Nugget Prospecting Tool

Project Specification Document

Chris Viray, James Wilcock, Jacob McCray, Kevin Gao

1 Overview

1.1 Executive Summary

The goal of the Nugget Prospecting Tool is to create a cheap alternative to the current handheld underwater gold detectors on the market. The method by which this project will be completed will be to modify the existing detector's enclosure to house two coils and create new hardware to better discriminate against metals at certain frequencies while keeping the detector as light and portable as possible. Finally, we will create software for signal processing to better discriminate metals. So far, we have deconstructed the metal detector our project partner provided to us to analyze and determine the electrical circuitry. We have found that the main components of the metal detector, such as the microcontroller, are unlabeled chips. The lack of labeling on the chips has led to the proposal of making our own metal detector. While there are multiple approaches to metal detection, namely pulse induction and very low frequency detection. It seems that very low frequency will have to be used as the discrimination capabilities are limited when it comes to pulse induction.We have done further research on methods on low cost metal detector with frequency discrimination to better focus on what the metal detector will be used for[1]. We have also calculated the inductance of the coil used in the pulse detection to see how much coil and the thickness of the coil used to better match the current specs of the deconstructed metal detector.

1.2 Team Contacts and Protocols

James Wilcock - Phone Number: (503)-799-9334
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Non-School Email: jameswilcock8@gmail.com
Primary Role: Software

Jacob McCray - Phone Number: (858)-752-3567
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Primary Role: Signal Processing

Kevin Gao - Phone Number: (503)-515-7388
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Primary Role: Hardware

Christopher Viray - (503)-941-8619
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Non-School Email: christopherviray.cv@gmail.com
Primary Role: Hardware(Power Systems)

Table 1.
Team Protocols

Topic	Protocol	Standard
On-time Deliverables and Team Collaboration	We keep track of deliverables during our monday meetings, during which we talk about what tasks we have done and what are needed to be done this week.	This task is handled by the group and any conflicts within the project should be told to the group ASAP.
Task Management	Covered in the monday meeting, we delegate tasks according to strengths.	We communicate as a group our current strengths and weaknesses, afterwards, we request and list out tasks needed to be done this week, if it involves software, we can have a raise of hands on whos interested, same thing goes for hardware and other various tasks
Meeting Expectations	We agree upon one place and time and afterwards expect each member to talk about contributions and/or struggles.	We meet at Dearborn every monday at 2-3 to discuss contributions/struggles/ concerns, and anything else project related.

1.3 Gap Analysis

Although there is a wide range of metal detectors on the market today, there are still some niche areas where metal detectors fall short. It is not uncommon for metal detectors to have some sort of “metal discrimination” where the metal detector is able to differentiate between different types of metals, such as gold and iron. There are also options for underwater metal detectors that are waterproof and maneuverable. However there are few, if any, metal detectors on the market that are able to do both.

Another problem with waterproof metal detectors is that it is easy to create leaks in areas where the electronics cannot be completely sealed off. Openings meant for replacing batteries create openings that undermine waterproofing done to the rest of the device.

Gold sniping is a hobby where people dive into rivers in order to find gold [2]. Most divers depend on finding pockets of gravel or sediment to find where gold might be. However, sifting through every sediment deposit in a river could be very time consuming. A metal detector that is both waterproof and able to only go off when gold is found would be beneficial for hobbyists who want to snipe for gold more efficiently.

1.4 Proposed Timeline

Week:
Research Materials
Gold Detection
Reverse Engineer Current Detector
Create Schematic
Software Design
Create PCB
Prototype
Test Design
Project Document Section 1
Project Partner Update
Communication Evaluation
Project Document Section 2
Design Impact Assessment Draft
Design Impact Assessment

Figure 1.4.1 Gantt Chart Tasklist

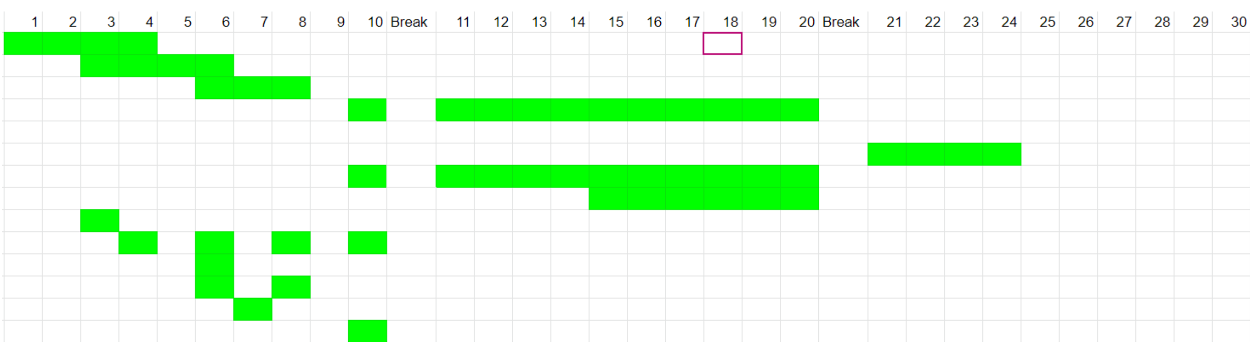


Figure 1.4.2 Gantt Chart Timeline

1.5 References

1.5.1 References

[1] M. S. Sharawi and M. I. Sharawi, “Design and implementation of a low cost VLF metal detector with metal-type discrimination capabilities,” *2007 IEEE International Conference on Signal Processing and Communications*, Dec. 2007.

[2] “Sniping for Gold. Placer Gold Prospection,” *Sniping for gold. Placer gold prospecting*. [Online]. Available: https://www.goldrushnuggets.com/snipingforgold.html. [Accessed: 14-Oct-2022].

1.5.2 File Links

1.6 Revision Table

Version	Date	Description	Author
1	10/14/22	First version of Overview	All group members
2	11/04/22	Added new knowledge to executive summary	James Wilcock
3	11/18/22	Added clear project vision as well as defined blocks to be worked on.	Christopher Viray
4	11/18/22	Fixed formatting issues and improved Gantt Chart readability	Kevin Gao

2 Overview

2.1 Design Impact Statement

This device should be designed to be flexible in its ability to detect metals and adapt to the user's needs, including the search for precious metals. However, prospecting within the US could raise issues if users search within others' borders or territories, particularly when certain finds have cultural significance. Furthermore, as this hobby becomes more popular, safety concerns such as drowning or being swept away by fast currents should be addressed with appropriate measures. Moreover, the device's design should consider potential legal issues such as patents and copyright infringement since it is currently using the enclosure of an existing product. It is essential to ensure that this product is significantly different from existing ones, given the goal of detecting different types of precious and ferrous metals. Lastly, the device could have a significant impact on the environment by identifying metal pollutants underwater and on the surface. Thus, the design should account for the potential impact and incorporate features that facilitate the detection and removal of these pollutants. By considering these factors, the device can be designed to be both effective and responsible in its use.

2.2 Risks

Risk ID	Risk Description	Risk category	Risk prob- ability	Risk impact	Performance indicator	Action Plan
R1	Broken Metal Detector Coils[12]	Timeline	M	L	Coils no longer out magnetic field	Create our own coils for metal detector
R2	Vendor delay	Timeline	M	M	Vendor Stock[10]	Change schematic to work around different parts that are in stock
R3	Part Price Increases	Cost	L	M	Price change[9]	If prices changes are significant enough options should be weighed as to whether parts need to be changed or if costs can be cut elsewhere.
R4	Injury/Sickness	Health	M	L	Pain/Sickness	Team members may have to take a break from working due to injury or sickness. Whether related to the project or not.

R5	Water leaks into enclosure	Cost	M	M	Moisture on the inside of the enclosure	Disconnect all power and attempt to fully dry all components. If that doesn't work we will need to order replacement parts.
R6	Double coil detection works differently underwater	Timeline	L	H	Research or testing shows different results underwater	We will have to redo the coil section for the project and research alternative methods for detecting metal.
R7	Team member has high workload[11]	Timeline	M	L	The team member notifies the group of their amount of schoolwork.	The group will discuss what is needed for the situation and will redistribute workload for that week.
R8	Metal Detector mechanism is patented	Legal	M	L	A patent that is registered pertains to the design in the metal detector.	The group will have to take special care to ensure that the patented technology is not used in our design.

R9	Team members disagree on what a block is supposed to do.	Timeline	M	L	Someone describes what a block does differently than what is expected.	The group will redefine what the block will do together.

2.3 References and Links

2.3.1 References

[1] G. Morgan. “Best Metal Detectors for Gold of 2022.” Popsci.com. https://www.popsci.com/gear/best-metal-detectors-for-gold/ (accessed Nov. 4, 2022).
[2] H. Kirkemo. “Prospecting for Gold in the United States.” usgs.gov. https://pubs.usgs.gov/gip/prospect2/prospectgip.html (accessed Nov. 4, 2022)
[3] Peden AE, Franklin RC, Leggat PAFatal river drowning: the identification of research gaps through a systematic literature review*Injury Prevention* 2016;**22:**202-209. https://injuryprevention.bmj.com/content/22/3/202

[4] National Parks Service, River and Stream Safety, https://www.nps.gov/articles/river-and-stream-safety.htm#:~:text=Learn%20About%20Common%20River%20and%20Stream%20Hazards&text=that%20can%20cause%20you%20to,and%20after%20floods%20and%20heavy
[5] “Reverse engineering,” *Legal Information Institute*, Apr-2021. [Online]. Available: https://www.law.cornell.edu/wex/reverse_engineering. [Accessed: 03-Nov-2022].

[6] “Patent infringement,” *Legal Information Institute*. [Online]. Available: https://www.law.cornell.edu/wex/patent_infringement. [Accessed: 03-Nov-2022].

[7]“Preservation matters: Remote sensing,” National Parks Service. [Online]. Available: https://www.nps.gov/articles/000/preservation-in-practice-metal-detecting.htm. [Accessed: 04-Nov-2022].

[8]EPA. [Online]. Available: https://archive.epa.gov/esd/archive-geophysics/web/html/metal_detectors.html. [Accessed: 04-Nov-2022].

[9] “Copper is the new oil, Goldman Sach's Currie says,” Bloomberg.com, 26-Jan-2022. [Online]. Available: https://www.bloomberg.com/news/videos/2022-01-26/goldman-s-currie-says-copper-is-the-new-oil-video. [Accessed: 07-May-2023].

[10]“Electronic component allocation & lead times: 2023 update,” Free Online PCB CAD Library, 14-Mar-2023. [Online]. Available: https://www.ultralibrarian.com/2023/03/14/electronic-component-allocation-lead-times-2023-update-ulc. [Accessed: 07-May-2023].

[11]D. A. J. Salvagioni, F. N. Melanda, A. E. Mesas, A. D. González, F. L. Gabani, and S. M. Andrade, "Physical, psychological and occupational consequences of job burnout: A systematic

review of prospective studies," in IEEE PloS one, vol. 12, no. 10, pp. e0185781, 2017, doi: 10.1371/journal.pone.0185781.

[12] O. Girish and A. Pranav,"Metal Discriminator",Indian Institute of Technology Bombay, http://www.ee.iitb.ac.in/~stallur/wp-content/uploads/2017/02/Project_report.pdf

2.3.2 File Links

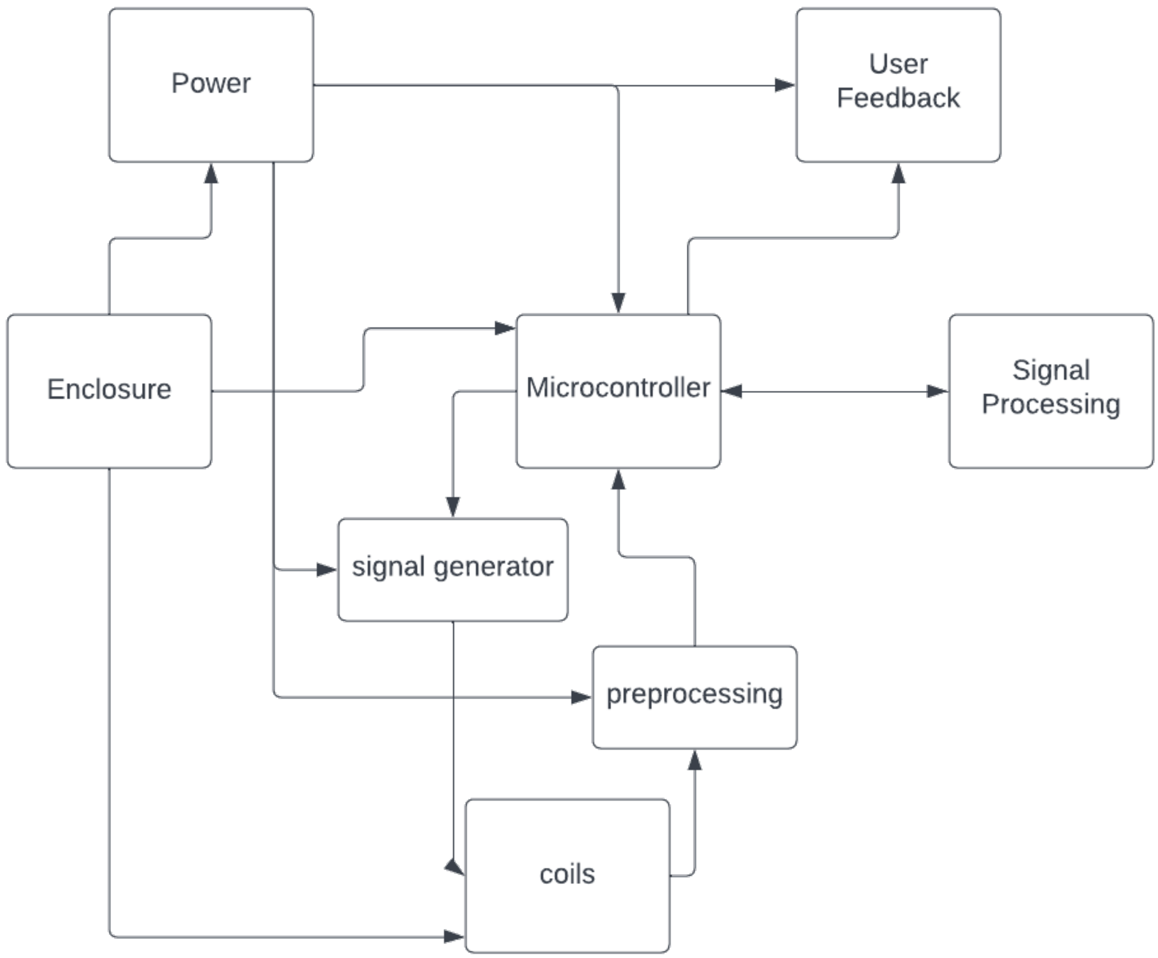
Design Impact

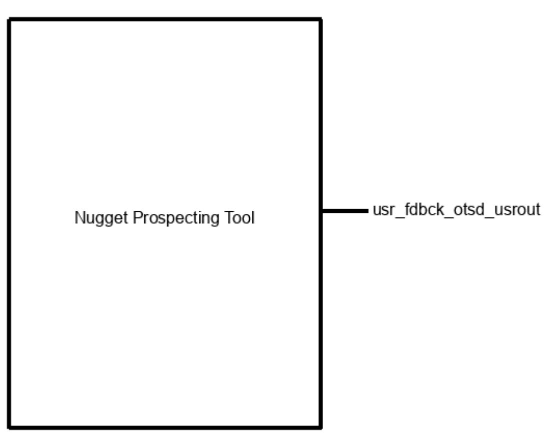
2.4 Revision Table

Version	Date	Description	Author
1	11/03/22	First version of Overview	James Wilcock and Jacob McCray
2	11/18/22	Added R8 risk	James Wilcock
3	11/18/22	Updated risk table	Jacob McCray
4	03/09/23	Added design impact statement	James Wilcock

3 Top-level Architecture

3.1 Block Diagram





3.2 Block Descriptions

Name	Description
Enclosure Champion: Kevin Gao	The Enclosure block fulfills the Waterproof requirement. The project partner requirement states that “the metal detector must be waterproof.” The engineering requirement version states that “the system must remain functioning after being fully submerged in water.” The Enclosure block encompasses the enclosures that hold the coils and a main body that holds all the electrical components of the system. The coil enclosure is a custom-printed disc with raised edges and an oblong-shaped block in the center of the disk that the coils will be wrapped around. The coil enclosure is 3D-printed and made of Polylactic Acid (PLA). Because PLA is not fully waterproof and will absorb water and swell [1], the coils enclosure will also be coated in waterproofing spray. The enclosure itself is 8 inches in diameter because the coils themselves are designed to be no larger than 7 inches in diameter. The coil enclosure is an inch wider in diameter to give the coils extra room in case they are not within 7 inches of diameter. The coil enclosure is 1 inch thick. Once the coils are placed in the coil enclosure, the enclosure will be filled with resin to hold the coils in place and keep them dry. The main body enclosure is an enclosure used by a non-discriminating metal detector that was provided to us by our project partner. It is made of plastic and consists of two parts, a 4 cm diameter handle and a curved 2 cm diameter rod that connects the enclosure to the coils. Both parts are hollow, with the handle's hollow area being 3 cm in diameter and the rod being 1.5 cm. The enclosure block will be tested by first observing if 9/10 signals can pass through the coils enclosure in either direction. The block will then be tested by submerging the system in water for 10 minutes and observing if the system functions properly while underwater.

User Feedback Champion: Kevin Gao	The User Feedback block fulfills the User Feedback requirement. The project partner requirement stated that the underwater gold detector needed to let users know when gold was detected. The engineering version of the requirement states that “9/10 users will be able to tell when the system detects gold versus when the system does not detect gold” The User Feedback block encompasses all components of the system that will alert the user when the system detects gold. This will be implemented using a Vybronics VCLP0820B004L coin vibration motor and a Vishay Ultrabright White LED. The vibration motor will be mounted on the PCB while the LED will be embedded at the head of the detector, above the coils. Upon detection of gold, the LED will turn on with an intensity of at least 52 lumens and the vibration motor will start vibrating with at a minimum of 50 hertz. Both components will remain active as long as the system continues to detect gold. As soon as the system does not detect gold anymore, both components will turn off. This behavior will be triggered by the system using a DC input signal from the microcontroller. The block will output light and vibrations to the user to fulfill the User Feedback requirement. The component input interface properties will be tested by powering them with a DC current at maximum, nominal, and minimum voltage and current levels for 1 minute at each level and observing if they function properly during that time. The component output will be tested by powering them at their tested levels in their datasheets to get a reference for the intended output of each component. Then each component will be tested for 10 seconds at maximum, nominal, and minimum voltage and current levels for 10 seconds at each level and comparing each component output to their datasheet test output.
Signal Generator Champion: James Wilcock	The signal generator plays a crucial role in the functioning of the metal detector. The output it generates is central for the coils to be able to perform optimally and for the whole system to accurately detect and discriminate metal objects. The output signal is a sine wave that oscillates between -12 and 12V, with a frequency of 10 kHz. It will be sustained at a nominal current of 150mA output to the coils of the metal detector. The wave's frequency is an essential factor in ensuring that the gold will be detected instead of other substances. The wave's stability is also necessary to minimize the chances of false readings and ensure consistent performance. One of the key considerations in this project is to minimize power consumption as much as possible. The project is powered by a battery, and the aim is to have a long usage time without having to replace or recharge the battery. In light of this, it is imperative that the signal generator is designed to consume as little power as possible without compromising its performance. Especially in this block which is one of the most power demanding of the project.

Preprocessing Champion: James Wilcock	Preprocessing is an intermediate step between receiving the signal from the coils and outputting a result to the user. This will be achieved by first a band pass filter that can filter the frequency generated, 10Khz. There will then be analog and digital logic that can detect the phase shift between the input and output signals, and then output a signal for the signal processing block to further process. This will also include sending a digital signal that will be high when only one wave is on. Thus communicating the phase shift of the waves.
Microcontroller Champion: Chris viray	This block covers the hardware portion of the design of the underwater metal detector circuit. The parameters we are using to confirm its working condition will be based on a similar underwater metal detector design in that we will stick to the dimensions of the design as well as the components needed to discriminate between different metals underneath the surface. It will need an amplifier for signal output as well as a microcontroller that runs at max from 3.3 to 5 v, since the previous design uses a 9 volt battery to power the device.
Power Champion: Chris viray	This block is the power supply for the entire design. The goal of this project is to create an underwater metal detector design for the user. One of the aspects important to the project is a power supply that is cheap and replaceable. The device the power supply will be used will be submerged in water for extended periods of time, as a result, having a disposable and easily replaceable power source would be ideal to reduce costs of replacement. The goal of the design is to keep the functionality of the device as far away from liquid as possible. The power supply will be in one part of the enclosure while the PCB, the design for metal detection, will separate as well. Since the part needs to be replaceable, it would be risky to have both of them exposed after opening the enclosure.

Coils Champion: Jacob McCray	The coils are what are responsible for detecting the metal. Current will pass through the detector coil and emit a magnetic field that will induce a current through the receiver coil. When this happens the coil will emit a sine wave signal. There are many ways to orient the coils, but for this project we are going with a double D pattern. Ideally this double D pattern will be shaped like two semi-circles that overlap in the middle. The two coils in this pattern will be named the transmitter coil (Tx) and the receiver coil (Rx). The size of the overlap depends on how much magnetic flux can pass from the transmitter coil to the receiver coil. The purpose of the coils is to emit a magnetic field and perceive changes in the magnetic field that are induced by different metals with different permeabilities. As per the requirements for the system, the coils must be able to emit a magnetic field of at least 10 cm in order to detect metals in that distance. The coils will be made from enameled copper magnet wire, and take up no more space than 7” in diameter. When the time comes for the metal detector to be fully put together, the wires will be put in the enclosure and then housed in epoxy resin.
Signal Processing Champion: Jacob McCray	This is a code block that will determine if the signal we receive means that we have found gold. The code will output a high signal when it is given a pulse signal with a length within the acceptable range.

3.3 Interface Definitions

Name	Properties
enclsr_cls_other	• **Other:** 9/10 Signals the can pass through the enclosure and to the coils • **Other:** Coils enclosure diameter is between 7-8" • **Other:** 9/10 Signals the coil sends pass through the enclosure
usr_fdbck_otsd_usrout	• **Other:** 9/10 Users can tell when the LED is on • **Other:** 9/10 Users can tell when the LED is off • **Other:** 9/10 Users can tell when the motor is vibrating

sgnl_gnrtr_prprcssng_asig	• **Max Frequency:** 20 KHz • **Other:** Vmin : -6V • **Vmax:** 6V • **Vrange:** 6V amplitude
sgnl_gnrtr_cls_asig	• **Max Frequency:** 20 KHz • **Other:** Vmin: -6V • **Vmax:** 6V • **Vrange:** 6V amplitude
prprcssng_sgnl_prcssng_dsig	• **Logic-Level:** Active High • **Vmax:** 5.5V • **Vmin:** 0V
mcrcntrllr_usr_fdbck_dcpwr	• **Inominal:** 30mA • **Ipeak:** 40mA • **Vmax:** 5V • **Vmin:** 2.7V • **Vnominal:** 3.3V
mcrcntrllr_prprcssng_dcpwr	• **Inominal:** 30mA • **Ipeak:** 40mA • **Vmax:** 5.3V • **Vmin:** 4.5V • **Vnominal:** 5V
pwr_sgnl_gnrtr_dcpwr	• **Inominal:** 150mA • **Ipeak:** 200mA • **Vmax:** 9.6V • **Vmin:** 6V
pwr_mcrcntrllr_dcpwr	• **Inominal:** 40mA • **Ipeak:** 50mA • **Vmax:** 12v • **Vmin:** 7v

cls_prprcssng_asig	• **Impedance:** |Z| < 1 KOhm • **Max Frequency:** 20 KHz • **Other:** Vnom < 0.1V • **Vrange:** <6V amplitude
sgnl_prcssng_mcrcntrllr_data	• **Datarate:** clock speed > 360*10kHz • **Messages:** Logical high when gold is detected • **Other:** Code is able to ignore rapid fluctuation (bouncing) in the incoming signal

3.4 References and File Links

[1] UltiMaker. “How to 3D print waterproof parts”
https://ultimaker.com/learn/3d-print-waterproof-parts (accessed March 11, 2023)

3.5 Revision Table

03-11-23	James Wilcock	Added block diagram, interface definitions and block descriptions

4 Block Validations

4.1 Signal Generator

4.1.1 Description

The signal generator plays a crucial role in the functioning of the metal detector. The output it generates is essential for the coils to be able to perform optimally and for the whole system to accurately detect and discriminate metal objects. The output signal is a sine wave that oscillates between -6 and 6V, with a frequency of 10 kHz. It will be sustained at a nominal current of 100mA output to the coils of the metal detector. The wave's frequency is an essential factor in ensuring that the gold will be detected instead of other substances. The wave's stability is also necessary to minimize the chances of false readings and ensure consistent performance.

One of the key considerations for our system is to minimize power consumption as much as possible. The project is powered by a battery, and the aim is to have a long usage time without having to replace or recharge the battery. In light of this, it is imperative that the signal generator is designed to consume as little power as possible without compromising its performance; especially in this block which is one of the most power demanding of the project.

4.1.2 Design

The block described in this validation is a crucial component of the metal detector project and plays a vital role in generating the sine wave needed for the metal detector coils. The heart of the block is the Wien Bridge Oscillator, which uses noise inherent to a circuit along with feedback to generate the sine wave. This oscillator is a proven solution for generating stable sine waves and has been used in numerous applications in the past.

The oscillator alone is not enough to generate the desired output from the signal generator. There are additional components needed to achieve the desired -6 to 6V output while being powered from a 9V battery. Before the oscillator, a voltage boost circuit is needed to increase the voltage from 9V, the battery's output, to 12V, which is required for the oscillator to be able to have a 6V reference in order to have a -6V and 6V source for the Wien Bridge Oscillator. It is important that this voltage boost circuit is of high efficiency to minimize the power consumption and prevent excessive current draw from the battery.

After the oscillator, an amplifier circuit is required to achieve the desired 12Vpp sine wave at the desired current requirements. The amplifier needs to be designed to have the correct gain and stability to ensure the output waveform meets the requirements of the metal detector. The sine wave that is output from this amplifier is what will be fed into the coils and preprocessing and as such needs to be of a reliable frequency and amplitude so that the circuitry can effectively detect and discriminate metal objects.

The wave will be output to both the coils and preprocessing circuitry. The coils will output this signal to the metal and preprocessing will need to use this signal to compare to the received wave in order to discriminate metal. As such it is important for the signal to be both high enough frequency to enable the detection range that our engineering requirements demand, as well pass enough current through the coils to have a strong enough field.

In this black box diagram we have the input power (pwr_sgnl_gnrtr_dcpwr) from the battery to the signal generator of 9V and on the left the output sine wave going to both the coils (sgnl_gnrtr_cls_asig) and preprocessing (sgnl_gnrtr_prprcssng_asig).

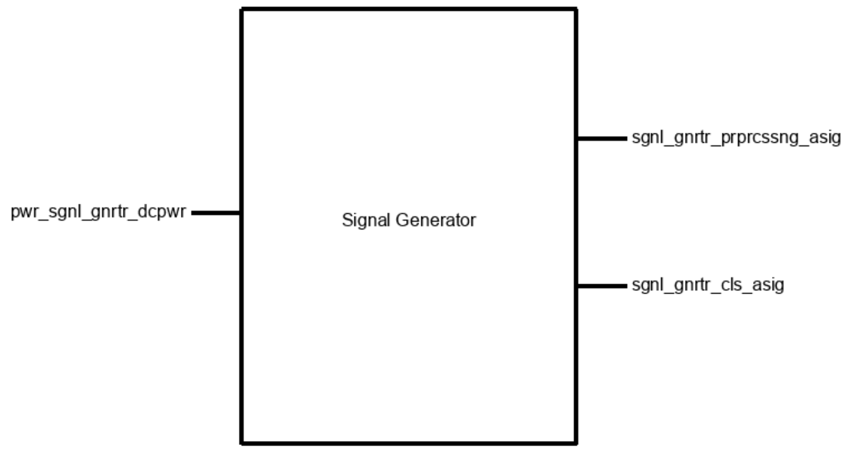


Figure 1: Black Box for the Signal Generator

Below is the schematic for the Oscillator starting from the top the Voltage boost IC xl6019 will be used to generate a 12V output from the 9V battery. On the bottom left there is a rail splitter[3] connected to GNDREF which will use the opamp in LM358DR to generate the negative voltage needed for the oscillator. Then with Q1 we have a BJT amplifier in order to create the 12Vpp wave. This is necessary as the Wien Bridge Oscillator only outputs a 1.4Vpp wave due to stabilizing diodes.

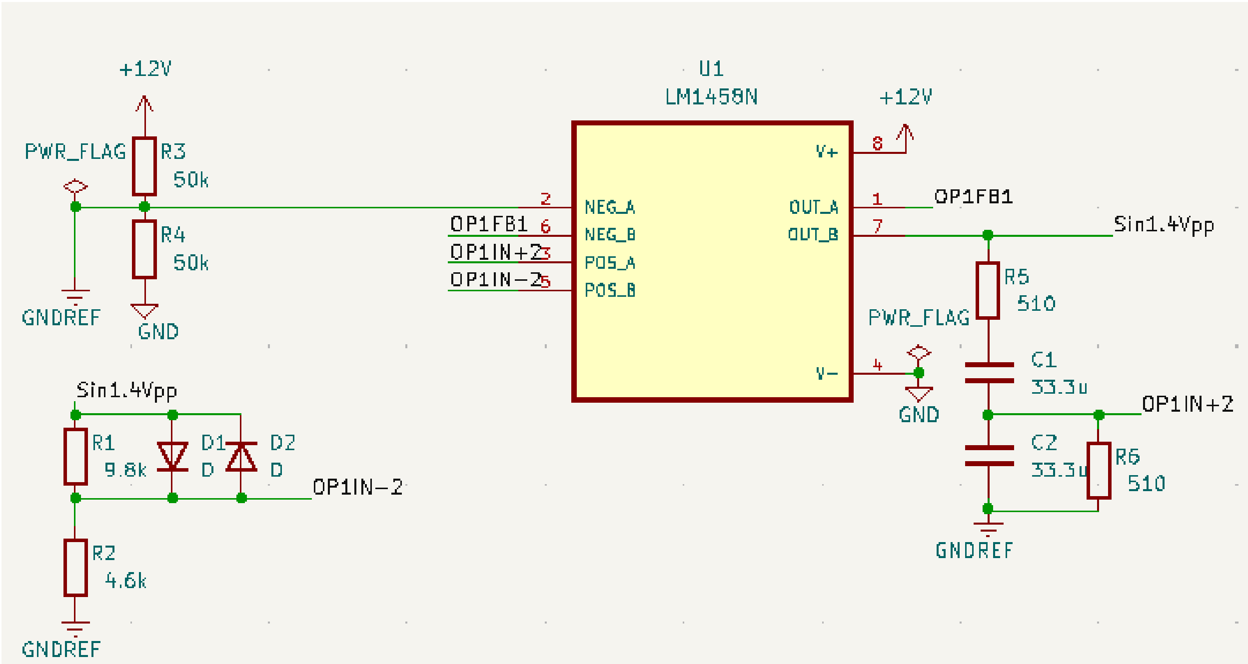


Figure 2: Signal Generator Schematic

4.1.3 General Validation

This block is based on a wien bridge oscillator which works by amplifying the background noise inside of the circuit into a feedback loop in order to generate the sine wave. This oscillator will generate a 10 kHz 12V peak to peak sine wave output. The resistors that are used to change the frequency of the oscillator are R9 and R10, these will be important to find the optimal value in order to generate exactly the frequency that the project needs. Having these changeable as a i think these are called trim pots will be extremely helpful for development as there may be tolerances in parts that result in different values of resistors being necessary to fulfill the correct filters to create the desired frequency with the Wien Bridge Oscillator. Being able to change the frequency will be valuable in making this design more resistant to differences in part tolerances, in that new parts will be less likely to be necessary to create a functional block.

R9, R10 will be what determines the frequency generated and thus will be set with a dual potentiometer. This will allow altering the frequency output by this block in order to allow more freedom for the design, especially during testing depending on the effectiveness of each frequency. Having this controllable with a trim pot is important to make it easy for the assembler to alter the frequency but to also be resistant to changing frequency during operation. The user should not need to alter this frequency and thus will be unable to as the circuitry will be inside of the controller. If multiple of this block are necessary to be created this may be valuable in ensuring that each time we are outputting the correct frequency from the oscillator.

An alternative design for the signal generator block could be a Colpitts Crystal Oscillator. This design is based on the Colpitts oscillator circuit, which uses a series-tuned circuit in conjunction with a crystal resonator to generate a very clean, specific frequency. In some cases, a Colpitts Crystal Oscillator may be necessary to detect metal with sufficient sensitivity if a much higher frequency is required.

One of the main benefits of the Colpitts Crystal Oscillator is that it can generate a very stable and accurate frequency[7], which is critical in ensuring that the metal detector operates as it's intended. The crystal resonator acts as a reference, ensuring that the frequency generated is highly stable and consistent over time. This makes it ideal for applications where a specific frequency is required, such as in the case of a metal detector.

However, a potential drawback to this design is that the frequency would be much harder to adjust than with a Wien Bridge Oscillator as the frequency is determined by the crystal resonator. The crystal oscillator part oscillates at a set frequency, and if a specific frequency is desired, it may be necessary to obtain a different crystal. This could be problematic, as it would require a redesign of the block and could add significant time and cost to the project.

In summary, this block will take in power at 9V and output a 10 kHz signal to the metal detector coil block at a peak-to-peak voltage of 12V. The Wien Bridge Oscillator design will be the chosen approach due to its adjustability and ease of implementation.

4.1.4 Interface Validation

Interface Property	Why is this interface property this value?	Why do you know that your design details for this block above meet or exceed each property?

Pwr_sgnl_gntr_dcpwr: Input

Ipeak: 1A	Wein bridge oscillator should be efficient enough to not draw much current	Simulation of wien bridge oscillator design as well as suggests current demand ~700uA
Vnominal: 9V	In order to create a wave with the wien bridge oscillator, the circuit requires a negative voltage in order to supply the op amp rails. To achieve this we will use a rail splitter which will halve the voltage and result in a 12V supply and -12V supply. As such 9V will need to be boosted to 24V in order to create 24V peak to peak waves as is necessary for the coils.	The Art of Electronics pg. 437[2] describes a wien bridge oscillator design that this was adapted from.
Vmax 9.6V	According to a standard duracell MN1604 9V battery datasheet at full capacity a 9V battery can actually be as high as 9.6V[5].	The voltage boost circuit that will be used can take between 0.5V and 22V for desired 24V output[6].
Vmin 6V	According to a standard duracell MN1604 9V battery datasheet at close to empty capacity a 9V battery will output 6V[5].	The voltage boost circuit that will be used can take between 0.5V and 22V for desired 24V output[6].
Inominal: 150mA	Desired current by coil block, thus is necessary to be supplied from signal generator	According to boost ic datasheet input from 6-9.6V with output of 24V can safely supply at 600mA[6] at least so well above our needs.

Sgnl_gntr_cls_asig

Frequency: 10Khz	Other Metal discrimination projects found that 10Khz was an effective frequency to work off of to not reduce the range too much[1]. Higher frequency may be needed to detect smaller gold pieces.	Frequency is best guess based on other metal detector research papers[1].
Peak to Peak Voltage: 12V	Desired voltage by coil block champion to avoid losing signal form voltage drops during transmission.	Ensures strong enough magnetic field for sensitivity needed[1].
Vmax: 6V	Desired voltage by coil block champion to avoid losing signal form voltage drops during transmission.	Ensures strong enough magnetic field for sensitivity needed[1].
Vmin: -6V	Desired voltage by coil block champion to avoid losing signal form voltage drops during transmission.	Ensures strong enough magnetic field for sensitivity needed[1].

Sgnl_gnrtr_prprcssng_asig

Frequency: 10Khz	Other Metal discrimination projects found that 10Khz was an effective frequency to work off of to not reduce the range too much[1]. Higher frequency may be needed to detect smaller gold pieces.	Frequency is best guess based on other metal detector research papers[1].
Peak to Peak Voltage: 12V	Desired voltage by coil block champion to avoid losing signal form voltage drops during transmission.	Ensures strong enough magnetic field for sensitivity needed[1].
Vmax: 6V	Desired voltage by coil block champion to avoid losing signal form voltage drops during transmission.	Ensures strong enough magnetic field for sensitivity needed[1].
Vmin: -6V	Desired voltage by coil block champion to avoid losing signal form voltage drops during transmission.	Ensures strong enough magnetic field for sensitivity needed[1].

4.1.5 Verification Process

1. Using a powered off lab bench power supply capable of supplying 9V at 1A of current, connect the High input of the signal generator block to the High output of the power supply. And connect the ground from the power supply to the ground of the signal generator.
2. Attach an oscilloscope probe to the output of the signal generator and make sure to connect the probe's ground to the ground of the circuit.
3. Set the lab power supply to 9V and current limit of 1A and then turn the power supply on.
4. Observe the oscilloscope output and make sure the frequency of the sine wave is within the frequency range; this can be done by noting the time of one peak and measuring the time to the next peak of the wave. 1/(the amount of time between peaks) will get the frequency of the wave.
5. Check that the current draw is not capping at 1A and is below that number on the power supply
6. Decrease the voltage to 8V and see that the wave frequency and amplitude is still acceptable
7. Decrease the voltage further to 7V and see that the wave frequency and amplitude is still acceptable
8. Turn off the lab bench power supply and remove the probes.

4.1.6 References and File Links

4.1.6.1 References

[1] G. O, “Metal Discriminator.” [Online]. Available: https://www.ee.iitb.ac.in/web/index.php. [Accessed: 18-Jan-2023].

[2] P. Horowitz and W. Hill, *The Art of Electronics*, vol. 3. New York: Cambridge University press, 2015.

[3] B. Laumeister, “Rail splitter, from Abraham Lincoln to virtual ground,” *Rail Splitter, from Abraham Lincoln to Virtual Ground | Analog Devices*, 19-Dec-2008. [Online]. Available: https://www.analog.com/en/technical-articles/rail-splitter-from-abraham-lincoln-to-virtual-ground.html. [Accessed: 07-Feb-2023].

[4] “Discharge tests of 9 volt transistor radio style batteries,” *Discharge tests and capacity measurement of 9 volt transistor radio batteries at high current, 100mA to 500mA engineering data*. [Online]. Available: https://www.powerstream.com/9V-Alkaline-tests.htm. [Accessed: 07-Feb-2023].

[5] “MN1604 size: 9V (6LR61) - Duracell,” *Alkaline-Maganese Dioxide Battery MN1604*. [Online]. Available: https://www.duracell.com/wp-content/uploads/2016/03/MN1604_US_CT1.pdf. [Accessed: 08-Feb-2023].

[6] “Datasheet - XLSEMI.” [Online]. Available: http://www.xlsemi.net/datasheet/XL6019%20datasheet-English.pdf. [Accessed: 12-Feb-2023].

[7] W. Storr, “Colpitts oscillator tutorial and Colpitts oscillator design,” *Basic Electronics Tutorials*, 04-Aug-2022. [Online]. Available: https://www.electronics-tutorials.ws/oscillator/colpitts.html. [Accessed: 11-Feb-2023].

4.1.7 Revision table

1-20-23	James Wilcock	Finished rough draft from validation template
2-6-23	James Wilcock	Added Block description and validation plan. Added decimal headings and general formatting to what changed to what was desired.
2-10-23	James Wilcock	Revised wording to make points clearer and go into more depth on interface reasoning
2-11-23	James Wilcock	Changed voltage boost part to xl6019
3-9-23	James Wilcock	Changed voltage for wave from 24Vpp to 12Vpp

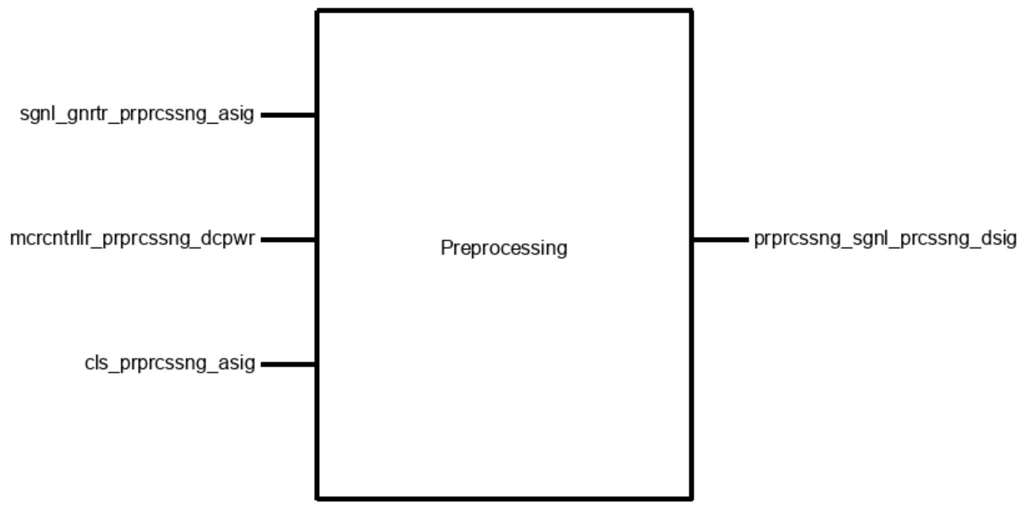
4.2 Preprocessing

4.2.2 Description

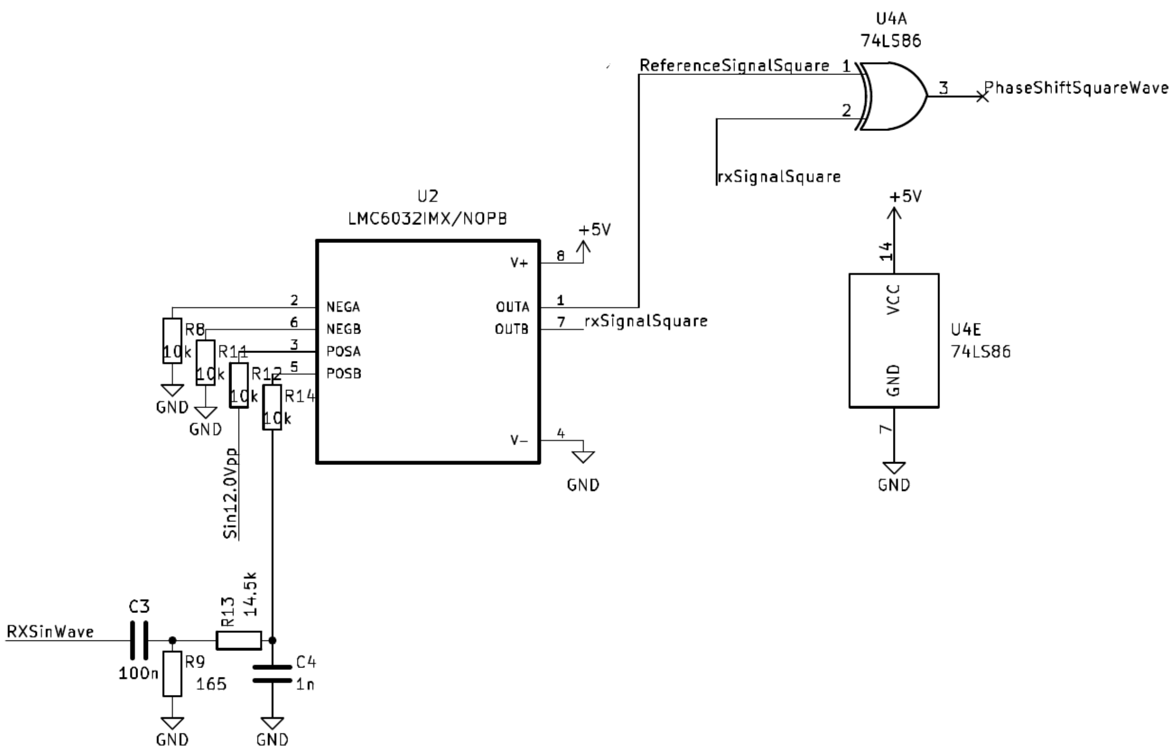
Preprocessing is an intermediate step between receiving the signal from the coils and outputting a result to the user. This will be achieved by first a band pass filter that can filter the frequency generated, 10Khz. There will then be analog and digital logic that can detect the phase shift between the input and output signals, and then output a signal for the signal processing block to further process. This will also include sending a digital signal that will be high when only one wave is on. Thus communicating the phase shift of the waves.

4.2.2 Design

Preprocessing will be achieved by a number of pieces, firstly the signal coming into our coils as well the one generated will have some level of noise, thus a band pass filter will be necessary to filter out any unwanted frequencies. This will have an upper pass band of 11Khz and a lower bound of 9.6Khz. This should satisfactorily filter out frequencies that are not the one generated by the signal generator and those that are received after being transmitted to the world. After this part the phase detection will be done. To achieve this first we must turn the sin wave coming from the receive coil and the reference signal from the signal generator into a square wave that is low when then sine wave is below 0V and 5V high when above 0V. This will be achieved with a comparator that will take in both the signal and a reference with ground, which when lower than the reference will pull to the low rail outputting 0V when below 0 and when above the reference pull to the positive rail outputting 5V. This square wave describes when the sine wave is above zero and for how long, we can then put both square waves through a xor gate which will output when only one sine wave is high at a given time. The length of this xor output will directly correspond to the phase shift of the two waves. This phase shift is key in being able to differentiate between different kinds of materials in our metal detector.



Black Box Diagram for Preprocessing



Preprocessing Schematic

4.2.3 General Validation

This block centers on the XOR operation on the output of a zero crossing detector to send a signal which shows when the sine waves are shifted from one another. The band pass filter is pretty straightforward and you can simply choose the frequencies that you want to filter out using two filters, high pass for the lower bound and low pass for the higher bound, these two together leave the desired range of frequencies left intact. C3, R9 and R13, C4 are band pass. C3 and R9 form a high pass filter letting through frequencies above 9.6kHz and R13 and C4 form a low pass letting through frequencies under 11kHz.

After this the signal from the receiving coil and the reference signal from the signal generator are put into the LMC6032, a general purpose op amp which is used as a comparator, outputting whether high or low when the signal is greater or less than 0. The outputted square waves are then fed into the 74LS86 XOR gate IC which outputs high when only one wave is currently above 0, thus showing how out of phase the signals are.

An alternate design could have been a zero crossing detector that works by sending a pulse when a zero crossing is detected. This could similarly allow the microcontroller to deduce how out of phase the signals are by comparing the times at which the pulses were triggered. Circuitspedia has a zero-crossing detector implemented with an optocoupler[2] that could have been valuable if this route had been chosen. One reason to not go this route is that this method could be harder to debounce if that had been an issue, as the signal is not a continuous wave as we are currently doing. Which would mean more care would need to be taken to make sure false pulses were not happening.

4.2.4 Interface Validation

Interface Property	Why is this interface property this value?	Why do you know that your design details for this block above meet or exceed each property?

mcrcntrllr_prprcssng_dcpwr**:** Input

Inominal: 30mA	Current draw from the two main ICs at nominal voltage.	Current draw that was seen at nominal voltage supply when the block was put together.
Ipeak: 40mA	Current draw from Vmax	This current draw was seen at Vmax when block was tested.
Vmax: 5.3V	Voltage supplied from the microcontroller should never be higher than this.	According to the LM1117, the voltage regulator in the microcontroller, the datasheet voltage should go above 0.1V of desired voltage[3].
Vmin: 4.5V	Voltage supplied from the microcontroller should never be lower than this.	According to the LM1117, the voltage regulator in the microcontroller, the datasheet voltage should go under 0.1V of desired voltage[3].
Vnominal: 5V	Voltage supplied from the microcontroller stay near to this.	According to the LM1117, the voltage regulator in the microcontroller, datasheet voltage should go stay within tolerable range of desired voltage[3].

Prprcssng_sgnl_prcssng_dsig: Output

Logic-Level: Active High	This logic-level was chosen because it is easiest to take	If digital read is used to check the logic-level of this signal, 0

	in by the microcontroller.	to 5V, active high makes the most sense on the arduino side[4].
Vmax: 5.5V	This value is chosen so that the voltage will not negatively affect the microcontroller's electronics.	The input that powers the XOR gate has a max voltage of 5.3V, which the XOR gate should not exceed on high output.
Vmin: 0V	This value is chosen to be simply read by the microcontroller	This value is chosen as the low supply for the XOR is put to ground and thus should not go below this value.

Sgnl_gnrtr_prprcssng_asig: Input

Frequency: 10Khz	Other Metal discrimination projects found that 10Khz was an effective frequency to work off of to not reduce the range too much[1]. Higher frequency may be needed to detect smaller gold pieces.	Frequency is best guess based on other metal detector research papers[1].
Peak to Peak Voltage: 12V	Desired voltage by coil block champion to avoid losing signal form voltage drops during transmission.	Ensures strong enough magnetic field for sensitivity needed[1].
Vmax: 6V	Desired voltage by coil block champion to avoid losing signal form voltage drops during transmission.	Ensures strong enough magnetic field for sensitivity needed[1].
Vmin: -6V	Desired voltage by coil block champion to avoid losing signal form voltage drops during transmission.	Ensures strong enough magnetic field for sensitivity needed[1].

Cls_prprcssng_asig: Input

Impedance: |Z| < 1 KOhm	The impedance to the needs	The design number of loops

	to be above a certain point in order to keep a voltage without drawing an unreasonable amount of current.	in the coil will not be enough to create this high of an impedance.
Max Frequency: 20 kHz	Because the coils are not powered components they will not be able to produce any signal that is not the same frequency as the input signal, therefore the max output frequency is the same as the input max frequency.	The lack of powered components means that this block will only output a frequency similar to what is given by the input.
Other: Vnom < 0.1V	The output voltage will stay low while no metals are passed through the magnetic field, meaning that the normal voltage is very low.	From the research that I have done it seems like all that is needed from the design is to place the coils in a certain sweet spot overlapping each other.
Vrange: <6V	The output voltage should be similar to the input voltage, but smaller in order to account for small losses in voltage due to the environment and resistances in the wires.	The coils will be lossless enough that the Vrange of the wave when detecting gold will stay high enough.

4.2.5 Verification Process

1. Using a powered off lab bench power supply capable of supplying 5V at 0.5A of current, connect the 5V input of the preprocessing block to the High output of the power supply. And connect the ground from the power supply to the ground of the signal generator.
2. Attach an oscilloscope probe to the output of the xor gate and make sure to connect the probe's ground to the ground of the circuit.
3. Attach another oscilloscope probe to the RXSinWave signal and to ground. Attach one more oscilloscope probe to the rxSignalSquare signal and to ground
4. Using a lab bench signal generator setup a 10kHz sine wave at a 12Vpp and attach the high to RXSinWave and ground to ground on the preprocessing block.
5. Using a lab bench signal generator setup a 10kHz sine wave at a 12Vpp and attach the high to Sin12.0Vpp and ground to ground on the preprocessing block.

6. Set the lab power supply to 5V and current limit of 0.5A and then turn the power supply on. Turn both signal generators on.
7. Observe the oscilloscope output and make sure that RXSinWave is at the correct 12Vpp and 10kHz. Observe that the rxSignalSquare is 5V when RXSinWave is above 0V and 0V when below 0V.
8. Check that the current draw is not capping at 0.5A and is below that number on the power supply
9. Turn off the power supply and signal.
10. Move the rxSignalSquare wave oscilloscope probe from rxSignalSquare to ReferenceSignalSquare
11. Set the lab power supply to 5V and current limit of 0.5A and then turn the power supply on. Turn both signal generators on.
12. Observe the oscilloscope output and make sure that Sin12.0Vpp is at the correct 12Vpp and 10kHz. Observe that the ReferenceSignalSquare is 5V when Sin12.0Vpp is above 0V and 0V when below 0V.
13. Turn off the power supply and signal.
14. Attach an oscilloscope probe to PhaseShiftSquareWave, and ground to the circuit.
15. Set the lab power supply to 5V and current limit of 0.5A and then turn the power supply on. Turn both signal generators on.
16. Observe that PhaseShiftSquareWave is 5V when only ReferenceSignalSquare is high or only rxSignalSquare is high.
17. Turn off the lab bench power supply and signal generators and remove the probes.

4.2.6 References and File Links

4.2.6.1 References

[1] G. O, “Metal Discriminator.” [Online]. Available: https://www.ee.iitb.ac.in/web/index.php. [Accessed: 18-Jan-2023].

[2] “What is zero crossing detector: Zero cross detector using OP amp working,” *circuitspedia.com*, 11-Mar-2022. [Online]. Available: https://circuitspedia.com/zero-crossing-detector-circuit-working-uses/. [Accessed: 11-Mar-2023].

[3] “Analog | Embedded Processing | Semiconductor Company | ti.com,” *LM1117 800-mA, Low-Dropout Linear Regulator*, Feb-2000. [Online]. Available: https://www.ti.com/lit/ds/symlink/lm1117.pdf. [Accessed: 11-Mar-2023].

[4] A. Team, “Digital Pins: Arduino documentation,” *Arduino Documentation | Arduino Documentation*, 09-Mar-2023. [Online]. Available: https://docs.arduino.cc/learn/microcontrollers/digital-pins. [Accessed: 11-Mar-2023].

4.2.7 Revision table

03-10-23	James Wilcock	Created validation for preprocessing
03-11-23	James Wilcock	Added correctly formatted references

4.3 Power

4.3.1 Description

This block is the power supply for the entire design. The goal of this project is to create an underwater metal detector design for the user. One of the aspects important to the project is a power supply that is cheap and replaceable. The device the power supply will be used will be submerged in water for extended periods of time, as a result, having a disposable and easily replaceable power source would be ideal to reduce costs of replacement. The goal of the design is to keep the functionality of the device as far away from liquid as possible. The power supply will be in one part of the enclosure while the PCB, the design for metal detection, will separate as well. Since the part needs to be replaceable, it would be risky to have both of them exposed after opening the enclosure.

4.3.2 Design

This product includes a 9 volt battery and two wires, one that leads to the microcontroller input, labeled Vin, and another that leads to the signal generator voltage input. This connection leads to the buck converter needed to step up the 9 volts from the battery with the input labeled VIN.[Fig.2] The design uses a 600mAh battery however it can use a 1200mAh 9 volt if needed for longer lasting battery life.

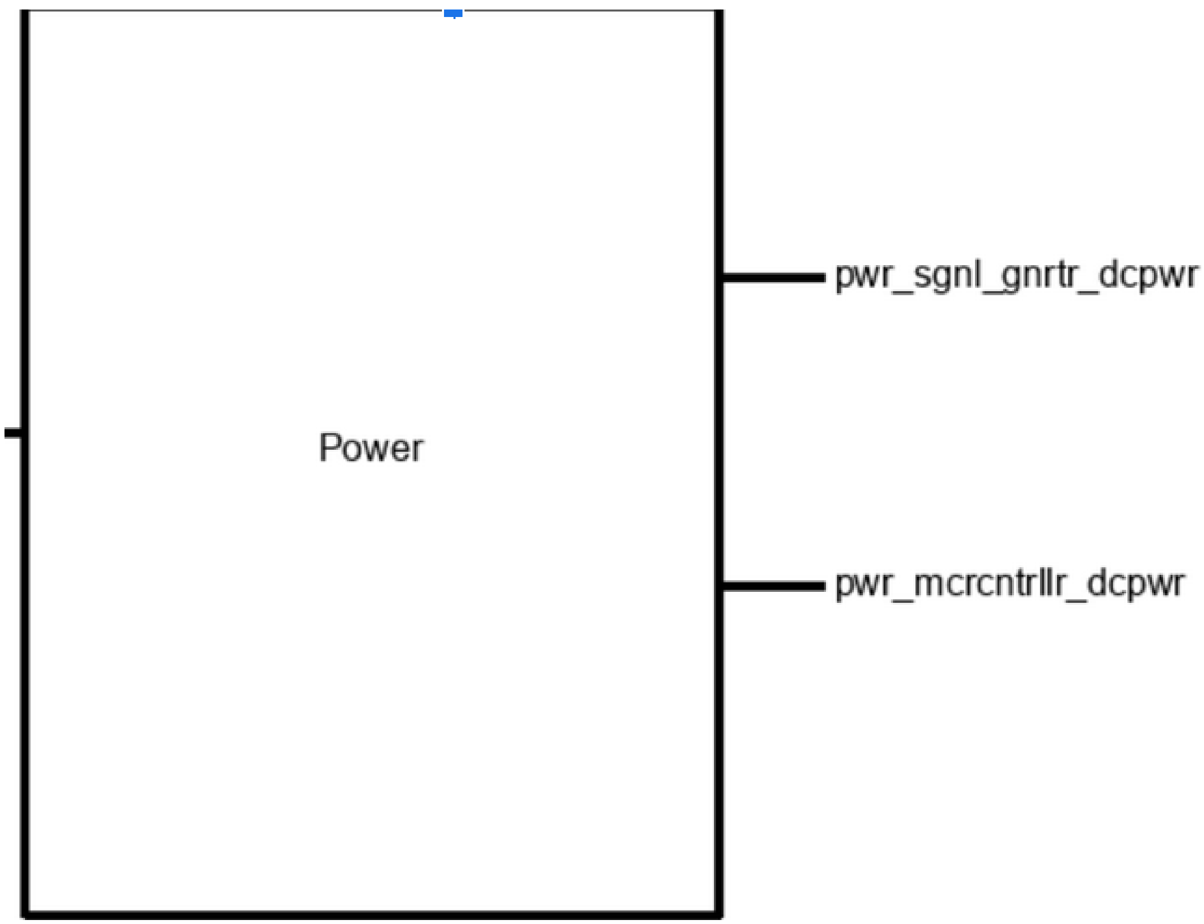


Fig 1. Power Diagram Block

The purpose of this figure is to explain in the high level how this block will interact with other components within the design, for this case, the power block has to power both the signal generator and the microcontroller.A datasheet of the 9 volt battery indicates the amp hours of the device in relation to the current draw of the entire device, accounting the amount of current needed for the microcontroller and the signal generator, which is around 200 mA, the battery can provide 1200mAh worth of power or max around 6 hours worth of battery life. This calculation is for completing our goal of having a power supply to last throughout the entire day.[2]

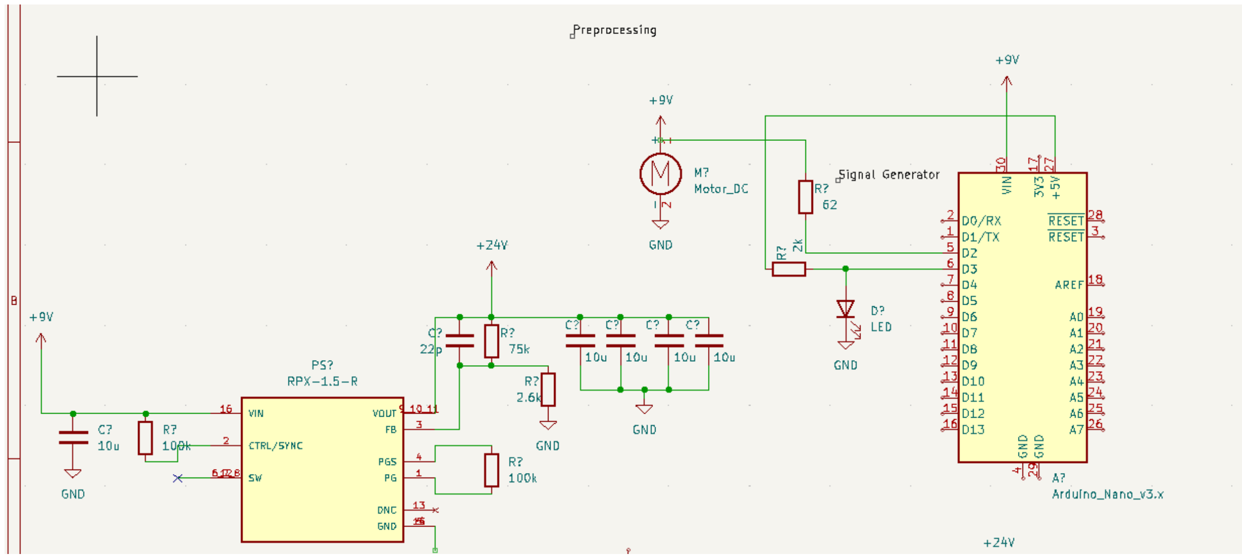


Fig 2. Schematic for connections relative to power supply

This block explains which components that the power block interacts with. The Power is the main input of the system and can be affected by the size of the enclosure, which explains the input coming into the power block. The two outputs, which go to the signal generator and the microcontroller, both require power in order for it to function. The microcontroller we will use, the arduino nano, will require anywhere between 7-12 volts, which the battery can provide. The other important interface, the signal generator, will require 5 volts as well, which can be provided from the 5 volt rail from the microcontroller. The 9 volt battery is represented by the arrow labeled 9v which will connect to the boost converter connected to the signal generator and the microcontroller.

4.3.3 General Validation

In this block, the power supply I decided to use will be a 9 volt battery. The list of requirements that this power supply fits under, including it being relatively cheap, lightweight, and fits the power requirements for the microcontroller.

Our requirements for it being cheap, or the product costing less than $150 works when using a disposable battery, and helps to keep down costs in comparison to using a rechargeable battery, which if damaged, will be harder and more expensive to replace.

This power supply works under the requirements of being lightweight, our goal is to keep the metal detector's weight under 10 lbs, as a result, there are more efficient power supplies that can last longer, but would either increase the weight of the object or increase risk of it being damaged and harder to replace in the future. The constraint of it having to be lightweight as a result also constrains the dimensions of our design, as a result, the type of power supply we can use is limited, so for the type of design we want for the enclosure, we decided upon the 9 volt battery as something that fits within those constraints.

The block also fits within what our microcontroller needs for the project, as we are using an Arduino Nano, a simple disposable 9 volt battery for an underwater metal detector is ideal. In terms of availability as well, you can buy a 9 volt battery in nearly any store.

One thing wrapped within the requirements of it being lightweight would also be its size. To keep the metal detector light, we also reduced the size of the enclosure we will use to house the PCB and power supply, and the 9 volt battery works best under these conditions rather than buying a DC power supply. One alternative solution that could work for this as well would be 6 AA batteries as well, which would fit under the size, affordability, and power requirements, however not as efficient since the cost of buying that many batteries overtime would be more expensive.

One of the few disadvantages associated with using a disposable battery would be that the cost overtime would be more expensive than using a reusable power supply that is integrated within our circuit, however, that would as a result drive up the cost of the build as well as make the metal detector components harder to replace, because if it were all integrated into the PCB and water managed to get into the design, the user would have to buy a new one as a result unless they have an electrical background.

Another disadvantage of the design would be the power of the metal detector throughout the whole day, as a result of the components within the PCB design requiring at least 200mA worth of current from the battery and from research on the battery we plan on using, it will last at most 6 hours since the specs indicate it having a 1200mAh rating. Some designs out there can have integrated circuit power supplies that can last for days but would drive up the price of the metal detector as a result.

The decision to use a 9 volt battery as well doesn't decrease the usability of the product majorly, most people in the world with common sense understand how to replace the battery and insert it correctly within the socket. The design of the existing enclosure allows us to reuse the air tight screw cap design for the metal detector housing the 9 volt battery for quick and easy replacement, as well as having a sealed waterproof housing between the power supply and its more expensive components to save on replacement costs.

4.3.4 Interface Validation

Interface Property	Why is this interface property this value?	Why do you know that your design details for this block above meet or exceed each property?
pwr_sgnl_gnrtr_dcpwr		

Nominal: 5V	That's the voltage needed to power the signal generator from the microcontroller	So I can give the correct amount of power for the signal generator block.
$I_{nominal}$=150mA	This is the value drawn from the battery to power the generator and coils	The battery will be able to supply this current, it's just that it might not be able to last throughout the whole entire day if using a carbon zinc battery.
I_{peak}= 1A	This is the max current draw for the signal generator before permanent damage occurs to the circuit.	The battery won't be able to output more than 600mA total, as listed in the datasheet.[3]
pwr_mcrcntrller_dcpwr		
$V_{min\ 7\ v}$ 7v	It's the listed values for input voltage needed(Electrical Characteristics pg.2)	That's the voltage needed to power the microcontroller. Electrical Characteristics pg.2[1]
V_{max} = 12 V	That's the voltage taken from the specifications for the arduino nano(Electrical Characteristics pg.2)	That's the max voltage that the microcontroller can handle Electrical Characteristics pg.2[1]
Binomial = 8 v	This will likely be the voltage output throughout the day.	This is going to be near the expected value output from the battery over the course of the day.[2]
$I_{nominal}$ = 50 mA	This is the power draw required from the microcontroller.	Look at electrical characteristics.(pg.2)[1]
I_{peak} = 1 A	The amount of current before it damages the device	Look at electrical characteristics.[1]

4.3.5 Verification Process

pwr_mcrcntrller_dcpwr

1. Connect the positive(red) and negative ends(black) of the disposable 9 voltage battery into the 9 volt socket.

2. Measure the voltage output with a digital multimeter(DMM) on the microcontroller voltage, if the voltage lies between 7-12 volts between the power supply and the microcontroller, the pwr_mcrcntrller_dcpwr interface works.
3. Measure the voltage outputs with a DMM on the signal generator, if the voltages stay above 5 volts the pwr_sgnl_gnrtr_dcpwr interface passes the V nominal and Vmin, if it does not surpass the list Vmax value, the system works..
4. Attach the positive and negative leads on the battery socket into two separate rows for gnd and power.
5. Connect a resistor in series with the battery on a breadboard.
6. Using a DMM, measure the voltage drop across the resistor, use ohm's law and calculate voltage from the battery over the resistance to get your current drop across the resistor. If the value holds for around 30 seconds, it will pass the Inominal test, if it does not surpass the listed Peak value, it passes that test.

   Pwr_sgnl_gnrtr_dcpwr

7. Connect the positive(red) and negative ends(black) of the disposable 9 voltage battery into the 9 volt socket.
8. Measure the voltage output with a digital multimeter(DMM) on the microcontroller voltage, if the voltage lies between 7-12 volts between the power supply and the microcontroller, the pwr_mcrcntrller_dcpwr interface works.
9. Measure the voltage outputs with a DMM on the signal generator, if the voltages stay above 5 volts the pwr_sgnl_gnrtr_dcpwr interface passes the V nominal and Vmin, if it does not surpass the list Vmax value, the system works..
10. Attach the positive and negative leads on the battery socket into two separate rows for gnd and power.
11. Connect a resistor in series with the battery on a breadboard.
12. Using a DMM, measure the voltage drop across the resistor, use ohm's law and calculate voltage from the battery over the resistance to get your current drop across the resistor. If the value holds for around 30 seconds, it will pass the Inominal test, if it does not surpass the listed Peak value, it passes that test.

4.3.6 References and File Links

[1]“Arduino nano - farnell.” [Online]. Available: https://www.farnell.com/datasheets/1682238.pdf. [Accessed: 12-Feb-2023].

[2]“Product datasheet - energizer.” [Online]. Available: https://data.energizer.com/pdfs/l522.pdf. [Accessed: 12-Feb-2023].

4.3.7 Revision table

2/11/23	Jazmin Cartegna	Added (I)current requirements
2/11/23	Rachael Cate	Formatted document in IEEE
2/11/23	Treven Headly	Added more to the 1st section Project Description, Added Schematic for further context to design
2/11/23	Don Heer	

4.4 Microcontroller

4.4.1 Description

This block covers the hardware portion of the design of the underwater metal detector circuit. The parameters we are using to confirm its working condition will be based off a similar underwater metal detector design in that we will stick to the dimensions of the design as well as the components needed to discriminate between different metals underneath the surface. It will need an amplifier for signal output as well as a microcontroller that runs at max from 3.3 to 5 v, since the previous design uses a 9 volt battery to power the device.

4.4.2 Design

The block consists of the arduino nano and 4 different connection, two inputs and two outputs. The two inputs include the power supply and the signal processing block. The two outputs include the preprocessing and the user feedback block. Power comes from the power supply and the software or code is given from the signal processing block to communicate with our signal generator and preprocessing analog devices.

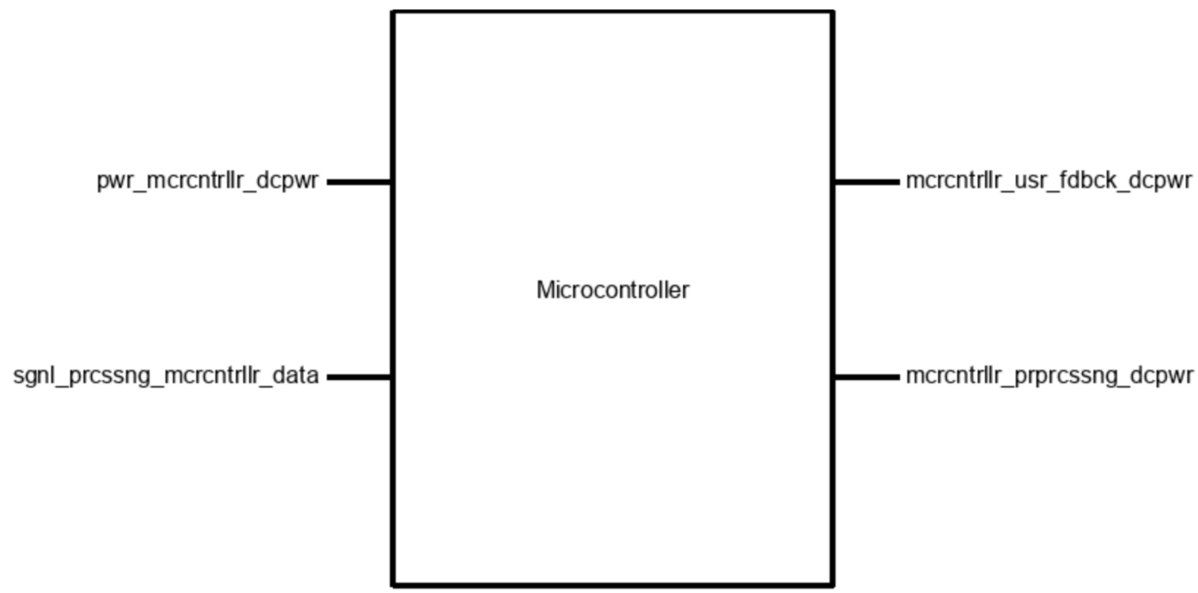


Fig 1. Block diagram for Microcontroller

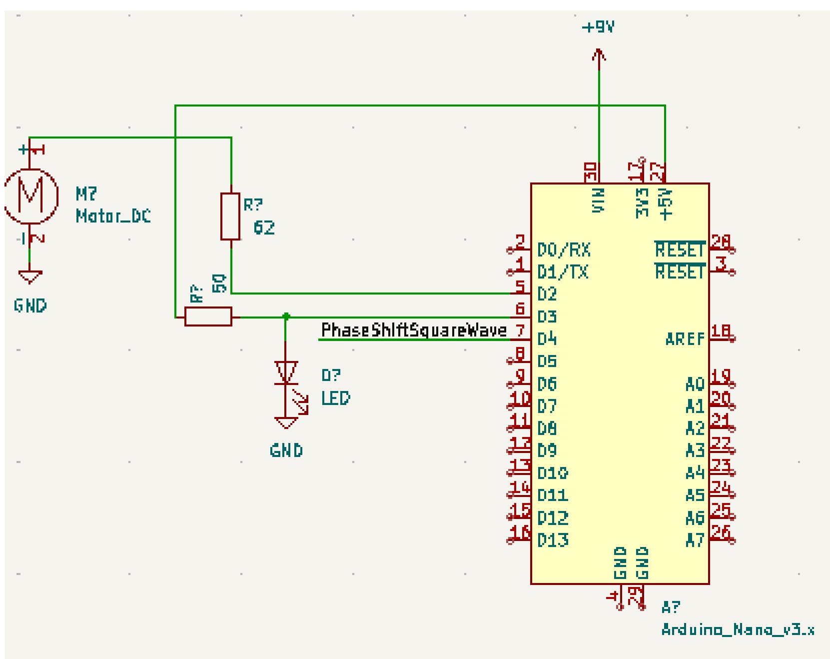


Fig 2: schematic and connections for Microcontroller.

4.4.3 General Validation

The microcontroller block is included to communicate with the preprocessing block and the signal generator block. The purpose of this block is to transfer the code written from the signal processing block or the code block and provide dc power from its connections to the preprocessing and the signal generator block. The decision was to use the arduino nano module. The reason why this completes the system needs is because it fits within the design constraints of the enclosure, has a high enough sampling rate, enough dc power from its connections to power the rest of the circuit design. This microcontroller can also be powered by a 9 volt battery, in which for the existing previous design, used. If we were in need of an alternate solution to this problem, you could also use the ESP32, it is also programmable on the arduino language and has a high enough sampling rate for the metal detection design.

4.4.4 Interface Validation

Interface Property	Why is this interface property this value?	Why do you know that your design details for this block above meet or exceed each property?
mcrcntrllr_usr_fdbck_dcpwr	• **Inominal:** 30mA • **Ipeak:** 40mA • **Vmax:** 5V • **Vmin:** 2.7V • **Vnominal:** 3.3V **(DC Power lines require the following properties. I am leaving this one as not met to be sure you read this comment: Vmax, Vmin, Inominal, Ipeak.)**	See design specifications for user feedback.[2]
mcrcntrllr_prprcssng_dcpwr	• **Inominal:** 30mA • **Ipeak:** 40mA • **Vmax:** 5.3V • **Vmin:** 4.5V • **Vnominal:** 5V	See design specifications for microcontroller[1]
pwr_mcrcntrllr_dcpwr	• **Inominal:** 40mA • **Ipeak:** 50mA • **Vmax:** 12v • **Vmin:** 7v	The rated specifications for the battery is able to maintain current specifications.[3]
sgnl_prcssng_mcrcntrllr_data	• **Datarate:** clock speed > 360*10Hz • **Messages:** Logical	The rated spefications for the software should be able to run these specifications.

	high when gold is detected ● **Other:** Code is able to ignore rapid fluctuation (bouncing) in the incoming signal	[2]

4.4.5 Verification Process

Mcrcntrllr_usr_fdbck_dcpwr

1. Plug in the power supply to power the microcontroller. Provide 7 volts to the Vin pin of the design.
2. Run the code provided
3. Use a electronic load and take note of the voltage and current ratings outputted, if the voltage and current fits within the specified rating, the design works.

Mcrcntrllr_prprcssng_dcpwr

1. Plug in the power supply to power the microcontroller. Provide 7 volts to the Vin pin of the design.
2. Run the code provided
3. Use a electronic load and take note of the voltage and current ratings outputted, if the voltage and current fits within the specified rating, the design works

Pwr_mcrcntrllr_dcpwr

1. Connect the positive and negative leads from the 9 volt battery socket into the Vin and Gnd pins of the microcontroller.
2. Use an electronic load and connect the positive and negative leads into the Vin and Gnd pins of the microcontroller. If the voltage and current fits within the specified ratings, the design works.

Sgnl_prcssng_mcrcntrllr_data

1. Write in the code provided
2. Turn on the power supply and set to 7 volts.
3. Use an electronic load and connect the positive and negative leads into pins D10 and Gnd pins of the microcontroller.
4. If you see a voltage of 5 volts on the electronic load, the pin will output a digital high and means that the microcontroller can output a digital high, certifying that that aspect of the system works.
5. Next place a surface mount switch and plug two of the lead on pin d10 and two pins into GND.
6. Plug an oscilloscope probe to pins d10 and GND.
7. Press the button a couple of times, note on the waveform from the oscilloscope any changes within the wave form.

8. To check for debouncing, check for ripples within the signal. Ripples within the signal are moments within seconds of pressing the button when it goes from low to high in which the signal fluctuates significantly. If there are ripples within the signal that last longer than 100uS, the system design doesent meets specifications.

4.4.6 References and File Links

[1]“Arduino nano - farnell.” [Online]. Available: https://www.farnell.com/datasheets/1682238.pdf. [Accessed: 11-Mar-2023].

[2]“Coin Vibration Motor - VCLP0820B004L,” *Vybronics*, 02-Nov-2022. [Online]. Available: https://www.vybronics.com/coin-vibration-motors/with-brushes/v-clp0820b004l. [Accessed: 10-Mar-2023].

[3]“Product datasheet - energizer.” [Online]. Available: https://data.energizer.com/pdfs/l522.pdf. [Accessed: 12-Feb-2023].

4.4.7 Revision table

4.5 User Feedback

4.5.1 Description

The User Feedback block fulfills the User Feedback requirement. The project partner requirement stated that the underwater gold detector needed to let users know when gold was detected. The engineering version of the requirement states that “9/10 users will be able to tell when the system detects gold versus when the system does not detect gold.” The User Feedback block encompasses all components of the system that will alert the user when the system detects gold. This will be implemented using a Vybronics VCLP0820B004L coin vibration motor and a Vishay Ultrabright White LED. The vibration motor will be mounted on the PCB while the LED will be embedded at the head of the detector, above the coils. Upon detection of gold, the LED will turn on with an intensity of at least 52 lumens and the vibration motor will start vibrating with at a minimum of 50 hertz. Both components will remain active as long as the system continues to detect gold. As soon as the system does not detect gold anymore, both components will turn off. This behavior will be triggered by the system using a

DC input signal from the microcontroller. The block will output light and vibrations to the user to fulfill the User Feedback requirement. The component input interface properties will be tested by powering them with a DC current at maximum, nominal, and minimum voltage and current levels for 1 minute at each level and observing if they function properly during that time. The component output will be tested by powering them at their tested levels in their datasheets to get a reference for the intended output of each component. Then each component will be tested for 10 seconds at maximum, nominal, and minimum voltage and current levels for 10 seconds at each level and comparing each component output to their datasheet test output.

4.5.2 Design

The User Feedback block consists of a Vybronics VCLP0820B004L coin vibration motor and a Vishay Ultrabright White LED. The vibration motor vibrates at 9000 rpm (rotations per minute) [2] and the LED has a luminous intensity range of 5600 mcd (millicandela) to 11200 mcd. The User Feedback block will perform its purpose once it receives a signal from the microcontroller, in the form of a DC current. Figure 1 below shows the input **mcrcntrllr_usr_fdbck_dcpwr** which has a nominal voltage of 3.3V and a nominal current of 30 mA. Both components will receive the same DC input voltage from the microcontroller, but they will be connected to separate output pins to allow for the microcontroller to control each component individually. This will allow for future modifications to the block to provide further functionality like scaling the intensity of the LED, whether it be through a brighter light or through a flashing light. Figure 1 also shows the output **usr_fdbck_otsd_usrout** which is a list of conditions the components of the block must meet. Below figure 1 is table 1, which shows the properties of each interface displayed in figure 1. **mcrcntrllr_usr_fdbck_dcpwr** has a maximum voltage of 5V, a minimum of 2.7V and a nominal of 3V.

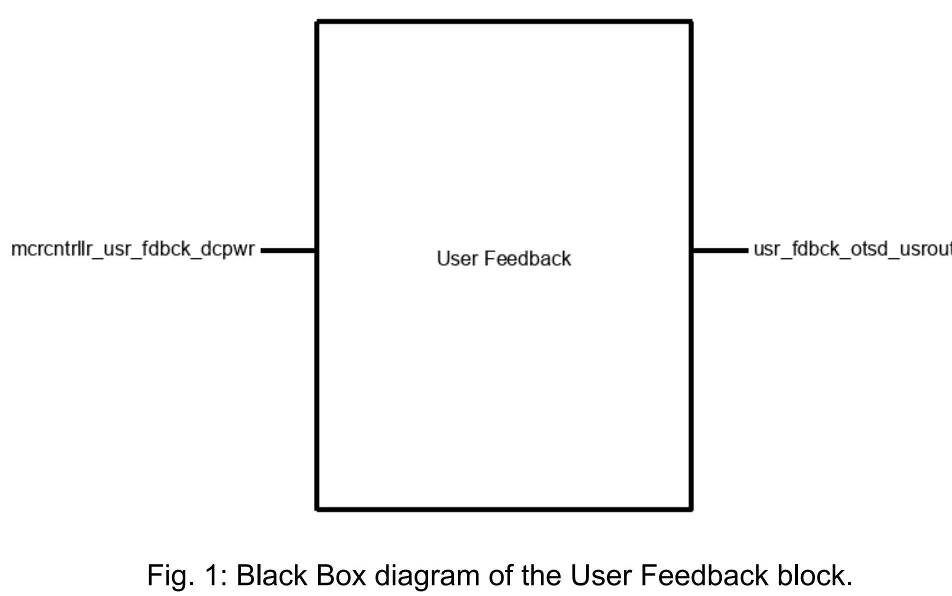


Fig. 1: Black Box diagram of the User Feedback block.

Table. 1: User Feedback Block Interfaces & Properties

Interface Name	Properties
mcrcntrllr_usr_fdbck_dcpwr	• Inominal: 30mA • Vnominal: 3.3V • Ipeak: 40mA • Vpeak: 5V • Vmin: 2.7V
usr_fdbck_otsd_usrout	• 9/10 Users can tell when the motor is on • 9/10 Users can tell when the LED is on • 9/10 Users can tell when the LED is off

4.5.3 General Validation

For this block, the LED and vibration motor were chosen because the intended operating conditions of the system are underwater in environments with flowing water, e.g. rivers. In such an environment, the user's sense of sound is likely to be impaired by the flowing water around them, while the user's other senses like smell or taste would be impaired by breathing equipment. This means the system would need to relay information to the user via sight or touch. Additionally, our project partner provided us with multiple underwater metal detectors to study, for purposes of learning from or modifying. All of the provided detectors utilized an LED and vibration module to relay information to the user, so our chosen method for this block has evidence of feasibility.

Both components were chosen so that they had current and voltage requirements within the 50mA and 5V range that our chosen microcontroller could provide from its I/O pins.[1] The Vishay LED was chosen because it has a luminous intensity range of 5600 mcd to 11200 mcd.[3] At a 180 degree angle—since the LED is embedded in the head of the coil enclosure—this equates to a lumen range of 35 to 70, which is an average of 52 lumens. The intensity of 52 lumens is not high enough to be considered bright, but the operating environment of the system is underwater, where light levels are low so 52 lumens will be visible in the environment. Additionally, the purpose of the LED is to let the user know that the system has detected gold, not to illuminate the area and increase visibility for the user. The VCLP0820B004L was chosen because it has a similar rpm to another pcb mounted vibratory motor that we found on one of the non-discriminating underwater metal detectors that was provided to us by our project partner. This vibratory motor (the VZ7AL2B1692612) functioned with a rate of 12000 rpm[4] which is equivalent to 200 Hertz whereas the VCLP0820B004L vibrates with a rate of 9000 rpm which is equivalent to 150 Hertz.[3] The 12000 rpm motor was physically held while running, and we observed that the vibration of the enclosure was quite strong and noticeable already. This led us to determine that the 25% decrease in Hertz from using the VCLP0820B004L was acceptable. We chose to use the VCLP0820B004L instead of the VZ7AL2B1692612 because the latter part required more voltage than what could be provided by the microcontroller. Table 2 in the section below goes into more detail about each interface property, why it was chosen and why it meets the block's requirements.

The properties of each interface will be validated through testing each component by sending them differing levels of current and voltage. The input interfaces will be tested by providing each component with the maximum, minimum, and nominal values of voltage and current and observing them for 1 minute to ensure that they remain functional during the entire time to prove that they can function at each current and voltage level. One thing to note is that the maximum voltage and current levels are based off of the microcontroller I/O pin outputs which is likely to be too high for the components, which is why a resistor in series with each component will be used during testing.

4.5.4 Interface Validation

Table 2: Block Interface Properties Explained

Interface Property	**Why is this interface this value?**	**Why do you know that your design details <u>for this block</u> above meet or exceed each property?**
usr_fdbck_otsd_usrout : Output		
Other: 9/10 Users can tell when the LED is off	Users must be able to consistently tell when gold is detected	N/A
Other: 9/10 Users can tell when the LED is on	Users must be able to consistently tell when gold is detected	N/A
Other: 9/10 Users can tell when the motor is on	Users must be able to consistently tell when gold is detected	N/A
mcrcntrllr_usr_fdbck_dcpwr : Input		
Inominal: 30mA	Both components are rated to function at this current value according to their datasheets. [2][3]	The microcontroller manufacturer does not give a current range for the I/O pins of the microcontroller in the technical specifications, so we are assuming that the listed value is the max value and also the only current value the microcontroller can output to the block. Thus the nominal current is

		determined by using resistors in series to reduce the current from the microcontroller.
Ipeak: 40mA	This value is given by the DC current value for the I/O pins on the microcontroller.[1]	The input current the block receives does not matter because if the current is too high, it can be lowered through the use of resistors in series with the components of the block.
Vmax: 5V	This voltage value was chosen because it is the operating voltage of the microcontroller.[1]	The input voltage the block receives does not matter because if the voltage is too high, it can be lowered through the use of resistors in series with the components of the block.
Vmin: 2.7V	Both components of the block are rated at a minimum of around 2.7V according to their datasheets. [2][3]	The microcontroller technical specifications do not provide a minimum I/O pin voltage output so the minimums of the components are used.
Vnominal: 3.3V	Both components of the block rated operate at 3.3V according to their datasheets. [2][3]	The microcontroller manufacturer does not give a voltage range for the I/O pins of the microcontroller in the technical specifications, so we are assuming that the listed value is the max value and also the only voltage value the microcontroller can output to the block. Thus the nominal voltage is determined by using resistors in series to reduce the current from the microcontroller.

4.5.5 Verification Plan

mcrcntrllr_usr_fdbck_dcpwr: Input

1. Connect the LED and vibration motor to a DC power source that fulfills the input interface properties.

2. Have the power source send current to the components at the nominal voltage and current rate and check if the components turn on.
3. Continue to send power to the User Feedback block for 1 minute to ensure that the components stay on.
4. Turn off the power and check if the components have turned off.
5. Change the power source to send the minimal voltage rate of 2.7V to the components and check if the components turn on.
6. Continue to send power at 2.7V for 1 minute to ensure that the components stay on.
7. Repeat step 4.

usr_fdbck_otsd_usrout : Output

1. Provide power to the components and show them to 10 different people
2. Have each person verify if the components are on
3. Remove power from the LED and show it to 10 different people
4. Have each person verify that the LED is off

4.5.6 References and File Links

[1] Arduino. "Arduino Nano." https://store.arduino.cc/products/arduino-nano (accessed Jan. 20, 2023)

[2] Vybronics. "Vybronics VCLP0820B004L, Low Current Coin Vibration Motor Datasheet" https://www.vybronics.com/wp-content/uploads/datasheet-files/Vybronics-VCLP0820B004L-datasheet.pdf (accessed Feb. 11, 2023)

[3] Resistore. "Ultrabright White LED, Ø 5 mm Untinted Non-Diffused Package" https://resi.store/products/336/white5mm.pdf (accessed Feb. 11, 2023)

[4] Vybronics. "Through-Hole Vibration Motor - VZ7AL2B1692612 | Vybronics" https://www.vybronics.com/erm-cylindrical-vibration-motors/through-hole/v-z7al2b1692612 (accessed Feb. 11, 2023)

4.5.7 Revision Table

Revision Description	Revision Date
First version. Added content to all sections.	1/20/23
Updated all sections according to peer and instructor feedback.	2/11/23

4.6 Enclosure

4.6.1 Description

The Enclosure block fulfills the Waterproof requirement. The project partner requirement states that “the metal detector must be waterproof.” The engineering requirement version states that “the system must remain functioning after being fully submerged in water.” The Enclosure block encompasses the enclosures that hold the coils and a main body that holds all the electrical components of the system. The coil enclosure is a custom-printed disc with raised edges and an oblong-shaped block in the center of the disk that the coils will be wrapped around. The coil enclosure is 3D-printed and made of Polylactic Acid (PLA). Because PLA is not fully waterproof and will absorb water and swell [1], the coils enclosure will also be coated in waterproofing spray. The enclosure itself is 8 inches in diameter because the coils themselves are designed to be no larger than 7 inches in diameter. The coil enclosure is an inch wider in diameter to give the coils extra room in case they are not within 7 inches of diameter. The coil enclosure is 1 inch thick. Once the coils are placed in the coil enclosure, the enclosure will be filled with resin to hold the coils in place and keep them dry. The main body enclosure is an enclosure used by a non-discriminating metal detector that was provided to us by our project partner. It is made of plastic and consists of two parts, a 4 cm diameter handle and a curved 2 cm diameter rod that connects the enclosure to the coils. Both parts are hollow, with the handle's hollow area being 3 cm in diameter and the rod being 1.5 cm. The enclosure block will be tested by first observing if 9/10 signals can pass through the coils enclosure in either direction. The block will then be tested by submerging the system in water for 10 minutes and observing if the system functions properly while underwater.

4.6.2 Design

The Enclosure block consists of a main body enclosure for all the electrical components and an enclosure for the coils. The enclosure block performs its purpose by keeping the coils and electrical components dry when the system is submerged in water. Figure 1 below shows the black box diagram of the enclosure block. **enclr_cls_other** is a bidirectional interface between the coils and the coil enclosure that represents the signals the coils will send out from the system, and the signals the environment will send into the system. Table 1 below goes into further details about interface properties. 9/10 signals will be able to pass through the enclosure from the coils to the environment and from the environment to the coils.

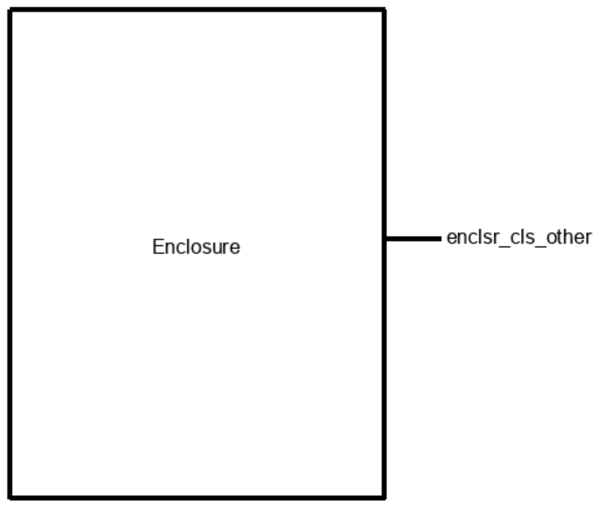


Figure 1: Black Box diagram of the Enclosure block.

Table 1: Enclosure Interface & Properties

Interface Name	Properties
enclr_cls_other	• Coils enclosure diameter is between 7-8" • 9/10 Signals the coil sends pass through the enclosure • 9/10 Signals from the environment can pass through the enclosure and to the coils

Figure 2 below shows the coils enclosure. It is 8 inches in diameter with a thickness of 1 inch at the edges. The base of the enclosure is 0.75 inches below the top of the edges. The middle oblong block of the enclosure has a height of 0.55 inches and a maximum width of 2 inches. The length of the block is 6 inches. The center of the block is at the center point of the enclosure. Figure 3 below shows the main body enclosure. It is made of two parts, a handle and a rod that connects the main enclosure to the coils enclosure. The handle is 4 cm in diameter and the rod is 2 cm in diameter. Both parts are hollow in the middle, with the handle having a 3 cm diameter middle and the rod having a 1.5 cm diameter middle.

Figure 2: The coils enclosure

Figure 3: The main body enclosure

4.6.3 General Validation

For this block, PLA was chosen as the material for the coils enclosure because it is cheap and water absorbent. Its waterproofness can be improved with waterproofing sprays which fulfills the Waterproof requirement and the price of a gram of PLA is priced around the single-digit cent range [2] which keeps the price low enough to fulfill the Cheap requirement. The use of resin to fill in the coils enclosure has precedent because the metal detectors provided to us by our project partner also used a similar enclosure design with the coils being covered in resin or epoxy to waterproof the enclosure. The main body enclosure was chosen because it comes from a metal detector design that is already proven to function underwater in the environment the system is intended to be used in.

4.6.4 Interface Validation

Interface Property	**Why is this interface this value?**	**Why do you know that your design details <u>for this block</u> above meet or exceed each property?**
enclsr_cls_other : Output		
Other: Coils enclosure diameter is between 7-8"	The coils will be no larger than 7” in diameter so the coil enclosure must be large enough for the coils to fit inside them.	N/A
Other: 9/10 Signals the coil sends pass through the enclosure	Signals from the coil must be able to reach the environment outside the coil consistently.	N/A
Other: 9/10 Signals the can pass through the enclosure and to the coils	Signals from the environment must be able to reach the coils consistently.	N/A

4.6.5 Verification Plan

enclr_cls_other: Bidirectional

1. Place coils inside coil enclosure
2. Power the coils and send 10 signals out of the coils
3. Observe if the signals the coils send pass through the enclosure
4. Send 10 signals from the environment to the coils
5. Observe if the signals sent to the coils pass through the enclosure

4.6.6 References and File Links

[1] UltiMaker. “How to 3D print waterproof parts” https://ultimaker.com/learn/3d-print-waterproof-parts (accessed March 11, 2023)

[2] Jacobs Hall Material Store. “Ultimaker Filament: PLA (priced per gram)” https://store.jacobshall.org/products/ultimaker-filament-white-pla-priced-per-gram (accessed March 11, 2023)

4.6.7 Revision Table

Revision Description	Revision Date
First version. Added content to Description and Interface Validation sections	3/10/23
Completed all sections	3/11/23

4.7 Coils

4.7.1 Description

The coils are what are responsible for detecting the metal. Current will pass through the detector coil and emit a magnetic field that will induce a current through the receiver coil. When this happens the coil will emit a sine wave signal. There are many ways to orient the coils, but for this project we are going with a double D pattern.

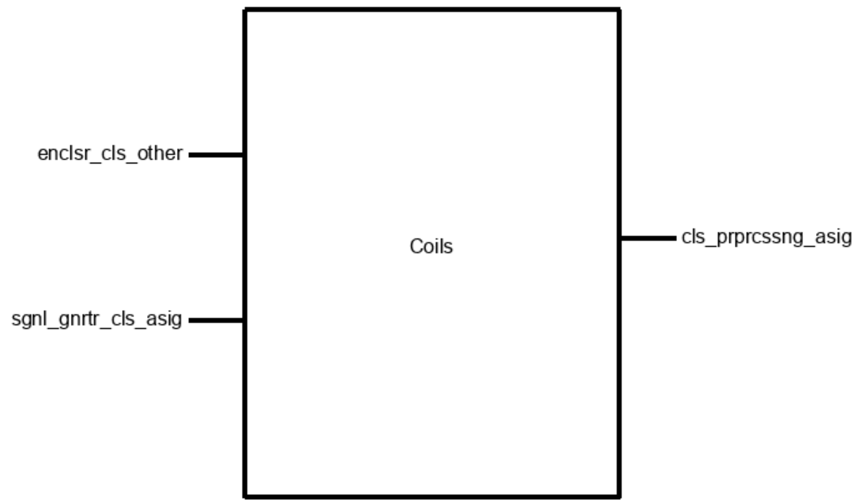
Ideally this double D pattern will be shaped like two semi-circles that overlap in the middle. The two coils in this pattern will be named the transmitter coil (Tx) and the receiver coil (Rx). The size of the overlap depends on how much magnetic flux can pass from the transmitter coil to the receiver coil.

The purpose of the coils is to emit a magnetic field and perceive changes in the magnetic field that are induced by different metals with different permeabilities. As per the requirements for the system, the coils must be able to emit a magnetic field of at least 10 cm in order to detect metals in that distance.

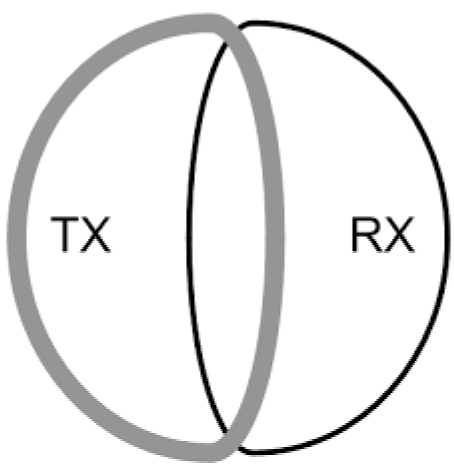
The coils will be made from enameled copper magnet wire, and take up no more space than 7” in diameter. When the time comes for the metal detector to be fully put together, the wires will be put in the enclosure and then housed in epoxy resin.

4.7.2 Design

The purpose of the coils is to take in a signal from the signal generator and then send a signal to the preprocessing block. The idea is that the signal sent to the preprocessing block will contain information about what is placed in front of the coils. The preprocessing block will then use this information combined with the signal from the signal generator to create a digital signal to send to the microcontroller. As you can see in the block diagram below, this means that the coils need to be connected to the signal generator and the preprocessing, as well as being held in the enclosure as a whole so that the system can be waterproof.



The design will consist of two lengths of magnet wire that are both placed in D shapes. The coils will be positioned so that the net magnetic flux entering the RX coil is Net 0 when no metal is disrupting the magnetic field around it. Because the coils overlap somewhat the magnetic flux through the Rx coil will be going in one direction in the area where the coils overlap, and in the opposite direction where there is no Tx coil overlapping. This prevents any current or voltage on the Rx coil if there is no change in the magnetic fields around the coils. However, if there is metal present, the change in permeability will cause more electric flux to go through the Rx coil in one direction, causing a current to travel through the coil.. The Signal Generator will be connected to the TX coil, and the RX coil will connect to the preprocessing block. The coils will be mounted directly to the enclosure in the final design.



(example of what a double D coil design looks like)

The coils will not have any kind of metallic core, unlike most inductors. The coils will be held in place by the resin that is used to encase the head of the metal detector. Although the relative permittivity of epoxy resin is approximately 3, the relative permeability is close to 1, meaning that there should be no significant change to the magnetic field once the coils are encased. The reason that the coils are going to be encased in epoxy resin is to keep the system waterproof. Although the wires themselves are insulated enamel wires, the connection to the rest of the system would allow water into the main body of the metal detector if the coils are not entirely encased.

Both of the coils will be designed in identical ways. Each coil will have one half shaped like a semi-circle with the diameter being 6”, and the other half of the coil will be shaped by hand so that the magnetic fields will cancel out any current for the second coil. Allowing this part of the design to be done by hand will allow for much more precise fine tuning. This should lead to a circumference slightly larger than $\pi * 6" + 6" = 24.8"$ per turn, or approximately 50ft for 24 turns.

4.7.3 General Validation

The system needs a way to interact with the outside world in a way that can sense the difference between different types of metal. As is the case with most metal detectors, we need a coil block that emits a magnetic field in order to detect metal.

There are several different types of ways to detect metal by creating a magnetic field using coils, however, because this method also needs to tell the difference between different types of metals, i.e. iron and gold, we are going with the VLF method. VLF metal detectors can have different configurations of coils, the most common are named concentric coils and double D (DD) coils. Most research papers that can be found on this subject go more into detail on the design of a double D coil.

Out of all of the different design configurations for the coils to be in, the design that consistently came up with the most information with research was the double D configuration. Building the coils in a double D configuration allows us to be able to have plenty of data for building our system. Although a concentric coil design could be used to detect metals, the signals generated would be different and would require a different way of processing the signal. Because of this, once the design of the coils has been chosen it is more or less locked in, otherwise the rest of the blocks would need to undergo significant changes as well.

4.7.4 Interface Validation

Interface Property	**Why is this interface this value?**	**Why do you know that your design details <u>for this block</u> above meet or exceed each property?**
enclsr_cls_other : Input		

Other: Houses the coils and prevents their connections with the rest of the system from getting wet	The coils will have electrical current running through them, so it is important that the components remain protected from water.	The coils will be covered in an insulator (and possibly resin as well) which will give the detector coils a resistance to water.

sgnl_gnrtr_cls_asig : Input

Impedance: |Z| > 100 Ohms @ 10kHz	The impedance to the needs to be above a certain point in order to keep a voltage without drawing an unreasonable amount of current.	Since the coils will need to be massive inductors, it will be easy to reach a high enough impedance.
Max Frequency: 10 MHz	Assuming that the speed of electricity traveling through the signal is around $2^{8} m/s$, 10MHz allows us to have a length of $2 * 10^{8}/10^{6} = 200m$ without worrying about transmission line side effects.	The coils will be well below 200 meters, and the frequency will be provided by the signal generator from another block.
Vrange: 12V amplitude	According to the papers that we have for research, 12 volts is an appropriate voltage to send through the coils in order to have enough power to detect metal with the generated magnetic fields.	The wire that the voltage is running through should be able to handle, and the signal generator is able to step up the power received from the power supply.

cls_prprcssng_asig : Output

Impedance: |Z| < 1 KOhm @ 10kHz	The output should have a low enough resistance so that the voltage doesn't drop when the signal is being processed by another block.	The design number of loops in the coil will not be enough to create this high of an impedance.
Max Frequency: 10 MHz	Because the coils are not powered components they will not be able to produce any signal that is not the same frequency as the input signal, therefore the	The lack of powered components means that this block will only output a frequency similar to what is given by the input.

	max output frequency is the same as the input max frequency.	
Other: Vnom < 0.1V	The output voltage will stay low while no metals are passed through the magnetic field, meaning that the normal voltage is very low.	From the research that I have done it seems like all that is needed from the design is to place the coils in a certain sweet spot overlapping each other.
Vrange: 12V amplitude	The output voltage should be similar to the input voltage, but smaller in order to account for small losses in voltage due to the environment and resistances in the wires.	The coils will be lossless enough that the Vrange of the wave when detecting gold will stay high enough.

4.7.5 Verification Plan

Step1: I will hook up the signal generator in the lab to the Tx coil. Starting at 1KHz and 6V. The probes will be hooked up to the two ends of the Tx coil (orientation does not matter). The frequency and voltage will be incrementally increased until the frequency is 10kHz and the voltage is 12V peak to peak. Frequency will be raised first in order to create a higher impedance from the coils. The only point of failure at this point will be if the wires are not capable of handling the power and overheat.

Step2: I will hook up the oscilloscope to the output of the Rx coil, and another probe at the Tx coil/Signal generator. At this point the coils should not be near any metal. The readout from the Rx coil should be approximately zero. The only voltage read from the oscilloscope from the Rx coil will either be noise or small amounts of the Rx coils signal, due to imperfect coil placement. The amount of voltage on the Rx coil allowed at this point of the testing process is less than 0.1V.

Step3: I will pass some iron under the coils, preferably in the form of a screw so that it is similar in shape and in size to what some of the garbage a user may find in rivers. The voltage read on the oscilloscope should jump up to a readable voltage. The voltage from the Rx coil should read the same frequency as the Tx coil, but should be phase shifted. The phase shift of the coil will be written down so that it can be used in the code later on.

Step4: I will pass a gold nugget under the detection coils and check the oscilloscope to see if the output is within the voltage range. Similarly to the iron screw passed in the last test, we should see voltage on the oscilloscope with a matching frequency to the input wave. However, because we are passing a different type of metal through the magnetic field, the phase shift seen on the oscilloscope should be different than the previously written down phase shift. This phase shift will also be written down so that we can determine a cutoff point in the code for when we detect different metals.

Step5: To test the output impedance of the coils, I will keep one of the test pieces of metal (either iron or gold, whichever generates the largest voltage), and put a 1kOhm resistor across the output and probe across the resistor. If the output impedance is exactly 1000kOhms then the will drop to half of what it was previously. If the output impedance exceeds 1000kOhms, the voltage drop will be more than half. As long as the voltage drop across the resistor is less than half, then the coil passes the validation.

4.7.6 References and File Links

[1] Carl Morland, Coil Basics
http://www.treasuresweeper.com/wp-content/uploads/2014/07/coil-basics.pdf

4.7.7 Revision Table

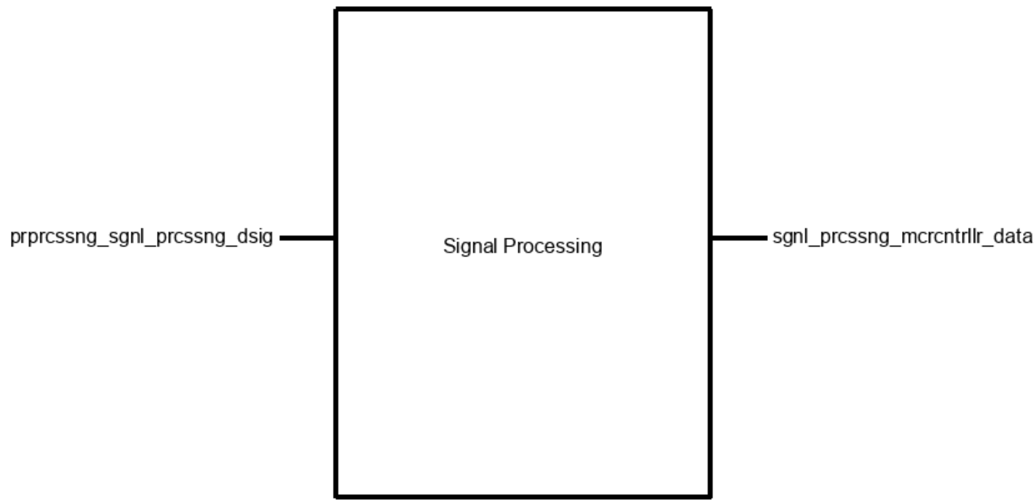
Revision Date	Summary	Revisor
1/20/23	Finished making a rough draft.	Jacob McCray
2/11/23	Added more to the document, mostly to the verification plan.	Jacob McCray

4.8 Signal Processing

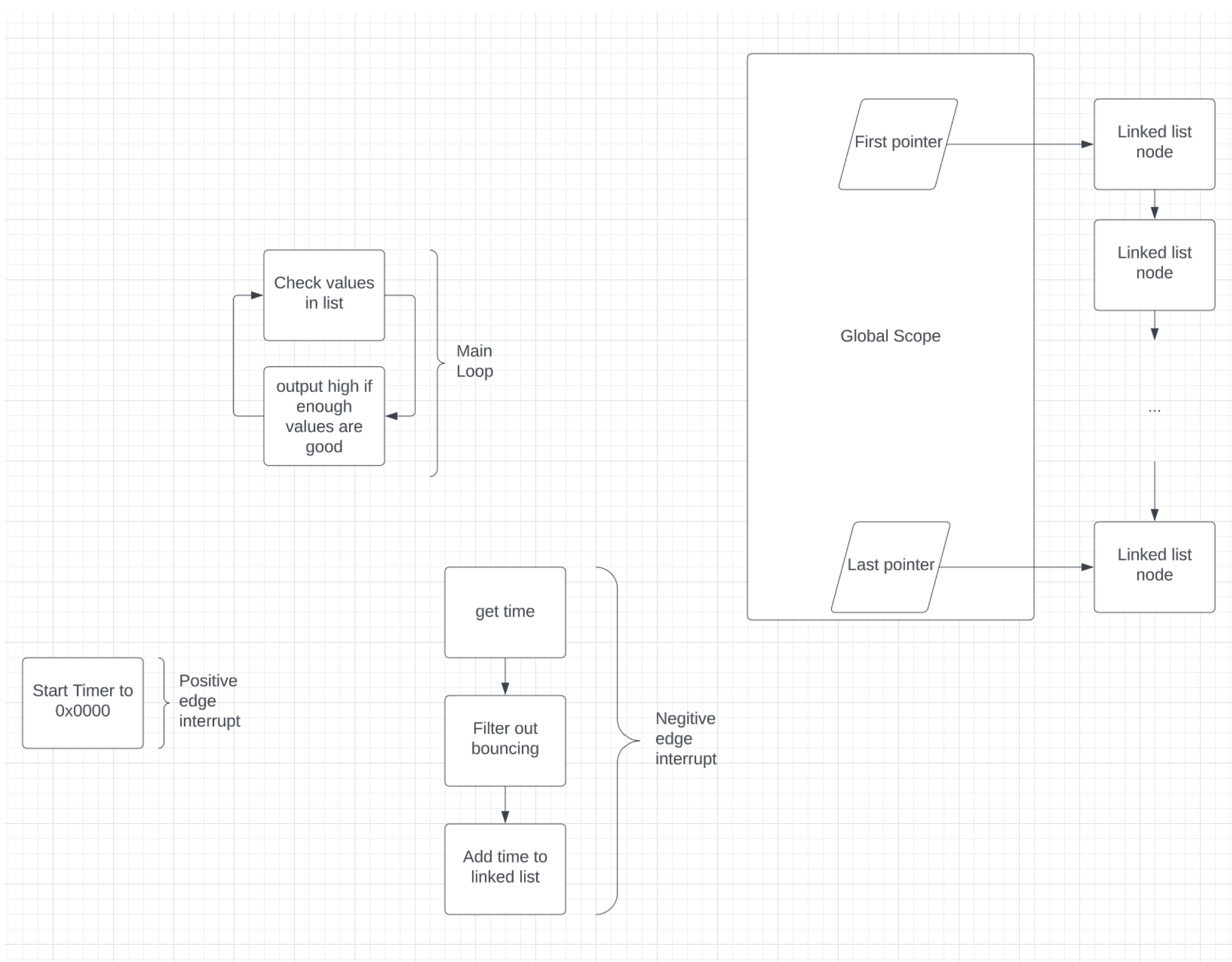
4.8.1 Description

This is a code block that will determine if the signal we receive means that we have found gold. The code will output a high signal when it is given a pulse signal with a length within the acceptable range. The code will need to be able to distinguish small differences in the phase shift at high frequencies. In order to take full advantage of our microcontroller we will need to use interrupts in order to determine the phase shift of the incoming signal so that the code will be able to process the information at least as fast as the information is coming in.

4.8.2 Design



The code will be running on an arduino nano with a clock speed of 16MHz. The diagram below shows how we plan to efficiently determine the pulse length.



The design revolves around recording the the values of the time it takes from a positive edge to a negative edge and storing them in a linked list. This is accomplished through the two interrupts on the arduino. The posedge interrupt will set the timer on the microcontroller to be zero and start counting. Once the negedge comes into the board the timer will be read out to the input capture register (ICR1). Afterwards a new linked list node will be made with the contents of the input capture register.

Since the recording of data is done entirely with interrupts, the main loop is free to calculate if the time delay of the pulse is within the range of what would be expected for gold. While the main loop may take longer than the rest of the code, it doesn't matter because all of the data is still being recorded and will eventually be processed.

4.8.3 General Validation

The incoming signal is 10kHz. For the incoming signal we expect two changes every 100μS, one positive edge and one negative edge. The clock speed(16MHz) is only 800 times faster than the average speed of incoming signals. Because of this we cannot afford to waste time resizing arrays. This is why a linked list is the best choice for this application. Every interrupt will add one node to the end and remove a node from the beginning.

4.8.4 Interface Validation

Interface Property	**Why is this interface this value?**	**Why do you know that your design details <u>for this block</u> above meet or exceed each property?**

prprcssng_sgnl_prcssng_dsig : Input

Logic-Level: Active High	The microcontroller will need to produce power to the other parts, and therefore will need a voltage when it is on.	A logical output is trivial to produce using code
Vmax: 5.5V	The arduino has set maximum and minimum voltages that we cannot change	The arduino cannot produce more than this amount of voltage
Vmin: 0V	The arduino has set maximum and minimum voltages that we cannot change	The arduino cannot produce less than this amount of voltage

sgnl_prcssng_mcrcntrllr_data : Output

Datarate: clock speed > 360*10kHz	The clock speed must be several times faster than the signal's frequency.	The clock speed of the arduino is 16MHz
Messages: Logical high when gold is detected	The microcontroller will need to produce power to the other parts, and therefore will need a voltage when it is on.	A logical output is trivial to produce using code
Other: Code is able to ignore rapid fluctuation (bouncing) in the incoming signal	The block for preprocessing is unfortunately unable to ignore noise, and will therefore produce bouncing.	The code includes a block to ignore any rapid fluctuations.

4.8.5 Verification Plan

Step1: hook up the arduino to power and hook up its inputs to a signal generator and have its output be hooked up to a digital multimeter.

Step2: Turn on the signal generator, making sure that the generator is in pulse mode with the duty cycle set to 0%. The multimeter should be reading out 0 volts right now.

Step3: Slowly increase the duty cycle of the pulse generator. Once the pulse gets to be a certain length the output of the digital multimeter should read 5V

4.8.6 References and File Links

https://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-7810-Automotive-Microcontrollers-ATmega328P_Datasheet.pdf

4.8.7 Revision Table

Revision Date	Summary	Revisor
3/12/23	Finished making a rough draft.	Jacob McCray

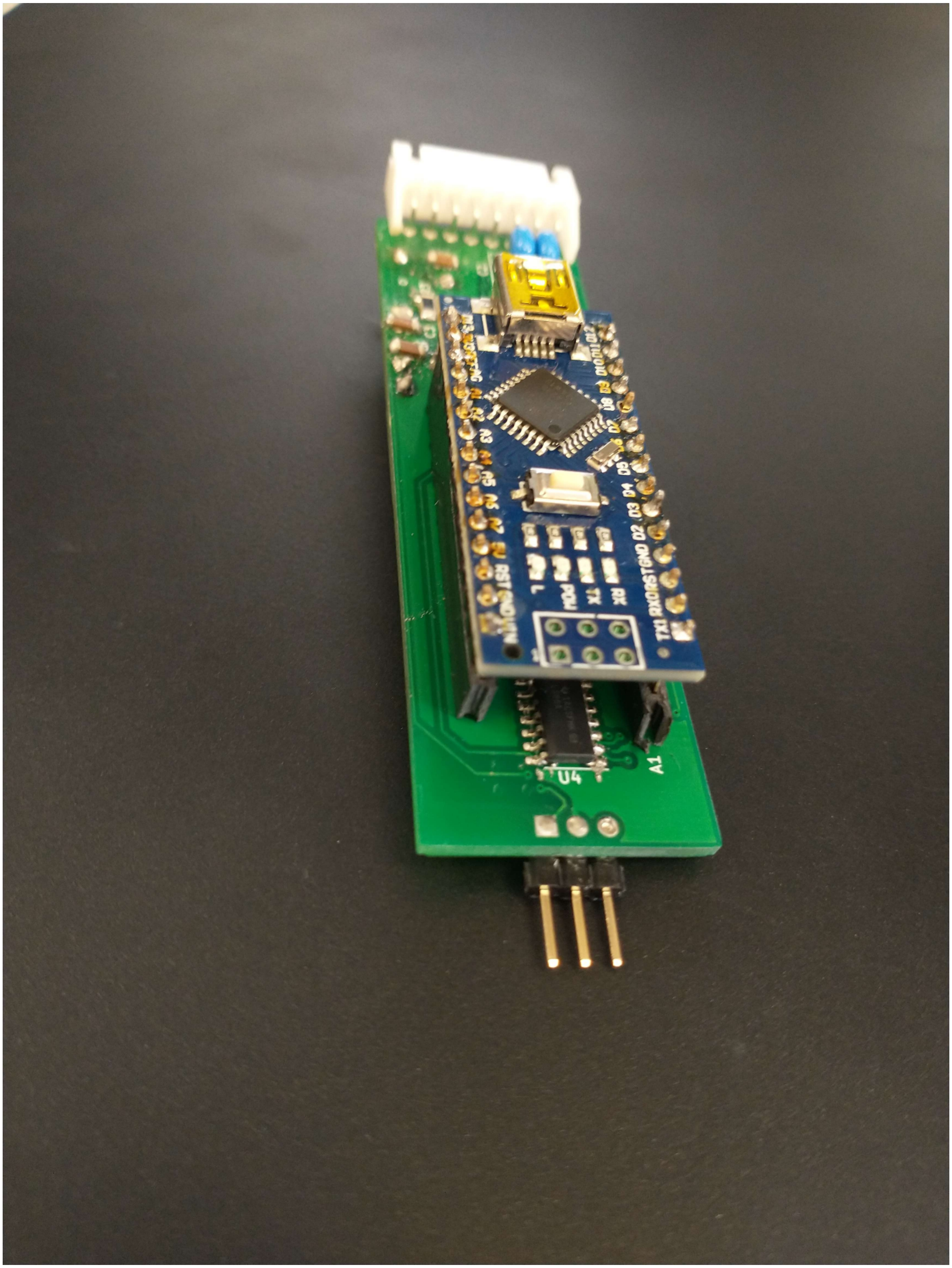
5 Overview

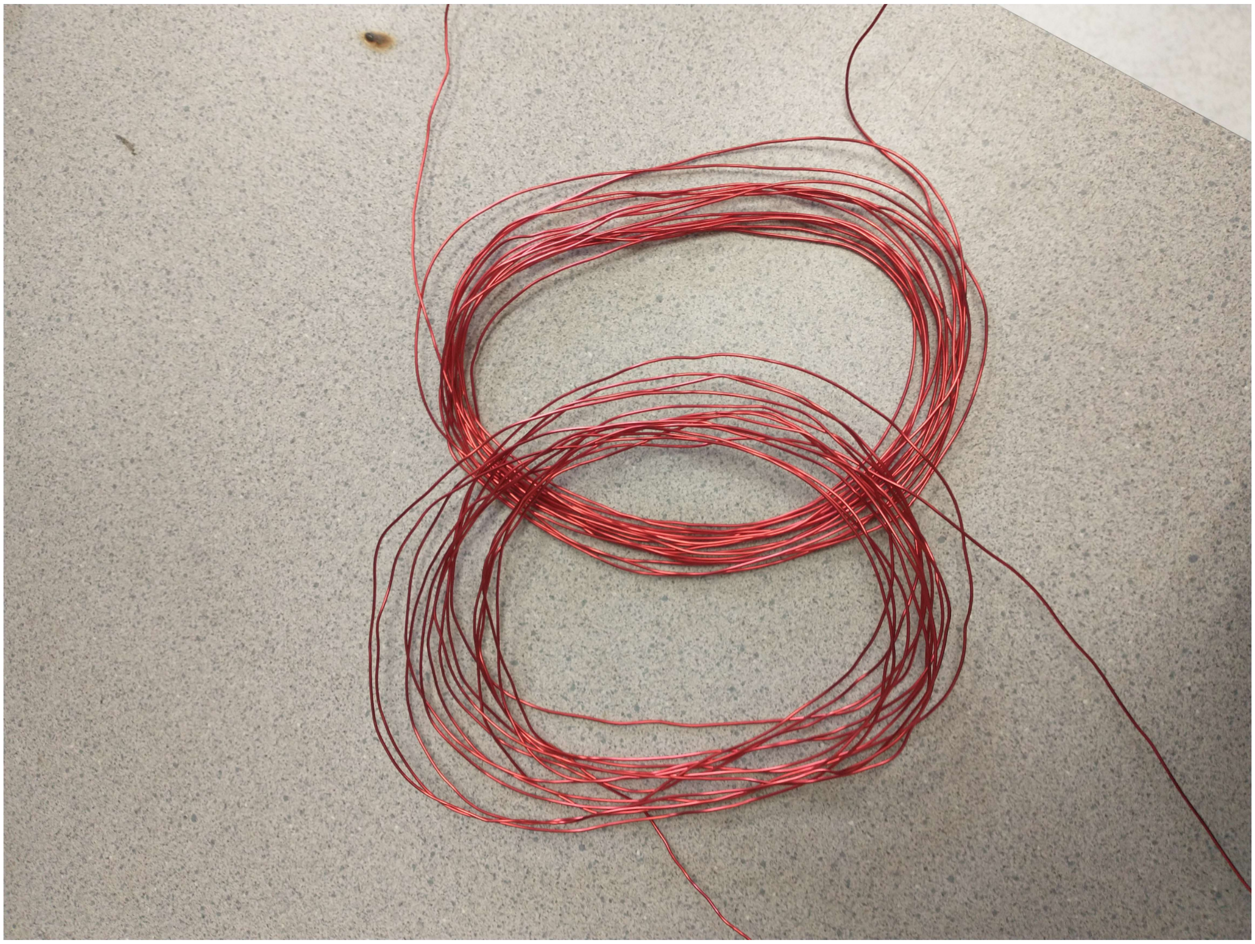
5.1 Universal Constraints

5.1.1 The system may not include a breadboard

Our project currently does meet specifications as the components for the signal generator and preprocessing block , this will later change in the final design as it will be imported onto a PCB. (place pic of full design here)

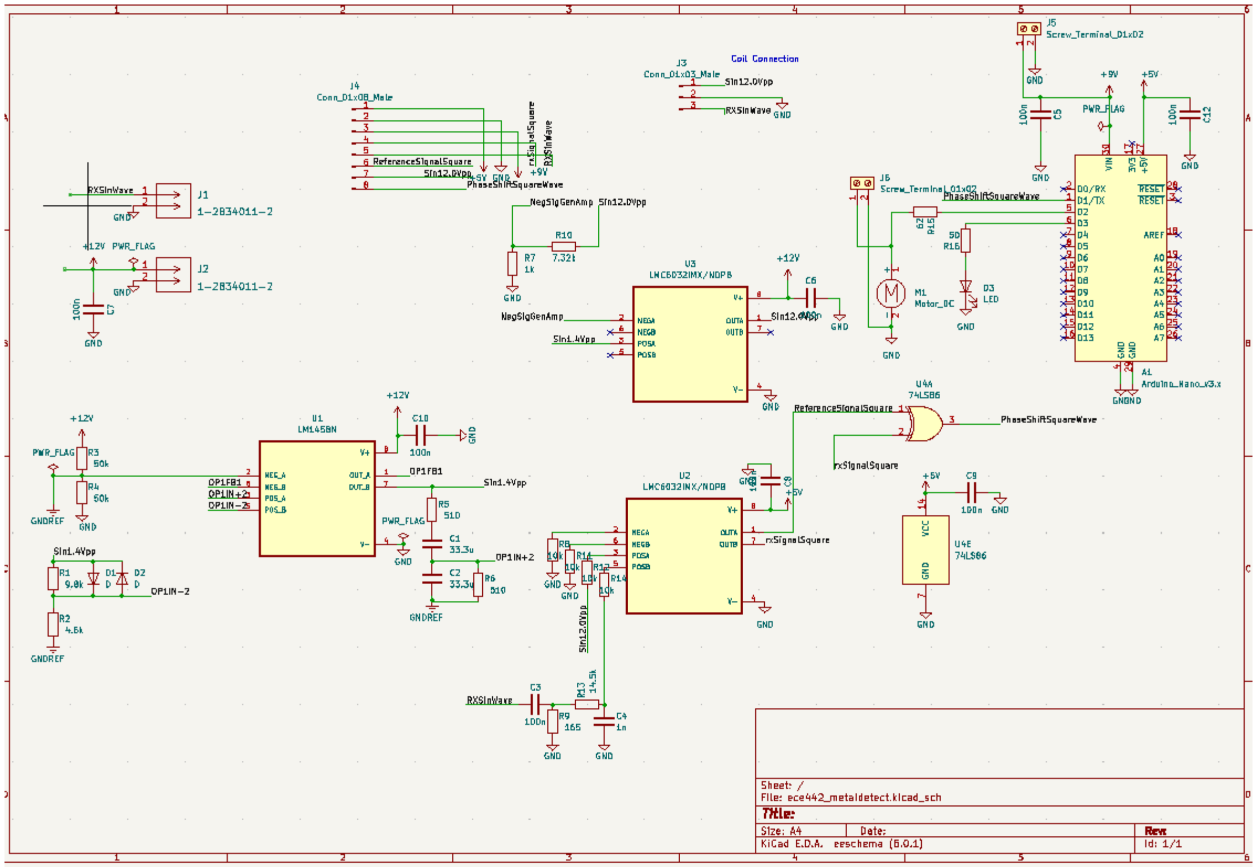

Pinpointer

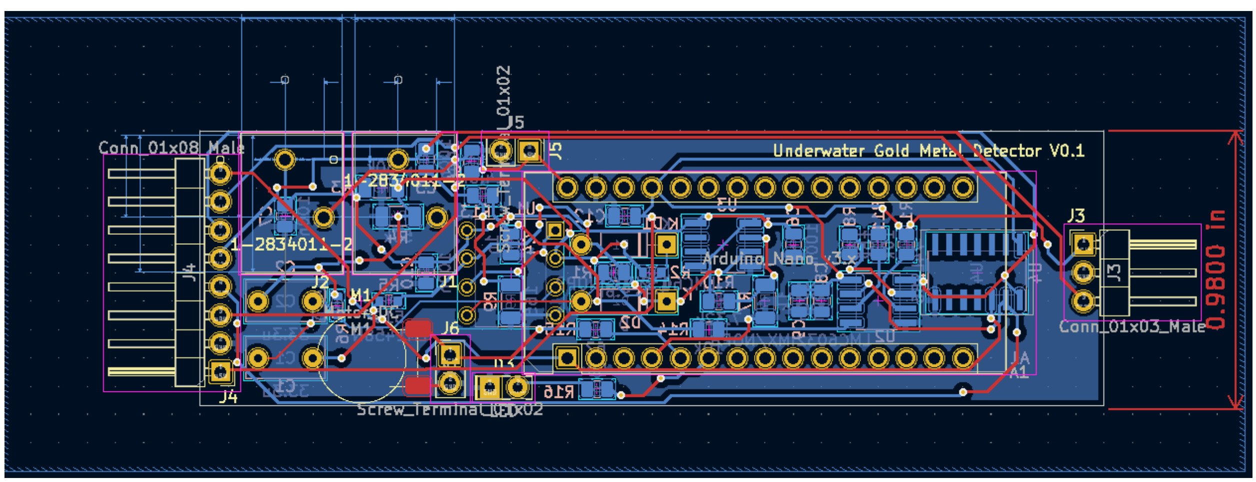

U4
A1
TX
RX



5.1.2 The final system must contain a student designed PCB

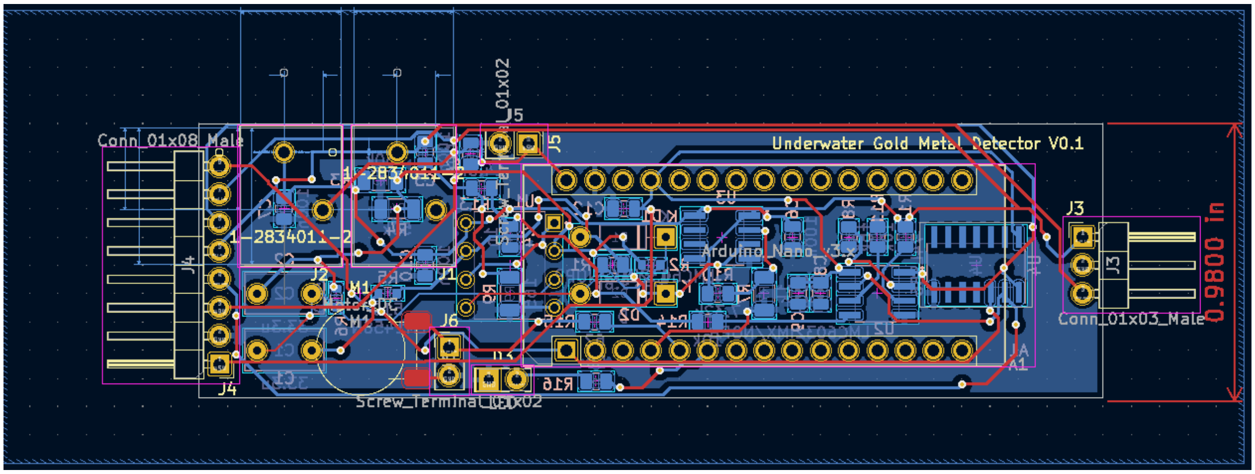
The current final system uses a student designed lithium battery to 5V converter. For the purposes for the system requirements currently, it passes this requirement. For the future end product, the whole design will be on pcb.
(Place pic of design and schematic of PCB)





5.1.3 All connections to PCBs must use connectors.

All the connections on the pcb currently use connectors to and from the PCB. The DC DC converter uses screw terminals for any connectors used within the system that are free wires. (Place pic of PCB and # of connectors used)



5.1.4 All power supplies in the system must be at least 65% efficient.

The power supplies and converters used are a lithium 9 volt battery and a 9 to 12 volt DC converter. Typical 9 volt batteries used are at least 80% efficient and the specific DC converter we are using, the XL6019, has an efficiency of 93%.
(Place pic of datasheet used for efficiency calculations)

400KHz 60V 4A Switching Current Boost / Buck-Boost / Inverting DC/ DC Converter

XL6009 Electrical Characteristics

$T_a = 25$℃;unless otherwise specified.

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
System parameters test circuit figure4						
VFB	Feedback Voltage	Vin = 12V to 16V, Vout=18V Iload=0.1A to 2A	1.213	1.25	1.287	V
Efficiency	ŋ	Vin=12V ,Vout=18.5V Iout=2A	-	92	-	%

5.1.5 The system may be no more than 50% built from purchased 'modules.'

The method our group is evaluating if our system or specific module is built or bought will be based on each individual block and will determine how much of the design is built or purchased. The 8 modules we are evaluating include the enclosure, user feedback, coils, signal processing, microcontroller, power, preprocessing, and signal generator. The blocks that were built include the enclosure, user feedback, coils, preprocessing, and signal generator blocks. These were blocks built from scratch to support our very low frequency circuit design. The other three blocks, the microcontroller used is a bought module to interface with the rest of the pcb, the power supply used is a 9 volt battery, which is bought, and the signal processing block is a coding block which can't be included as to whether the block is built or purchased.
(place table of listed requirements here, listing whether built or bought)

Block	Built or Bought?
Preprocessing	Built
Signal Generator	Built
Coils	Built
Enclosure	Built
Power Supply	Bought
Microcontroller	Bought
Signal Processing	Built
User Feedback	Built
Total % built	75%

5.2 Requirements

5.2.1 Cheap

5.2.1.1 Project Partner Requirement

The metal detector should not be as expensive as a high end metal detector

5.2.1.2 Engineering Requirement

The system will have a total cost of less than $150.

5.2.1.3 Verification Process

We will compile the list of components used and catalog the price of the components used as well as construction costs, if the total cost is below $150, it passes this requirement.

5.2.1.4 Testing Evidence

With the current compilation of components used and cataloged in one document, it shows the final total of the entire project.

Block	Part	Cost($)
Microcontroller	Arduino Nano	6
Power Supply	9 volt battery	10
Signal Generator and Preprocessing		$11.15
Enclosure	3d Print	$6.48
User Feedback	Motor and LED	$4.1
PCB		3.5
Coils		22.12
Total		63.35

5.2.2 Detect Gold

5.2.2.1 Project Partner Requirement

Modify the components to increase power/sensitivity and decrease its range of targets

5.2.2.2 Engineering Requirement

The system will detect 0.5g of gold within sensing range 9 out of 10 times and not detect 0.5g of iron 9 out of 10 times.

5.2.2.3 Verification Process

We will run our design 10 times with gold scattered across the area, we will run our metal detector head over these areas and if it detects gold 9 out of those 10 times, the project works.
1. Plug in battery
2. Close Cap on enclosure to battery slot
3. Bring head within 5cm of gold within test environment

5.2.2.4 Testing Evidence

We have collected and verified that the metals used are gold and that the conditions that the metal detector is used will be similar to how the customer would want to use said product/design.
(Put Video Here)

5.2.3 Detection Range

5.2.3.1 Project Partner Requirement

Metal Detector is capable of identifying items.

5.2.3.2 Engineering Requirement

The system will detect 0.5g of gold within 5 cm, 9 out 10 times.

5.2.3.3 Verification Process

We will use a 0.5 gram of gold and bury it under 5 cm of dirt and run the test 10 times under controlled conditions, if the metal detector goes off and notifies the user correctly 9 times out of 10, the system works.

1. Plug in battery
2. Close Cap on enclosure to battery slot
3. Bring head within 5cm of gold within test environment
4. measure using either using ruler or other method of measuring distance to confirm 5cm distance.

5.2.3.4 Testing Evidence

The gold will be buried under the notified depth and measured for accuracy, the metal detector should give off a signal if the detector finds the gold under these conditions.
(Put Video Here)

5.2.4 Lightweight

5.2.4.1 Project Partner Requirement

It should be light enough to carry around for the day.

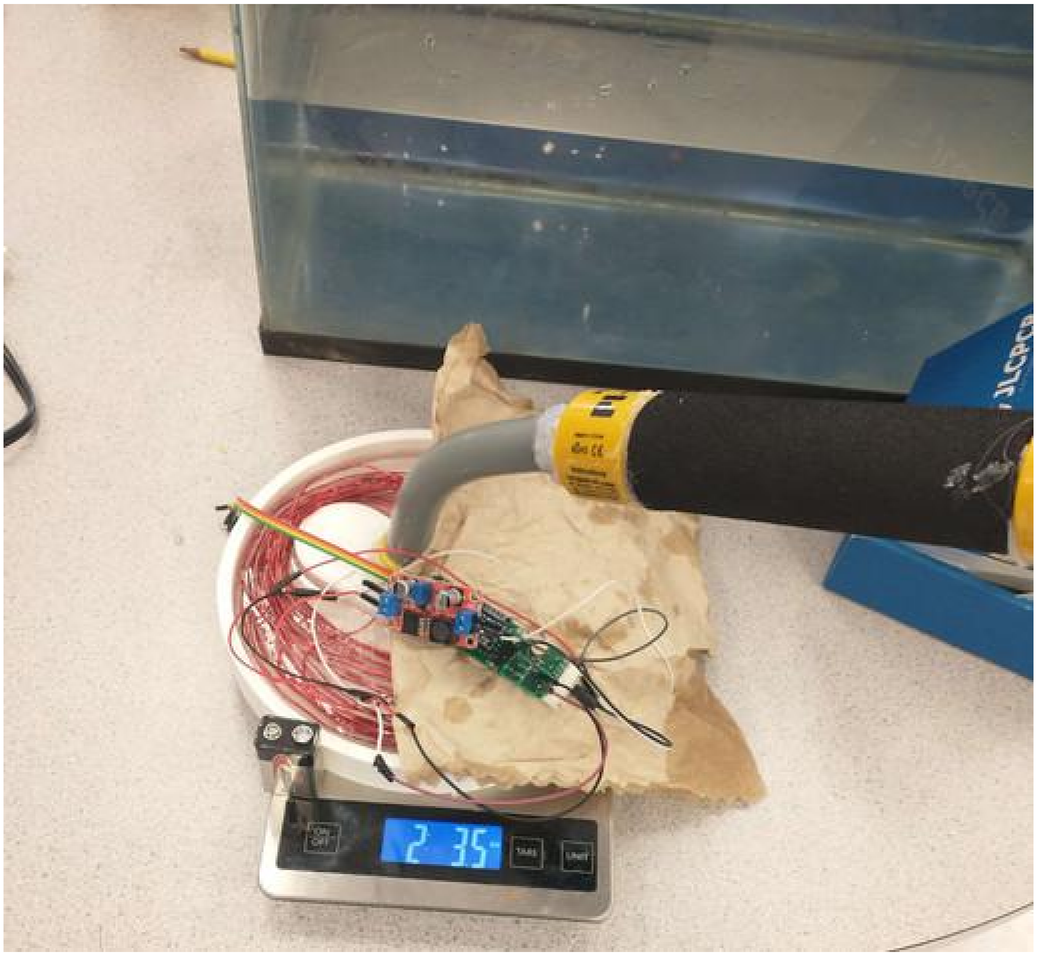
5.2.4.2 Engineering Requirement

The system will weigh no more than 10 lbs.

5.2.4.3 Verification Process

We will put the metal detector on a scale and ensure that the output weight of the scale is less than 10 lbs.

5.2.4.4 Testing Evidence



5.2.5 Power

5.2.5.1 Project Partner Requirement

The product should be able to work for the whole entire day

5.2.5.2 Engineering Requirement

The system will operate for at least 4 hours from a single battery replacement.

5.2.5.3 Verification Process

The mAH draw of each electrical component will be calculated and summed to ensure that the system will be able to operate for at least 4 hours before the battery needs replacing.
Steps:

1. Unplug positive terminal of battery
2. Put one multimeter probe on positive terminal of battery
3. Connect other multimeter probe to +9v wire of system
4. Observe Current draw on multimeter.
5. Divide battery (750mAh) mAh by mA draw observed, if the number is >=4, the test works.

5.2.5.4 Testing Evidence

https://data.energizer.com/pdfs/l522.pdf

750mAh / 66.1mA = 11.34 hrs. Battery life > 4 hrs from requirement.

Project power(2).MOV

5.2.6 Usability

5.2.6.1 Project Partner Requirement

Metal detector is easy to use

5.2.6.2 Engineering Requirement

The system will have 9 out of 10 users report they detect gold within 5 minutes of use.

5.2.6.3 Verification Process

We will bring our test environment for other people to try out, if the user is able to understand how to use the product and find gold within the allotted time, it passes those system requirements.

5.2.6.4 Testing Evidence

We will upload a video in the future as proof of our trials.

5.2.7 User Feedback

5.2.7.1 Project Partner Requirement

The metal detector needs to be easy to understand

5.2.7.2 Engineering Requirement

9 out of 10 people can understand the basics on how the metal detector works using the manual.

5.2.7.3 Verification Process

10 people are given a copy of the manual. After reading the manual they are asked to fill out a form answering the questions of whether they know how to turn on the metal detector and operate the metal detector to detect gold.

5.2.7.4 Testing Evidence

Name/Username:	After reading the manual, I know how to turn on the gold detector.	After reading the manual, I know how to operate the gold detector and detect gold.
Minion	Yes	Yes
Hubert Johnson Smith	Yes	Yes
jgao222	Yes	No
Benjamin	Yes	Yes
MainMann	Yes	Yes

doomman205	Yes	Yes
Kritty	Yes	Yes
Gabby N	Yes	Yes
Gregory	Yes	Yes
ArtsySheep	Yes	Yes

5.2.8 Waterproof

5.2.8.1 Project Partner Requirement

The metal detector must be waterproof.

5.2.8.2 Engineering Requirement

The system must remain functioning after being fully submerged in water to a depth of at least 6 inches.

5.2.8.3 Verification Process

The system will be submerged in a tank of water for 10 minutes and used while submerged.
1. Fully submerge the device in water for 30 seconds
2. Take out metal detector from environment, let it dry.
3. Unplug and replug the battery.
4. If the device vibrates after initial power on, the system works.

5.2.8.4 Testing Evidence

https://drive.google.com/file/d/1hqTVN_ykKE3qTnkJHamYdPCAJb20nQ_5/view?usp=sharing
https://drive.google.com/file/d/1x2b1uzRqLmei5SRcBZh85q3zPZNLRayJ/view?usp=sharing

6 Project Closing

6.1 Future Recommendations

6.1.1 Technical Recommendations

analog circuit design- The choice between method of discrimination of metals is extremely important depending on the desired outcome and requirements of your project. It is integral for the other design aspects of the metal detector, size, power requirements, coil designs, whether it can discriminate metals, etc. A solution would be pulse induction but this method would not be able to discriminate metals. An option if discrimination is needed would be VLF, or very low frequency design.[1]

coil design.- The coils are necessary for detection and discrimination between metals, as a result, it is integral that a large amount of research is done on deciding the type of coil to be used. A simple solution to the issue would be buying the coils based on the design or type of coil you are trying to create, in order to avoid the team spending time finding effective ways to design coils to your specifications, this will reduce build time of the detector and reduce the amount of issues when system integration comes around[2].

signal detection- Signal detection is the method in which the metal detector will be able to discriminate between metals like iron or gold, in order to find such precious metals, research is needed on what properties these metals have in order to tell them apart. One method that can be used includes zero crossing, which involves taking a signal and using a comparator that compares the signal with zero reference voltage the output wave will be a square wave that is high when input signal is above 0 and low when signal is below 0 output when it crosses the zero reference voltage this is useful for our project to transform the received and transmitted waves sine waves into the above or below zero square waves in order to detect the phase shift of the waves[3]. Another solution that could simplify the circuit design would be to use a phase detector IC, that can handle this for you.

Signal Processing analog v. software- Communicate with your group mates what blocks do you want to implement on software compared to hardware, analog circuit design can be hard to implement, so be mindful of possibly Digital signal processing techniques for the detector. Zero Crossing could be a solution to your problem in order to digitize the signal, as most microcontroller do not support reading in negative voltages into the ADC[4].

Sources

[1] O. Girish and A. Pranav,”Metal Discriminator”,Indian Institute of Technology Bombay, http://www.ee.iitb.ac.in/~stallur/wp-content/uploads/2017/02/Project_report.pdf

[2] M.S. Sharawi, and M.I. Sharawi, “Design and Implementation of a Low Cost VLF Metal Detector With Metal-Type Discrimination Capabilities”, Philadelphia University, https://www.researchgate.net/profile/Mohammad-Sharawi/publication/224363371_Design_and_Implementation_of_a_Low_Cost_VLF_Metal_Detector_with_Metal-Type_Discri

mination_Capabilities/links/54635d780cf2837efdb2b41b/Design-and-Implementation-of-a-Low-Cost-VLF-Metal-Detector-with-Metal-Type-Discrimination-Capabilities.pdf
Desc: Possible research on working discrimination metal detector

[3]How can phase shift be found using DSP?
https://en.wikipedia.org/wiki/Cross-correlation
Cross correlation measures the similarity between two signals and could be used to compute the shift

[4] R. Y, "What is zero crossing detector? definition, circuit diagram, working and applications of zero crossing detector," Electronics Coach, https://electronicscoach.com/zero-crossing-detector.html (accessed May 13, 2023).

6.1.2 Global impact recommendation

It is important to consider the environmental impact of such a device. Encouragement of diving for gold may disturb river habitats. Encouraging diving in rivers may also pose a danger to people that are inexperienced and/or don't understand the risks. In general it is recommended that people exercise caution when around streams [1]. For this we recommend that a warning is issued in the manual giving an overview of the risks involved for the use of this device in rivers and streams. Removal of certain artifacts from regions may be culturally significant and as such it is important to recommend the users to only search for gold in regions they have permission to be in. Therefore this may be another good candidate for a warning in the manual.

According to the USDA one major aspect of safety is to not tie anything to yourself that can produce drag [2]. Specifically it recommends that you unbuckle waist straps and avoid tying yourself to a safety rope. Because of this it would be best to stick to a small design to reduce drag, and to avoid adding any kind of wrist strap to the design.

[1] National Parks Service, River and Stream Safety, https://www.nps.gov/articles/river-and-stream-safety.htm#:~:text=Learn%20About%20Common%20River%20and%20Stream%20Hazards&text=that%20can%20cause%20you%20to,and%20after%20floods%20and%20heavy

[2] US Department of Agriculture, Water Safety,
https://www.fs.usda.gov/visit/know-before-you-go/water-safety

6.1.3 Teamwork Recommendations

Splitting up the analog circuit design and research evenly- One of the first priorities in tackling this project includes a well cemented idea and a developed understanding of what the analog circuit design entails based off the method of metal detection your team wants to handle, the values as well as noise involved in the design create many different questions the team has to answer. [1]

Defining the Project Partner requirements and your team's requirements- The requirements requested from the project partner, whether it be the same project partner or a different team, understanding what type of metal detector the team wants to create helps focus your time and focus on what's needed.

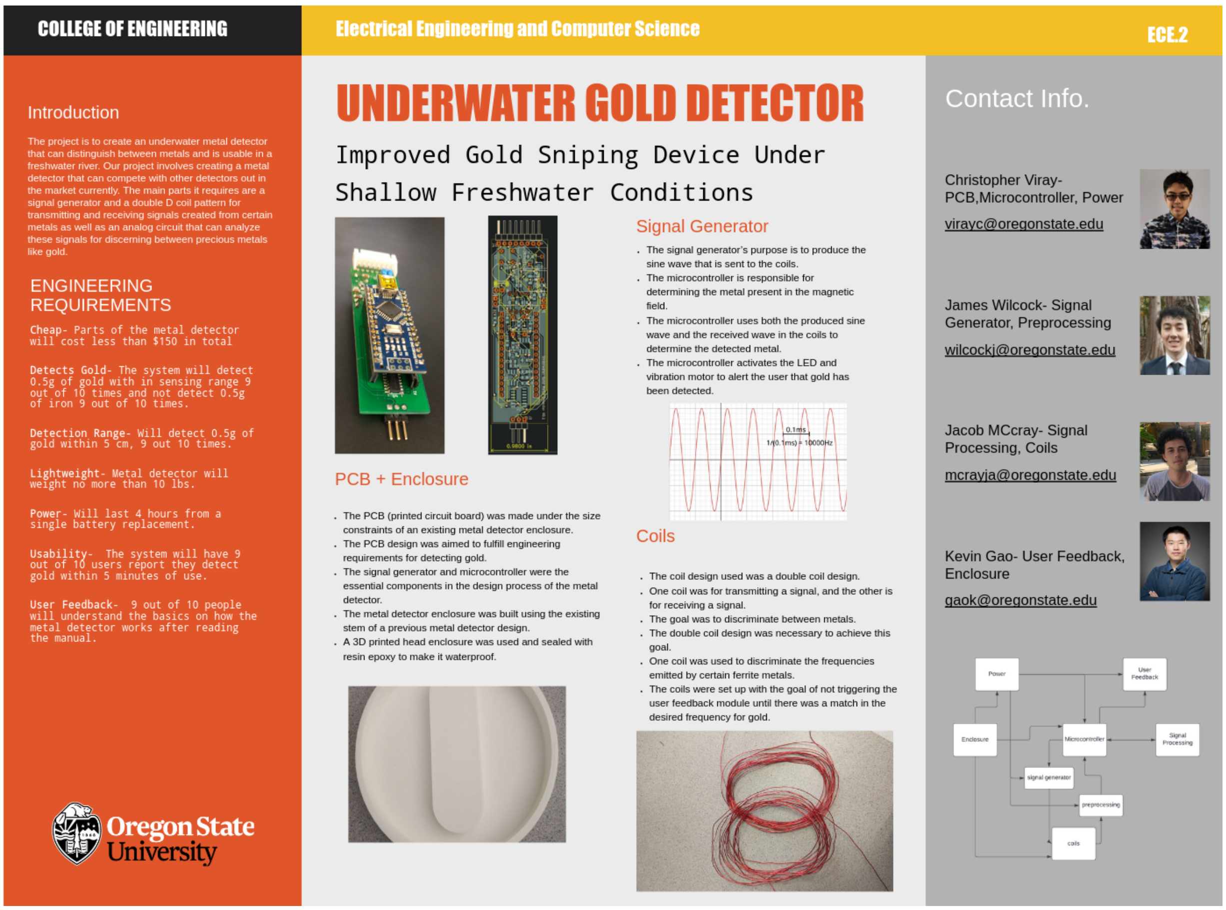
[1] Clifford A., Whitcomb, Leslie E., *Effective interpersonal and team communication skills for engineers.* IEEE Press, 2013. Ch 8, 9, 10.

6.2 Project Artifact Summary with Links

Project Artifact	Link	Description
PCB design	https://github.com/xerorck01/Metaldetect	Pcb design was made in Kicad, implementation of inspired VLF design used for discrimination between ferrous and non ferrous metals
Schematic	https://github.com/xerorck01/Metaldetect	Schematic Design made in Kicad for Detector
Enclosure Design	https://github.com/xerorck01/Metaldetect	Enclosure designed on Solidworks.
Code	https://github.com/xerorck01/Metaldetect	Code programmed in arduino IDE, used for discrimination and receiving and transmitting signals from detector.

Manual	https://github.com/xerorck01/Metaldetect	Document used to explain features and functions of metal detector.
Cost of Product	https://docs.google.com/document/d/13dcx_In84buZmMDU53kpY2O8TB7jW1KKDUjx9f8BxPo/edit	For proof of project requirement including itemized list of items and respective costs.

6.3 Presentation Materials



Project Showcase Link
https://eecs.engineering.oregonstate.edu/project-showcase/projects/?id=bzIKGs3pi6qQGKIl