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MARITIME SECURITY CENTER
A DEPARTMENT OF HOMELAND SECURITY CENTER OF EXCELLENCE

Radio Frequency Surveillance System (RFSS)

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Research Project Overview

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Problem Statement

- The United States Coastguard (USCG) plays a crucial role in the nation's efforts for interdicting and countering dangerous illegal vessels in maritime environments
- Illegal vessels carrying drugs, contraband and illegal immigrants need to communicate with their accomplices on land or at sea
- Detection and localization of RF communication signals radiated from crews of illicit boats and their accomplices can provide a source of significant intelligence

Objectives

- Investigate various opportunities for the development of a low-cost radio frequency (RF) monitoring system that can detect and localize various RF emitters on land and at sea
- Provide the opportunity to enhance the USCG mission capabilities by providing persistent surveillance of ports, coastal approaches, maritime sanctuaries, and smuggling activities that will reduce personnel costs without degrading mission performance

Milestones and Performance Metrics

No.	Milestone	Percentage Completed	Completion Date	Summary / New Plans / Contingency
M1	Kickoff Meeting	100%	Oct. 2019	Meeting took place on Oct. 4th, 2019 to discuss project scope and deliverables
M2	Experimental RFSS for land and ship application tested in the lab	100%	Feb. 2020	As set of RF surveillance setups were constructed and tested in the lab. These setups were successfully deployed in the field to validate theoretical signal reception expectations from handheld radios.
M3	Integrated SDR Platform for UAS based RFSS setup tested in the lab	80%	May 2020	A RFSS test platform using laptop computer as main processor has been designed in lieu of integrated compute system. Simulation of expected signals developed to aid in processing pipeline and algorithm, design while forced outside of the lab.
M4	Feasibility tests of RFSS setups for land and ship application on the NJ Coast using Stevens research vessels		*Originally Planned June 2020*	Contingency plan is to perform laboratory testing of the RFSS test platform upon regaining access to facilities. The goal is to validate design and methodology.
M5	Feasibility tests at the NJ coast using RFSS installed on the UAS		*Originally Planned August 2020*	Contingency plan is to create a set of requirements for compressing the RFSS into an integrated SDR platform that is capable of being installed on a UAS and determine if such a design is feasible.
P1	The prepared setups have to provide detection at a distance above 10 miles with a bearing accuracy of 3 degrees.		*Originally Planned June 2020*	Contingency plan is to use laboratory-based testing to evaluate expected bearing estimate accuracy at various ranges
P2	Successful setup has to provide a detection of a mobile transmitter power of 1 watt or greater at sea level over water at a distance of 10 miles from a land based system.		*Originally Planned October 2020*	Contingency plan is to use laboratory-based testing to measure expected system detection range by controlling the SNR at the input to the RFSS test platform

Research Work and Accomplishments

Preliminary Research Work

- Investigated viable, commercially available radio frequency bands easily operated by bad actors
  - Identified the VHF, UHF, and CB bands as most likely source of target signals
  - Acquired COTS radio equipment to use as signal sources for testing

- Performed estimation of RF signal detection distance using theoretical modeling
  - Signal to noise ratio can be improved by the addition of amplification and filtering stages at the front end of the system
  - Determined line of sight (LOS) obstructions between the target signal and RFSS receive antenna system will likely be largest factor in detection range
  - Most likely source of LOS loss on open water will be due to curvature of the Earth

- Investigated methods of Direction Finding to meet performance metrics and determined which would be the best approach to research in depth

Research Work and Accomplishments

Direction Finding Methodologies Considered

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Mechanically Steered Array

- Physically rotating a directional antenna in the direction of target signal to find location

Time-Difference of Arrival

- Multiple, time-synchronized receivers are deployed in locations that surround the are to be monitored
- By estimating the arrival time of RF signals, the distance from each receiver to the target transmitter can be estimated using the fact that wave speed is approximately the speed of light. Multilateration is then used to estimate a target location.

***Watson-Watt*/Adcock Antenna**

- The Watson-Watt technique utilizes dual Adcock antenna (i.e. a pair of monopole/dipole antennas which outputs the vector difference between them)
- The two Adcock antennas are set at right angles to each other, and the phase angle is calculated by taking the arctangent of the ratio between the vertical antenna signal and the horizontal antenna signal (i.e. finding the signal phase)

Phased Array

- A set of identical antenna elements are arranged in a geometric array, each with their own receiver
- Each receiver must be phase locked and all measurements time-synchronized
- Combination of measured signals facilitates beamforming, increasing antenna directivity and therefore derive a bearing estimate of incoming signals

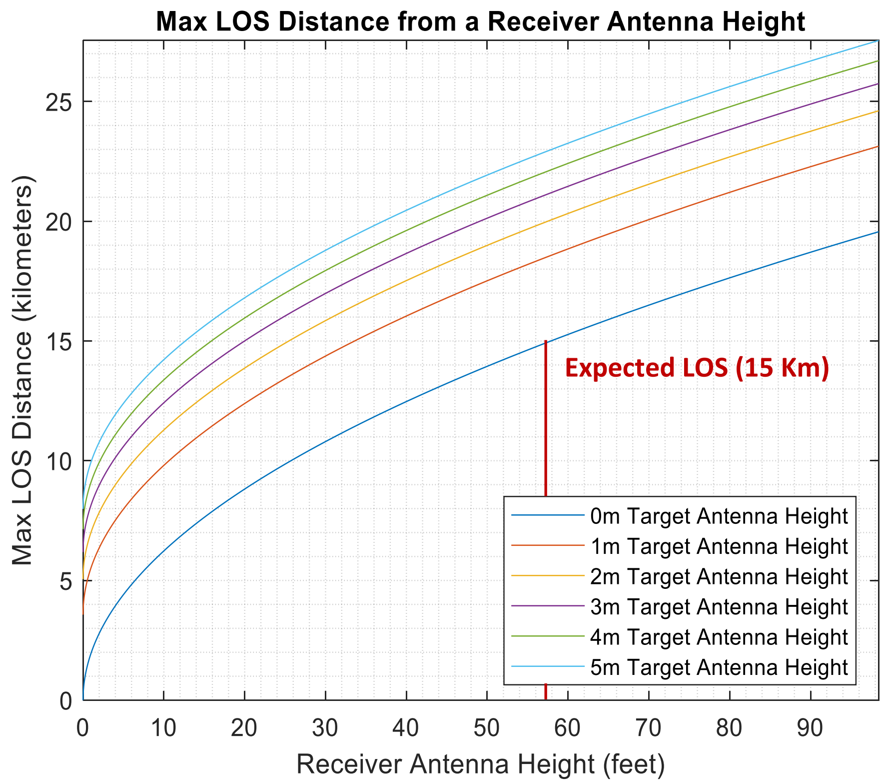
Pseudo-Doppler

- Utilizes a rotating antenna induces a Doppler shift on received signals which can be used to estimate a bearing estimate to the target signal source
- An analogous system can be built by creating a circular antenna array all of which are connected to switch system. By switching between the antennas in a circle, the Doppler effect of mechanically rotating a single antenna is reproduced without needing to physically move the antenna system. This allows much higher rotations rates to be stably achieved.

Research Work and Accomplishments

Preliminary Research Work – Range Expectations

- Theoretical estimation of detection distance: after evaluation of various parameters, the largest contributing factor to signal loss on open water is curvature of the Earth
- A set of curves were generated that can be used to estimate LOS distance based on both the Transmit and Receive antenna heights
- The takeaway is that the higher the antenna is relative to sea level, the greater the expected detection distance



Note: In addition to the LOS expectation, signal to noise ratio is also a contributing factor to detection range which is dependent on the systems RF noise figure and operating environment.

Research Work and Accomplishments

Preliminary Field Test – Design and Goal

- The three RFSS setups were placed on the shoreline while an experimental target signal emission setup was placed on a surface vessel
- The surface vessel was instrumented with GPS to provide ground truth measurements of target while it performed maneuvers in the maritime environment near the RFSS setup.
- The goal was to gain practical measurements of signal propagation from some commonly available target RF signal sources
- These signal measurements will inform future modeling and design of a low-cost RF direction finding system

Transmitter Antenna Setup

57 Ft MSL

32 Ft MSL

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Research Work and Accomplishments

Preliminary Field Test – Expectations and Results

Lessons Learned

- Theoretical motivation for estimating received signal power of target signals has been validated, albeit with the addition of occasional losses due to target antenna placement and orientation
- Signals were observed out to a range of 13 Km (maximum tested)
- Additional radio traffic in both the VHF and UHF frequency bands was consistent and significant

Takeaways

- System modeling can be reliably based upon theoretical considerations with the addition of persistent, in band signal sources occurring randomly in the adjacent frequency channels
- The presence of many possible target signals will require methodologies for grouping signals together via their specific properties [power, direction, modulation and so on]

Preliminary Field Setups

Research Work and Accomplishments

Integrated SDR Platform Design Components

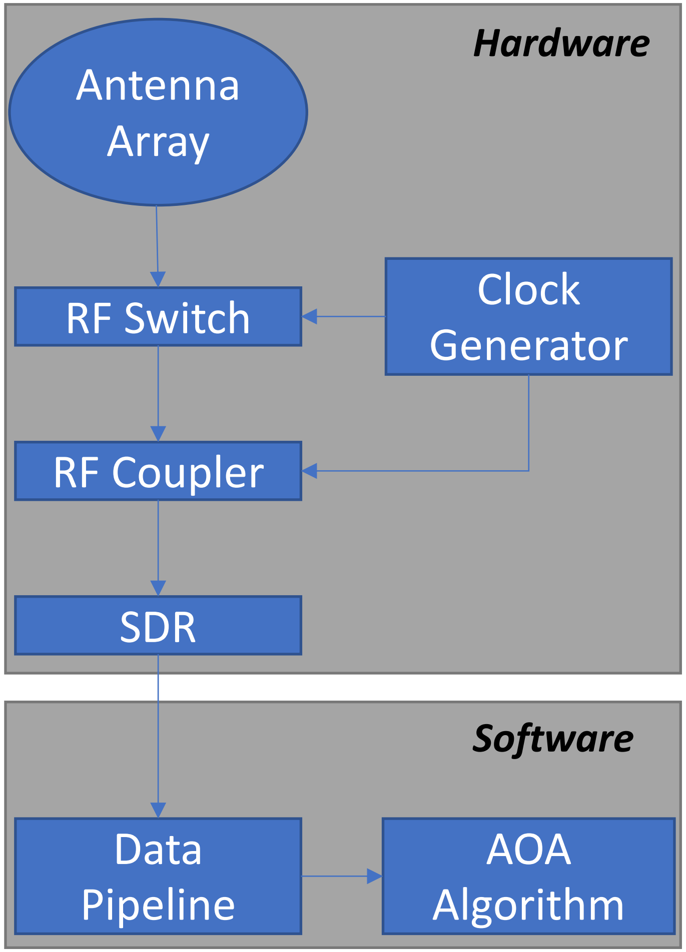
Three major components:

1. Hardware setup;
2. Data acquisition and processing pipeline;
3. Detection/AOA algorithms.

The hardware system aims to maximize sensitivity while inducing RF spectral components into the SDR baseband which provide information on a target signal's incident phase angle (and therefore direction of arrival).

The software system provides two main components, a data pipeline which provides the stable acquisition of RF data into time synchronous chunks which is then passed to a processing block that performs signal detection and angle-of-arrival estimation.

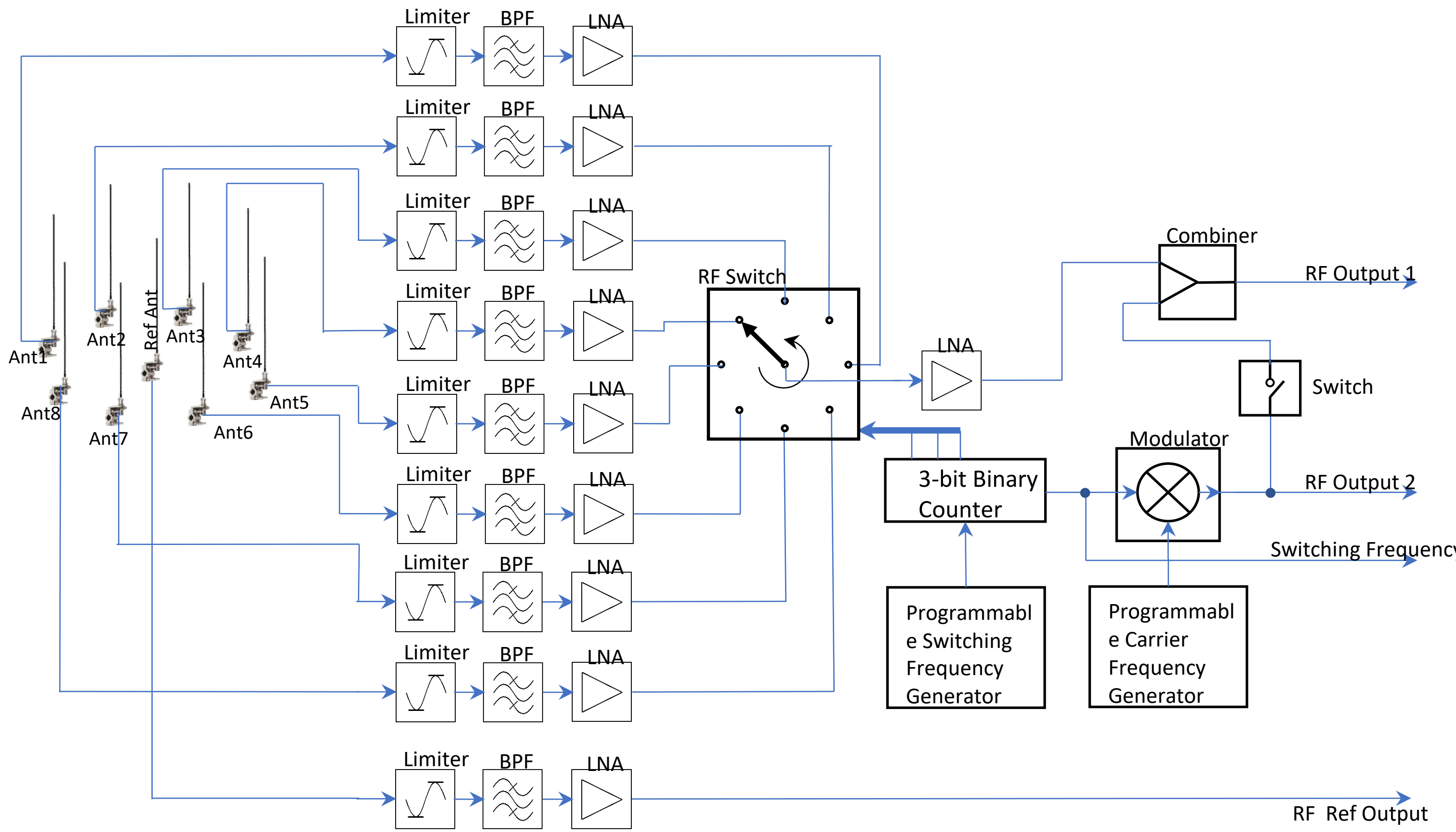
RFSS Hardware / Software Partitioning



Research Work and Accomplishments

Radio Direction Finding Antenna Switch Design and Antenna Array

- A custom switching solution was designed and built to provide the desired pseudo-Doppler phase shifts necessary to estimate an incoming RF signals direction-of-arrival

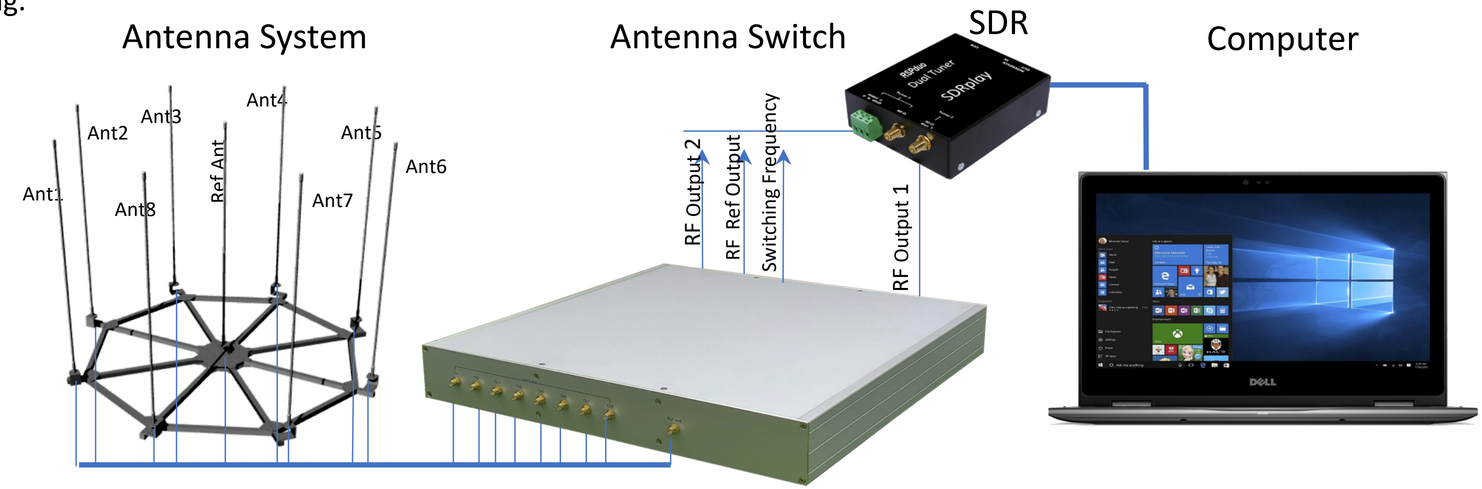


Research Work and Accomplishments

Test SDR Platform

The main components of the test SDR platform to perform direction finding are:

1. **Antenna System** – include 8 antennas mounted in a circular array with a diameter 7 ft on an aluminum frame. An additional ninth antenna is installed in the center, which can be used as a reference antenna for the differential pseudo-Doppler algorithm. This antenna system can be mounted on the top of the mast in the case of a stationary system or on the roof of the van in the case of a mobile installation.
2. **Antenna Switch-** provides band-pass filtering of the frequency band of interest, low noise amplification for each antenna channel. This device also provides sampling of a circular antenna array in a wide range of frequencies from kHz to MHz. In addition this device capable to generate a carrier frequency and modulate it with the antenna switching frequency , and then inject this signal into a switched signal or this signal can be applied to the second channel of the SDR.
3. **SDR** – either a single-channel or one equipped with two synchronized receiving channels can be used. In case of two channels the first channel is used to receive a signal from a circular array. The second channel is a multipurpose channel and can be used to receive the switching frequency directly or as a modulated carrier frequency. In some cases it can be used to receive central antenna signals.
4. **Computer**- processing of the SDR digital data , a multichannel receiver with ability to detect the presence RF signals in each channel separately, calculation the direction to the source of the RF signal, display of the results, data storage for the post processing.



End User Engagement

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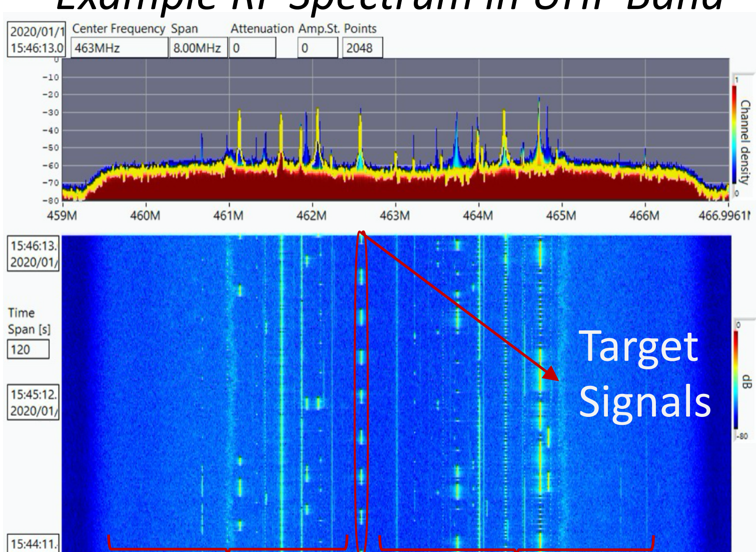
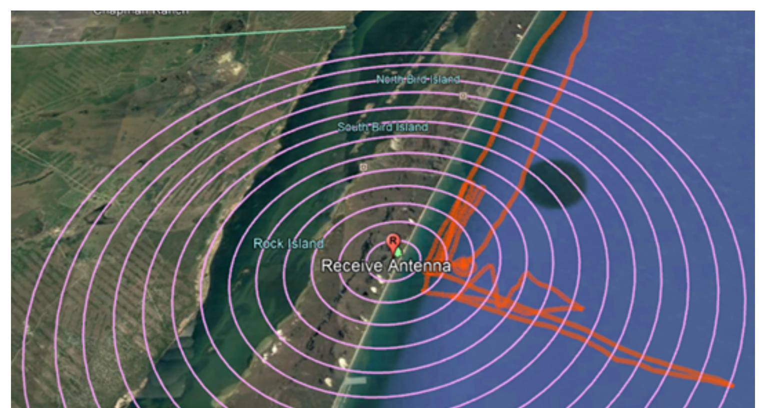
- Obtained RF frequencies of interest from USCG
- Discussed test parameters with USCG Sector Corpus Christi
- Conducted initial test at Padre Island
- Shared preliminary test results with USCG Project Champions
- Sharing of project information with a larger audience is being achieved during this Research Review Meeting

Example RF Spectrum in UHF Band



Additional Nearby Signals

Example Data Collection Run during Padre Island Test



Project Transition

After completing the design, construction and testing of the RFSS test setup, a set of tasks will be performed that cover the work completed and carve out a path forward

- Evaluation of the direction-finding methodology being investigated will be summarized, providing detailed information on the efficacy of the approach to detecting and locating target RF signals in the maritime environment

- Suggestion for future work will be provided including the design for building an optimal prototype system capable of finding a variety of target transmitting devices

- Our aim is to have a working prototype at the end of the project, and we are currently evaluating the best transition paths (patents, licensing, etc.)

Anticipated Project Impact

- The proposed RFSS should be capable of delivering surveillance capabilities of illegal vessels and their accomplices through detection and direction finding of radio communications

- The proposed RFSS will be able to remotely monitor hard to reach areas and provide a means of finding patterns of behavior in radio communications

- The proposed RFSS should help enhance the USCG mission capabilities without increasing operational costs or degrading mission performance

Plans for the next year

- The remaining project tasks and milestones involve the construction, test and validation of an experimental RFSS
- Due to quarantine restrictions, the contingency plan is to build, test and report on an experimental RFSS platform evaluated in the laboratory environment once access to the lab is gained
- The aforementioned laboratory testing will be executed to evaluate the performance of the experimental platform measured against project performance metrics
- A final report containing all of the investigations, analyses, designs and results will be compiled and submitted

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