5.8-GHz FMCW Radar System for Drone Tracking

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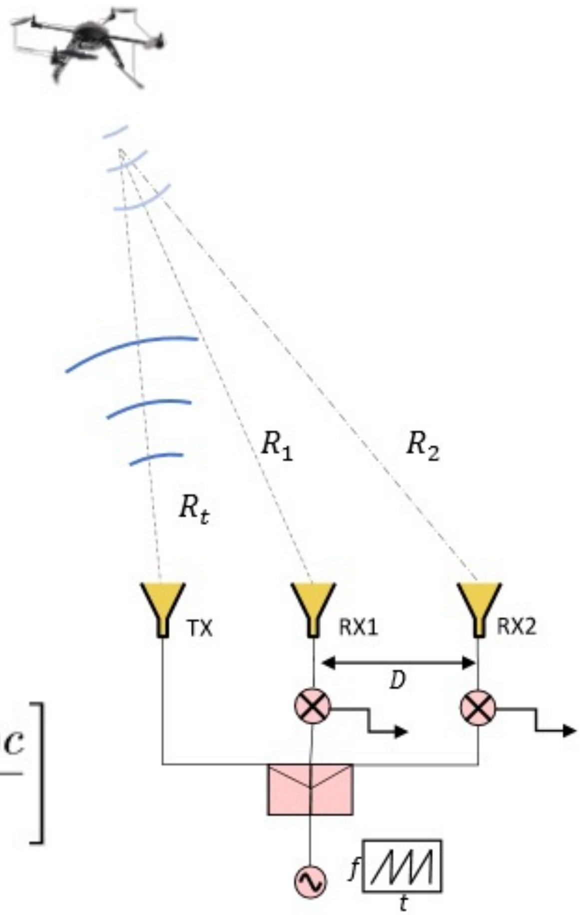
Introduction

- Significant increase in the consumer drones poses many challenges in every day life
- Potential misuse could lead in violations of privacy, safety and property damage
- Radar is a great candidate for wireless aerial sensing
- Many radar works have worked on the micro-Doppler response for classification, but not as much for drone tracking.

Drone picture from https://www.nytimes.com/2020/01/01/us/drones-FAA-colorado-nebraska.html

Theory and Signal Processing

FMCW radar theory



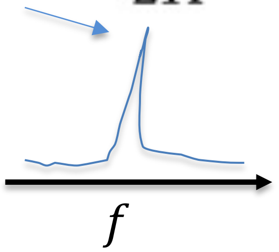
Range:

$$s(t) = \cos\left[2\pi\left(f_0 t + \tfrac{K}{2}t^2\right)\right]$$

$$v_1(t) = \cos\left[2\pi(K\frac{R_t + R_1}{c})\right]$$

$$v_2(t) = \cos\left[2\pi(K\frac{R_t + R_2}{c})\right]$$

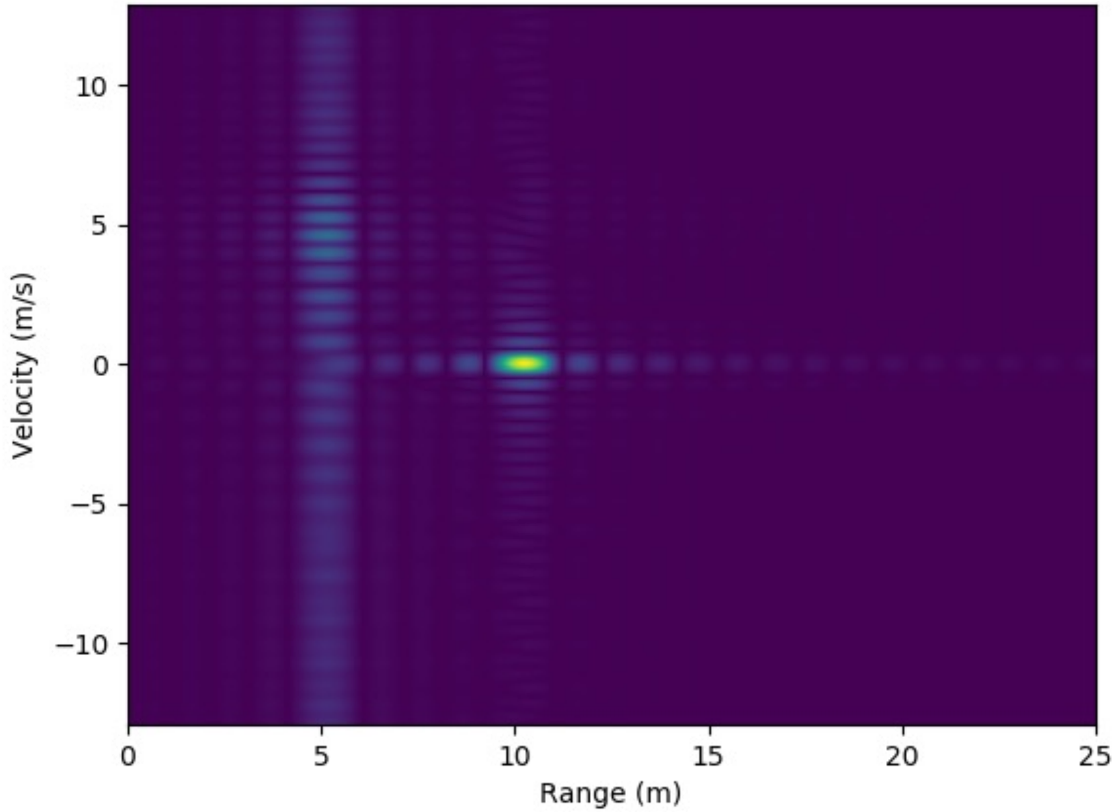
$$R_i = \frac{f_i c}{2K}$$



Angle: $\sin\theta = (R_1 - R_2)/D$ or $\theta = \sin^{-1}\left[\frac{(f_1 - f_2)c}{KD}\right]$

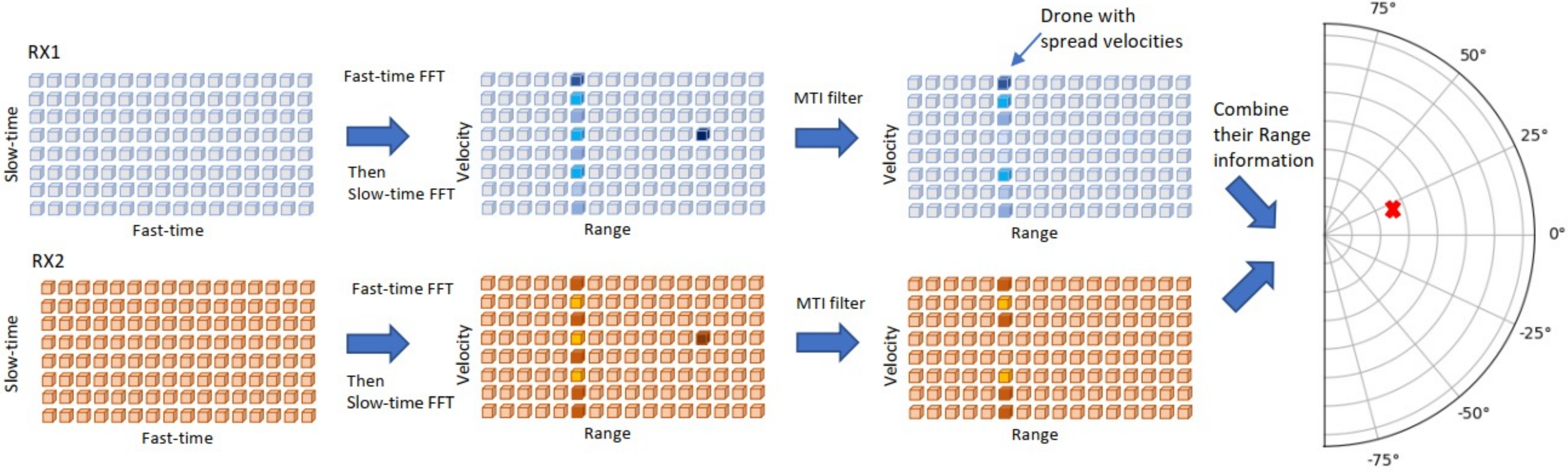
Differentiating the drone

- Drone reflection can be very weak compared to the clutter
- Is there any information about the drone we could use to differentiate it?
- Turns out drone have a very unique velocity spectrum



Range-Doppler map

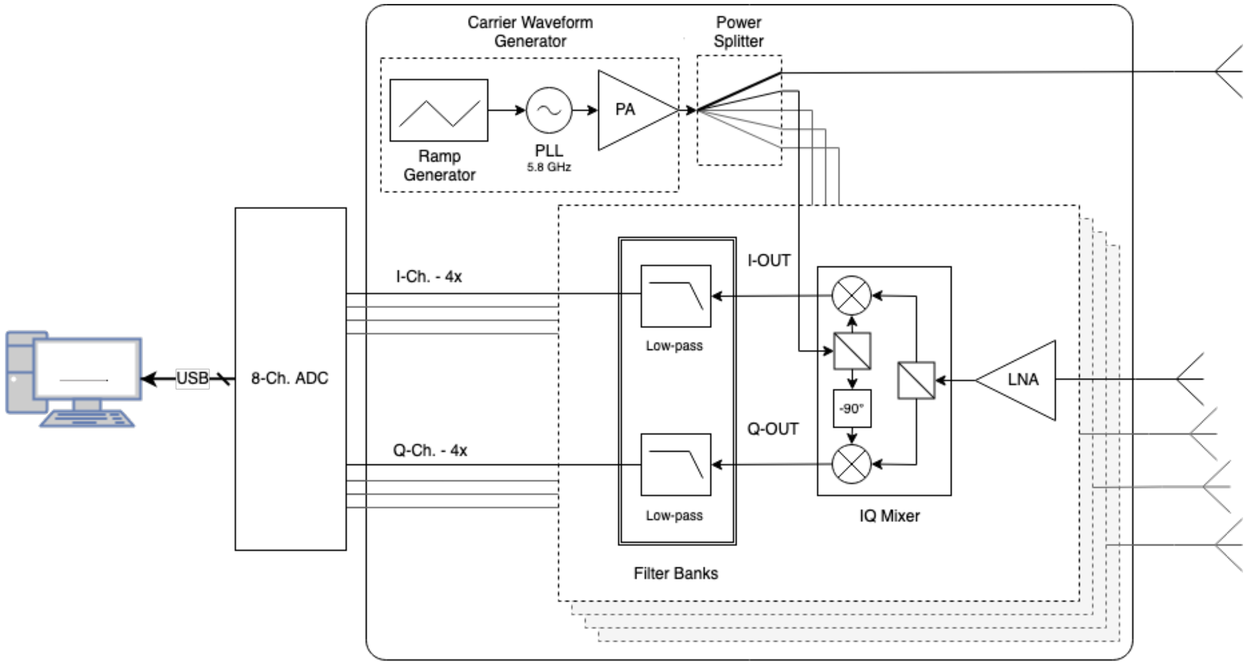
Algorithm overview



Radar System Design

Radar System – Architecture

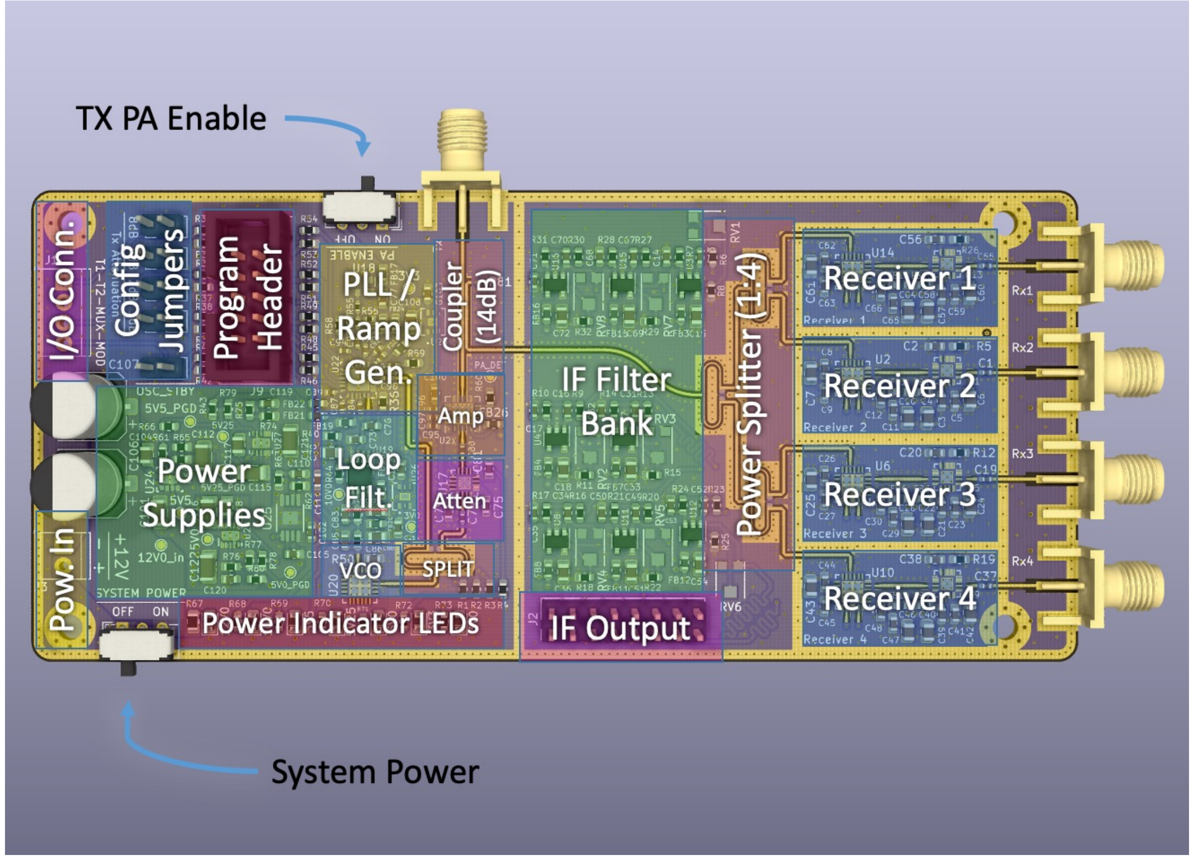
- Transmitter
  - TI LMX2491 PLL and Ramp Generator
  - Qorvo 32 dB Power Amplifier with variable attenuation
- Receiver – 4x
  - ADI 14.5 dB LNA
  - ADI Active IQ downconverter
  - Active IF filters
- Data Acquisition
  - Measurement computing USB-1608-Plus
    - 100 kSps 8-channel simultaneously sampling



Radar system schematic

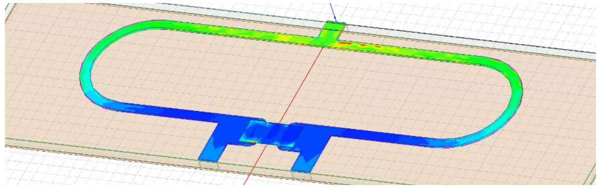
Radar System – Architecture

- Power
  - 10.8–13.2V Power Input
  - 10V, 5.5V, 5.25V, 5.0V, 3.3V, and 3.0V rails were required
  - Ferrites and decoupling capacitors were added to further isolate devices
- Noise Isolation
  - Board was sectioned by device sensitivity to noise and noise emission of device
  - Via fencing used to isolate sections
  - Via stitching used between multi-level ground planes

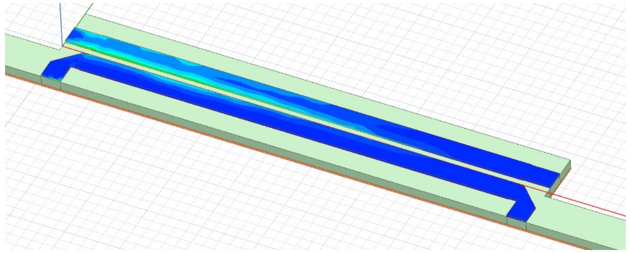


Radar System – Planar Elements

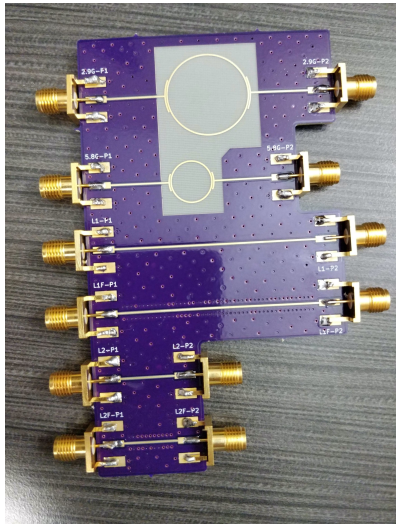
- 3 dB Wilkinson Divider
  - Used in:
    - PLL feedback and transmitter split
    - 1:4 splitter for IQ demodulator LO drive inputs
- 14 dB Coupled-line Coupler
  - Used in transmitter split into 1:4 splitter for LO drives
- SMA To Microstrip Transition
  - Initial test board showed ~10 dB loss at SMA transition
  - Coplanar to microstrip transition
    - Removed ground planes below pin
    - Achieved minimal reflection by optimizing the length and width of the spacing from the center conductor at the transition
      - Reduced transition loss from ~10 dB to ~0.3 dB



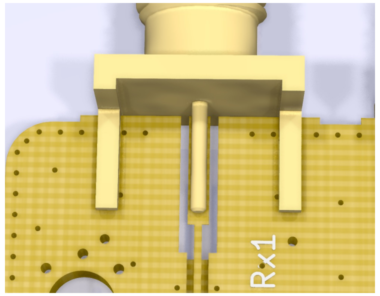
3 dB Wilkinson Divider



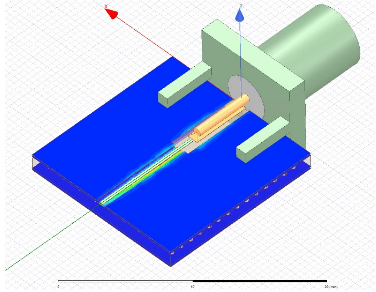
14 dB Coupler



Substrate Characterization Test Board

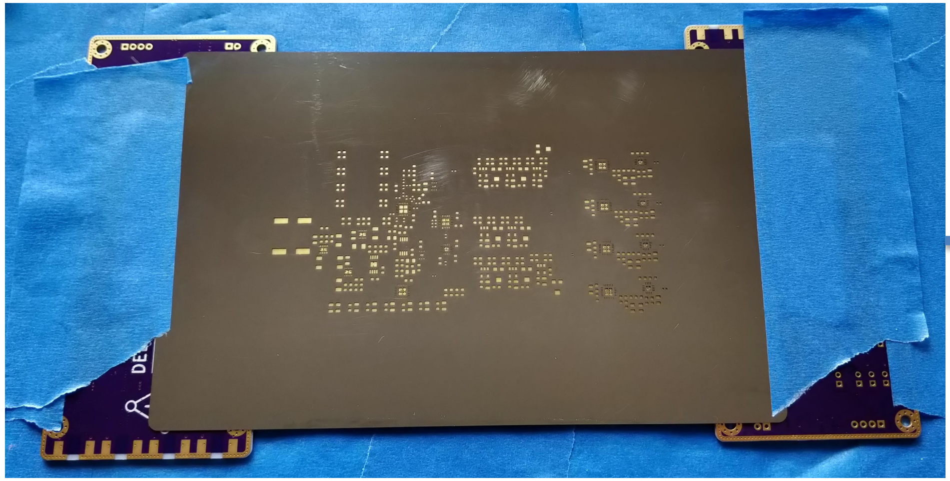


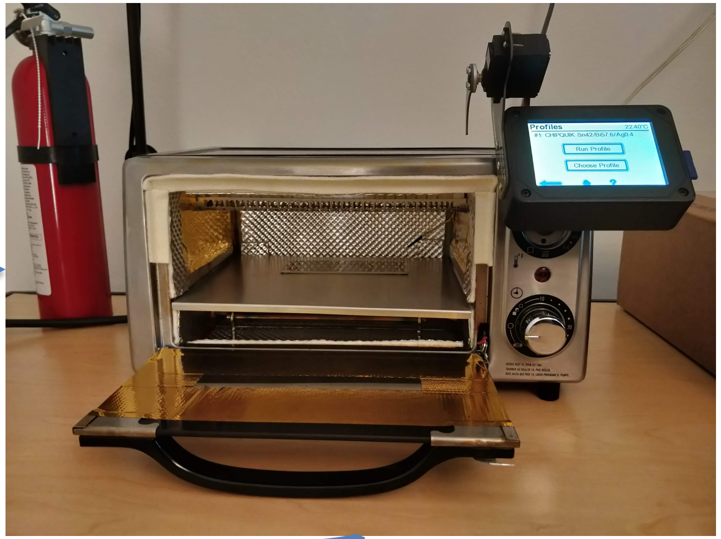
SMA To Microstrip Transition Render

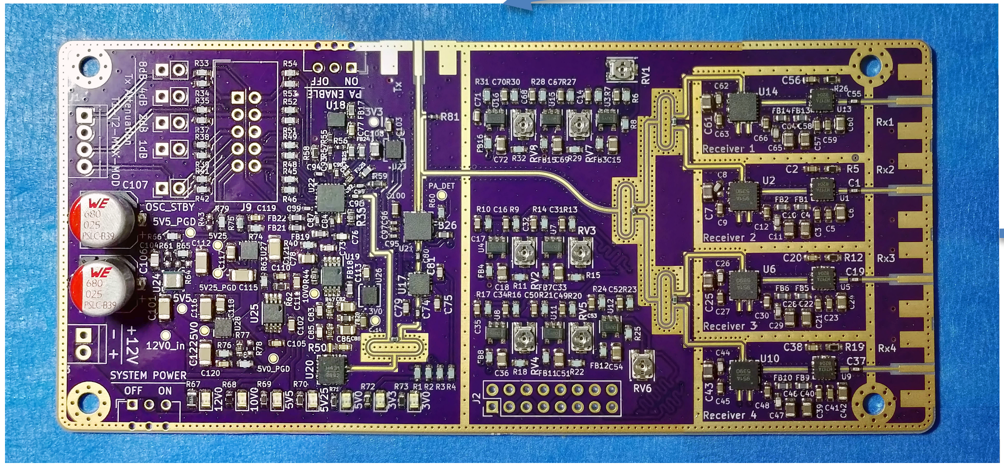


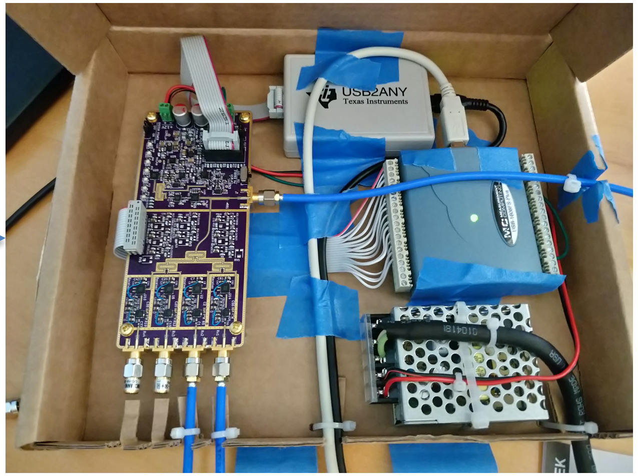
SMA To Microstrip Transition Simulation

Radar System – Assembly









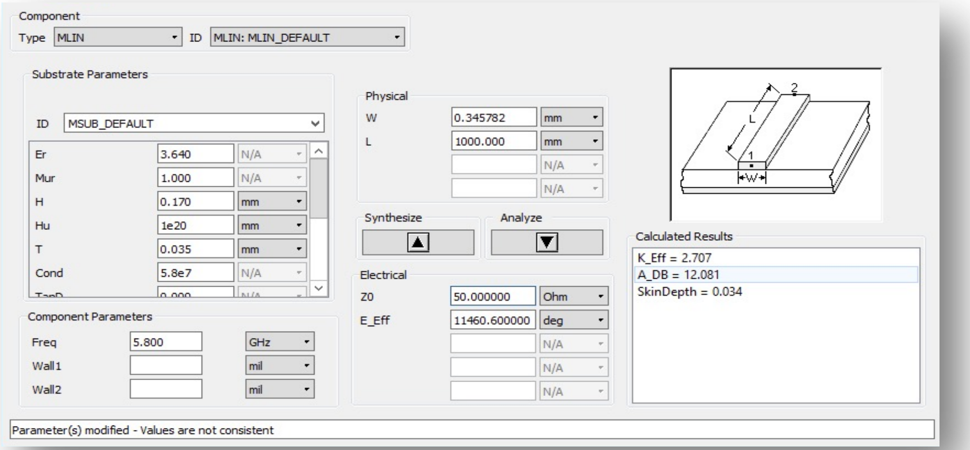
Antenna Design

Antenna Theory

- Antenna Dimensions[1]: $W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_R+1}{2}}}$; $\varepsilon_{eff} = \frac{\varepsilon_R+1}{2} + \frac{\varepsilon_R-1}{2}\left[\frac{1}{\sqrt{1+12(\frac{h}{W})}}\right]$

$$L = \frac{c}{2f_0\sqrt{\varepsilon_{eff}}} - .824h\left(\frac{(\varepsilon_{eff}+0.3)(\frac{W}{h}0.264)}{(\varepsilon_{eff}-.258)(\frac{W}{h}+0.8)}\right)$$

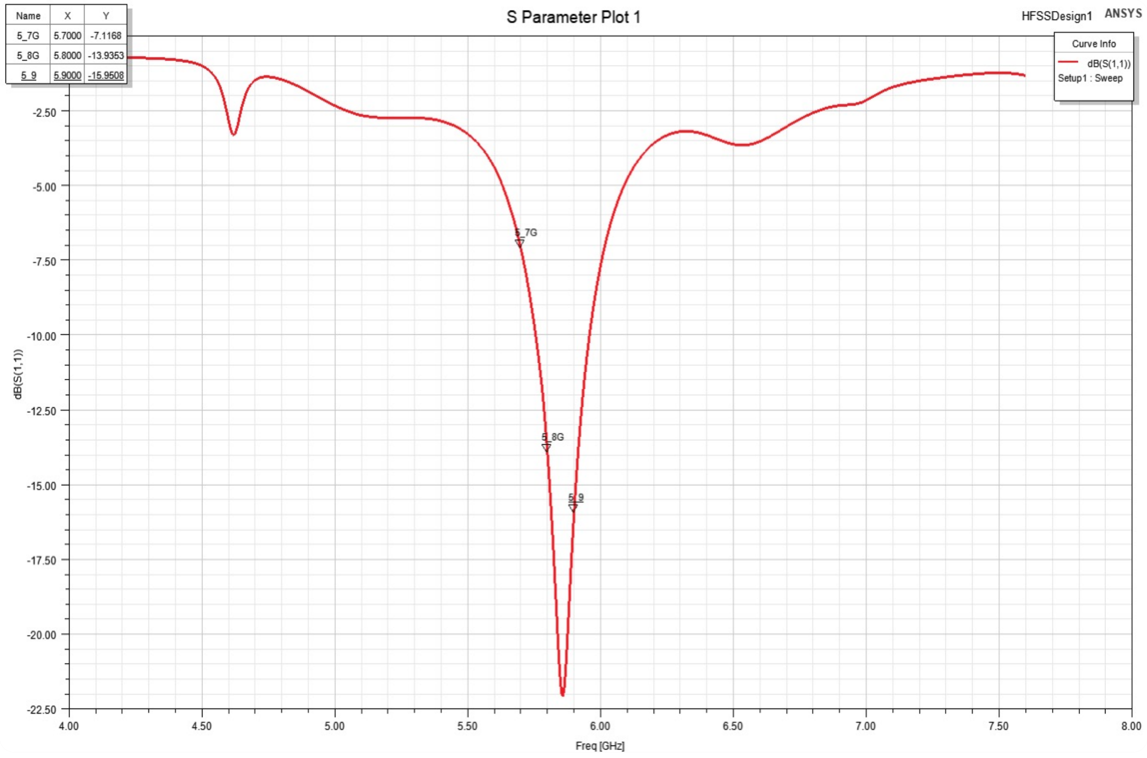
- Microstrip Dimensions: Calculated via LineCalc



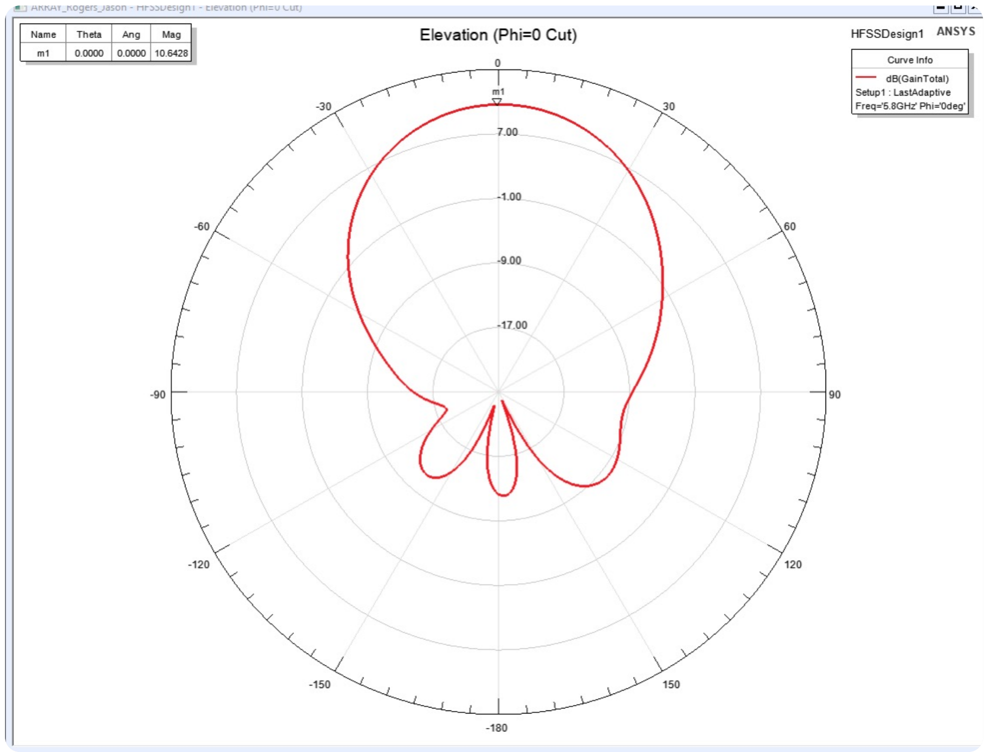
1. C. A. Balanis, Antenna theory: analysis and design. John wiley & sons, 2016.

2x2 Simulated Measurements

S11 Simulated

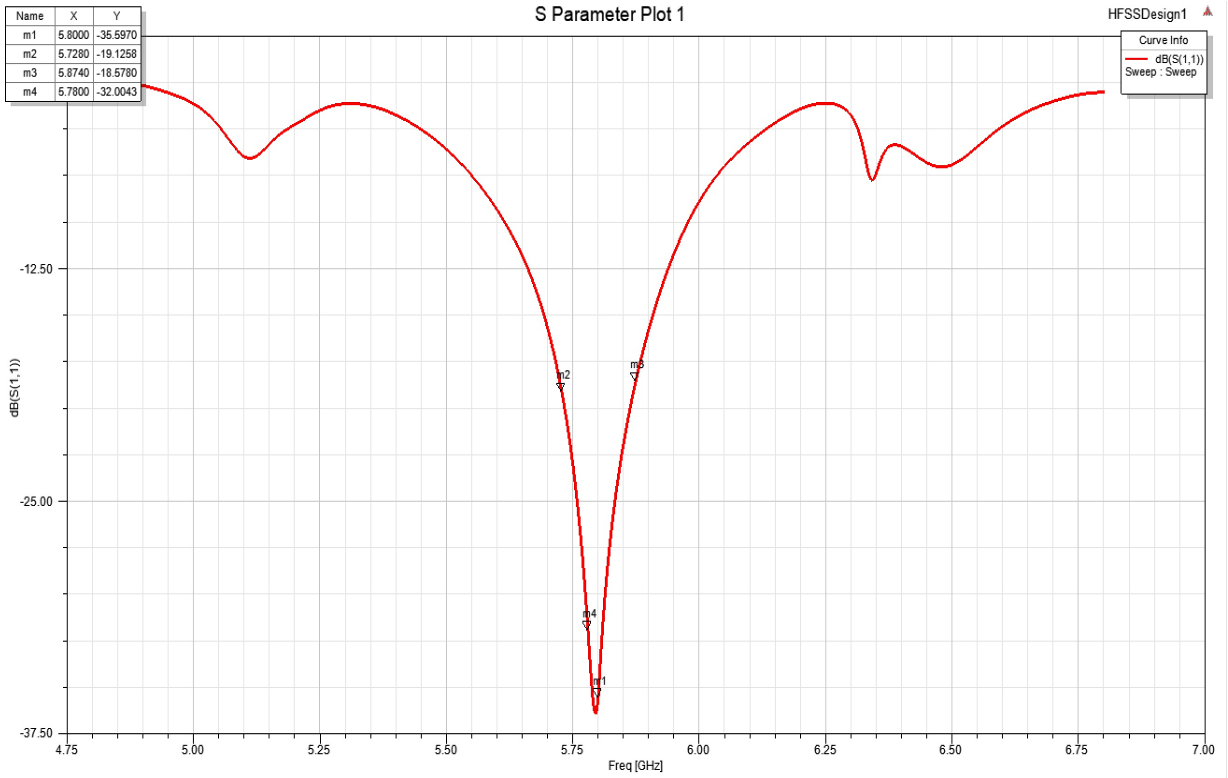


Gain Simulated

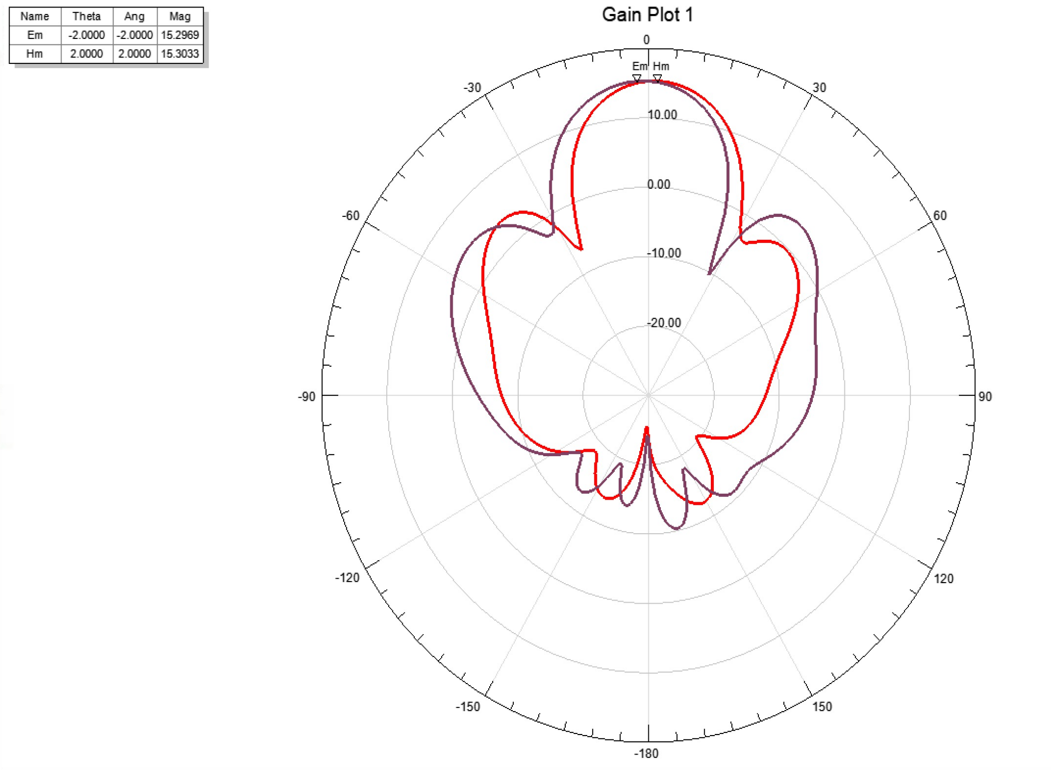


4x4 Simulated Measurements

S11 Simulated

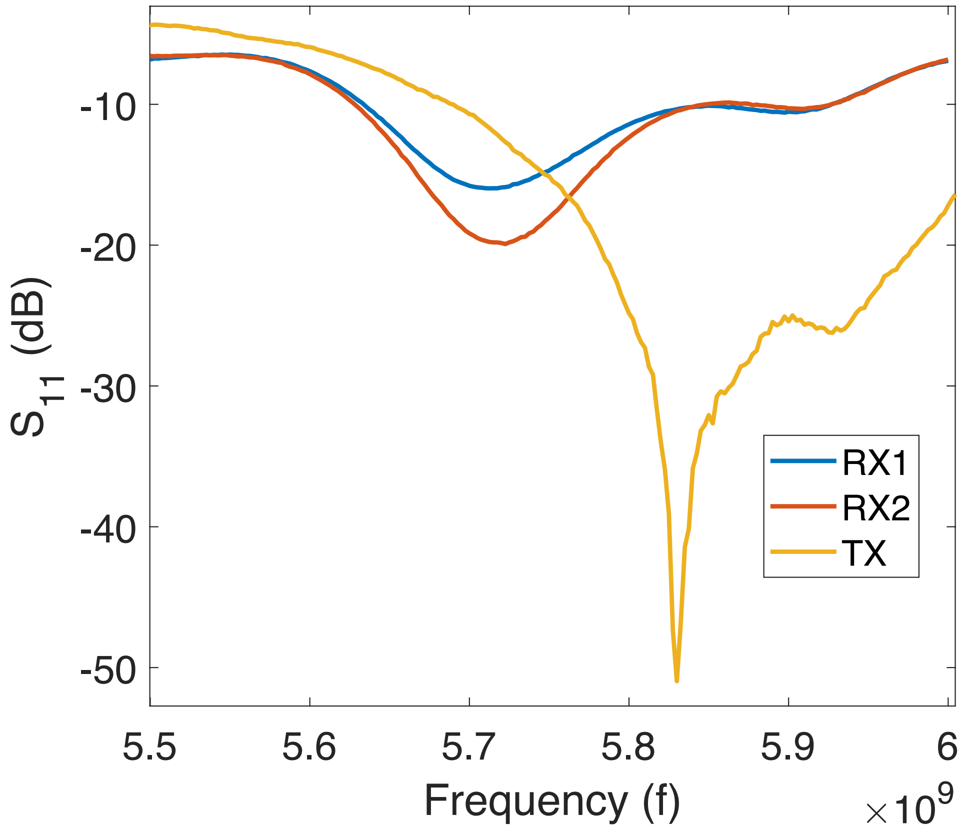


Gain Simulated

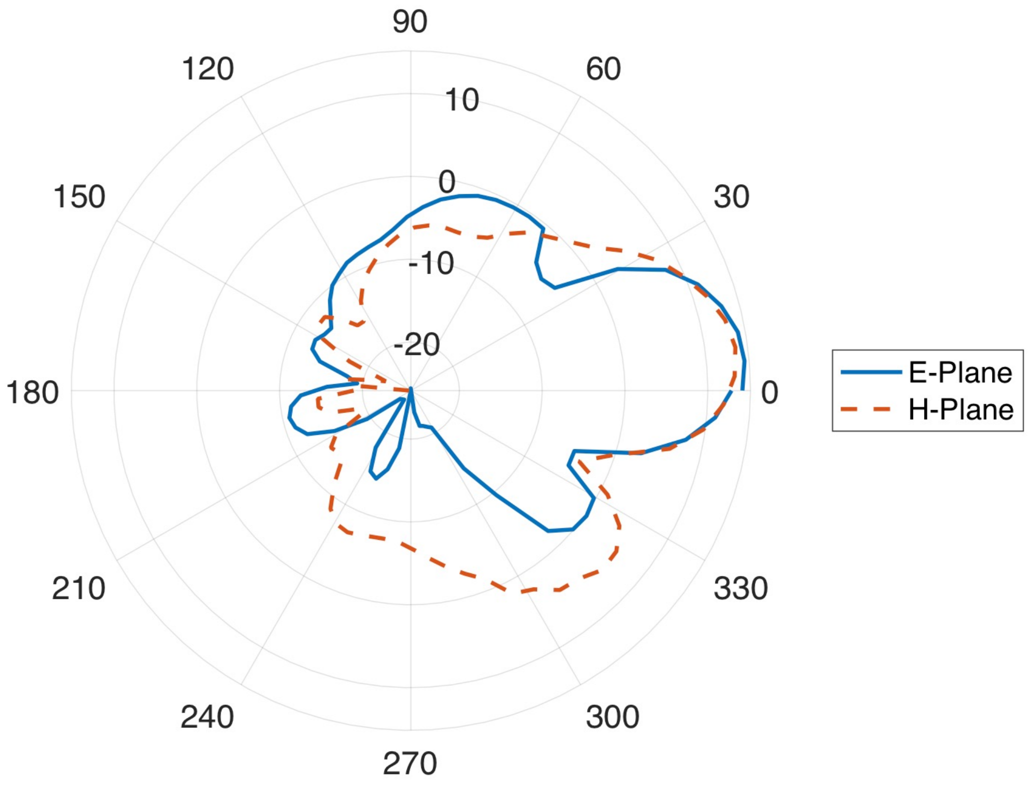


Measured S11 Response

Measured S11 for 2x2 and 4x4 Arrays

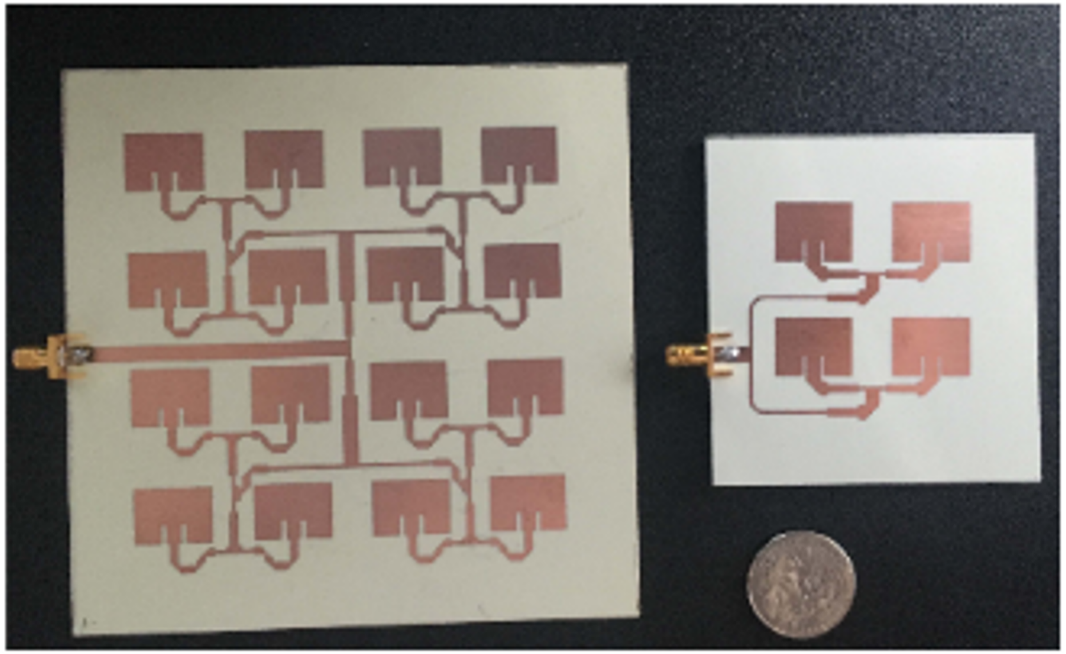


Measured 4x4 Array Gain

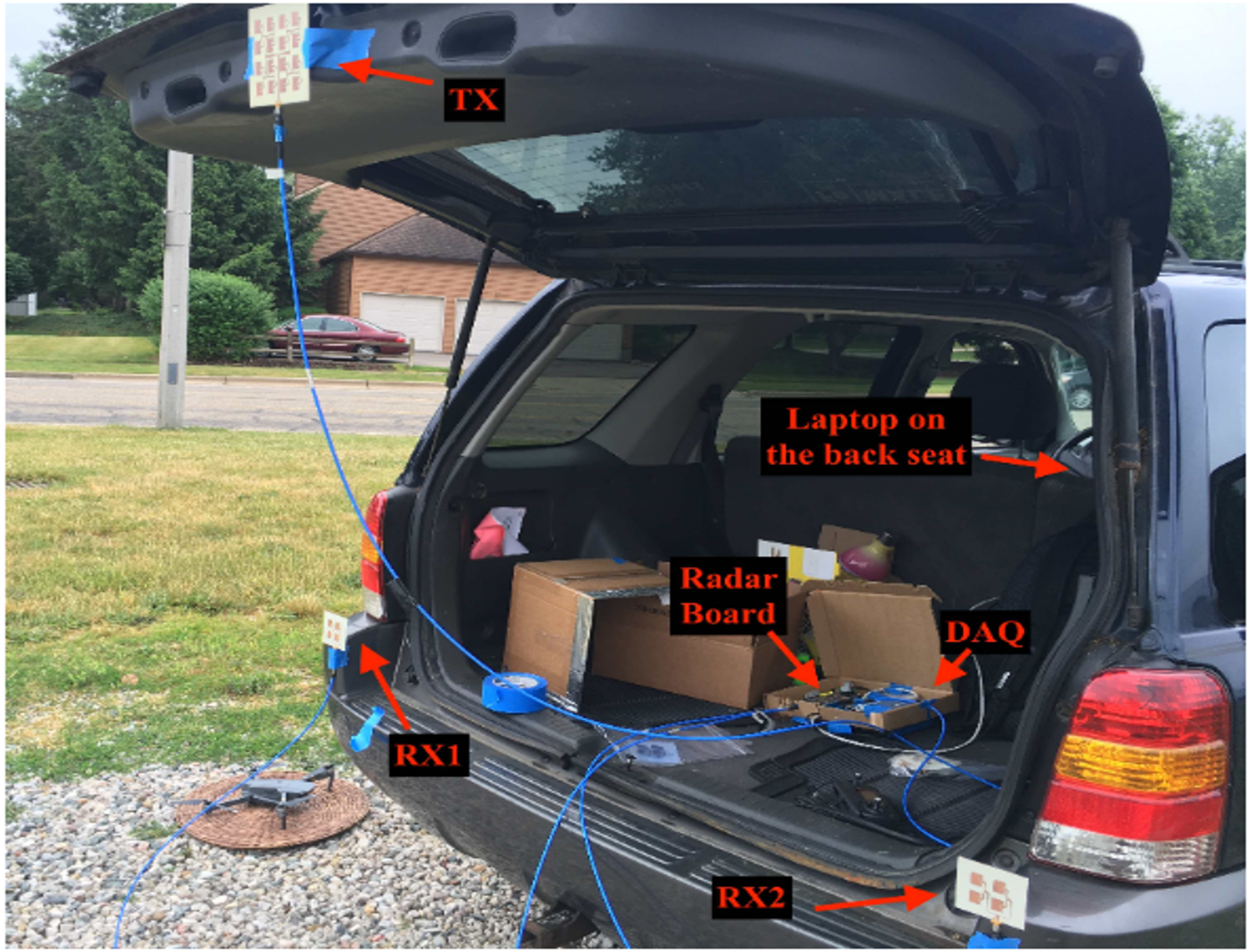


Manufactured Antennas

- Estimated 1.5% over-etching
  - Mask dilated to compensate
- Side feed employed to minimize coupling
- Feed line of 50Ω to100Ω branching with quarter-wave transformer network

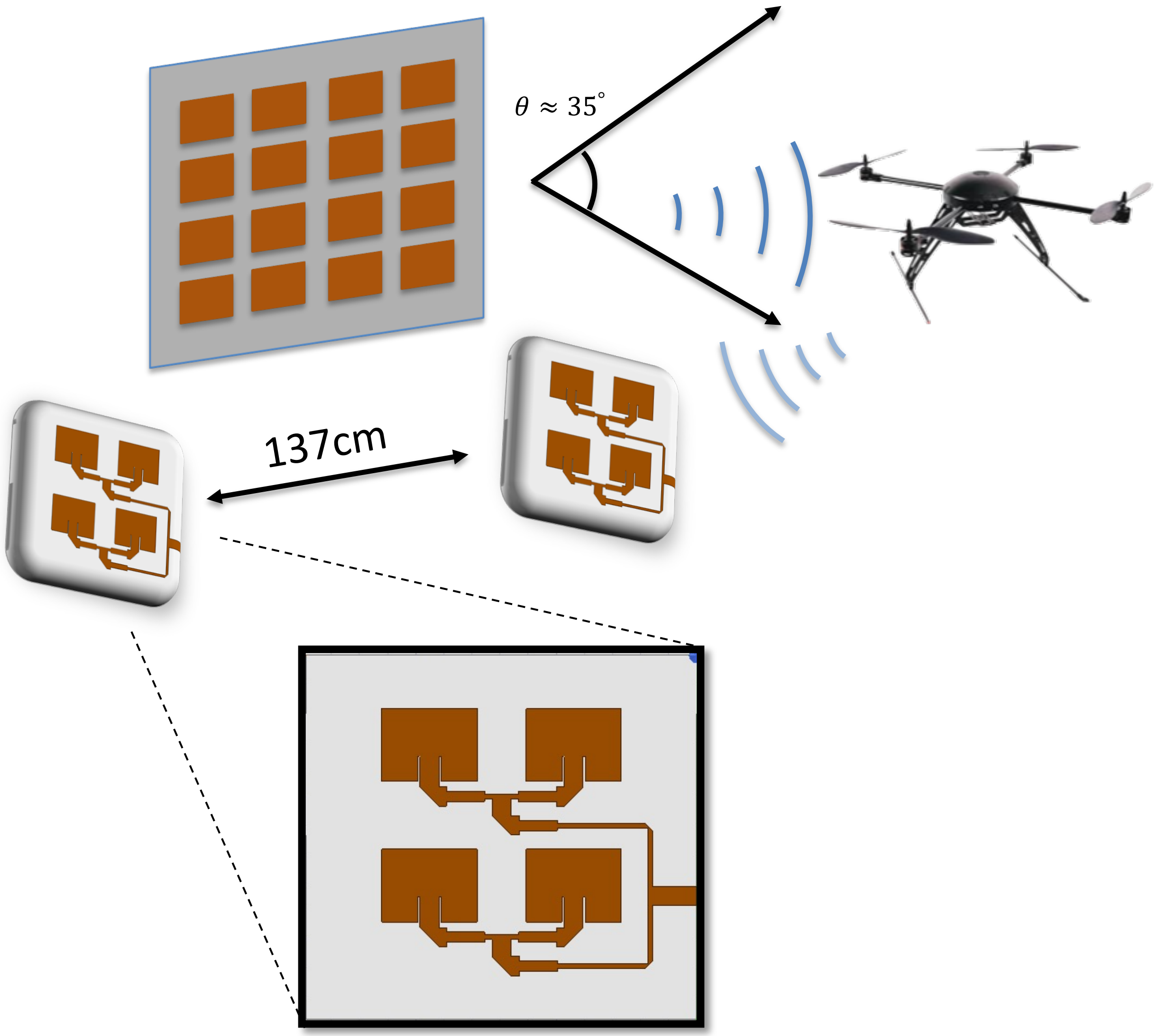


Radar Setup



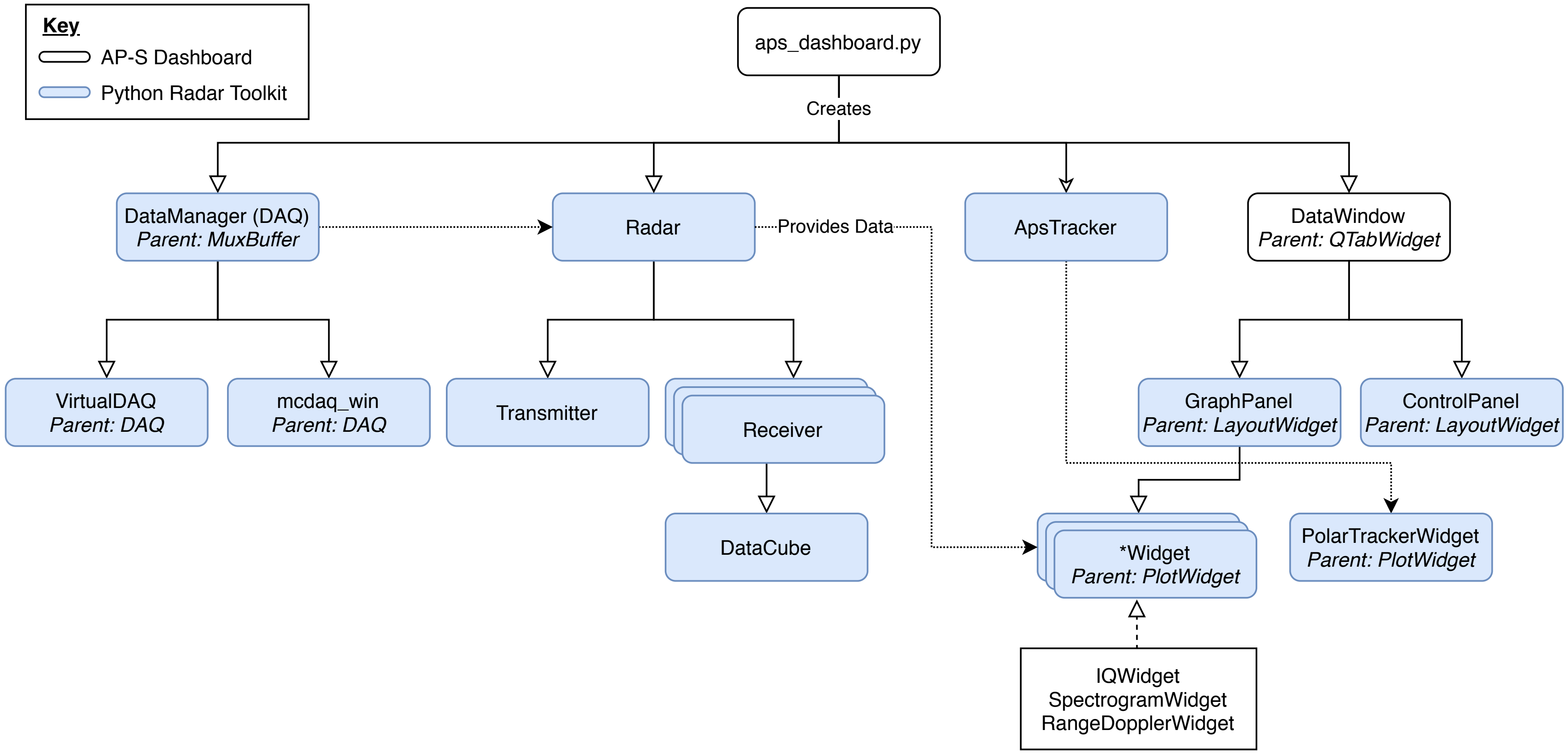
Antenna Application

- 4x4 array beamwidth estimated to be 30 degrees
- 2x2 array beamwidth estimated to be 60 degrees
- 4x4 array has more focused beamwidth compared to 2x2
  - Improves DoA range performance
  - Reduces DoA field of view



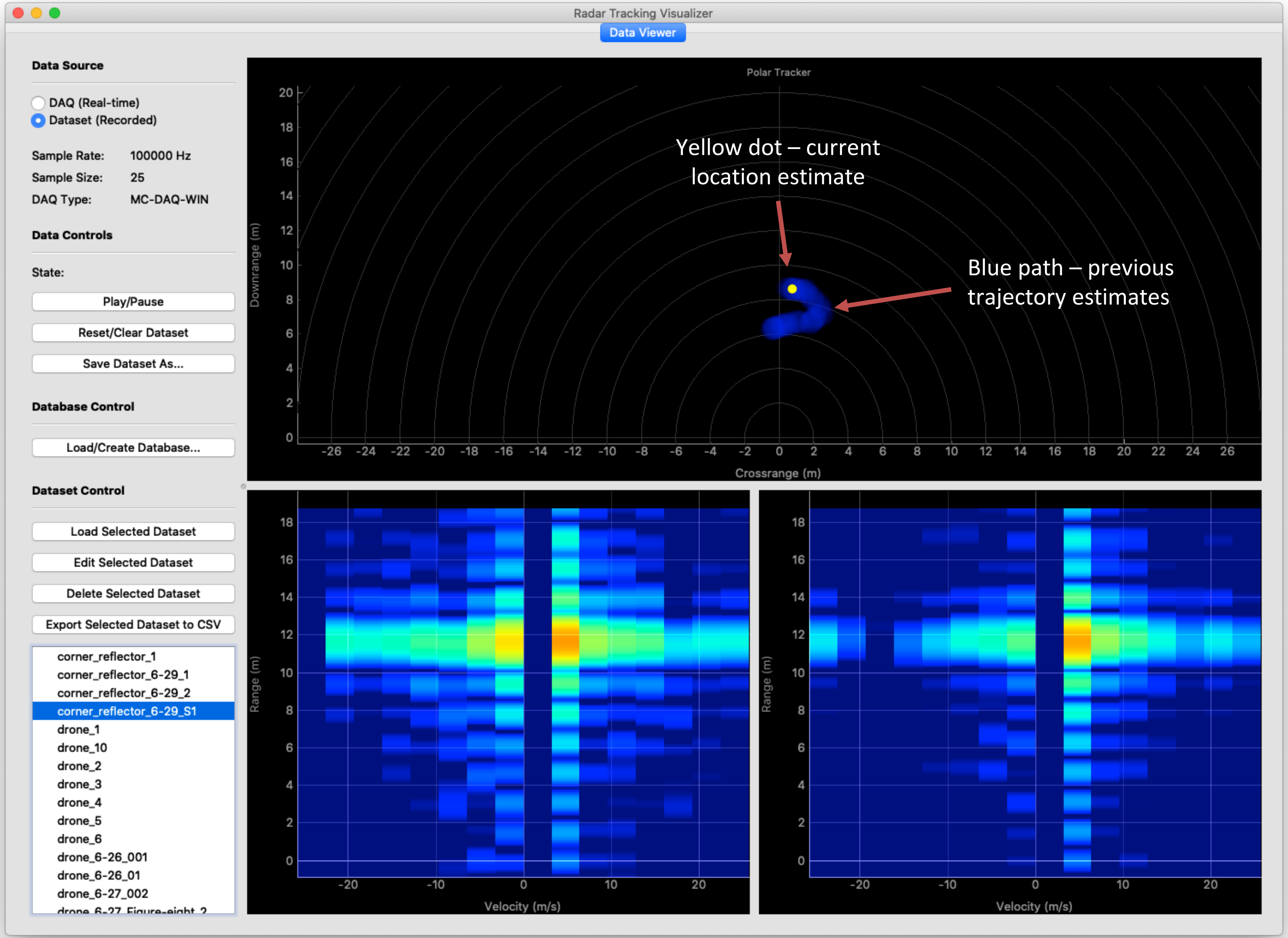
Software Implementation

AP-S Radar Dashboard – Software Architecture



DAQ settings and recording/playback controls

Save/load databases and datasets (recordings) + notes and labels for offline playback and processing



Polar localization and tracking visualization

Scaled range-Doppler plots from all channels active during recording

Experimental Results

Conclusions

All software and hardware for this project may be found at:

https://gitlab.msu.edu/delta/aps2020-competition