Solumspect

c/o School of Engineering Science
Simon Fraser University
8888 University Drive
Burnaby BC V5A 1S6
E-Mail: ensc440-cyab@sfu.ca

March 11, 2010

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, BC V5A 1S6

Re: ENSC 440 Project Design Specifications for a Landmine Detection System

Dear Dr. Rawicz,

Solumspect is in the process of developing a portable landmine detector as our project for ENSC 305W/440W. We aim to build a system that caters to the needs of humanitarian organizations by being both low-cost and robust using off-the-shelf components. The attached document, *Design Specifications for a Landmine Detection System*, gives the technical design details for the model version of our device.

The document can be separated into two key parts. In the first half, we provide an overview of the system design, followed by detailed specifications of each of the individual modules that make up the device. The second half describes how we plan to test each of the modules and the system as a whole. We are scheduled to have a working model of our design available for demonstration by mid-April 2010.

Solumspect is a dedicated team of fifth-year engineering students: Michael Ages, John Berring, Graeme Cowan, and Jeremy Yoo. Should you have any questions about our project or the attached functional specifications, please do not hesitate to contact us by e-mail at ensc440-cyab@sfu.ca.

Sincerely,

Michael Ages	*John Berring*	*Graeme Cowan*	*Jeremy Yoo*
Michael Ages	John Berring	Graeme Cowan	Jeremy Yoo

Enclosure: *Design Specifications for a Landmine Detection System*

Solumspect

Design Specifications for a Landmine Detection System

Project Team: Michael Ages
John Berring
Graeme Cowan
Jeremy Yoo

Contact Person: Jeremy Yoo
jty@sfu.ca

Submitted to: Dr. Andrew Rawicz – ENSC 440
Mr. Steve Whitmore – ENSC 305
School of Engineering Science
Simon Fraser University

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Executive Summary

This document is a technical description of the design and implementation requirements for Solumspect's ground penetrating radar landmine detection system. It addresses the means by which Solumspect intends to achieve the product standards set forth by the functional specification [1].

Solumspect's system will detect landmines buried up to a half-metre deep in various types of soil. It will work by analyzing and displaying the delay and intensity of frequency modulated radar signals reflected by objects buried within the earth. To achieve this, Solumspect has designed the following components:

- Radio frequency signal transmitting and receiving module
- Low frequency signal generating and sampling module
- Image processing and analysis software
- Mechanical structure
- System power module

The design of these components is discussed along with the relevant background information required for a full understanding of the device.

The product produced from this design will be a model device which will adhere to the "-I" standards from the functional specification. Upon its completion, the device will be run through a series of tests described in this document. These tests will be used to verify that the capabilities of each component and the device as a whole comply with the intended design.

Table of Contents

List of Figures

List of Tables

Glossary

Clear Area	A safe space of land known to be free of any landmines
DCE	Data Collection Enable
DLA	Data Listener Application
EM	Electromagnetic (Waves)
FMCW	Frequency Modulated Continuous Wave – A transmitted waveform, often used in radar, having a linearly modulated range of frequencies
Frame	Extendable structure, measuring approximately one square metre, attached to the base of the system and supports the scanning components
GPR	Ground Penetrating Radar
GUI	Graphical User Interface
ISR	Interrupt Service Routine
Landmine	Any of a variety of unexploded ordnance buried beneath the surface of the earth
LF	Low Frequency
MCU	Microcontroller Unit
RF	Radio Frequency
Rx	Receiving antenna
SPI	Serial Peripheral Interface
Sweep	A single pass of the antenna along the supporting scan bar
Tx	Transmitting antenna
VCO	Voltage Controlled Oscillator
User	An adult trained in the removal of landmines, typically belonging to a humanitarian demining organization

1 Introduction

Solumspect is developing a portable low-cost landmine detector for use by humanitarian organizations. Ground penetrating radar (GPR) is used to produce a visual representation of underground objects within a region. Using the generated images, the user will be able to quickly determine if there are potential landmines that should be further investigated.

1.1 Scope

This document provides an overview of Solumspect's proposed landmine detection device and details the design for each of its components. The designs fully comply with the functional requirements set out for the model version of the device in [1]. This document also includes a complete test plan.

1.2 Intended Audience

Written for the Solumspect team, this document gives direction for the development and testing of the system. The team will refer to the document in the development phase to drive the construction of the device and to measure project progress. During the testing phase, the document will be used to guide the test plan and verify that the model conforms to the intended design.

2 System Functionality/Specifications

Solumspect's landmine detection device will use GPR technology to scan an area of terrain and map out underground objects within the region.

Typical use of the system begins with the user unfolding the scanning frame over the region to be investigated. The controls on the base are then used to initialize the scan and move the scanning head. When a scan is finished, the results will be displayed as images on the user's computer. These images can assist in identifying potential landmines in the area.

3 System Overview

3.1 RF and Low Frequency Electronics Overview

The electrical system of the GPR Landmine Scanner can be separated into two subsystems – low frequency (LF) electronics and radio frequency (RF) electronics. The LF electronics serve primarily as a driver and sampler for the RF frequency modulated continuous wave (FMCW) radar transmitter and receiver. A high-level flowchart of the two subsections is shown in Figure 1.

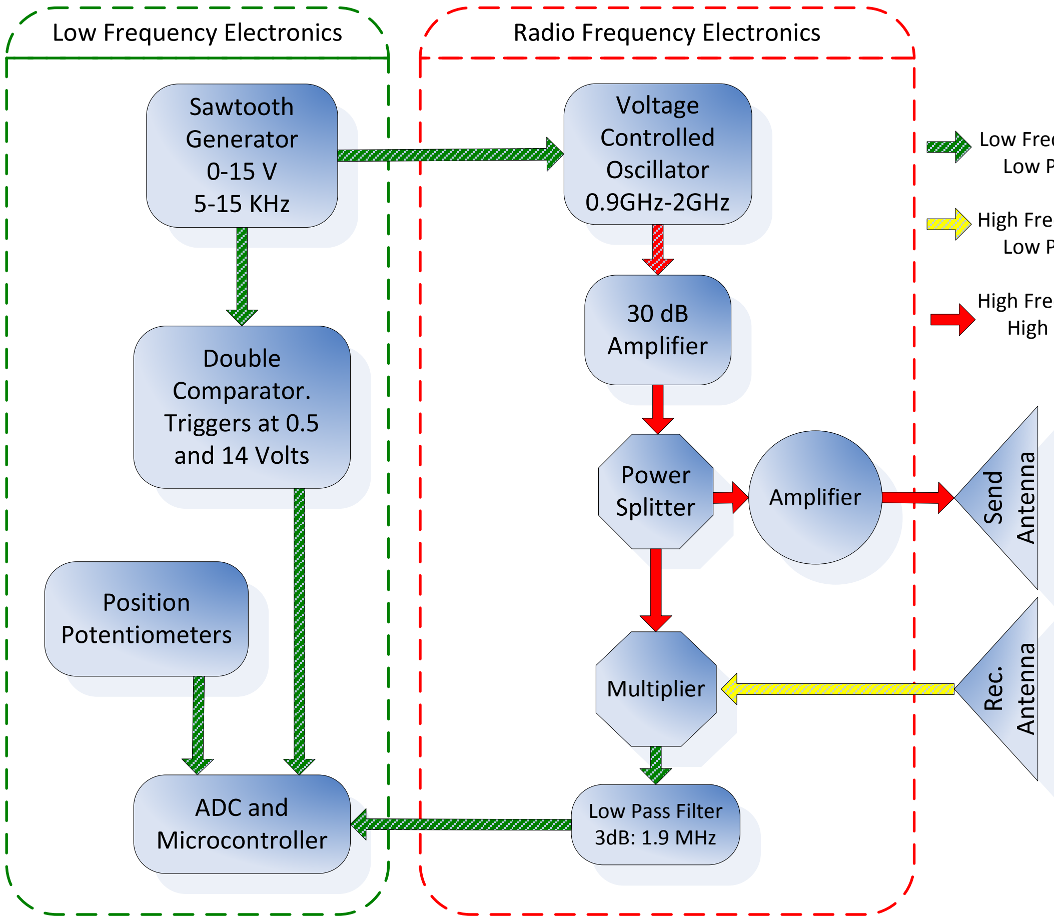

Figure 1: High level overview of the LF and RF electronics subsystems

3.1.1 RF Overview

The RF subsystem consists of six radio frequency electrical components and two Yagi antennas, as detailed in Section 4.2. It will be located on movable scanning head and be powered by two 12 V batteries located on the base.

FMCW radar involves transmitting a signal with a linearly modulated frequency, receiving its reflection, mixing the two signals to obtain the frequency difference, and calculating the time delay between the two using the Fourier transform of the result (see Section 4.1 for further details). The device will emit 1 W of directional electromagnetic (EM) waves over the 0.9 GHz to 2.0 GHz frequency range and receive reflections of these signals attenuated to 0.001 W to 0.020 W. Mixing the transmitted and received signals will result in a signal with frequency components from 5 kHz to 100 kHz, corresponding to reflection distances of 5 cm to 50 cm.

As shown in Figure 1, the process begins with a sawtooth waveform generator. This generator linearly sweeps from 0 V to 15 V, which drives a voltage controlled oscillator (VCO) to produce low powered EM signals. These signals are amplified before being passed through a power splitter and emitted into the ground. The emitted waves are reflected off the surface of the ground or objects within the ground. The receiving antenna captures these reflections and the signal is mixed with the transmitted signal before being going through a low pass filter. The resulting mixed signal contains frequency components which correlate to the distance travelled by the reflected waves. The correlation can be calculated by sampling the mixed signal in time domain and processing the result using a computer, as detailed in Section 8.2.

3.1.2 Low Frequency Overview

The low frequency subsystem consists of the electronics that generate the RF sweep pattern and sample the mixed signal. A 15 V sawtooth waveform with a frequency between 5 kHz and 15 kHz drives the RF VCO. A comparator circuit will also use this waveform to produce the data collection enable (DCE) trigger for the sampling device.

The sampling device will be a Teensy++ microcontroller (MCU) paired with a high-speed external ADC. The MCU will use sample the mixed signal over a single sawtooth period as determined by the DCE trigger. These samples will be transferred to a computer over USB.

The LF subsystem will also include a set of position measurement devices. In order to obtain an accurate location value for the scanning head, rotational potentiometers will be mounted on two of the three sliders to which the scanning head is attached. Linear motion from the scanning head will be translated into rotational motion via a belt and pulley system and the resulting change will be measured by potentiometers. The positions will be transferred to a computer via the MCU.

3.2 Power Module Overview

The power module is designed to ensure that the device is able operate for up to 12 hours a day [1] using portable power sources that are readily available. The model device will be driven by two 40Ah 12V car batteries. However, any pair of 12V sources with at least 25 Ah of available charge could be used.

Due to the range of voltage and current requirements, regulators will be used to step down the 24 V output to 15 V and 18 V. The batteries and corresponding electronics will be affixed to the base of the scanning device.

3.3 Mechanical Overview

The main structure of the device is shown in Figure 2. It consists of two main components – the frame and the base. The frame is designed to be suspended over uninvestigated terrain, with the entire weight of the device supported by the base.

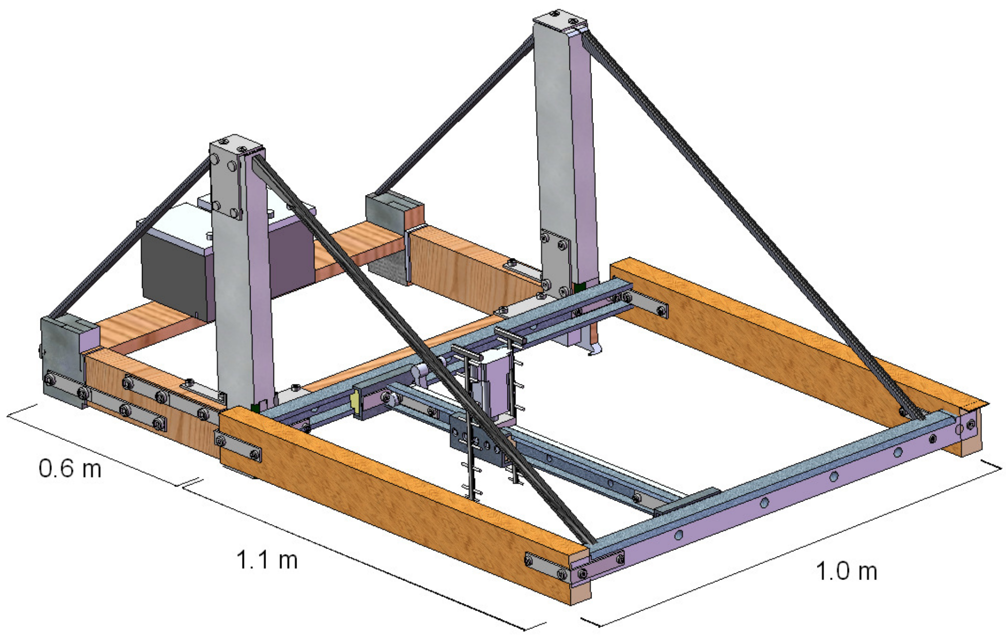

Figure 2: 3D CAD rendering of the GPR system

On the right of Figure 2, the frame can be seen supporting the scanning head; on the left, the base anchors the system in a clear area with the weight of the batteries. In the centre, a tower supports the frame that is suspended above uninvestigated ground. For the model device, most of the frame will be constructed using spruce lumber (shown in brown). The remaining parts will be constructed of metal. However, in the model version, the tower will also be built with lumber to reduce cost.

The overall dimension of the scanning frame will be 1.1 m by 1.0 m. In order to support the weight of the frame, 3/16'' cable will be attached to the corners of the frame and counterbalanced with the base.

3.4 Software Overview

The system software will serve two purposes – to control the data capture and process the data for viewing. A custom GUI running in MATLAB along with a small command line application will facilitate these operations. While data is being sampled and transferred to the computer from the MCU during a scan, the transferred data will be simultaneously converted from the time-domain to the frequency domain using Fourier transform techniques. The resulting frequency data will then be used to generate top-down and cross-sectional views of the scanned area. The user will use the GUI to navigate through these views and apply any further transformations to the images.

4 RF Electronics Module

4.1 FMCW Radar

The RF module generates FMCW radar signals which reflect off buried objects. A block diagram of the RF module is shown in Figure 3.

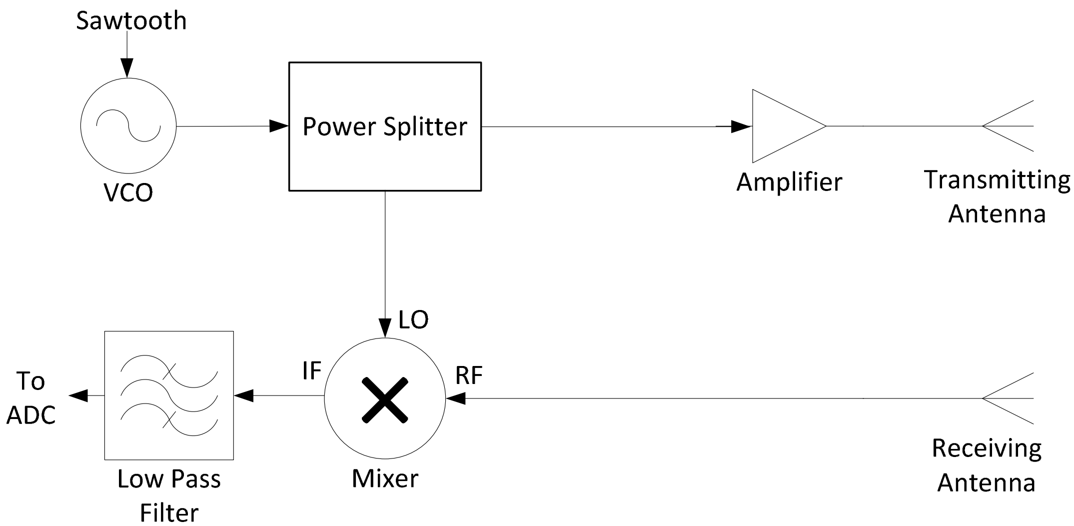

Figure 3: RF module schematic

The VCO outputs a sinusoidal signal of the form

$$V_{VCO} = A_o \sin\big((\omega_o + 2\pi\alpha t)t\big), \quad (1)$$

where ω_o is the initial frequency and α is the frequency sweep rate in Hz/s. The VCO signal is then split by the power splitter. Part of the signal is sent to the LO input of the mixer and part of the signal is transmitted by the transmitting antenna (Tx). Any reflections off of the surface of the ground or buried objects are then picked up by the receiving antenna (Rx) and sent to the RF input of the mixer. The RF signal will be of the form

$$V_{RX} = B_0 \sin\Big(\big(\omega_o + 2\pi\alpha(t-\tau)\big)t\Big), \quad (2)$$

where τ is the time for the signal to travel from the Tx to the reflecting surface and back to the Rx. This is identical in form to the LO signal, with the exception of the time difference τ.

The LO signal is oscillating at a frequency $\alpha\tau$ Hz greater than the RF signal when the two signals meet at the mixer. The IF output of the mixer is the product of the two input signals, which after applying a trigonometric identity is

$$V_{IF} = C_o(\cos(2(\omega_o + 2\pi\alpha)\cdot t + 2\pi\alpha\tau\cdot t) - \cos(2\pi\alpha\tau\cdot t)). \quad (3)$$

The first term is at a much higher frequency than the second term and is easily removed by the low pass filter. The second term is the signal of interest which is sent to the ADC. It is seen that the second term is a constant frequency sinusoid whose frequency is proportional to the travel time τ of the reflected signal. After applying a Fourier transform to the low-pass filtered signal, the frequency components f correspond to a travel time $\tau = f/\alpha$. We can then infer the distance to the object causing the reflection from the formula

$$d = \frac{cf}{2\alpha}, \qquad (4)$$

where c is the speed of light.

4.2 RF Components

Table 1 lists the components in the RF module. All parts (excluding the antennas) are manufactured by Mini-Circuits and are selected based on three main design considerations: power delivery, frequency response, and noise level.

Table 1: Components in the RF module

Component	Part #
VCO	ZX95-2500W-S+
Amplifier	ZRL-3500
Power Splitter	ZN2PD2-50
Mixer	ZEM-4300MH+
Low Pass Filter	BLP-1.0+
Antennas	Wilson 204411

4.2.1 Voltage Controlled Oscillator

The VCO will be powered by 5V DC. The VCO receives a 15V sawtooth wave between 5 kHz and 15 kHz. This generates a signal frequency output of 1-2GHz from the VCO. The power output of the VCO will vary from 2.5 dBm to 4.3 dBm, with peak power occurring at 1.6GHz.

4.2.2 Amplifier

The amplifier will be powered by a supply voltage of 12V DC. The gain of the amplifier is 24 dB. The power delivered to the transmitting antenna will be 23.5 dBm.

4.2.3 Power Splitter

The power splitter splits the input signal into two equal signals, each attenuated by 3.5 dB. As a result, the power delivered to the amplifier and the mixer's LO input will be -0.5 dBm.

4.2.4 Antennas

The antennas are highly directional with antenna gain ranging from 7 dBi at 1 GHz to 10 dBi at 2 GHz. Technical details of the antennas and signal propagation are discussed further in Section 4.3.

4.2.5 Mixer

The mixer's LO input will receive -0.5 dBm input power from the power splitter. The usable signals received by the receiving antenna and delivered to the mixer's RF input will be reflected by objects no deeper than 0.5 m below the surface**.** The conversion loss between the RF input and the IF output is roughly 6 dB throughout the given frequency range. The power of a single frequency component at the IF output of the mixer will be approximately 6dB below the RF input power.

4.2.6 Low Pass Filter

The losses at the frequencies of interest will be effectively zero through the low pass filter. Frequency components greater than 5 MHz will be attenuated by at least 60 dB, successfully removing the unwanted FMCW components that will be ≥1GHz. The desired signals will be in the range of 25 kHz to 150 kHz when sent to the ADC.

4.2.7 Connections

All the RF components will be connected using SMA coaxial cables with the exception of the sawtooth input to the VCO and the low pass filter output to the ADC which will be standard wire connections.

4.3 Signal Transmission and Range

Signal range is the distance over which reflected waves from buried objects can be considered useful. It was stated in [1] that the device would produce valid results from soil depths of up to 0.5 m, as based on the necessary capabilities for the device's application (landmines are very rarely buried any deeper).

RF signals will be emitted from the transmitting antenna at a power of 1 W and a beam spread of 30°. The signal range is given as a function of reflected signal strength. This value is obtained by considering loss over the path of the beam.

Propagation losses can be broken down into seven categories: antenna efficiency loss L_e, antenna mismatch loss L_m, transmission loss from air to ground L_{t1}, retransmission loss from ground to air L_{t2}, antenna spreading losses L_s, attenuation loss of material L_a, and target scattering losses L_{sc}.

Attenuation caused by antenna efficiency and antenna mismatch was obtained from [2], where it is suggested that our transmitted signal will experience a 3 dB loss as a result of these factors.

Transmission coupling loss (in dB) in both directions can be calculated by

$$L_t = 20\log_{10}\left(\frac{4Z_mZ_a}{|Z_m + Z_a|^2}\right), \qquad (5)$$

where Z_m is the characteristic impedance of the ground and Z_a is the impedance of the air (377 Ω). Given a ground impedance of 125 Ω (common for soil), a loss of 2.5 dB should result for transmission across the boundary in each direction [2].

Antenna spreading loss will be the greatest source of attenuation for the device. It comes about as a result of the natural expansion of the beam width as it propagates [2]. The resulting loss (in dB) is governed by the gain of the transmitting antenna G_t, the area of the receiving aperture A_r, the range to the target R, and the cross-section of the reflected object σ:

$$L_s = 10\log_{10}\left(\frac{\sigma G_t A_r}{|4\pi R^2|^2}\right). \qquad (6)$$

Given a cross-sectional area of 30 cm, an antenna area of less than 10 cm and an object depth of 0.5 m to 1.0 m, a loss of 11 dB to 21 dB is obtained. This form of power loss will prove to be the primary limiting factor for the design.

Attenuation loss of the ground and target scattering loss were also obtained from [2]. In dry sand, there will be net a loss of 0.1 dB/m to 20 dB/m at a frequency of 1 GHz. In moist soil, this could net a greater loss value of 10 dB/m to 60 dB/m. Target scattering loss depends on the geometry of the object that is being detected. Given a flat plate 30 cm in diameter, a net loss of 1.6 dB is expected.

The total predicted loss for depth ranges of 0.5 m to 1 m in dry sand are given in Table 2.

Table 2: Depth range predicted loss

L_e (dB)	L_m (dB)	L_{t1} (dB)	L_{t2} (dB)	L_s (dB)	L_a (dB)	L_{sc} (dB)	Total (dB)
1.5	1.5	2.5	2.5	11.0-20	0.1-10	1.6	20.7-39.6

Given a 30 dBm (1 W) output, a 20.7 dB power loss will result in a signal of 8.5 mW. This is well above the required power level, measured in the lab to be approximately -50 dBm. The maximum predicted 39.6 dB loss would net a 0.1 mW return signal. With an attached 20 dB signal amplifier after the receiver, this would also result in an acceptable signal power level.

5 Low Frequency Electronics

The low frequency electronics provide the starting reference for generating an FMCW and act as the bridge from hardware into software.

5.1 Sawtooth Generator

A highly linear ramp voltage must be used in order to create a low-distortion VCO signal. A possible way of generating such a waveform is through the use of a microcontroller. Unfortunately, this offers limited linearity, especially at high frequencies. To solve this problem, an analog sawtooth generator circuit is being designed.

A high-speed, low-distortion amplifier (such as the LM6171) will be used in a Howland current pump to generate a constant current. An LM555 timer can then be used to control the charge and discharge to produce the sawtooth waveform.

Trimpots are used at strategic circuit points to allow for precision control and fine-tuning of the output waveform. This will enable adjustments to the sawtooth frequency and linearity during the optimization stage of integration. These trimpots will be kept in the final product as sawtooth frequency and linearity accuracy are vital in producing undistorted images. The circuit schematic is given in Figure 4.

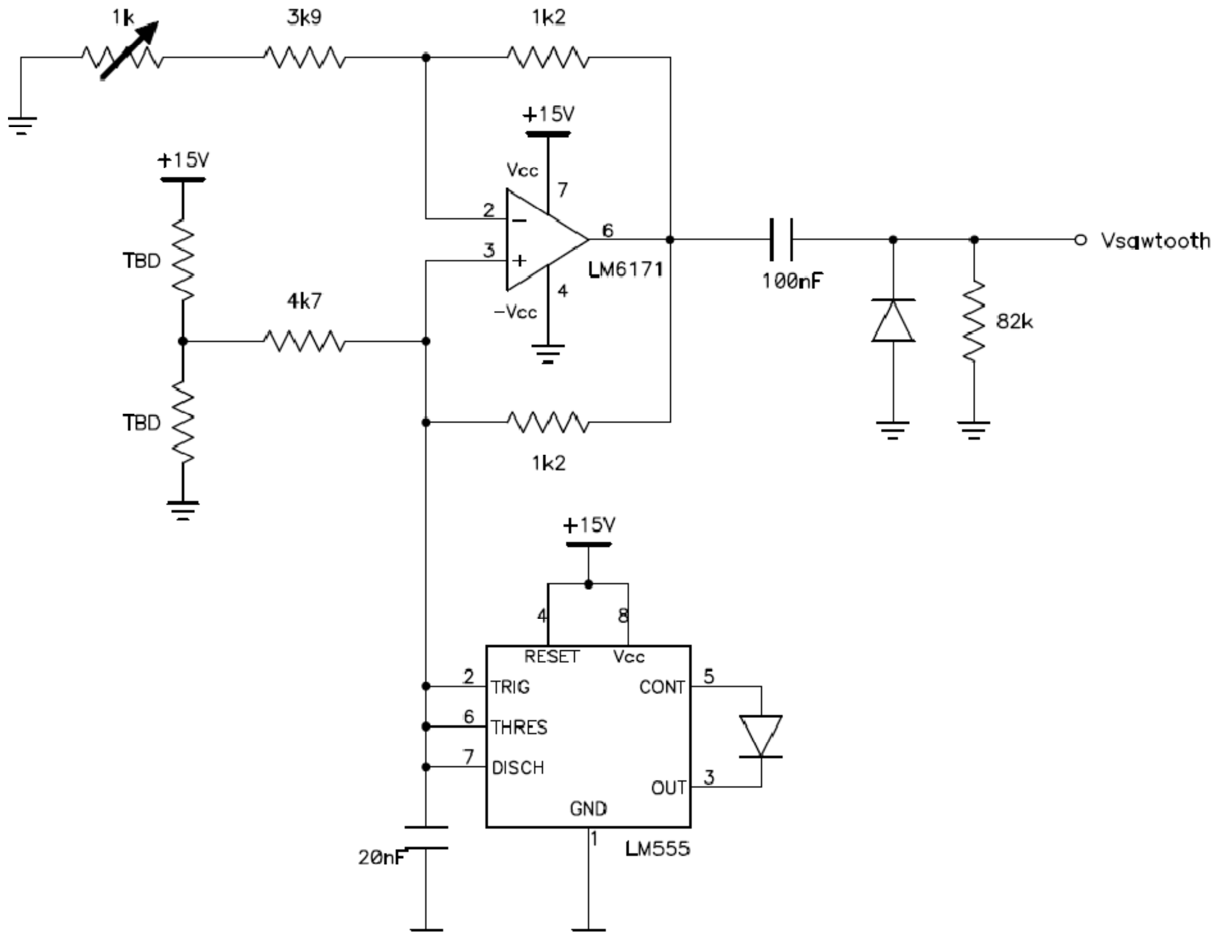

Figure 4: Sawtooth signal generator

5.2 Digital Data Collection Enable

To avoid extra noise and distortion in the output signal during the quick voltage drop of the sawtooth waveform, data will only be collected when the VCO has a steady linearly increasing input voltage. To control this, a set of comparators will monitor the sawtooth wave and output a digital enable signal to the microcontroller only when the voltage is increasing from 0.6 V to 14.5 V. Power supply bypass capacitors will be used to prevent ringing in the digital output.

The effect of these comparators is shown in Figure 5. Here, the top signal corresponds to the linearly sweeping frequency input to the VCO, the middle signal represents the sampling period of the microcontroller, and the lowest signal corresponds to the output RF signal. As the frequency sweep nears its peak, the comparators are triggered and a low voltage is sent to the microcontroller. Sampling occurs only when the DCE signal is high. By sampling periods individually, we avoid capturing frequency components that result from the periodicity of the sweep and the discontinuous sawtooth voltage drops.

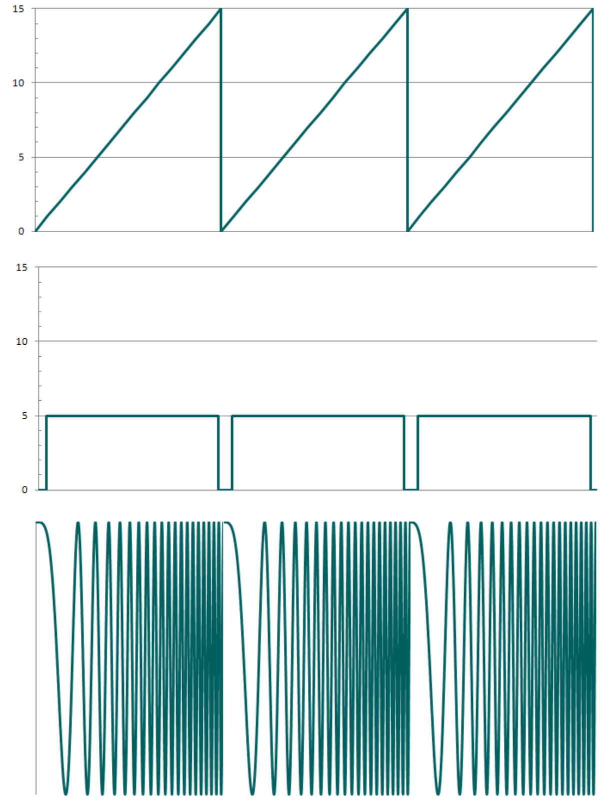

Figure 5: Sample analog circuit output
Top: sawtooth wave, middle: digital data collection enable, bottom: visualization of modulated RF sine wave

The comparator schematic is shown in Figure 6.

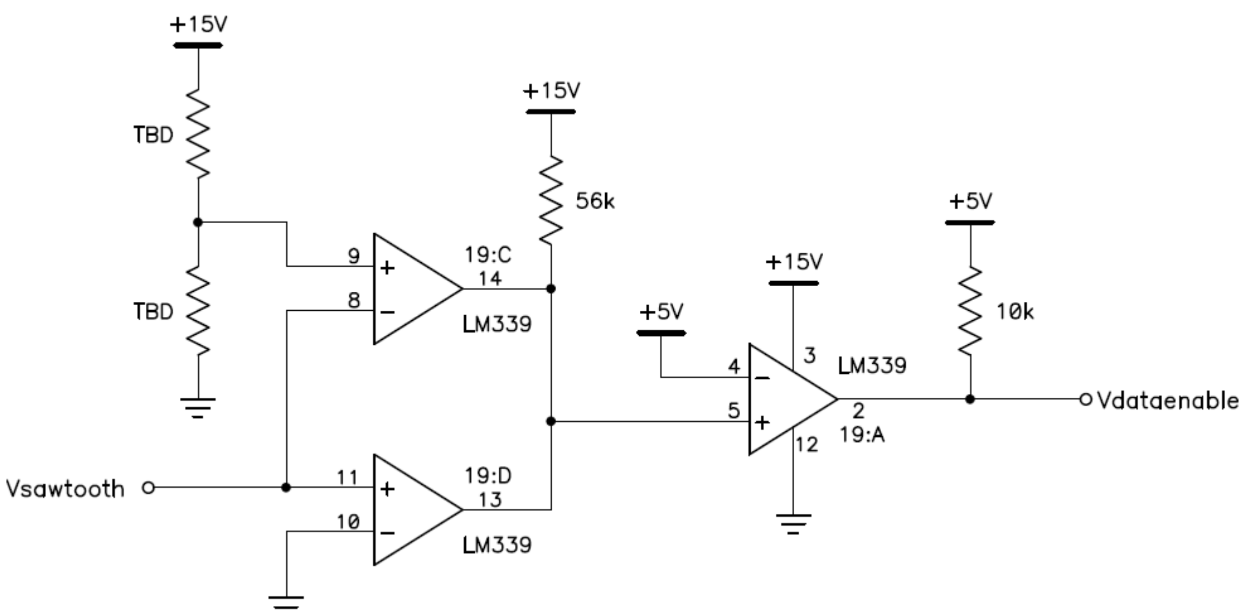

Figure 6: Digital data collection enable circuit

5.3 Data Collection

Incoming mixed and filtered radar signals will be converted into a digital signal using the ADC121S051, a high-speed, single channel, 12-bit analog to digital converter. Using the standard Serial Peripheral Interface (SPI) bus, the high frequency output will be sampled 400 000 times per second and transmitted to the Teensy++ MCU. The MCU will then send the data to the user's computer via USB 2.0 to be processed. The flow of the data capture process is detailed in Figure 7.

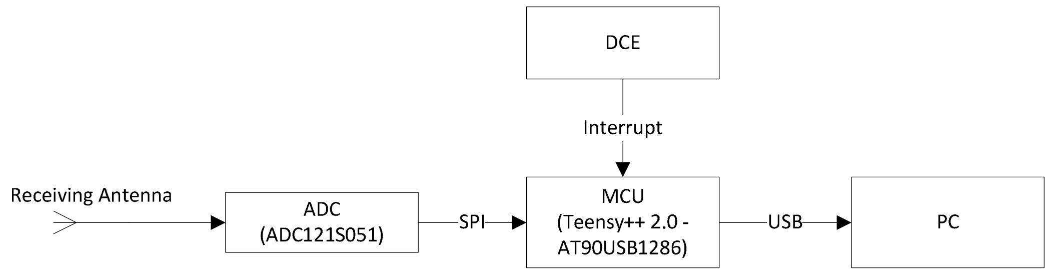

Figure 7: Flow of data capture process

As the ADC is a read-only device, only three pins are required to establish communication with the MCU via the SPI interface, as shown in Table 3. The remaining three pins on the ADC are for power, ground, and input.

Table 3: ADC pin assignments

Pin (ADC)	Pin (MCU)	Description
1	+5V	Power
2	GND	Ground
3	n/a	Input
4	PB1 (SCLK)	SPI clock
5	PB3 (MISO)	ADC data to MCU
6	PB0 (SS)	Pull low to start A/D conversion

The MCU is programmed in the C language. The interface between the MCU and the PC is USB, communicating via a virtual serial port that is capable of handling 12 megabits/second.

A flow chart describing the MCU algorithms is shown in Figure 8.

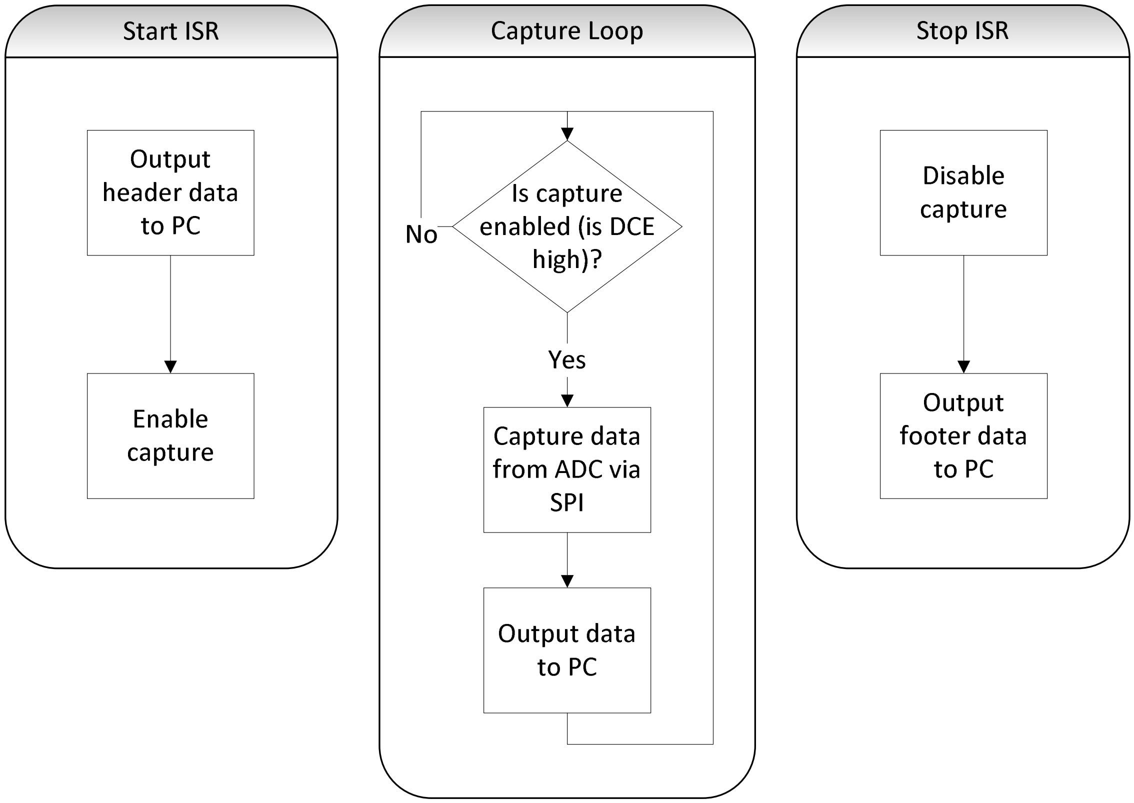

Figure 8: MCU algorithm flowchart

When powered, the MCU will run in a tight loop routine to collect data. This routine waits for the DCE signal to go high, at which point it continuously outputs ADC readings to the serial output until the DCE signal goes low. The logic required for SPI communication is handled internally by the MCU via simple request commands.

Each interrupt service routine (ISR) will add a short message to the serial output such that the PC can distinguish the start and end of a single set of data. The DCE signal is generated as described previously in Section 5.2.

5.4 Antenna Positioning

For the model device, the scanning head will scan a 0.95 m by 0.95 m area. The head's position in each dimension will be determined using a 10 turn, 100 kΩ potentiometer. Linear motion will be translated into to rotational motion using a 5 cm diameter pulley and a 1.9 m rubber timing belt. The belt and pulley system is further described in Section 7.1.1.

Given these dimensions, six turns of the potentiometer will be required to measure the radar head's movement from one end of the frame to the other. Consequently, the potentiometer will experience a linear impedance difference of 16.7 kΩ per turn or 1.06 kΩ per centimetre. Connected to a 5V power source, this change in resistance will read by the analog pins of the microcontroller (bypassing the external ADC) before being sent to the computer. With an analog input resolution of 5mV, the MCU is capable of measuring displacement to a resolution of 2 mm.

6 Power Module

Each of the components will be powered independently. The power consumption estimates are shown in Table 4 with their corresponding voltage current and current requirements.

Table 4: Component power consumptions

Component or Circuit	Voltage (V)	Current (A)	Power (W)
Voltage Controlled Oscillator	15	0.04	0.6
Amplifier	12	0.4	4.8
Sawtooth Generator/DCE	18	0.025	0.45
	Total	**0.465**	**5.85**

Given their availability, the system will be powered by two 40 Ah, 12 V car batteries. These will be stepped down to the required voltages using L78xx series regulators. Overall, the current requirements will allow the device to operate for 86 hours on a single set of batteries.

7 Mechanical System

The physical and mechanical components of the entire device can be split into two sections – the frame and the base.

7.1 Frame

The frame will consist of three Rollon 41" linear slide bearing systems and two support beams as shown in Figure 9. The antenna and RF module (i.e. scanning head) are mounted on the centre slider and may be moved in two dimensions within the frame. As noted in [1], the model's frame will be entirely unpowered. Moving the RF module in the Y direction will be facilitated by a small crank and rubber belt as illustrated in Figure 10. The user will slide the device in the X direction by pushing the closest slider to the left or right while standing in the clear area. In both cases, the position of the sliders is determined from the embedded potentiometers.

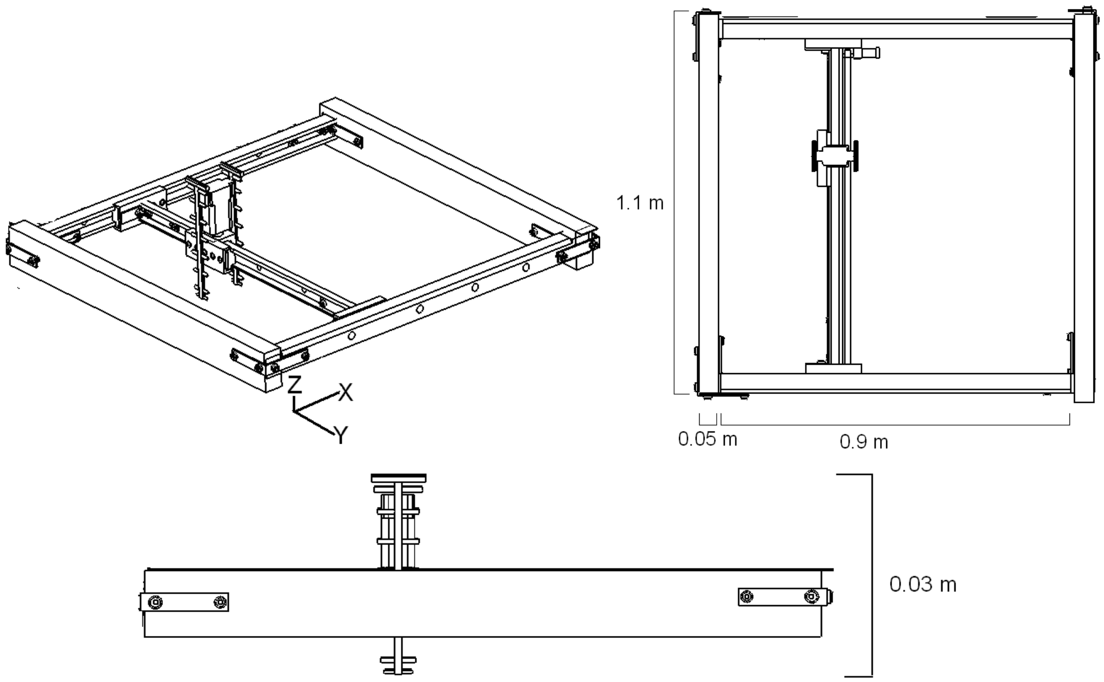

Figure 9: Scanner CAD illustration

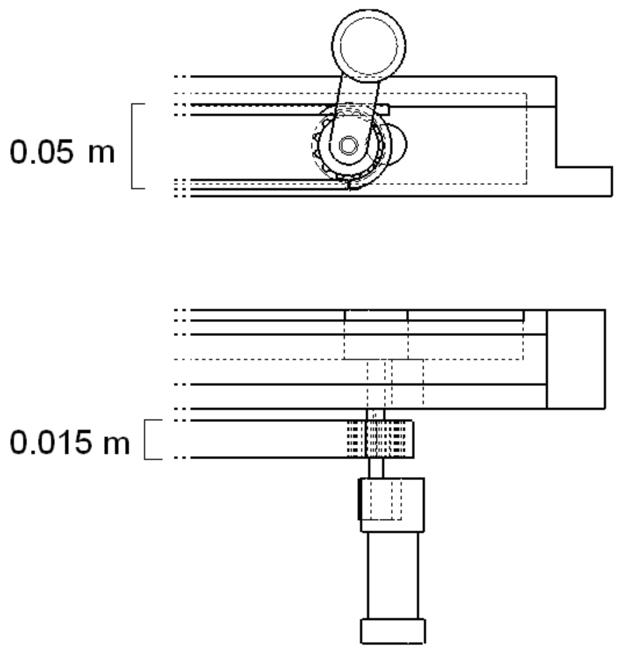

Figure 10: Belt and pulley system diagram

7.1.1 Linear Slides

The linear sliders facilitate the movement of the RF module. Rollon 41'' steel sliders were chosen due to their dimensions and low cost. With these devices, the scanning head will achieve 0.99 m of motion in each dimension. The sliders can individually support up to 1500 kg, well above the support necessary to support the scanning head (7 kg). The specifics of the sliders are given in Table 5.

Table 5: Linear slider specifications

Component	Function	Material	Quantity	Length	Width	Height	Total Mass
Sliders	Allows RF module movement	Zinc plated steel	3	1.04 m	0.02 m	0.04 m	6.6 kg

As mentioned in the system overview, the position of the sliders will be obtained using a 10 turn 100 kΩ potentiometer. This potentiometer is attached via a direct drive to a plain bore, 50 mm diameter drive pulley [3]. The pulley will drive a 1.5 mm wide, 1.9 m rubber timing belt [4] and will be driven by a hand crank, as shown in Figure 10. These components will be located at the end of the centre slider which is closest to the base of the system.

The belt will be affixed to the RF module slider via a metal clamp and will allow the user to scan the in the Y direction. The slider directly attached to the base will have an identical system used to measure the X position of the RF module.

7.1.2 Scanning Head

The RF module and antenna casing will be affixed to the central slider via two 0.25" hex bolts. Each antenna will be mounted using three 0.25" by 3" bolts driven into opposite ends of the RF case. The case itself will be constructed of plastic with a metal base. The specifics of the scanning head are given in Table 6.

Table 6: RF casing specifications

Component	Function	Material	Quantity	Length	Width	Height	Total Mass
Scanning head	Contains RF components	Plastic	1	0.03 m	0.03	0.15	7.1 kg

Beneath the RF casing, the antenna will have 5 cm of clearance to the ground. In order to reduce unwanted interference, AEP-18 broadband pyramidal absorbers from Advanced Electromagnetic will be glued between the antennas. This will dramatically attenuate any signals travelling directing between the send and receive devices.

7.1.3 Support Beams

The wooden support beams provide support for the linear sliders. Spruce was chosen over metal or plastic due to its strength, weight and low cost. Each beam will be affixed to the base and sliders using 4" by 4" right angle brackets. These will be secured using 0.25" by 6" bolts. The specifics of the support beams are shown in Table 7.

Table 7: Support beam specifications

Component	Function	Material	Quantity	Length	Width	Height	Total Mass
Beam	Provide support to the sliders	Spruce	2	1 m	0.05 m	0.1 m	3.5 kg

7.2 Base

The base and support tower support the low frequency electronics and act as a counterweight to the frame. The base consists primarily of wooden scaffolding while the tower is an aluminum beam which supports a steel cable as shown in Figure 11.

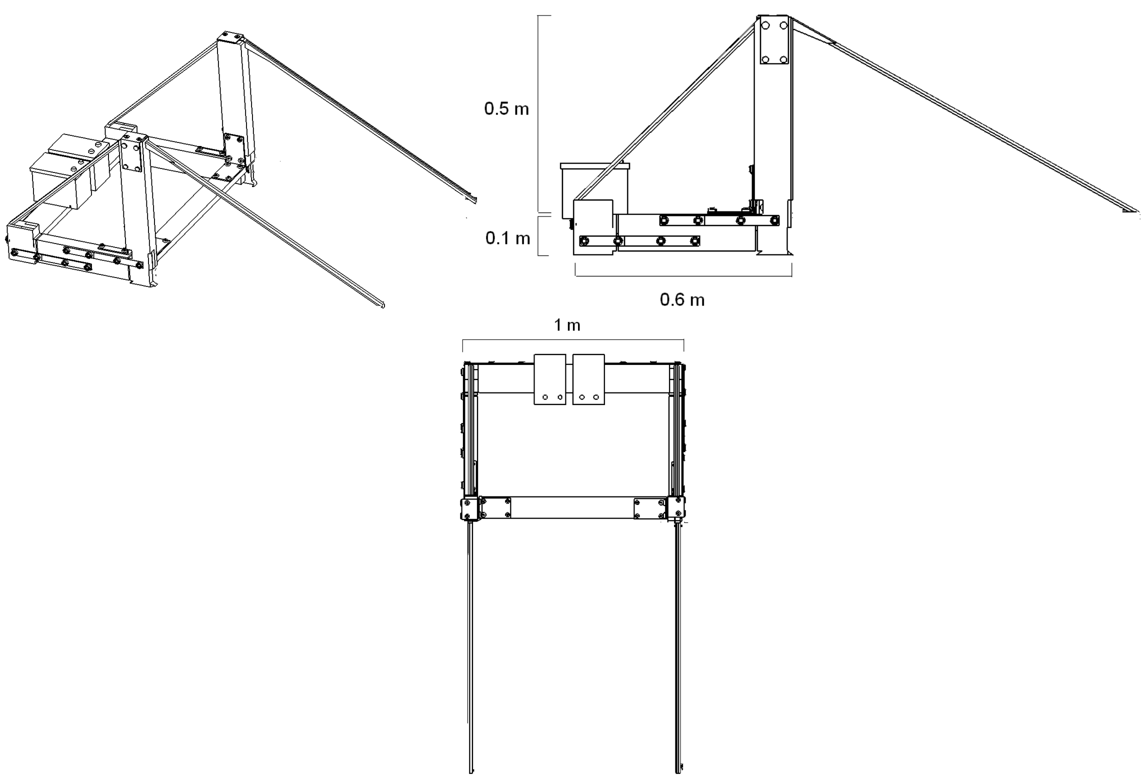

Figure 11: Base and tower CAD diagram

7.2.1 Support Beams

Like the frame, the base will be supported by segments of 2'' by 4" spruce. The specifications of the beams are given in Table 8.

Table 8: Support beam specifications

Component	Function	Material	Quantity	Length	Width	Height	Total Mass
Beam	Provide Support to the Base	Spruce	4	0.5 m,1 m	0.05 m	0.1 m	5 kg

7.2.2 Tower, Cable, and Anchor

The 50 cm support tower will be constructed with 2" by 4" spruce. It will be affixed to the base and frame using four angle brackets and two linear brackets. In the final product, this component will be constructed of aluminum to reduce weight. The specifications of the support beam are included in Table 9.

Table 9: Support beam specifications

Component	Function	Material	Quantity	Length	Width	Height	Total Mass
Tower Beam	Supports cable	Spruce	2	0.5 m	0.05 m	0.1 m	2.5 kg

The support cable ensures that the mass of the scanner remains safely suspended over the uninvestigated area being scanned. Summing the mass of each component of the frame nets a total mass of 10.5 kg. This value is distributed over the entire front half of the device. However, in order to account for error, it is assumed that the mass is concentrated entirely at the end of the frame.

Figure 12 illustrates the static forces required to suspend this mass. By assuming static equilibrium, we calculate that the tension T_1 required to suspend the mass is 143.2 N. This value would be distributed evenly between the two parallel cables. Given that $T_1 = T_2$, the force required to anchor the frame M_2 is 121.9 N or 12.4 kg.

Summing the mass of the two batteries and the rear components of the base, the total counterbalance mass is 17.5 kg. While this is sufficient to ensure that the scanner does not tip forward, for safety, the final version will either include base pegs or twice the required counterbalance mass.

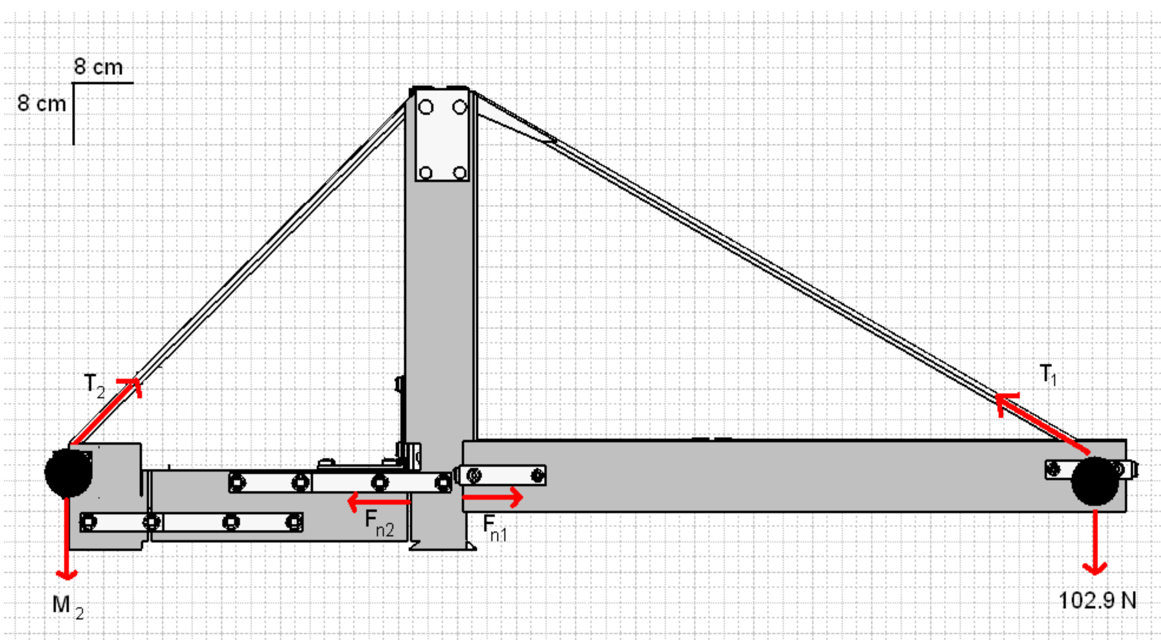

Figure 12: Support system static equilibrium diagram

Based on tension and mass requirements, the suspending cable will be 2.5 metres of 3/16'' steel aircraft cable which will be anchored to each corner of the frame. Woven cord of this material and dimension has a breaking strength of 1224 kg, far above the required value. The cord will be anchored to the tower using two angle brackets.

8 Software

Software for the scanner will initially run using a custom data listener application and MATLAB graphical user interface (GUI) application. The data listener application will facilitate the data capture process and the MATLAB GUI will process and display the data to the user.

8.1 Data Listener Application

The data listener application is a small command-line application that will run on the user's PC when the user is capturing data. The application will be written in C#, which provides built in libraries to handle serial port data communication.

The listener sits idle until data to become available on the virtual serial port. Once data is available, the listener will create a new text scan file to output the serial data into the text file until it sees the footer data. This process will continue indefinitely as is illustrated in Figure 13 until the listener is terminated. The text scan files will be named in sequential numerical order, starting with 1.txt as the first file.

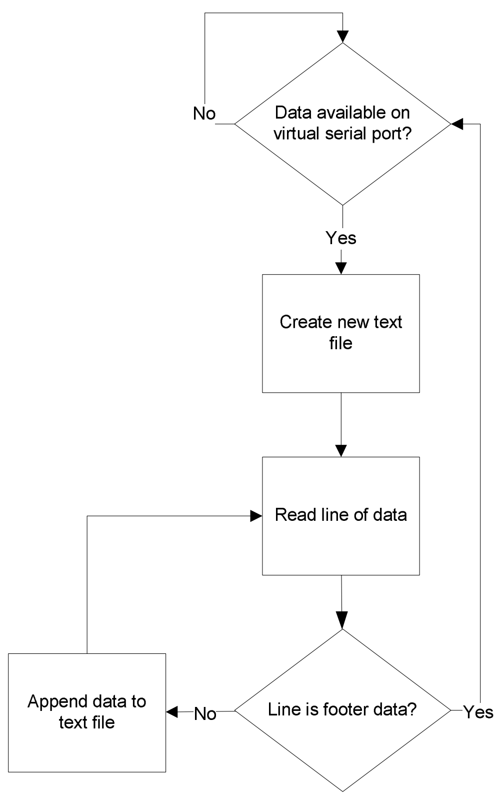

Figure 13: Data listener application flowchart

8.1.1 Raw Capture Text File

Output produced from the data listener application will be formatted as space separated values as detailed in Figure 14.

Text File Convention:

```
XPosition YPosition Reading1 Reading2 Reading3 Reading4 Reading5 ...
```

Sample Data Reading:

```
124 203 1022 404 530 594 283 596 803 586 493 1038 1124 ...
```

Figure 14: Raw capture text file format

The first two values respectively give the x and y position of the antenna as captured with the analog pins on the MCU, with the remaining values the continuous readings from the ADC.

8.2 Signal Processing

To obtain the cross-section and top-down views, Fourier transform and basic image processing techniques will be employed using the built in MATLAB libraries.

The process will begin by parsing the data from the text scan file. Each file is a single sweep, with each line representing a position in that scan. The processing will be performed line by line. The first two values in each line represent the position. They will be recorded and discarded, leaving the remaining sampled radar signal.

A Fourier transform of the radar samples will be taken using the 1D fast Fourier transform. The transformed waveform will be sampled to capture the intensities at varying frequencies. The frequency gives the return time of the signal (a higher frequency indicates a longer return time), which will be correlated to an actual depth using an estimated value of the speed of light in the ground being scanned.

This data will be organized into columns, with each column corresponding to a single position within the scan. Once this data has been processed for each position, a two dimensional matrix array will result. It is noted that in this form, each row corresponds to a specific depth, with each column representing a depth greater than the row above it.

This matrix can be displayed as an image by taking each reflection intensity value to be the pixel greyscale intensity. This effectively gives a cross-sectional view of the ground at the sweep location.

After all of the sweeps have been completed and processed, the 2D matrices for each sweep can be arranged into a 3D matrix. When organized in this form, a top-down view of the ground may be produced for a specified ground depth by taking the same row from each sweep's 2D matrix and arranging these vectors into a new 2D matrix. Displaying this matrix as an image, again corresponding reflection intensities into greyscale pixel intensities, gives the top-down view.

A visual representation of the matrix and how it correlates to each scan is shown in Figure 15. A sample of the cross-sectional and top-down views can be seen in Section 8.3.1.

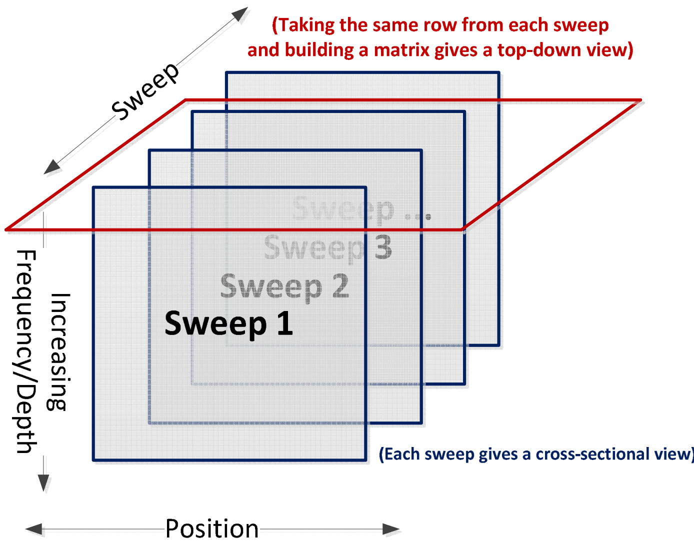

Figure 15: Visual representation of 3D data matrix

8.3 User Interface

Figure 16 shows the scan control window from which the scan operation will be controlled.

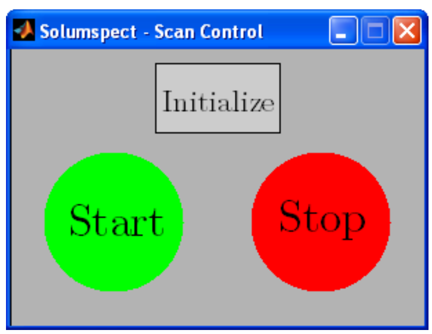

Figure 16: MATLAB GUI based scan control window

As outlined in Table 10, the user will be able to initialize the system, start a scan, and stop a scan.

Table 10: Scan control options

Operation	Action
Initialize Scan	User will be prompted to enter a scan project name and select a directory for the output.
Start Scan	The MATLAB GUI will start up the Data Listener Application, which will enable the MCU to begin collecting and sending data to the computer.
Stop Scan	The MATLAB GUI will terminate the Data Listener Application, stopping the collection of data.

When a scan is initialized and started, MATLAB will launch the data listener application (DLA), which begins the data collection process and outputs the results to the specified directory during initialization.

As a scan is taking place, the MATLAB GUI will continuously monitor for new files in the raw data output directory. As soon as data from a single sweep is available (i.e. one text file as formatted in Figure 14), MATLAB will begin processing the data for this set, as detailed in Section 8.2.

Stopping the scan process (after the entire scan has finished) will terminate the DLA. Once MATLAB finishes processing any remaining data, the image view window will appear for the user to view and manipulate the processed images.

8.3.1 Image View Window

The data from a scan will be presented to the user in the form of images showing the intensity of reflection at each point. The image viewing application is written in MATLAB and allows the user to view images from a scan and perform images processing functions on them. Figure 17 shows a sample image viewing window.

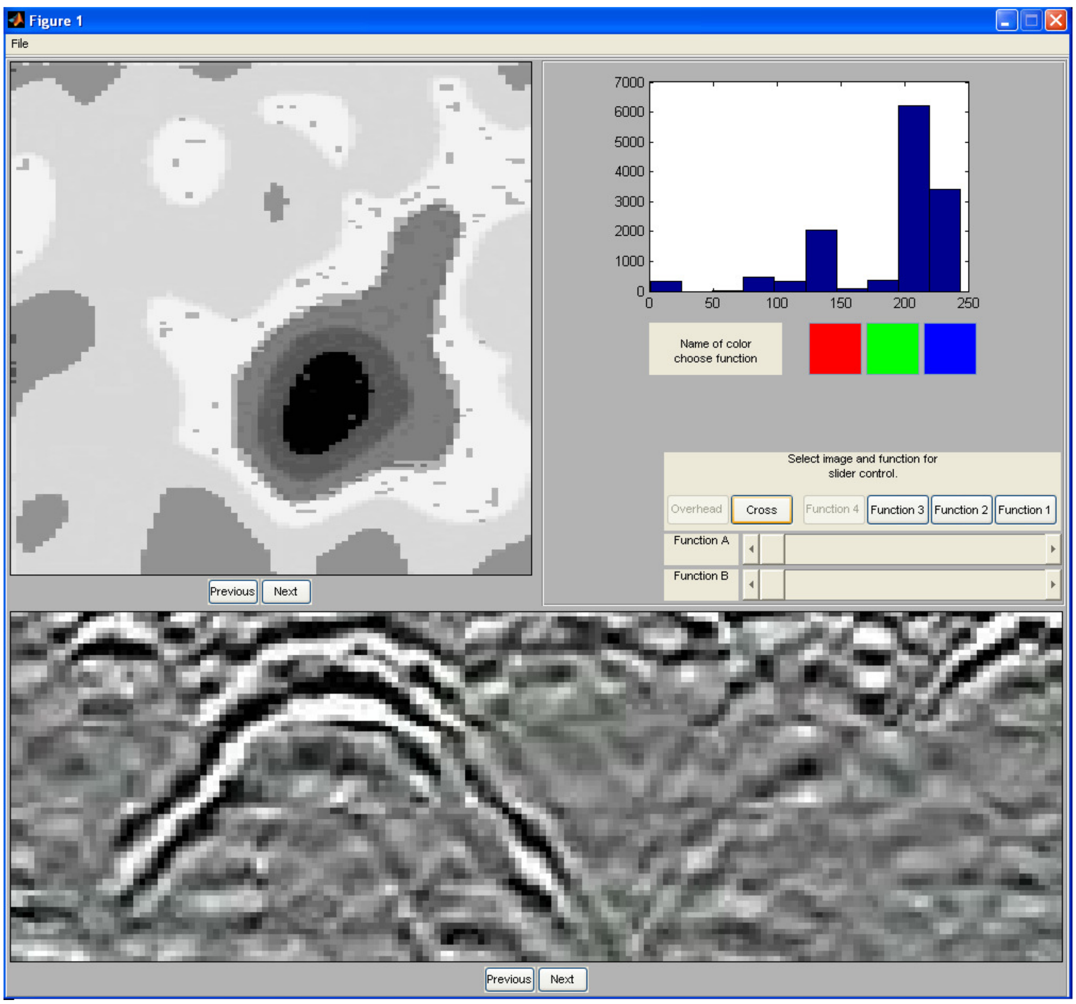

Figure 17: Screen capture of the image viewing window with sample top-down [5] and cross-section views [6]

The top-most overhead view will be loaded in the top left panel, and the left-most cross-section image will be loaded in the bottom panel.

The top-right panel gives the user access to the image processing tools. The graph at top is a histogram of pixel intensities from the selected image. Selecting one of the coloured buttons below and then clicking on one of the histogram bars will change all pixels of that intensity to the selected colour.

8.4 Functions

A small set of image processing tools will be available to the user in the model version's software. They will allow the user to adjust contrast, brightness, uneven pixel intensity and noise.

8.4.1 Contrast

The contrast function will allow users to linearly scale the value of pixels so that a larger or smaller difference between the minimum and maximum pixel intensities can be changed (i.e. shrink or expand the pixel intensity histogram of the image). This function will access the *imadjust* command in MATLAB in order to carry out the command.

8.4.2 Brightness

Brightness will be controlled by an exponential scaling factor α. For an individual pixel, the scaling command is given by

$$I_{out} = (I_{in})^{\alpha}, \quad (7)$$

where I_{in} is the initial pixel intensity and I_{out} is the final pixel intensity.

8.4.3 40 dB/m Loss Conversion

As a result of antenna spreading loss, signals originating from sources at greater distances will have considerably lower intensities. Given the inverse quartic dependence of signal intensity on signal range, a difference of 1 m in signal origin will result in a 40 dB loss in intensity. To account for this, a +40 dB/m filter may be applied to the image. This command would increase pixel intensities by a value determined by their distance from zero reflection time. The command is given by

$$I_{out} = (I_{in})^{4/m}, \quad (8)$$

where m is the estimated distance from the transmitting antenna to the receiving antenna (as determined by its time delay) of the pixel intensity's source.

8.4.4 Low Pass Noise Filter

A low pass noise filter may be implemented in order to reduce unwanted signal intensity spikes. In the model version, this will be implemented using the MATLAB image processing toolbox.

9 Safety Considerations

Over exposure to high powered RF electromagnetic waves can lead to internal and external localized heating of flesh and organs and an increase in body temperature. While the device emits at a relatively low power, the power density at the very tip of the transmitting antenna borders on dangerous. Solumspect's device will adopt the standards set by the Ontario Ministry of Labour for RF exposure limits. The Ministry demands that workers may not be exposed to more than 33 W/m^2 to 50 W/m^2 of 1 GHz to 2 GHz radiation for longer than 6 minutes [7]. As such, users will be instructed to never put their hand beneath the transmit antenna during operation, as the device can emit at 45 W/m^2 directly at the tip. To add awareness, the scanning head will be labelled with clear warnings of RF exposure.

10 Test Plan

The components will be easily tested individually using certain pieces of laboratory equipment.

10.1 Unit Tests

- The low frequency sawtooth and DCE have a simple input and output setup. By powering this module, the correct output can be verified using an oscilloscope to observe and measure the signals. A correct output will resemble the upper two signals in Figure 5.
- The data collection module will be verified by inputting constant sinusoidal and triangular waves from a common laboratory function generator. The result will be verified by comparing the sampled data with the input signals.
- The radar portion is verified using a spectrum analyzer. The full scanning head will be assembled and driven with the sawtooth waveform. Signals will be sent between antennas to produce a delay. The frequency component of this delay will be viewed using the spectrum analyzer. Antenna positions will then be varied (thus increasing or decreasing delay) and the predicted change in frequency will be confirmed.
- A specially generated data set with a known pattern will be inputted to the software processor. The resulting image can then be verified for integrity.

10.2 System Tests

To test the accuracy and quality of the system as a whole, a number of increasingly challenging landmine detection scenarios will be tested. For each scenario, a 1 m by 1 m area will be scanned and the output images will be compared to the designed area.

10.2.1 System Test 1 – Above Ground, One Object

The device will be set up 50 cm above a flat, non-conductive material (for example, a solid wood floor). A 30 cm diameter metal sheet circle will be placed 25 cm above the floor in the middle of the 1 m by 1 m scanning area.

To increase complexity, the metal sheet will then be moved to various locations in the scanning area. Passing these tests, the metal object will be replaced with a similar plastic object, and the tests repeated.

10.2.2 System Test 2 – Above Ground, Multiple Objects

For testing resolution (minimum object separation) and quality of image, various objects will be planted and identified. A combination of metal and plastic objects of various sizes and shapes will be placed at varying locations between the ground and scanning frame. The image can then be compared to the scanned area.

10.2.3 System Test 3 – Underground, Dry Sand

Acting as a simulated metal landmine, the metal sheet from the first system test (Section 10.2.1) will be buried in a sandbox with a flat bottom and a depth of 50 cm. The sand surface will be smoothed flat and the scanner frame will be suspended over the area. The location of the landmine will be attempted to be determined. The process will then be repeated with a plastic simulated landmine. An assortment of landmine types and shapes can be added for increased complexity.

10.2.4 System Test 4 – Underground, Wet Sand and Soil

Increasing ground moisture will dramatically increase signal attenuation. The third system test (Section 10.2.3) will be repeated with moist sand and soil in place of dry sand.

10.2.5 System Test 5 – False Positive Test

The simulated metal landmine will be buried alongside varied sizes of aluminum, steel and copper pieces representing shrapnel. A scan will be run and the resulting cross-sectional and top-down views will be produced. These images will be shown to a third party who did not participate in burying the objects and whom will try and identify the landmine. This test will verify the ability of the device to produce images in which landmines and false positives are easily distinguishable.

10.2.6 System Test 6 – Real-World Conditions

Should the device prove effective at all preceding system test scenarios, a more complicated simulated minefield can be set up. This can involve a variety of difficult scenarios:

- Differing soil types and saturations
- Varying object materials, shapes, and burial locations
- Added rocks and debris
- Non-uniform ground surface including, but not limited to, small hills and holes, grass, or weeds
- Added metallic and plastic refuse to the area

11 Conclusion

This document gives the complete design for the model version of Solumspect's ground penetrating radar landmine detection system. The Solumspect team will use this document as a guide throughout the building process to keep the project on track. Once complete, the contained test plan will be fully executed to ensure the system meets its goals. A fully functional and tested system will be ready for demonstration by the middle of April 2010.

12 References

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