FM Passive Bistatic Radar

Group Members:
Habiba Ajour
Khodor Safa
Marc Mahouly

Advisor:
Ibrahim Abou Faycal

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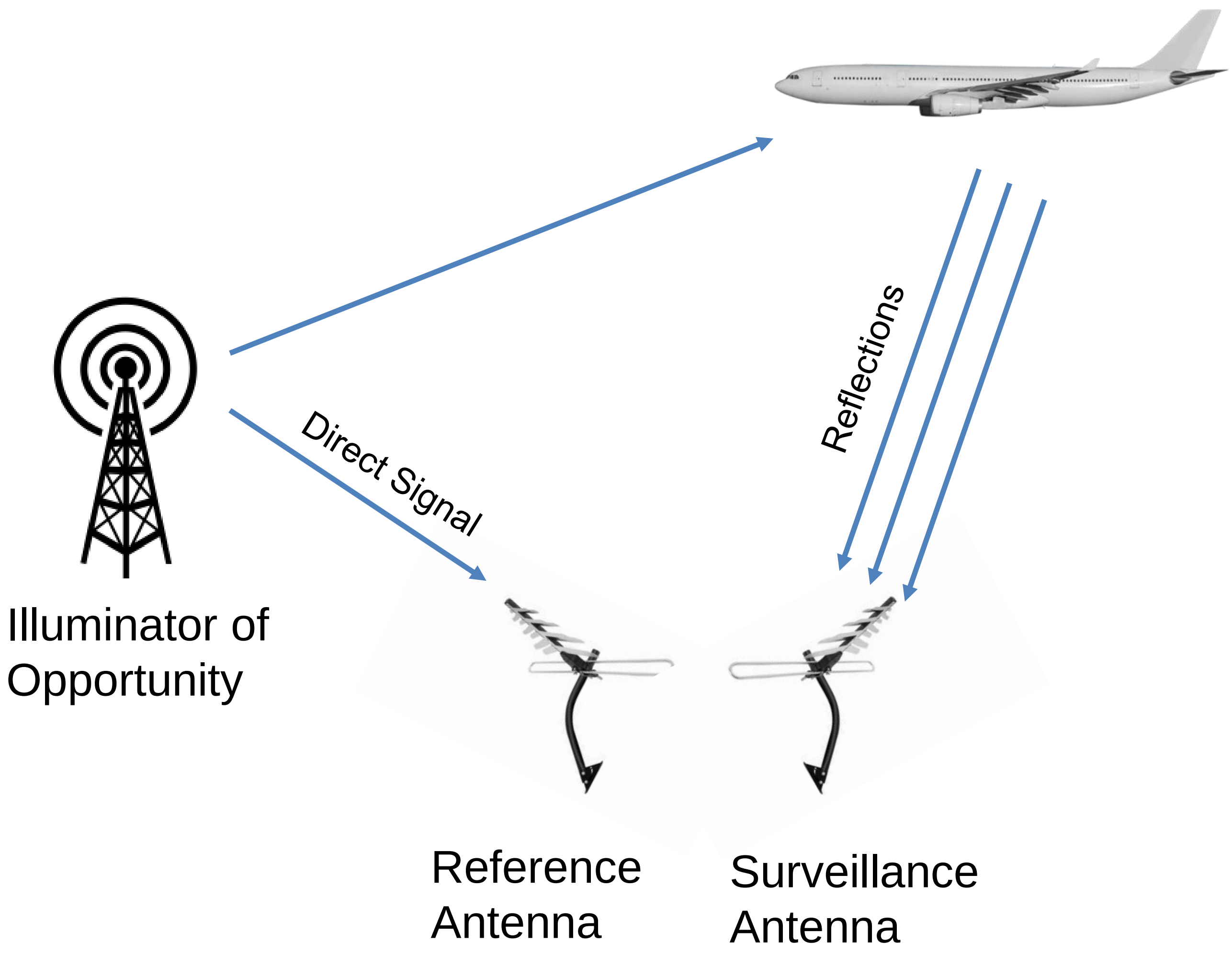
Project Overview: What are Passive Radar Systems

- Passive radar systems consist only of receivers. They rely on non-cooperative third party transmitters known as “illuminators of opportunity”.



Motivation

- Dedicated transmitters and receivers
- Detectable
- Requires Frequency Allocations
- More Complex Deployment
- Higher COST

- Receivers only
- Silent
- Third Party Transmitters
- Simple Deployment
- Cheaper

Desired Needs

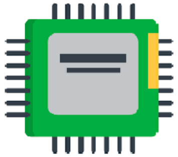
The Detection of Flying Objects

Estimate of their Range & Velocity

Technical Constraints

Choice of Illuminator of Opportunity

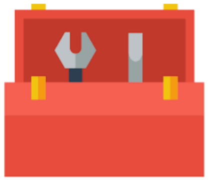
Non-Cooperative Transmitters



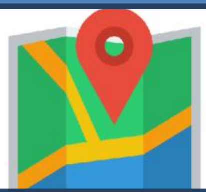
Computational Complexity

Choice of Antennas

Non-Technical Constraints



Available Lab Equipment



Location of Project Setup

Distance from the Illuminator

Weather Conditions

Requirements & Specifications

- Detection of aircraft and airborne objects
- FM based Passive Radar System
- Range and resolution of at most 750m
- SDR based passive radar system
- Virtual real-time detection
- Minimal Computational Complexity
- Probability of detection of at least 95%

Methodology

Hardware Setup

- Software Defined Radio Choice
- Synchronization
- Cables & Connections

Software

- Choice of Software

Signal Processing

- Matched Filtering
- Adaptive Filtering
- Statistical Thresholding

Visualization & Testing

- Display Results
- Results Validation & Testing

Overall Design Alternatives: Hardware Setup

Software Defined Radios:

RTL-SDR

HackRF One

USRP

Overall Design Alternatives: Hardware Setup

Synchronization:

OctoClock

MIMO Cable

Overall Design Alternatives: Software

Computer Languages:

MATLAB

GNURadio

USRP

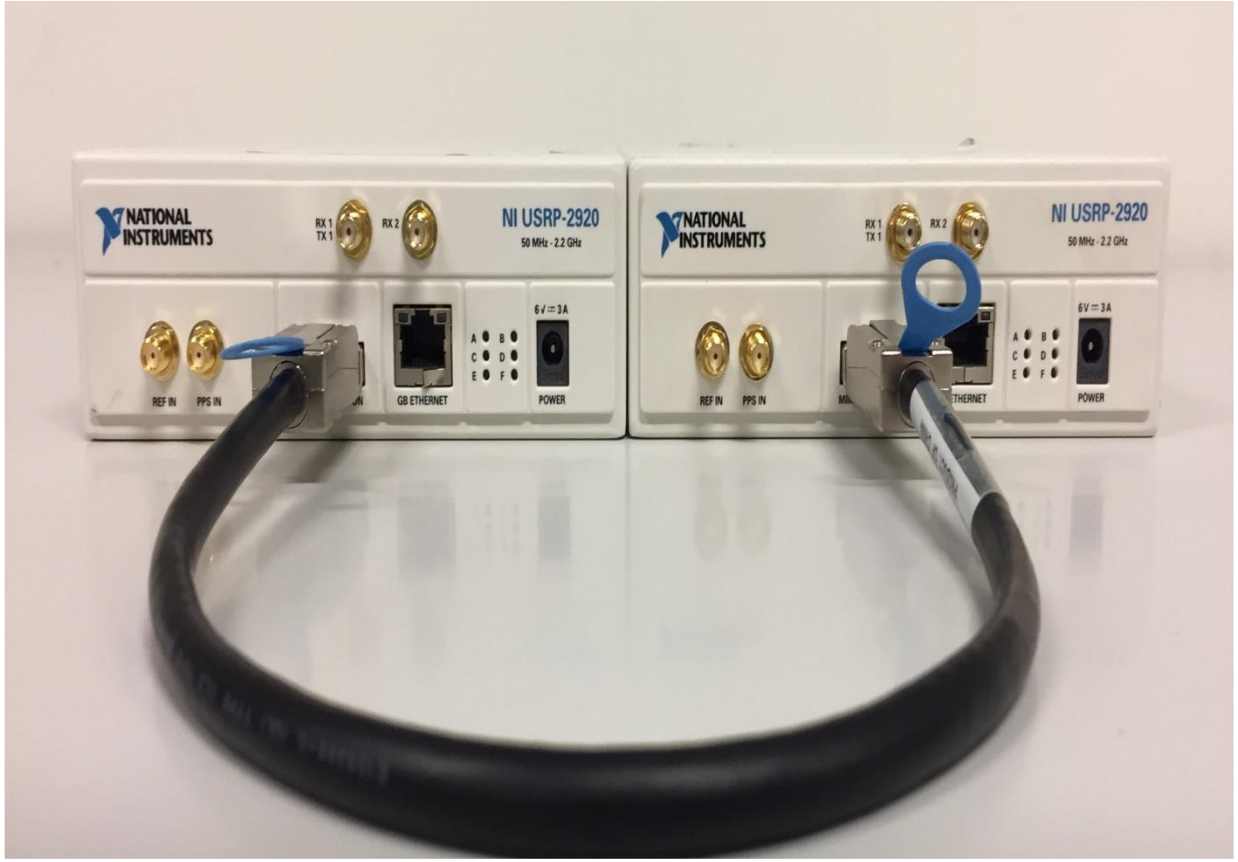
Overall Final Design Decision

USRP 2920
- Available in the lab
- High dynamic range

MIMO Cable
- Easy plug and play capability
- Less hardware complexity than using the OctoClock

GNU Radio
- Free software and flexibility
- No Licensing required

Implementation: Hardware



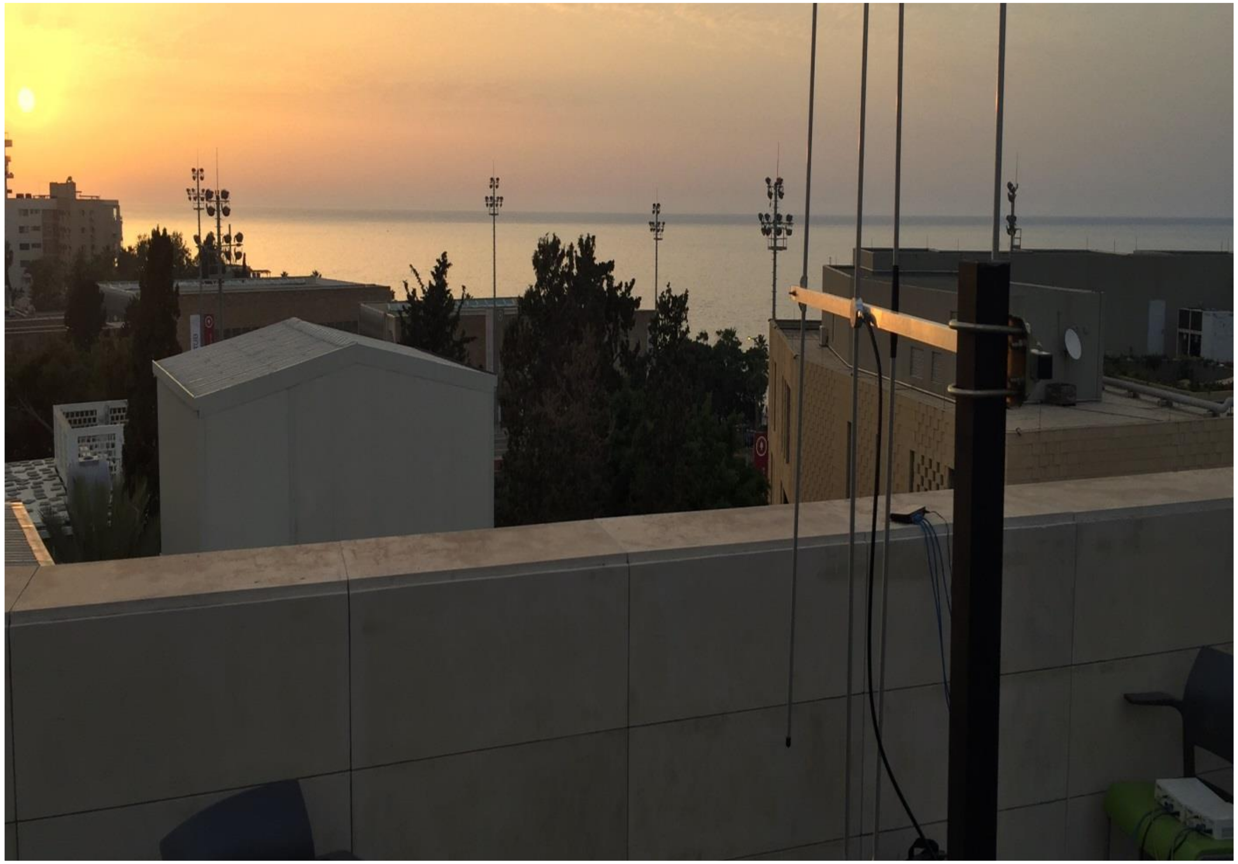
USRP 2920 & MIMO Cable

SDR:

- Each USRP represents a channel:
Surveillance And Reference channel

- Synchronization through the MIMO Cable

Implementation: Hardware

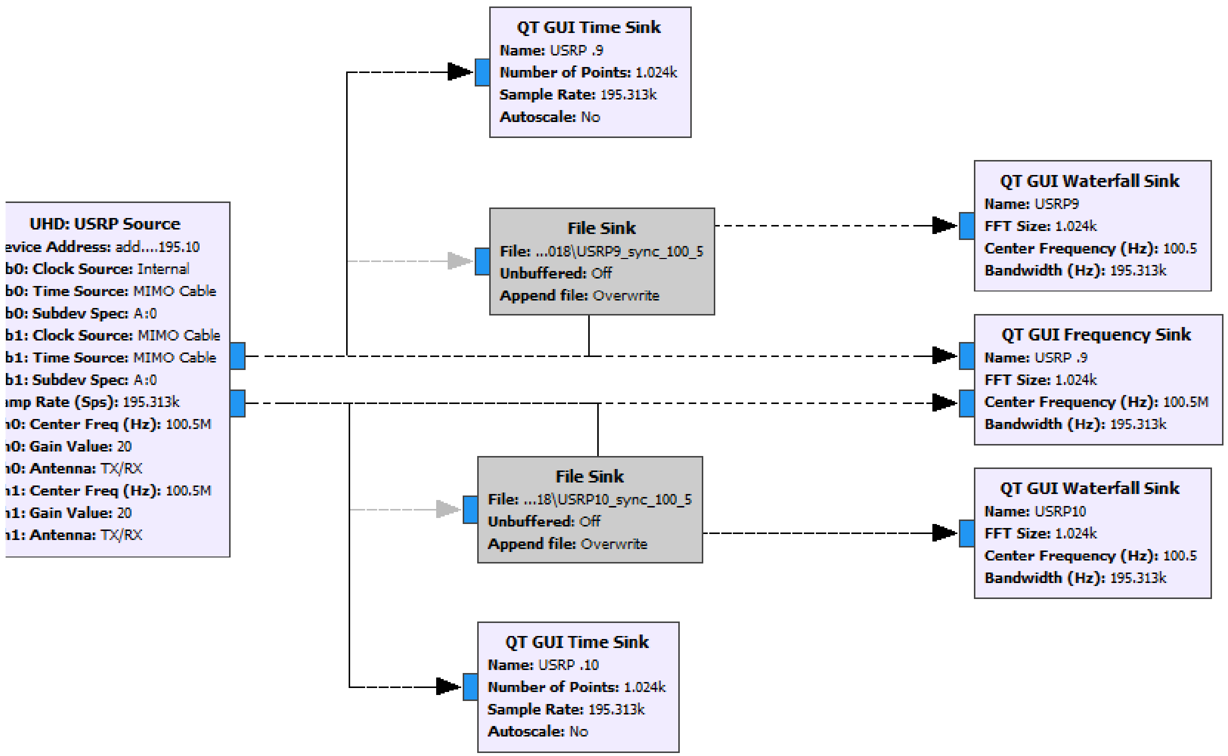


FM Yagi Antennas

Antennas:
-Three elements FM Directive Antennas

- Connected to the USRP’s with RG6 cables

Implementation: Software



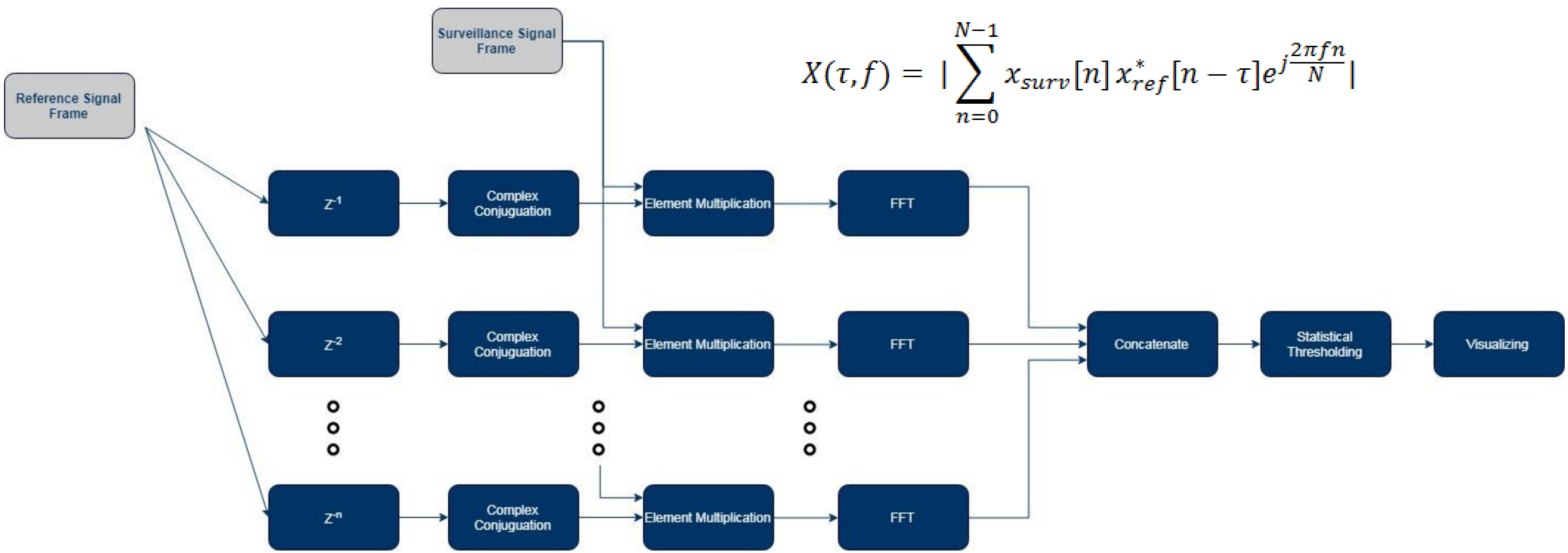
GNU Radio

Software:

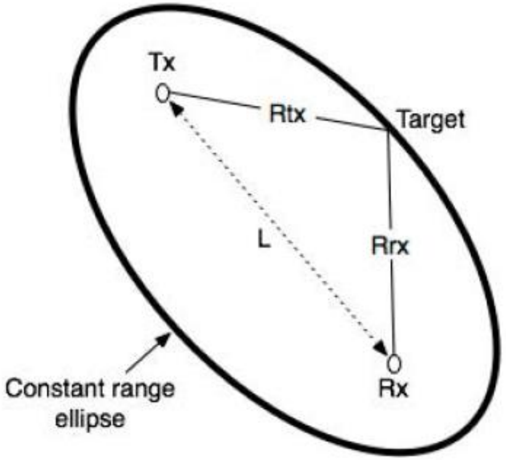
-GNU Radio along with Python used for Data Acquisition and Signal Processing part

Implementation: Signal Processing

- **Ambiguity Analysis:**
- **-**This represents a bank of matched filters as shown:



Implementation: Signal Processing



$$R = \frac{c}{2B}$$

R: Range Resolution
c: Speed of Light
B: Bandwidth

$$v = \frac{f_d c}{2 f_c}$$

v is the speed
f_d is the Doppler shift
f_c is the carrier frequency

Implementation: Signal Processing

- **Neyman Pearson Thresholding:**

$$\frac{P_{Y|H}(y|H_1)}{P_{Y|H}(y|H_0)} \underset{H_0}{\overset{H_1}{\gtrless}} \lambda$$

$$P_y(y) = \frac{1}{\pi^N \sigma_\omega^{2N}} \exp\{-\frac{1}{\sigma_\omega^2}(\boldsymbol{y}-\boldsymbol{m})^H(\boldsymbol{y}-\boldsymbol{m})\}$$

$$|\boldsymbol{m}^H y| \underset{H_0}{\overset{H_1}{\gtrless}} T$$

Implementation: Signal Processing

Coherent Integration Time:

- Longer integration time means better Signal to Noise Ration (SNR) and thus decreases the probability of error

$$X(\tau, f) = \left|\sum_{n=0}^{N-1} x_{surv}[n]\, x^{*}_{ref}[n-\tau] e^{j\frac{2\pi f n}{N}}\right|$$

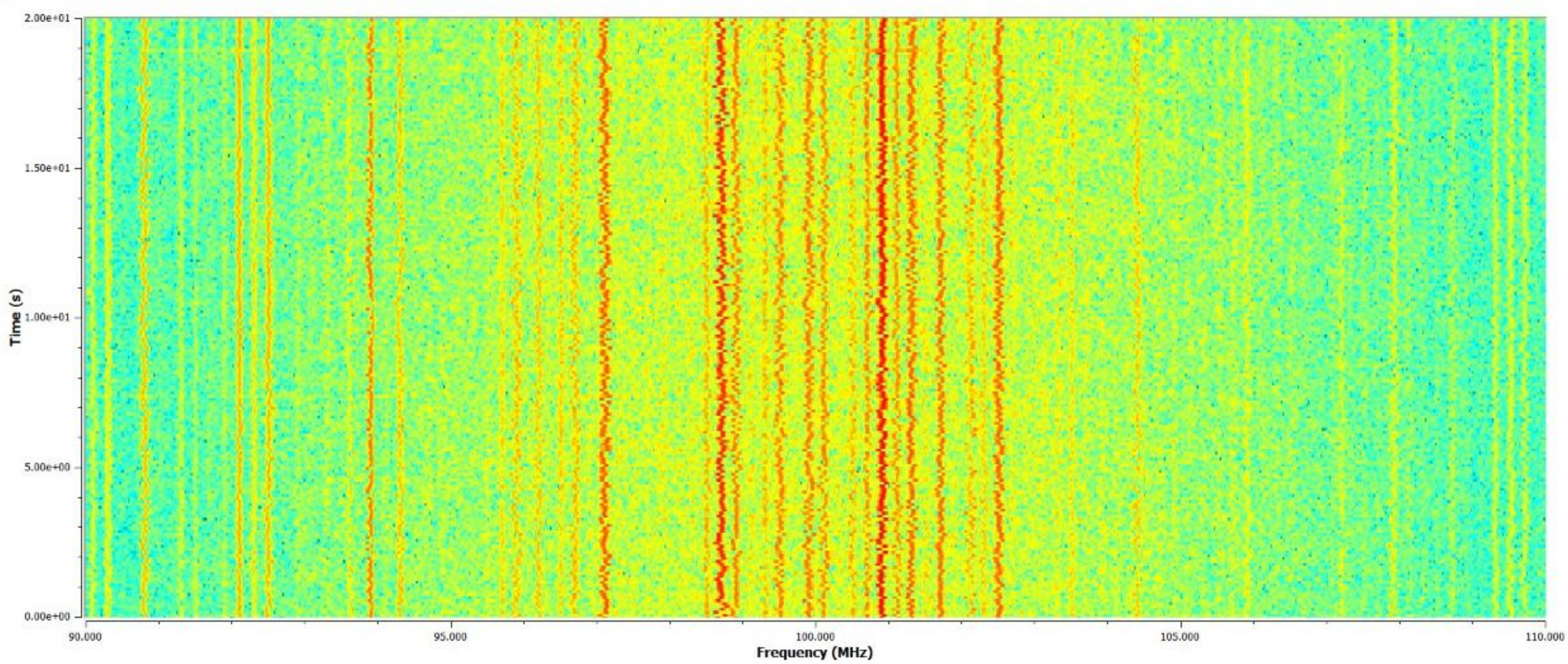
Range & Doppler Walk:

- Longer integration time can lead to range and Doppler walks
- chosen to be equal for 1 second, based on what was found in the literature for FM Stations and the detection of commercial aircraft

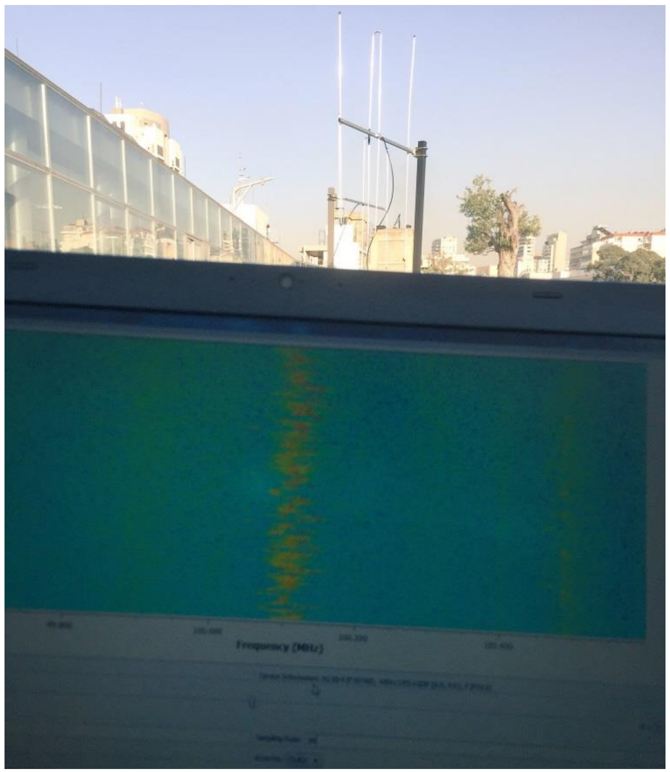
$$v_{\mathrm{B}} T_{\mathrm{I}} \ll \frac{c}{B}$$

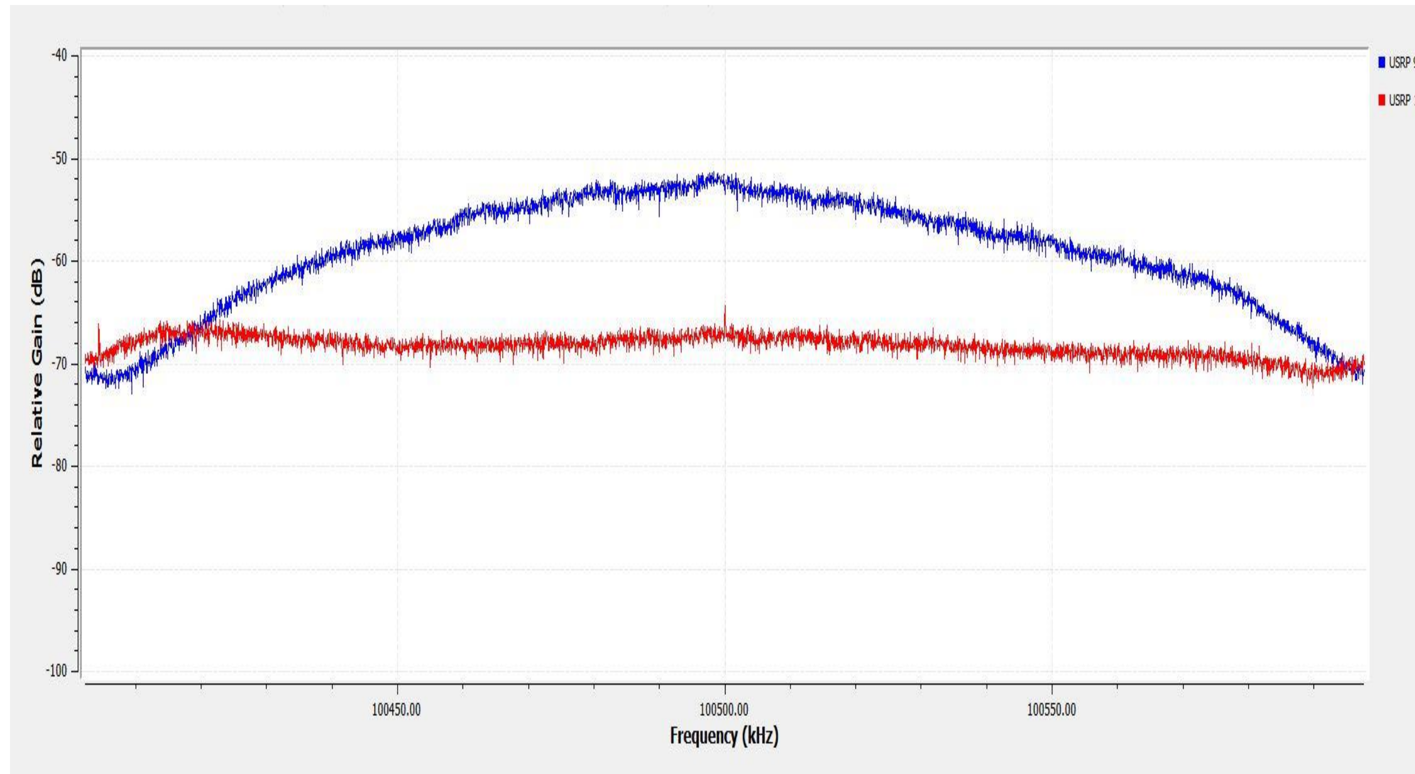
Preliminary Testing: Spectrum Monitoring

Antenna Testing & FM Station Choice:

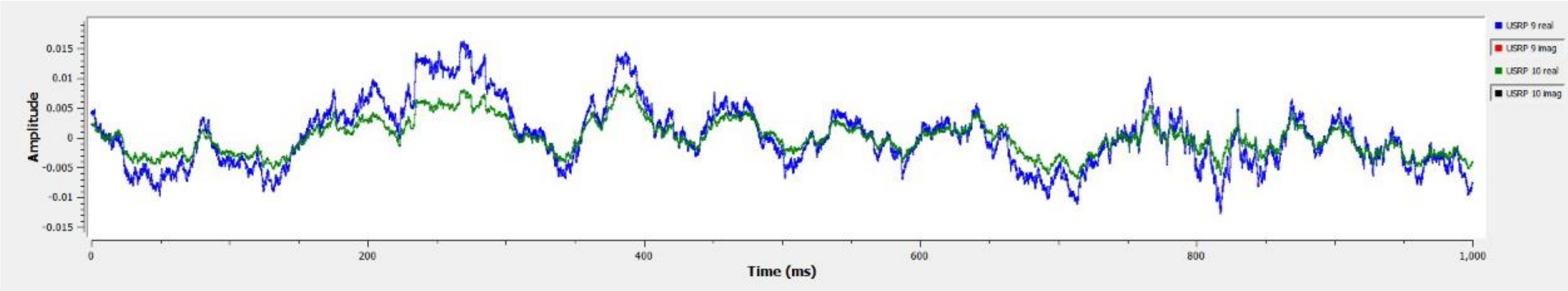


Preliminary Testing: Direct Signal Attenuation





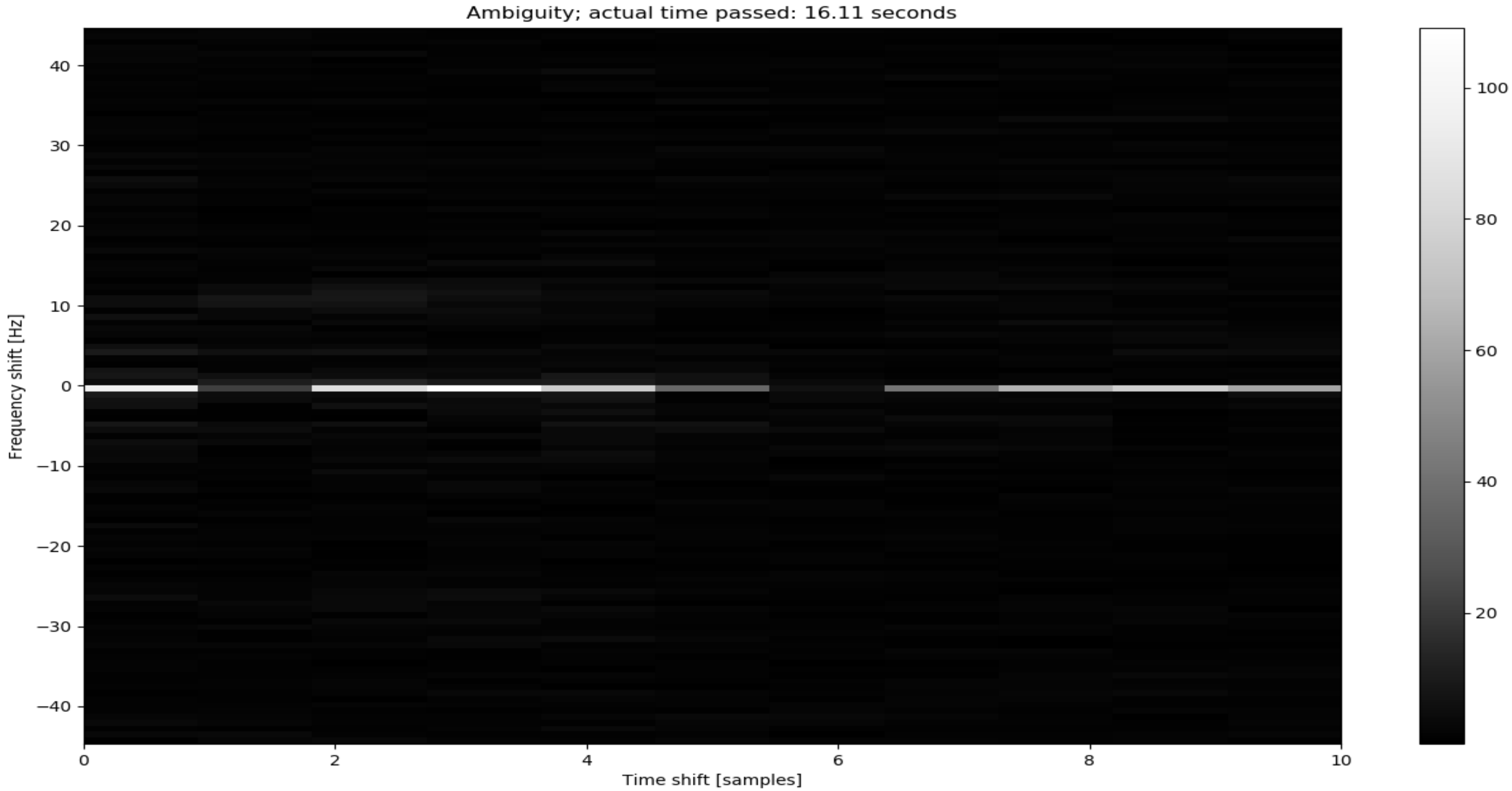
Preliminary Testing: Synchronization



Both channels need to be synchronized in time and frequency using the MIMO Cable.
Changes in amplitudes are due to noise

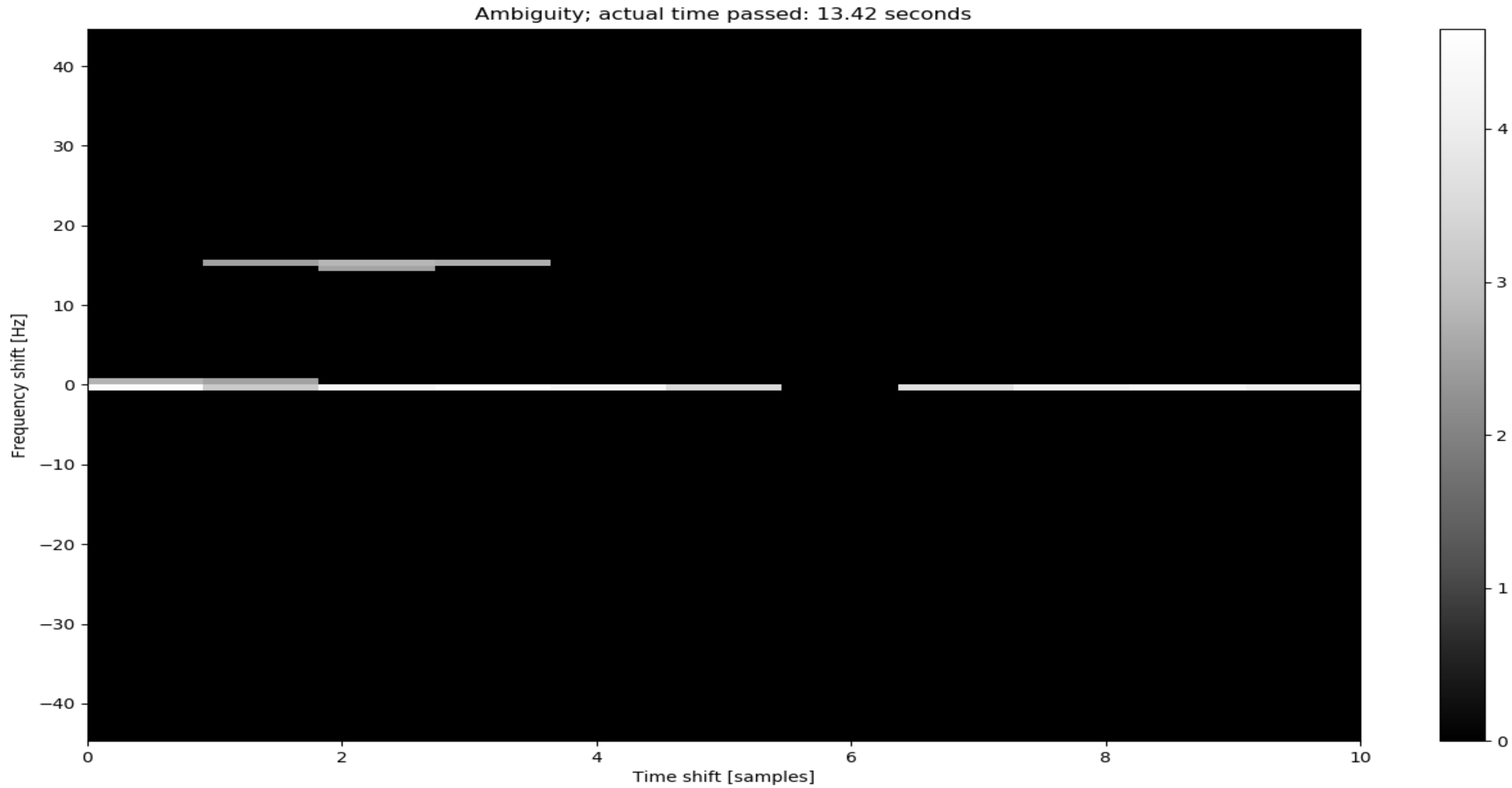
Target Detection Testing: Iteration 1

Without Neyman-Pearson Thresholding

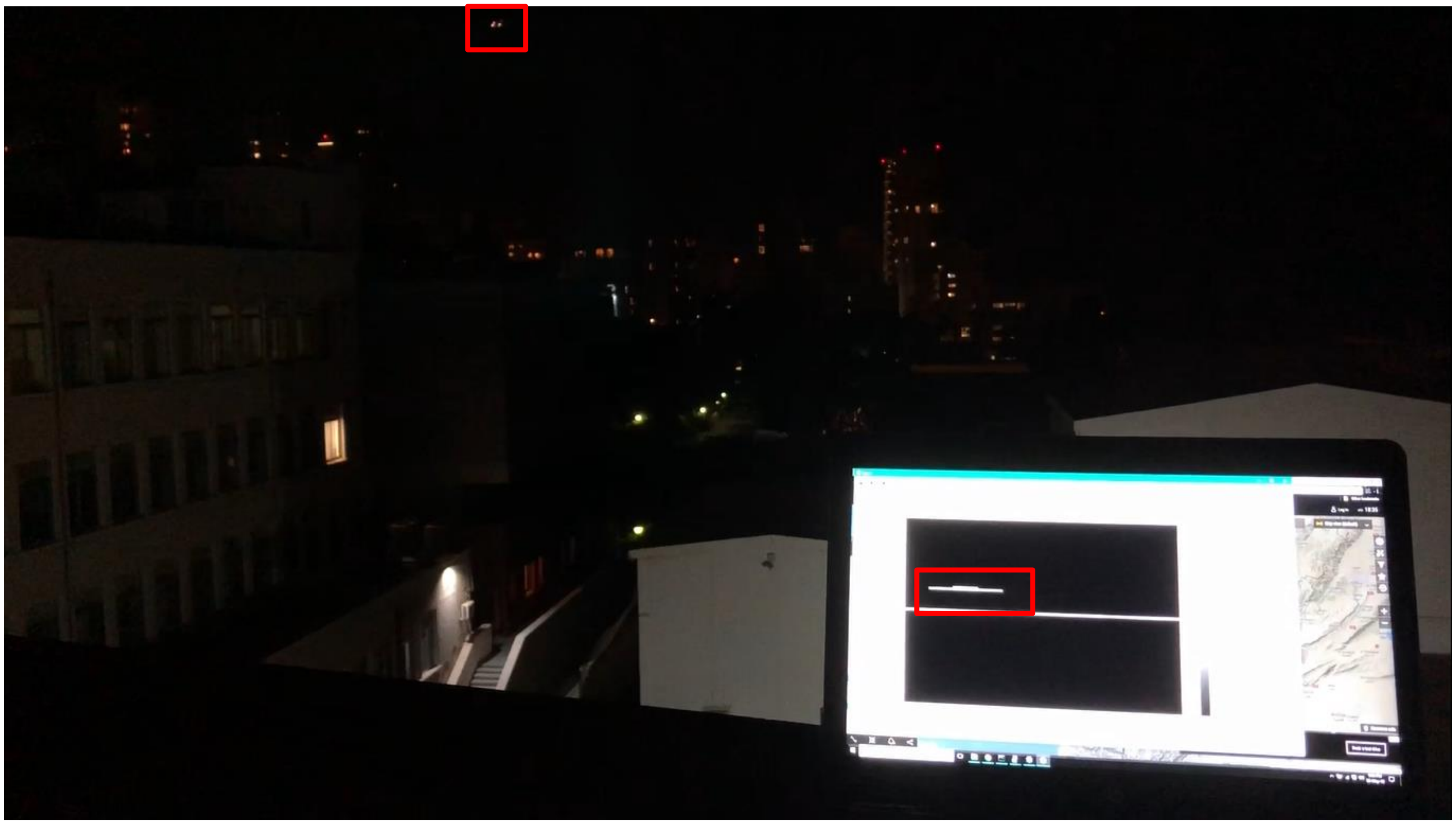


Target Detection Testing: Iteration 2

With Neyman-Pearson Thresholding

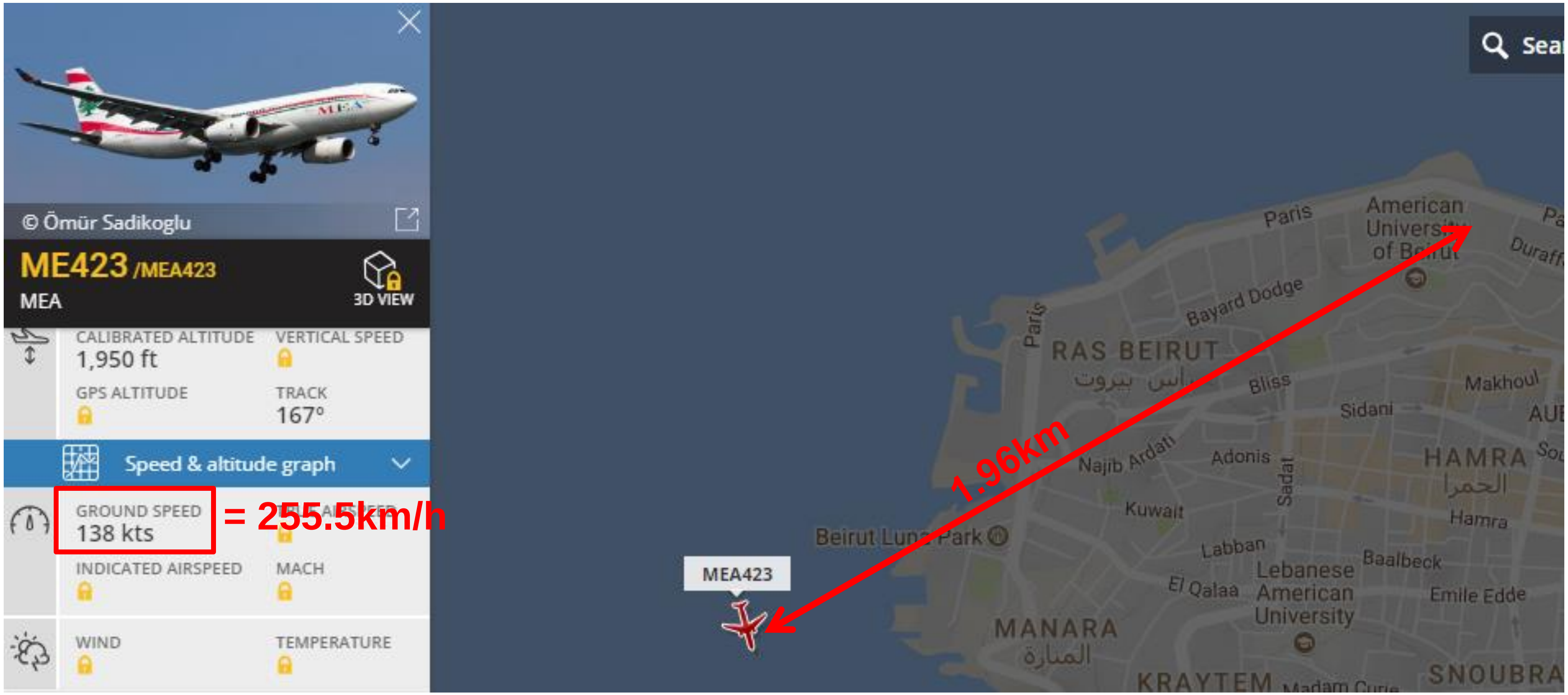


Real Time Target Detection



Target Detected at:
- Range centered at 2 kilometers
- 250 km/h

Testing Validation: FlightRadar24



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Questions?