Software Defined Radar

Group 33 – Ranges and Test Beds

MQP Final Presentation

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Overview

- Project Introduction & Deliverables
- Radar Background
- Radar System Design
- Time Synchronization
- Radar Processing
- Summary

Project Introduction

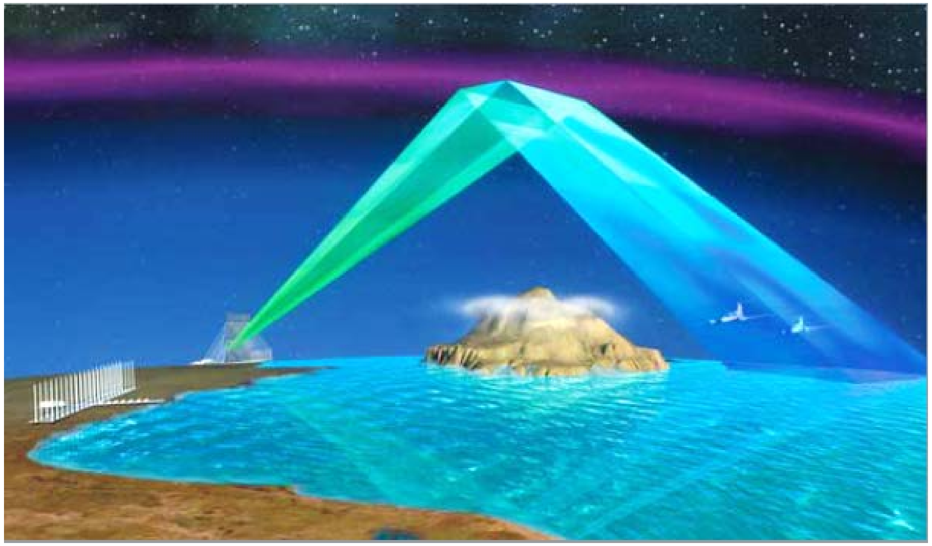
- **Project objective: build an inexpensive multistatic radar receive system using Ettus Universal Software Radio Peripheral (USRP2)**
- **Deliverables:**
  - **Time Synchronization**
  - **Radar Processing**
    - **Range**
    - **Doppler**
    - **Direction**

- **Software Defined Radio**
  - **Radio whose typical hardware components are implemented in software**
  - **Digital filters & mixers, modulators/demodulators**

http://cwnlab.ece.okstate.edu/images/facilitiesimg/usrp2.jpg

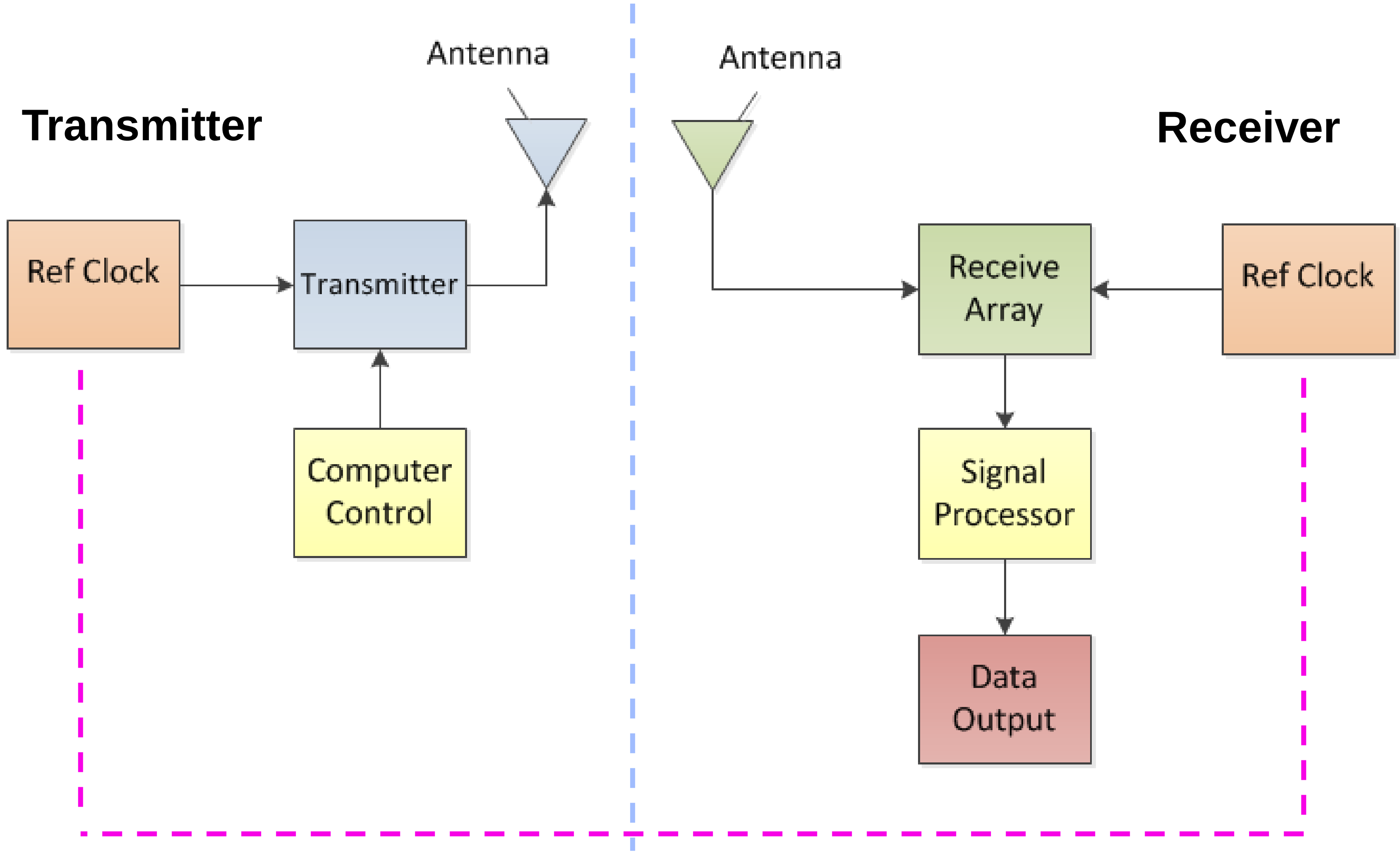
Radar Background

- **Radar, short for Radio Detection and Ranging, is a method of detecting targets using electromagnetic waves**
- **Two different types of Radar:**
  - **Pulse Radar**
  - **Continuous Wave Radar**
- **Over the Horizon Radar:**
  - **Continuous Wave**
  - **3-30 MHz Frequency**
  - **Multistatic configuration**
  - **Large antenna arrays (~2-3 km)**



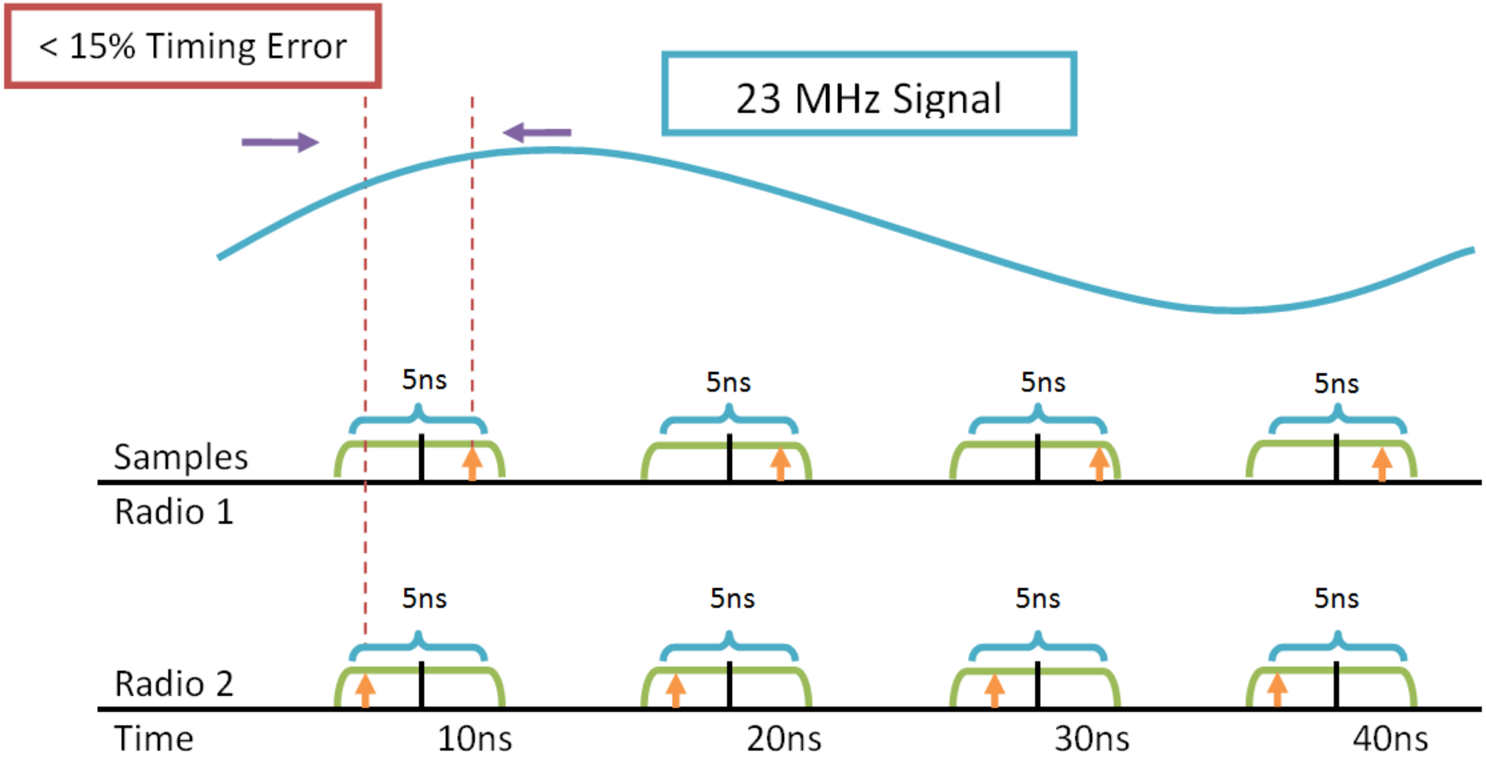
[1]http://www.raytheon.com/capabilities/products/stellent/groups/public/documents/legacy_site/cms01_049201.pdf

Multistatic Radar System



Clock Synchronization

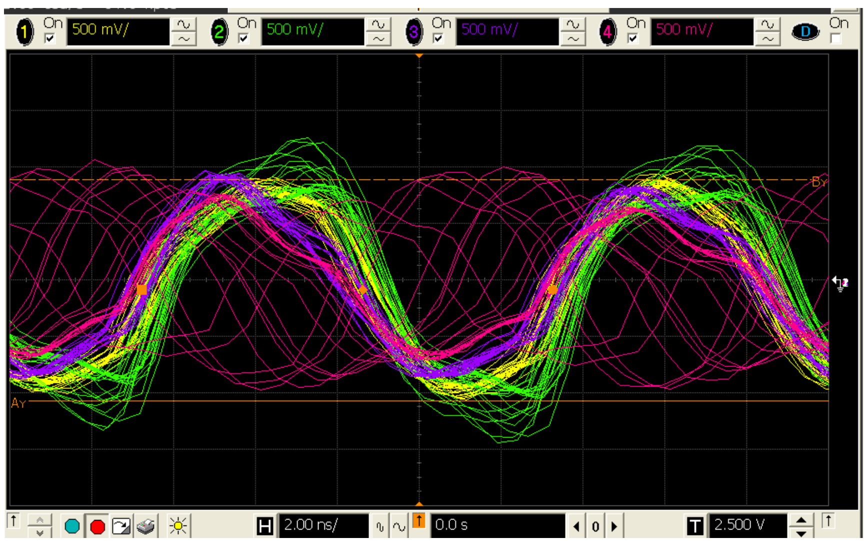
- **Sampling rate of the system is 100 MHz**
  - **Our radar system operates in HF (3-30 MHz)**
  - **Tolerance of 5 ns minimizes the error to less than 15% for the HF band**



Clock Stability

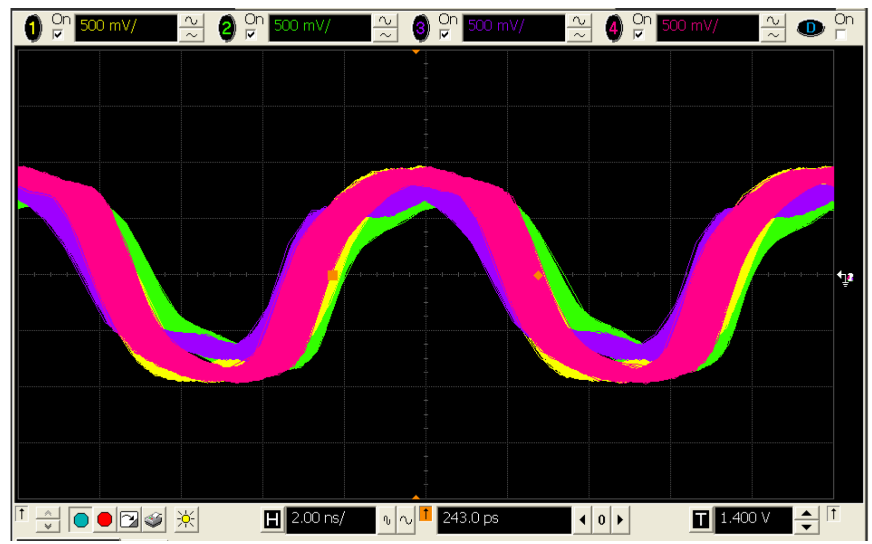
Current Performance

3 Synchronized, 1 Not



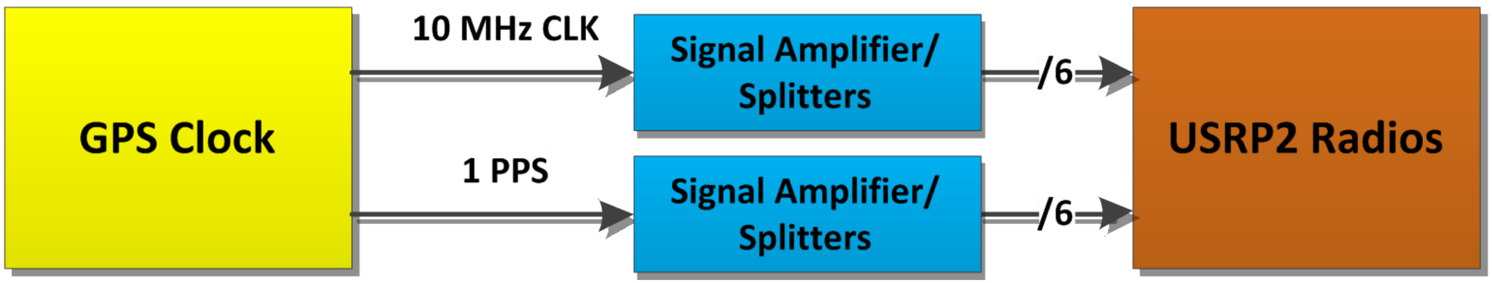
Target Performance

4 Synchronized Radios

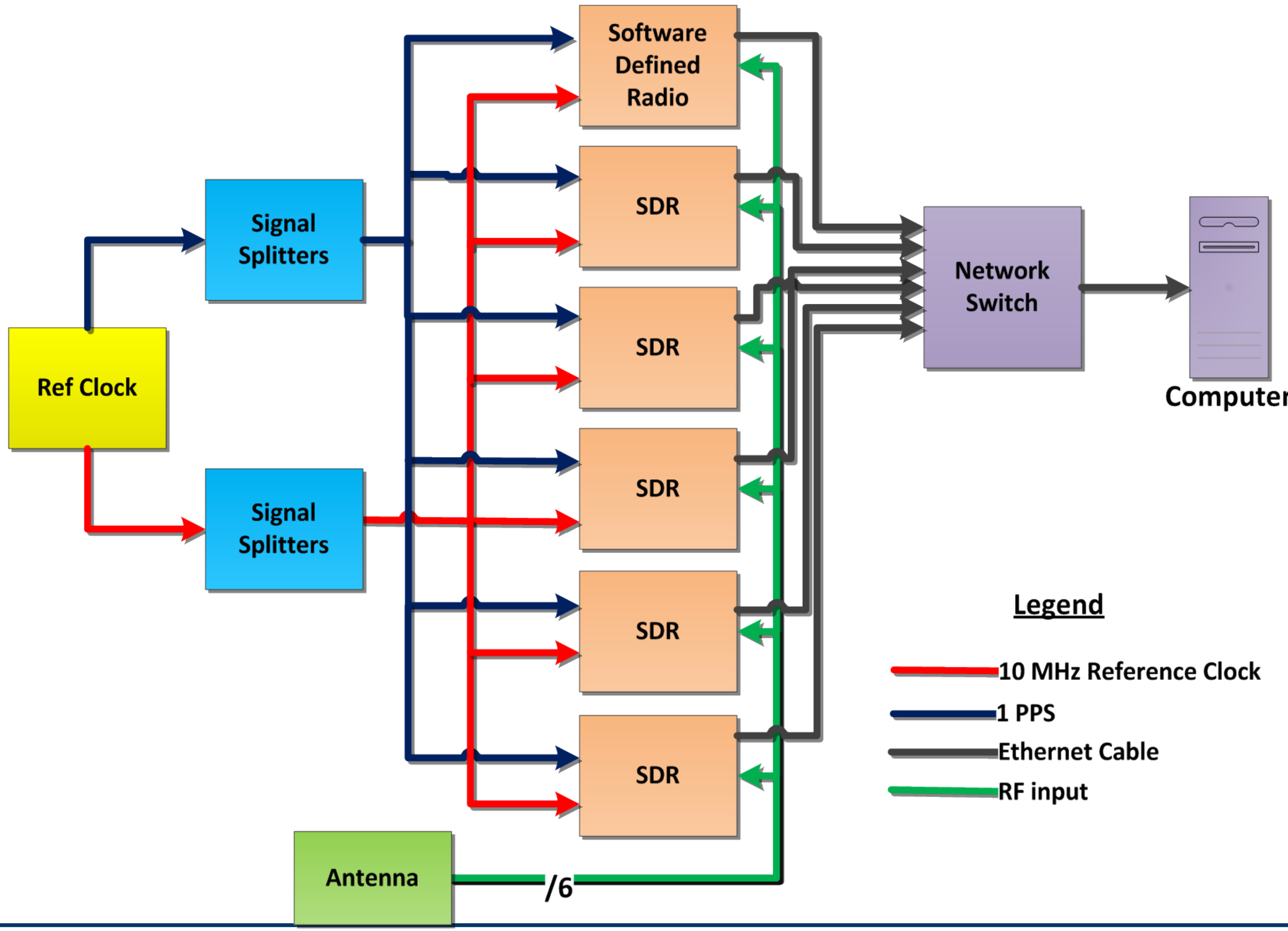


USRP2 Clock Synchronization

- Synchronizing USRP2 ADC Clock
  - 100 MHz Internal Oscillator controlled by a Phased Locked Loop
  - Inputs to Phase Locked Loop
    - 10 MHz Reference Clock
    - 1 pulse per second (PPS)
  - Input Power/Level Requirements
    - 10 MHz Ref. Clock Power: 5-15 dBm
    - 1 PPS: 5V Peak-to-Peak



Receiver System Design

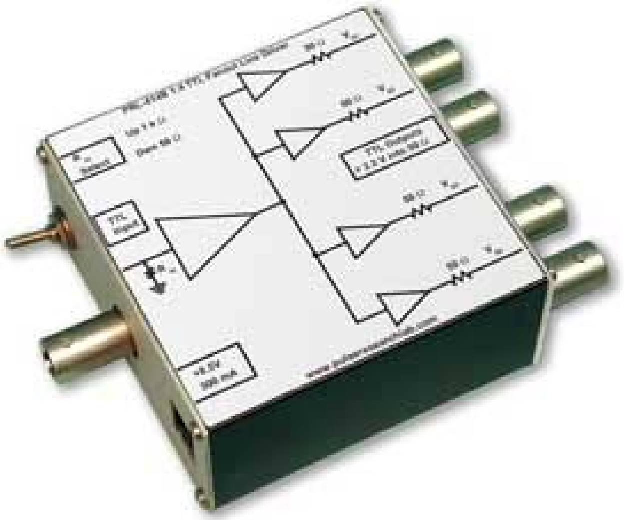


Radar System Design

- **Selected the following Components:**

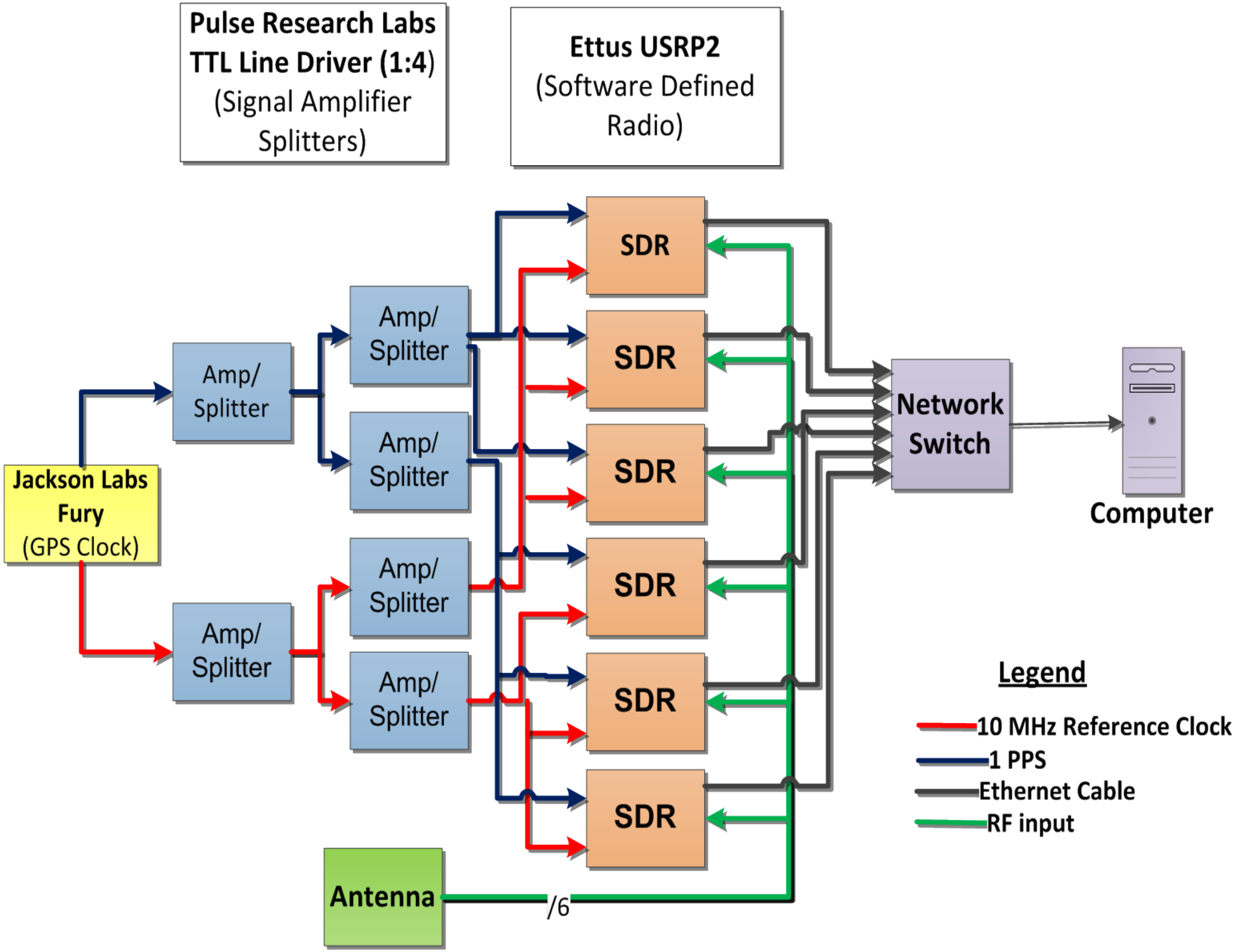
- **Jackson Labs GPS Disciplined Oscillator**
  - 10 MHz output
  - 1 PPS output

- **Pulse Research Labs 1:4 Fanout Buffer**
  - Clock/PPS Signal Distribution
  - Freq < 100 MHz
  - Four in-phase 50Ω TTL Outputs



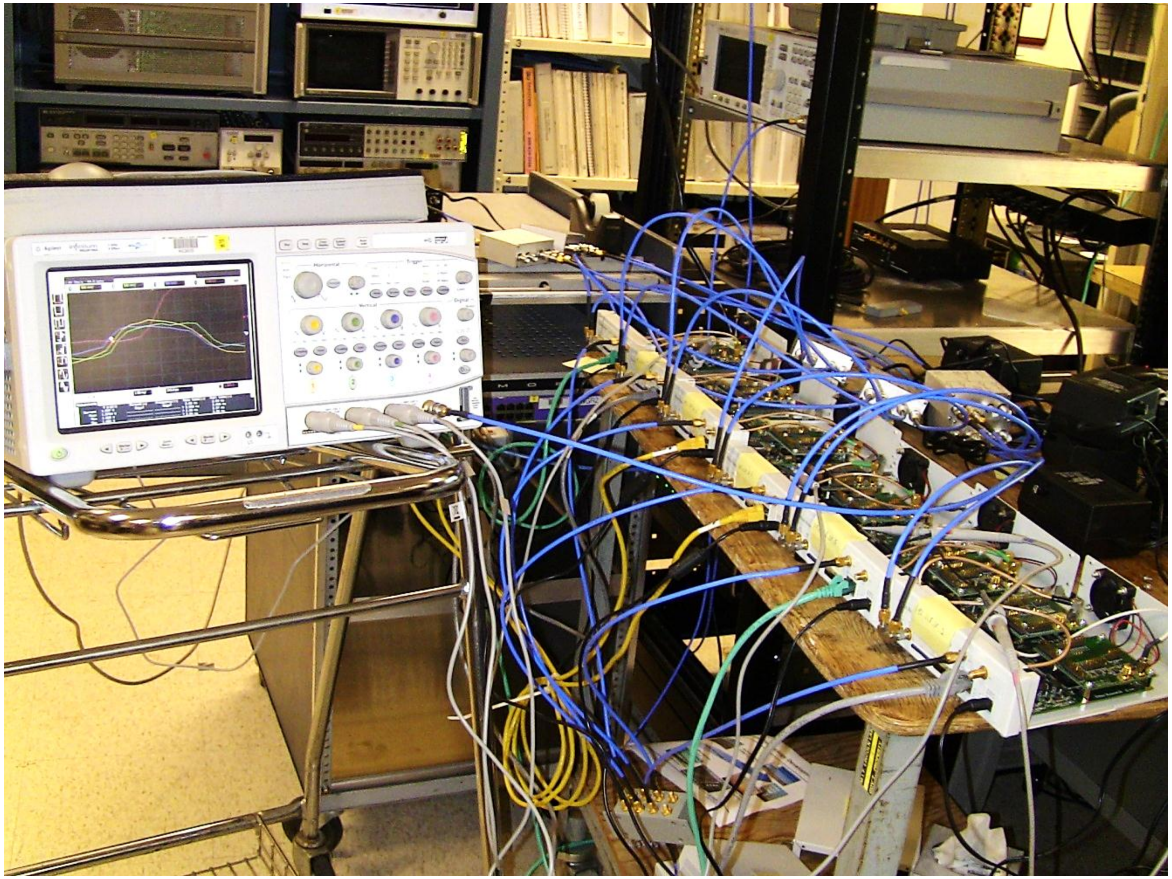
[1]http://media.marketwire.com/attachments/200706/MOD-346700_Fury_bezel_small.jpg
[2]http://www.pulseresearchlab.com/products/fanout/prl-414B/images/PRL-414B_small.jpg

Our Implementation



Synchronization Testing

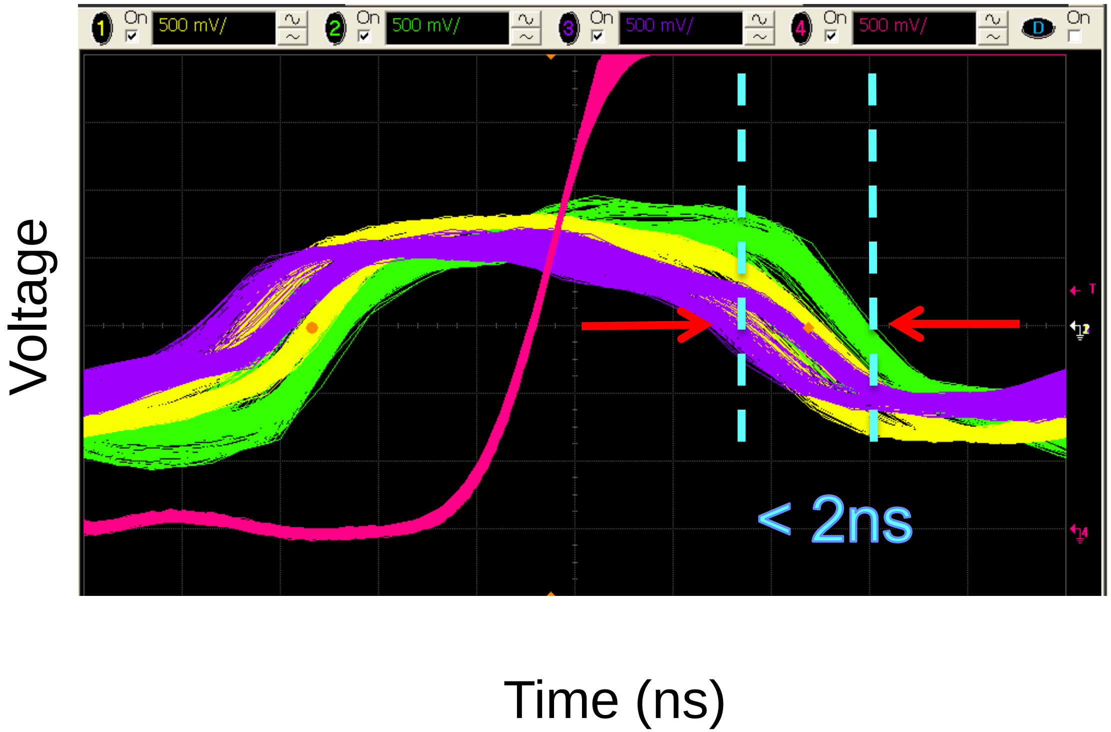
- **We used an oscilloscope and the USRP2 clock debug pins to record the ADC clock drift**



PPS Trigger Test

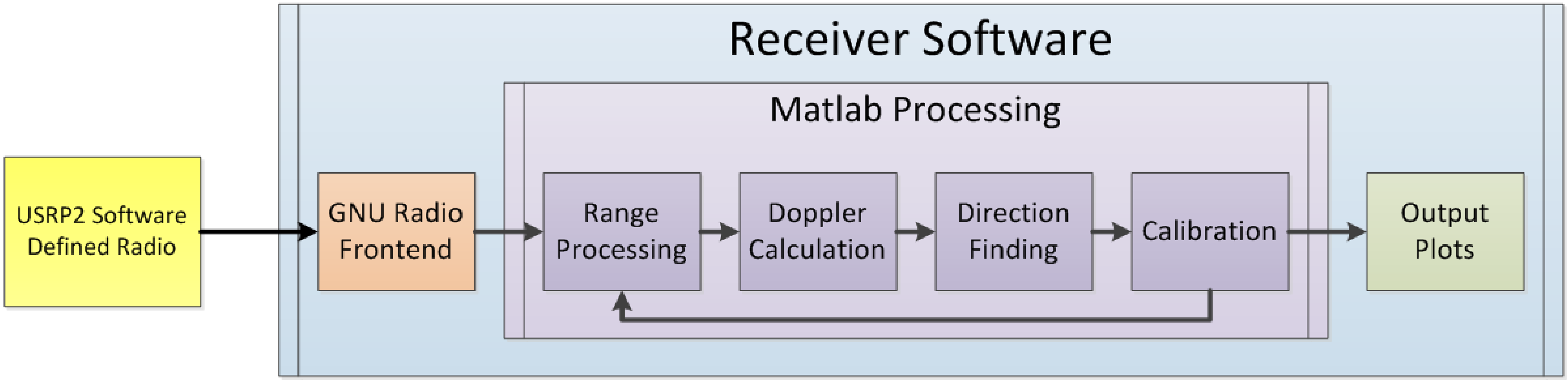
- The purpose of this test was to determine whether the radios could consistently trigger off the 1 PPS
- Channels 1-3 were connected to USRP2s and Channel 4 was connected to the GPSDO PPS output
- The PPS signal served as a reference for measuring drift

30 Minute Persistence Plot



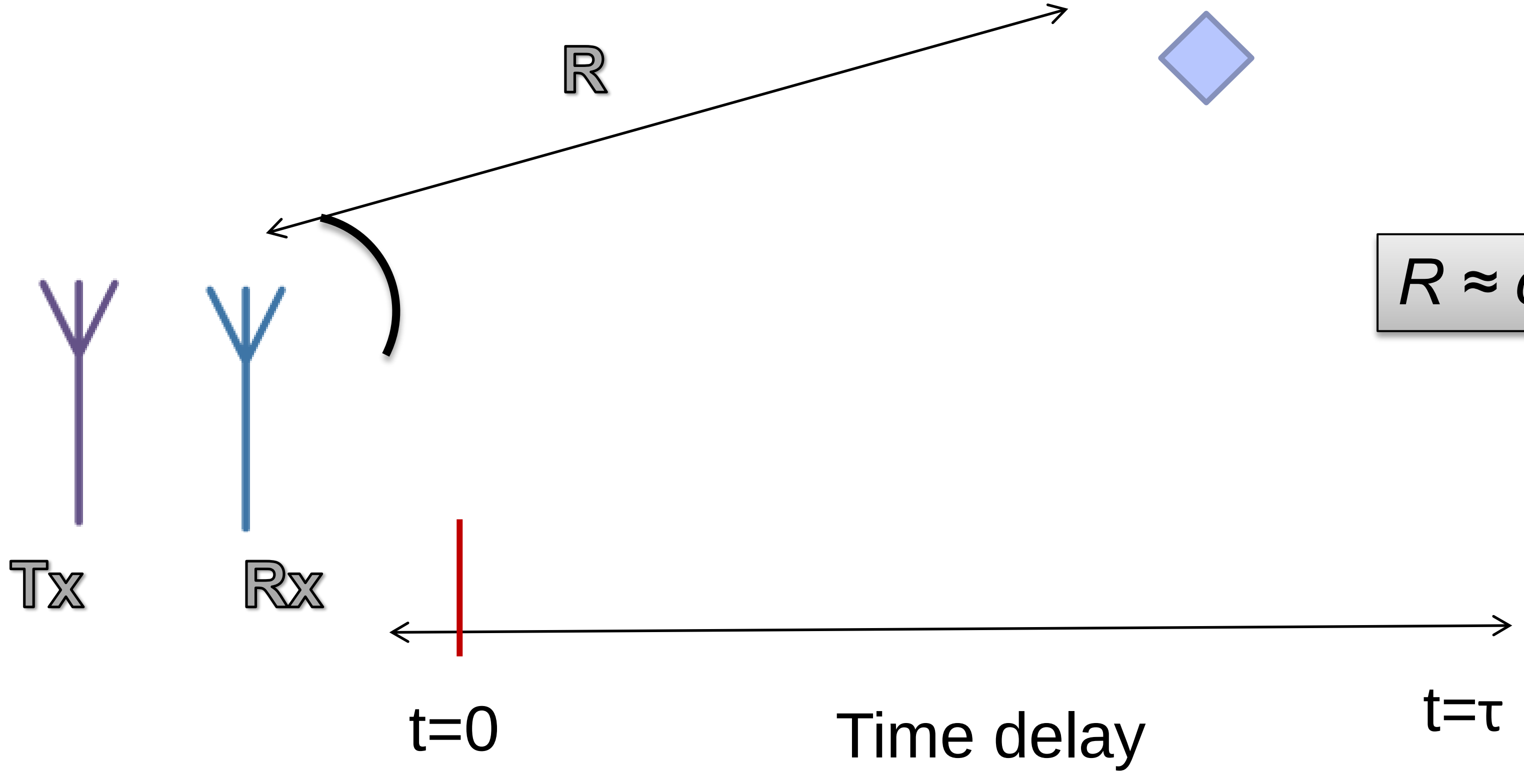
Radar Receiver

- **GNU Radio provides the means to interface the USRP2 array and record data**
- **Radar processing implemented in Matlab**
  - **Range**
  - **Doppler**
  - **Direction**



Range Processing

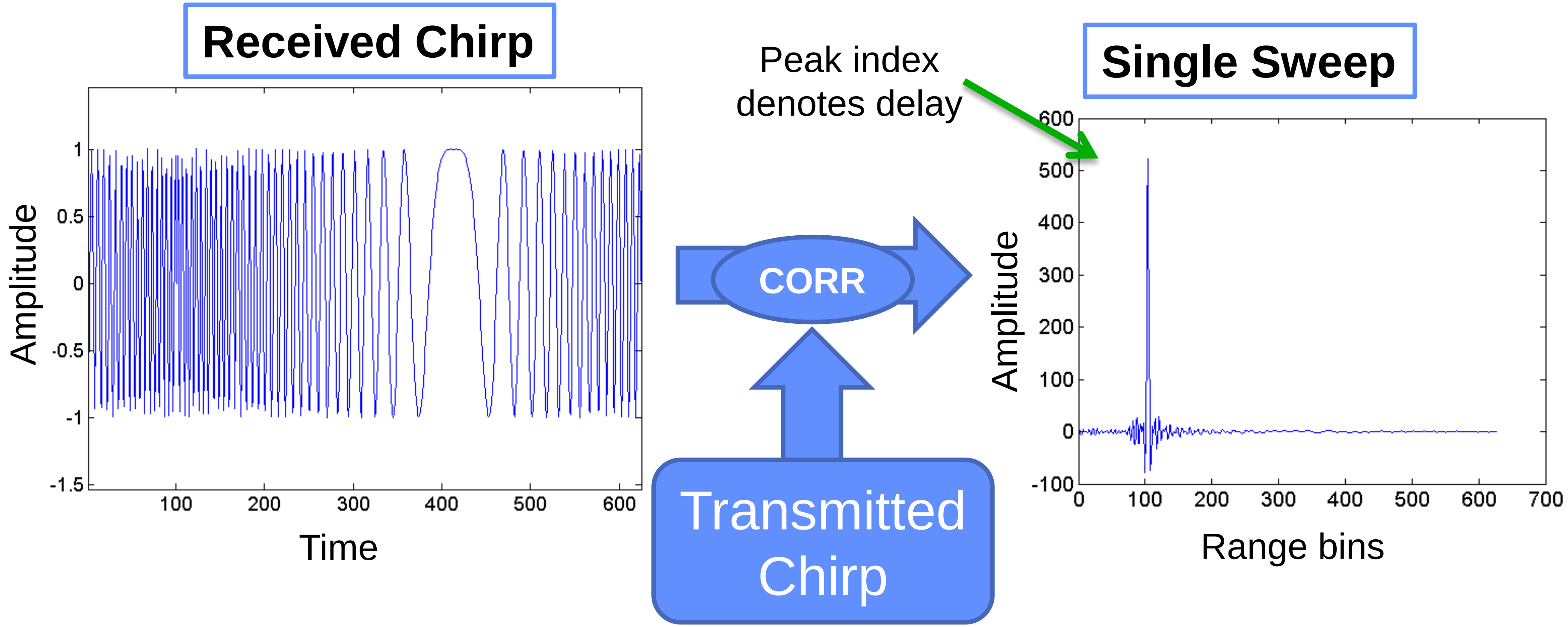
- Range is determined by the time delay between the transmitted and the received signals
- Assuming the transmitter and receiver are synchronized, the delay equals the travel time



$R \approx c\,\tau/2$

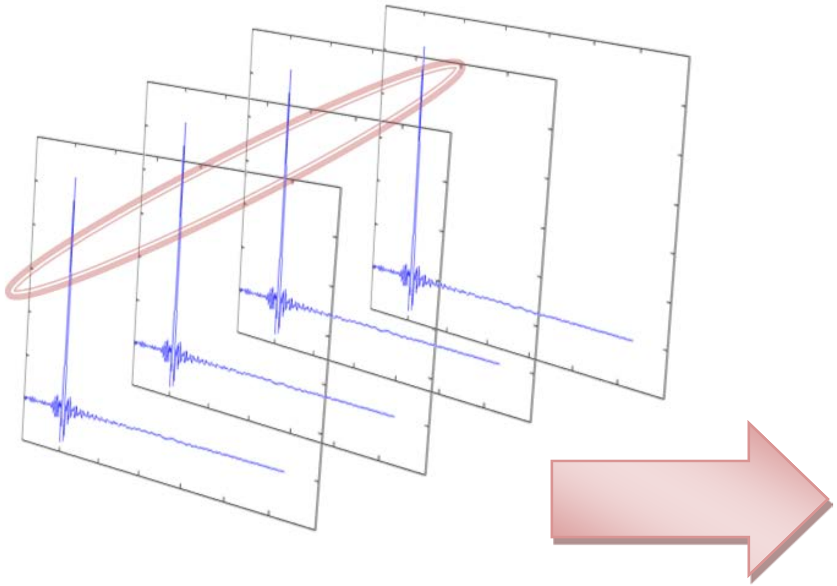
Range Processing (cont.)

- The delay can be computed by determining when the chirp was received via correlation
- Correlating the received signal with the transmitted chirp is known as pulse compression

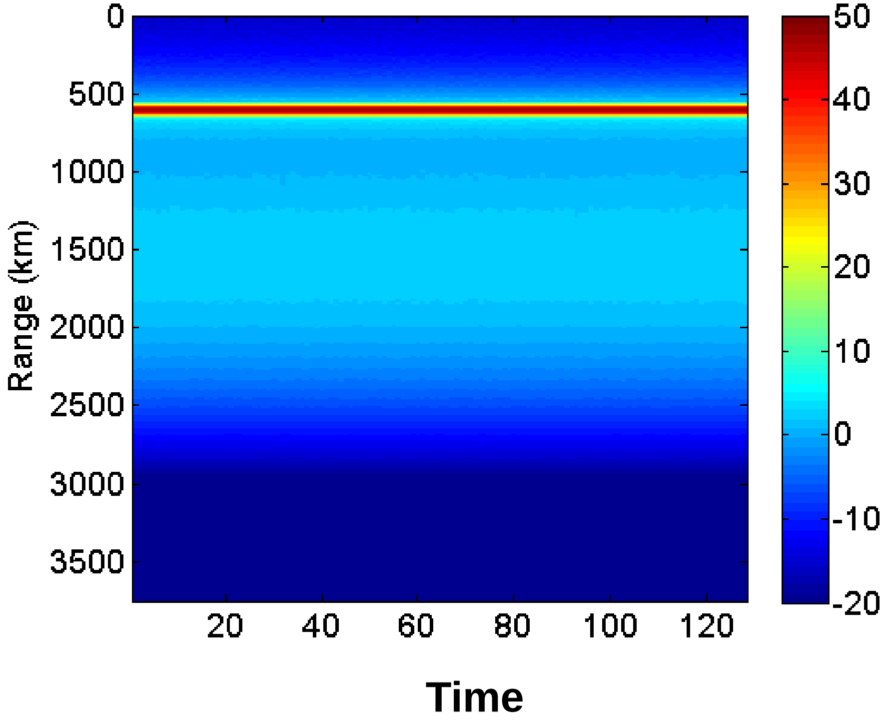


Range Plot

Multiple sweeps over time

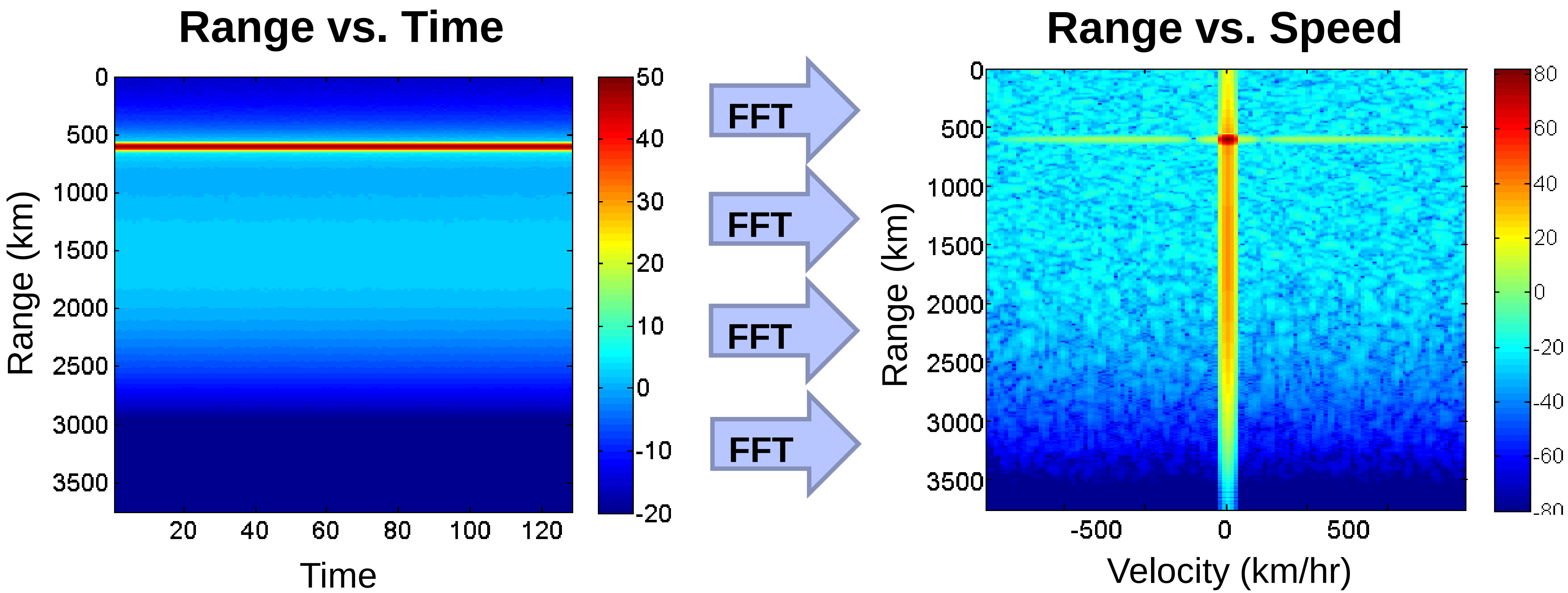


Range vs. Time



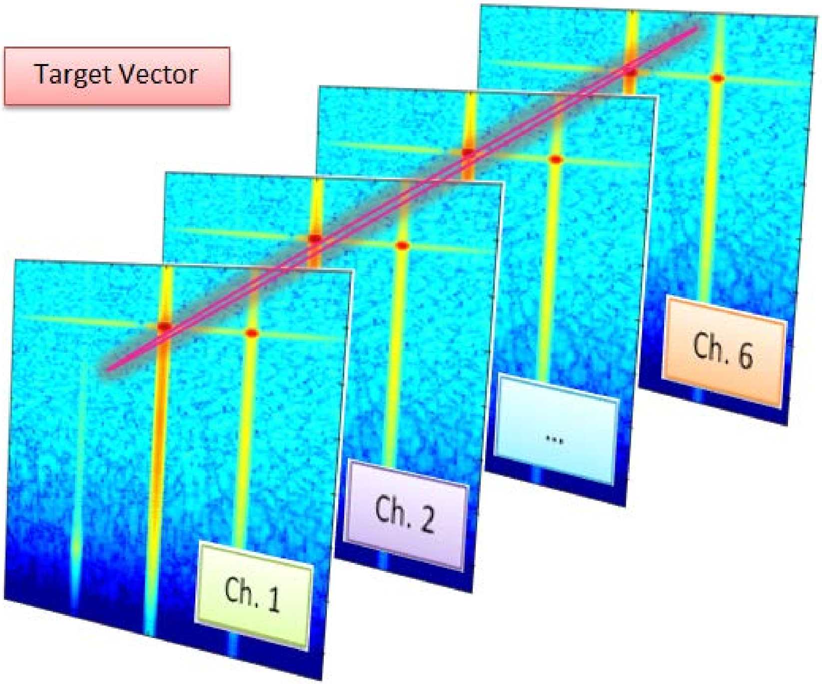
Doppler Processing

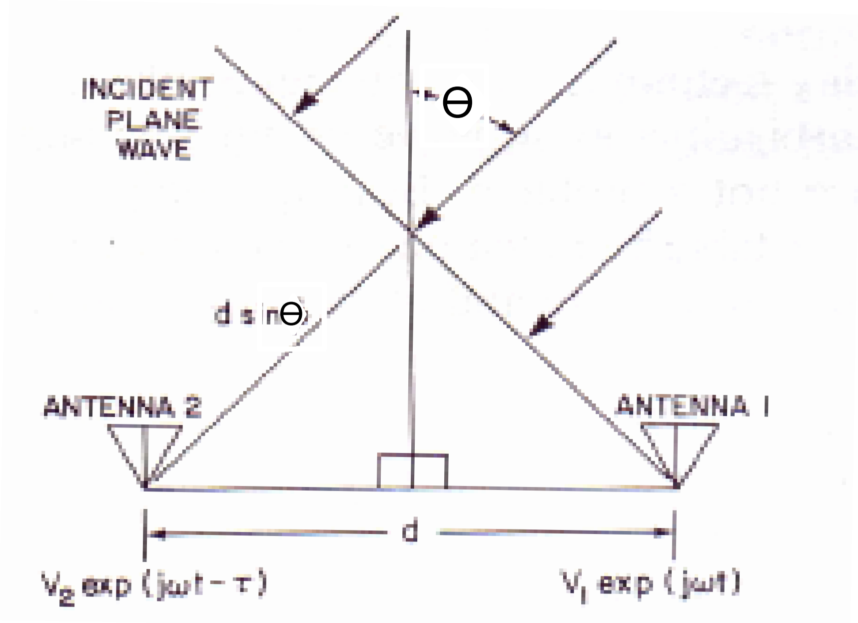
- **Used to identify target velocity**
- **Doppler is a phase progression from sweep to sweep**
  - **The Fourier Transform of a periodic function produces an impulse function at the center frequency**
  - **Taking the FFT of the range cells creates a peak at the intersection of the target's range and Doppler Frequency**



Direction Finding

- **Direction finding requires a vector of the complex samples from each channel's Range-Doppler plot**
- **Assuming a flat wave front (far field transmission), each sample has magnitude M and phase Φ:** $Me^{j\phi}$

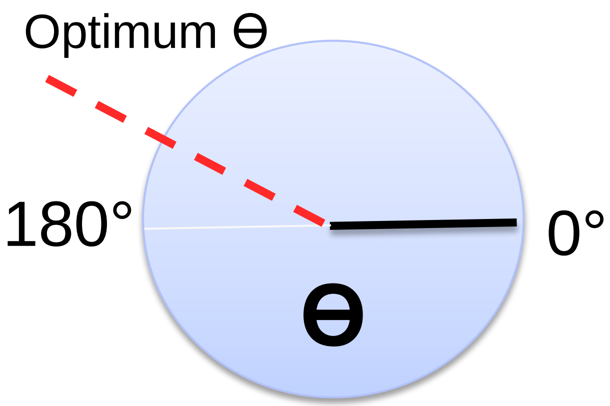


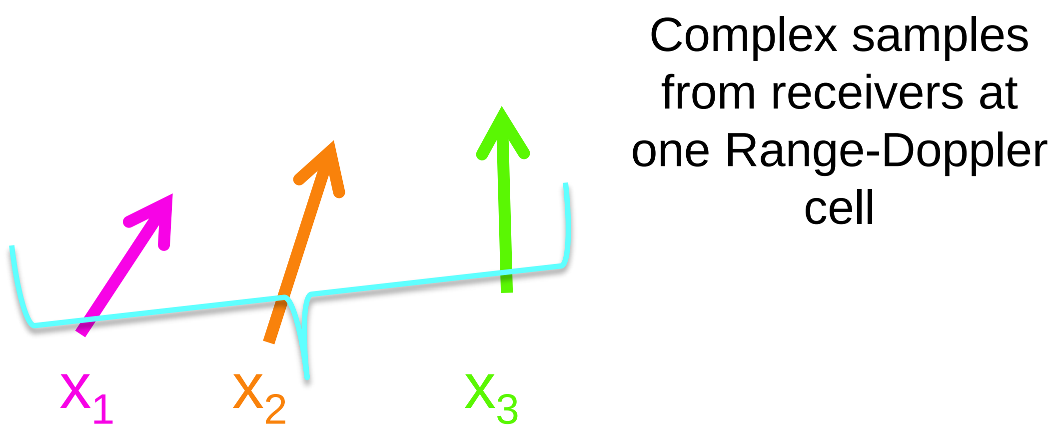


$$\Phi(n) = \frac{2\pi}{\lambda} d(n-1)\sin\theta, n = 1, 2, \dots, 6$$

Direction Finding (cont.)

- **Each point is multiplied by a candidate 'zeroing vector' defined for different theta values**
- **The value theta that optimizes the sum is the incident angle**



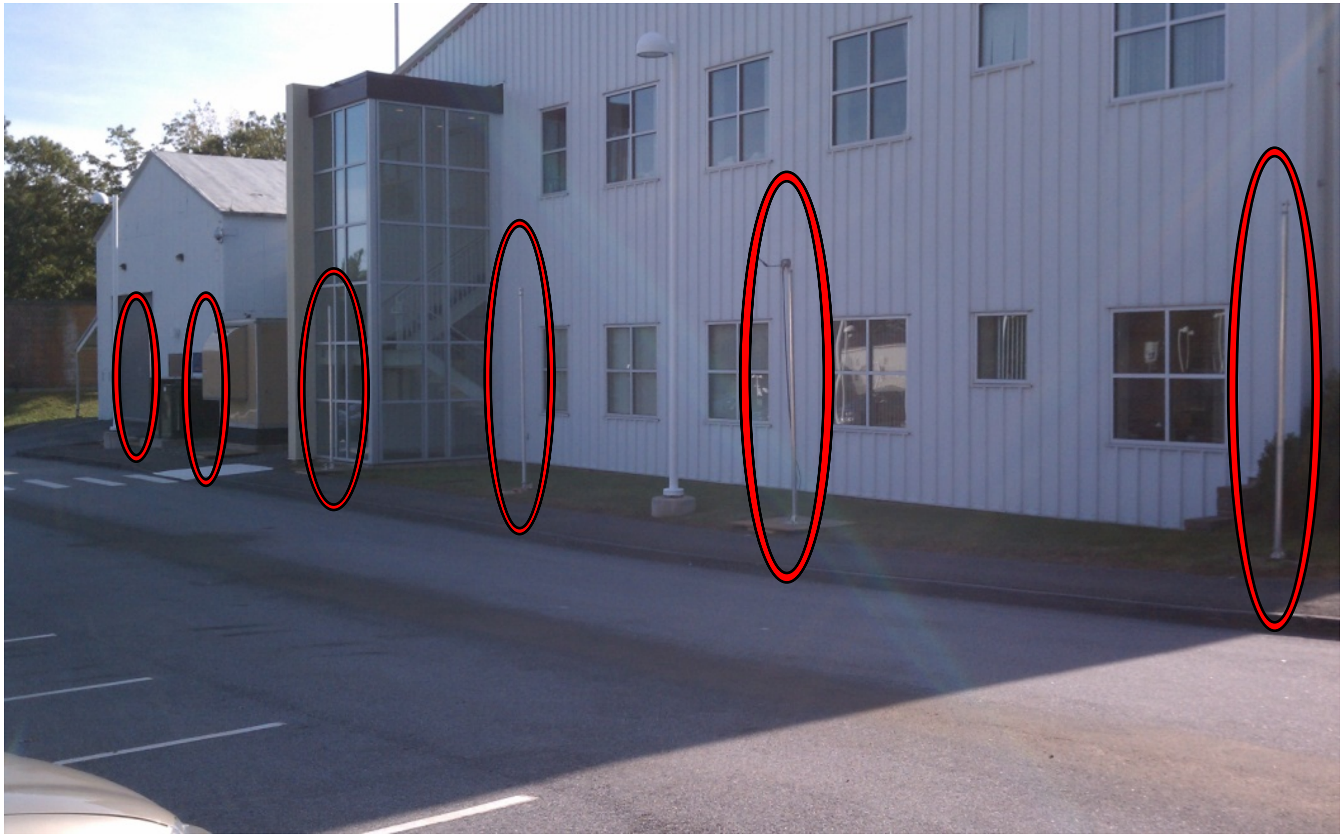


$$\Phi(n) = \frac{2\pi}{\lambda} d(n-1)\sin\theta, n = 1, 2, \ldots, 6$$

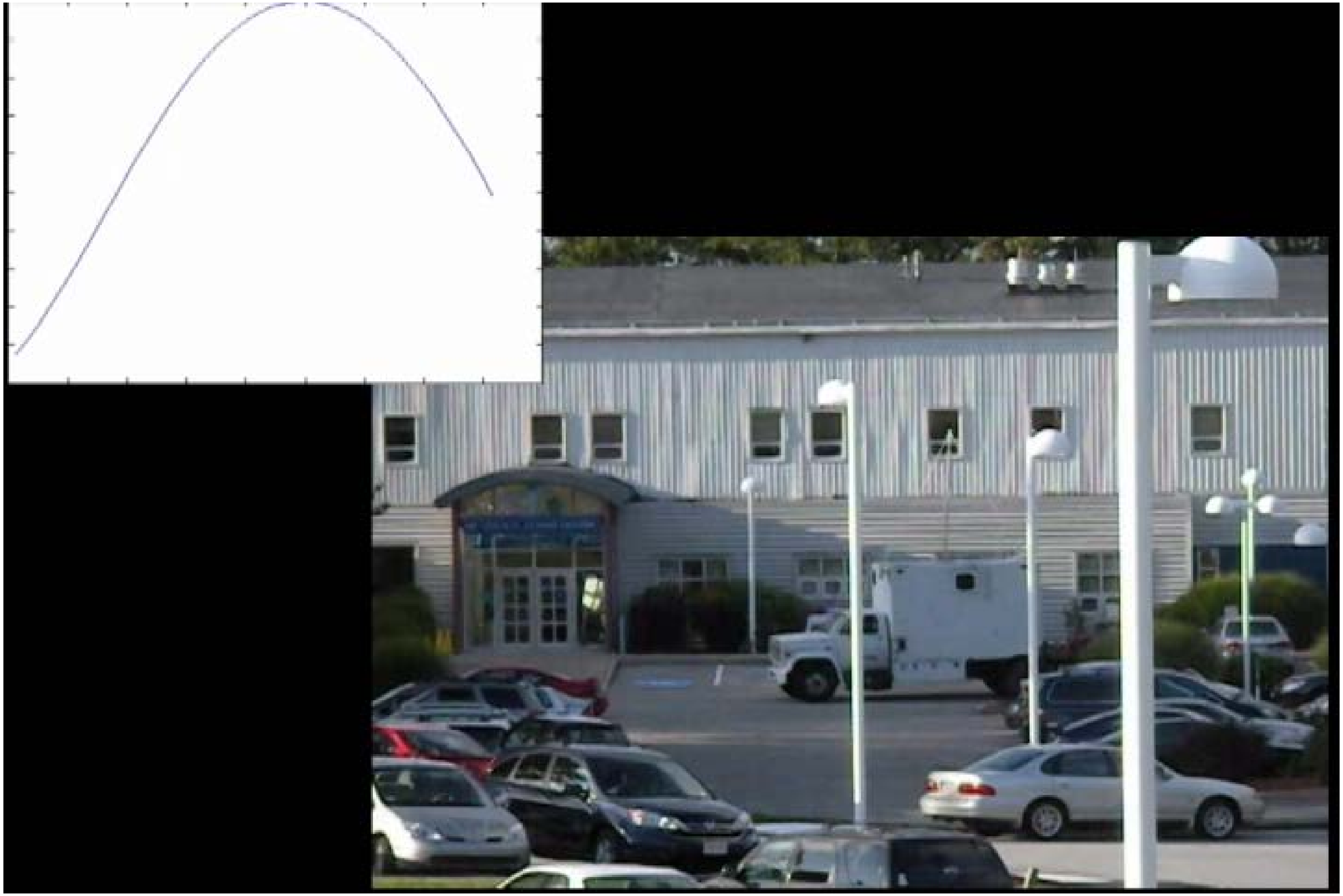
$$Me^{j\phi} * e^{-j\phi} = M$$

Our Receive Array

- **Six, 10 ft antennas arranged in a linear array outside Katahdin Hill**



Direction Finding Demonstration



Summary

- **Purpose: Develop an inexpensive phased receive array using the USRP2 SDR**
- **Deliverables:**
  - **Synchronized array**
  - **Array form factor**
  - **Radar processing code**
- **Future Works**
  - **Setup larger line array**
  - **Improve synchronization by modifying FPGA firmware**
  - **Implement Real-time Processing**

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Group 33

Questions?