Autonomous Aerial Mine Detector

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خطر!! ألغام!!
DANGER!! MINES!!

Outline

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- Landmines
  - Overview and Impact of landmines

- Objectives

- Ground-Penetrating Radar
  - Overview of Continuous Wave Radar System
  - GPR Principles

- Software Defined Radio
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  - Types of antennas used
  - Oscillator
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  - Components used and Autonomous Setup
- Long term improvement possibilities
- Results and Conclusion

Introduction

Problem Statement

- Mines are the number one war leftover an estimated 15,000 to 20,000 people are killed every year

- It has been estimated that children account as victims for one in every five landmines

Introduction

Project Need and Objective Statement

- There are 110 million landmines in 64 countries, one of those countries is Lebanon which has 550 thousand mines embedded in its ground

- Damage caused by landmines doesn’t only hurt humans directly

- The aim of this project is to design an automated system that can detect mines in efficient and risk free method

Landmines

Overview

- A landmine by definition is an explosive device concealed under the ground made specifically to either destroy or to disable enemy targets
- Landmines are one of the oldest weapon systems and can be traced back to 2500 BC
- The technique was borrowed by military engineers who dug mines and packed them with explosives

Landmines

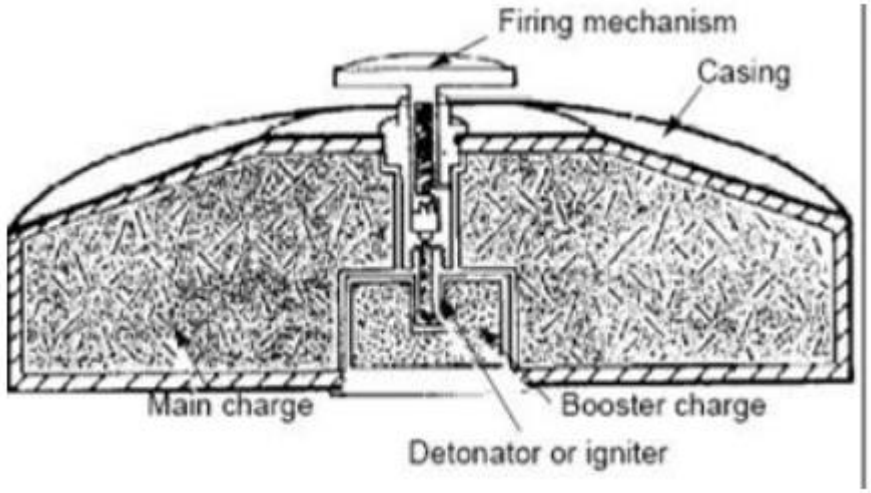
Types

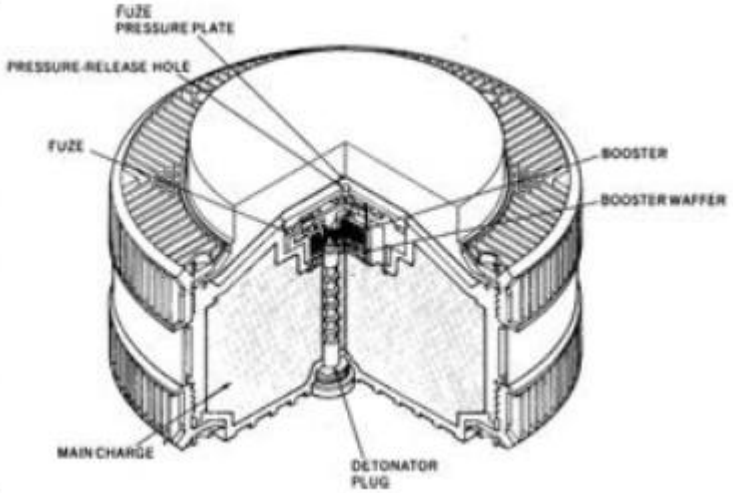
- Anti-Personnel Mines (AP), Anti-Vehicle Mines (AV), Cluster Bombs

- The main difference is between them:
  - Size
  - Shape
  - Buried Depth

- Main component targeted is the metal casing

Landmines


Firing mechanism
Casing
Main charge
Booster charge
Detonator or igniter


FUZE
PRESSURE PLATE
PRESSURE-RELEASE HOLE
FUZE
BOOSTER
BOOSTER WAFFER
MAIN CHARGE
DETONATOR
PLUG

Landmines

Lebanese Soil Contamination

- Lebanese wars and clashes that occurred:
  - Civil War from 1975 till 1990
  - Clashes with Israel in the south 1990 till 2000
  - War of July 2006

- As a result:
  - 4.5 million landmines are embedded in Lebanese Soil
  - the July war alone left 4 million cluster bombs
  - An estimated area of 55 Km^2 is contaminated
  - Around 250 million USD are needed for clearing these landmines by the year 2021

Ground-Penetrating Radar

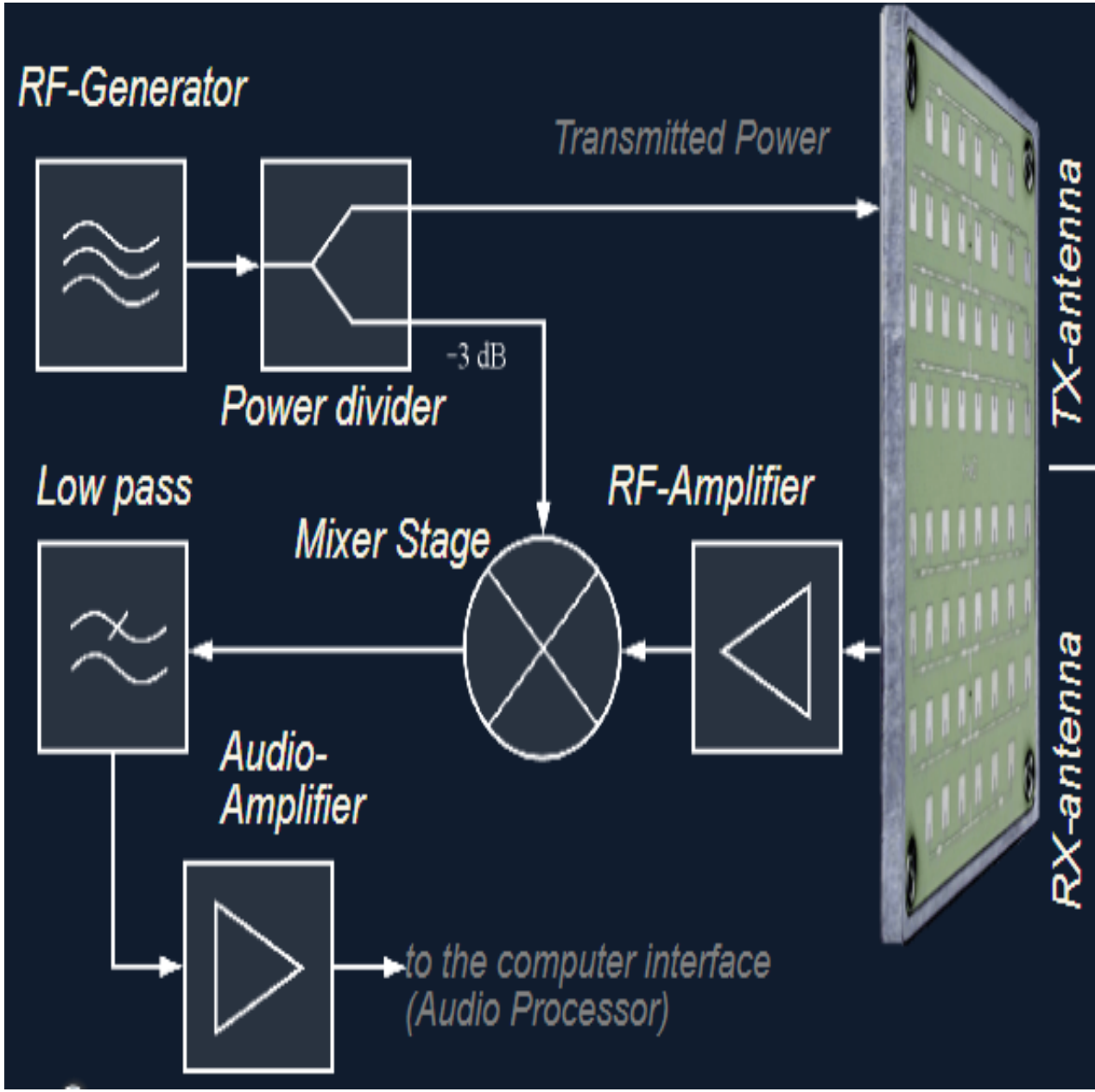
Introduction

- Radar System:
  - A transmitter sends out an electromagnetic signal in a specific direction
  - The wave then travels through space until it reaches an object like a plane or in ground landmine
  - The signal then bounces off the object and some it gets reflected back to the radar system

Ground-Penetrating Radar

Introduction

- Radar System:
  - Signal is generated using an RF-Generator
  - The Transmitter antenna, transmits an RF electromagnetic wave at 750 MHz
  - The Receiver antenna receives a bounced back signal from the target that is absorbed by the receiving antenna



Ground-Penetrating Radar

Definition

- Ground-penetrating radar (GPR) is a sensor which has a good potential for use in buried landmine mine detection

- GPR works by sending a tiny pulse of energy into a material and recording the strength and time required for the return of any reflected signal

- Reflections are produced whenever the energy pulse gets reflected from material with different electrical conduction properties or dielectric permittivity

Ground-Penetrating Radar

Properties

- Materials with a high dielectric will slow the wave making; it's not able to penetrate any further into the ground, since, the velocity with which electromagnetic waves propagate through a dielectric medium is always less than the velocity with which they propagate through a vacuum

  $v = \frac{c}{\sqrt{\varepsilon r}}$ (m/s)

- Materials with high conductivity will attenuate the signal rapidly, such as metals that are considered to be complete reflectors

Ground-Penetrating Radar

Types

- Continuous Wave Radar
  - Frequency Domain
  - Emit EM radiation continuously
  - Measures instantaneous rate-of-change

- Pulse Wave Radar
  - Time Domain
  - Emit EM radiation as pulses
  - Uses time intervals for detection

Ground-Penetrating Radar

GPR Principles

- Electromagnetic Wave Propagation in Soil
- Reflection of Electromagnetic Wave from Landmines in Soil
- Signal Power Loss
- Time Delay Model

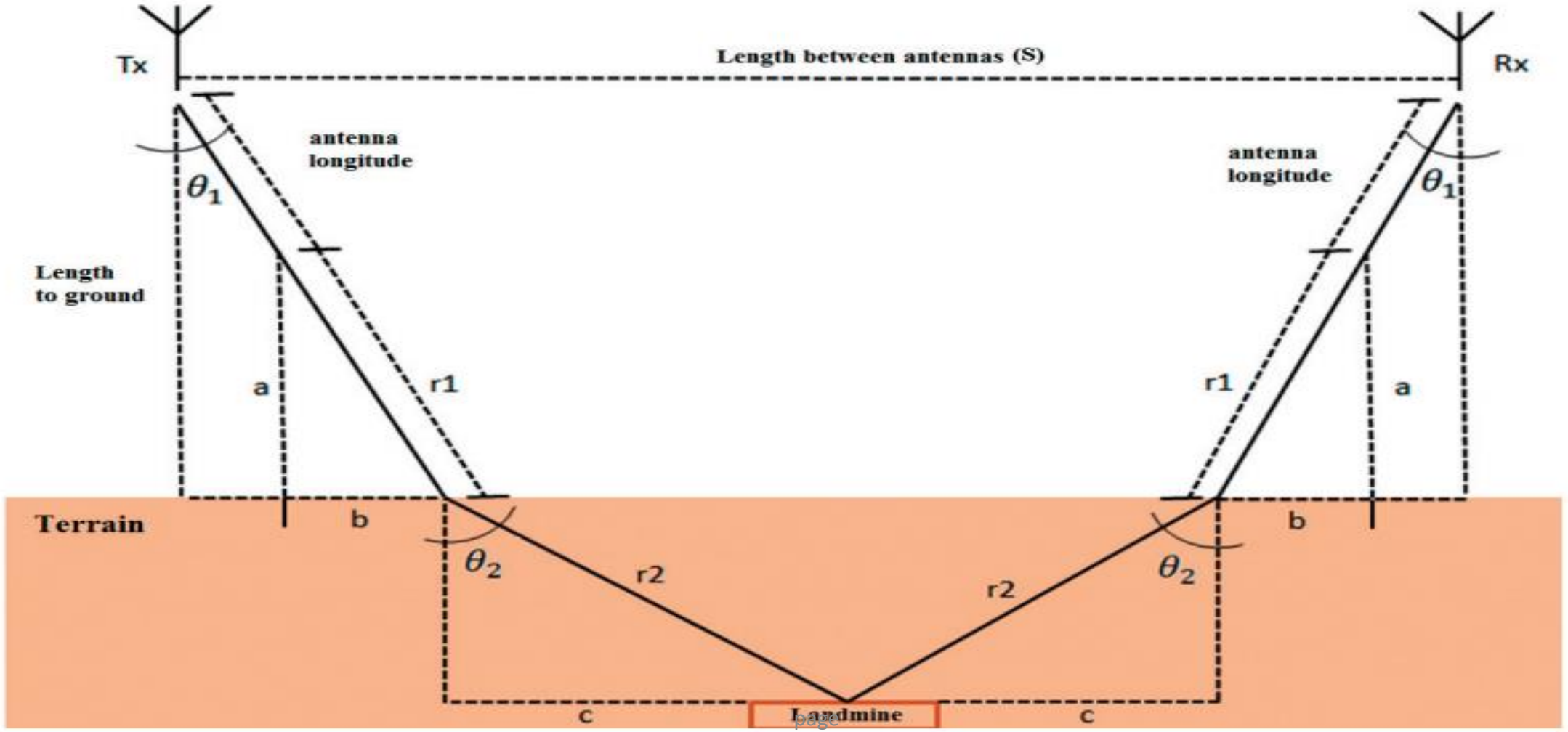
Ground-Penetrating Radar

Electromagnetic Wave Propagation in Soil

- Electric properties of the materials is determined by their conductivity, permittivity and permeability.
- Permittivity is the most important parameter for GPR
- GPR measures the reflected electromagnetic wave from the subsurface structure.

Ground-Penetrating Radar

Reflection of Electromagnetic Wave from Landmines in the Soil



Ground-Penetrating Radar

Reflection of Electromagnetic Wave from Landmines in the Soil

- Important parameter calculations:
  - Snell law: $\frac{\sin(\theta)_2}{\sin(\theta)_1} = \frac{n_1}{n_2}$
  - $\sin(\theta_1) = \sqrt{\Sigma_2}\ \sin(\theta_2)$
  - $a = 0.4 - 0.33\cos(\theta_2)$
  - $r_1 = \frac{a}{\cos(\theta)_1}$, $r_2 = \frac{0.15}{\cos(\theta)_2}$
  - $S = 2[\sin(\theta_1)\,(0.33 + r_1) + \sin(\theta_2)\,r_2]$

Ground-Penetrating Radar

Signal Power Loss

- The signal faces different changes of medium not only from the air to the subsoil but also within the soil itself
- Signal phenomena should be considered as well like multi-trajectories by reflections of the same signal on the different media surrounding the measurement area
- Take into account the distance and alignment between the transmitting and receiving antennas and the backscattered signals

Ground-Penetrating Radar

Signal Power Loss

$$L_T = L_e + L_m + L_{vd} + L_{t1} + L_{t2} + L_s + L_a + L_{sc}$$

- Signal phenomena should be considered as well like multi-trajectories by reflections of the same signal on the different media surrounding the measurement area

- Take into account the distance and alignment between the transmitting and receiving antennas and the backscattered signals

Software Defined Radio

Introduction

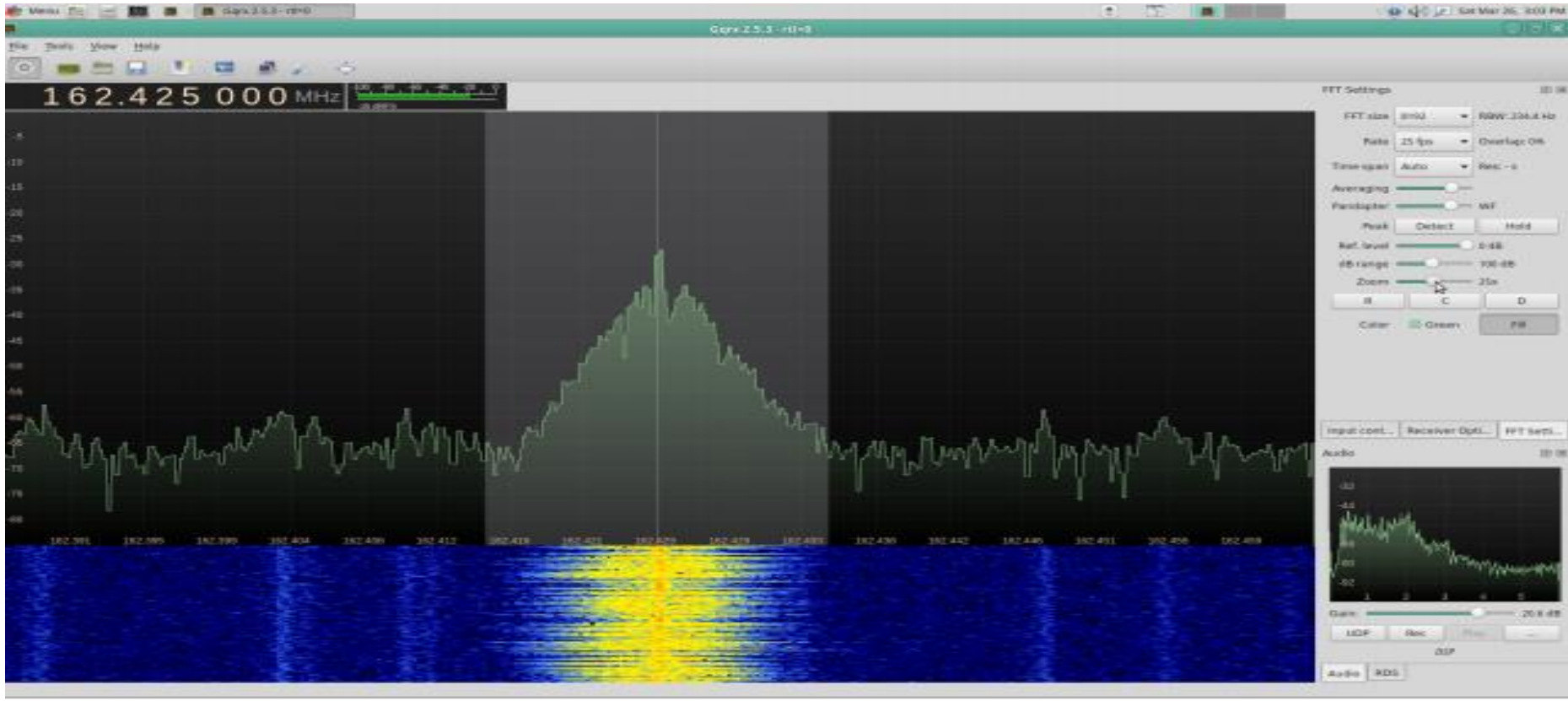
- Software-defined radio is a Radio Frequency communication system that incorporates a significant amount of software-based signal-processing functionality.

- Software-defined radio module used is the Realtek RTL2832U
  - Provides better sensitivity
  - Lower noise
  - Broadband Receiver from 24 MHz to 1766 MHz

- Software-defined radio in our case is placed on the receiving antenna.

Ground-Penetrating Radar

Software Used



- GQRX:
  - GQRX can operate as an AM/FM/SSB receiver with audio output or as an FFT-only instrument.
  - GQRX is Linux Based

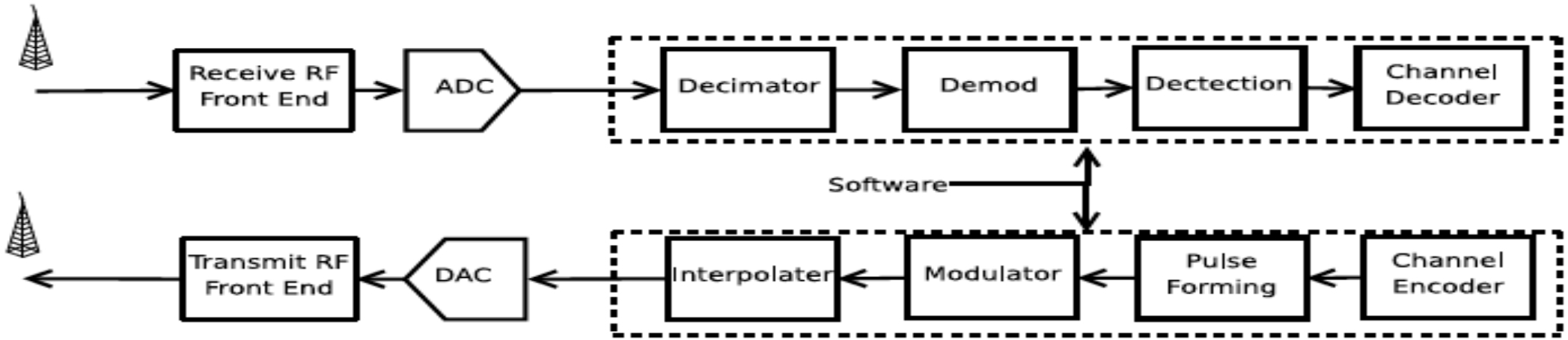
Ground-Penetrating Radar

Software Used

- SDRSharp:
  - Like GQRX it can operate as an AM/FM/SSB receiver with audio output or as an FFT-only instrument.
  - Windows Based

Software Defined Radio

Block Diagram



- Software-defined radio is made up of:
  - ADC
  - Decimator
  - Detection
  - Channel Coding

Antenna Design

Types of Antennas Used

- Definition:
  - Antennas by definition is a metal rod or dish that catches and transmit radio and electromagnetic waves and turns them into electrical signals

- Two Antenna Types were used in this project:
  - Vivaldi Antennas
  - Crossed Dipole Antennas

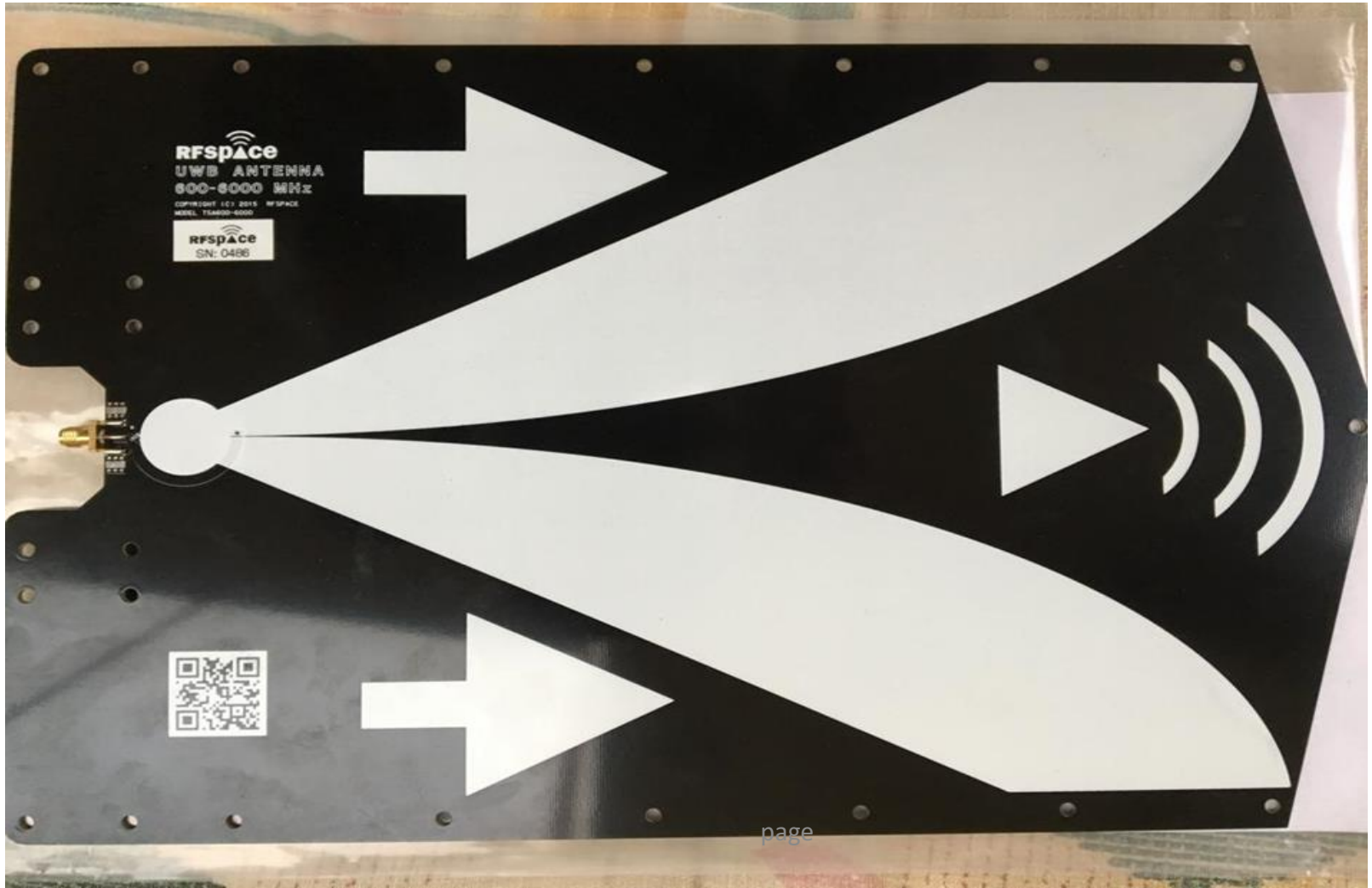
Antenna Design

Types of Antennas Used – Vivaldi Antenna

- Vivaldi Antenna Definition

- Vivaldi Antenna Specs are:
  - Ultra-Wideband (UWB) PCB
  - Operating range from 600-6000 MHz
  - Power Handling: 25 Watts
  - 50 Ω SMA edge mount connectors
  - 3dbi gain at 750 MHZ

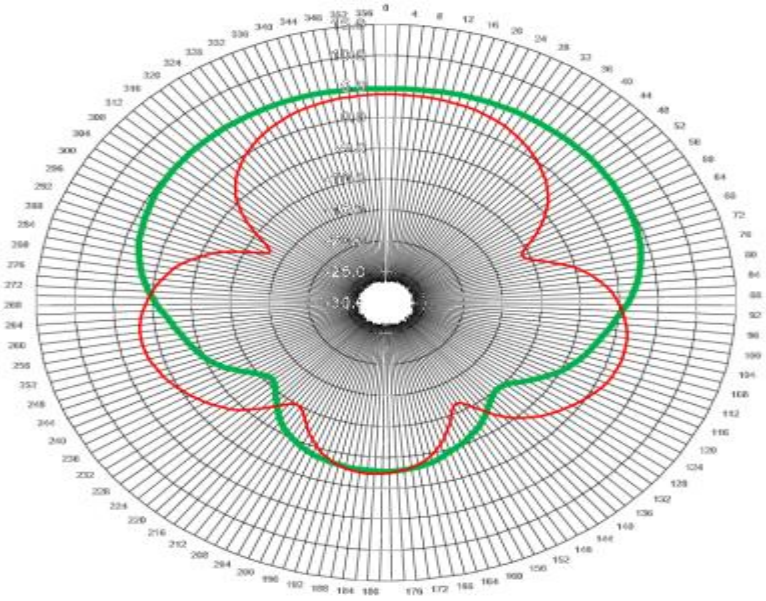
Antenna Design

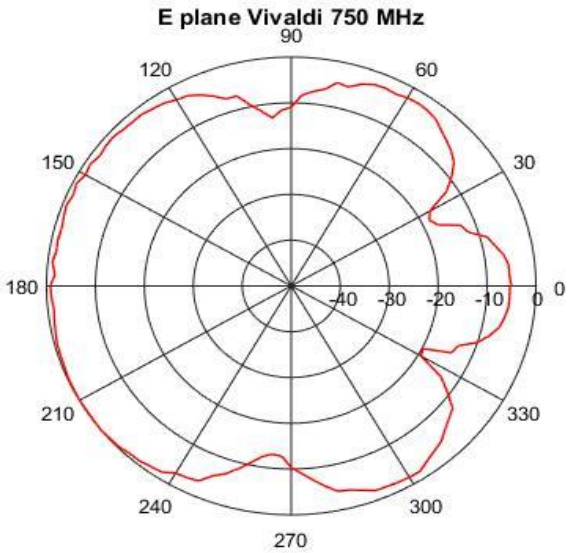


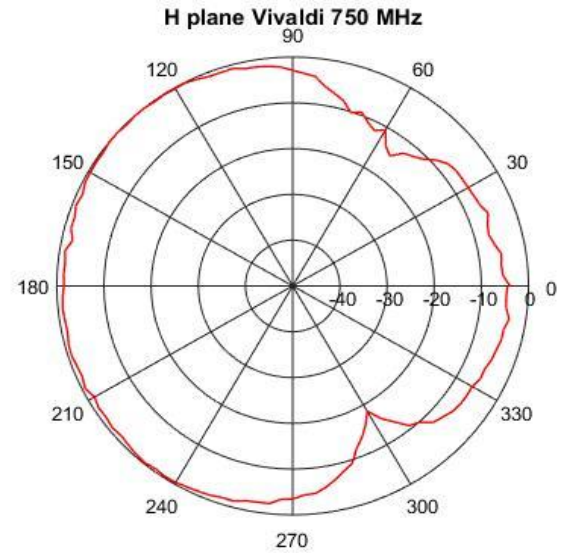
Antenna Design

Results – Vivaldi Antenna

- Radiation Patterns that were obtained theoretically vs practically





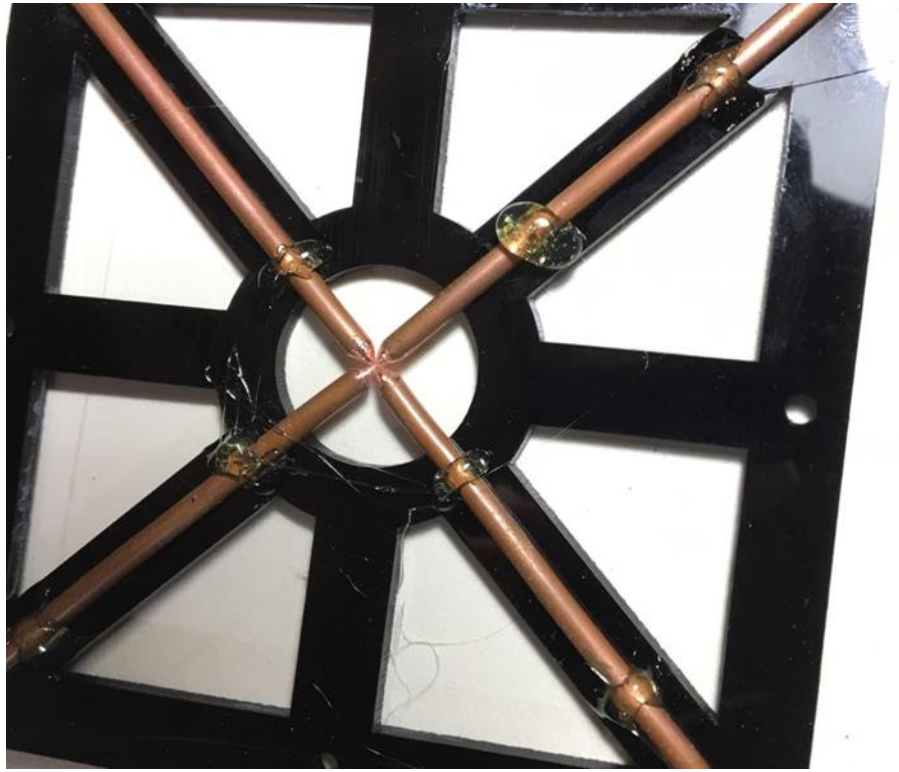


Antenna Design

Types of Antennas Used – Crossed Dipole

- Crossed Dipole Antenna Definition

- Crossed Dipole Antenna Specs are:
  - Circularly Polarized
  - Operates at 750 MHz
  - Having a $\lambda = \frac{C}{f}$ =40 cm
  - Each Monopole is 10 cm

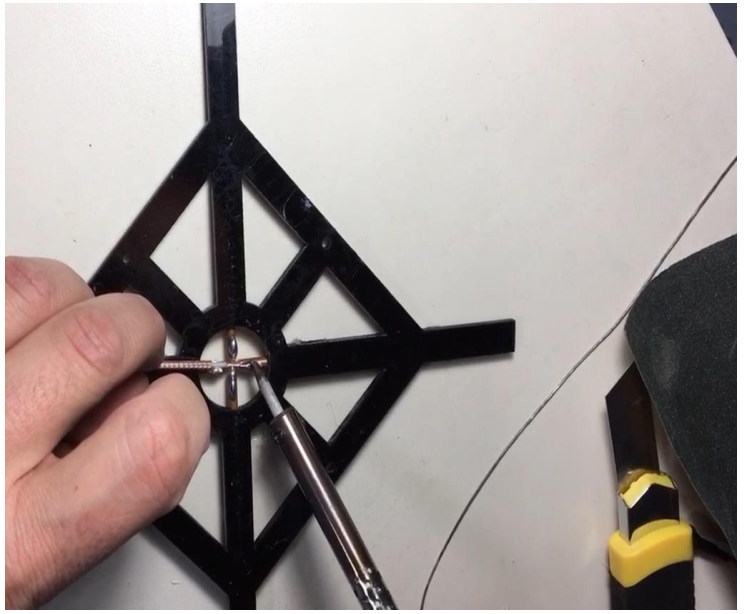


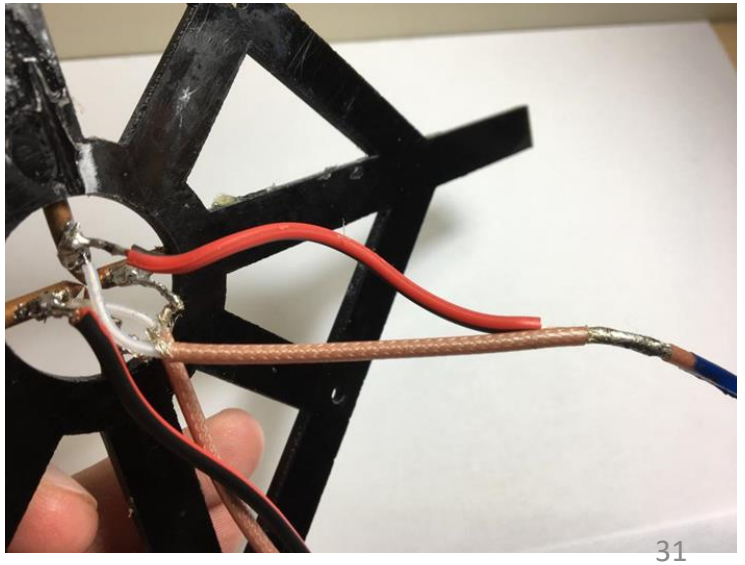
Antenna Design

Fabrication Process – Crossed Dipole

- Crossed Dipole Antenna Architecture
  - Phase Shift
  - Balun
  - Matching

- Crossed Dipole Antenna fabrication

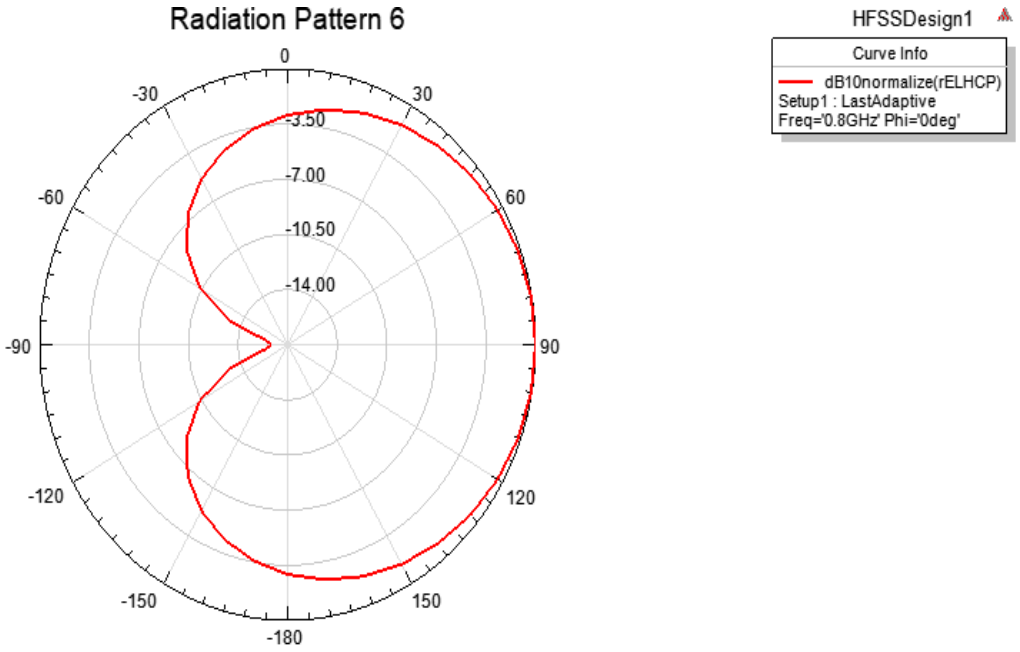


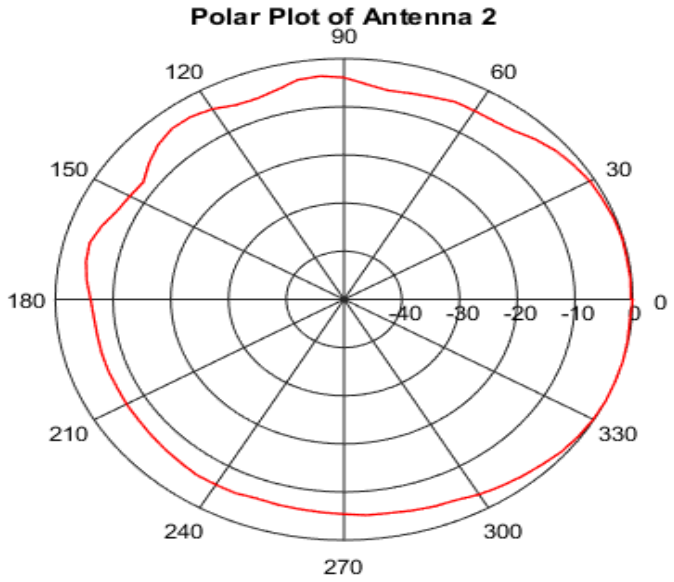


Antenna Design

Results – Crossed Dipole Antenna

- Radiation Patterns that were obtained theoretically vs practically



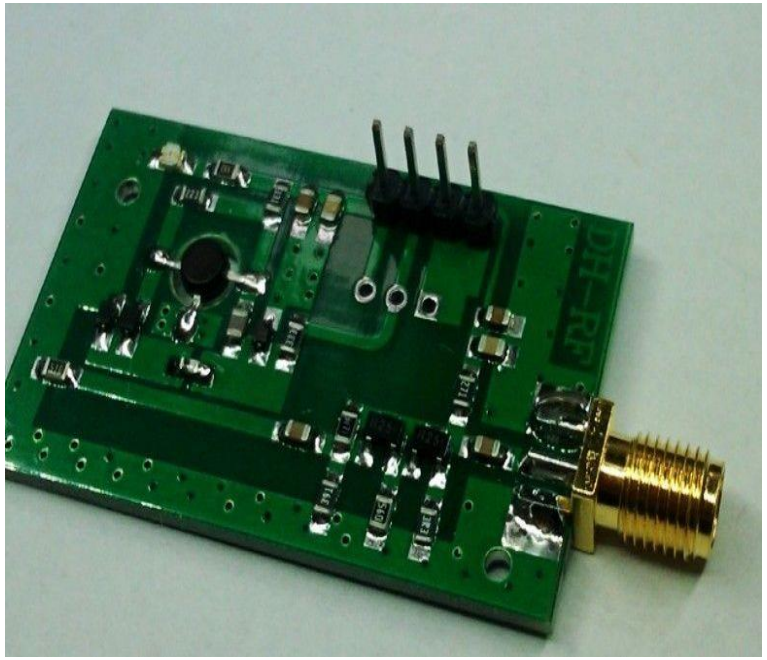


Antenna Design

Oscillator

- Used to generate a pulse through the transmitting antenna.

- Specs:
  - Frequency range from 515 MHz to 1150 MHz
  - The RF Pin is the output fed to the amplifier
  - Pin layout from right to left is V_{cc}, V_{tune}, GND, GND
  - V_{cc} = 12V, Current = 50mA

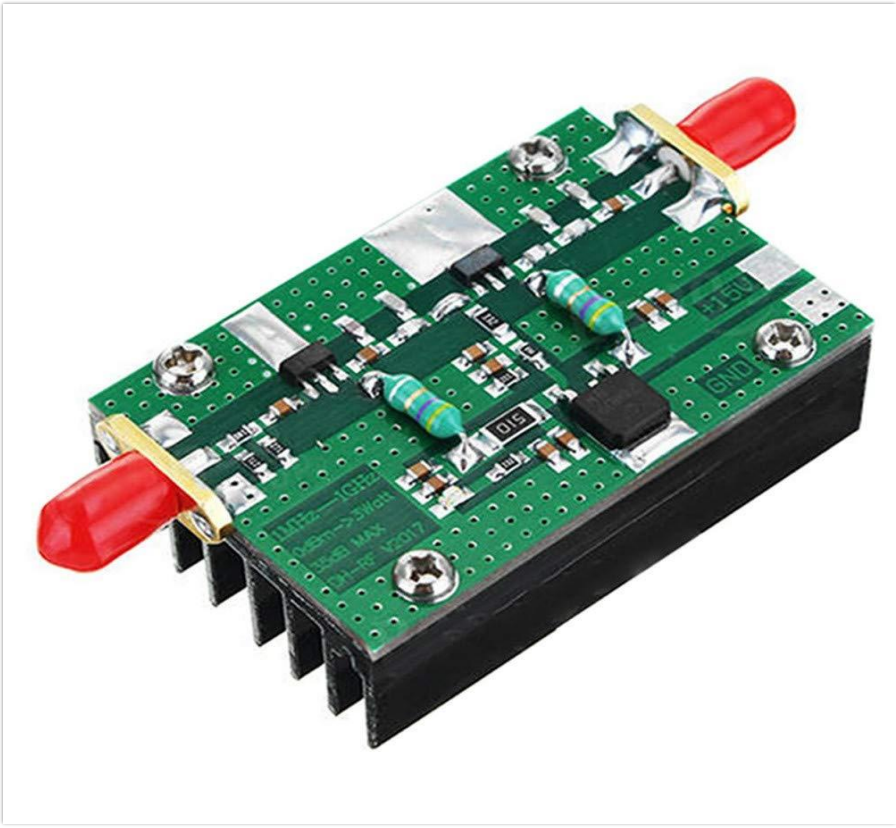


Antenna Design

Amplifier

- Used to amplify the signal by 35 dBm gain

- Specs:
  - Supply voltage 15 V
  - Frequency range 1 Mhz-1000Mhz
  - Output range: 35 dBm
  - Has a heat sink



Drone

Design

- We assembled our own Quadcopter

- A Quadcopter is a multirotor helicopter that is lifted and propelled by four brushless motors.

- Quadcopter boost is generated by a group of rotors which is vertically leaning propellers.

Drone

ArduPilot Mega

- ArduPilot Mega is a specialized quality IMU autopilot that is based on Arduino Mega platform
- This autopilot manages fixed-wing multirotor helicopters
- ArduPilot is a full autopilot capable for automated stablization

Drone

M7N GPS Module

- Offers good accuracy
- Is an excellent solution for multirotor
- hard case with built-in collapsible pedestal mount, provides a suitable method of mounting the compass away from sources of interference.

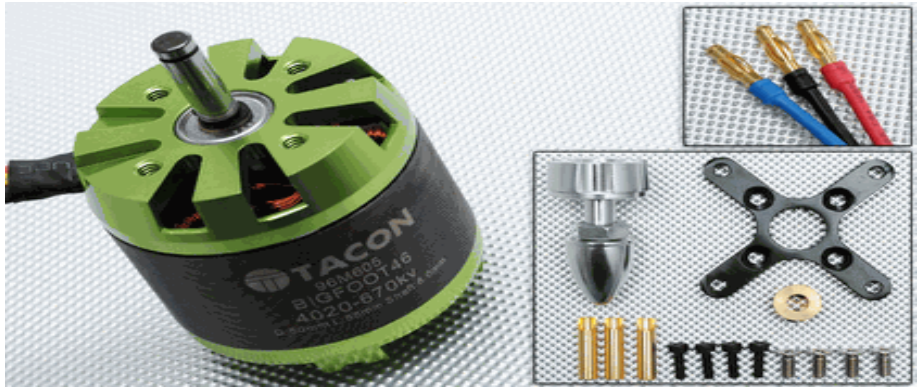
Drone

APM 2.8 Power Module

- Offers good accuracy
- Is an excellent solution for multirotor
- hard case with built-in collapsible pedestal mount, provides a suitable method of mounting the compass away from sources of interference.

Drone

APM 2.8 Power Module



- The brushless motors of the drone create thrust to enable the drone to fly.

- A brushless motor contains a group of electromagnets (coils) which are coupled together in specific pairs.

Drone

Carbon fiber propellers 12x5.5 inch

- Carbon fiber propellers are enormous lightweight
- heavy-duty
- cause a boost in motor efficiency due to the ultra thin and stiff
- carbon fiber construction.

Final Implementation

Long term improvements?

- **Detection Technique**
- **Quadcopter enhancements**
- **Structural Enhancements**
- **Oscillator Behavior Enhancements**

Conclusion and Results

The Autonomous Aerial Mine Detector system serves as a proof of concept project that can be researched and improved by future teams that are willing to tackle this issue.

The results obtained showed that the detection of metallic objects at distance from 30 to 40 cm was successful with a change in the waterfall

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Thank you for your attention