21	Fri 1/29/21
57	✓	✦	Test 3: power supply	5 days	Mon 2/8/21	Fri 2/12/21
58	✓	✦	Test 4: driver	10 days	Mon 2/8/21	Fri 2/19/21
59	✓	✦	Begin combining subsystems	17 days	Fri 2/19/21	Mon 3/15/21
60	✓	✦	Final Requirement Specifications (Signed)	3 days	Wed 1/20/21	Fri 1/22/21
61	✓	✦	Project Phase 2 Gantt	3 days	Wed 1/20/21	Fri 1/22/21
62	✓	✦	Revised LLD	5 days	Sun 1/24/21	Thu 1/28/21
63	✓	✦	Schedule Mid semester design review	6 days	Sun 1/31/21	Fri 2/5/21
64	✓	✦	Test Specifications (signed)	6 days	Sun 2/7/21	Fri 2/12/21
65	✓	✦	<b><u>Mid-Semester Presentation</u></b>	5 days	Mon 3/15/21	Fri 3/19/21

66	✓	★	Report Draft	20 days	Mon 3/1/21	Fri 3/26/21
67	✓	★	Schedule Technical Presentation and Demonstration	5 days	Mon 3/29/21	Fri 4/2/21
68	✓	★	PEER Assesment	3 days	Wed 3/31/21	Fri 4/2/21
69	✓	★	Project Poster (Final)	12 days	Sat 3/20/21	Mon 4/5/21
70	✓	★	Final Technical Presentation	19 days	Mon 4/5/21	Thu 4/29/21
71		★	Project Function (Finished Build)	34 days	Mon 3/15/21	Thu 4/29/21
72	✓	★	Final Presentation to IAB	21 days	Sun 4/4/21	<u>Fri 4/30/21</u>
73	✓	★	Final Report	27 days	Sun 3/28/21	<u>Sat 5/1/21</u>
74		★	Peer Assesment on Group Project	6 days	Mon 4/26/21	Mon 5/3/21
75		★	Submit Final Paper to Library	3 days	Mon 5/3/21	Wed 5/5/21
76	✓	📢	<b>Weekly Progress Report</b>	<b>65 days</b>	<b>Sat 1/16/21</b>	<b>Fri 4/16/21</b>
77	✓	★	Weekly Progress Report 1	6 days	Sat 1/16/21	Fri 1/22/21
78	✓	★	Weekly Progress Report 2	6 days	Sat 1/23/21	Fri 1/29/21
79	✓	★	Weekly Progress Report 3	6 days	Sat 1/30/21	Fri 2/5/21
80	✓	★	Weekly Progress Report 4	6 days	Sat 2/6/21	Fri 2/12/21
81	✓	★	Weekly Progress Report 5	6 days	Sat 2/13/21	Fri 2/19/21
82	✓	★	Weekly Progress Report 6	6 days	Sat 2/20/21	Fri 2/26/21
83	✓	★	Weekly Progress Report 7	6 days	Sat 2/27/21	Fri 3/5/21
84	✓	★	Weekly Progress Report 8	6 days	Sat 3/6/21	Fri 3/12/21
85	✓	★	Weekly Progress Report 9	6 days	Sat 3/13/21	Fri 3/19/21
86	✓	★	Weekly Progress Report 10	6 days	Sat 3/20/21	Fri 3/26/21
87	✓	★	Weekly Progress Report 11	6 days	Sat 3/27/21	Fri 4/2/21
88	✓	★	Weekly Progress Report 12	6 days	Sat 4/3/21	Fri 4/9/21
89	✓	★	Weekly Progress Report 13	6 days	Sat 4/10/21	Fri 4/16/21
90	✓	★	Weekly Progress Report 14	6 days	Sat 4/3/21	Fri 4/9/21

# Bill of Materials

Magnetic Levitation system				IUPUI				
Bill of Materials				Names: Zach Snyder				
Updated: 4/27/2021				CodyMartin				
Line Item #	Part Name	Value or Description	Vendor	Vendor Item #	Quantity	Unit Price	Total Price	
1	LM2676-ADJ	3A 20V Step-Down voltage regulator, TO-220	<a href="https://www.digikey.com">https://www.digikey.com</a>	LM2676T-ADJ/NOPB-ND	1	\$5.06	\$5.06	
2	Resistor	(feedback) 15.4K ohm resistor, axial lead, 1/4 W, +-1%	<a href="https://www.digikey.com">https://www.digikey.com</a>	15.4KXBK-ND	1	\$0.10	\$0.10	
3	Resistor	(feedback) 1K ohm resistor, axial lead, 1/4 W, +-1%	<a href="https://www.digikey.com">https://www.digikey.com</a>	1KADTR-ND	1	\$0.70	\$0.70	
4	Inductor	33uH inductor, toroid, shielded, radial lead, for 20V regulator	<a href="https://www.digikey.com">https://www.digikey.com</a>	553-1122-ND	1	\$4.24	\$4.24	
5	Inductor	47uH inductor, toroid, radial lead, for 5V regulator	<a href="https://www.mouser.com">https://www.mouser.com</a>	542-2109-V-RC	1	\$2.49	\$2.49	
6	Ceramic Cap.	0.01uF 50V Ceramic Capacitor for C Boost pin on regulators, radial lead	<a href="https://www.mouser.com">https://www.mouser.com</a>	810-FG18C0G1H103JNT0	2	\$0.34	\$0.68	
7	Ceramic Cap.	0.47uFCeramic Cap. for filtering input and output of regulator, radial lead	<a href="https://www.mouser.com">https://www.mouser.com</a>	594-K474K20X0UF63H5H	2	\$0.55	\$1.10	
8	Electrol. Cap.	560uF input capacitor for 20V regulator, radial lead	<a href="https://www.mouser.com">https://www.mouser.com</a>	67-EEU-FM1H561	1	\$0.98	\$0.98	
9	Electro. Cap.	220uF 160V rated, output capacitor for 20V regulator	<a href="https://www.digikey.com">https://www.digikey.com</a>	493-4788-1-ND	1	\$2.03	\$2.03	
10	Electrol. Cap.	100uF output capacitor for 5V regulator, radial lead	<a href="https://www.mouser.com">https://www.mouser.com</a>	667-16SEPC100MW+S	2	\$0.95	\$1.90	
11	LM2676-05	3A 5V Step-Down voltage regulator, TO-220	<a href="https://www.mouser.com">https://www.mouser.com</a>	926-LM2676T-5.0/NOPB	1	\$4.77	\$4.77	
12	Electrol. Cap.	470uF input capacitor for 5V regulator, through hole	<a href="https://www.mouser.com">https://www.mouser.com</a>	667-EEU-FM1H471	1	\$0.66	\$0.66	
13	1N5822 Schottky Diode	3A Schottky Diode, for 20V and 5 volt regulator, radial lead	<a href="https://www.mouser.com">https://www.mouser.com</a>	511-1N5822	2	\$0.39	\$0.78	
14	Bridge Rectifier	3A 50V bridge rectifier, 1Vf, BR-3	<a href="https://www.mouser.com">https://www.mouser.com</a>	583-BR34	1	\$0.53	\$0.53	
15	Transformer	115VAC/24VAC CT, 3A secondary, 72VA, chassis mount	<a href="https://www.digikey.com">https://www.digikey.com</a>	HM4431-ND	1	\$31.88	\$31.88	
16	Heat Sink Kit	Aluminum heat sink kit for TO-220	<a href="https://www.ebay.com">Ebay</a>		2	\$1.23	\$2.46	
17	Circuit Breaker	630mA 5mm x 20mm glass fuse for Primary side of transformer	<a href="https://www.digikey.com">https://www.digikey.com</a>	507-1244-ND	1	\$0.24	\$0.24	
18	Switch	16A 250V, DPST rocker switch, primary side, quick connect	Banggood: <a href="https://www.banggood.com">https://www.banggood.com</a>	IEC320 C14	1	\$0.00	\$0.00	
19	Enclosure AC plug	Enclosure mounted power inlet to provide interface for power cord	Banggood: <a href="https://www.banggood.com">https://www.banggood.com</a>	IEC320 C14	1	\$2.99	\$2.99	
20	USB Adapter	3V To 5V 1A USB Charger DC-DC Converter Step Up Boost Module	<a href="https://usa.banggood.com">https://usa.banggood.com</a>	946013	1	\$1.71	\$1.71	
21	Digital Controller	Raspberry Pi Zero W w/ SD Card	<a href="https://www.adafruit.com">https://www.adafruit.com</a>	3409	1	\$24.50	\$24.50	
22	A/D Converter	ADS1115 16-Bit ADC - 4 Channel with Programmable Gain Amplifier	Adafruit: <a href="https://www.adafruit.com">https://www.adafruit.com</a>	1085	1	\$14.95	\$14.95	
23	IR -Transistor	5mm IR transistor as sensor receiver, 940nm	<a href="https://www.amazon.com/gp/product/B07TLBJR5">https://www.amazon.com/gp/product/B07TLBJR5</a>		1	\$0.26	\$0.26	
24	Resistor	10k Ohm Resistor, 1/4 W, for IR receiver voltage divider			1	\$0.10	\$0.10	
25	Resistor	330 Ohm Resistor, 1/4 W, for IR emitter			1	\$0.04	\$0.04	
26	LED	5mm IR LED as sensor emitter, 940nm	<a href="https://www.amazon.com/gp/product/B07TLBJR5">https://www.amazon.com/gp/product/B07TLBJR5</a>		1	\$0.04	\$0.04	
27	Driver	Opto-driver isolates 5V controller from 20V electromagnet	<a href="https://usa.banggood.com">https://usa.banggood.com</a>	1248733	1	\$0.04	\$0.04	
28	Wire for Electromagnet	1485ft spool 22-gauge insulated copper wire for electromagnet	<a href="https://www.amazon.com">https://www.amazon.com</a>	BNTECHGO 22 AWG Magnet W	1	\$55.94	\$55.94	
29	Steel Core	25mm X 90mm steel core for electromagnet			1	\$0.00	\$0.00	
30	1f=3A, Vf=1.3V Schottky, flyback diode for the electromagnet	<a href="https://www.digikey.com">https://www.digikey.com</a>	1N5822	1	\$0.49	\$0.10		
31	fuse holder	fuse holder, for 5mm x 20mm fuse, chassis mount	<a href="https://www.digikey.com">https://www.digikey.com</a>	708-2488-ND	1	\$2.80	\$2.80	
32	Wood	Wood used as envelope material.	Menards	103-1093	1	\$35.00	\$35.00	
33	Power Supply PCB	Custom PCB for buck converter power supply circuit	<a href="https://jlcpcb.com/">https://jlcpcb.com/</a>		1	\$5.16	\$5.16	
34	Electrol. Cap.	2700uF filtering capacitors for powersupply			2	\$1.73	\$3.46	
<b>TOTAL COST</b>							<b>\$207.69</b>	

DIGITAL MAGNETIC LEVITATION SYSTEM

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Zachary Snyder and Cody Martin

# User Operation Manual

ZACHARY SNYDER AND CODY MARTIN

# **User Operation Manual**

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Senior Design 2021 IUPUI  
Advisor: Dr. Robert Weissbach  
Sponsor: Dr. Robert Weissbach

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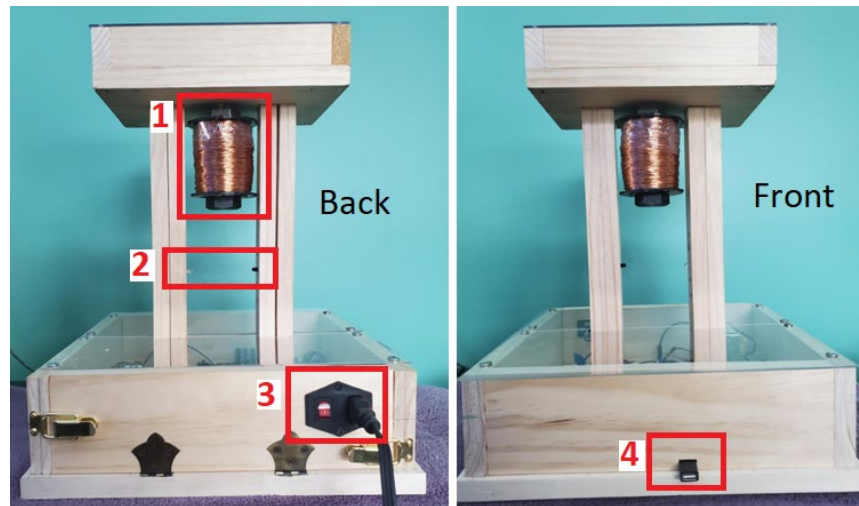
## Safety Warnings

**Warning:** To reduce the risk of burns, fire, or electric shock:

1. Never operate this system if there are signs of damage to the power cord or plug.
2. To avoid the risk of electric shock, do not immerse the system in water.
3. When the system is not in use, turn the power switch into the off position (“O” symbol on the power switch).
4. To avoid electric shock, never touch any wires within the circuit while the power cord is plugged in or the system is turned on.
5. Keep the power cord away from hot surfaces.

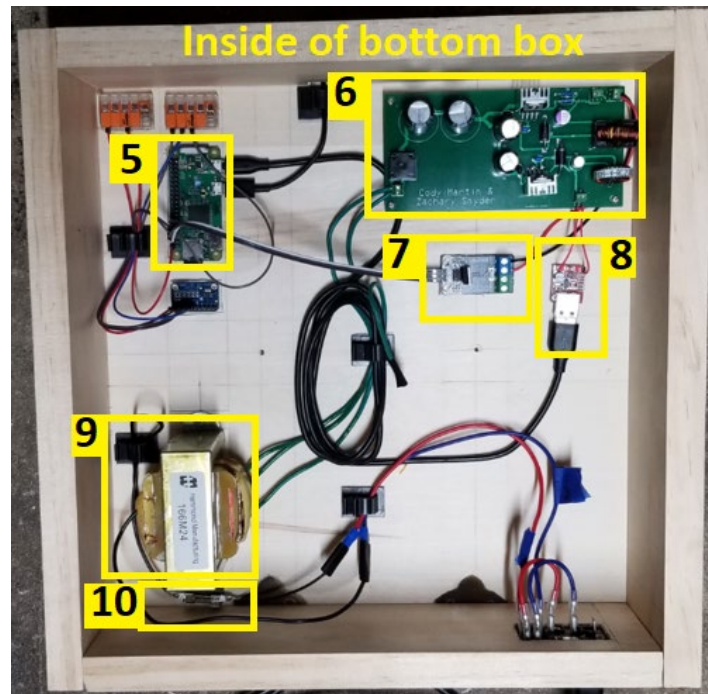
**Caution:** The electromagnet will reach temperatures up to 134°F if the system is left on for many hours.

## External Parts



1. Electromagnet
2. IR Emitter (clear), IR Receiver (black)
3. Power Switch and AC Power Port
4. USB Adapter for Raspberry Pi Zero W

## Internal Parts



5. Raspberry Pi Zero W
6. DC Power Supply Circuit
7. Optocoupler Switch Module
8. 5V USB Adapter
9. 120VAC to 24VAC Transformer
10. Fuse Holder (5mm x 20mm glass fuses)

# Digital Magnetic Levitation System

# Powering On, Connecting In, and Tuning Up.

*This manual will go through the generalized actions required for the successful operation of the system. Previous knowledge is assumed of the reader when pertaining to the functionality of the Raspberry Pi digital controller. If the operations are not understood or clarification is necessary, please visit <https://www.raspberrypi.org/documentation/>.*

The Magnetic Levitation System operation utilizes a digital embedded system which alters the amount of current being introduced into an electromagnet using readings from an IR sensor. The following instructions were created to help the user navigate through the steps to take in order to have successful operation.

MLS Magnetic Levitation System

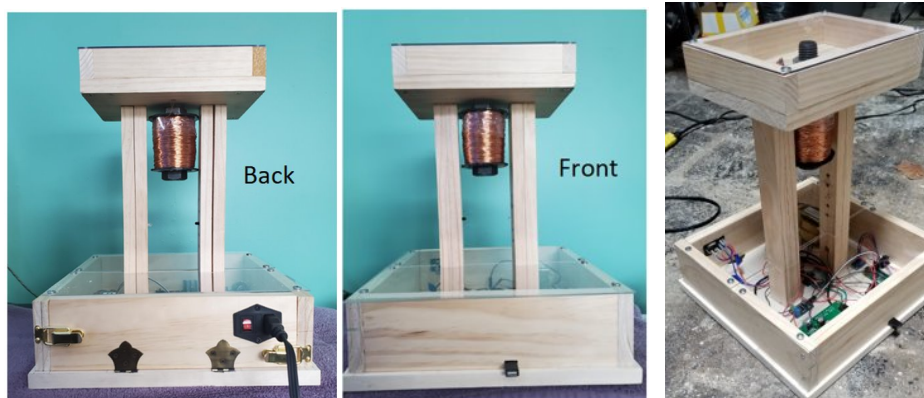
DES Digital Embedded System

PID Proportion-Integral-Derivative

Pi Raspberry Pi Zero W

## How to Power Up the MLS.

The MLS includes a typical three prong AC power cable. The power switch is located next to the AC in port. Power to the system will be indicated by the **Red** status light on the USB module. The green light on the Pi will blink a few times and then will be ready for connections.



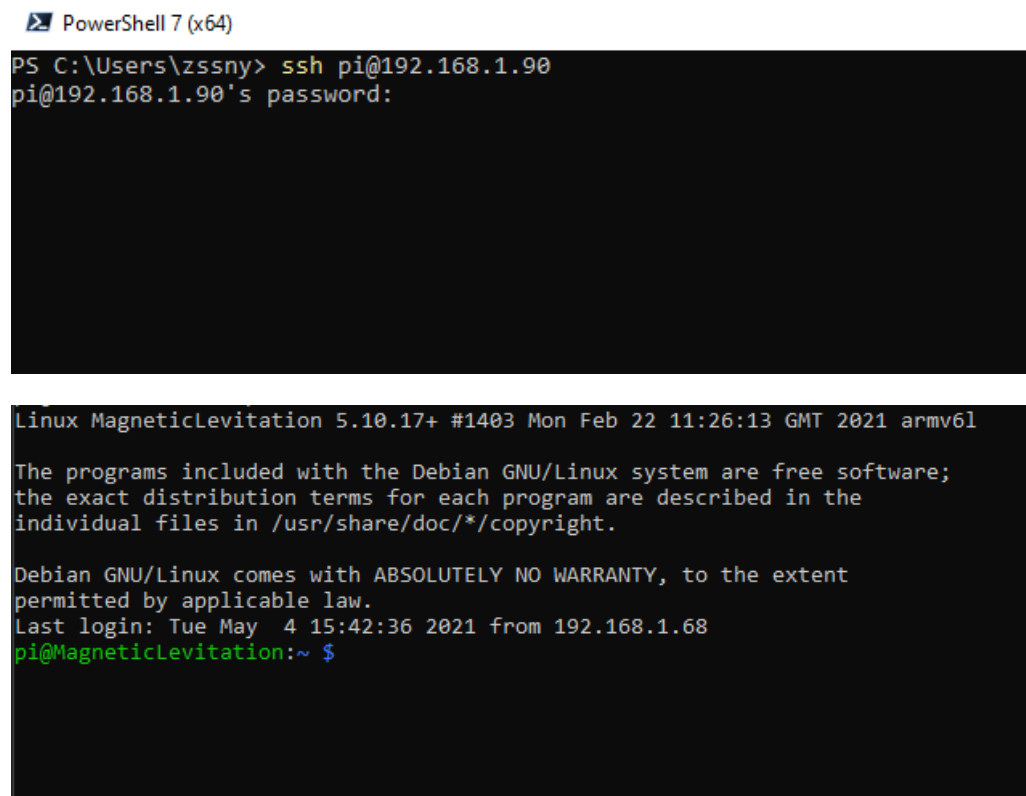
## Connecting to the Pi

The front of the enclosure was designed to allow connectivity to the Pi through an external USB hub. You may attach any USB compatible device. Be warned, if you try to connect a device that requires too much power for the Pi to boot, the Pi will crash and get into a boot loop. All commands should be run as “sudo”.

### Connection using SSH (Preferred)

Previous connection of the Pi to the internet assumed. This guide will not include a reference on how to connect the Pi to the internet. **\*\***Phone hotspots make great connections in environments with Username and Password authentication into the SSID.

The configuration of the Pi has default enabled connections using SSH protocol, and the IP address for the Raspberry Pi. To connect using SSH, enter any command line terminal, the author’s preferred is Windows PowerShell. To find the PowerShell app, type “powershell” into the desktop search bar. After PowerShell opens, type “ssh pi@IP Address”. The prompt may ask you to trust as a local host. **Confirm** this option. Next it will ask for the **Password**.



```

PowerShell 7 (x64)
PS C:\Users\zssny> ssh pi@192.168.1.90
pi@192.168.1.90's password:

Linux MagneticLevitation 5.10.17+ #1403 Mon Feb 22 11:26:13 GMT 2021 armv6l
The programs included with the Debian GNU/Linux system are free software;
the exact distribution terms for each program are described in the
individual files in /usr/share/doc/*/copyright.
Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Tue May 4 15:42:36 2021 from 192.168.1.68
pi@MagneticLevitation:~ $

```

### Hardwire connection (Requires External Monitor & Display Cable)

The Pi has a mini-HDMI connection soldered to the logic board. Attaching a display cable to an external display when booting the Pi will show the command line for the Pi. When asked to log in. Use the **Username** and **Password**

#### Username and Password

“Pi” is the username when logging into the Raspberry Pi. “Engineering!” is the password. Note\* the password will not display when you are typing it.

## Running/Editing Python Scripts

**Editing:** Any Linux text editor may be used. ie: “sudo nano ScriptName.py”

**Running:** Any Python Compiler may be used, ie: “sudo python3 ScriptName.py”

For this manual, only the above two methods will be referenced.

## Ensure Functional System Operations

The DES includes a few peripherals that allow for correct system operation. The following section will describe how to ensure each device is operating under expected conditions. This only includes the devices that are attached to the Pi and are necessary for full functionality of the system. **\*FYI!!! Spelling in Python is important\***

### ADS 1115, IR Emitter, IR Sensor

Run the command, “sudo python3 SensorOperation.py” If the ADC and IR emitter and receiver are operating correctly, there should be a flurry of values in the command line REPL. If there are errors, or the device does not operate as expected refer to the troubleshooting guide at the end of this document.

### N-Channel, Optocoupler Driver Module (Opto-Driver)

Run the command, “sudo python3 PWMTTest.py”. The REPL will ask for a duty cycle value. The user may enter any value from 0.0 to 100.0. Correct operation is indicated by the blue power light emitted by the module. If there are errors, or the device does not operate as expected, refer to the troubleshooting guide.

## Tuning Full System Operations

Once the modules for the DES are in working order. Full system operations may be fully calibrated. Calibration will allow the object to float.

### Running the Code

Run the command, “sudo python3 EvilGenius.py”. The system will begin to run and the debugging text will appear. The REPL view will mirror the SensorOperation.py file. Based on the information used by Simon Monk, variables A, B, and C act as the manipulation variables for the PID control. Variable D is a time delay for the loop at the end of the code. Correct manipulation of these variables has shown to float the object.



# **Troubleshooting and Parts Reference Guide**

## **Disclaimer**

**WHILE FOLLOWING SAFETY PROTOCOLS THERE IS STILL RISK FOR INJURY OR DAMAGES IF USED INCORRECTLY.**

**CAUTION: ELECTROMAGNET WILL GET HOT WHEN LEFT ON.**

**DO NOT PUT ELECTRONICS ON THE PLEXIGLASS WHEN MAGNET IS IN OPERATION**

## **Tools Required**

- PH1 – Phillips Head Screwdriver
- 2mm – Small Flathead Screwdriver

## Parts Index

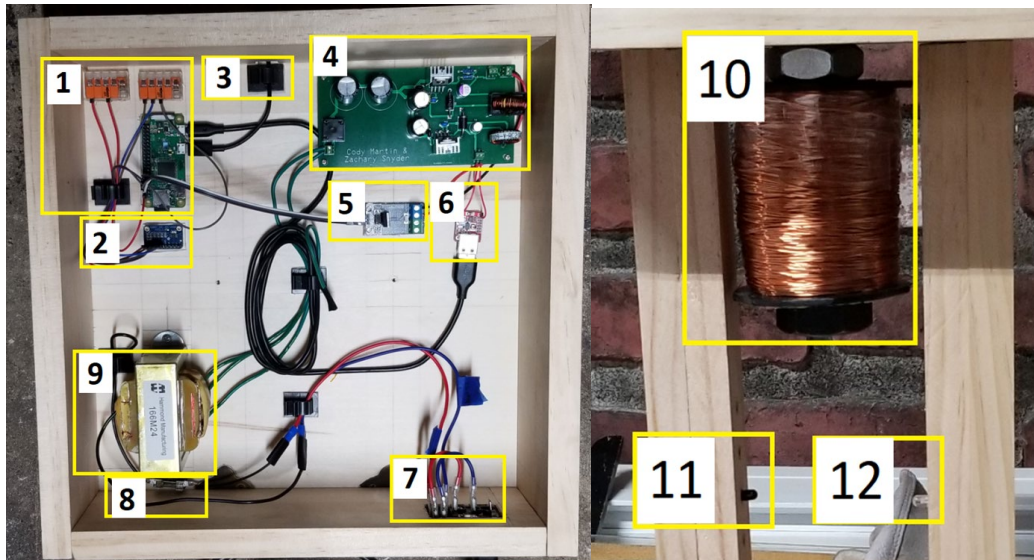


Figure 18: The major components of the magnetic levitation system are listed 1 through 12.

1. Raspberry Pi, 5v and GND connections.
2. ADS1115 Analog to Digital Converter
3. External USB Connector
4. Internal Power Supply PCB
5. N-Channel MOSFET/Optocoupler Module (Opto-Driver)
6. 3.3 – 5v USB Module
7. AC Inputs to Transformer
8. Over-current Fuse
9. Transformer
10. Electromagnet
11. IR Receiver
12. IR Emitter LED

## Step-by-step Troubleshooting

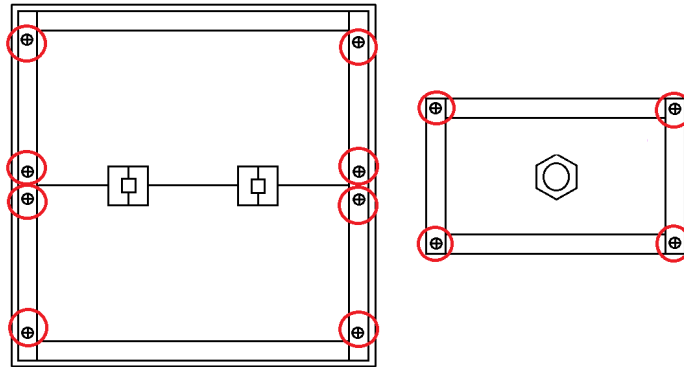


Figure 2: To remove the plexiglass sheets, remove the screws circled in red.

This guide will give step by step trouble shooting methods for all the hardware components of the Digital Magnetic Levitation System. For setup and configuration of the Pi Zero W, refer to the User Manual.

Remember to remove all plexiglass before manipulating with the items inside the envelope. To remove the plexiglass, unscrew the twelve screws as depicted in Figure 2.

## **Power and Ground Connections: Digital Embedded System & AC input**

### **Digital Embedded System**

- ◇ The two clear and orange wire connectors in the enclosure, located nearest the Pi, act as a 5V bus and a GND bus for the GPIO headers to be connected.
- ◇ To replace wires connections, the connectors will flip open. Grab only the orange flap and lift. The wires will pull out with little effort.
- ◇ Connectors support 14-24 AWG wire.

### **AC Input**

- ◇ The red and blue wires connected to the AC plug are the 120VAC “line” and “neutral” wires respectively.
- ◇ They are connected to the primary side of the transformer (black wires).
- ◇ The green wires between transformer and power supply “xformer” terminals are 24VAC
- ◇ To adjust/remove connections or change the overcurrent fuse. Undo the clips at the back of the device allowing the door to swing open. The terminal blocks can be loosened/tightened with a 2mm flat head screwdriver.
- ◇ Ensure the device is off before attempting to remove any connections.

### **External USB**

The external USB was added for general accessibility usage.

IE. If your network requires authentication using a specific Username and Password. The external USB will allow the user to connect using an ethernet adapter.

## Raspberry Pi Zero W

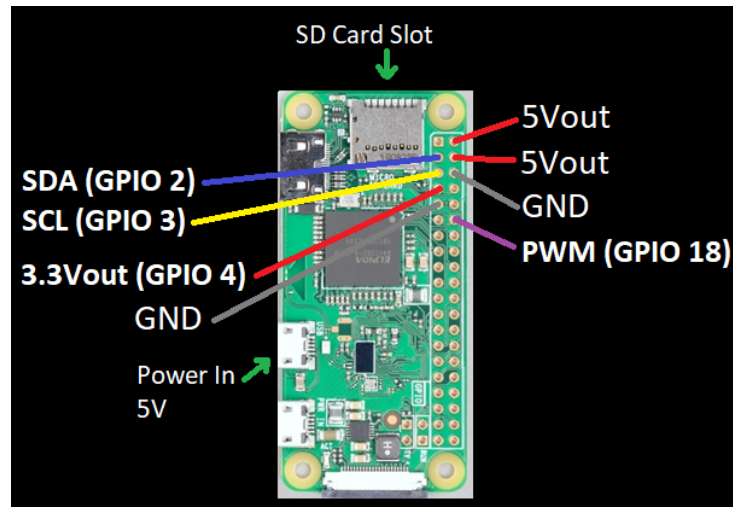


Figure 3: All the connections to the Pi's GPIO are labeled here.

### ◇ GPIO Header Connections:

All Header connections are made using BCM mode. This denotes the GPIO number for the pin.

\* Refer to Figure 3 and to Pi documentation for more details:

<https://www.raspberrypi.org/documentation/>

- ◇ GPIO 4: Power pin for the IR emitter. Supplies 3.3v through software declaration.
- ◇ GPIO 18: PWM output connected to Opto-Driver “S” pin. This alters the duty cycle of the magnet source allowing current manipulation.
- ◇ I2C\_SDA & SCL: The I2C bus is used to connect to the ADC. The setup correlates to that of the ADS1115 header pins.

## IR Sensor System

The position of the sensor cannot be changed without loosening the inner side of the support columns. Refer to Figure 4 for positions of the screws.

- ◇ The emitter and receiver position are changed by removing the Philips head screws located at the top and bottom of the envelope.
- ◇ Once the screws are removed, the inner half of the support column will come free. Gently pull away the sides to allow easy access to the emitter/receiver and their wires.
- ◇ It is recommended to move one side at a time rather than unfastening both at once.

### ◇ IR Receiver Connections

- ◇ BLACK: Ground wire connected into the flip connectors.
- ◇ RED: 5v power connecting into the flip connectors.
- ◇ GREEN: Ground side of the Sensor connected to A0 of the ADS 1115

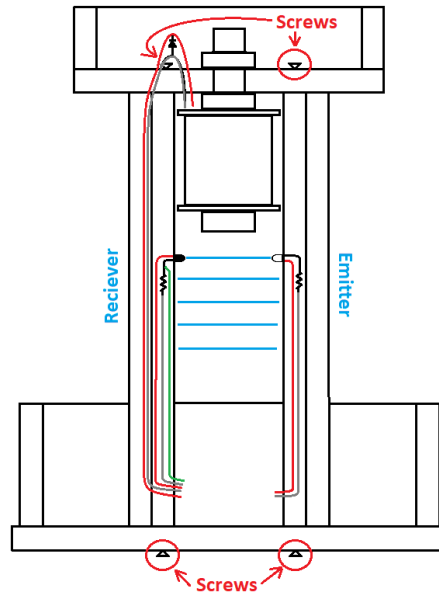


Figure 4: The locations of the screws that must be removed are circled in red. The wiring within the hollow columns is represented by the colored wires.

### A/D Converter: ADS 1115

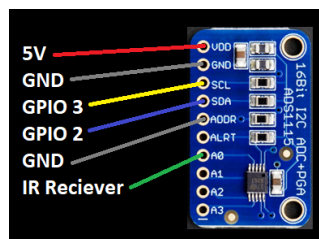


Figure 5: The pin connections for the ADC.

The ADC is an Adafruit ADS 1115 which is required for the Raspberry Pi to receive data from the sensor.

- ◇ The System utilizes the wiring schema, connecting the ADDR pin to GND, connecting to channel 0x48. The SDA and SCL pins of the ADC are connected to the Pi's GPIO2 and GPIO3 pins respectively. Figure 5 shows all connections to the ADC.

- ◇ Further instructions and setup assistance can be found on <https://learn.adafruit.com/adafruit-4-channel-adc-breakouts/python-circuitpython>

## Power Supply PCB

The terminal block connections are loosened/tightened using a 2mm flat head screwdriver. The following parts are connected to the power supply PCB

- ◆ Transformer 24VAC secondary to “xformer” terminal block
- ◆ 5V USB adapter Module to “5V\_OUT” terminal block
- ◆ Opto-Driver to “20V\_OUT” terminal block

The 5V USB adapter module is connected to the Raspberry Pi utilizing a standard, USB A to USB micro cable.

If the Pi does not boot, check the connections to the “xformer” and “5V\_OUT” terminal blocks. Typical operating voltage was 4.96 V.

If all connections seem correct, check the fuse on the primary side of the transformer to make sure that it hasn't blown.

## MOSFET-Optocoupler Module (Opto-Driver)

- ◆ The “20V\_OUT” terminals of the DC power supply provides 20VDC for the opto-driver output through the “IN +” and “IN –” terminals on the opto-driver. The red wire is positive, the black wire negative.
- ◆ The control input of the opto-driver is through the three pins labeled “S”, “GND”, and “VCC”.
  - ◆ These pins are connected to the PWM (GPIO 18), GND, and 5V pins on the Pi.
- ◆ The 20VDC power output of the opto-driver energizes the electromagnet. The output terminals are labeled “OUT +” and “OUT –”.
- ◆ A blue LED on the opto-driver will be lit while the opto-driver is conducting.

If the electromagnet does not seem to be energizing, make sure all the wires are connected to the opto-driver correctly. If the wires are connected correctly and the problem persists, the python code within the Pi will have to be debugged.

## Electromagnet

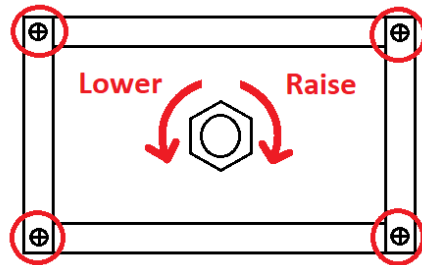


Figure 6: Top view the top box where the electromagnet is suspended. Turn CCW to lower; CW to raise.

- ◇ The electromagnet is connected to the “OUT +” and “OUT –” terminals on the optocoupler driver/switch module. Red wire positive, black wire negative.
- ◇ To improve the performance of magnetic levitation, it may be necessary to raise or lower the position of the electromagnet. The orientation of the top nut is depicted in Figure 6.
  - ◇ Lower the electromagnet by loosening the top nut.
  - ◇ Raise the electromagnet by tightening the top nut.