School of Engineering Science
Simon Fraser University
8888 University Drive
Burnaby, BC
V5A 1S6

March 8, 2012

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

Re: ENSC 440 Design Specification for Portable Emergency Response FMCW Radar

Dear Dr. Rawicz,

Attached to this letter is our team's design specifications for a Portable Emergency Response FMCW Radar. Our design will give emergency personnel the ability to enhance their vision in low-visibility environments. By interfacing the radar-hardware with an iPhone application, we will create a portable product that can be used in a variety of professions. What makes our product so appealing is its versatility — it is hand-held, durable, and adaptable to variable range scales. At Shift Technologies, we see this as the future "must-have" product for emergency response personnel.

This document outlines all of the necessary information and specifications for our proposed Portable Emergency Response FMCW Radar and all of its sub-components. The purpose of this document is to provide an in-depth look into the design process required to meet the basic functional specifications for a proof-of-concept model. We will also occasionally be discussing future design considerations that will be required for a finished, marketable product; however these iterations will not be implemented in this stage of development.

Shift Technologies is composed of a five-member team whose knowledge and skill set is exemplary. Borna Vojdani, Laurent Ye, Mehdi Stapleton, Nelson Meira, and Steve Rickards are all fourth-year engineering students majoring in electronics, computer, or systems engineering. Should you have any questions or concerns regarding our design specification, please feel free to contact myself via email at mps8@sfu.ca.

Sincerely,

Mehdi Stapleton

Mehdi Stapleton
President and CEO
Shift Technologies

Enclosure: *ERadar - Design Specification for Portable Emergency Response FMCW Radar*

*ER*adar

Design Specifications
Portable Emergency Response FMCW Radar

Project Team	Mehdi Stapleton Steve Rickards Laurent Ye Borna Vojdani Nelson Meira
Contact Person	Steve Rickards sdr2@sfu.ca
Submitted to	Dr. Andrew Rawicz —ENSC 440 Steve Whitmore — ENSC 305 School of Engineering Science Simon Fraser University
Issued Date	March 8, 2012
Revision	1.0b

Executive Summary

At Shift Technologies, we aim to develop a Portable Emergency Response Frequency-Modulated Continuous-Wave (FMCW) Radar System. This system will help emergency response personnel in low visibility environments where the visible spectrum used by our eyes is easily absorbed or blocked. Our device is designed to be portable and cheap, to work with ranges up to one hundred meters, and to provide a resolution of approximately twelve and a half centimetres using 2.4 GHz microwaves. This document will outline the design of our solutions as well as provide justification for certain design considerations. However, this version will only embody the functional requirements labelled A in the functional specification.

The Portable Emergency Response FMCW Radar System consists of three constituent components: the radar hardware, the software processing, and the hardware packaging. The hardware of the radar is designed to use the 2.4 GHz microwave spectrum to penetrate light absorbing obstacles and utilize FMCW theory to calculate the range and velocity of objects. The iOS platform was chosen to meet our software processing needs because it provides a very capable ARM processor, a beautiful retina display and a friendly-form factor. Furthermore, App development on the iOS platform is prominent and thus, our team was able to consult other developers for invaluable advice. The hardware packaging is the final component of our solution; it ensures the operability of the radar in hostile environments. For the prototype device, ABS plastic is used to reduce costs and manufacturing complexities. The final product will have a more ergonomic and sleek high temperature and waterproof case to help resist the tough conditions.

In conclusion, Shift Technologies aims to use FMCW radar as an imaging device for rescuers in low visibility situations by creating an overhead view of the environment to view potential hazards and obstacles from many angular snapshots. This document will describe and justify the design choices for the three components of our system: the hardware radar, the software processing, and the hardware packaging.

Table of Contents

List of Figures

Glossary

1D: Denotes 1-Dimensional

1GB: The gigabyte is a multiple of the unit byte for digital information storage

ABS Plastic: Acrylonitrile Butadiene Styrene. Material used in the hardware packaging of this system.

Accelerometer: An accelerometer is a device that measures physical acceleration.

Altium Designer: Computer program used to design the layout of the printed circuit board

Android: Android is a mobile operating system developed by Google and is based upon the Linux kernel and GNU software.

Anti-Alias Filter: A filter applied prior to down sampling in order to restrict the bandwidth of the signal to acceptable levels satisfying the Nyquist criterion.

ARM: ARM Holdings; the ARM A7-A9 cortex processor is one of its products

API: Application programming interface. An interface implemented by a software program

ARC: Automatic reference counting. A feature in Apples iOS to automatically manage references.

Baseband: In telecommunications and signal processing, describes signals and systems whose range of frequencies is measured from close to 0 hertz to a cut-off frequency, a maximum bandwidth or highest signal frequency

CCRS: Canada Center for Remote Sensing

Core Image: Core Image is an image processing technology built into iOS that employs hardware to provide near real-time processing.

Coupling : In telecommunications, coupling is the undesirable transfer of energy from one medium to another.

Deinterleave : An artificial intelligence process designed to lock-on to target's trajectory.

Digital Compass: A measuring instrument used to measure the strength or direction of magnetic fields.

DPST Switch: Dual pole, single throw switch. Type of switch used to control both battery packs for the radar hardware.

Dual-core: A dual-core processor is a single computing component with two independent actual processors.

Embedded System: An embedded system is a computer system designed to perform one or a few dedicated functions often with real-time computing constraints.
that enables it to interact with other software.

ESSEF: Engineering Student Society Endowment Fund

FFT: Fast Fourier transform. An efficient algorithm to compute the discrete Fourier transform (DFT) and it's inverse.

FFT Resolution: This form of resolution pertains to the number of discrete samples achieved on the continuous frequency domain representation of the pertinent waveform (ex. return echo signal).

FIR : Finite Impulse Response Filter. Whose impulse response is of finite duration; for a discrete-time FIR filter the output is a weighted sum of the current and a finite number of previous signal values.

FMCW: Frequency Modulated Continuous Wave

Guard Interval: A buffer of adequate size to shield data collection from analog start-up and cool-down processes.

Gyroscope: A gyroscope is a device for measuring or maintaining orientation.

High Fidelity: Term used to describe a sampling rate with high quality sound reproduction from sampled data (commonly at 44.1 kHz).

HUD: Heads up display.

iOS: Apple's mobile operating system. Developed originally for the iPhone, it has

iPad: The iPad is a tablet computer designed and developed by Apple.

LIDAR: Light Detection and Ranging

LPF: Low-pass filter

Matlab: Matrix Laboratory; a numerical computing environment and fourth-generation programming language

MIT: Massachusetts's Institute of Technology

MRX: Frequency mixer

Multipath: An interference phenomenon whereby a wave travels from a source to a detector via two or more paths resulting in interference patterns at the detector

Noise Artefact: A coherent and persistent noise distortion present within a information signal

Nyquist Criterion: Commonly known as the Nyquist-Sampling Theorem, the criterion dictates the lowest sampling frequency at which the signal can be reconstructed from its sampled information. The Nyquist rate or minimum sampling frequency is at twice bandwidth of the sampled signal

OSC: Oscillator

PA: Power amplifier

PD: Pulse Doppler (radar methodology)

PCB: Printed circuit board

Point Scatters: Refers to objects in the field of view of the radar device which return a characteristic/fixed dot at the location of the object relative the antenna

RAM: Denotes random access memory, RAM is the high speed program memory.

RF: Oscillations in the range of about 3 kHz to 300 GHz, which correspond to the frequency of radio waves and the alternating currents which carry radio signals

RF Components: Hardware components that directly pertain to the generation of the electromagnetic waves used by the radar.

RX: Receiving Antenna

SIMD: Single instruction, multiple data. Describes computers with multiple processing elements that perform the same operation on multiple data simultaneously.

Sinc Function: A mathematical function defined as sin(▯x)/▯x.

Storyboard: A visual representation of the user interface of an iOS application, showing screens of content and the connections between those screens.

SMA: *SubMinature* version A connector. Coaxial RF connectors designed for limited internal resistance.

SMT: Surface-mount technology. The term used for electronic components that are soldered onto the surface of the printed circuit board.

Target Resolution: This form of resolution pertains to the AI's ability to differentiate targets which are very close together in range.

Three Tier Detection Systems: An element must pass through three filters of increasing stringency to be labelled as a peak/resolved target.

TX: Transmitting Antenna

VCO: Voltage-controlled oscillator; an electronic oscillator designed to be controlled in oscillation frequency by a voltage input

VRS: Variable Range Synthesizer. A FMCW radar signal processing block which facilitates sacrificing maximum range performance for increased FFT bin resolution.

vDSP: Vector based digital signal processing. Provides mathematical functions for applications such as speech, sound, audio, and video processing and other scientific data processing.

WAV File: Waveform Audio File Format. The extension type of the output of the radar hardware

Windowing: In signal processing applications a window function is a time-limited mathematical function which is applied on a data set of interest- resulting in a more manageable duration set for processing. The window must be chosen in order to minimize effects of truncating the original data set in the frequency domain.

1. Introduction

The Portable Emergency Response FMCW Radar System is a device that provides emergency response personnel with a detailed overhead image of a low-visibility environment. Regardless of the amount of light, smoke, or vegetation in a user's foremost direction, an accurate picture of the surroundings can be produced. The design of our radar has been broken down into three modules, the hardware radar, the hardware packaging, and the software processing. For each module, a design was chosen and this document will explain our design choices and provide concise explanations for each choice.

1.1 Scope

This document will expand on our reasoning behind our design choices and will lay out the hardware and software design blocks for the Portable Emergency Response FMCW Radar System. The design specification includes and discusses all the requirements for a proof of concept system which are labelled 'A' in the functional specification. Furthermore, a series of test plans for the system and its modules are provided at the end of the specification to help guide and evaluate the function of our prototype device.

1.2 Intended Audience

This document will be used by all members of Shift Technologies throughout the development of our radar system and serves as a guideline for the design and implementation process. The President and CEO, Mehdi Stapleton, will use this as a measure of compliance and progress of our project and direct future tasks. For implementation, the engineers of Shift Technologies will refer to this document in order to ensure that the current design complies with the goal of our product. Lastly, during testing, this document will serve as a template against which the final product is evaluated.

2. System Specifications

The ERadar Portable Emergency Response FMCW Radar system high-level block diagram is shown below in Figure 1.

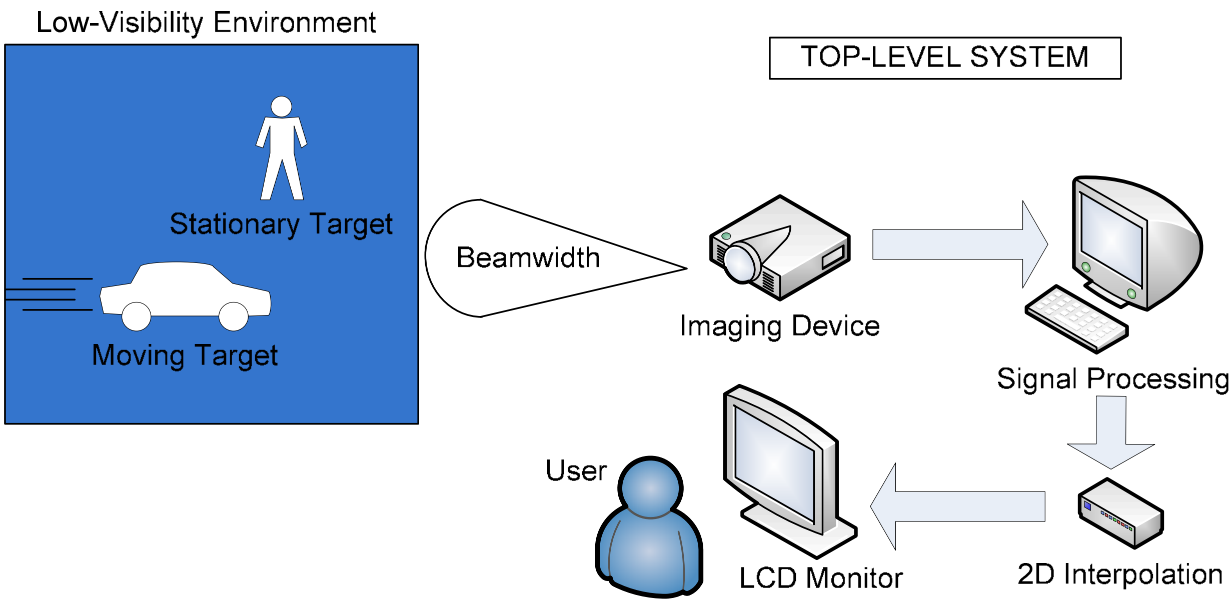


Figure 1: FMCW Radar system high-level block diagram

The product design consists of three main sub-systems: the imaging device, the real-time processing terminal and the user interface. The imaging device will comprise of a directional beam transmitting antenna and receiver capable of penetrating low-visibility environments in order to reveal targets within its beam-width. The transmitting antenna will be optimized for transmission of a 2.4 GHz (centre frequency) signal and capable of producing a sufficiently powerful signal to range profile moving and stationary targets at 150 meters from the hand-held radar system. The transmitter will be paired with a directional receiving antenna able of detecting return echoes from objects at ranges in excess of 150 meters. The antennas will be packaged compactly with the front-end function generation circuit and back-end analog filtering circuit alongside the signal processing terminal and user interface unit. The antennas will be light and unobtrusive to the personnel carrying the device.

The signal processing terminal will be able to filter undesirable artefacts and noise from the received echo and determine the range profile of the terrain within the field of view of the antenna. The processing will be able to parameterize the achievable range resolution given the proximity of the targets to the radar system as well as provide sufficient target-tracking to accommodate subsequent 2D interpolation of the radar range profiles – gathered at varying azimuthal angles relative a user-defined zero position.

The 2D interpolation hub and signal processing terminal must be compact and light -weight0020to reinforce the portability of the radar system. The terminal must also be capable of real-time processing of the incoming data in order to achieve tolerable processing delays of the target terrain.
The user interface unit will provide an intuitive and aesthetically pleasing representation of the signal processed target terrain.

The interface will clearly identify targets (persons) of interest and both stationary and moving obstacles. The user interface will support display functions for the various ranger-resolution modes the signal processing hub will be capable of generating as well as guide the user in interpretation of the data.

For the proof of concept phase of the product, the antennas will service the minimum requirements in ranging profiling objects up to 150 meters with limited directionality or antenna gain. The signal processing will be able to meet the desired filtering characteristics of a final product; however, an optimally short processing delay will not be achieved until further into production.

3. Overall System Design

This section of the document provides a general overview of our ERadar system and its components. Further descriptions and specifications of each sub-component are outlined in detail in their respective sections later on in this report.

3.1 Portability

Various radar systems currently exist for a wide range of applications that differ in both capabilities and size. What makes our product at Shift Technologies so valuable, however, is its portability. In order for this to be an effective tool for emergency response personnel, this device must meet the following requirements:

- power to the radar circuitry and heads-up display must be supplied by battery,
- provide versatile imaging for close and long-range target sensing,
- weigh less than three kilograms,
- be a relatively compact unit than can be held with one hand, and
- be able to withstand mild mechanical forces and weathering.

The first component of the power requirement in the above list was accomplished simply based on the radar hardware that was chosen for this project. After extensive research, a radar system, developed by Dr. Gregory L. Charvat's at Massachusetts Institute of Technology's (MIT) Lincoln Laboratories [1], was chosen based on its portability and low-cost. This design features two coffee can antennas, nicknamed "cantennas", and all of the necessary radio frequency (RF) and signal amplification components and is powered by only two, 6 volt (V) power sources. Each source contains four, 1.5 V battery cells commonly known as AA batteries. Furthermore, by deciding to utilize an iPhone application for the signal processing, the portable power requirements for our heads-up display were also met.

The second portability requirement is intended to allow ERadar to be used in a variety of scenarios by emergency response personnel in their respective fields. For example, the desired range is substantially different for a search and rescue member looking for a lost hiker versus a fire fighter inside a smoky room. This variable range option acts as an improvement in resolution and is accomplished within the signal processing of the iPhone application. Once the waveform audio (WAV) file has been uploaded from the radar circuitry, changing the resolution of the image produced is accomplished by adjusting variables within the software. This is accomplished by means of signal processing, and will be elaborated in subsequent sections.

The final three portability requirements all relate to the hardware packaging of the radar system. The radar hardware and iPhone must be packaged together in a single enclosure that is both compact and rugged. The size restrictions for the case are hampered by the cantennas and the electronic components. However Shift Technologies intends to decrease the electronic footprint by converting the signal amplification and modulator circuit of the hardware into surface mount (SMT) components and place them on a printed circuit board (PCB). Future iterations that would help reduce the overall size of the enclosure would be to also convert the RF components to SMT and to find smaller antennas to replace the coffee cans. The drawback however to finding smaller antennas is that it would significantly increase the cost of the radar kit.

Furthermore, the radar enclosure must be able to withstand minor impacts and weathering. Our prototype model has been designed to withstand a 30 centimetre (cm) drop test and protect its electrical contents from rain or other debris. Beyond our proof of concept model, all of the openings or slots on the radar enclosure must be chemically or mechanically sealed to limit water or heat damage. For example, this can be done by a series of o-rings designed to protect the electrical components from external water and heat. As well, a heat resistant material should be used in order to protect the integrity of the case; such options include, but are not limited to, aluminum or a powder coated metal.

3.2 FMCW Radar Theory

Unlike classical pulse radar systems which measures the round-trip time from transmitter to receiver ass a phase shift in the carrier wave, frequency-modulated continuous wave (FMCW) systems utilizes the difference between the time-dependent frequency characteristics at the transmitter and the frequency of the received echo for range detection. If the frequency is modulated by a triangular waveform, the transmitted and received frequency is shown in Figure 2 [2].

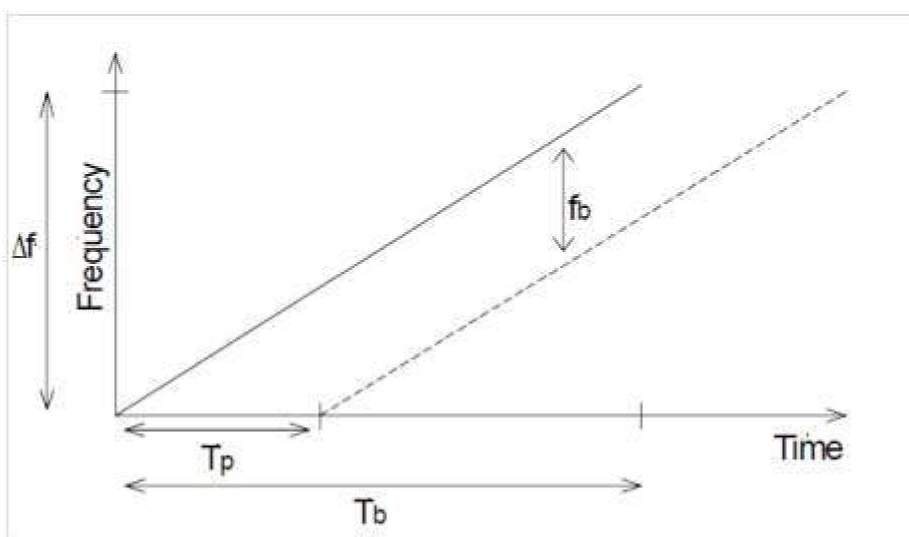


Figure 2: The up-ramp portion of the transmitted frequency sweep of the FMCW radar and its delayed received counterpart

Derivation of FMCW Radar Range Detection

Given the standard frequency modulation waveform shown below in equation 1:

$$y = A_C \cos(2\pi f_c t + 2\pi k_f \int_{-\infty}^{t} m(t)dt) \ , \quad (1)$$

Where f_c is the carrier frequency, k_f is the sensitivity factor of the modulation, and *m(t)* is the modulating signal. Substituting in the up-ramp linear portion of the triangle waveform for *m(t)* and assuming a unity sensitivity factor, the above equation becomes the following signal:

$$y = A_C \cos(2\pi f_c t + 2\pi \int_{-\infty}^{t} f_0 + \left(\frac{\Delta f}{T_b}\right) t \, dt) \ , \quad (2)$$

Taking the integral results in:

$$y = A_C \cos(2\pi f_c t + 2\pi f_0 t + \frac{1}{2}\left(\frac{\Delta f}{T_b}\right) t^2) \ , \quad (3)$$

The term f_o refers to the initial frequency at the start of the frequency sweep and $\Delta f/T_b$ is the chirp rate of the FM waveform. The received echo will be a time-delayed version of the above transmitted by waveform presented in equation 3, by some time τ:

$$r = A_C \cos(2\pi f_c t + 2\pi f_0 (t - \tau) + \frac{1}{2}\left(\frac{\Delta f}{T_b}\right)(t - \tau)^2) \ , \quad (4)$$

The transmitted and received waveforms are subsequently 'mixed' or multiplied together at the front-end of the receiver circuit and low passed filtered to remove the high frequency mixer output:

$$z = \frac{A_C}{2} \cos(2\pi f_0 \tau + 2\pi \left(\frac{\Delta f}{T_b}\right) t\tau + 2\pi \left(\frac{\Delta f}{T_b}\right) \tau^2) \ , \quad (5)$$

The frequency of the low-passed filtered mixer output shown above in equation 5 is equal to $\left(\frac{\Delta f}{T_b}\right)\tau$, which is the chirp rate multiplied by the round-trip time delay. Hence, the range to the target can be calculated given that the time delay is equal to *2R/c*; whereby, *R* and *c* are the range of the target and the speed of light, respectively.

4. Radar Hardware

The radar hardware used in Shift Technologies' portable radar system was procured from Dr. Gregory L. Charvat's project webpage at MIT's Lincoln Laboratories [3]. Dr. Charvat has generously provided all the necessary schematics and assembly instructions to motivate student's interest in radar system design [1]. The radar hardware creates the sync pulse sent by the transmitting antenna and then amplifies the resulting received signal before it is sent to the signal processing unit via the audio jack. As a finished product, Shift Technologies intends to convert the modulator and video amplification circuitry onto a PCB in order to reduce any possible noise. All of the components mentioned in this section correspond to through-hole components and hence surface-mount components will need to be eventually sourced for the PCB assembly. The PCB will be designed using Altium Designer, due to one of our team members' past experience with this program, and will be made and assembled most likely at MyRO PCB [4]. This section of the document describes the radar system's sub-components and their basic functionalities.

4.1 Power Supply

The overall radar circuit has a relatively low power requirement and hence it is possible to only use AA batteries as a supply. Specifically, the modulator and video amplifier circuits require 12 *V* of direct current (DC). This is achieved by placing two 6 V battery packs in series with one another- each battery pack contains 4 AA batteries. Furthermore, the RF components require a nominal 5 V supply. Hence the power circuit contains a 5 V voltage linear regulator (National Semiconductor, LM2940CT-5.0-ND); this component operates by stepping down a voltage above 5 V, up to 26 V DC [5], down to a stable 5 V. The input to the voltage regulator is 6 V provided by only one battery source. Figure 3 shows the schematic diagram for the power circuitry.

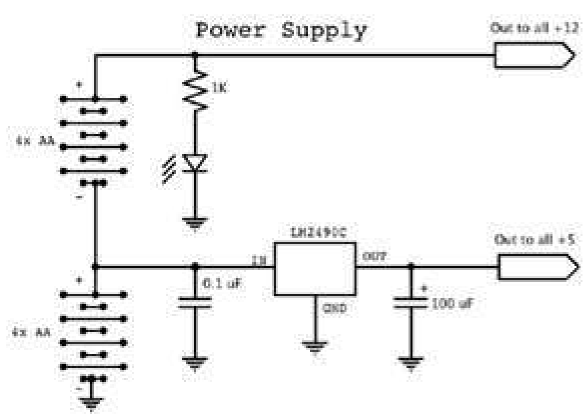


Figure 3: Power circuitry for portable radar system [1]; specific part numbers can be seen in Appendix A (MIT BOM)

4.2 Radio Frequency Components

Below, Figure 4 shows a simplified top level block diagram of the RF circuit and its interface with the function generator chip in the next section (providing the triangle modulating signal) as well as the interface with the back end circuit including the low pass filter (LPF) and video amplifier which are mentioned in the subsequent sections.

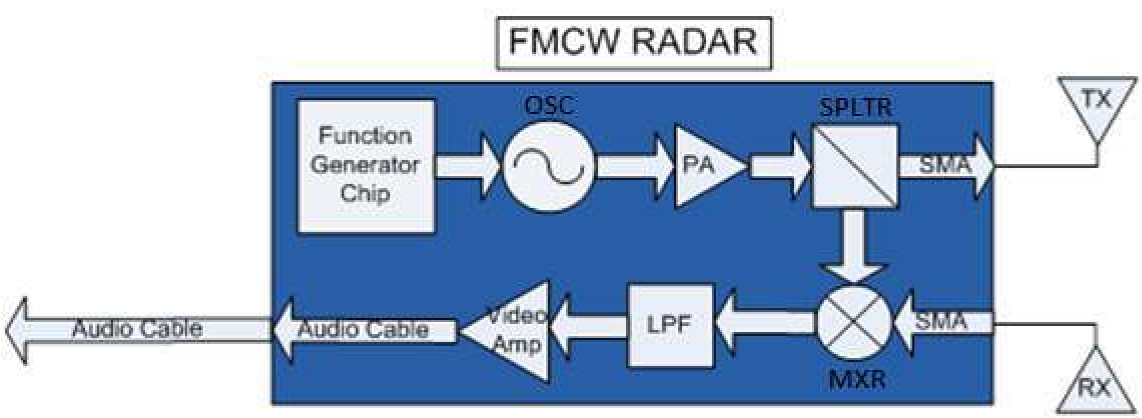


Figure 4: Simplified schematic of the RF components based off the design of Dr. Chavat's portable radar system

In the figure, OSC/VCO is the oscillator, PA is a power amplifier, SPLTR is a power splitter, TX and RX are the transmitting and receiving antennas respectively, MXR is a frequency mixer, and LPF is the baseband low-pass filter.

The function generator XR-2206 chip, seen in Figure 4, is a function generator circuit that creates the required modulating waveform for the VCO. Figure 5, below, shows the schematic diagram for the modulator portion of the circuit. Note that the function generator also produces a synchronization square waveform of equal duty cycle and period as the modulating signal, which serves to later partition the individual 'ramp segments' (refer to *Important Characteristics of Return Echo Signal* for details) within the signal processing terminal.

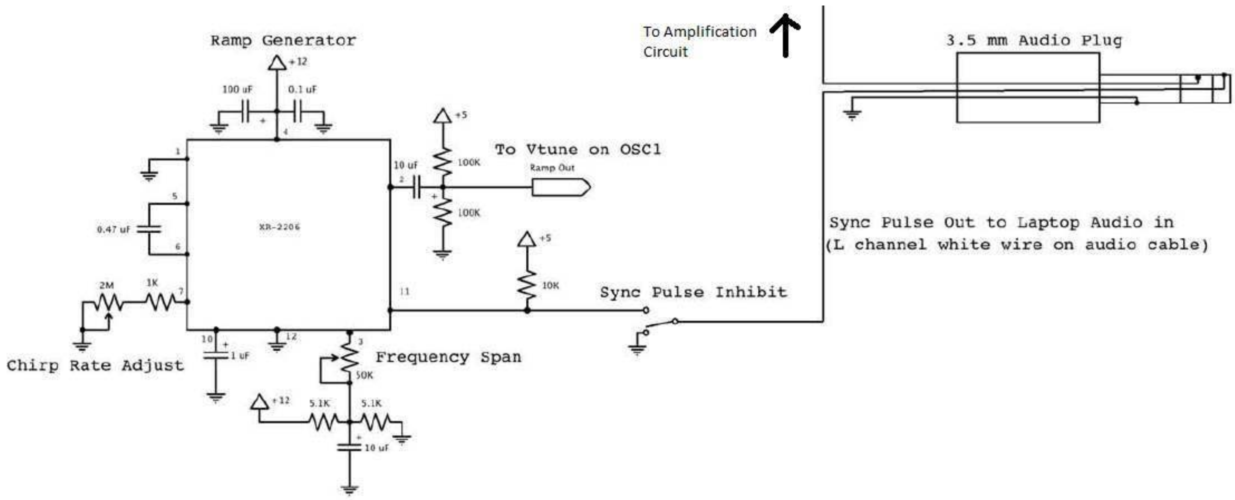


Figure 5: Modulator circuitry for portable radar system [1]; specific part numbers can be seen in Appendix A (MIT BOM)

4.3 Back-End Circuitry

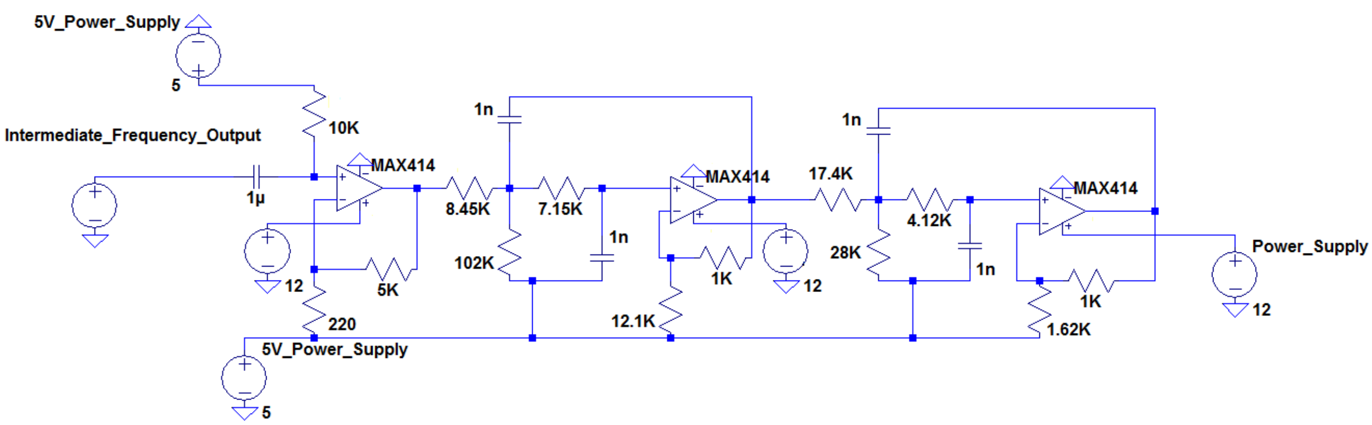


Figure 6: Back-end circuit

The back-end circuit (i.e. following the RF circuitry prior to sending off signal via audio cable to signal processing hub) is comprised of two amplifier stages. The first stage seen as the leftmost operational amplifier with Figure 6 above, amplifies the intermediate frequency output (or return echo signal) -an approximately 22 decibel gain. The following two amplifiers in cascade with the aforementioned gain stage are used to low pass filter the return echo signal with a cut-off frequency of 15kHz.

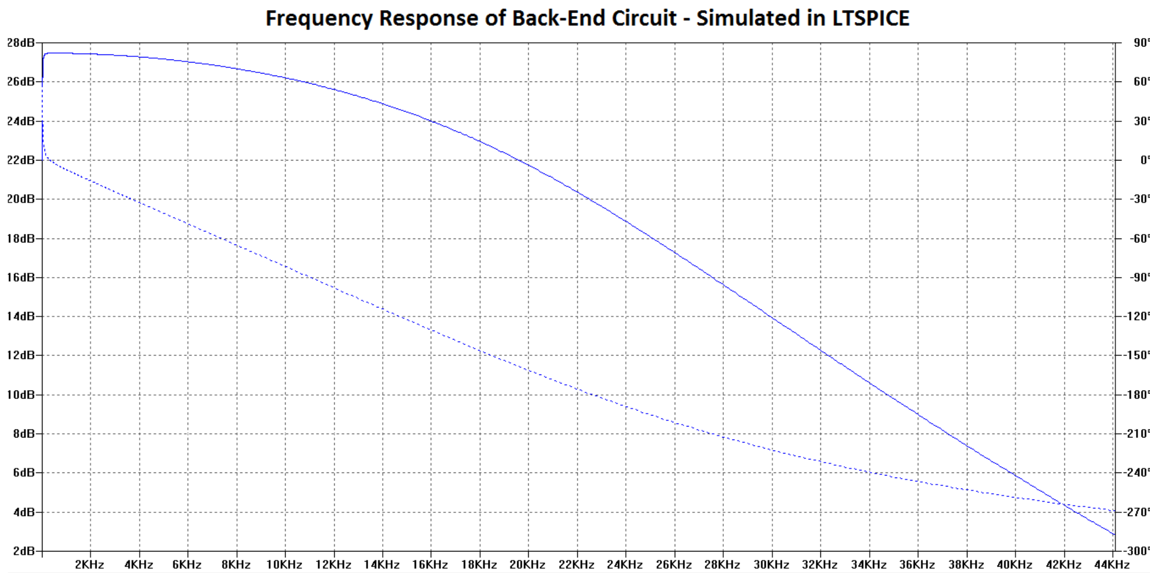


Figure 7: Frequency response of back-end circuit (aka amplification circuit)

5. Signal Processing

5.1 Preface

Important characteristics of the Return Echo Signal

The following section describing the various components of the signal processing hierarchy make heavy use of the term ‘up/down ramp segment’ when describing information content of the return echo signal. The up-ramp segment of the return echo signal refers to the signal received at the receive antenna during the transmission of the ‘up-ramp’ or linearly increasing section of the triangle modulating waveform. The down-ramp segment refers to the signal received at the receive antenna during the transmission of the ‘down-ramp’ or linearly decreasing section of the triangle modulating waveform. During the scanning process the receive antenna will receive several hundreds of both down and up ramp segments which are recorded onto the iPhone during the scan process.

It is unfeasible to determine where a down ramp segment ends and an up ramp segment begins, or vice versa, without some form of synchronization. For this reason a synchronization square waveform (‘sync wave/sync pulse’) is input simultaneously with the echo data for signal processing directly following or concurrent with scan. Each consecutive up ramp segment corresponds to another ‘snapshot’ of the field of view of the radar. Hence, the segments chronicle the state of the terrain within the beam width of the antenna in correlation with time; a segment is a snapshot of the terrain at a point in time later than the segments preceding it.

Note-worthy is the fact that the signal processing descriptions below treat the synchronization waveform and return echo signal as vectors of samples which have been already recorded into memory following radar scanning.

5.2 Signal Processing Overview

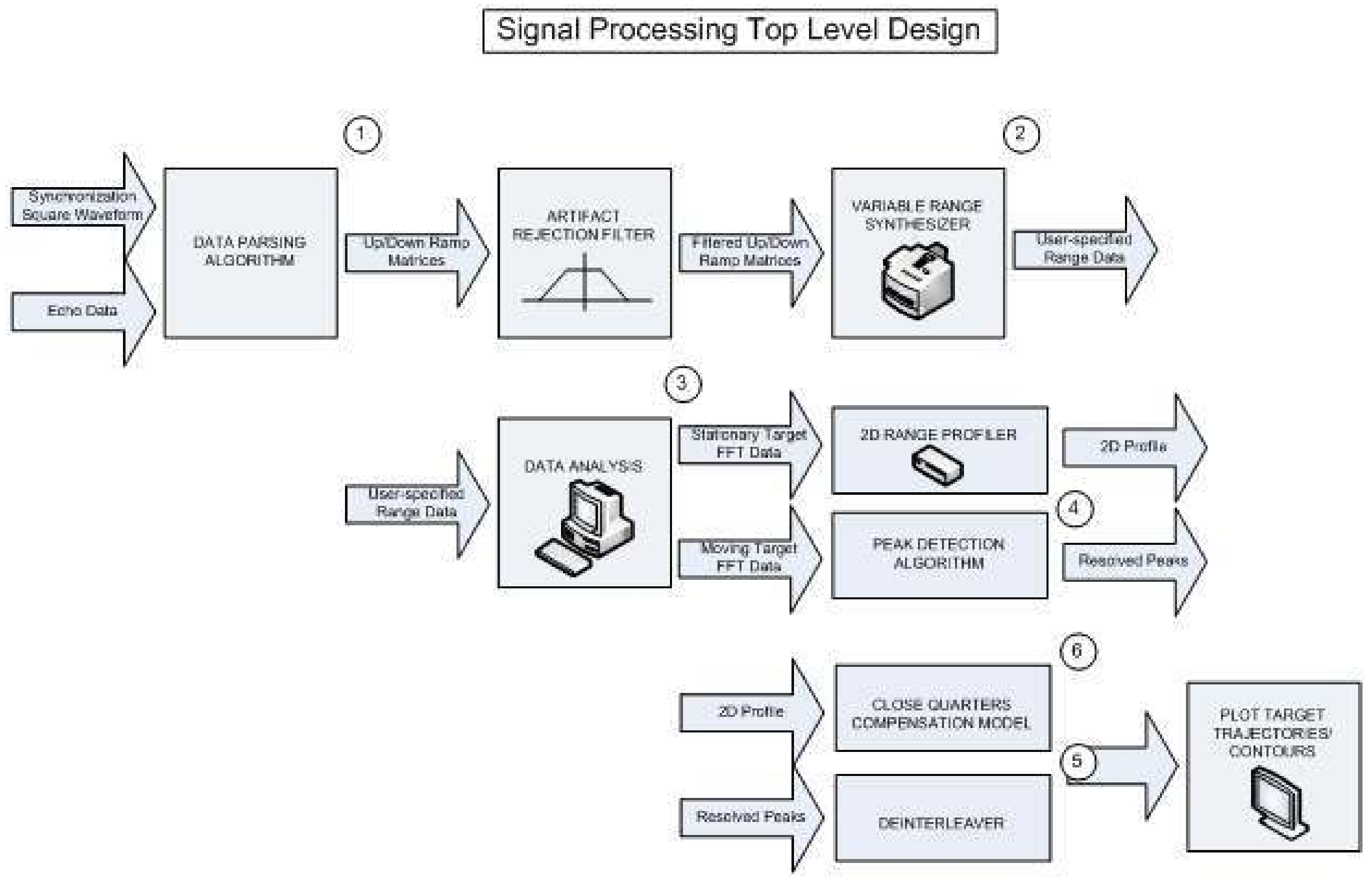


Figure 8: Top Level Hierarchy of FMCW Radar Signal Processing

The FMCW radar system will send echo return signal range information and a synchronization waveform (sync signal) via the left and right channel of the audio cable. The two data streams are input into a processing-time-optimized data parsing algorithm (labelled 1 on Figure 8, above). The data parsing algorithm is designed to partition the aforementioned up and down ramp frequency segments (from here on referred to as just ‘ramp segments’ or ‘segments’) from the raw echo signal using the sync signal. The segments are packaged as two matrices (‘ups’ matrix and ‘downs’ matrix).

The matrices are subsequently fed to an artefact rejection filter which is selectively tuned to attenuate large noise artefacts such as direct coupling between the receive and transmit antenna circuitry. The filter is implemented using a high order finite impulse response (FIR) filter to reject certain frequencies within the return echo signal.

The resultant filtered ramp segment matrices are processed by the variable range synthesizer (VRS) which pre-conditions matrix for optimal range resolution given user-specified radar application. For instance, if the user-specified a short range application for a close-quarter scenario, then the VRS will maximize the FFT bin resolution within the close-proximity maximum range. The VRS will also apply a custom window function on the matrix to optimize target resolution.

The 'user-specified range optimized' matrices are then received by the Data Analysis Block which divides the matrix data into stationary and moving target data. The moving and stationary target data is stored in separate matrices after division and an FFT is performed along the rows of the matrices corresponding to post-processed individual ramp segments of the echo signal. The absolute value of the FFT is then taken for each segment and a smoothing filter is applied row-wise. Three sets of matrices now co-exist with an up and down ramp matrix for the moving target filtered FFT data and a stationary target filtered FFT matrix.

The stationary target data is further processed by a 2D range profiler which meshes the newly received data with the 'previously' scanned target data based on azimuthal angle stamps associated with each 1D scan. The resultant 2D cross-section of the target terrain is then assessed by a close-quarters compensation model which uses compiled experimental trial data to recognize key landmarks within rooms.

A robust peak detection algorithm processes the moving target data, and generates an unsorted matrix of 'resolved targets' based on a three tier detection criteria. The detection algorithm is paired with a sophisticated and robust 'deinterleaving' algorithm which implements target-locking techniques to sort resolved peaks into independent vectors representing a target's complete trajectory.

The signal processing is concluded by delivery of results to a plotting function to map out the target trajectories or contours for the 1D and 2D range profiler, respectively.

5.3 Signal Processing System Practical Considerations

The signal processing terminal must embody the three cornerstones of the successful product as a whole: efficiency, portability, and feasibility. The system must be able to process radar data in real-time with minimal delay between scanning and graphical display of terrain/targets. For this reason, each block of the system has undergone run-time optimization by reducing the amount of operations performed for each second of data captured. Special considerations were also weighted in order to a achieve a robust algorithm for target detection and locking.

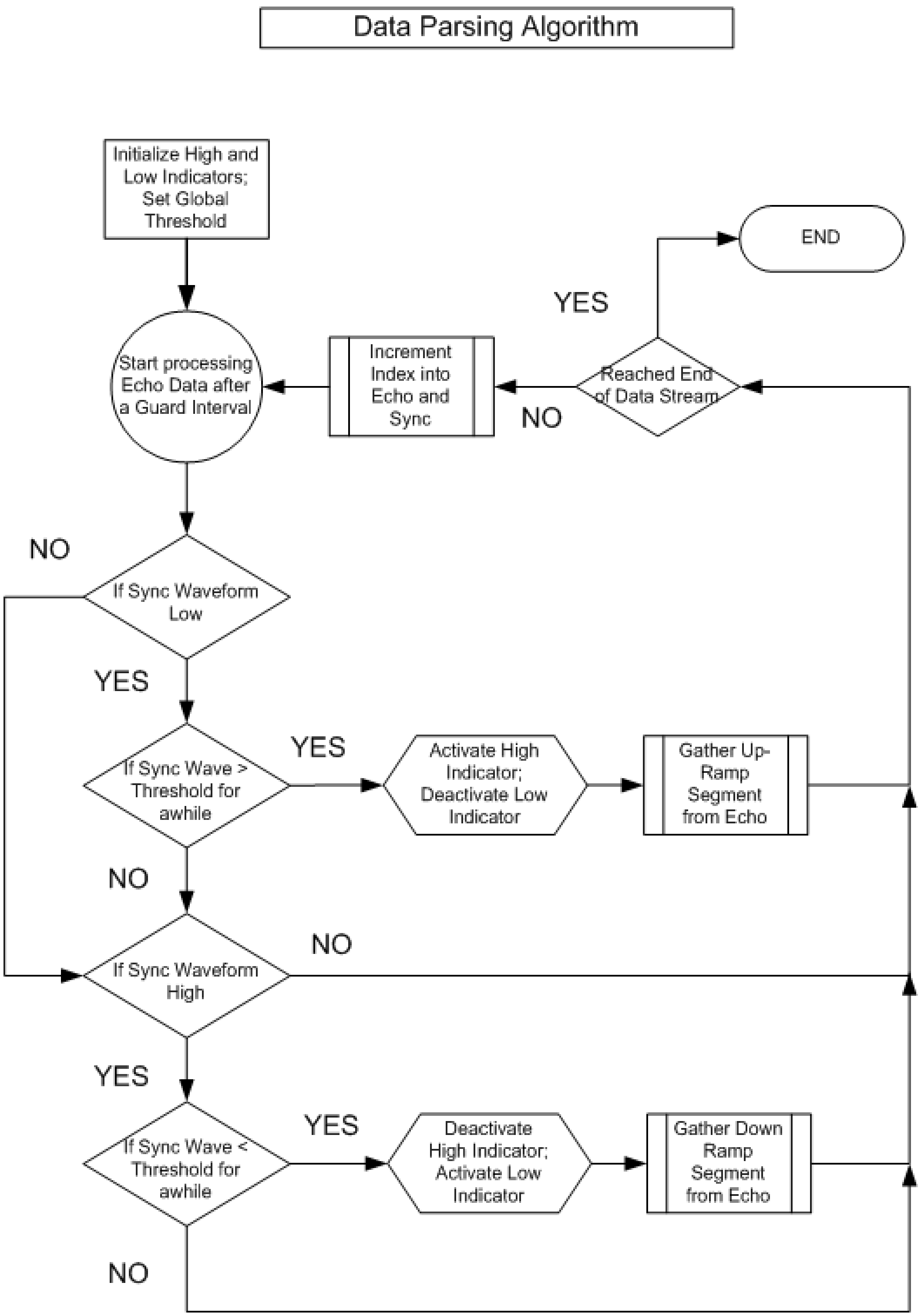


Figure 9: High-level flowchart of Data Parsing Algorithm

5.4 Data Parsing Algorithm Overview

The signal processing terminal accepts a synchronization waveform and a return echo signal. The signals are both sampled at a high-fidelity 44.1 kHz prior to delivery to the signal processing hub. The synchronization waveform is an approximately square wave, its toggled high to indicate an up-ramp segment is being sent from the transmitting antenna and low when a down-ramp segment is being sent. The synchronization signal is prone to noise which motivates a more robust determination of the start of each ramp segment. This robust approach is evident through the conditions that the 'sync wave' or synchronization waveform must be greater or smaller than the threshold for 'awhile' as shown in the figure above. To limit this relatively time consuming calculation a high and low variable are introduced to streamline the data parsing. Guard intervals are also established at the beginning and end of the data stream in case of undesirable noise upon start-up.

5.5 Variable Range Synthesizer Overview

The maximum range of the FMCW radar system is given by the following equation:

$$Maximum\ Range\ (m) = \frac{c}{2B}T(\frac{F_S}{2}),$$

where c is the speed of light ($3\text{x}10^8$ m/s), B is the bandwidth of the radar system (frequency range of ramp), T is the duration of the ramp or half the period of the modulating waveform, and lastly F_s is the sampling frequency. Another important attribute of the radar system is the achievable range resolution which is given by the following:

$$Range\ Resolution\ (m) = \frac{c}{2B}T(\frac{F_S}{N}),$$

where the constant N is the FFT size. There is an obvious trade-off between the maximum range and FFT bin resolution or range resolution. Therefore, by accepting a user-specified descriptor of the application (long range, medium range or short range), the VRS system will acknowledge the need for improved range resolution in shorter range applications by reducing the effective sampling frequency and performing the necessary anti-aliasing filtering required. As part of the practical considerations when designing the signal processing blocks is the recurring theme of run-time efficiency and feasibility; therefore, the VRS is designed to use a constant N sized FFT independent of selected range application for ease of implementation and code efficiency.

Since point scatters in the field of vision of the radar system will produce a sinusoid at a frequency proportional to its range from the radar in the return echo signal. The sinusoid will ideally appear as a frequency-shifted impulse in the FFT matrix. However, due to the time-limited nature of the input signal, the response is more characteristic of a frequency-shifted sinc function. Hence, the VRS system will also apply specific windowing functions unto the matrices in order to optimize peak resolution by condensing the main lobe of this frequency response as well as reduce 'ringing' which may interfere with neighbouring responses.

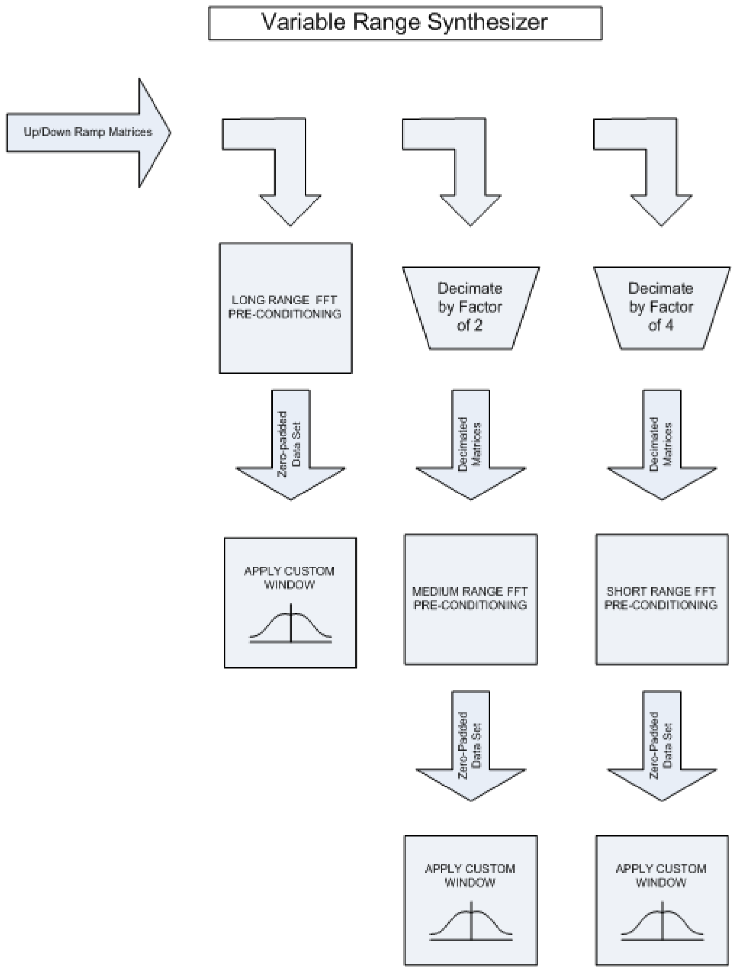


Figure 10: Variable Range Synthesizer high-level block diagram

5.6 Data Analysis Block Overview

The data analysis serves as a preconditioning process between the generation of a noise-filtered and application-specified segment matrix and more sophistication algorithms such as target-tracking and 2D interpolation techniques. The main purpose of the data analysis block is separate the stationary target data from the moving target data for the high-level processing blocks. The first step of the data analysis block is to subtract the average all down ramp segments from each individual down ramp segment and likewise for the up ramp segments.

This process eliminates a large degree of noise and clutter from the range profiles contained within the down and up ramp matrices. The stationary targets-only data is extracted from the matrices by performing a time-wise low pass filter along the collected segments. This operation removes any fast moving targets while preserving the 'low-frequency' characteristics of the matrix in time. The reverse operation is performed to extract the moving target data by applying a high order high-pass filter. As mentioned in the FMCW theory section, the range information of the scatters in the field of view of the radar is contained within the frequency components present in the ramp segments. Hence, the absolute value of the FFT is collected for all ramp segments for further post-processing. The data analysis also reduces the computational load on peak detection and target-locking algorithms down-stream from the block, by performing a smoothing filter on the FFT frequency bins.

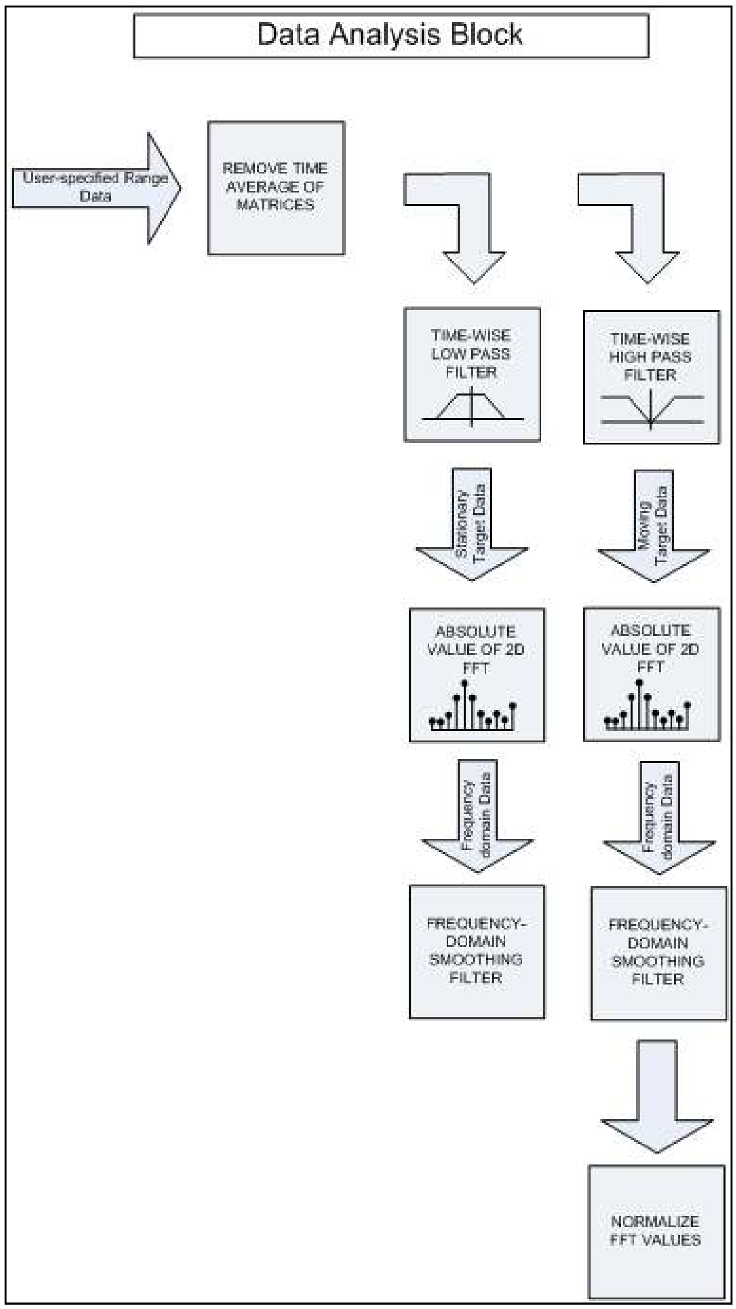


Figure 11: Data Analysis high-level block diagram

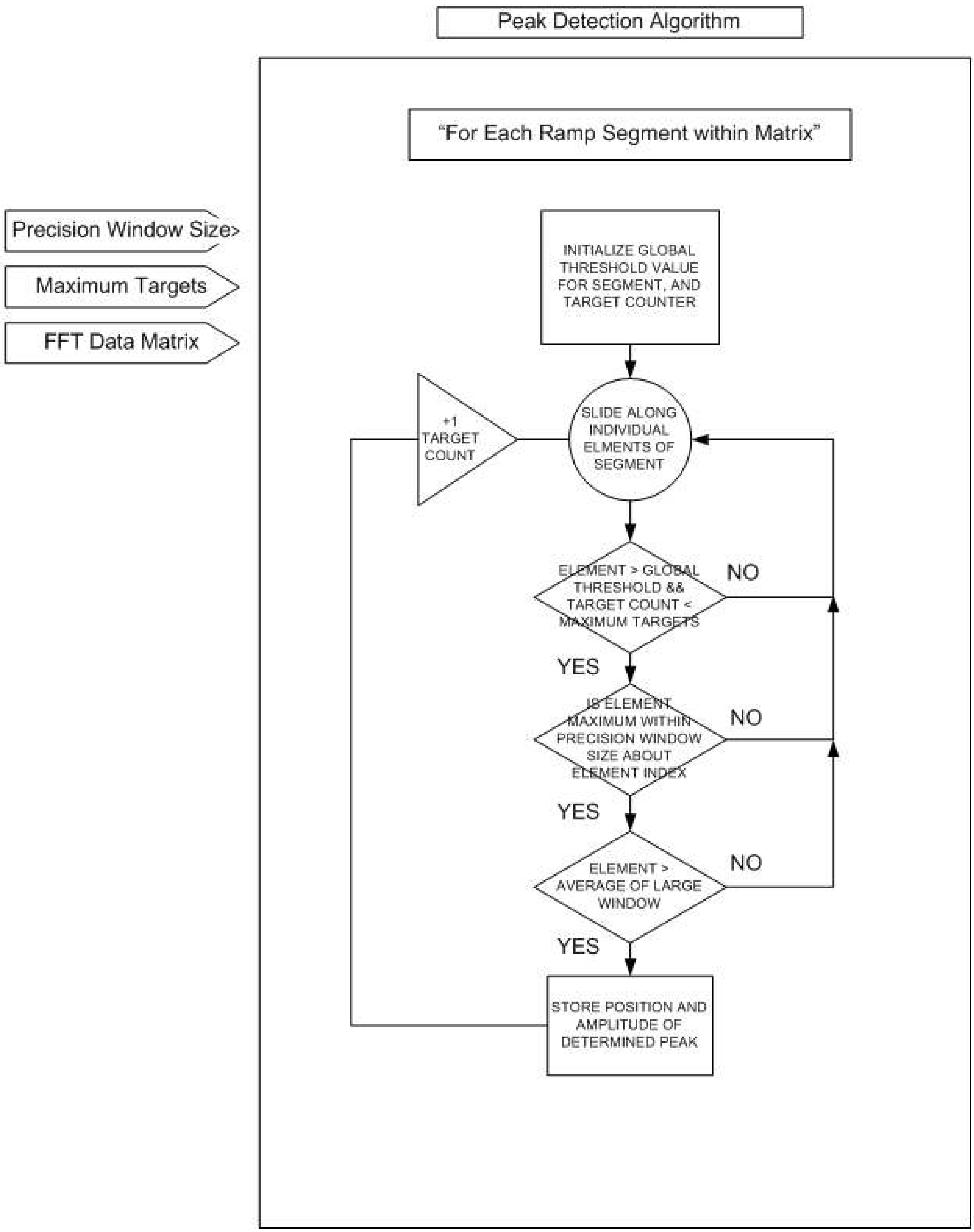


Figure 12: High-level flowchart of Peak Detection Algorithm

5.7 Peak Detection Algorithm Overview

Despite, measures taken to minimize noise and variability in the up and down ramp matrices, the FFT matrices passed from the data analysis block will contain imperfectly defined peaks representative of targets within the radar's beam width. For this reason a three tier system for resolving peaks is employed. A global threshold is first established in order to suppress any minor peaks mostly a product of noise or processing imperfections. The global threshold is chosen between the mean of the ramp segment of interest and one standard deviation above this mean. The second tier of the system is a large window which centers itself about the index (frequency bin) of interest within the ramp segment FFT. The large window gathers rough characteristics of the surrounding clutter and targets while maintaining a degree of adaptability by not considering global traits of the segment. Lastly, the third (top) tier of the system is the small precision window which enforces a strong local constraint on a value being labelled a peak. The peak detection accepts user defined parameters specifying the maximum amount of targets resolved within each ramp segment as well as the half-width of the precision window size.

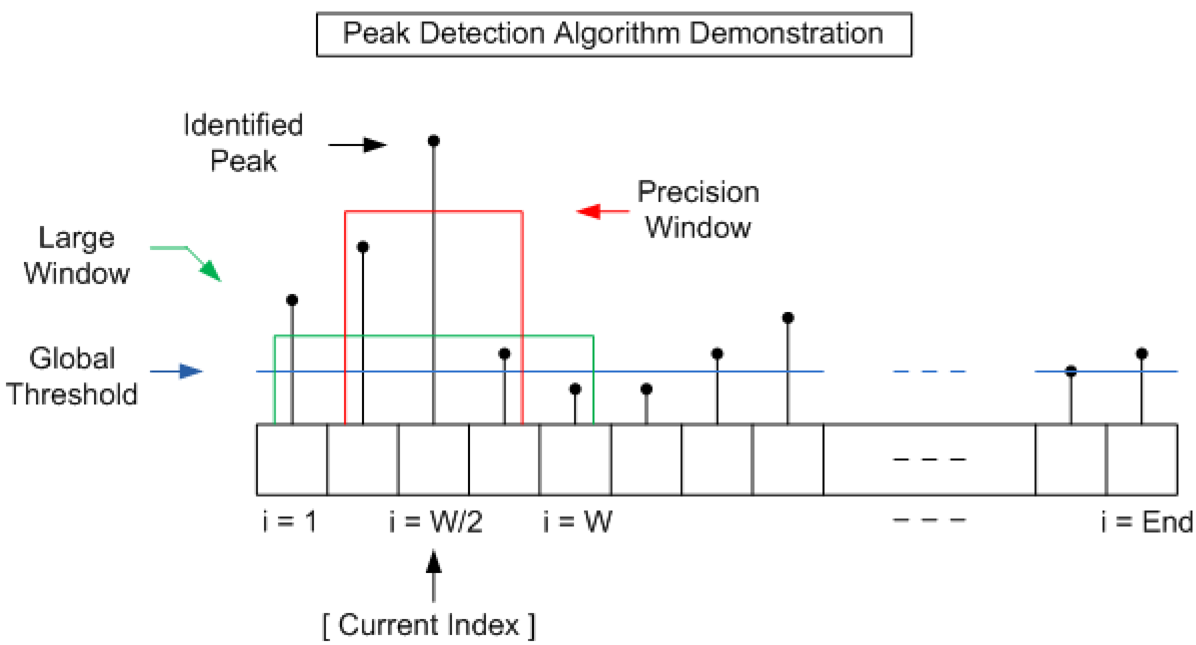


Figure 13: Demonstration of Peak Detection Algorithm

5.8 Deinterleaving Algorithm Overview

The peak detection algorithm will produce a matrix containing the position and amplitude of the resolved peaks as well as the corresponding ramp segment it was detected on; thereby, also containing the time interval during the existence of the peak. The peaks which correspond to 'targets' on the terrain are raw with no clear relationship between peaks nor any establishment of target trajectories which would complete the 1D range profiler as well as provide an important stepping stone in stitching together 2D range profiles of moving targets.

The deinterleaving algorithm employs a sophisticated target-locking scheme to determine clear target trajectories for the user and downstream signal processes. The algorithm must supervise three main events to determine multiple target trajectories simultaneously: entrance events, exit events, and persistence events. An entrance event is shown on the above figures; it refers to the determination of whether a new trajectory needs to be mapped out for a target which has recently entered the field of view. Exit events correspond to the opposite of entrance events whereby a target leaves the field of view. Lastly persistence events are a tool used by the deinterleaving algorithm to combat noise in the peak detection process or any underlying imperfections such as multipath resulting in intermittent peak resolution from ramp segment to segment.

The algorithm is established on a few key ideas: firstly that the ‘minimum distance peak’ in a later segment corresponds to the same target as a peak in the adjacent previous segment; earlier established target trajectories have priority in competing trajectory events; the amount of persistence allocated to a target trajectory is proportional to its ‘true length’.

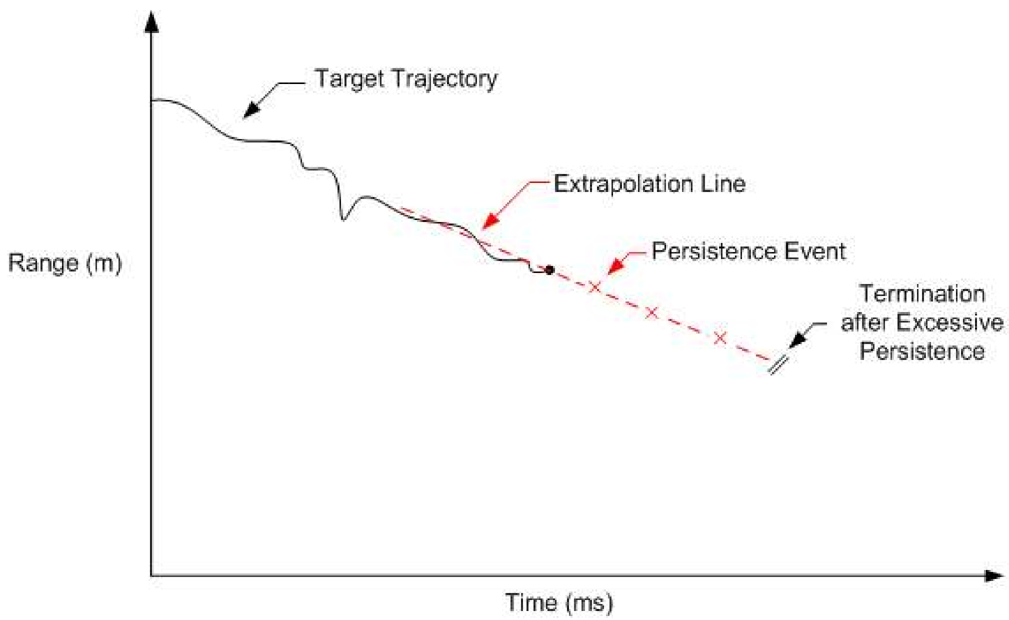


Figure 14: Demonstration of persistence events within Deinterleaving algorithm

As an aside, time frames lend themselves as a more intuitive term for describing ramp segments; hence, the use of frames and segments will be used interchangeably for the remainder of this section.

The algorithm begins by selecting the resolved peaks in the first segment (i.e. first in a temporal sense as well) as anchors for the target-locking process (if no peaks are present in first segment, the algorithm moves on to the subsequent segment). Each anchor then searches for the peak in the subsequent frame with the minimum distance between itself and it as well as being with a specified maximum distance based on the maximum observable speed of the target. This process is observable in Figure 15.

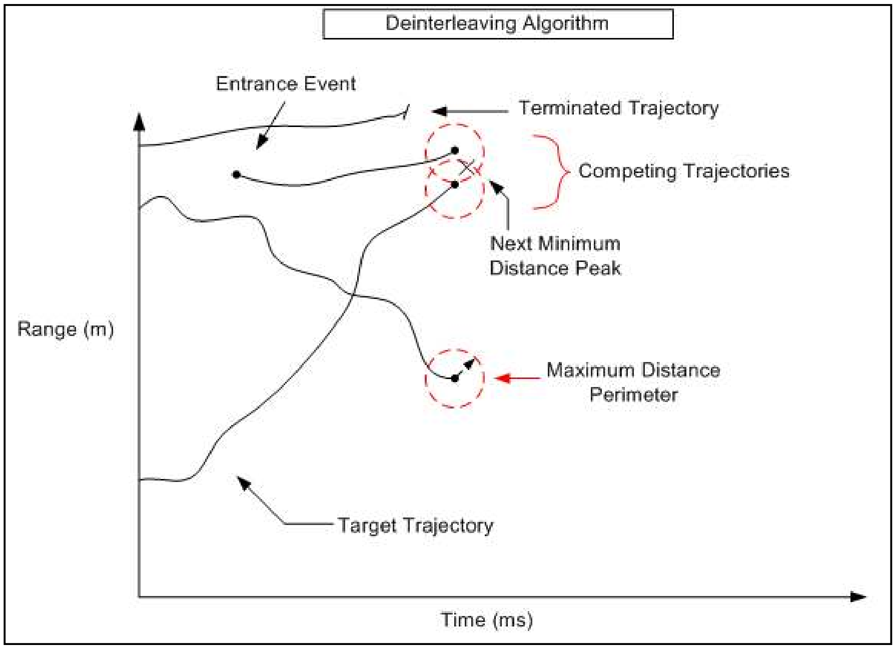


Figure 15: Pertinent scenarios in Deinterleaving operation

The process is repeated with the subsequent peak becoming the new anchor point. The process is complicated upon introduction of competing trajectories and combinations of the three main events outline previously. In competitive environments with multiple closely spaced targets, the earlier trajectories and hence the longer trajectories assume priority. The minimization of competition events is achieved by more advanced persistence techniques which allow for more precise minimum distance parameters. The continuity of target trajectories is in large part due to the idea of custom persistence, which results in fast termination or cancellation of 'false targets' due to noise and slow termination of well-resolved target trajectories. The following table outlines some key terminology used in the signal processing environment with regards to the deinterleaving process.

Table 1: Algorithm parameters and their descriptions

Algorithm Terminology	Description
Custom Persistence	Each target trajectory has an associated custom persistence factor which determines the amount of consecutive frames the trajectory will persist (ie. without finding a pertinent target peak) prior to trajectory termination or cancellation
True Length	The amount of points (peaks) associated with a trajectory not including persistence events
Velocity	A measure of the trajectory slope used for extrapolating/estimating target's next location
Taken	A Boolean number label for whether a peak in a subsequent frame has been chosen by another target trajectory
Tag Number	The number representing the order of conception each target trajectory

6. Firmware and Interfacing

6.1 iOS Platform

The iOS platform, built around Apple's mobile device technologies, was chosen as the primary development platform to create the ERadar's heads-up-display features. In addition to the cross-platform device migration features that the iOS development platform is built upon, developers can take advantage of powerful built in libraries that allow the rapid usage of features such as image and data processing, "storyboard" layout workflow interface design, and SIMD accelerated mathematical algorithms. With an increasingly powerful profile of mobile devices in various form-factors and physical characteristics, the Apple/iOS platform will allow ERadar to remain a sophisticated product built around a solid platform that is device extensible and readily available for future upgrades. Along with these characteristics, Apples mobile devices are owned by millions of users world-wide. This is an important factor in the success of ERadar, as a consumer and professional device will allow minimized production and retail cost; furthermore it will maximize the desirability and adaptability of the product to the end user. The following in Table 2 are base features which were critical in choosing the Apple/iOS platform. Many of which are not readily available in other mobile platforms such as Google's Android platform.

Table 2: The iOS development advantage for ERadar

Apple's iOS platform and development tools advantages
Built in GUI designer with transition control ("Storyboard")
Powerful SIMD accelerated vector and complex mathematic algorithms ("vDSP")
Advanced image processing and enhancement library, allowing rapid design ("Core Image")
Built-in and device specific cross-platform device simulator with debugging functions
Real-time debugging of externally connected device
Built in orientation sensors for radar data processing (digital compass, accelerometer , gyroscope)
Access to dual-core mobile devices with up-to 1GB of RAM for data processing and rendering
Automatic Reference Counting (ARC), allowing rapid, hassle free and design focused coding

Extensibility

Along with the cross-platform advantages of the iOS development environment, there are the extensibility features of iOS throughout Apple's mobile product line. With the ERadar prototype built around the iPhone, a 3.5 inch constraint is introduced with respect to the screen real-estate of the final product. By using iOS technology, the bulk of the software code and the software itself can be instantly run on devices with larger screen sizes without any modifications. In order to allow the ERadar software to run fluently on future hardware, only minor aesthetic modifications are required hence allowing seamless interface coexistence through an assortment of interchangeable devices. This will allow the end-user to have the final choice between using a lighter and more portable device such as the iPhone, or take advantage of the 9.7 inch screen on the iPad line of tablets to improve the output distinction and detail clarity of the scanned results.

Heads-Up Display and Processed Output

The concept of the ERadar heads-up display (HUD) software is to allow the user to rapidly scan areas for targets through the user of a fluid and responsive general user interface (GUI). This HUD can manipulate all aspects of the radar's function and maintain a high level of feedback and sensitivity to the user. This feedback will help minimize potential run-time frustration and confusion by keeping the user informed of the device's status at all times. Once a radar scan has been completed, the software will compile and process the data from multiple scan instances and render them into a results display pane. This screen will provide the user with the radar scan results and other vital real-time information that can assist emergency personal in a rescue operation. An example of a potential final design for the radar results page is illustrated in the Table 3. The following indexes and describes the features highlighted in this design. Furthermore, the proposed final design for the 1D discrimination can be seen in Figure 16. Note that this image was developed in Photoshop and the exact animations in the results pane are only a proof of concept at this point.

Table 3: Potential, tabulated list of the results pane features and their functions

Feature	Description
Target Count	Display the number of stationary and moving targets found within a scan
Max Range	The theoretically calculated maximum radar scan range line
Scan Line & Number	These lines illustrate the bearing of the device through numbered scan instance
Compass	Displays the current compass bearing to aid the operator in poor conditions
Stationary Targets	Color coded and size specific stationary targets are seen throughout the range
Scan Button	Allows the initiation of a new scan directly from the results pane
Moving Targets	Moving targets identified are connected with an arrow to iterate their bearing

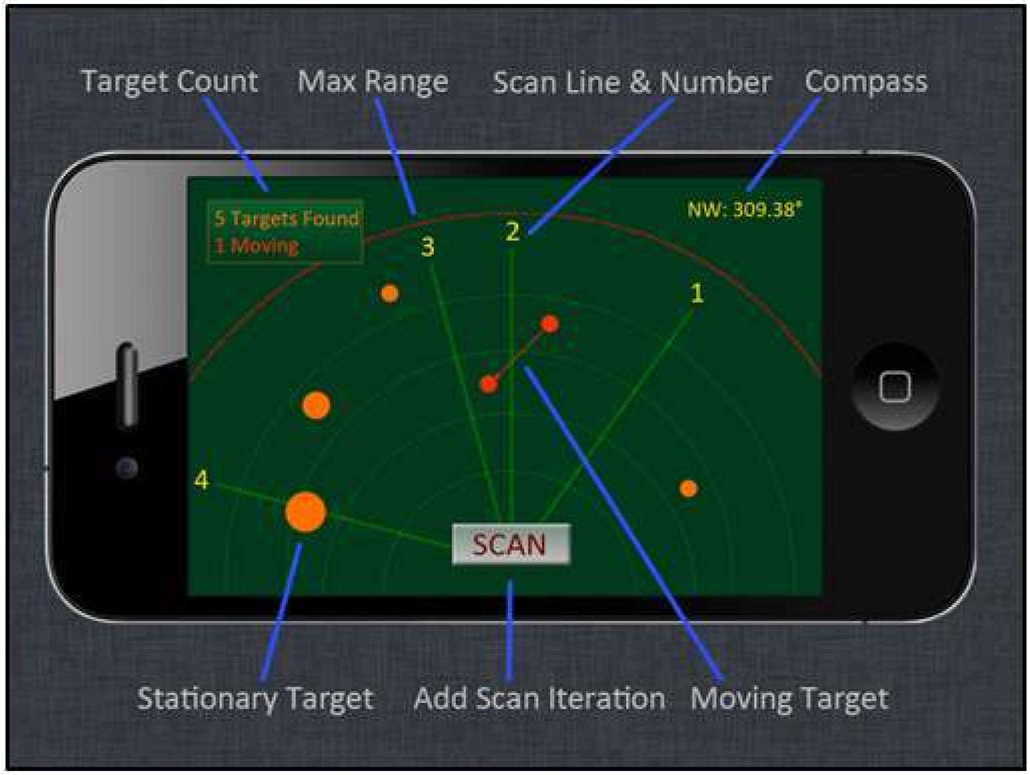


Figure 16: A concept final design for the 1D discrimination of targets within the results pane

6.2 User Interface

This GUI incorporates all HUD feature of the radar, along with the necessary setup features built into the radar device. Along with data acquisition and processing, the user-interface will also allow fluid guidance and intuitive navigation throughout the use of the device. The user interface is broken down into four major subsections: the home, or command, screen, the scan dialog, the settings selection page, and the results pane. There are also additional diagnostic screens, such as the digital signal processing diagnostics screen, and the compass function test page that will aid in troubleshooting and keep the device calibrated.

Command Menu

This is the primary screen that loads when the software is initiated. It allows access to the different functions of the software with one touch. The user can access the settings dialog from this screen, allowing the predetermination of device operation criteria before radar data is collected. A large and easily accessible button labelled "SCAN" allows direct and hassle-free initiation of data collection.

Scan Page

This page contains the scan procedure. The device will prompt the user with a three second count-down in order to direct the radar in the intended direction. After the countdown, the screen will alert the user that a scan is in progress for the duration of time selected within the software settings. This screen will disable any user interaction for the duration of the scan for maximum reliability.

Settings Dialogue

The settings dialogue will allow for vital data acquisition and processing dependencies to be selected prior to device operation. This page will allow the length of time for the data capture and record window process, the approximate target range resolution requirement and, optionally, an identification variable for the saved radar data for future access and use.

Results Pane

This screen renders the results of a scan instance. Denoted as view 3 in the GUI transition figure below, a large button marked "SCAN" allows the direct initiation of a new scan instance from the results pane without the need to cycle through the command Menu.

Figure 17: ERadar GUI; the command menu

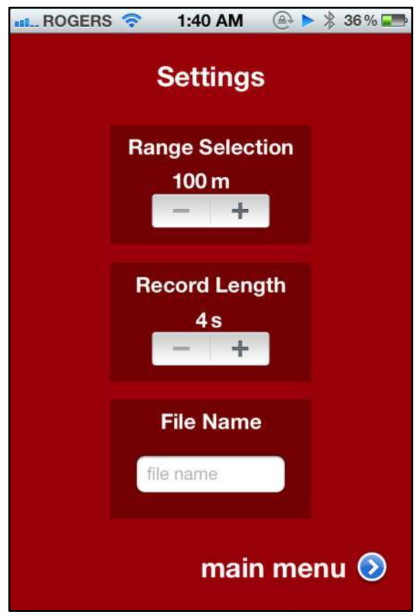


Figure 18: Settings dialogue view

These various views and the transitions between them are diagrammed in Figure 19 below.

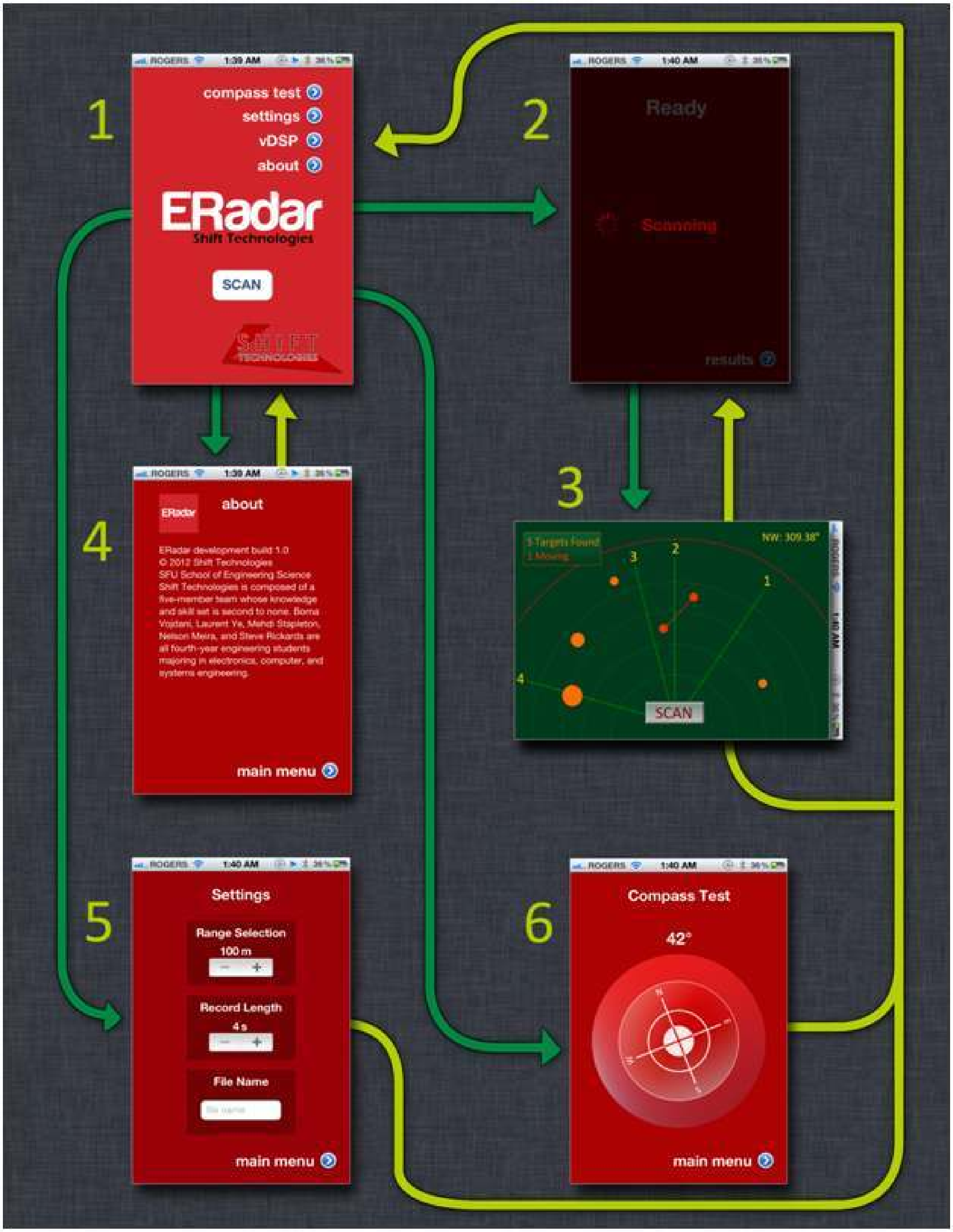


Figure 19: Interface transition chart for the ERadar HUD graphical user interface

6.3 Maintenance and Firmware Updates

Unlike the majority of portable devices that employ embedded systems in their function, ERadar takes advantage of a platform with open communication means and the ability for the end-user to download the newest software. This allows the user to upgrade their software, automatically and remotely, in order to fix potential software bugs, increase the efficiency of the device and add new features that take advantage of any enhanced signal processing algorithms and techniques.

6.4 Digital Signal Processing and Data Acquisition

Input and Sampling

In order to parse the returned radar data within the iOS capable device, the two signals will be fed into the device via audio input (microphone) ports available on all mobile iOS devices. The signals will then be samples at a high-fidelity 44.1kHz sampling frequency, and written to a buffer for processing and storage.

Code Translation

As described in the signal processing overview section of the FCMW radar theory, the ERadar software must meet the portability, efficiency and feasibility requirements of a successful design. As such, the software must maintain efficient processing speeds and device extensibility. This introduces the challenge of converting the proprietary and complex processing functions built into the Matlab suit, employed in the design of the radar, into iOS specific device code.

The vDSP API

The vector based digital signal processing (vDSP) application programming interface is an iOS specific API which provides mathematical functions; such processes include speech processing, audio and video processing, diagnostics imaging, radar signal processing and other scientific data routines. The vDSP functions operate on both real and complex data types and are capable of vector-to-vector and vector-to-scalar operations, both of which are required for FCMW signal processing. In particular, the vDSP library provides built in windowing and FFT algorithms that are inherently SIMD accelerated. These optimizations will allow the device to compete in performance to its powerful and future-rich desktop based predeceasing design platform based on the Matlab studio.

Core Image

Core Image is an image processing technology built into iOS that takes advantage of graphics hardware to facilitate near real-time image and video enhancement and modification. The Core Image application API provides access to built-in digital signal filters for still images and video, and provides routines for creating filters suited for specialized functions. Core Image allows for the enhancement, conditioning and post-processing of generated data frames from the 1D and 2D profiler in order to enhance target distinction in a number of environments.

7. Hardware Packaging

The packaging of Shift Technologies' portable radar system is vital to fulfilling its portability requirement. All of the radar hardware must be contained within the interior of the case while the user's iPhone must be secured, but still accessible for operation, on the exterior. As for the physical requirements, the case must be rugged enough, yet lightweight, in order to withstand general abuse from its user's environment. With these considerations in mind, this section will outline the basic design of a proof-of-concept model.

7.1 Physical Design

The most fundamental criteria taken into consideration during the design process of the case was the need to be lightweight. Obviously there existed a direct trade-off between a lightweight design and one that could withstand harsh environmental abuse; however it was decided that a lightweight design was more important than its ruggedness. Hence one of the first aspects of the design that needed to be determined was the material of the case. After considering different options, it was decided that the material of the case would be 3 mm, acrylonitrile butadiene styrene (ABS) plastic. ABS plastic was chosen over other options, such as powder-coated aluminum or polycarbonate, based on its availability, price, and ability to be shaped and manipulated. Furthermore, ABS plastic had extremely desirable properties for both physical durability and resistance to heat [6].

Once the material was chosen, the next significant design consideration to address was the ability to easily access the contents of the case. This posed a small challenge as it directly opposed one of the other design requirements- to be discussed in further detail later in this section- of needing the case to be sealed to protect heat or water damage. Hence the proposed design for a case, where the contents were accessible, involved a top piece that could be taken off once a series of screws were removed.

A precise and detailed drawing of a prototype case can be viewed in Appendix B. A set of brief, build instructions, not considering exact measurements, for the proposed type of case is described in List 1; Figure 20 and Figure 21 show the completed pieces of the case with the appropriate labels.

List 1: A brief set of build instructions for the proof-of-concept case for Shift Technologies' ERadar

1. Six pieces of 3 mm ABS plastic were cut out and designated as Piece A, B, C, D, and E.
2. Using a hole saw, cut out two circular holes from Piece B.
3. On Piece A, both sides of the plastic were bent by ninety degrees.
4. Pieces B and C then slid in between the bends on Piece A. Glue was applied to Piece A where Pieces B and C were to be placed.
5. Piece D is the cover of the case and is manipulated to have a slight bend to accommodate for the iPhone and have its sides folded down similar to Piece A.
6. Two small pieces of plastic, designated as Piece E, are glued to the folded-up edges of Piece A.
7. Piece D is placed on the top of the Piece A and is secured by four screws into the pieces marked E.

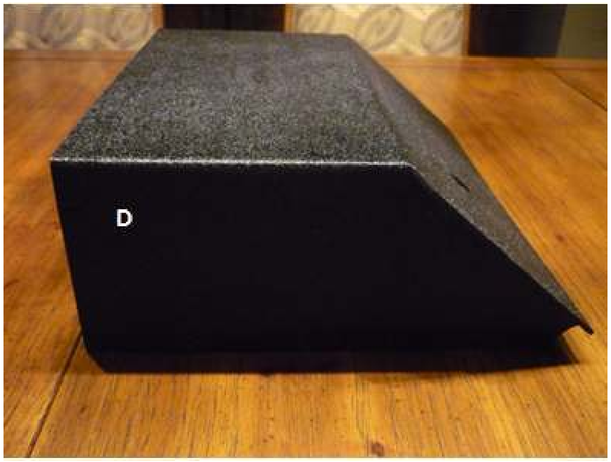


Figure 20: D that has been manipulated, through a series of bends, to be used as the top of the case.

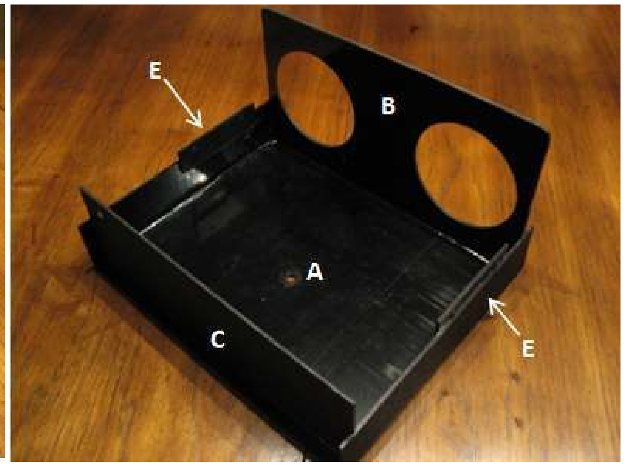


Figure 21: Pieces A, B, C, and E that have been bent and glued together.

The best method for bending ABS plastic is to first to cut along the fold line of the material with a ¼" pointed router bit. Once a groove has been notched out, place the plastic near a heat source for approximately sixty seconds and then proceed to bend the plastic to the desired angle. Once cooled, the plastic has a smooth bend to it and has not lost any of its structural integrity. Furthermore, the type of glue used in List 1 is called methylene chloride. This compound is ideal for plastics because it breaks down and reforms the material between the adjoining pieces.

The design outlined in List 1 is very effective for this project not only because of the desired structural integrity, but it also shields the contents of the case from rain and small pieces of debris. Although water may reach the interior of the case if improper seals are used, it will not be directly from the rain. Furthermore, the plastic is not prone to weathering and stainless steel screws can be used to prevent rust from forming on the fasteners; we believe that this is an adequate proof-of-concept case for our portable radar system. Figure 22 shows the assembled prototype case.

Figure 22: Assembled prototype case for portable radar system; note that the handle is not shown in this image

7.2 Interior Component Layout

One of the portability requirements of the case, described in an earlier section, to is to be as compact as possible. This is achieved by designing a case that is just big enough to accommodate the coffee cans, the RF components, the battery packs, and the printed circuit board (PCB) amplification and modulation circuitry. Table 4 lists the size requirements for the interior components taken into consideration for the layout of the case.

Table 4: Size specifications for the various interior components of the radar case

Specification	Coffee Cans	RF Components	Battery Packs	PCB Amplification Circuit
Shape:	Cylinder	Rectangles, Cylinders	Square	Rectangle
Quantity:	2	6	2	1
Dimensions:	Diameter: 9.9 *cm* Length: 13.3 cm	*Various Sizes* *Total Real-estate* ≅ 60 cm^2	Length: 6.5 cm Width: 6.8 cm	*Unknown* *Total Real-estate* ≅ 32 cm^2

Using the data shown in Table 1, we are able to construct a general layout for the interior components of the radar case. Figure 23 shows an approximation of real-estate requirement for each the components. Based off this information, it was determined that the case should be designed with a base having approximately 30 cm x 23 cm of real-estate.

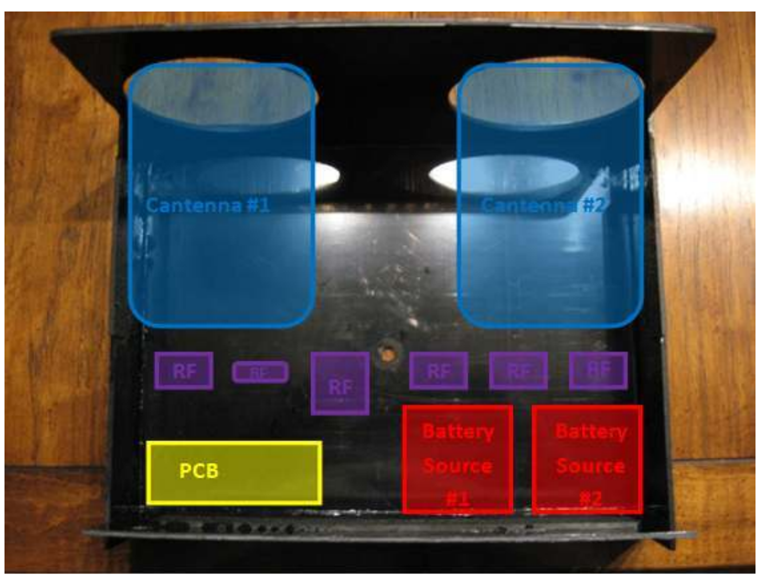


Figure 23: Approximate layout and real-estate allocation for the interior components of the portable radar system; note that the no coaxial cables or interconnecting wires are shown in this image; all components will be secured to the base of the case via nuts and bolts

Furthermore, it is worthy to note that the only interior components that have a significant height restriction are the coffee cans. Therefore, based off the specifications of the cans, the height of the case should be at least 15 cm in order to accommodate for the cantennas.

7.3 Exterior Components

There are three exterior components to consider for our portable radar system: the handle, a structure to hold the iPhone, and a master on-off switch for the radar hardware. The handle is a generic requirement and does not have any extensive specification. Shift Technologies' proof-of-concept model utilized an old handle from a Makita power tool.

The unit that the iPhone would mount to needed to be simple and lightweight. After considering the possible options for creating our own mounting mechanism, it was decided that the easiest method would be to simply mount a pre-existing iPhone case to the exterior of the radar. The only requirement for the case is that it would need to have a hard backing to it in such that it could be mounted to the radar case. The chosen iPhone case for our prototype model was the Griffin Reveal Etch Graphite case. It was mounted to the radar case by a small wood-screw with a tapered head; in order to prevent the screw from scratching the back of the iPhone, the head of the screw was countersunk into the iPhone case.

As per the original design of the radar hardware, the power supply for the electrical components is controlled by a slide-switch on each of the battery packs. Realistically, however, the power to the radar should be controlled by a switch on the outside of the case. Hence the need for a dual-pole single-throw (DPST) switch is required; the dual-pole specification is required because both battery packs must be controllable through a single switch. Several switches were considered however an on-off switch from the company E-Switch was chosen (PA4R1201000-116). Figure 24 shows both the selected iPhone case and DPST chosen for the prototype model.

Figure 24: Exterior components, excluding the handle, of the radar case shown mounted into their respective locations

7.4 Water and Heat Protection

In order to protect the interior components of the radar from water or heat from the environment, certain sealing precautions must be considered. Depending on whether or not the adjoining pieces are a permanent corner, chemical or mechanical sealants are both possible solutions.

Water damage is the primary concern for the portable radar system. Most of the joints of the ABS plastic have already been chemically sealed when the pieces were glued together. As mentioned above, methylene chloride essentially melts the surface of the plastic and then bonds the two pieces together. Assuming the pieces are the correct size, the re-bonding process should be sufficient enough to create a seal suitable for keeping out water. As for the non-permanent joints, rubber seals or o-rings would be the primary method for keeping the interior dry. There are also two non-corner openings that water could potentially enter from: the holes for the cantennas and the DPST switch. The two holes for the cantennas can be sealed simply by placing o-rings around the coffee cans. As for the hole for the DPST switch, the E-Switch unit ordered is a fully sealed switch hence eliminating the risk of water damaging the interior of the case.

Protecting the interior components from environmental heat poses one of the biggest physical problems for the radar case. One of the immediate issues to overcome would be to determine what material is best suited against high temperatures and not too heavy. Polycarbonates are a possible solution based on the fact that they have a melting temperature over twice as high compared to ABS plastic [4] [7]. As for the seals of the case, there exist a type of silicone o-ring that is primarily meant for high temperature applications [3]. Most of the precautionary measures to prevent heat damage were not taken into account for the prototype model.

7.5 RF Shielding

After initial field tests of the hardware provided by Dr. Charvat [1], it was noticed that the radar was quite susceptible to noise. The majority of the interference is believed to be caused by a combination from noise in the amplification electronics and the wrap-around of propagating electromagnetic waves from the transmitter to the receiver cantennas. It is hoped that the majority of the noise picked up from the amplification circuit will be reduced once the circuit is converted into a PCB. However it is also believed that encasing the PCB within a metal container will limit the effect from external noise. In order to combat possible interference between the two cantennas, it is believed that placing a metal plate on the outside of the case, between the cantennas, will limit this internal feedback. Figure 25 shows the location of this physical barrier on the radar case.

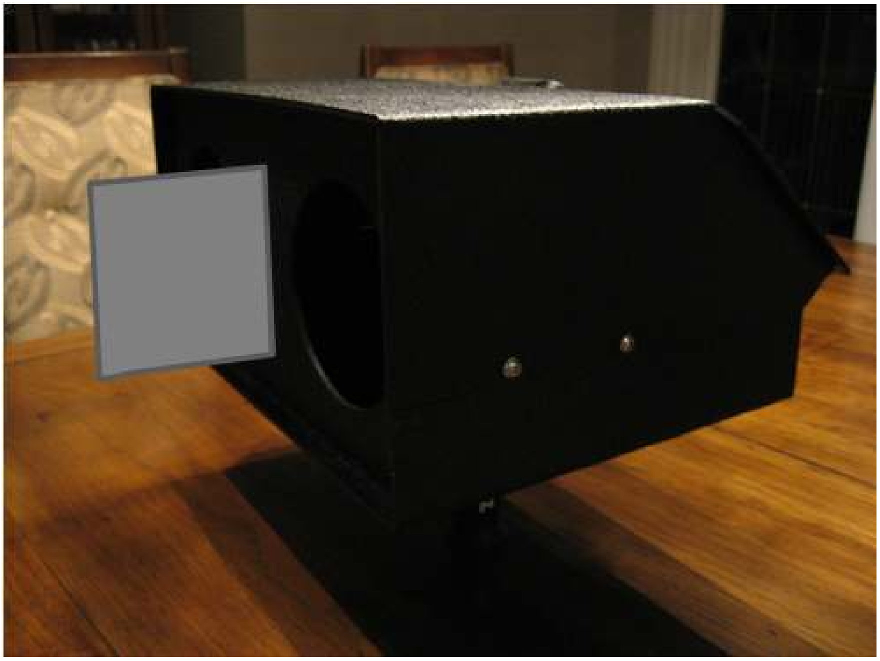


Figure 25: Physical barrier designed to limit the amount of internal noise between the two cantennas

8. System Test Plan

Our tests are divided into unit tests and field tests. The unit tests are essential to validate and verify the functionality of each module or component. The field tests are used to simulate real world rescue situations and verify the functionality.

Unit Tests

These are tests used to verify the functionality of the hardware radar, the software processing and the iOS application.

8.1 Radar Electronics Tests

Unit Test 1: Correct audio output of received microwave signals
User Input: The user turns on the radar.

Conditions: A two channel oscilloscope is used to separately monitor the left and right audio out generate by the circuit. The radar is point towards stationary or moving objects.

Expected Observations: On the oscilloscope, one channel should display a square synchronization pulse, which corresponds to ramp up and down events. The other channel should display the received signal, which is a delayed version of ramped transmission signal. Furthermore, if the target is moving, the received pulse will be Doppler shifted.

8.2 Signal Processing Tests

Unit Test 2: Processing and displaying intensities from raw audio in data

User Input: The user turns on the radar and starts capturing data in Matlab and only wants to display intensities.

Conditions: The correct Matlab scripts are running and capturing data from the two channel audio line in. Scripts are only designed to process the audio line in and display a color coded time lapse of the reflection intensity for objects in the radars field of view.

Expected Observations: Objects of high reflectivity will appear red while objects of low reflectivity will appear in blue. The Y axis is the distance, in meters, in front of the radar, and each distance is assigned a color coded intensity. The length of the X axis is the length that the data was captured for.

Unit Test 3: Target locking and de-interleaving of processed intensity data

User Input: The user turns on the radar and starts capturing data in Matlab and only wants to only stationary or moving targets.

Conditions: The correct Matlab scripts have run and captured data from the two channel audio line in. The processing of the audio line in, as described in Unit Test 3, has already been done.

Expected Observations: The Matlab should isolate and track targets for the duration of the scan. The result is then presented in a graph where the target's distance from the radar is plotted over the time of the capture. Stationary targets will remain at the same distance away from the radar while moving targets will not.

Unit Test 4: Two Dimensional Scanning

User Input: The user turns on the radar and starts capturing data in Matlab and takes a 120° beam patter of the area in front of him.

Conditions: The user correctly orients and rotates the radar system as the Matlab is capturing data.

Expected Observations: The Matlab should piece together the different beam patterns and produce a birds eye view of the area the user scanned, including any moving or stationary targets.

8.3 iOS application Testing

Unit Test 5: Results of the iOS application is the same as the signal processing from Matlab

User Input: The user inputs a file containing received data to both the Matlab and the iOS application.

Conditions: The data has been captured and store in a WAV format.

Expected Observations: The result of the iOS application and the Matlab should be identical, but the iOS device should take less time to complete.

Unit Test 6: Stability of iOS application

User Input: Random sequence of API calls and cancellations.

Conditions: iOS application has been debugged and loaded on to an iOS device.

Expected Observations: The functionality and stability of the iOS application should not be affected by random user inputs.

8.4 Field Testing

These are tests used to verify the functionality of the prototype device in real world situations.

Field Test 1: Standing stationary human targets

User Input: User presses start on the prototype device.

Conditions: Four human targets standing 20 m, 40 m, 60 m, and 80 m in a zigzag pattern in front of radar. The prototype device has the correct software running on the iOS device and the stereo audio line in is connected.

Expected Observations: The radar should display four targets at their respective distances. Furthermore, the targets should remain at their distances for the duration of the scan.

Field Test 2: Human targets moving perpendicular to the radar

User Input: User presses start on the prototype device and captures for 5 seconds.

Conditions: Four human targets standing 20 m, 40 m, 60 m, and 80m in a zigzag pattern in front of radar. At the start of the capture, the human targets will move towards the radar at different velocities. The prototype device has the correct software running on the iOS device and the stereo audio line in is connected.

Expected Observations: At the start, the radar should display four targets at their respective distances. The distances of each target should get closer to the radar with respect to time. The faster the target, the steeper the slope would appear on the scan.

Field Test 3: Human targets moving towards the radar in intersecting paths

User Input: User presses start on the prototype device and captures for 5 seconds.

Conditions: A pair of human targets standing at 40m and 60m in a square pattern in front of radar. At the start of the capture, the human targets will move towards the radar at 45 degrees and criss-cross. The prototype device has the correct software running on the iOS device and the stereo audio line in is connected.

Expected Observations: At the start, the radar should display four targets at their respective distances. The distances of each target should get closer to the radar with respect to time. As the targets cross, the radar shouldn't lose track of the targets.

Field Test 4: Human targets standing in room

User Input: User presses start on the prototype device and captures for 5 seconds.

Conditions: An "unconscious" human target at a distance of less than 20m from the radar. The prototype device has the correct software running on the iOS device and the stereo audio line in is connected.

Expected Observations: The radar should be able to detect the human target and correctly calculate and display the distance to the target.

Field Test 5: Preliminary 2D scanning outdoors

User Input: User presses start on the prototype device and captures separate beam patterns in a 180 degree field of view.

Conditions: Outdoors environment with various obstacles. At the start of the scan, the radar will direct the user to the correct bearing to start the scan. It will then indicate a new angle for the user to orient the radar towards. Once this is complete, the radar will take the next beam pattern.

Expected Observations: The radar should display a 2D over head view of the scanned area. The radar will be able to display any obstacles in the scanned area.

9. Conclusion

The design solutions discussed in this document will help Shift Technologies fulfill the A requirements in the functional specification, resulting in a prototype device. This document will serve as a guideline for adherence and compliance to the original function specifications and design requirements. Furthermore, the design specification will provide clear goals for the completion of each requirement. The proof of concept device is well under development and we are excited and confident in the completion of the final product by April 25, 2012.

References

[1] Gregory L. Charvat. (2011, January) MIT IAP 2011 Laptop Based Radar: Block Diagram, Schematics, Bill of Material, and Fabrication Instructions. [Online]. http://ocw.mit.edu/resources/res-ll-003-build-a-small-radar-system-capable-of-sensing-range-doppler-and-synthetic-aperture-radar-imaging-january-iap-2011/projects/MITRES_LL_003IAP11_proj_in.pdf

[2] Graham Brooker. (2006) High Range-Resolution Techniques. [Online]. http://www.acfr.usyd.edu.au/pdfs/training/sensorSystems/11%20High%20Range-Resolution%20Techniques.pdf

[3] Gregory L. Charvat. (2011) MIT IAP 2011 Radar Course Cantenna Radar System. [Online]. http://www.glcharvat.com/Dr._Gregory_L._Charvat_Projects/Cantenna_Radar.html

[4] MyPro PCB. 2012 Prototype PCB Assembly. [Online]. http://www.myropcb.com/

[5] National Semiconductor. (2007) LM2940CT-5.0-ND Datasheet. [Online]. http://www.ti.com/lit/ds/symlink/lm2940-n.pdf

[6] Stratasys. (2007) ABS. [Online]. http://www.nrri.umn.edu/NLTC/ABS07.pdf

[7] Sealing Specialties Inc. (2006) O-Ring Materials. [Online]. http://www.sealingspecialties.com/materials.htm

Appendix A

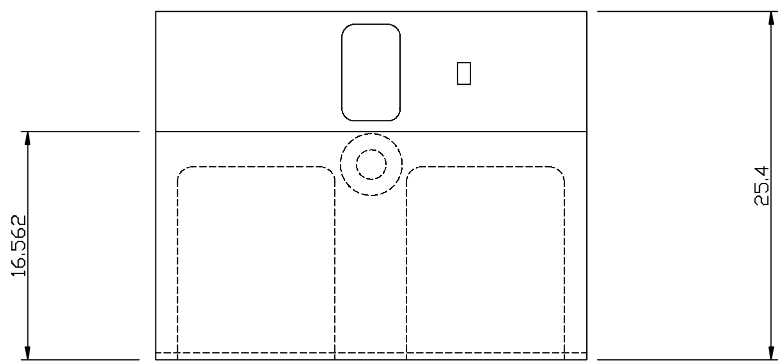
Callout:	Qty/Kit	Part#:	Description:	Unit Cost:	Subtotal:
RF Radar					
OSC1	1	ZX95-2536C+	2315-2536 MC VCO, +6 dBm Out	$42.50	$42.50
ATT1	1	VAT-3+	3dB SMA M-F attenuator	$9.95	$9.95
PA1/LNA1	2	ZX60-272LN-S+	Gain 14 dB, NF=1.2 dB, IP1= 18.5 dBm	$39.95	$79.90
SPLTR1	1	ZX10-2-42+	1900-4200 Mc, 0.1 dB insertion loss	$34.95	$34.95
MXR1	1	ZX05-43MH-S+	13 dBm LO, RF to LO loss 6.1 dB, IP1 9dBm	$46.45	$46.45
SMA M-M Barrels	4	SM-SM50+	SMA-SMA M-M barrel	$5.45	$21.80
Cantenna					
Can	2	TBD	TBD	$5.00	$10.00
L bracket	2	N/A	L-bracket, 7/8", zinc plated	$0.35	$0.70
SMA F bulkhead	2	901-9889-RFX	SMA bulkhead F solder cup	$4.27	$8.54
6-32 screws	1	N/A	6-32 machine screw, 5/8" length, pk of 100	$3.49	$3.49
6-32 nuts	1	N/A	6-32 hex nuts, pk of 100	$1.09	$1.09
6-32 lockwashers	1	N/A	lock washers for 6- 32 screws, pk of 100	$0.71	$0.71
6" SMA M-M Cables	3	086-12SM+	SMA-SMA M-M 6" cable	$9.65	$28.95
Miscellaneous					
Wood Screws	1	N/A	brass #2 wood screws 3/8" long, pk 100	$3.70	$3.70
Wood	1	N/A	12" wide by 1" thick 8' long wood	$14.37	$14.37
Modulator1	1	XR-2206	Function Generator Chip	$4.05	$4.05
Video Amp1	1	MAX414CPD+	low-noise quad op-amp	$14.46	$14.46
Solderless Breadboard	1	EXP-300E	6.5x1.75" solderless breadboard	$7.00	$7.00

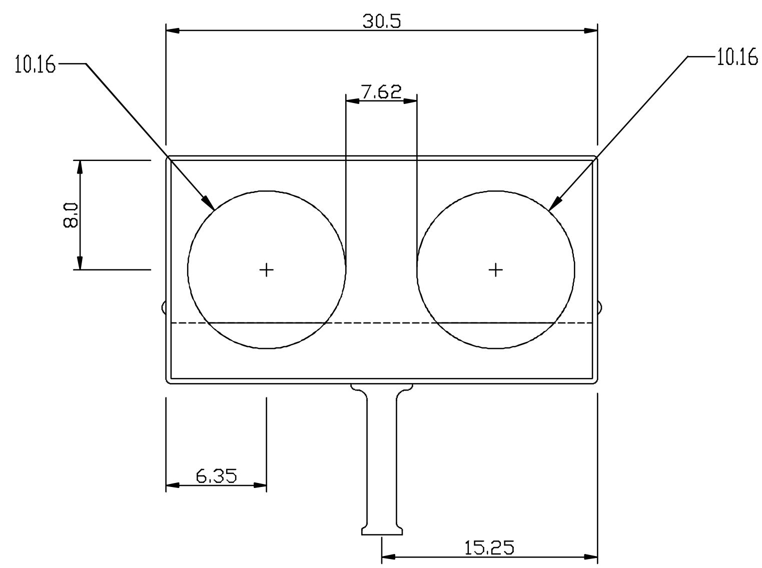
C1-4	4	SA105A102JAR	1000 pf 5% capacitor	$0.22	$0.86
R1a_1	1	MFR-25FBF-8K45	8450 ohm 1% resistor	$0.11	$0.11
R1b_1	1	MFR-25FBF-102K	102K ohm 1% resistor	$0.11	$0.11
R2_1	1	MFR-25FBF-7K15	7150 ohm 1% resistor	$0.11	$0.11
Rf_1_2	3	MFR-25FBF-1K00	1K ohm 1% resistor	$0.11	$0.34
Rg_1	1	MFR-25FBF-12K1	12.1K ohm 1% resistor	$0.11	$0.11
R1a_2	1	MFR-25FBF-17K4	17.4K ohm 1% resistor	$0.11	$0.11
R1b_2	1	MFR-25FBF-28K0	28K ohm 1% resistor	$0.11	$0.11
R2_2	1	MFR-25FBF-4K12	4120 ohm 1% resistor	$0.11	$0.11
Rg_2	1	MFR-25FBF-1K62	1620 ohm 1% resistor	$0.11	$0.11
Decoupling Cap	2	K104Z15Y5VE5TH5	0.1 uf	$0.05	$0.10
Decoupling Cap	2	UVR1E101MED1TD	100 uf	$0.03	$0.06
Trimmer Potentiometer	1	PV36Y103C01B00	10k	$0.92	$0.92
Gain Resistor	1	CFP1/4CT52R201J	200 ohm, 5%	$0.05	$0.05
Battery pack	2	SBH-341-1AS-R	4xAA battery pack with power switch	$0.95	$1.90
AA batteries	8	PC1500	AA battery	$0.54	$4.32
5V regulator	1	LM2940CT-5.0/NOPB	5V low dropout regulator	$1.77	$1.77
Audio cord	1	172-2236	3.5 mm plug to stripped wires	$2.42	$2.42
Wire ties	2	41931	4" cable ties	$0.04	$0.08
Tuning Capacitor	1	FK28Y5V1E474Z	0.47 uf capacitor	$0.21	$0.21
2M Trimmer Potentiometer	1	PV36W205C01B00	2M trimmer potentiometer	$0.92	$0.92
50K Trimmer Potentiometer	1	PV36W503C01B00	50K trimmer potentiometer	$0.92	$0.92
1uF Cap	1	UVR1H010MDD1TD	1 uF electrolytic cap	$0.04	$0.04
10 uF Cap	1	UVR1H100MDD1TA	10 uF electrolytic cap	$0.03	$0.03
5.1K Resistor	2	MF1/4DCT52R5101F	5.1K resistor	$0.05	$0.10
10K Resistor	2	CCF0710K0JKE36	10K resistor	$0.04	$0.08
LED	1	TLHR5400	Red LED	$0.07	$0.07

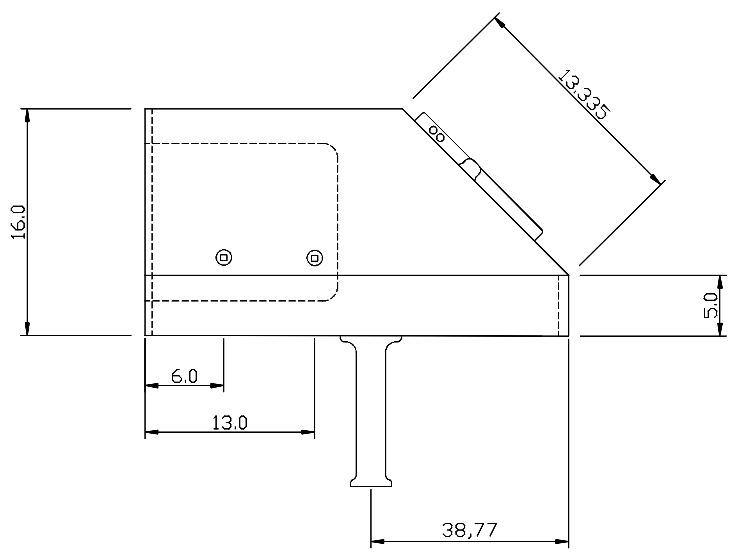
1K LED Resistor	1	CCF071K00JKE36	1K resistor	$0.04	$0.04
100K Resistor	2	CCF07100KJKR36	100K resistor	$0.04	$0.08
47K Resistor	12	CCF0747K0JKR36	47K 5% resistor	$0.04	$0.48
1 uF Cap Unpolarized	1	T356A105M020AT73 01	1 uf tantalum capacitor	$0.31	$0.31
Total:					**$348.74**

DESIGN NOTES:

1. All components of this prototype are to be made from 3 mm ABS plastic.
2. Contents of the case must be accessable. This prototype uses a series of screws to access interior.
3. iPod Case with a hard backing. Model used in this prototype: Griffin Reveal Etch Graphite.
4. Single-Throw, Dual-Pole pushbutton. Model used in this prototype: E-Switch PA4R1201000-116.
5. Exact location of iPod case, pushbutton, and screws are not significant in this model.
6. Exact type of handle is not significant in this model. Handle used in this prototype: power tool handle.







UNLESS OTHERWISE SPECIFIED		NAME	DATE	TITLE:	
DIMENSIONS ARE IN [redacted] CENTIMETERS	DRAWN	SDR	02/22/12	ERadar Case	
TOLERANCES: FRACTIONAL ±	CHECKED				
ANGULAR: MACH ± BEND ±	ENG APPR.				
TWO PLACE DECIMAL ±	MFG APPR.				
THREE PLACE DECIMAL ±					
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			SIZE B	DWG. NO. 00001	REV 1
MATERIAL 3 mm ABS PLASTIC	COMMENTS: Prototype				
DO NOT SCALE DRAWING				SCALE: N/A WEIGHT: 1.25 kg	SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	