MINE DETECTING ROBOT
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COLLEGE OF
ELECTRICAL AND MECHANICAL ENGINEEERING
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# COLLEGE OF ELECTRICAL AND MECHANICAL ENGINEERING

## DE-42 MTS
## PROJECT REPORT

### Mine Detecting Robot

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# ACKNOWLEDGEMENT

We express our gratitude to Allah Almighty for His blessings in facilitating our extensive research on the design and development of a mine detection rover. Our sincere appreciation goes to Dr. Mohsin Tiwana, our supervisor, for his insightful advice, and to Brig. Dr. Nasir Rashid, our co-supervisor, for his invaluable guidance. Finally, we thank our parents, friends, and colleagues for their encouragement and assistance.

# ABSTRACT

Landmine detection capability of metal detectors is very sensitive to the gap between buried landmines and the sensor heads. Therefore, human deminers manually scan the ground surface with the metal detectors in such a manner that the sensor heads follow the ground surface. The use of autonomous robots to discover explosives in surface-laid landmines is becoming more common. Hardware design and construction of remote-controlled Land Mine Detection Troops Safety Robot (LMDTSR) scan a specified area and determine the presence of landmines.[1]In case of robot assisted landmine detection, this function can be performed accurately and safely by controlling the gap and attitude of the sensor heads. In this investigation, the effectiveness of the gap and attitude control of the sensor head by some mechanical manipulator on the landmine detection performance has been addressed quantitatively [2].The crucial problem of land mines and resolves the trouble with the ultra-cutting-edge technological solution a ROBOTIC SYSTEM. Land Mine basically is an explosive device that is mainly designed to be installation underground and is exploited at the same time as on the presence of any object like people animals etc. The emergence of the decision landmine became in particular from the concept of digging the tunnels later filled with explosive fabric beneath the targets residence. New technology is needed to be introduced so that you can easy mines, to collect proper efficiency, protection and consistency.[3]

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# CHAPTER 1- INTRODUCTION

The menace of landmines and improvised explosive devices (IEDs) poses a grave threat to military personnel and civilians in conflict zones. In `the contemporary world, numerous nations are developing various technologies for national security. Therefore, it is important to think about the safety of military personnel who defend the national security of their individual nations. Numerous soldiers perish during a battle in desolate places or near borders. Landmines are explosive weapons that can be hidden in the ground and are set off when someone steps on them with just 9 kg of pressure.[4]More than 100 million antipersonnel (AP) mines have been laid in the world, killing or maiming innocent civilians every day. (Bruschini, Gros, Guerne, & Pièce, 1998). The development of remotely operated mine-detecting robots equipped with metal detector and path planning arrays represents a critical advancement in counter-IED and defense strategies. This literature review provides an overview of research and developments in this field, focusing on the application of such robots for military purposes.

# CHAPTER 2- BACKGROUND AND LITERATURE REVIEW

## Historical Context:

The use of landmines and IEDs in warfare dates back to World War I. Traditional methods for mine clearance relied heavily on manual detection and disposal, which were labour-intensive and dangerous. The advent of robotic technology has significantly improved safety and efficiency in this domain. Early mine-detecting robots laid the foundation for the development of remotely operated systems with metal detector arrays.(Topolsky, D., Topolskaya, I., Plaksina, I., Shaburov, P., Yumagulov, N., Fedorov, D., & Zvereva, E. (2022). Development of a mobile robot for mine exploration. Processes, 10(5), 865.) UAVs or drones have found widespread use in both military and civilian purposes in recent years, and anti-drone systems have been created to reduce risks using AI and GPS systems.[5]

## Metal Detector Array Technology

1. **Sensing Principles of metal detectors**
   a) Pulse Induction-based Sensor:
   Metal detector arrays, based on electromagnetic induction principles, emit electromagnetic fields and detect disturbances caused by metallic objects. Arrays of detectors allow for improved sensitivity, accuracy, and coverage compared to single detectors. They can effectively identify buried mines and IEDs, making them indispensable in defense applications.[6]

   b) Ground Penetrating Radar:
   GPR uses radar pulses to create an image of the subsurface. It can detect buried objects, including metal, by sending electromagnetic waves into the ground and measuring the reflected signals. GPR is effective for locating buried utilities, archaeological artifacts, and other objects.[7]

   c) Beat Frequency Oscillation (BFO) Metal Detector:
   These detectors are relatively simple and are often used for beginners. They operate on the principle of comparing the frequencies of two oscillating coils. When metal objects disrupt the magnetic field between the coils, it produces a signal that can be detected.[8]

d) Very Low Frequency (VLF) Metal Detector:

VLF detectors are among the most popular and versatile. They use two coils, one for transmitting and one for receiving signals. These detectors can discriminate between different types of metals and are used in various applications, from coin shooting to relic hunting, [9] .

e) Walk-Through Metal Detector:

These are commonly used in security settings, such as airports, government buildings, and public events. They are designed to detect metallic objects on a person's body as they pass through the detector's portal.[10]

### 2. Signal Processing

Signal processing techniques, such as digital signal processing (DSP) and data fusion algorithms, play a crucial role in optimizing detection accuracy and minimizing false positives. Researchers have explored various algorithms to enhance the robot's ability to differentiate between target explosives and metallic clutter. A persistent problem with traditional, narrowband EMI sensors involves not just detection of metal objects, but discrimination of targets of interest from clutter. When each piece of buried metal must be excavated to determine whether it is a target of interest, significant cost is incurred both due to lost time, and costs associated with digging. In order to facilitate the discrimination of targets of interest from other pieces of metal, several modifications to traditional EMI sensors will be considered.[11][12]

### 3. Sensor Array Vertical Stabilization system

Vertical stabilization in a metal detector is an essential feature that helps maintain the stability and accuracy of the detector's performance, especially in challenging ground conditions. It plays a crucial role in ensuring that the detector provides reliable target identification and discrimination. [13]

### 4. Discrimination and Target ID:

Metal detectors often include discrimination features to distinguish between different types of metals (e.g., ferrous and non-ferrous) or specific target categories (e.g., coins, jewelry, relics). Vertical stabilization helps ensure that these discrimination features work effectively, minimizing the chances of misidentifying targets due to ground interference.[14]

# Operational Considerations

## 1. Remotely Operated vs. Autonomous

1. Advantages of Autonomous Robots:

   While autonomous robots have gained popularity in mine detection, remotely operated robots offer distinct advantages in military contexts. They provide real-time control and decision-making capabilities to human operators, ensuring adaptability to dynamic situations and reducing the risk to personnel. [15]
2. Advantages of Remotely Operated Robots:
   Research advances allowed robots to be increasingly used in time- and safety-critical applications such as robot-assisted search and rescue (SAR), hazardous environment inspection, and disaster response. Such complex and demanding applications require flexible, efficient, and robust robotic platforms. The field of remotely controlled mobile robots has been extensively researched from the point of view of traditional pure teleoperation approaches for such applications.[16]
3. Comparison of Real-time Decision-making Capabilities:
   Visual tracking is one of the most important and fundamental problems in the fields of computer vision and it has been utilized in many applications, such as automated surveillance, human computer interaction, and robotics. Also known as model-free object tracking, visual tracking algorithms aim to track an arbitrary object throughout a video segment, given the object's initial location as a bounding box representation. [17]
4. Adaptability to Dynamic Situations
   Rovers are always impeded by obstacles along the traveling path which can destabilize the rover's body and prevent it from reaching its goal destination. ANN is a multilayer network made out of three layers: an input, a hidden, and an output layer. The network is trained in offline mode using back-propagation supervised learning algorithms. A software-simulated rover was experimented on by a team and it revealed that it was able to follow the safest trajectory despite existing obstacles. As future work, the proposed ANN is to

be parallelized so as to speed-up the execution time of the training process.[18]

## 2. Teleoperation Interfaces

1. Enhancing Operator's Situational Awareness:

   User-friendly teleoperation interfaces have evolved to facilitate seamless control of mine-detecting robots. Advanced interfaces include haptic feedback systems, augmented reality displays, and immersive control environments, enhancing the operator's situational awareness and precision.[19]

2. Haptic Feedback Systems:

   Teleoperated mobile robots are widely used in order to carry out complex tasks in hazardous environments. In this type of apparatus, often the operator can take advantage only of visual information about the environment and in the majority of the cases they are not sufficient to carry out complex tasks because of the limited visual fields of cameras. Therefore, besides the possibility of errors and failure of the task, remote teleoperations turn out to be tiring activities requiring a specific training to the human operator. But certainly they can be helpful and can  be integrated in this project.[20][21]

3. Augmented Reality Displays:

   Current trends in Industry 4.0 vision [22] show that human interaction in Cyber-physical systems (CPS) cannot be eliminated but, on the contrary, it should be supported and emphasized. Apparently, humans cannot be replaced by robots in some specialized product processing tasks, so the cooperation between humans and robots [23] needs to be supported. Users are also shifting from repeated manual work to more specialized roles. Such roles, as mentioned by Gorecky et al.[24], cover mainly servicing and maintenance of manufacturing plants, but also monitoring, planning, and simulation of production processes.

4. Precision in Robot Control:

   In general, a robot system comprises a mechanical arm, motors, and a controller. The primary role of the controller is to provide feedback control for the motors. The consistent relationship between a set of joint variables and the resulting position and orientation (pose) of the robot's hand in space is crucial. Achieving this requires precise feedback loops for each joint and a well-built mechanical arm, characterized by low friction and minimal backlash. When these conditions are met, the robot is deemed repeatable. The manual teaching mode for programming the robot relies on its repeatability: the robot is initially moved to a desired pose under manual control, and the corresponding joint variables are then read and recorded. Whenever these values are input into the controller, the robot reliably reproduces the same pose in space.[25][26]

## Challenges and Advancements

1. Terrain Variability:
   The effectiveness of mine-detecting robots can be influenced by factors like soil composition, moisture levels, and rugged terrain. Ongoing research focuses on adapting robots to diverse operational environments and improving their mobility. [27]
2. Payload Integration:
   Apart from metal detectors, military robots often carry additional payloads, such as cameras, chemical sensors, and robotic arms for controlled detonation. Integrating these elements while maintaining robot stability and mobility is a technical challenge.
3. Path planning:
   Path planning for an autonomous mine-detecting robot involves using sensors and algorithms to navigate complex terrains, avoiding obstacles and optimizing routes for efficient and safe mine detection. It adapts to real-time environmental changes, focusing on maximizing coverage while ensuring the safety of both the robot and its operators. The primary objective is to reduce risks in demining operations by efficiently identifying and marking potential threats. [28]
4. Sensor Technology and Sensitivity:
   In a pulsed induction metal detector system, the sensitivity variation for detectable minimum metal target and the maximum detection distance are investigated as the winding geometry of the search coil is varied. A number of planar square spiral mono

coils with various fill ratios and wire spacing-to-width ratios are comparatively analyzed based on a numerical simulation. Five representative coils are fabricated and applied to a pulsed induction metal detector system as a search coil. It is demonstrated that a search coil with a larger fill ratio has a high size sensitivity for a minimum metal target at close distances, which may be missed by coils with smaller fill ratios. A search coil with a smaller wire spacing-to-width ratio is shown to have a high depth sensitivity for maximum detection distances. [29][30]

5. GPR vs Coils:

   In the realm of mine-detecting robots for military defense, continuous advancements and challenges persist. Innovations focus on integrating multi-modal sensors, incorporating machine learning and artificial intelligence for adaptive decision-making, and enhancing human-robot collaboration interfaces. Concurrently, challenges encompass refining sensor technology for improved sensitivity and reducing false positives, ensuring reliable communication and energy efficiency in adverse conditions, and developing sophisticated algorithms for autonomous navigation and obstacle avoidance. These efforts collectively aim to enhance the robots' capability to navigate diverse terrains, detect threats accurately, and reduce risks in demining operations, reflecting the evolving landscape of mine detection technology.[31][32]

6. Energy Efficiency:

   Robots usually carry limited energy, such as batteries; thus energy conservation is an important concern for mobile robots. This paper focuses on energy efficient robot exploration. To our knowledge, this is the first study for energy-efficient robot exploration in an environment with random or structured obstacles, such as walls. [33]

7. Multi-modal Sensing Integration:

   Previous surveys conducted on robotic interaction with non-rigid objects include the work of Khalil and Payeur[34], which provided comprehensive coverage of the subject, as well as a comparison with algorithms for handling rigid objects and giving particular attention to multi-sensory feedback systems. Jiménez [35]presented an overview of modeling and control techniques, with a strong focus on the manipulation of planar objects such as thin sheets and cloth-like material. A very recent review by Sanchez et al.[36]also provides a broad coverage of the topic, focusing on the classification of control tasks based on the type of object being handled as well as on the specific subtask that is performed in the various steps of manipulation and shape control. However, the quantity and variety of recent advances on the topics of sensing and manipulation of non-rigid objects is such that a single review cannot hope to capture them all.

## Future Directions

Future research and development directions in the field of remotely operated mine-detecting robots for military defense include:

1. Miniaturization and Portability: Developing compact and lightweight robots for rapid deployment in diverse military operations.
2. Human-Robot Interaction: Advancing human-robot interaction technologies to ensure seamless control and communication between operators and robots.
3. Multi-modal Sensing: Integrating multiple sensor modalities, such as visual, thermal, and chemical sensors, for comprehensive threat detection.
4. Machine Learning: Leveraging machine learning algorithms for real-time data analysis and decision-making.

## Conclusion

The development of remotely operated mine-detecting robots equipped with metal detector arrays has revolutionized defense strategies by enhancing safety and efficiency in counter-IED operations. As we will embark on our final year project, we will consider building upon the insights and advancements discussed in this literature review to contribute to the field of defense-based mine detection, ultimately ensuring the safety of military personnel and civilians in conflict zones.

# CHAPTER 3- METHODOLOGY

## 3.1 – Mechanical

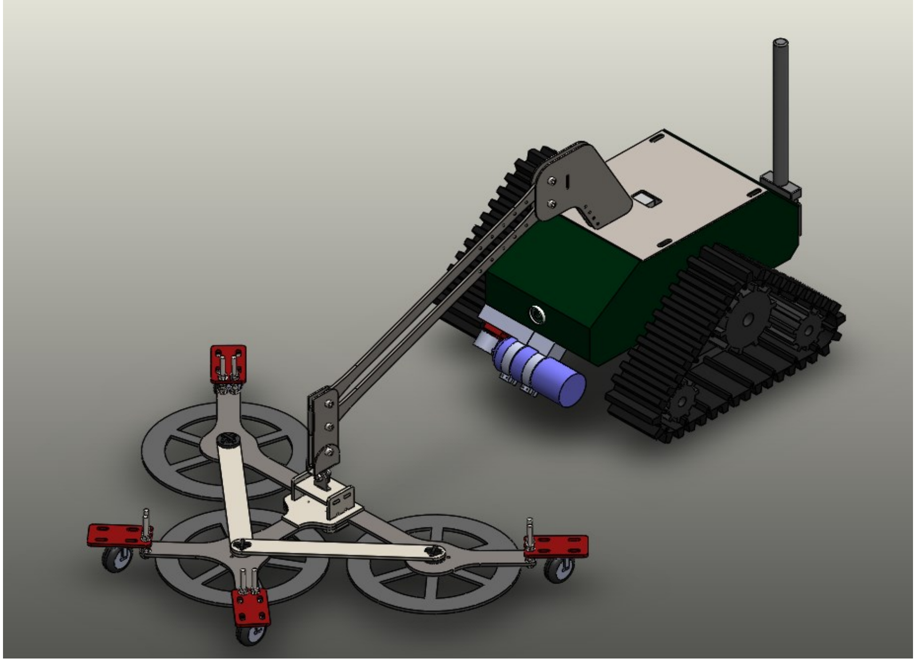


*Figure 1 robot with complete structure*

### 3.1.1 Introduction

Land mines, haunting remnants of past conflicts or grim indicators of ongoing ones, continue to pose a significant threat in war-torn regions, exacting a toll long after the guns fall silent. Our Mine Detecting Robot (MDR) aims to provide a solution for governments and humanitarian organizations seeking to curb this problem. A crucial part of our MDR is the physical mechanism on which the sensors are mounted, crawling over the ground at a fixed offset. Important considerations regarding the design and manufacture of this mechanical structure were taken to ensure optimal performance and sufficient durability of boom arm mechanism and the sensor carriage. This sub chapter goes over all of the design constraints and explaining all of the design choices that were made, ending with the results and conclusions.

In our design, two major assembles were designed, analyzed, manufactured and tested. These are:

#### 3.1.1.1 Boom Arm Mechanism:

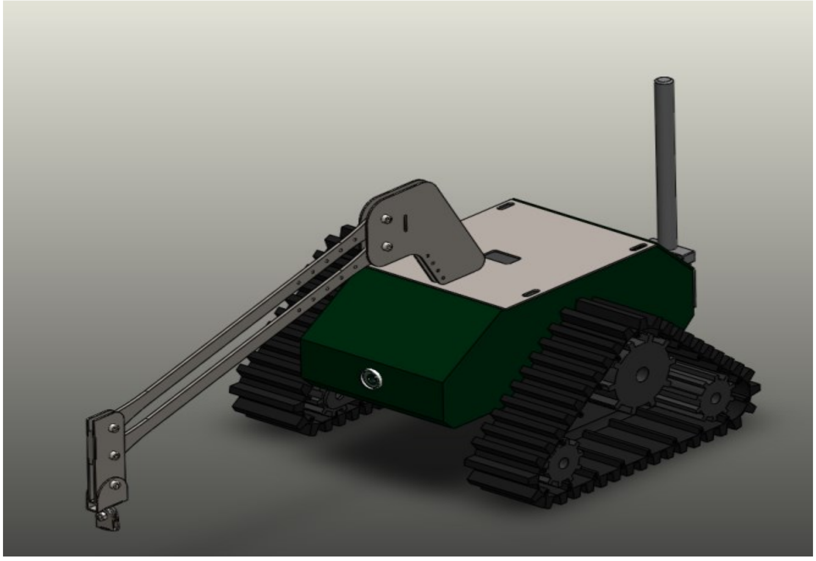


*Figure 2 robot with only articulating structure*

The boom arm mechanism is a three degree of freedom arm that connects the body of the robot, which in our case is a tracked rover, and the metal detector coil housing carriage. This ensures that the robot is effortlessly pushing the coil housing carriage without it getting stuck as well as making sure that the coil housing carriage maintains parallel alignment with the surface below.

#### 3.1.1.2 Sensor Coil Carriage:

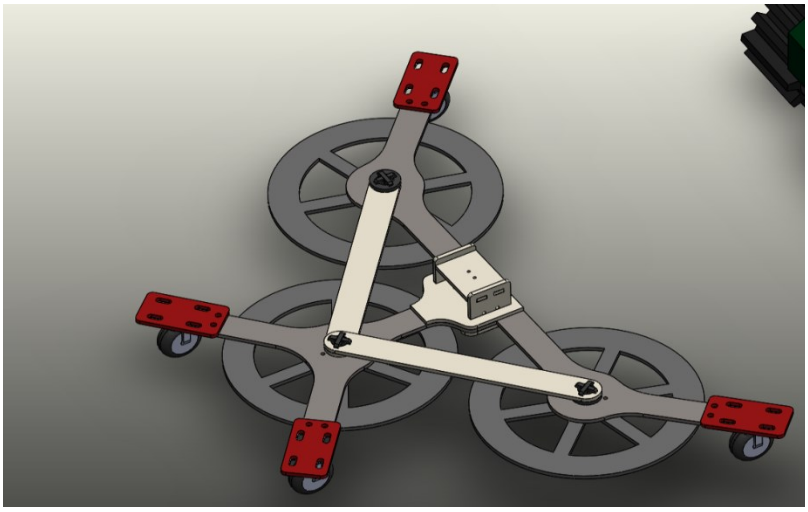


*Figure 3 sensor carriage housing*

The sensor coil carriage is the part of the overall physical structure on which the actual sensor coils are mounted. These coils are responsible for creating the electromagnetic induction fields that would detect a metallic object in the ground. For its optimal performance, it is necessary for the coils to maintain a consistent distance from the ground with as little of an air gap as possible. It is the responsibility of the sensor coil carriage to maintain this distance and traverse over the ground smoothly. The sensor coil carriage houses three coils which can be up to 30 cm in diameter.

#### 3.1.1.3 Land Mine Marking Mechanism

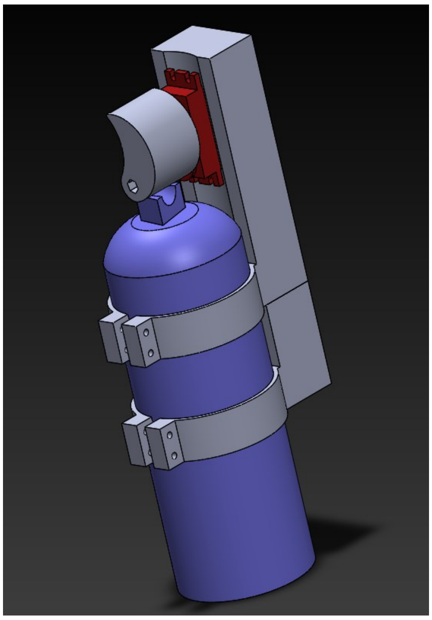


*Figure 4 Marking mechanism*

Once the presence of a land mine has been established, it is critical to have a feedback mechanism with the operator. A digital approach of achieving this is discussed in later chapters however a mechanical method to mark a potential landmine location is necessary. This is where we implement the land mine marking mechanism which sprays a distinct colored paint on the ground. This gives visual feedback to Explosive Ordnance Disposal (EOD) Specialists on where exactly to look for potential explosives.

### 3.1.2 Design Constraints

#### 3.1.2.1 Design Constraints of Boom Arm Mechanism:

a. Geometric Constraints: The boom arm mechanism had to fit on the existing robot chassis. The robot is a small, tracked platform with a plane top surface, this surface is where we chose to mount the boom arm. We mounted the boom arm by making it on a plate with the same dimensions as the cover plate for the robot as well as with screw holes matching the existing screw hole pattern. The overall dimension of the mounting plate became 300mm x 260mm and 10mm slots for the screws, we went with slots instead of holes to allow for small adjustments in the overall setting. The mounting plate also features a cutout which serves a path for the various wires from the sensors, controllers etc. One of the key factors in determining the shape and geometry of the boom arm mechanism was the physical ability of the bot, in this case it being the max gradient it can climb over. This set the minimum articulation of pitch and roll of the coil housing carriage which is connected to the boom. The max gradient of the robot is 25 degrees so subsequently all the articulating attachments must cater to at least a 25-degree gradient.

b. Degree Of Freedom: A key design detail we had to follow was the degree of freedom for the mechanism. The carriage must be as level with the ground as possible for optimal performance of the sensors, this led us to develop a 3 Degree of freedom system; roll, pitch and translation in the z axis. To achieve roll and pitch a bearing supported pivot would be used whereas the vertical translation was achieved by a 4-bar parallelogram linkage. The 4-bar parallelogram linkage maintains parallelity with the ground, leaving the rest of the components for the other two degrees of freedom.

c. Material Constraints: We were limited by the choice materials at our disposal with the required material properties and cost the material. The robot is designed to be operated in rugged terrain and therefore the boom arm mechanism had to be rugged and sturdy in its construction all the while being lightweight as well since we were limited by the maximum weight capacity of the robot. For this reason, the decision to go with steel was taken. It was light enough for our purpose and was strong enough to bear the conditions we designed it for. The material selection was further aided by its relatively low cost, with all other options being prohibitive expensive or unavailable. Alternate material choices were carbon fiber composites or aluminum alloys, both were difficult to procure and work with within our budget.

d. Manufacturing: A major consideration while designing the boom arm mechanism was the processes used to manufacture the boom arm mechanism. Given the material we had chosen, our options were limited. Working with steel meant either machining; CNC or manual, casting, or CNC plasma cutting sheet steel. CNC plasma cutting was the best choice, the ease of manufacturing, relatively low cost and good part accuracy set it apart from the rest. Alternative methods such as CNC machining would have resulted in high quality parts as well but at the expense of a higher price. Casted parts would have been cost effective, but this would have resulted in parts with greater tolerances. CNC plasma cutting offered a blend of quality and cost which was superior then the rest. Choosing CNC plasma cutting came with its own set of challenges, this meant that the parts could only be designed in two dimensional parts, which would then be welded or fastened together with hardware. We based our design entirely on 2.8mm mild steel sheet and doubled the material used in places where extra strength was required. This allowed us to design pieces like a puzzle, putting them together and welding where required. This resulted in good quality parts with low tolerances.

#### 3.1.2.2 Design Constraints for Sensor Coil Housing:

a. Materials: Due to the nature of the application of the sensor, being a metal detector, any metallic components near the coils would trigger the sensor. For this reason, the entire body of the Sensor Coil Carriage had to be made out of a non-metallic material. This limits us to two major family of materials: plastics; Polylactic acid (PLA), Acrylonitrile butadiene styrene (ABS), acrylic etc., and composites, fiberglass, carbon fiber etc. Due to the difficult working nature, lack of availability of composite materials and their relatively high cost of composites, we chose to work with plastics.

b. Manufacturing: A major factor for the design of the Sensor Coil Carriage was the method of manufacturing. The two main options were 3D printing and Laser cut acrylic out of acrylic sheets. Both options have benefits and limitations. In the case of 3D printing, it provides significantly more flexibility in design, however it lacks the strength required for larger parts that are required and can get expensive. Standard 3D printers are also not designed to print high aspect ratio objects since they are limited by the size of the print bed. This means any large part would have to be printed in pieces instead of a solid piece, further decreasing the strength of the part and increasing cost. This leaves Laser cut acrylic sheets to be the ideal material and manufacturing process. Once cut in 2D parts, these parts can be joined together like Legos using epoxy resin. This resulted in all the parts being made from laser cut 6mm acrylic sheet, being stiffened up with extra material in areas with a higher load. The overall structure is also reinforced with carbon fiber rods in strategic areas to aid in stiffness.
c. Geometric Constraints: The size and shape of the Sensor Coil Carriage was mainly driven by the size and number of the coil as well as keeping metal objects and parts away from the coils. Three coils of 30cm each were used and placed in a triangular form. doing this results in:
    i. Reduced material usage.
    ii. Reduces the number of metallic parts in the coil's vicinity. The boom arm mechanism is made entirely of steel making it crucial to keep it as far as possible from the sensor coil.
    iii. Increased strength in a triangular form compared to a rectangular piece.

#### **3.1.2.3** Design Constraints for Land Mine Marking Mechanism

**3.1.2.3.1** Size: the mechanism must be light and compact to not take up excess space.

**3.1.2.3.2** Paint Canister: the mechanism must be designed around a standard aerosol-based paint canister.

**3.1.2.3.3** The mechanism must be able to exert the required amount of force on the paint can so that it may be actuated reliably.

**3.1.2.3.4** The spray canisters must be able to be removed and replaced once depleted.

### 3.1.3 Design Methodology

#### 3.1.3.1 Design of Boom Arm

Keeping in to considerations the various constraints, we designed a boom arm mechanism that fulfills our requirements while staying inside our design parameters.

The final design resulted in a mechanism made from 2.8mm steel. The whole mechanism was an assembly of various parts either fasted together or welded with all the moving joints having bearings in them to allow for free movement. The various parts of the assembly were:

a. Mounting plate: This was the junction between the robot and the boom arm mechanism, it hosted the slots for the screws to be fastened into. Welded to this were the L shaped plates which made one side of the 4-bar mechanism with the arms.

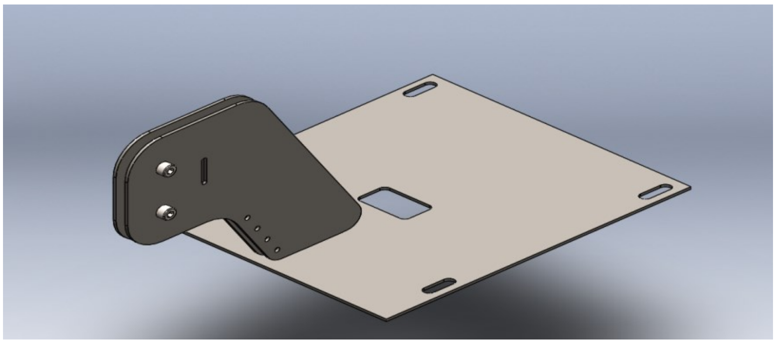


*Figure 5Mounting plate*

b. Arms: Made out of two sheets welded together for strength, the arms were the main extensions out of the bot footprint and were the main parts of the 4-bar parallelogram mechanism. This bridged the two sides of the mechanism.

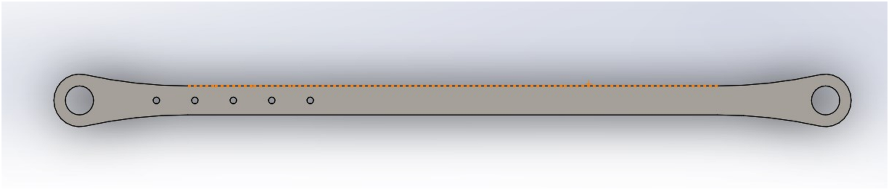


*Figure 6Arms*

c. Hub: The hub was the central part of this mechanism, pulling together all the different pieces of the mechanism to make one proper unit. Made out of three pieces of steel welded together, this part makes up the second half of the 4-bar linkage as well as being attached to the roll pivot bracket

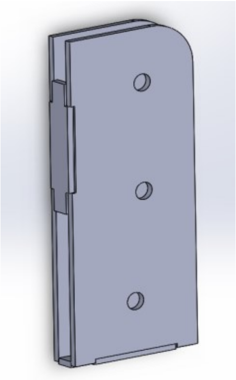


*Figure 7 HUB*

Roll Pivot Bracket: The roll pivot bracket was designed as a four-piece construction, welded together to make one part. This was responsible for the roll axis and was attached to the pitch pivot bracket.

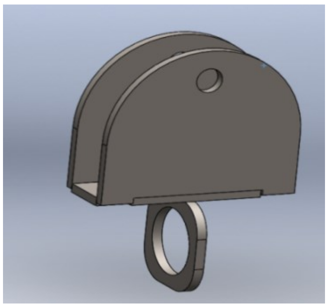


*Figure 8Roll Pivot Bracket*

d. Pitch Pivot Bracket: Similar to the previous bracket, this was a simple three-piece construction, welded together. This also featured holes in the bottom to facilitate mating with the coil housing carriage.

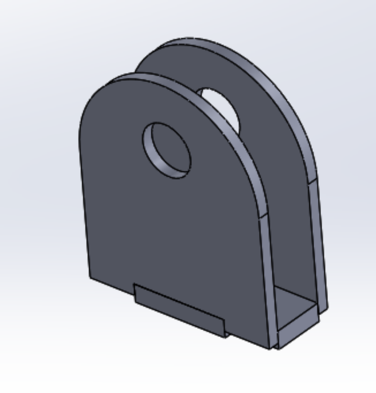


*Figure 9 Pitch Pivot Bracket isometric*

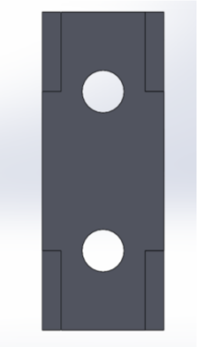
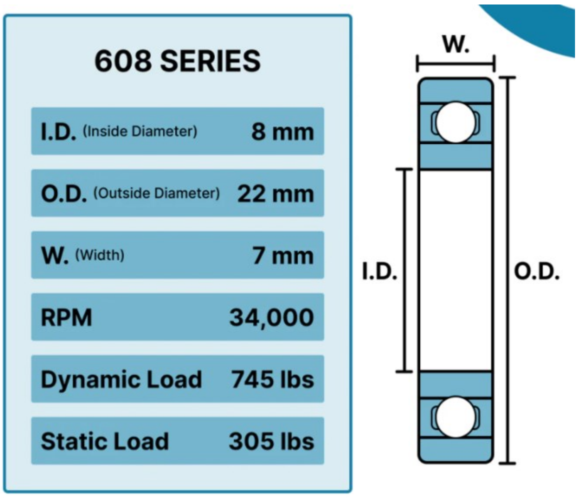


*Figure 10Pitch Pivot Bracket bottom*

e. Bearings: we used 608-2RS ball bearing on every moving joint to allow it to move freely.



**608 SERIES**

| | |
|---|---|
| **I.D.** (Inside Diameter) | **8 mm** |
| **O.D.** (Outside Diameter) | **22 mm** |
| **W.** (Width) | **7 mm** |
| **RPM** | **34,000** |
| **Dynamic Load** | **745 lbs** |
| **Static Load** | **305 lbs** |

*Figure 11 608 ball bearing*

**f.** Hardware: we used M8 screws and nuts as they matched the internal diameter of our bearing, simplifying assembly.

### 3.1.3.2 Design of Sensor Coil Housing:

The Sensor Coil Carriage comprises multiple laser cut parts from 6mm acrylic. Multiple smaller parts are joined together to form a larger part.

a) T Beam: the main backbone of the structure is made out of two acrylic pieces which are joined together in a shape of a T. The structure is reinforced at the junction point with two added layers of acrylic to strengthen it. The junction point, being the furthermost point from all the coils, is also the point of contact between the Sensor Coil Carriage and the Boom Arm. This piece holds the three coils and is also the attachment point for the wheels. To maintain Sensor Coil Carriage level with the surface, the wheels individual height is designed to be adjustable.

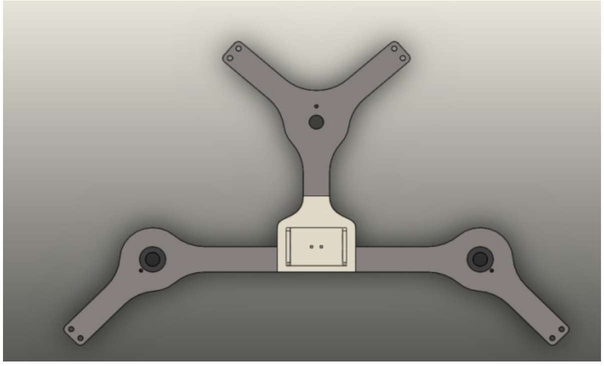


*Figure 12Top view T beam*

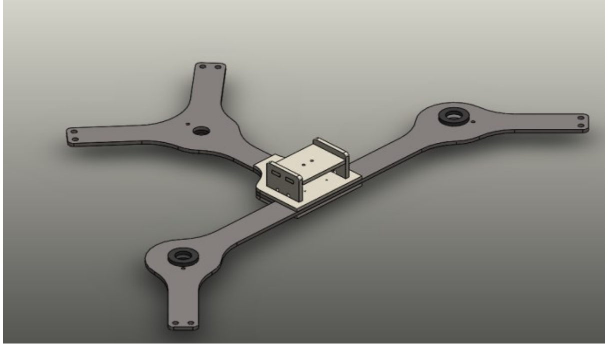


*Figure 13Fig Iso view T beam*

b) Coils plates: The coil plates are circular disks of 6mm acrylic on which the sensor coils are to be mounted. These plates were necessary to protect the coils from any damage and maintain their shape. The coil plates are also necessary to keep the coils at a constant distance from the ground.

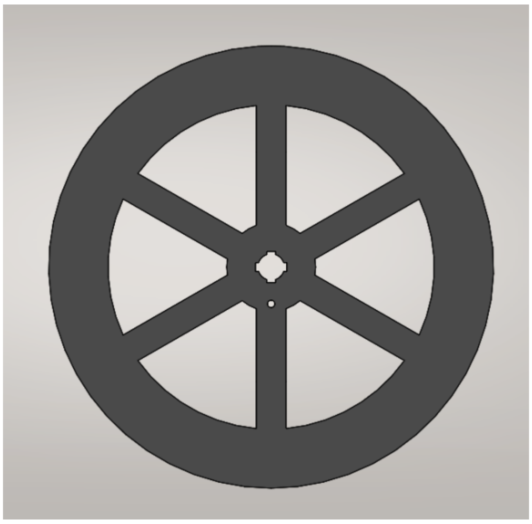


*Figure 14 Coil Plates*

c) Plastic Bolts: The coil plates are designed to be able to be removed easily, for this purpose a fastening mechanism needs to be used but due to the restriction on metal parts another solution would be needed. For this we designed a type of plastic bolt that could be manufactured through laser cutting acrylic. This part is a two-piece construction which holds the coil plate together with the T beam.

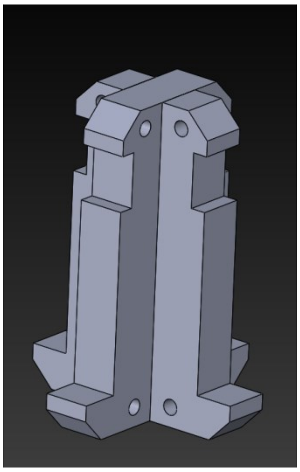


*Figure 15 plastic bolts*

d) Brace Bars: These are straight pieces of 6mm acrylic which complete the triangular design. They provide rigidity and stability to the whole structure.

*Figure 16 brace bars*

e) Wheel Mounts: The wheel mounts play an important role in the overall functionality of the sensor carriage mechanism, these wheel mounts are designed to be adjustable within about 50mm. This adjustability allows for the sensor coils to be at the optimal distance from the ground for optimal performance. The adjustment is done through two bolts on which are three nuts each. One of the nuts secures the bolt to the T beam while the other two nuts clamp on the wheel mounting plate, allowing it to move up and down depending on where the nuts are tightened.

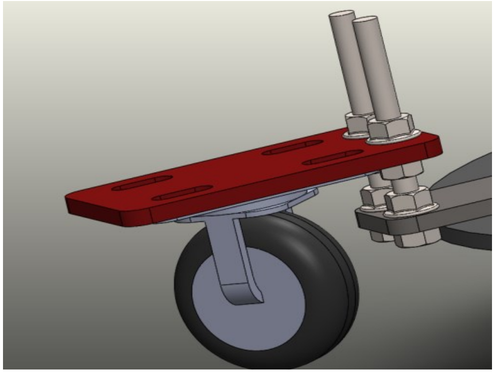


*Figure 17 wheel mounting low*

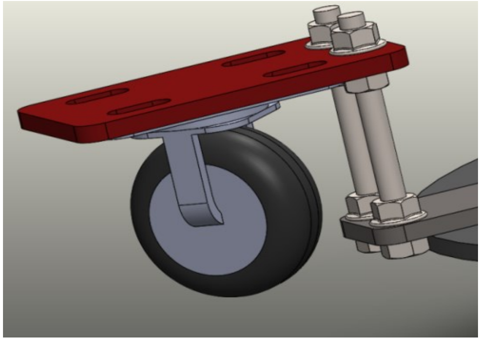


*Figure 18 wheel mounting high*

f) Wheels: The wheels are standard two inch industrial type caster wheels, free to align themselves in the direction of travel.

*Figure 19 industrial caster wheels*

### 3.1.3.3 Design of Land Mine Marking Mechanism

The Land Mine Marking Mechanism is integral for manual feedback and the safe disposal of landmines or other explosives. The mechanism consists of three major components, not including the spray canister itself. These parts are:

**3.1.3.3.1** Spray Can holder: This is the main body of the mechanism and holds the spray canister, has the mounting points for the servo motor and the mounting points to attach the mechanism to the main body of the bot. Made out of 3D printed PLA, the can holder has a sturdy design required to hold the spray can. The spray can is attached to the main body through two integrated clamp which tightens around the spray can when screwed into place using four M3 screws and nuts (two screws and nuts per clamp)

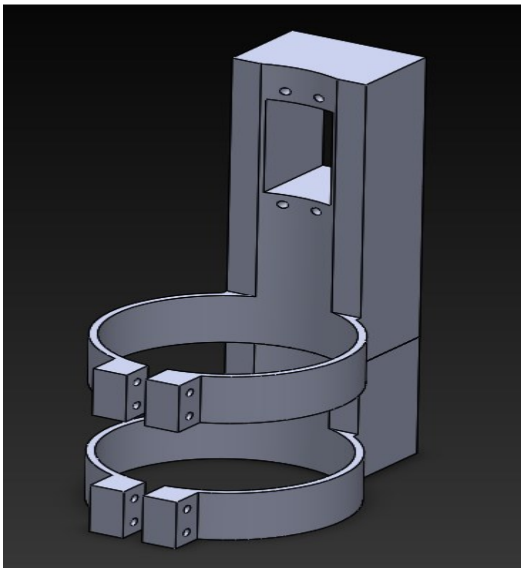


*Figure 20 spray can holder*

**3.1.3.3.2** Cam: This is the actuating mechanism to push down on the spray can with sufficient force so that the paint may be ejected

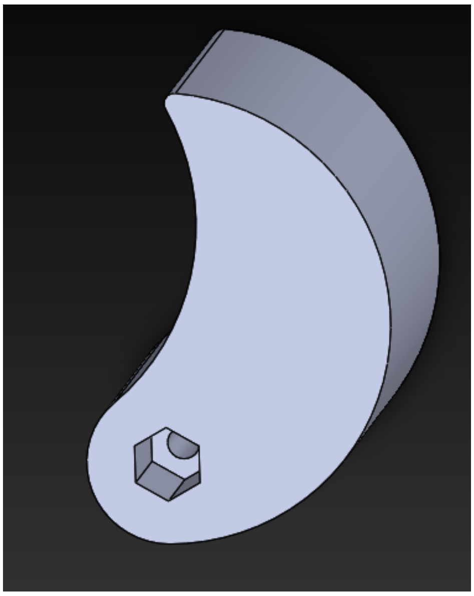


*Figure 21 cam*

**3.1.3.3.3** Servo: A standard MG996 servo motor.

*Figure 22 MG 996 servo*

#### 3.1.3.4 Calculations for force required to actuate the spray can

A certain force F is required to actuate the spray can, this force is generated by the torque of the servo motor through the cam action. By finding the required force F, we can design a cam to convert the torque of the motor into a vertical force path. Since

D = T/F :

D = distance (diameter of cam in this case)

F = force required for spray can (2kg ; found expermantly)

T = torque of motor (10 kg/cm ; given through the data sheet of the motor)

The diameter of the cam is therefore calculated to be 5cm.

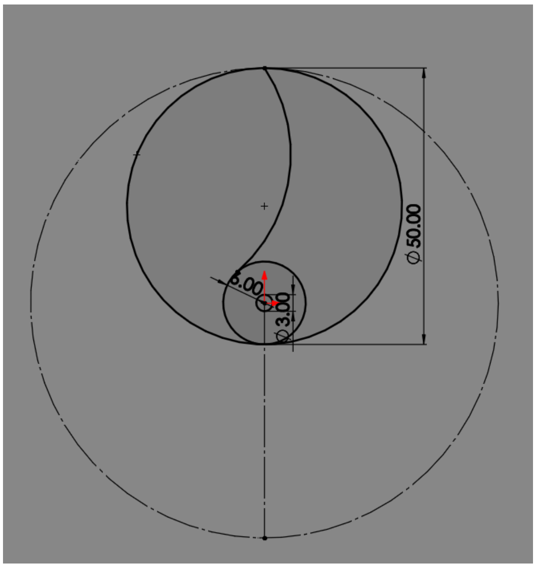


*Figure 23 dimentions of cam*

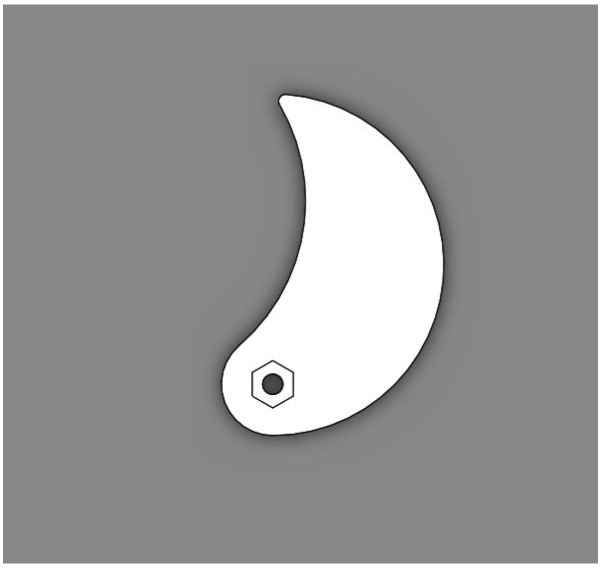


*Figure 24 cam front view*

### 3.1.4 Analysis

#### 3.1.4.1 Analysis of Boom Arm

Performing Finite Element Method (FEM) static dynamic analyses on a boom arm mechanism represents an important step in ensuring its structural integrity and functional performance. In our project, we conducted comprehensive simulations to evaluate its behavior under various loading conditions.

The initial FEM static analysis provided valuable insights into the stress distribution and deformation patterns within the component. By subjecting the part to simulated loads representative of real-world operating conditions, we identified areas of potential weakness and localized stress concentrations. This allowed us to iteratively refine the design, optimizing material distribution and geometry to enhance load-bearing capacity and minimize structural vulnerabilities.

Based on the insights gleaned from testing, we implemented minor improvements and changes to the part, addressing any identified deficiencies and further enhancing its performance and reliability. These modifications ranged from subtle adjustments to geometric features to reinforcement strategies, this can clearly be seen on the “Arms” which were doubled in thickness to improve their strength.

The iterative nature of this process allowed us to incrementally refine the part's design, iteratively improving its structural robustness, and functional efficacy. We achieved a comprehensive understanding of the part's behavior under different loading conditions, culminating in a final design that met our performance criteria and exceeded industry standards. The integration of FEM analysis into the design process facilitated the development of a highly optimized and resilient component. Through careful iteration and validation, we successfully translated theoretical simulations into real-world solutions, ensuring the integrity and performance of the part in demanding operational environments.

*Figure 25final design of L bracket*

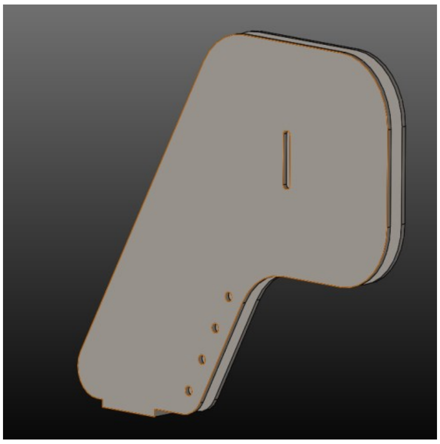


*Figure 26 initial design of L bracket*

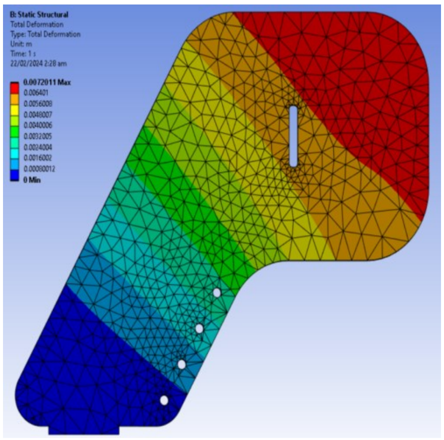


*Figure 27 deformation on final design*

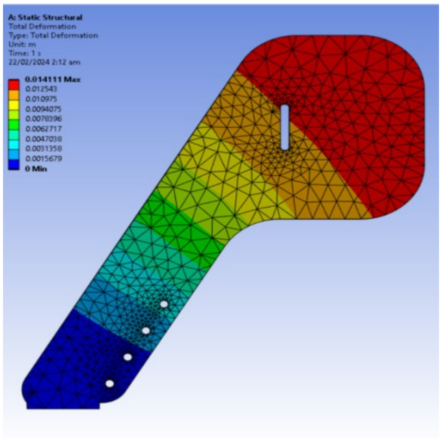


*Figure 28 deformation of initial design*

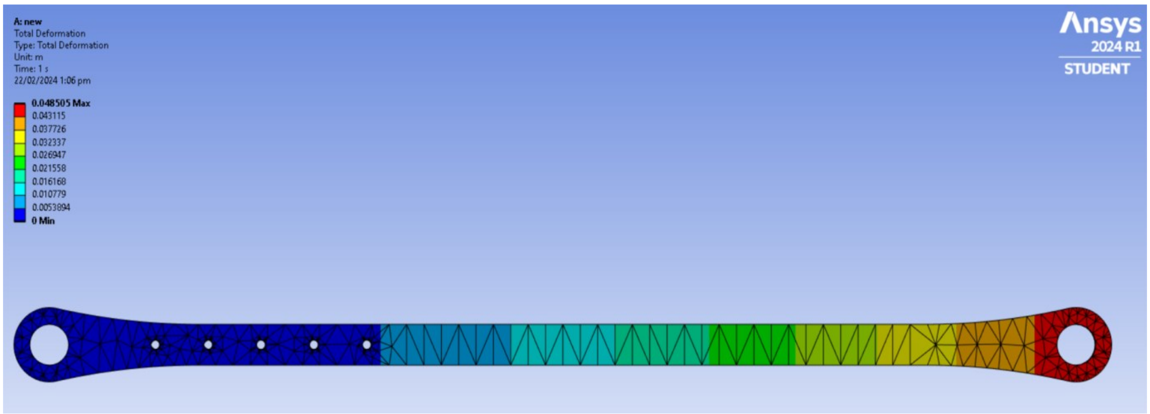


*Figure 29 deformation of 3mm arms*

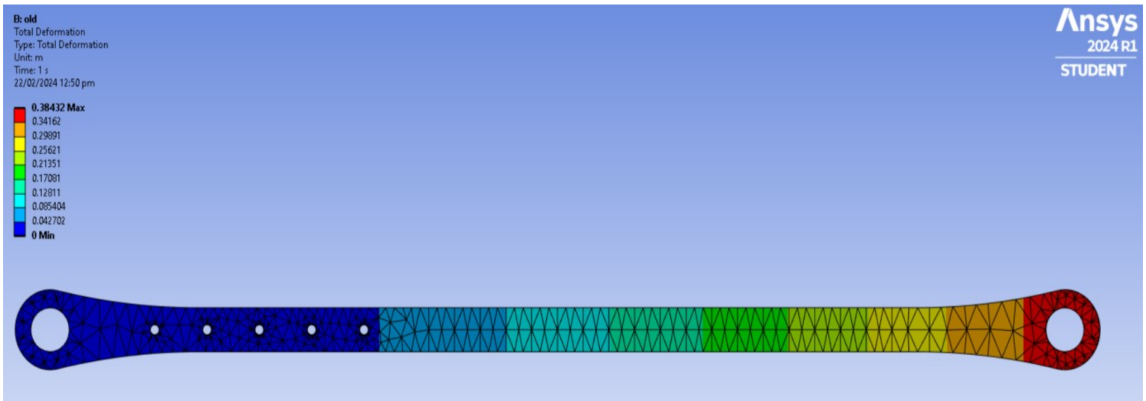


*Figure 30 deformation of 6mm arms*

#### 3.1.4.2 Analysis of Sensor Coil Housing

Conducting a Finite Element Method (FEM) static analysis on the Sensor Coil Carriage, provided valuable insights into its structural integrity and performance under various loading conditions. The objective of this analysis was to assess the carriage's ability to withstand forces and stresses encountered during operation, ensuring reliability and longevity in the field.

One key modification involved reinforcing critical load-bearing areas of the carriage to better distribute stress and to reduce the risk of structural failure. This was achieved through the addition of supplementary bracing and reinforcement elements, strategically positioned to bolster weak points identified during analysis. Additionally, adjustments were made to the geometry of certain components within the carriage to optimize their strength and enhance overall resilience. By fine-tuning these parameters, we were able to achieve a more robust and reliable design without compromising on weight or functionality.

Throughout the iterative design process, careful consideration was given to maintaining compatibility with existing manufacturing processes and materials, ensuring scalability and cost-effectiveness in production. By leveraging advanced simulation tools and empirical testing, we were able to refine the design of the Sensor Coil Carriage iteratively, resulting in a final product that exceeds performance expectations and meets the rigorous demands of real-world deployment. The FEM static analysis served as a foundational step in the iterative design and optimization of the Sensor Coil Carriage, enabling us to identify and address potential weaknesses while enhancing overall performance and reliability. Through continuous testing, refinement, and innovation, we have developed a component that fulfills the requirement imposed on it.

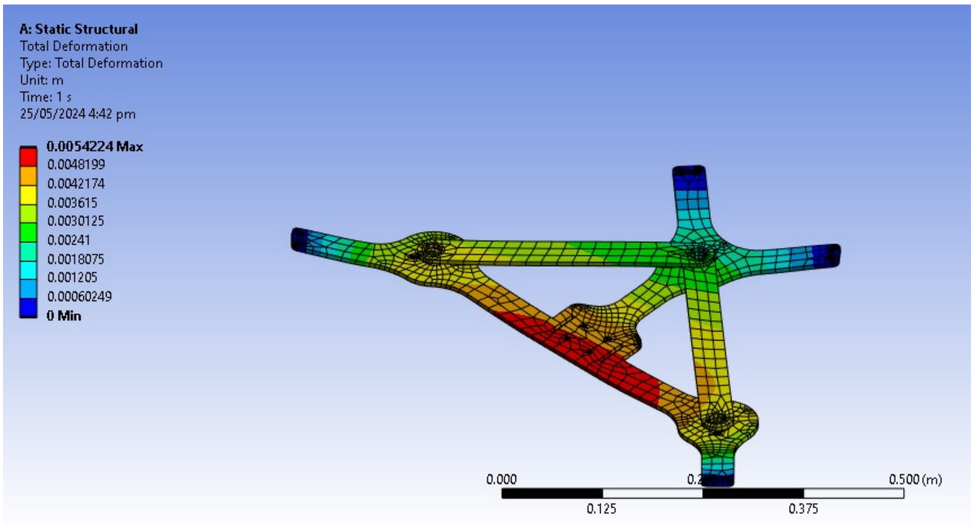


*Figure 31 deformation of coil carrage assembly*

### 3.1.5 Results and Complications

The final mechanism that we created does what it is designed to do, this was not without its challenges. A few unseen complications arose during the fabrication process. To be precise the quality of the welds with which all of our parts are fixed in place was not of the highest quality. During the welding process some parts did not maintain squareness and bowed slightly. This was not critical in some parts of the mechanism however in some parts, manual machining was required to bring the parts back to specification which required the parts to be milled slightly. Once all the parts were within specifications they were simply bolted together. A similar issue occurred when we tried aligning the parts properly before we could fix them with adhesive or epoxy. This caused a slight misalignment in one of the parts but was not critical enough to cause a problem.

### 3.1.6 Future work

A few aspects of this overall mechanism can be refined and fine tuned for even better operational performance. Since this mechanism is designed to be used in hard operational areas, it could be designed and improved with advanced materials which we do not have the manufacturing capacity for, such as carbon fiber composites. Along with this, a suspension system for the sensor coil carriage could be designed to absorb the shocks and bumps of the terrain and maintain an even level distance with the ground underneath

## 3.2 Electronics

### 3.2.1 Introductions

All land mines contain metal shrapnel and ball bearings. The enclosure encloses the whole explosive chemical and detonation mechanism, The enclosure itself is made of metal.

Our motive is to detect the metal buried in ground about 12inch deep in ground without any physical contact and triggering the mine.

For this there are many ways to detect it like:

- Metal detector
- Ground penetrating Radars (GPRs)
- Acoustic Methods

We will be looking forward to Metal detector sensor domain and develop a bespoke metal detector for detecting Land mine buried in the ground and provide a useable signal when any metal is detected.

#### 3.2.1.1 Selection of Electrical Components:

Military-grade metal detectors demand exceptional performance and reliability. It is important to source parts of military grade, making sure every parts has exactly the same value as calculated for optimal performance. Following is the detailed breakdown of key considerations:

**Importance of Tight Tolerances:**

Consistent Performance: Components with tight tolerances shows minimal variations in their electrical characteristics (resistance, capacitance, inductance). This makes sure that the sensor will work in any kind of environment in an effective way.

Accurate Detection: When it comes to military applications it is important to be accurate, having your tolerances tight can make sure that the signal is processed in a way that will lead to accurate detection of the landmines.

Enhanced Sensitivity: Noise and signal distortion can be made very less through tight tolerances, which will have the sensor working at its peak sensitivity (null point). This step is very important to detect landmines effectively.

**Component Selection Strategies:**

- Temperature-Stable Components: Military operations are often taken place at unstable temperatures. Choosing components with low temperature coefficients, which means that their electrical characteristics change very less with temperature changes. This makes sure consistent performance with varying.
- Environmental Considerations: Mine detectors might face harsh conditions like dust, moisture, and vibration. Selecting components with suitable ratings to make sure that they function well under these stresses. It is good to use sealed components, which are having industrial-grade connectors for added durability.
- Resistors: Metal-film resistors give better stability and good tolerances compared to carbon composed resistors. Look for 1% or 0.1% tolerance grades for such applications.
- Capacitors: Ceramic generally give good stability and tighter tolerances than electrolytic capacitors. Consider temperature-compensating capacitors for such applications.

- Inductors: High quality factor inductors give less signal loss and improve sensitivity. Look for pre-wound coils with tight tolerances of inductance or consider using specialized winding techniques for custom coils.
- Integrated Circuits (ICs): Military-grade or industrial-grade ICs are made with tighter tolerances and more temperature ranges compared to commercial ones.

#### 3.2.1.2 Additional Considerations:

**Matching Components:**

In some circuits, matching component values (e.g., pairing resistors or capacitors with identical values) provide improved performance and stability which is helpful.

**Testing and Calibration:**

Despite having tight tolerances, some initial calibration or adjustments can be required in the manufacturing or deployment process to make sure that the performance is optimal.

For this purpose, we have kept fine tuning resistor variable so we can fine tune the circuit and calibrate it with precision.

### 3.2.2 Boosting Sensitivity Pulse Induction (PI) Metal Detectors

Pulse Induction metal detectors excel at finding burried treasures, but increasing their sensitivity provides even greater potential. Below is a detailed breakdown of factors affecting PI detector sensitivity and strategies to increase their ability to detect small targets:

**Factors Affecting Sensitivity:**

**Pulse Characteristics:**

- Pulse Width: A wider pulse width provides more energy into the ground, increasing the depth of detection and sensitivity to bigger targets. However, very wide pulses can decrease overall detection speed (pulse repetition rate).
- Pulse Amplitude: A greater current amplitude in the pulse gets a stronger magnetic field, which results in good penetration and improved sensitivity. Limitations exist in this due to power consumption and the constraints in components.

**Search Coil Design:**

- Number of Turns: If you put more turns in the coil, what it does is that it increases sensitivity. But at the same time a higher coil resistance is created, which requires a more powerful transmitter circuit.
- Coil Size: Larger coils can cover more ground and detect targets with more depth. Still, they might also be less effective at pinpointing smaller objects.

**Signal Processing:**

- Filtering: Good filtering techniques remove background noise from signals, which allows the detector to differentiate faint target responses with others.
- Amplification: Amplifying the received signal increases its strength, which makes it easier to see weak responses from smaller or deeper targets. Even so, too much amplification can also amplify noise, which reduces the overall effectiveness of it.
- Integration Time: The integration time decides the window for taking the target signal. A greater integration time can better the sensitivity for weak signals but might also slow down the detection process.

**Strategies for Enhanced Sensitivity:**

- Optimizing Pulse Parameters: We experimented with pulse width and amplitude staying in reasonable limits to find the best balance between depth, sensitivity, and discrimination for our application.
- Coil Selection or Design: It is a common practice to use coils with more turns or a slightly larger size if your application wants deeper target detection. However, we are to ensure our circuit can handle the increased coil resistance.
- Advanced Signal Processing: It is a good practice to implement filtering techniques and using digital signal processing (DSP) methods to get weak target signals from noisy environments.

- Ground Balancing: Proper ground balancing takes away false positives caused by ground mineralization, allowing the detector to focus on actual target signals and improve sensitivity.
- Environmental Considerations: To reduce the effect of external noise sources like power lines or electromagnetic interference. We chose detection locations with minimal environmental noise for better sensitivity in the initial testing phase.

**Additional Considerations:**

- Trade-offs: Increasing sensitivity often involves trade-offs with other things such as discrimination, detection speed, or battery life. We designed our detector with minimum tradeoffs.
- Component Quality: We used high-quality components with tight tolerances to minimize the signal loss and improve overall system performance.
- Experience and Technique: Experienced detectorists can often improve their ability to identify small target signals by tuning their search techniques and understanding signal characteristics.

### 3.2.3 Putting it all together

**Pulse Generation:** The heart of our detector lies in the NE555 timer circuit. This IC generates short, high-current pulses that provide energy to the search coil. As the current travels through the coil, it creates a pulsed magnetic field.

- Improvement: The NE555 timer IC allowed us to control the pulse duration, affecting the depth of target detection and sensitivity to different object sizes. We experimented with different pulse widths while considering the impact on battery life.

**Eddy Current Induction**: When this expanding magnetic field encounters a conductive object (like metal), interesting physics comes into play. The changing magnetic field induces eddy currents inside the metal object. These are circulating electrical currents created by the interaction with the external magnetic field.

- Insight: The strength of the eddy currents depends on various factors like the size, conductivity, and depth of the metal object. A bigger or more conductive object will induce stronger eddy currents, providing a more prominent signal for detection.

**Signal Reception**: The beauty of a single-coil PI detector lies in its simplicity. The same coil that transmitted the pulse also acts as the receiver. As the magnetic field collapses after the pulse, the eddy currents in the metal generate a secondary magnetic field of their own. This opposing magnetic field is then "picked up" by the coil, inducing a voltage pulse in it.

- Challenge: This received signal is often weak, especially for deeply buried or small targets. This makes amplification more necessary and processing to make it usable for accurate detection.

**Signal Amplification**: To address the weak received signal, we had to incorporate an operational amplifier (op-amp) circuit. This circuit essentially takes the small voltage induced in the coil and amplifies it to a higher level.

- Improvement: To consider the type of op-amp to use. Selecting an op-amp with a high gain will significantly increase the signal strength. But, we had to ensure the chosen op-amp has a wide enough bandwidth to handle the frequency range of our detector's signal. Additionally, explore filtering techniques within the op-amp circuit to reduce unwanted noise before amplification. This ensures the microcontroller receives a clear and relevant signal for interpretation.

**Speaker Output**: Currently, the amplified signal from the op-amp is given to a speaker, creating an audible tone. The pitch or intensity of this tone might vary depending on the strength of the received signal, indicating the presence (or absence) of metal. However, this method can be subjective and lacks important information.

### Transitioning to Digital Feedback: Embracing Clarity

To provide a more informative user experience, we converted the analog signal from the op-amp into a digital format that the LCD display can understand. Here is a breakdown of the steps that were involved:

**Rectification**: As mentioned earlier, the speaker converts the AC signal (from eddy currents) into sound. However, for digital processing, we needed a DC voltage. This is where a rectifier circuit came in.

- Half-Wave Rectification: A simple and cost-effective solution. It uses one diode to allow current flow in one direction only, resulting in a pulsating DC voltage. While functional, it might not capture the full strength of the signal.
- Bridge Rectification: Offers full-wave rectification, converting both positive and negative halves of the AC waveform into positive DC voltage. This can improve the consistency and strength of the signal for processing by the microcontroller.

**Signal Amplification:** Even after rectification, the signal might still be weak. The op-amp circuit we already had in place plays an important role here. By adjusting the gain of the op-amp, we can further amplify the rectified DC voltage.

**Calibration:** Once we had integrated the rectifier circuit, we needed to fine-tune the gain of the op-amp to ensure the signal strength is within the optimal range for the ADC

### 3.2.4 Testing and observations

Having designed and fabricated the metal detector with a digital feedback system, the critical phase of testing arrived. This section details the testing procedures employed and the observed results:

**Laboratory Testing:**

- Multimeter and Oscilloscope: In a controlled lab environment. A multimeter proved invaluable in verifying circuit functionality by measuring voltages at various points. The oscilloscope served as a powerful tool for visualizing the signal characteristics. By observing the waveform of the transmitted pulse, received signal, and amplified voltage, we gained insights into the overall performance of the system.
- Testing Procedures: Specific details regarding the testing procedures employed with the multimeter and oscilloscope would be beneficial here. Mention the specific measurements taken (e.g., voltage levels at different circuit points, pulse width of the transmitted signal, frequency of the received signal). Additionally, describe how the

observed waveforms on the oscilloscope aided in understanding the system's behavior.

- Signal Strength Variations: During this phase, it was crucial to analyze how the signal strength varied based on the proximity and type of metal object introduced into the detection field. By systematically measuring the amplified voltage with the multimeter while introducing different metals at varying distances, a valuable understanding of the detector's sensitivity was established.

**Field Testing:**

- Following the successful lab trials, the metal detector was put to the ultimate test – a real-world environment. This provided an opportunity to assess its performance in various ground conditions and with diverse metal objects that might not have been readily available in the lab.
- Testing Methodology: Describe the chosen field-testing location and the types of ground conditions encountered (e.g., dry soil, sandy beach, mineralized ground). Explain the methodology for introducing different metal objects during the testing process.
- Detection Range: A critical aspect of field testing involved determining the effective detection range of the metal detector. This refers to the maximum distance at which the detector could consistently register a signal for a specific type and size of metal object. By systematically varying the distance between the search coil and the buried metal object, the detection range of 20cm for different ferrous metals was established.

### 3.2.5 Future considerations

While the current iteration successfully detects ferrous metals, there's always room for improvement:

- Ground Balancing: As you might have observed during field testing, mineralized ground can pose challenges for accurate metal detection. The inclusion of ground balancing functionality in the microcontroller code would allow the detector to compensate for these effects, leading to more reliable target identification in various environments.

- Discrimination Modes: Expanding the capabilities to differentiate between ferrous and non-ferrous metals would be a valuable addition. This could involve implementing signal processing techniques within the microcontroller or incorporating additional hardware components for more advanced discrimination.
- Search Coil Optimization: Exploring different coil sizes and winding configurations could be beneficial. A larger coil might offer increased depth penetration, while a smaller coil potentially provides better discrimination between closely spaced targets.

**Future Work: Pushing the Boundaries of our PI Metal Detector**

The success of your metal detector with digital feedback opens doors for exciting improvements:

**Enhancing Detection Capabilities:**

- Ground Balancing: Mitigate the effects of mineralized ground that can lead to false positives or mask smaller targets. Implement ground balancing functionality in the microcontroller code. This can be achieved by digitally subtracting the average ground signal from the received signal, resulting in a clearer picture of potential targets. Explore various software-based ground balancing algorithms like Automatic Ground Balancing (AGB) or Manual Ground Balancing (MGB).
- Discrimination Modes: Distinguish between ferrous and non-ferrous metals, offering a more informative search experience. Techniques for discrimination include:
    - Frequency Shift: Objects with different conductivities (ferrous vs. non-ferrous) will cause slight shifts in the received signal's frequency. By analyzing these shifts within the microcontroller code, the detector can potentially differentiate between material types.

    - Pulse Induction Delay (PID): This method relies on the decay time of the eddy currents within the target object. Ferrous metals typically have a slower decay compared to non-ferrous metals. By measuring the decay time, the microcontroller can potentially distinguish between the two categories.
    - Multiple Coils for Multiple scan frequencies: Advanced detectors utilize multiple coils with different frequencies. Analyzing the signal response from each coil can provide more information about the target's conductivity and size, allowing for more sophisticated discrimination capabilities.
- Search Coil Optimization: Experiment with different coil sizes and winding configurations to tailor the detector's performance:
    - Coil Size: Larger coils generally offer increased depth penetration for deeper targets. However, they might struggle with discrimination between closely spaced objects. Conversely, smaller coils can provide better target separation but might have a shallower detection range. Choose a coil size suitable for your primary search applications (e.g., deep relic hunting or shallow beach combing).
    - Coil Winding: Explore different winding configurations like Double-D coils or Concentric coils. Each design offers unique advantages and disadvantages in terms of sensitivity, discrimination, and depth penetration. Research the specific characteristics of different winding styles and choose one that aligns with your desired functionalities.

**Advanced Signal Processing:**

- Filtering Techniques: Implement digital filtering techniques within the microcontroller code to reduce noise and enhance the signal-to-noise ratio. This will lead to a cleaner signal for interpretation, improving target identification accuracy. Common filtering techniques include averaging filters and notch filters to eliminate specific noise frequencies.

- Fast Fourier Transform (FFT): For more advanced signal analysis, explore utilizing the Fast Fourier Transform (FFT) algorithm within the microcontroller's code (if processing power allows). FFT decomposes the received signal into its constituent frequencies, providing valuable insights into the target's characteristics. By analyzing the frequency spectrum, the microcontroller might be able to differentiate between different types of metals based on their unique frequency signatures.

**User Interface Enhancements:**

- Visual Signal Strength: Instead of a simple "Detect" or "Not Detect" message, explore displaying a visual representation of the signal strength on the LCD. A bar graph or numerical value could provide more nuanced information about the potential target's size or depth.
- Audio Feedback Options: While the focus has shifted to the LCD display, retaining some form of audio feedback can be beneficial. Consider implementing adjustable tones or beeps that vary in pitch or intensity based on signal strength, offering an additional layer of information to the user.

### 3.2.6 Conclusions

The journey of your PI metal detector is just beginning. By incorporating the suggested enhancements and exploring advanced techniques, you can transform it into a more sophisticated tool for treasure hunting. Despite its current success, the pulse induction metal detector continues to evolve, with future aimed at further enhancing its performance and capabilities. These plans include improvements in sensitivity, discrimination, and ease of use, as well as advancements in signal processing algorithms and integration with other technologies such as artificial intelligence and robotics. Additionally, research and development efforts are focused on reducing size, weight, and power consumption while maintaining or even improving detection performance.

Imagine the excitement of witnessing a visual representation of signal strength on the LCD, progressively increasing as you approach a potential treasure! Exploring options like bar graphs or even adjustable audio feedback can further enhance user engagement and satisfaction.

Looking ahead, the pulse induction metal detector holds immense promise for addressing emerging challenges in security, environmental monitoring, and humanitarian demining efforts. With ongoing innovation and collaboration across disciplines, it is poised to remain at the forefront of metal detection technology, ensuring safer and more efficient exploration and detection of buried metal objects in diverse settings and conditions.

## 3.3 Software

### 3.3.1 Introduction

After detection of the mines, it is crucial to implement a physical marking system as well as storing the data and displaying it. This chapter focuses on the design and implementation of the transmitter and receiver unit in the Mine Detection Rover (MDR) system, which plays a crucial role in detecting mines, marking their locations, and transmitting GPS coordinates to the receiver end for further action.

### 3.3.2 Design Considerations for the Transmitter Unit

The design of the transmitter unit is a complex process that requires careful consideration of various factors to ensure its effectiveness and reliability in real-world scenarios. Several key considerations drive the design process, aspects such as reliability, accuracy, power efficiency, and ease of integration. Each of these considerations plays a crucial role in shaping the design decisions and ultimately determining the performance of the transmitter unit.

**Reliability**

- Component Selection: Choosing high-quality components is fundamental to the design process. Factors such as the manufacturer's reputation, product specifications, and historical reliability data are taken into account during the selection process. Moreover, components are sourced from trusted suppliers to minimize the risk of counterfeit or substandard parts, which could compromise the overall reliability of the transmitter unit.

- Modular Design for Scalability: A modular design approach is adopted to enhance scalability and flexibility in the transmitter unit's architecture. Modular components, such as GPS module, radio modules, and power management modules, are designed to be easily interchangeable and upgradeable, allowing for seamless integration of new technologies and functionalities.
- Lifecycle Management and Obsolescence Mitigation: An integral part of the design process involves considering lifecycle management and obsolescence mitigation strategies to ensure long-term sustainability and supportability of the transmitter unit. Proactive planning for component lifecycle, including identification of potential end-of-life (EOL) parts, supplier discontinuations, and technology obsolescence, enables timely mitigation measures such as component substitutions, redesigns, or last-time buys. Moreover, partnerships with trusted suppliers and ongoing monitoring of industry trends allow for identification of emerging technologies and market developments, ensuring that the transmitter unit remains at the forefront of innovation and capability throughout its operational lifespan.

The transmitter unit is prepared to provide strong performance, reliability, and adaptability in the demanding and dynamic operational settings encountered in mine detection and localization missions by taking these thorough design concerns into account.

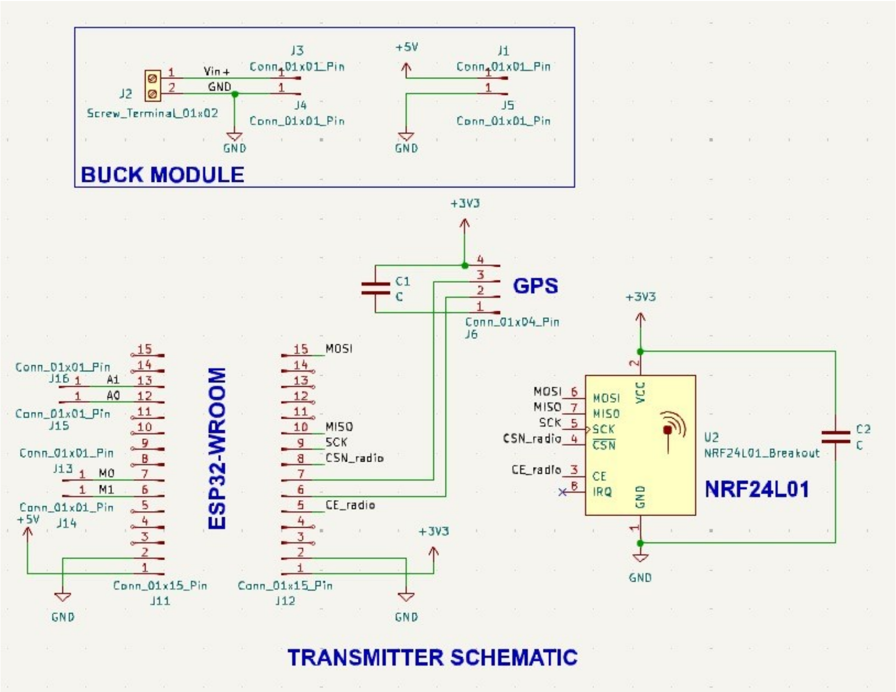


Fig32 Schematic of Transmitter

## Accuracy

- Signal Processing Algorithms: Signal processing algorithms play a crucial role in analyzing sensor data to extract meaningful information related to landmine detection. These algorithms are designed to filter out noise, enhance signal-to-noise ratios, and identify relevant features indicative of landmine presence. By leveraging these algorithms, the transmitter unit can achieve high accuracy and reliability in detecting landmines while minimizing false alarms, thus enhancing overall operational effectiveness.
- Actuator Precision: Precision actuators are essential for accurately deploying marking mechanisms to indicate detected landmine locations. Achieving actuator precision involves fine-tuning actuator parameters to ensure precise control of mechanical motion. For instance, servo motors, which are commonly used as actuators in mine detection systems. We are using a spray can to physically mark the mine location using  a servo motor.
- By emphasizing sensor calibration, signal processing algorithms, and actuator precision in the design of the transmitter unit, we ensure that it can effectively fulfill its role in detecting and localizing landmines.

**Power Efficiency**

- Low-Power Components: The selection of energy-efficient components is paramount in minimizing power consumption while maintaining optimal performance within the transmitter unit. By prioritizing low-power alternatives for key components such as microcontrollers, sensors, and communication modules, the overall energy consumption of the system is significantly reduced.
- Power Management: Sophisticated power management systems are integrated into the transmitter unit to regulate the distribution of electrical power among its various components effectively. These systems employ advanced techniques such as voltage regulation, power gating, and dynamic power scaling to optimize energy usage and minimize wastage. Voltage regulators ensure stable and efficient power delivery to sensitive components, preventing voltage fluctuations and ensuring consistent performance.

**Ease of Integration**

- Modular Design: The transmitter unit's modular design simplifies assembly, maintenance, and upgrades in field operations. Its modular components, like GPS modules and communication modules, allow quick replacement or customization without system disruption. This approach streamlines maintenance and enables swift field repairs, reducing downtime during mine detection missions.
- Scalability: The transmitter unit's scalable design allows for future upgrades and enhancements to accommodate evolving needs and technologies. Anticipating advancements in sensor technology or communication protocols, it permits incremental expansions without compromising existing functionality. This adaptability ensures peak performance and effectiveness, aligning with emerging demining methodologies and technological innovations.

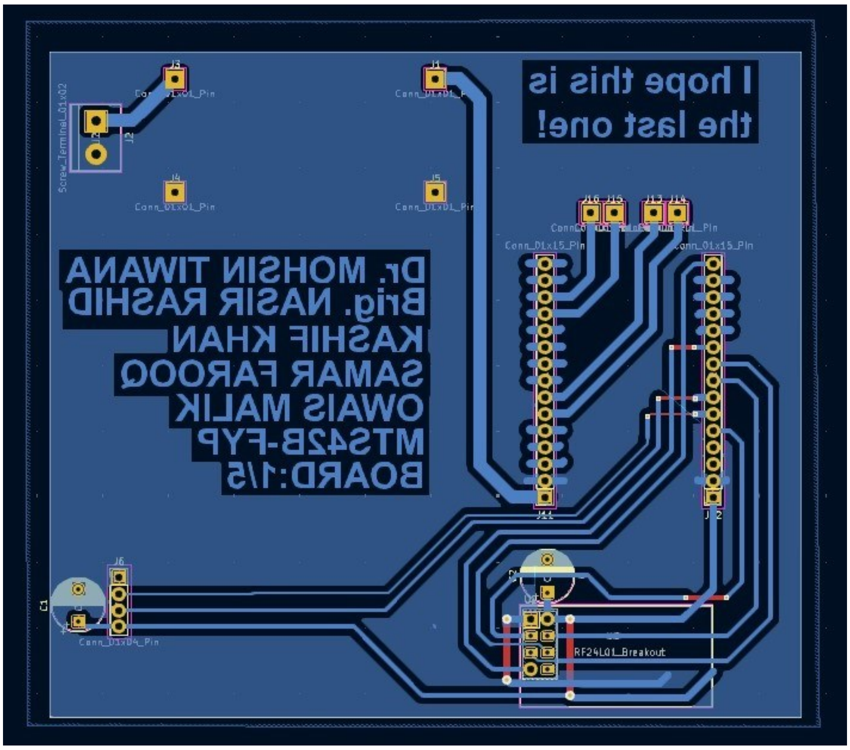


Fig33 PCB Layout of Transmitter Unit

### 3.3.3 Design Considerations for the Receiver Unit

Designing the receiver unit for the Mine Detection Rover system involves a meticulous process that prioritizes unique considerations tailored to its role and form factor. From ensuring reliability to optimizing user interaction, each aspect is carefully addressed to deliver a seamless and efficient receiver unit.

**Interoperability and Connectivity**

- Wireless Communication: In its design, the receiver unit integrates advanced wireless communication capabilities, enabling seamless reception of critical data such as GPS coordinates and other relevant information transmitted from the companion transmitter unit. This wireless functionality ensures real-time updates on mine locations, enhancing operational awareness and facilitating prompt decision-making during demining missions.
- Compatibility with External Devices: The receiver unit is engineered with a focus on interoperability, featuring standardized interfaces and

communication protocols that facilitate seamless integration with a wide range of external devices.

By addressing these design considerations, the receiver unit is tailored to meet the unique requirements of handheld operation while ensuring reliability, accuracy, and ease of use in mine detection applications.

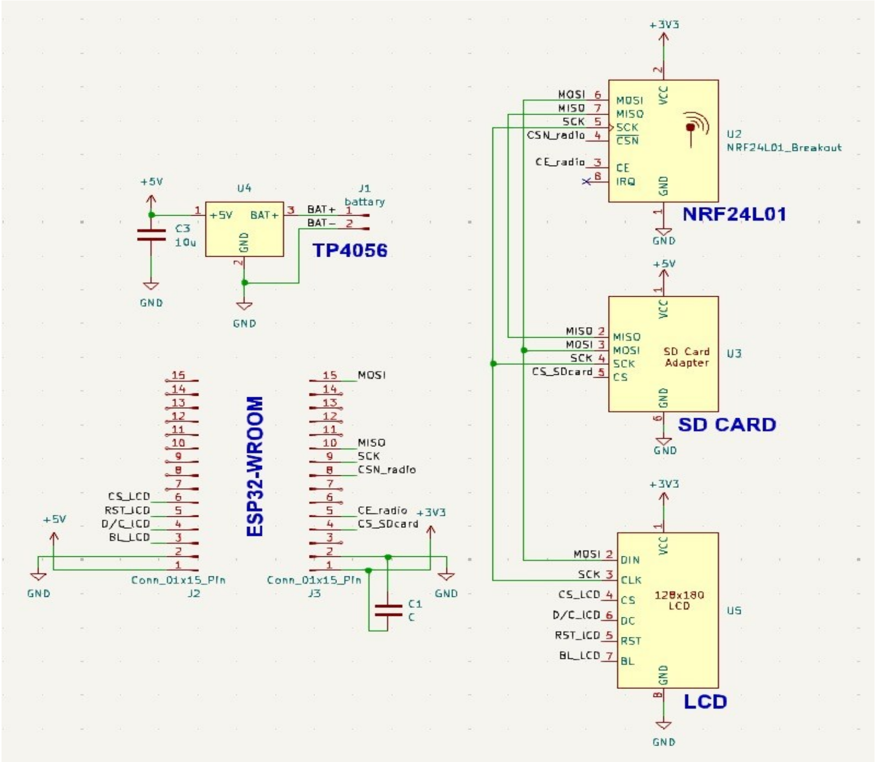


Fig34 Schematic of Receiver Unit

### 3.3.4 Hardware Architecture

The hardware architecture of the transmitter unit is meticulously designed to facilitate the seamless integration and operation of various components, each fulfilling a specific function critical to the mine detection process. This section provides an in-depth overview of the interconnected components comprising the hardware architecture:

**Metal Detector**

The transmitter unit receives signal from the metal detector and based on that, it operates the actuator and the physical and virtual marking system.

**Servo Motor**

The servo motor is used with a mounting and a spray can for a physical marking system.

**GPS Module**

In order to enable precise mapping and localization, the GPS module is essential in supplying the geographic locations of landmines that have been discovered.

**Microcontroller**

Considerations in microcontroller selection include processing power, memory capacity, and compatibility with peripheral devices and communication protocols. For our application, we didn’t need high computational power, so we used ESP32.

**Communication Module**

Factors such as transmission range, data rate, and interference resistance are crucial in selecting an appropriate communication module for integration into the transmitter unit. We have used the NRF-2401 radio transceiver module in order to communicate between transmitter and receiver.

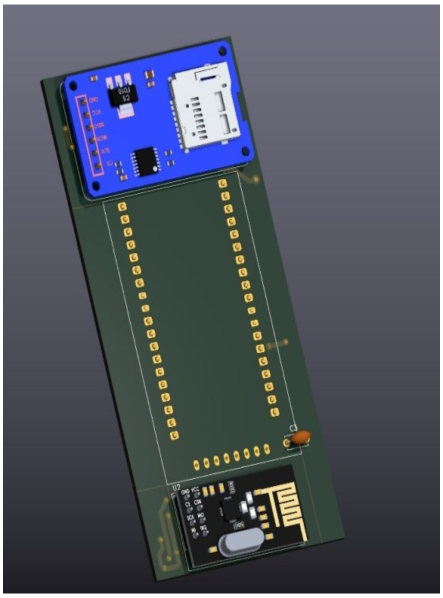


Fig35 PCB (front) of Receiver Unit

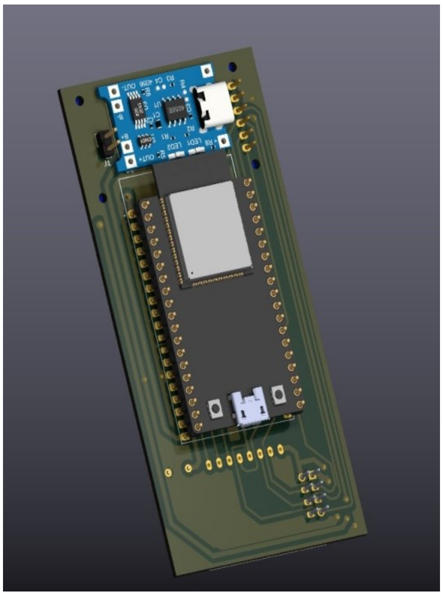


Fig36 PCB (back) of Receiver Unit

### 3.3.5 Software Implementation

The successful operation of the transmitter unit relies not only on its hardware components but also on sophisticated software algorithms that handle sensor data processing, actuator control, and communication protocols management. This section delves into the intricate software implementation of the transmitter unit, highlighting the development process, programming languages, and key functionalities.

**Key Functionalities**

The software algorithms developed for the transmitter unit encompass a range of key functionalities essential for its operation:

- Actuator Control: Actuator control algorithms regulate the exact functioning of actuators, namely servo motors, guaranteeing precise placement of marking devices at identified landmine sites. The movement of actuators is coordinated by these algorithms, ensuring accurate and effective marking.
- Communication Protocol Management: The smooth control of wireless communication protocols by communication protocol management algorithms allows for the dependable real-time transfer of vital mine location data from the transmitter unit to the receiver unit. These algorithms provide prompt reactions to landmine detections by guaranteeing reliable and effective communication routes.
- System Monitoring and Diagnostics: The transmitter unit's performance and health are regularly evaluated by the system monitoring and diagnostics processes, which identify abnormalities or errors and provide comprehensive diagnostic data for troubleshooting. This proactive strategy guarantees the unit's robustness and dependability in a variety of operating environments.
- User Interface: The software may provide an easy-to-use interface for configuring, monitoring, and interacting with the transmitter unit, depending on the particular requirements of the application. Even with little training, this interface's easy controls and visualization tools improve usability and effectiveness.

The transmitter unit can interpret sensor data, control actuators, and effectively handle communication by utilizing complex software algorithms written in Python or C/C++. This allows for dependable and accurate mine detection and localization operations.

### 3.3.6 Testing and Validation

The transmitter unit is put through testing and validation procedure after it has been manufactured and programmed to make sure it satisfies the required performance standards. This section describes the many testing and validation phases that are used to confirm the unit's correctness, robustness, and dependability. These phases include field testing, endurance testing, and functional testing.

**Functional Testing**

Functional testing is conducted to verify that each component of the transmitter unit performs its intended function accurately and reliably. This testing involves:

- **Sensor Accuracy Testing:** The accuracy of sensor measurements may be fully evaluated by carefully examining the differences between expected and observed data, guaranteeing dependable performance in actual mine detecting settings.
- **Actuator Functionality Testing** Mine detection activities can be performed to their fullest capacity by rapidly identifying and fixing any potential faults or functional shortcomings by closely examining the responsiveness, precision, and repeatability of actuator motions under various conditions.
- **Communication Protocol Testing:** The efficiency of communication protocols may be evaluated by looking at elements like data integrity, latency, and error handling methods. This will guarantee that crucial mine location data is continuously exchanged between units in the field.

### Conclusion

The development of the Mine Detection Rover (MDR) system has reached a noteworthy milestone with the design and installation of the transmitter unit.

As a cornerstone for effective and dependable mine detection and localization, the transmitter unit combines state-of-the-art sensor technologies, precise actuation mechanisms, and robust communication protocols. The transmitter unit is a key component in reducing the hazards involved with conventional demining techniques and providing a safer and more efficient substitute by utilizing cutting-edge technical solutions.

Even though the transmitter unit is a noteworthy accomplishment, more research and development efforts can benefit from it. The global endeavor to remove landmines and establish safer surroundings for impacted populations requires constant improvement of the system's functionality and dependability. Stakeholders may work together to achieve the common objective of a landmine-free future, in which vulnerable communities are no longer threatened by unexploded ordnance, by cultivating a culture of innovation and cooperation.

# CHAPTER 4 - RESULTS

This section includes the results that we achieved In our hardware and software section. We were able to acquire the desired penetration depth of 30cm and detect buried metal up to depth of 30cm. After extensive prototyping and simulation we finally finalized the circuit for our metal detector sensor.

## 4.1 Device Hardware:

We successfully fabricated the circuit of our device. We made a single layer PCB from the schematic describing chapter 3. Our hardware device include:

- ESP32
- NRF24L01
- GPS Neo-6 Ublox
- Batteries
- Tx and Rx coils
- On off switch
- Metal detector Circuit
- Acrylic structure

We were able to power-up the whole hardware and integrate multiple boards together. All 3 metal detector circuits work independently and the data they collect is fed into ESP32 where it is processed to register a mine into the system and give coordinates when a certain threshold value is triggered.

The operator end board receives data from the rover and the rover can be moved to any direction with a provided dedicated remote.

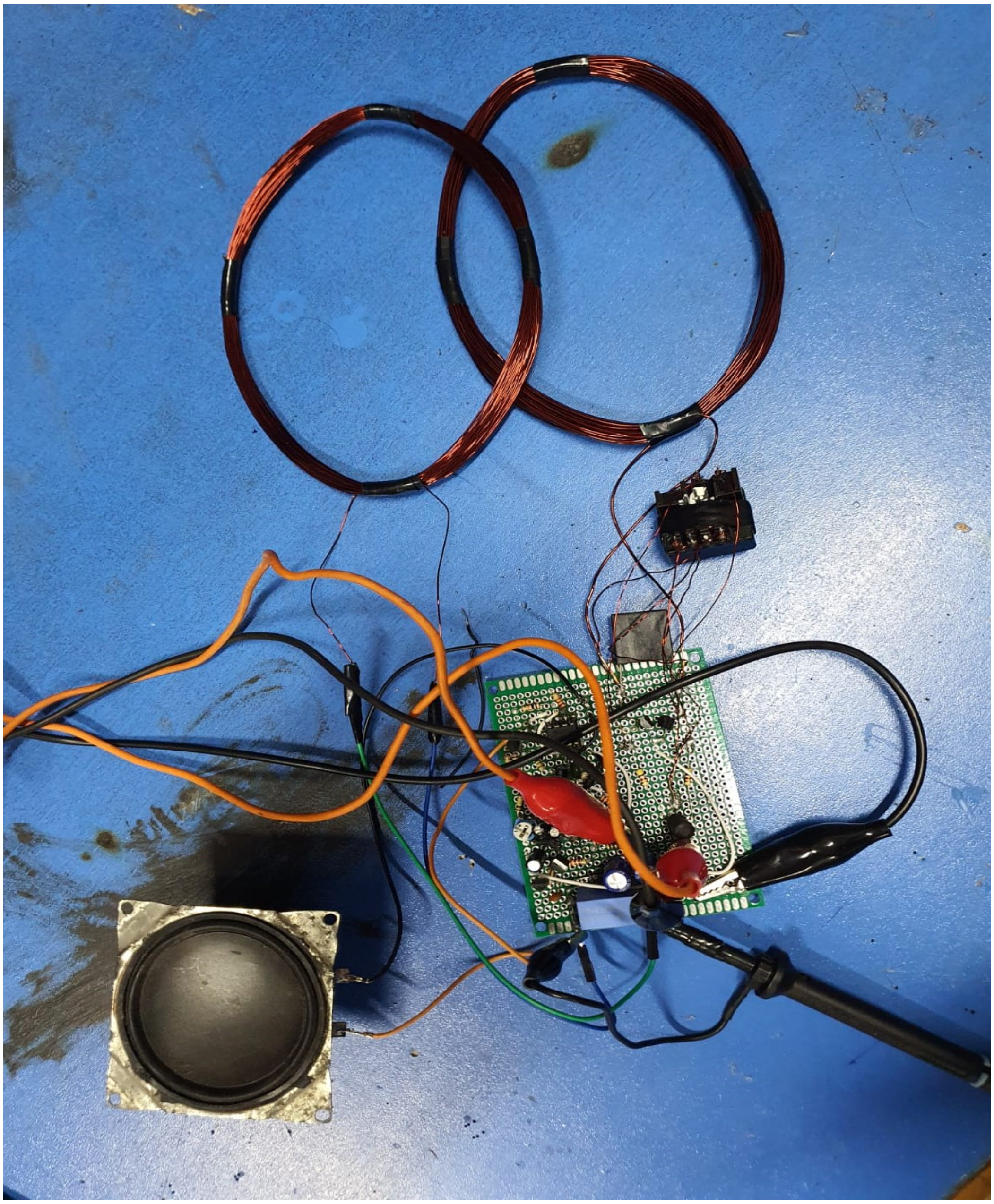


Figure 37 represents the complete hardware of our Metal detector.

We have our bespoke designed transformer for this use case which is pulled out of a used SMPS supply and unwound and then wound with 0.5mm gauge wire to get an oscillation frequency of around 12KHz.

The Transformer has 32 turns each using half a millimeter(0.5mm) diameter wire and 16 turns. This has reduced the value of base resistor of BC547 in the transmitter circuit to 4.7K. The secondary transmitter coil has 64 turns of 0.7mm which has significantly reduced the total power of the transmitter circuit. The value came out to be 820uH which can be seen in the figure: 43.

Figure 38

The transmitter coil has a frequency of ~12KHz. There is a parallel capacitor with the Tx coil to reduce the power draw furthermore. The consumption depends on the type of capacitor you use and it's still the same capacitance but it may draw different power based on the losses in the capacitor and coil.

The receiver coils has 30 turns of 0.3mm copper with 120mm diameter, THe inductance value came to 240uH can be seen in the figure 44:

Figure 39

And by using a better capacitor, We reduced the power consumption of the transmitter by about 40 percent and the capacitors have the same capacitance. Right now the current draw is 80mA at 5V.

There is about 2.5 volt on the Collector of the first transistor because we are actually interested in just the positive Half cycle. This makes more sense to give headroom to the positive side rather than to the negative side. So it has enough Headroom to swing into the positive, then there is this modulation transistor and the signal without loading this amplifier too much and it basically charges this capacitor to the peak level of this signal. Kind of a low pass filter that is still, of course, some high frequency capacitor, but not too much. And then the next stage is our frequency and low pass band pass, basically just a slow change on this capacitor. The bandwidth of it is something like from one quarter of a Hertz to about 5 Hertz or 10 Hertz, basically those frequencies that you can generate biomechanical motion by physically moving the coil. Then there is this first stage of the amplifier and its coupled into the next stage, which is an amplifier but also an active pass filter. It has negative feedback via this capacitor so it doesn't pass high frequencies and of course this is to get rid of stray interference and also to get rid of any noise between the silences.

The sensitivity goes down when you swipe too fast, capacitors are placed before bases  of the transistors to protect it against too high negative voltage.

For tuning the circuit using a potentiometer instead of moving the coils and it kind of works a small voltage comes from the transformer and you can set it using a potentiometer and the voltage from the receiver coil to basically set in a balance it with the transmitter coil, you can increase the voltage in One Direction or other direction. The most sensitive. When you tune it, to the steepest point of the curve and white impossible to completely cancel out the voltage. I think it's because the signal comes to the receiver coil with different phase shifts. Some of the signal comes from the transmitter coil directly but it also comes with some face shift and also maybe capacitively coupled to it by moving the coils. You can't cancel out the phase shifted signals and also the circuitry with the potentiometer couldn't cancel it with and we haven't tested it yet.

## 4.2 Transmitter Coils Signal:

Our transmitter coil has 50 turns of 0.7mm copper with a diameter of 120mm.

The coils is molded to D-shape instead of circular shape for better cancellation of signals.

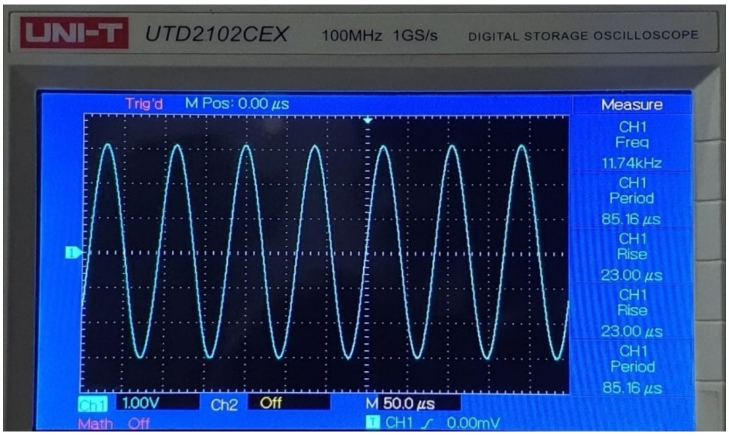


*Figure 40 Tx Singal*

This Shows frequency of 11.74KHz which is quite close to 12KHz what we wanted.

Amplitude of 6.0Vpk-pk with very nice sine form.

## 4.3 Null Setting/Calibration:

For this we have to manually place the coil in a way that they overlap each other with minimum amplitude on the receiver end of the circuit. This is very sensitive to motion and the Null setting is very critical and needs a lot of fine adjustment.

It can be more finely tuned with moving in or out  single turn of Rx coil.

After nulling out the circuit the best setting we got is:

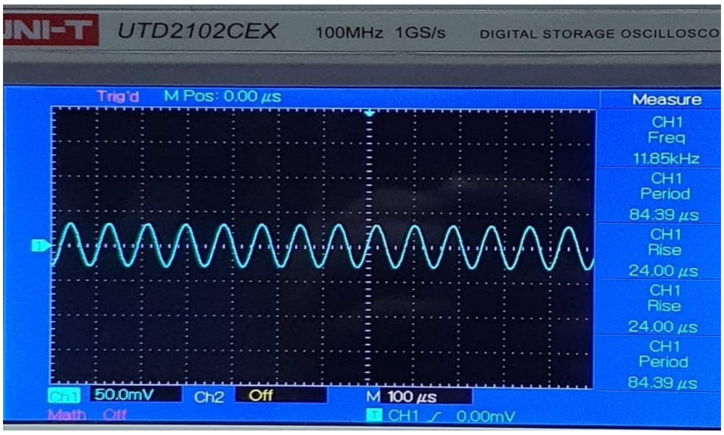


*Figure 41 Response of our complete circuit*

As it can be seen the Null setting gives almost 40mV pk-pk value and there is complete silence on the speaker.

# CHAPTER 5 - CONCLUSIONS AND FUTURE WORK

In this methodology, we have discussed the process of fabricating a metal detector sensor which will help to detect landmines buried underneath earth’s surface with a depth of up to 30cm. Precision machining and assembly techniques were employed to fabricate PCB and assemble the detector's electronic circuitry. The sensor underwent extensive testing to guarantee its dependability in practical scenarios. This involved field testing to replicate real-world operating situations and laboratory testing to assess its accuracy and robustness. These tests validated the sensor's reliable and consistent landmine detection functionality.

Along with this we have designed and manufactured a mechanism which will be mounted on a base, to which the metal detector coils will be attached. This mechanism was designed to maintain a constant ground clearance mechanically. To obtain a thorough understanding of the structure's stress distribution, deformation properties, and overall mechanical behavior under varied load circumstances, we have performed FEM analysis on it.

Finally, a transmitter and receiver circuit that can communicate and display landmine information over a 100-meter range has been fabricated by us. Ensuring precise and timely delivery of crucial information, the transmitter transmits real-time data to the receiver about the landmines identified. On the receiving end, this data is saved on an SD card for later use and shown on a user interface for instant examination. This configuration provides a dependable communication and data storage method across a considerable distance, which improves the effectiveness and safety of the landmine detecting procedure.

1. Enhanced Sensor Integration: Further research may concentrate on the integration of other sophisticated sensors, such infrared or ground-penetrating radar, to supplement the metal detector. Enhancing the detecting capabilities would enable the system to recognize non-metallic landmines and offer a wider range of coverage.
2. Enhanced Autonomy and Navigation: By creating complex algorithms for obstacle avoidance and autonomous navigation, the rover will be better equipped to function autonomously in a variety of difficult environments without the need for human

assistance. Using machine learning techniques can also enhance the rover's ability to make decisions and work more effectively while detecting mines.

3. Real-Time Data Analysis and Visualization: By adding these features to the system, it will be possible to get quick feedback and insights on the landmines that have been found. Providing operators with a graphical user interface (GUI) will improve their situational awareness and ability to make decisions.
4. Simulation Based Training Environment: By creating a comprehensive simulation, operators can get practice utilizing the mine detection rover in a safe and regulated environment. With the ability to replicate a variety of terrains, weather patterns, and mine types, this virtual training tool offers operators a realistic setting in which to hone their abilities. Operators can be better prepared for actual clearing missions by understanding their progress and pinpointing areas for development with the use of comprehensive performance reports and real-time feedback.
5. Energy Efficiency and Power Management: The rover's operating time can be increased and its requirement for regular recharging can be decreased by improving its energy efficiency and putting advanced power management procedures into place. Investigating renewable energy sources, such solar panels, can offer long-term missions sustainable power options.

In conclusion, further development of the mine detection rover can concentrate on incorporating cutting-edge sensors, boosting wireless communication, increasing autonomy, creating tools for real-time data analysis, building durability, carrying out comprehensive field testing, implementing a modular design, and increasing energy efficiency. These initiatives will help develop a landmine detecting system that is more efficient, dependable, and adaptable.

# APPENDIX A

```
#include<stdio.h>
#include"freertos/FreeRTOS.h"
#include"freertos/task.h"
#include"driver/uart.h"
#include"esp_system.h"
#include"esp_log.h"
#include"nvs_flash.h"
#include"RF24.h"
#include"TinyGPS++.h"
#include"esp_timer.h"
#include"driver/gpio.h"
#include"esp_serial_task.h"
#include"servo_control.h"

#defineRX_PIN16
#defineTX_PIN17
#defineGPS_BAUD9600
#defineMINE_PIN134 // Analog pin connected to the first mine detection
sensor
#defineMINE_PIN235 // Analog pin connected to the second mine detection
sensor
#defineSERVO_PIN9

RF24 radio(4, 5);  // CE, CSN
TinyGPSPlusgps;

staticconstchar *TAG = "MAIN";

voidgps_task(void *pvParameters) {
    while (true) {
        intbytes_read = uart_read_bytes(UART_NUM_2, data, BUF_SIZE, 20 /
portTICK_RATE_MS);
        for (inti = 0; i<bytes_read; i++) {
            gps.encode(data[i]);
        }
        vTaskDelay(100 / portTICK_RATE_MS);
    }
}

voidsend_location(constchar *location_str) {
    radio.write(&location_str, strlen(location_str));
}

voidapp_main() {
    ESP_ERROR_CHECK(nvs_flash_init());
```

```
    uart_config_tuart_config = {
        .baud_rate = GPS_BAUD,
        .data_bits = UART_DATA_8_BITS,
        .parity = UART_PARITY_DISABLE,
        .stop_bits = UART_STOP_BITS_1,
        .flow_ctrl = UART_HW_FLOWCTRL_DISABLE
    };
    uart_param_config(UART_NUM_2, &uart_config);
    uart_set_pin(UART_NUM_2, RX_PIN, TX_PIN, UART_PIN_NO_CHANGE,
UART_PIN_NO_CHANGE);
    ESP_ERROR_CHECK(uart_driver_install(UART_NUM_2, 2048, 2048, 10, NULL,
0));

    gpio_pad_select_gpio(MINE_PIN1);
    gpio_set_direction(MINE_PIN1, GPIO_MODE_INPUT);
    gpio_set_pull_mode(MINE_PIN1, GPIO_PULLUP_ONLY);
    gpio_pad_select_gpio(MINE_PIN2);
    gpio_set_direction(MINE_PIN2, GPIO_MODE_INPUT);
    gpio_set_pull_mode(MINE_PIN2, GPIO_PULLUP_ONLY);

    servo_control_init(SERVO_PIN);

    radio.begin();
    radio.openWritingPipe(address);
    radio.stopListening();

    while (true) {
        vTaskDelay(1000 / portTICK_RATE_MS);

        int sensorValue1 = analogRead(MINE_PIN1);
        int sensorValue2 = analogRead(MINE_PIN2);

        if (sensorValue1 >500 || sensorValue2 >500) {
            ESP_LOGI(TAG, "Mine detected!");
            servo_control_write_angle(60); // Rotate servo motor to 60
degrees
            vTaskDelay(1000 / portTICK_RATE_MS); // Wait for servo to move

            charlocation_str[50]; // Define character array for storing
latitude and longitude

            // Convert latitude and longitude to character arrays
            charlatitude_str[20];
            charlongitude_str[20];
            dtostrf(gps.location.lat(), 10, 6, latitude_str);
            dtostrf(gps.location.lng(), 10, 6, longitude_str);
```

```
            // Concatenate latitude and longitude into a single string
            sprintf(location_str, "%s %s", latitude_str, longitude_str);

            // Print location string
            ESP_LOGI(TAG, "%s", location_str);

            send_location(location_str);
        }
    }
}
```

# APPENDIX B

```
#include<stdio.h>
#include"freertos/FreeRTOS.h"
#include"freertos/task.h"
#include"freertos/event_groups.h"
#include"esp_system.h"
#include"esp_wifi.h"
#include"esp_event.h"
#include"esp_log.h"
#include"nvs_flash.h"
#include"driver/gpio.h"
#include"RF24.h"
#include"WebServer.h"

#defineWIFI_SSID"iPhone"
#defineWIFI_PASS"samarfrq"

#defineRX_PIN16
#defineTX_PIN17
#defineMINE_PIN2

staticconstchar *TAG = "MAIN";

WebServerserver(80); // HTTP server on port 80

String mineCoordinates = "N/A";
intnumMinesDetected = 0;

RF24 radio(4, 5);  // CE, CSN
constuint64_t address = 0x00001;

esp_err_twifi_event_handler(void *ctx, system_event_t *event) {
    switch(event->event_id) {
```

```
        case SYSTEM_EVENT_STA_START:
            esp_wifi_connect();
            break;
        case SYSTEM_EVENT_STA_CONNECTED:
            break;
        case SYSTEM_EVENT_STA_GOT_IP:
            ESP_LOGI(TAG, "Connected to AP");
            ESP_LOGI(TAG, "IP Address: %s", ip4addr_ntoa(&event-
>event_info.got_ip.ip_info.ip));
            server.begin();
            ESP_LOGI(TAG, "HTTP server started");
            break;
        case SYSTEM_EVENT_STA_DISCONNECTED:
            ESP_LOGI(TAG, "Disconnected from AP");
            break;
        default:
            break;
    }
    return ESP_OK;
}

voidwifi_init_sta() {
    tcpip_adapter_init();
    ESP_ERROR_CHECK(esp_event_loop_init(wifi_event_handler, NULL));
    wifi_init_config_tcfg = WIFI_INIT_CONFIG_DEFAULT();
    ESP_ERROR_CHECK(esp_wifi_init(&cfg));
    wifi_config_twifi_config = {
        .sta = {
            .ssid = WIFI_SSID,
            .password = WIFI_PASS
        }
    };
    ESP_ERROR_CHECK(esp_wifi_set_mode(WIFI_MODE_STA));
    ESP_ERROR_CHECK(esp_wifi_set_config(ESP_IF_WIFI_STA, &wifi_config));
    ESP_ERROR_CHECK(esp_wifi_start());
}

voidsetup() {
    ESP_ERROR_CHECK(nvs_flash_init());

    ESP_LOGI(TAG, "Initializing WiFi");
    wifi_init_sta();

    gpio_pad_select_gpio(MINE_PIN);
    gpio_set_direction(MINE_PIN, GPIO_MODE_INPUT);
    gpio_set_pull_mode(MINE_PIN, GPIO_PULLUP_ONLY);
```

```
    radio.begin();
    radio.openReadingPipe(1, address);
    radio.startListening();

    server.on("/", HTTP_GET, [](WebServerRequest request) {
        request.send(200, "text/html", getHomePage());
    });

    server.begin();
}

voidloop() {
    server.handleClient();

    if (radio.available()) {
        charlocationStr[50]; // Define a character array to store received
data
        radio.read(&locationStr, sizeof(locationStr)); // Read data into the
character array

        // Print received data on Serial Monitor
        ESP_LOGI(TAG, "Received data: %s", locationStr);

        // Update mine coordinates
        mineCoordinates = locationStr;

        // Increment the number of mines detected
        numMinesDetected++;
    }

    vTaskDelay(100 / portTICK_PERIOD_MS); // Delay to handle HTTP requests
}

String getHomePage() {
    String page = "<!DOCTYPE html><html><head><title>Mine Detection
System</title>";
    page += "<style>body { font-family: Arial, sans-serif; margin: 0;
padding: 0;}";
    page += "header { background-color: #333; color: #fff; padding: 10px;
text-align: center;}";
    page += "h1 { margin: 0; }";
    page += ".container { max-width: 800px; margin: 20px auto; }";
    page += ".info { margin-bottom: 10px; }";
    page += "</style></head><body>";
    page += "<header><h1>Mine Detection System</h1></header>";
    page += "<div class='container'>";
    page += "<div class='info'><strong>Mine Coordinates:</strong><br><span
id='mineCoordinates'>" + mineCoordinates + "</span></div>";
```

```
    page += "<div class='info'><strong>No of mines
detected:</strong><br><span id='numMinesDetected'>" +
String(numMinesDetected) + "</span></div>";
    page += "</div></body></html>";
    return page;
}
```

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