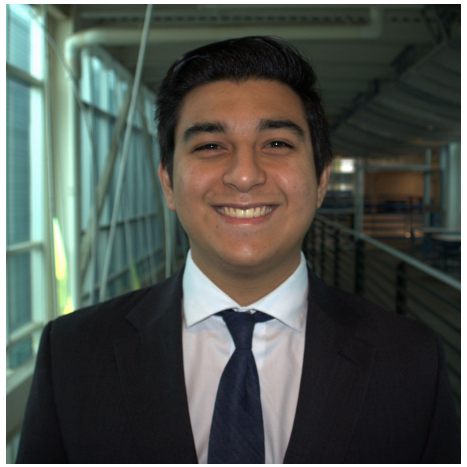
Digital Beamsteering Phased Array

Team 311
Sponsor: L3Harris
April 7th, 2022

Team Introductions

Katheryn Potemken
Antenna Lead

Tiernen Pan
Team Lead / Software Engineer



Christian Balos
Software Engineer

William Snyder
Hardware Engineer

Andrew Cayson
Hardware Lead

Sponsor, Advisors, and Assisting Instructor

Assisting Instructor:
Dr. Arigong

Advisor:
Dr. Uwe Meyer-Baese

Customer:
Dr. Hooker

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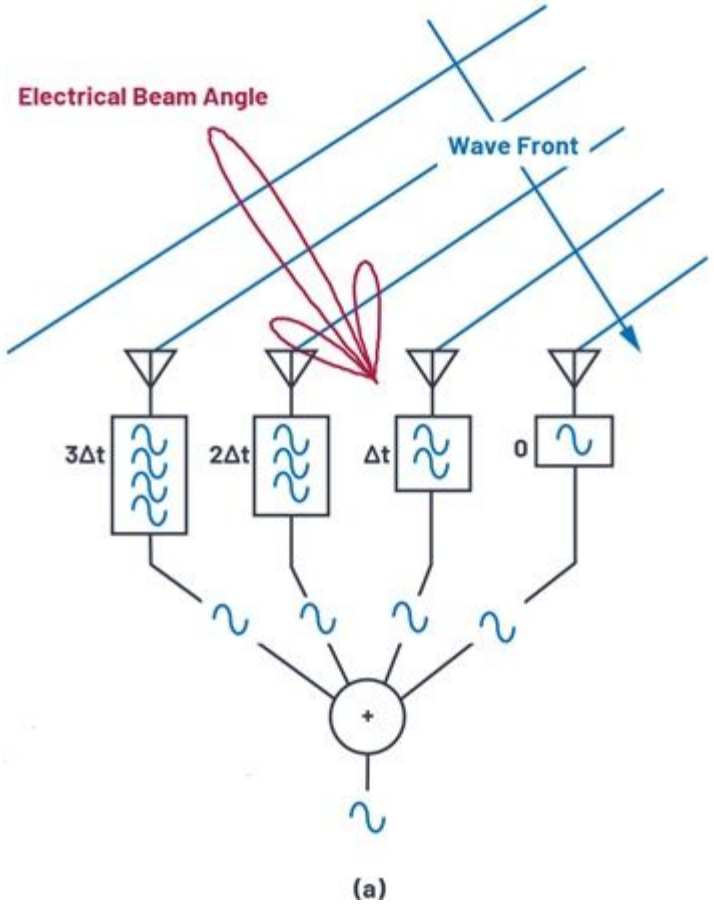
Sponsor:
L3Harris

Outline

- Project Background
- Design Components
  - Software Design
  - PCB Design
  - System Design
- System Results
  - Intermediate Testing
  - Hardware Assembly
  - Final Testing

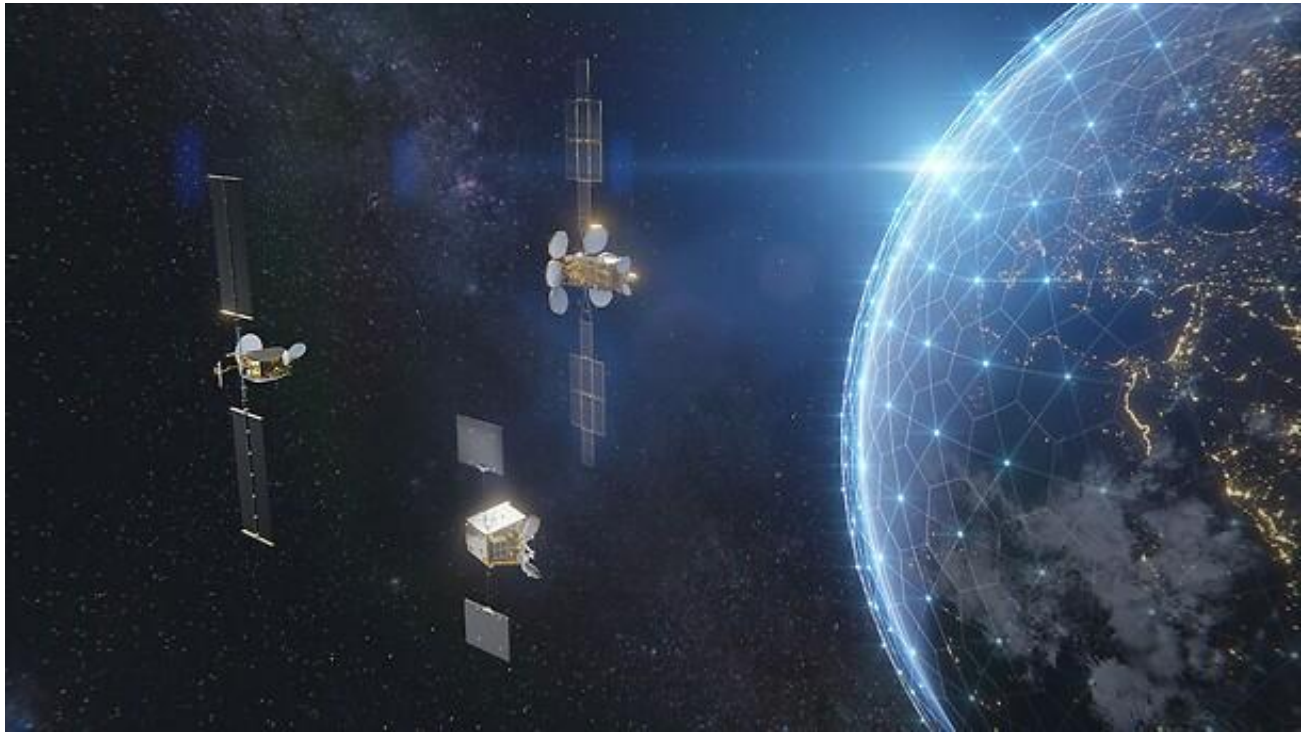
What is Beam Steering?

- What is Beam Steering?
  - Beam Steering is the usage of phase shifting within an antenna array to control the direction of the main lobe
  - This main lobe consists of each antenna's output constructively interfering with one another
- Why do we need Beam Steering?
  - The motivation for beam steering is the need for higher data transmission rates
  - Higher quality signal to receivers, with less errors



Market

- Civilian
  - 5G communications
  - Satellite to Ground Communications
- Military
  - Improving speed and range of Radar Systems

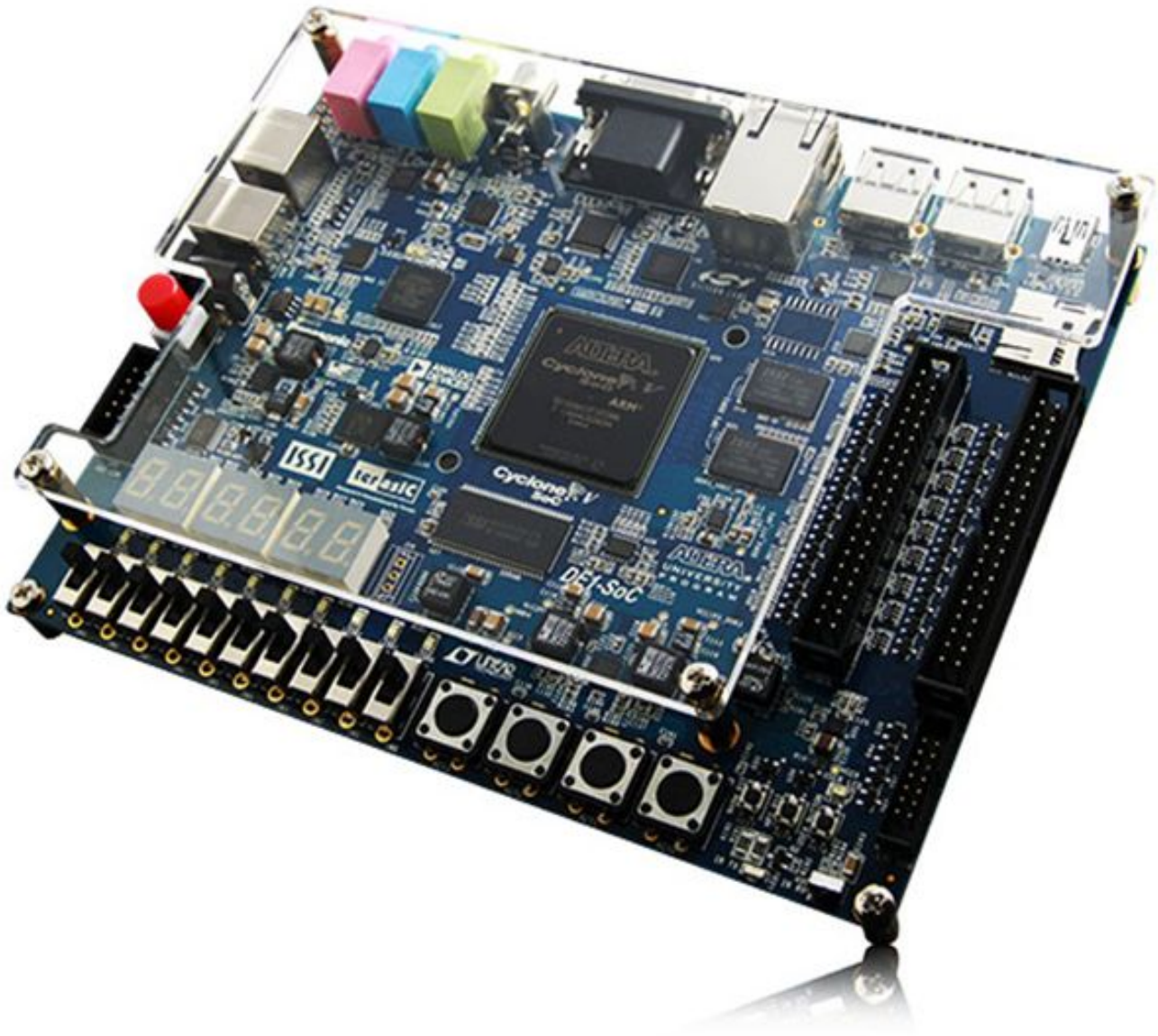


Project Specifications

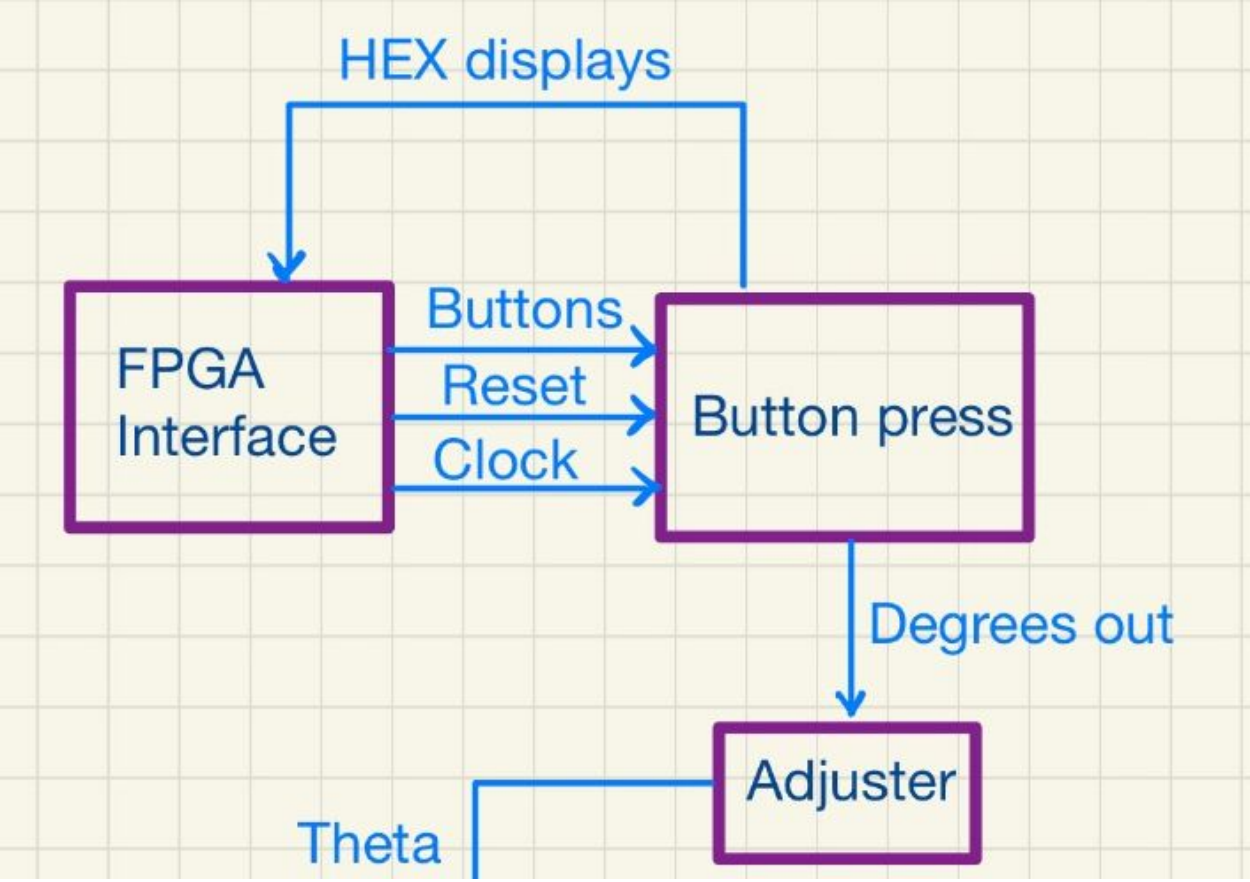
- Operate at 2.4 GHz, which is within the ISM band
- Project parts include:
  - Upconverters
  - 4 Antennas
  - FPGA
  - Direct Digital Synthesis (DDS)
  - PCB
  - Voltage Controlled Oscillators
  - Amplifiers

FPGA Interface

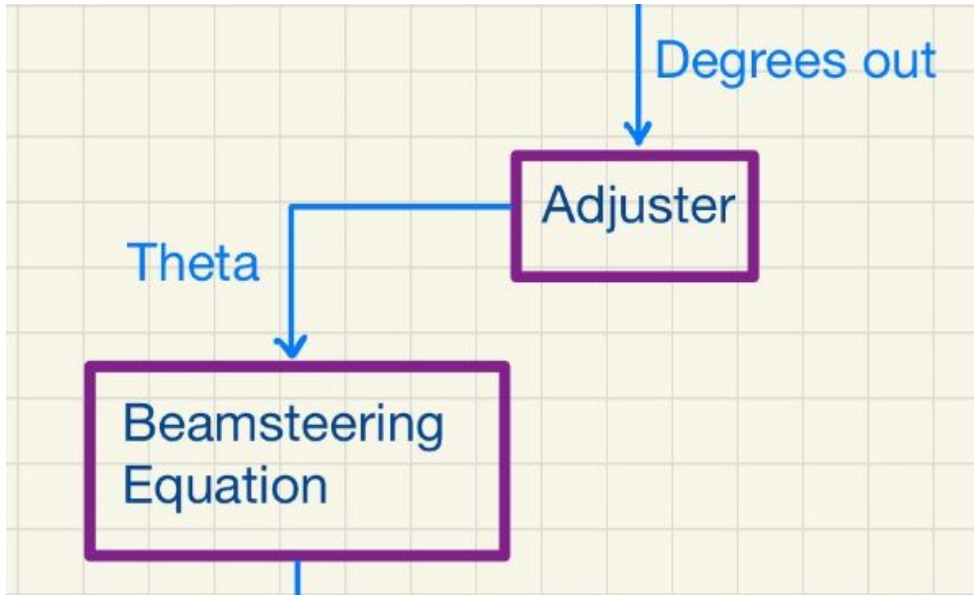
- Push Buttons and 1 switch
- HEX display

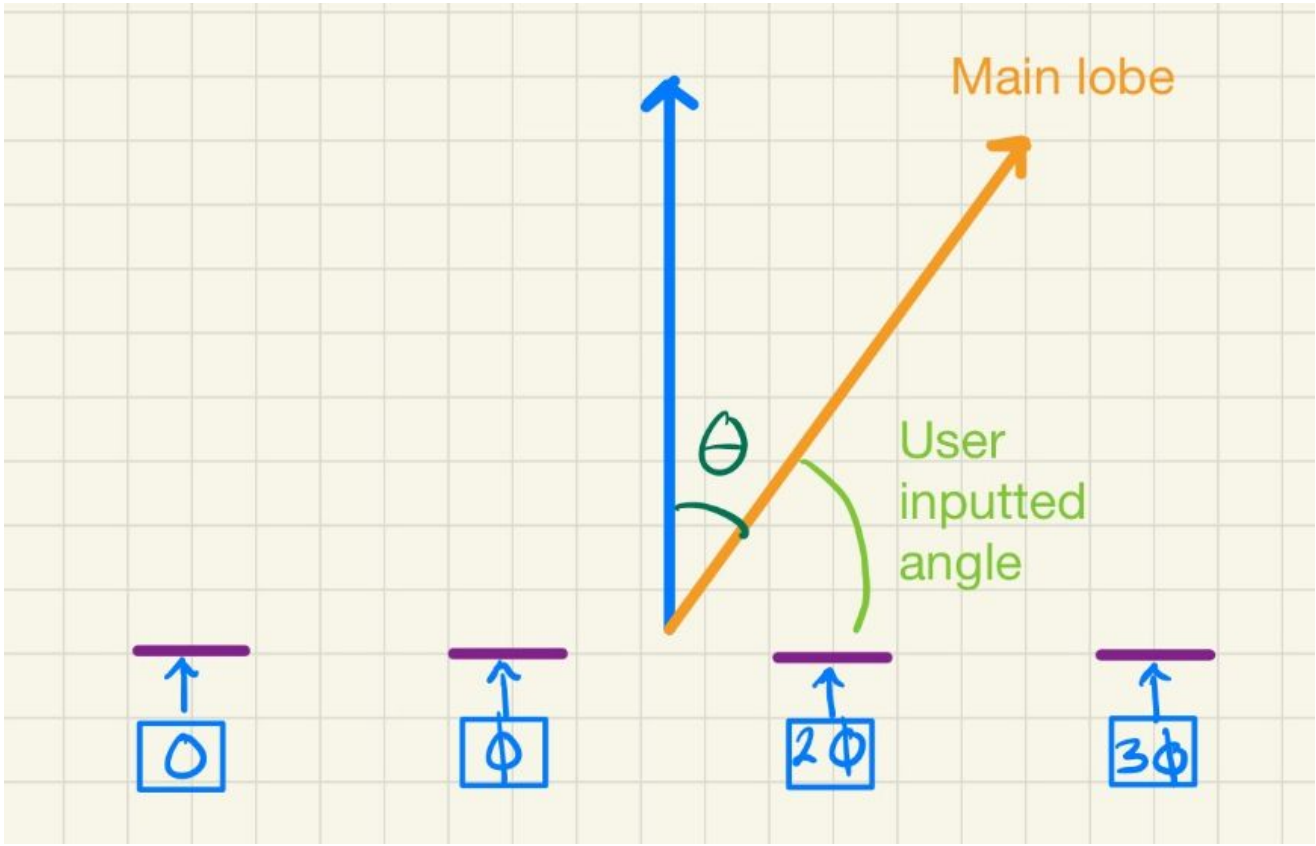


Button Press Component

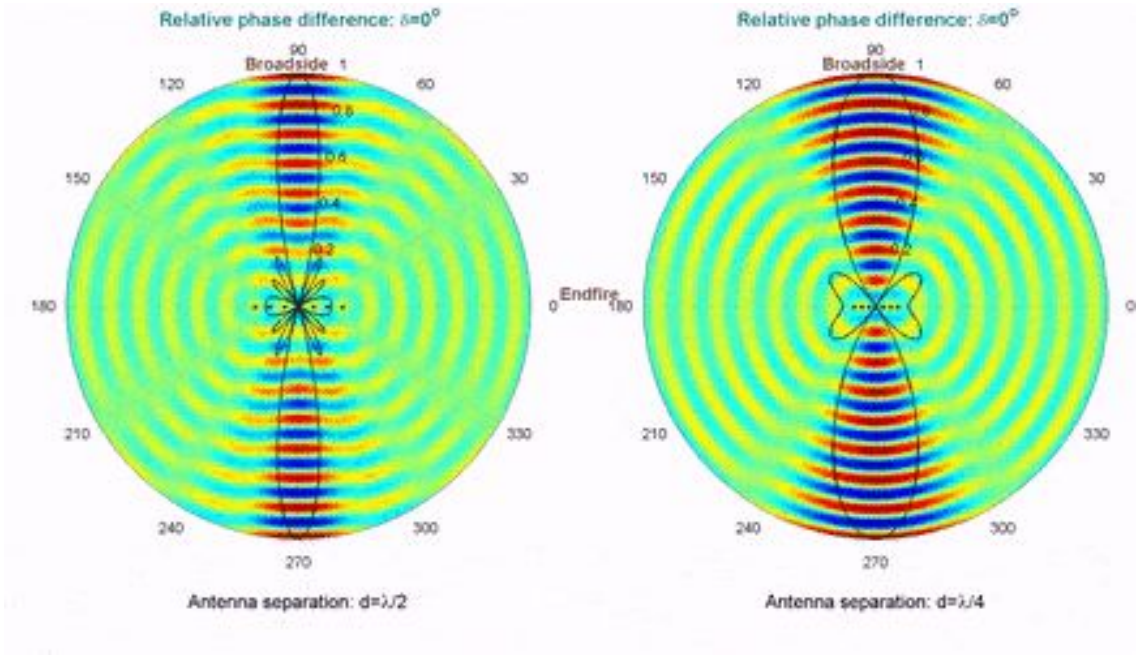


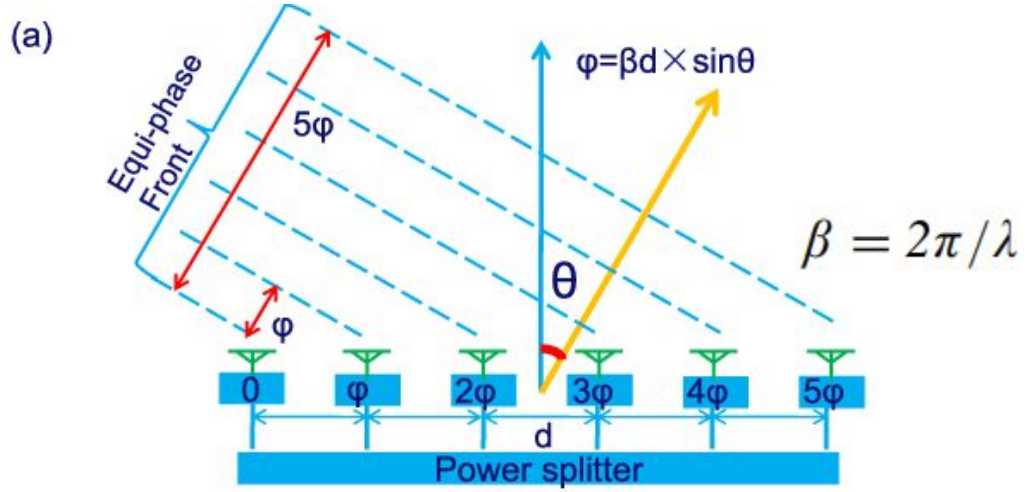
Adjuster Component





Implementing the Beamsteering Equation





$$\beta = 2\pi/\lambda$$

$$d = \frac{\lambda}{2}$$

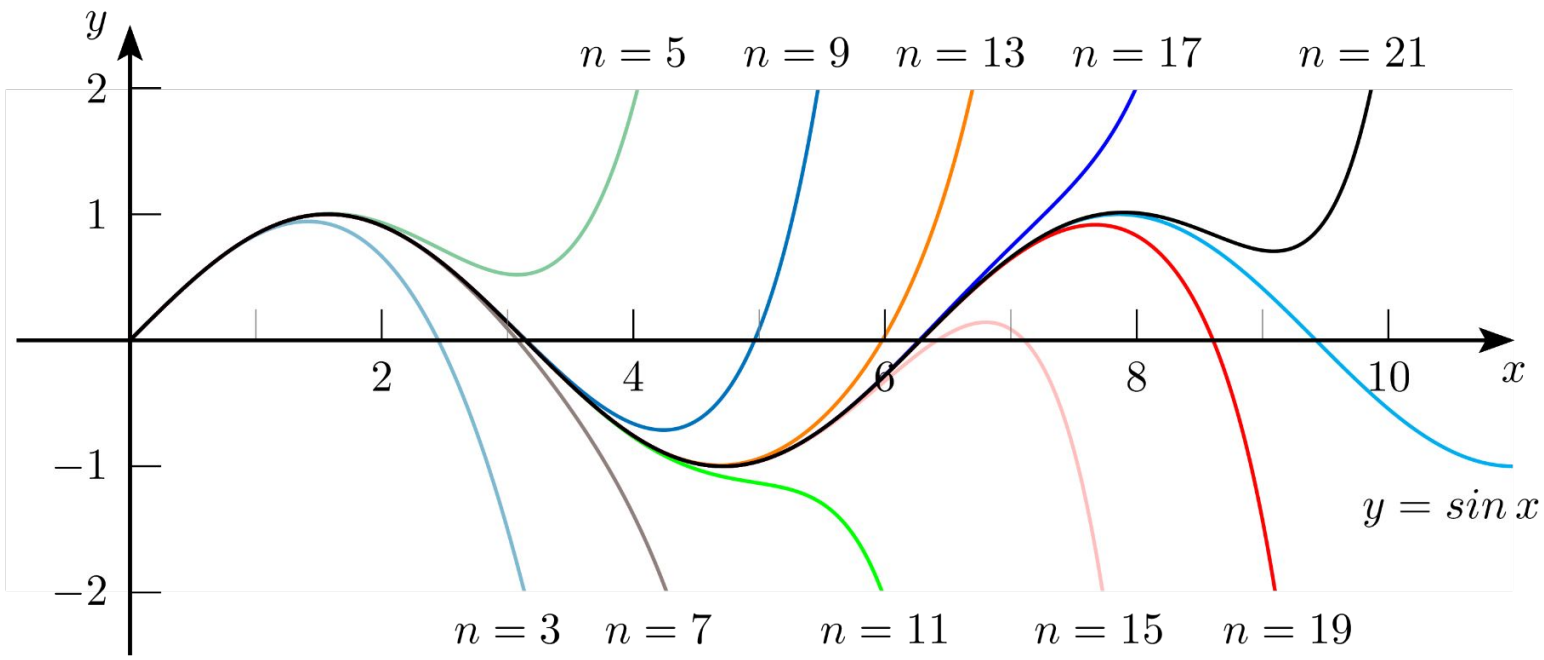
$$\phi = \frac{2\pi}{\lambda} d \times \sin(\theta)$$

$$\phi = \frac{2\pi}{\lambda}\frac{\lambda}{2} \times \sin(\theta) \rightarrow \phi = \pi \times \sin(\theta)$$

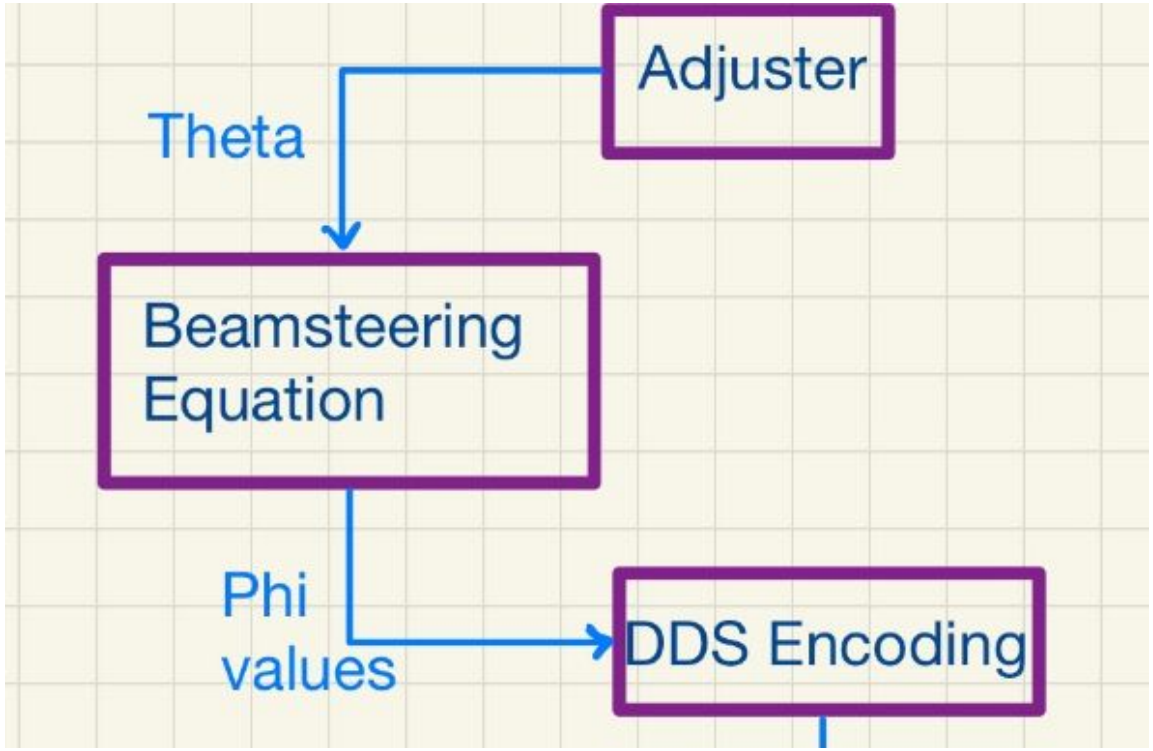
Taylor Series to Implement the Sine Function

$$\sin(x) = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \cdots$$

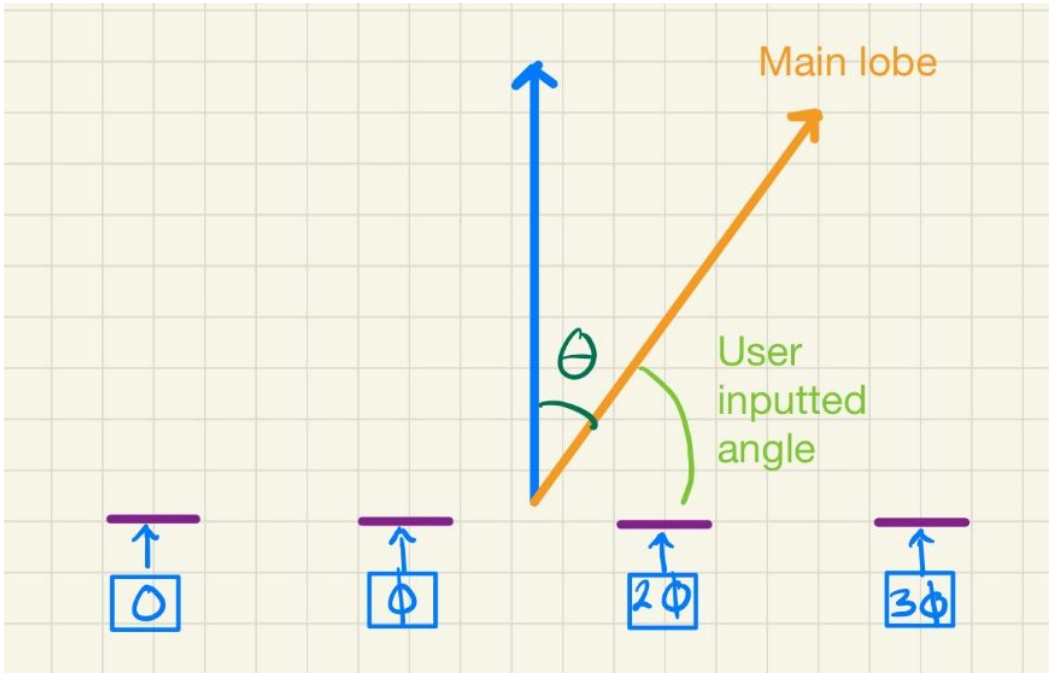
$$= \sum_{n=0}^{\infty} \frac{(-1)^n}{(2n+1)!} x^{2n+1}$$



Beamsteering Equation Component

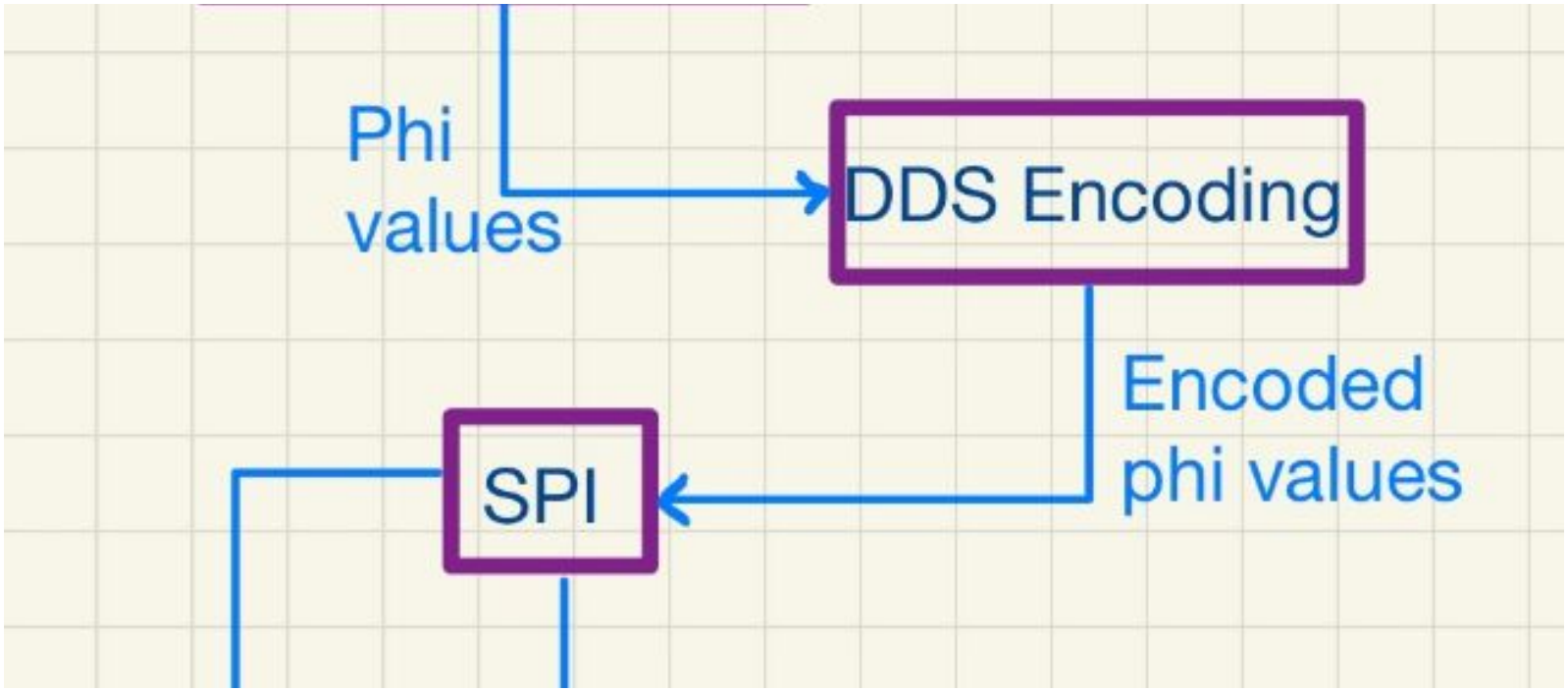


$$\phi = \pi \times \sin(\theta)$$

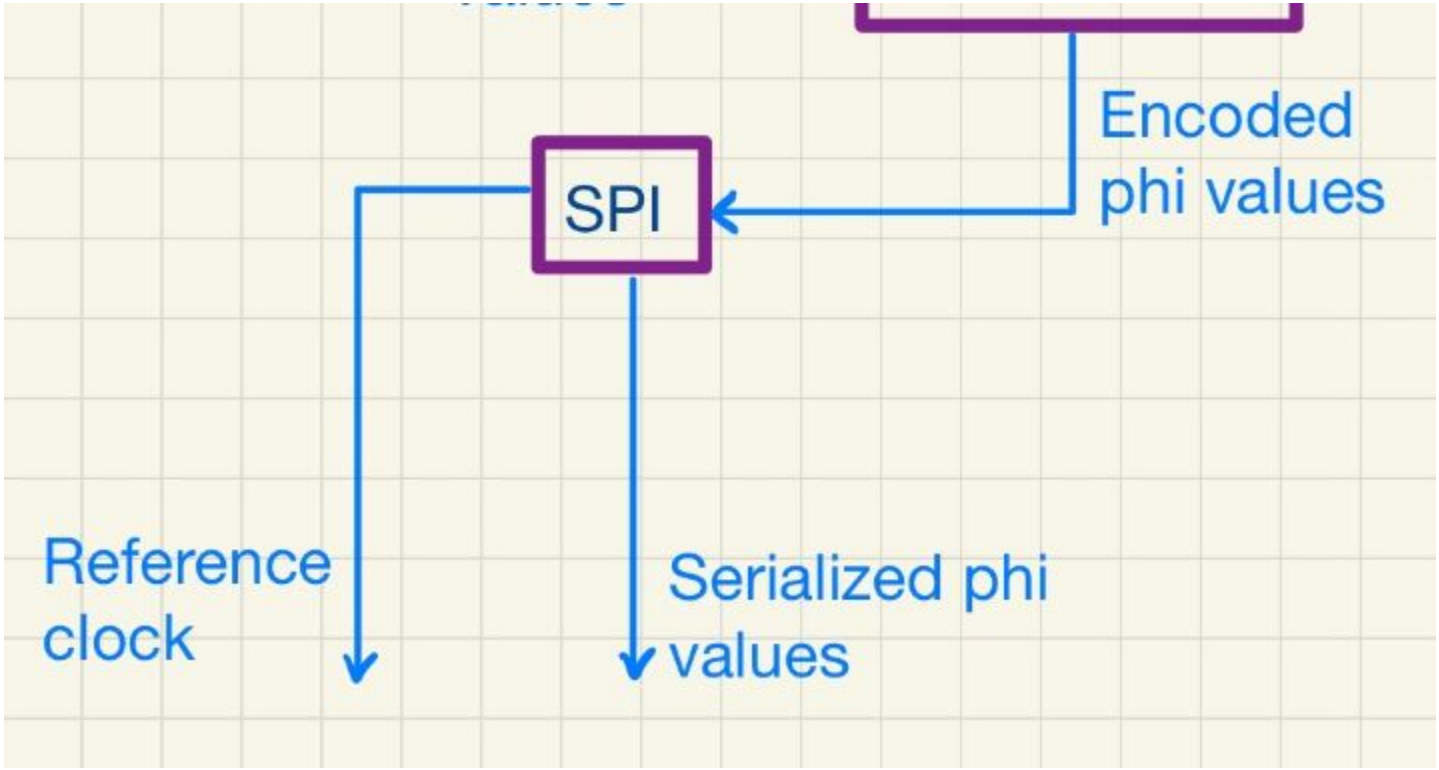


DDS Encoder Block

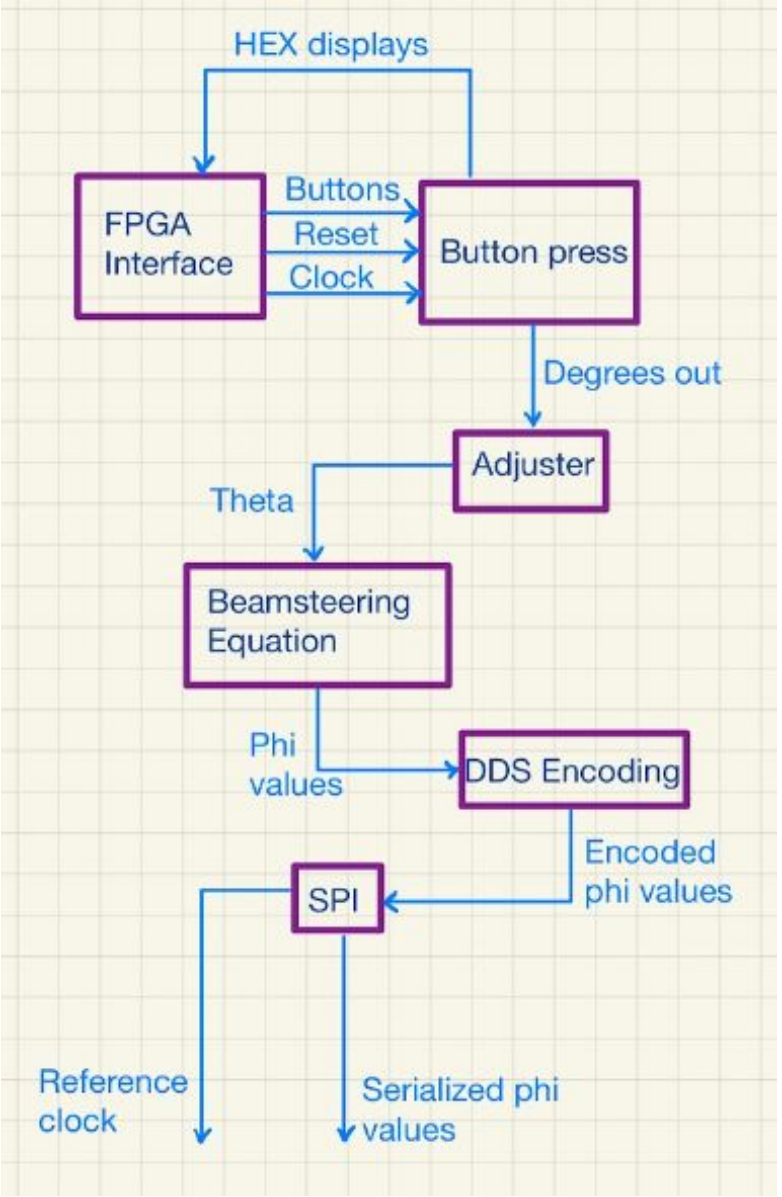
- Has a resolution of 0.02197 *degrees*
  - 0 = 0, 1 = 0.02197, 10 = 2 x 0.02197, 11 = 3 x 0.02197



SPI block

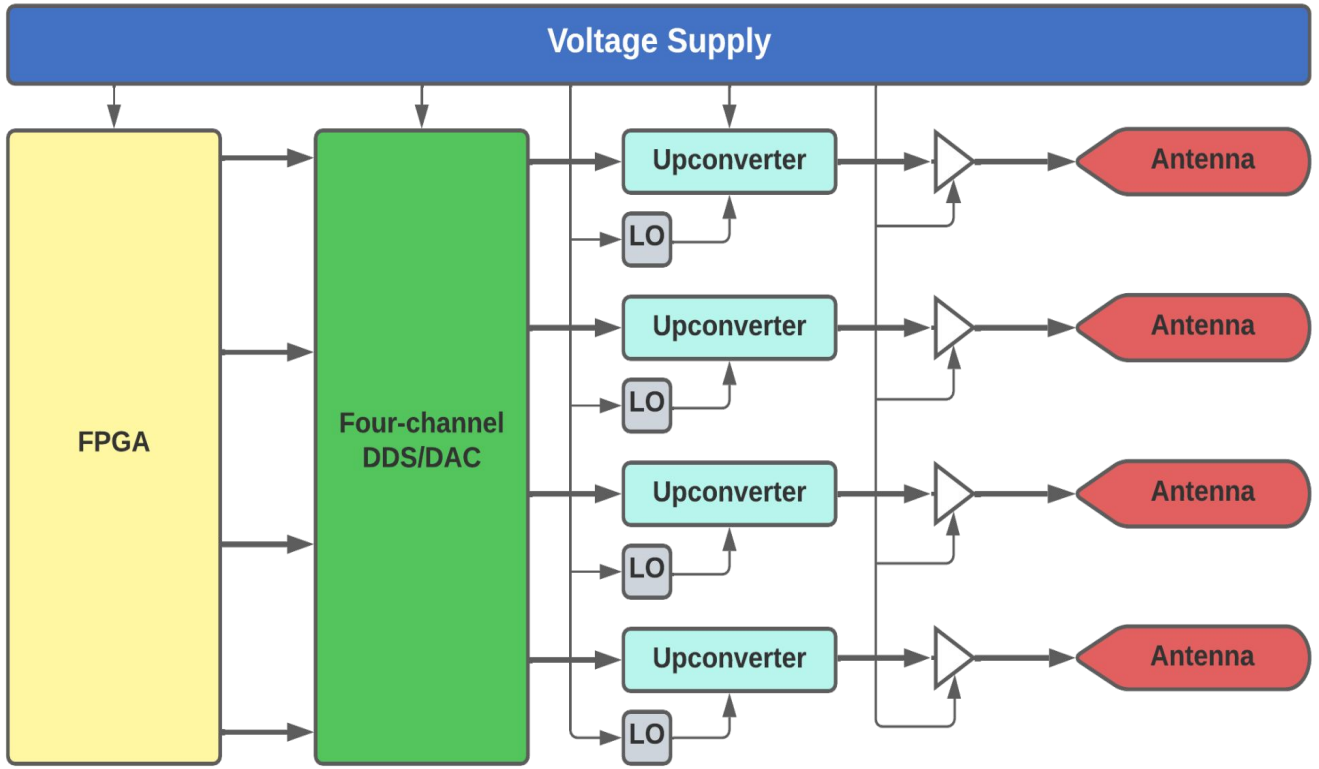

Encoded
phi values
SPI
Reference
clock
Serialized phi
values

Full Block Diagram



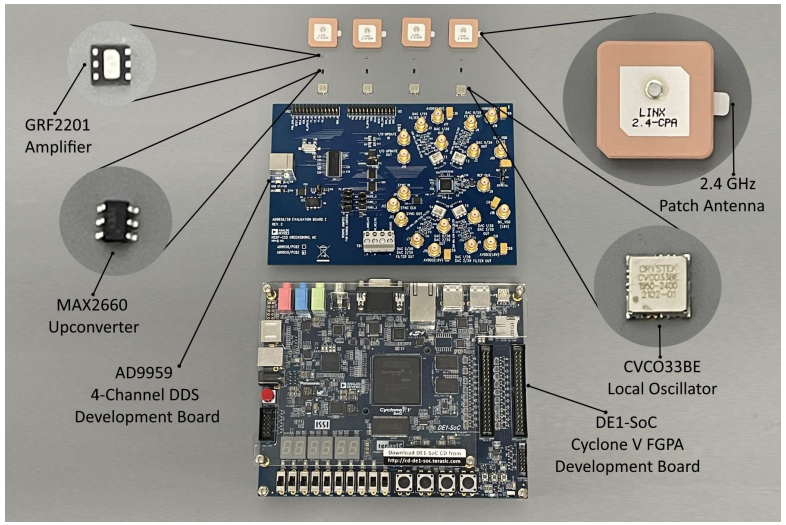
System Design

- Buttons on the Cyclone V serve as inputs for the array's desired beam angle
- The FPGA communicates with the DDS via SPI
- The DDS converts the signal from Digital to Analog and adjusts the phase as necessary.
- Finally, the analog signal will be upconverted to 2.4 GHz and will be transmitted via antenna.



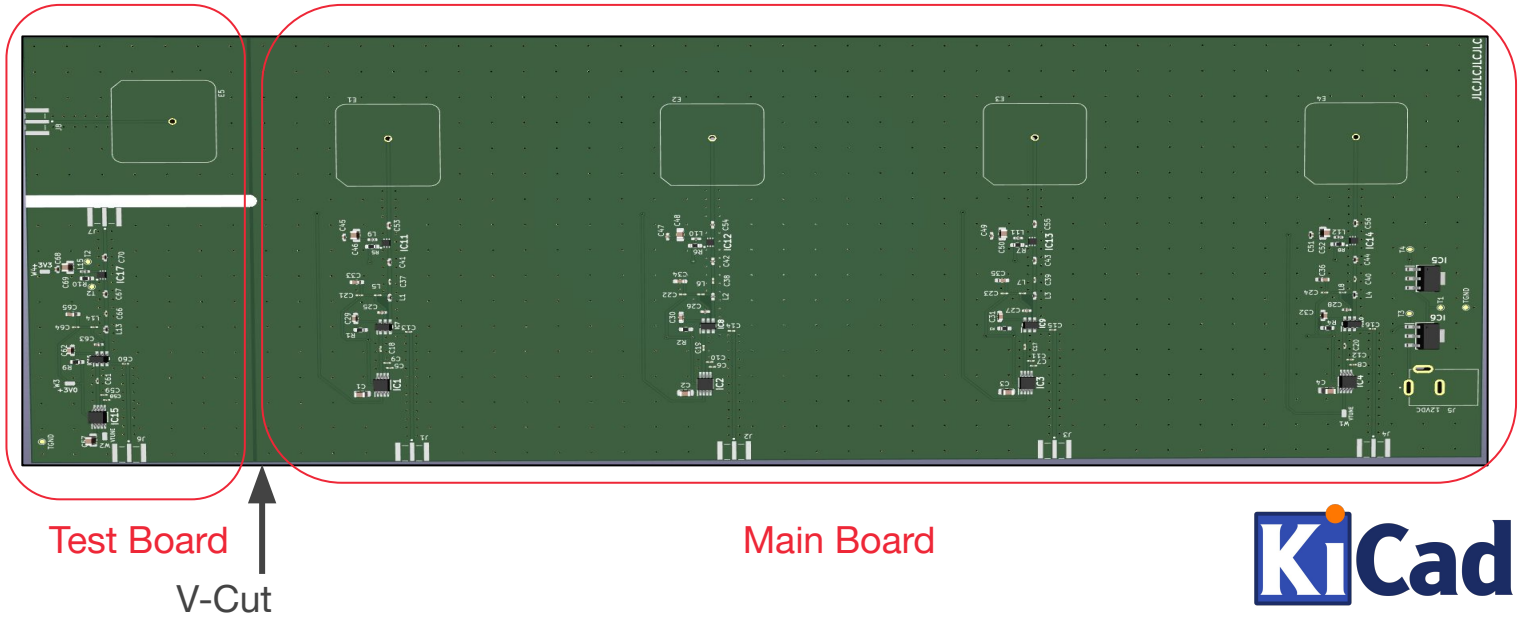
Components Design

- AD9959 generates a 200.5 MHz signal and adjusts the phase difference on each of the four channels.
- Each channel contains an oscillator, upconverter, and amplifier.
- Amplifier output is connected to 2.4 GHz patch antenna.
- Oscillator generates a 2.2 GHz signal and mixes with the 200.5 MHz signal to create the 2.4 GHz signal.
  - $\cos(2.2 \times 10^9) \cdot \cos(200.5 \times 10^6) = \frac{1}{2}(\cos(2.45 \times 10^9) + \cos(2.05 \times 10^9))$



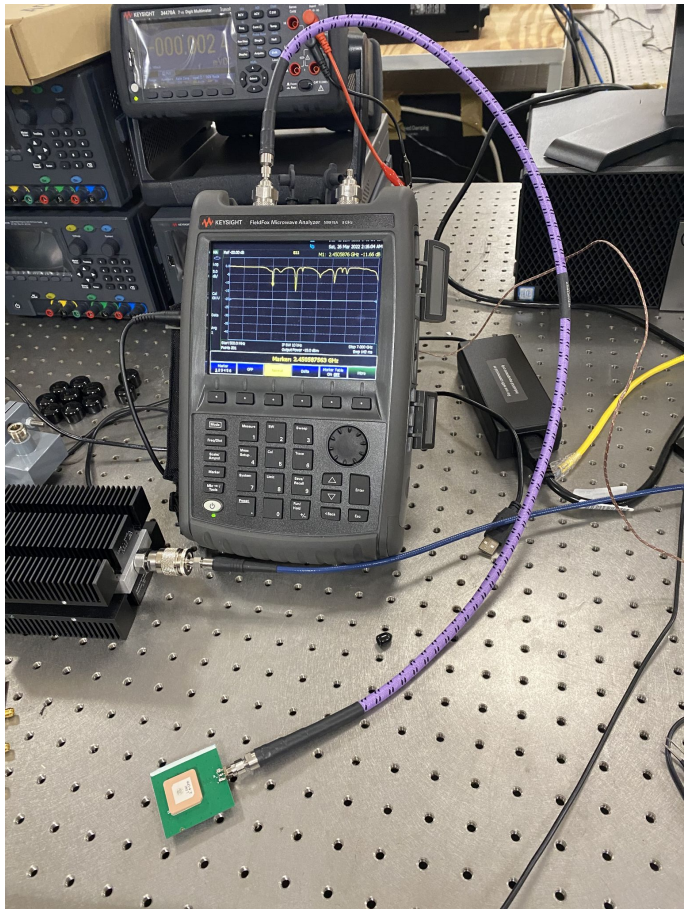
PCB Design

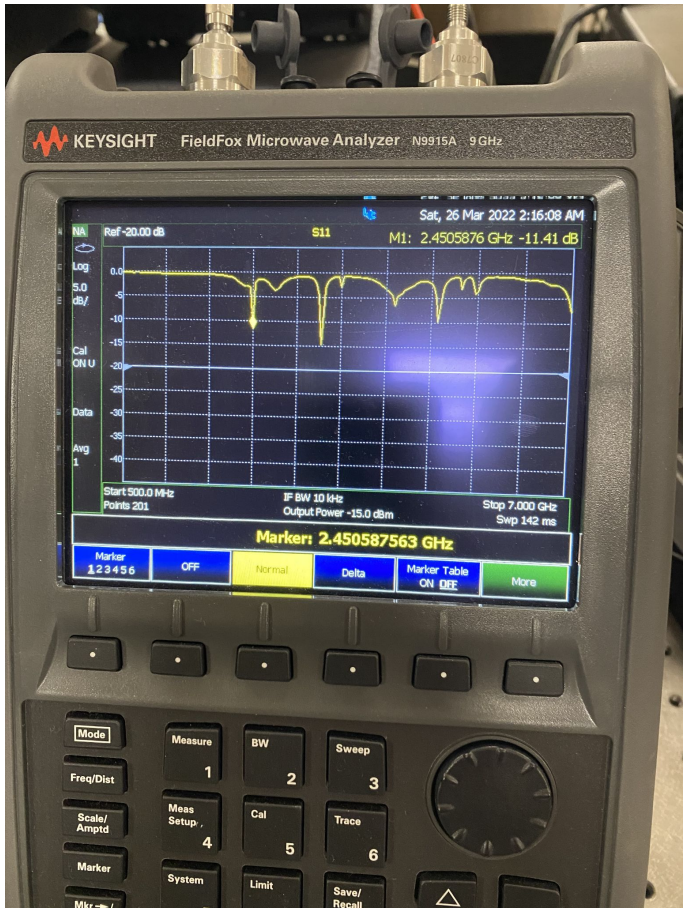
- RF Traces are **0.562mm** thick for **50Ω** line impedance
- Antennas placed λ/2 = **62.5mm** apart
- Vias in grid placed λ/20 = **6.25mm** apart
- Vias along traces placed λ/60 = **2.08mm** apart



Intermediate Testing - Antenna

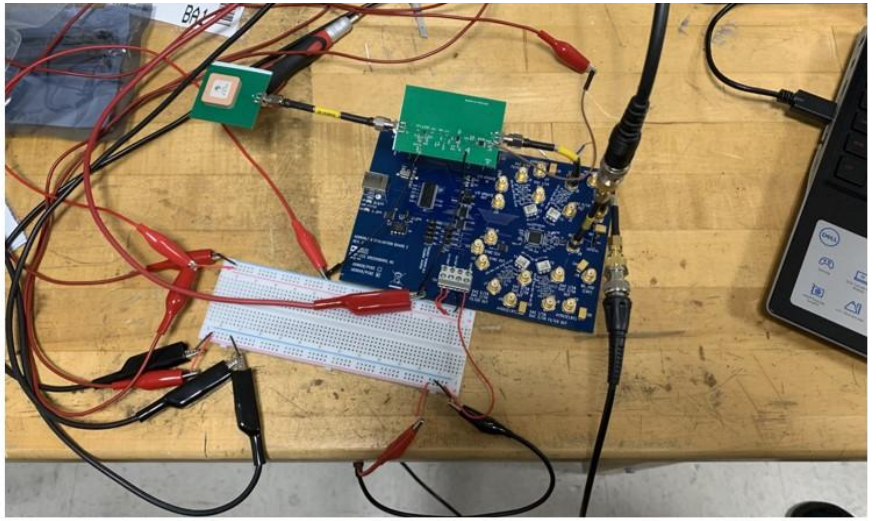
- Soldered two antennas to PCB cutouts
  - Two different solder jobs
  - Better quality solder job leads to greater antenna efficiency
- At 2.4 GHz, return loss is -11.41 dB

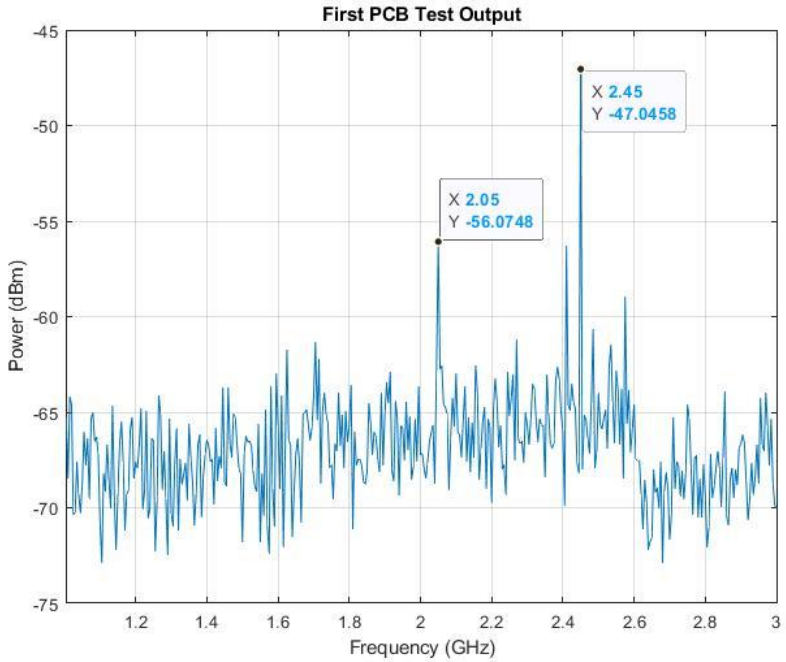




Intermediate Testing - Components

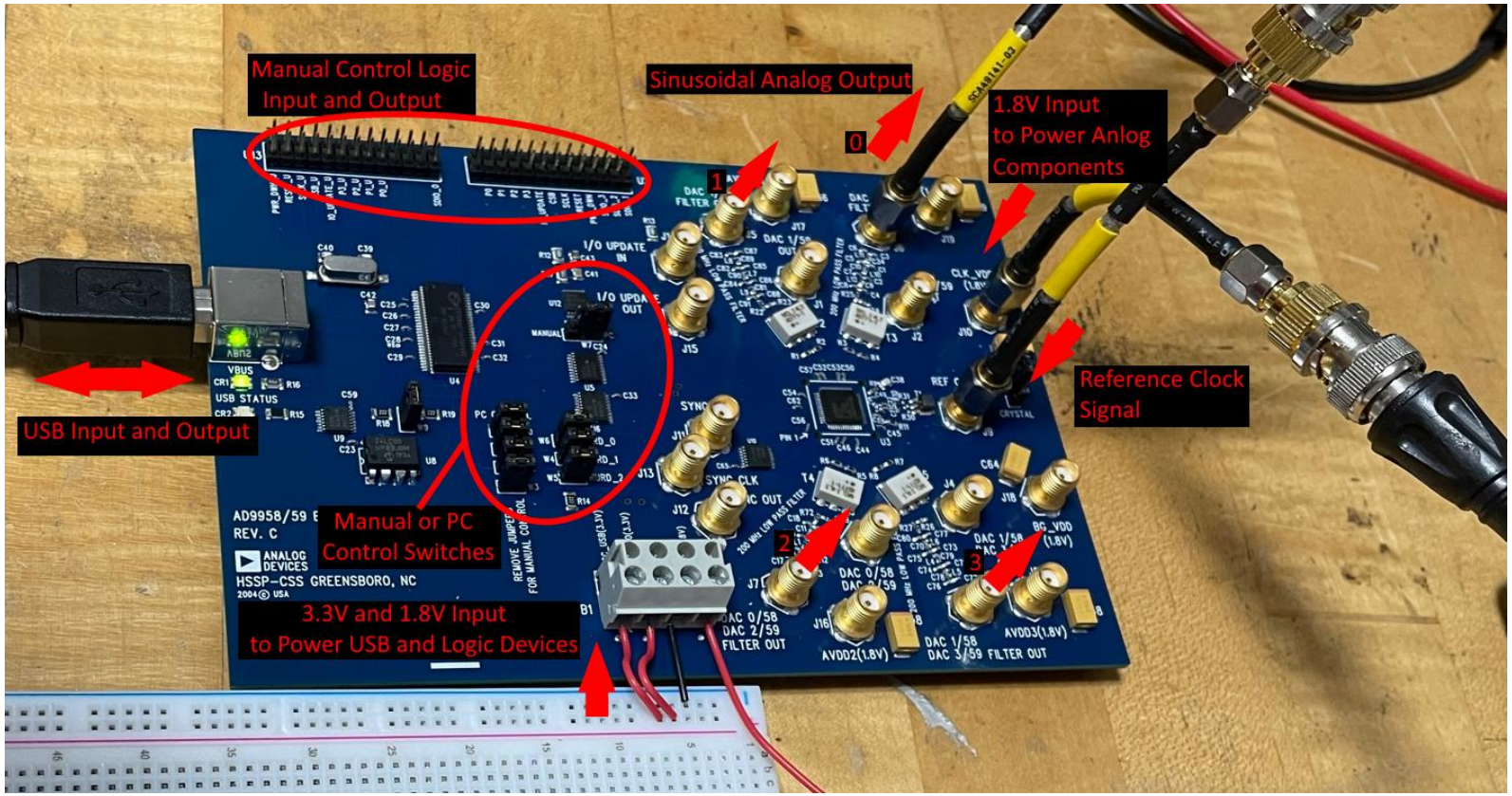
- Connected it to the DDS and powered the system through a breadboard
  - Measured output power through microwave analyzer
  - Two signals appeared
- At 2.45 GHz, out power is -47dBm
- SPECs are met for frequency but not power





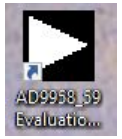
AD9959 Direct Digital Synthesis

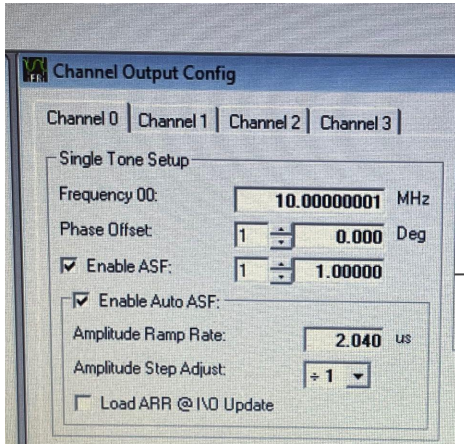
- Changes For Final Design
  - Power supply
  - No USB
  - Manual Mode
  - FPGA Wired to Logic Input and Output
  - Crystal Oscillator

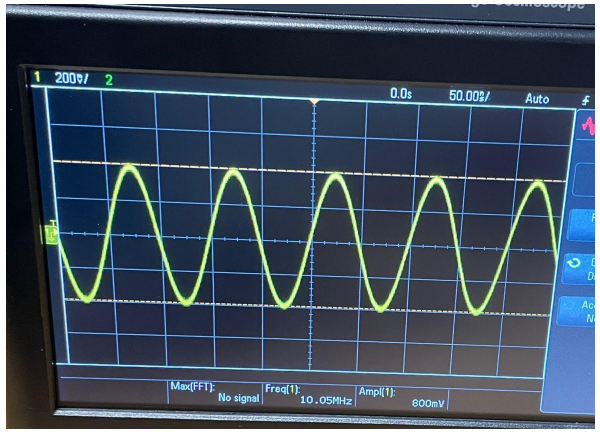


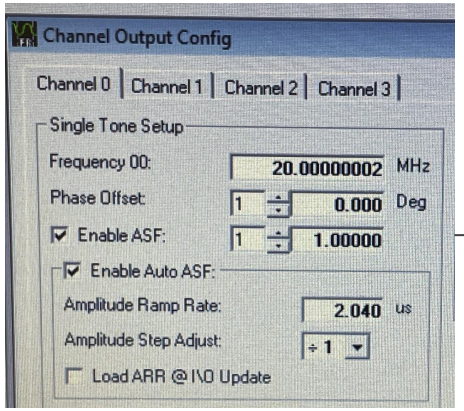
DDS Test Results

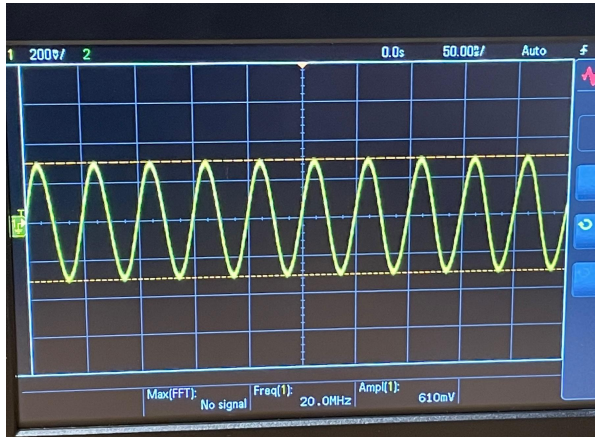
Evaluation Software

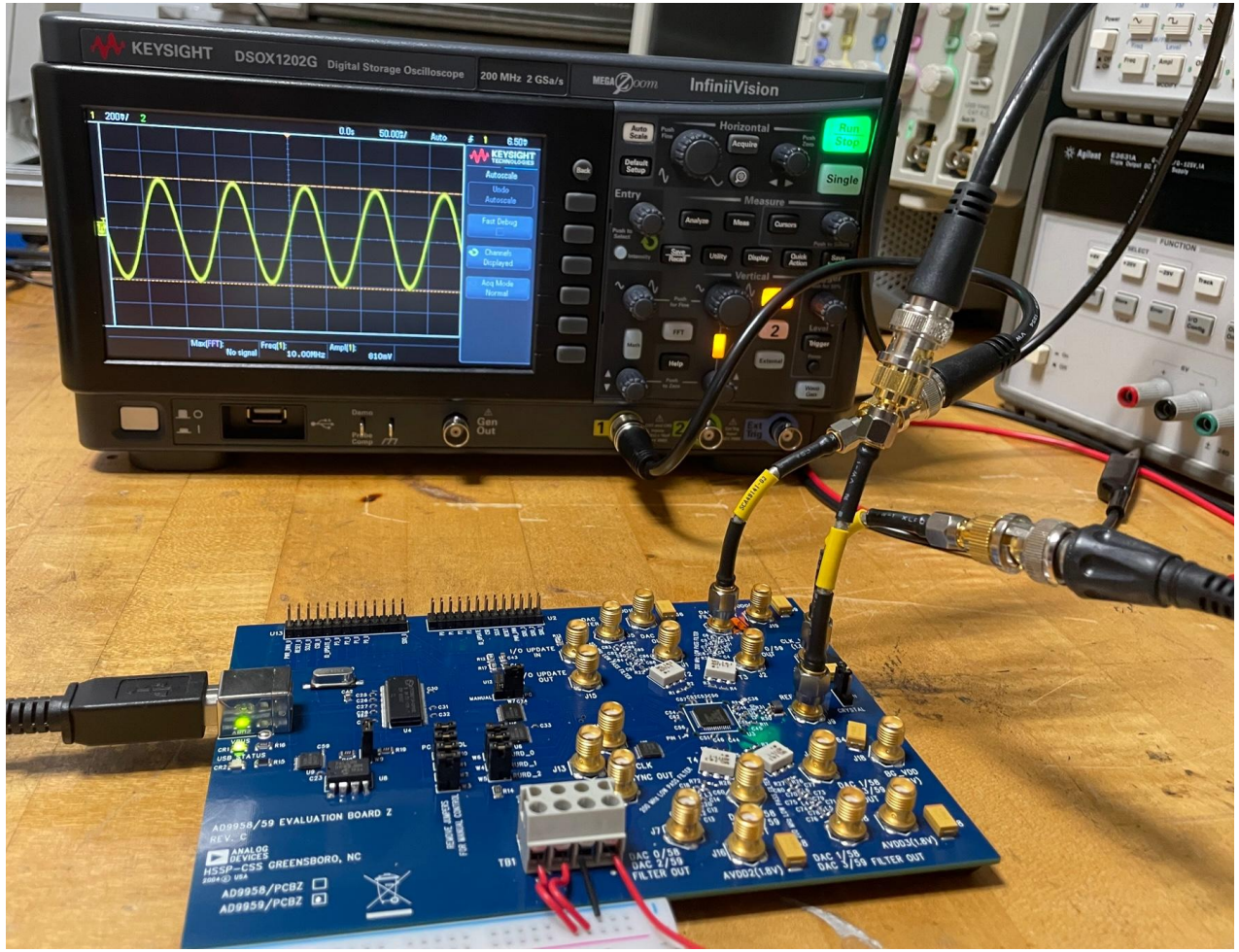




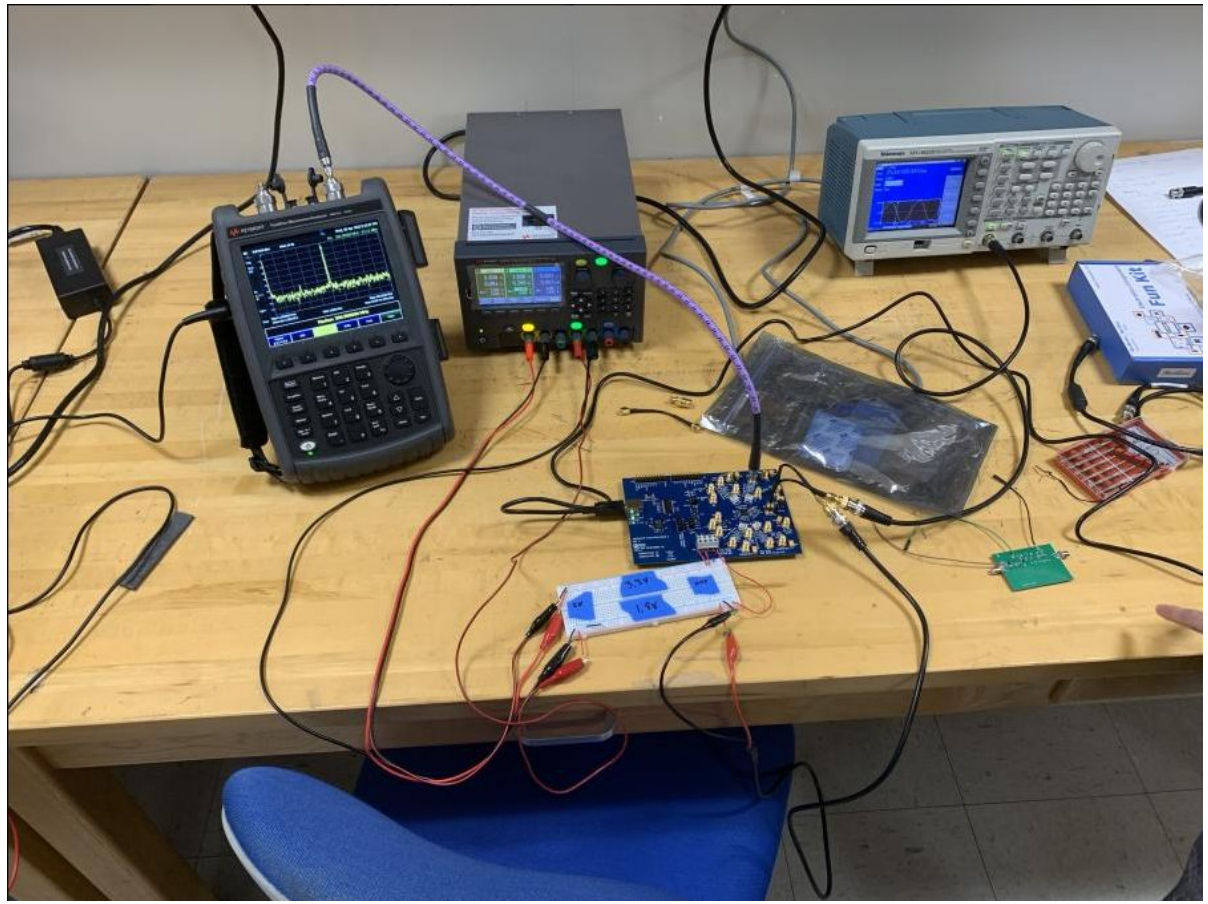


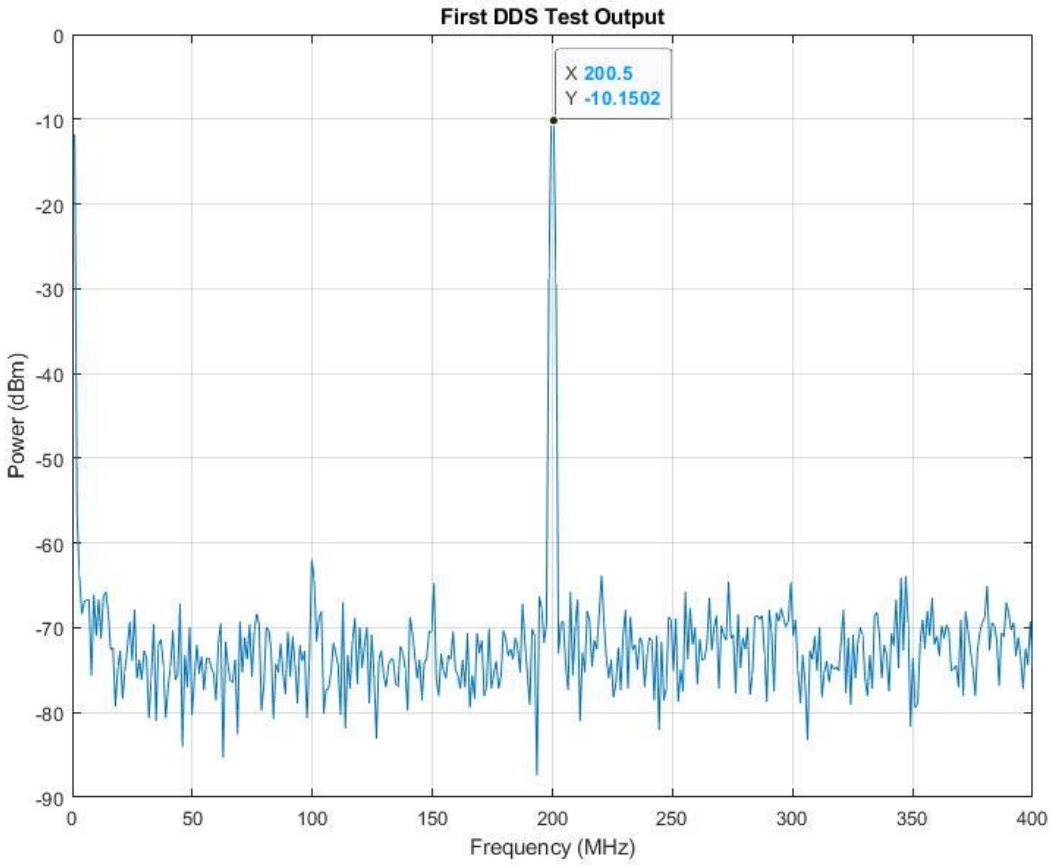






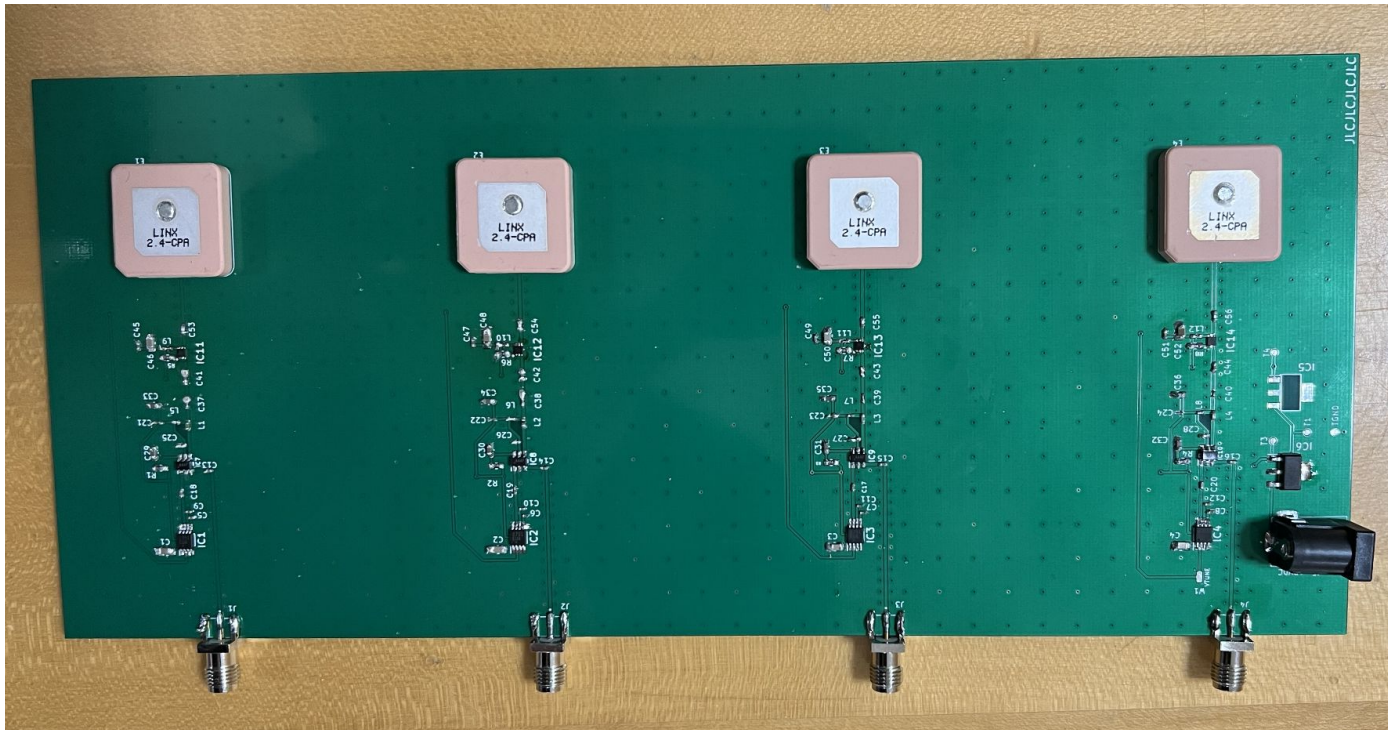
Frequency Analysis



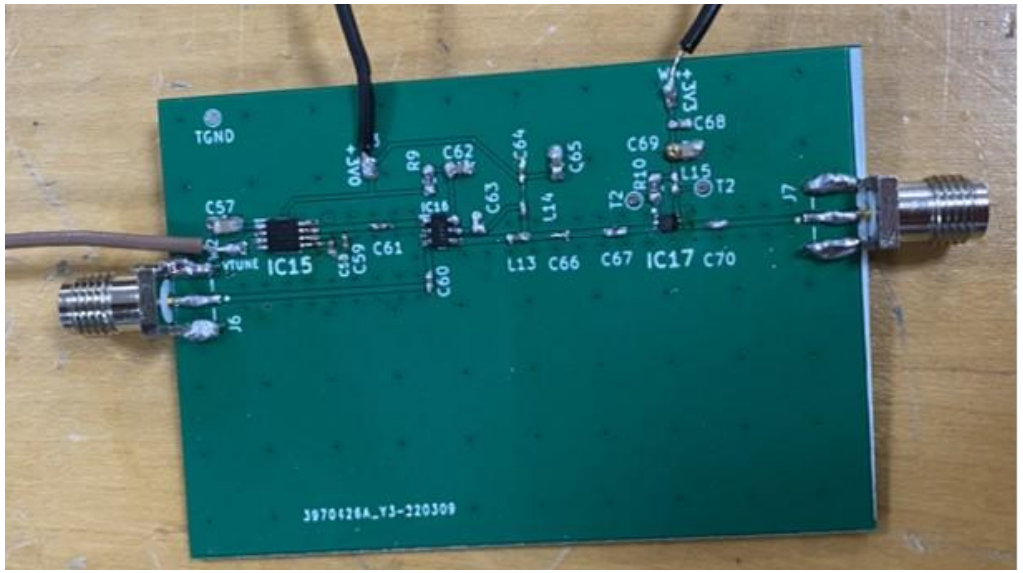


Hardware Assembly

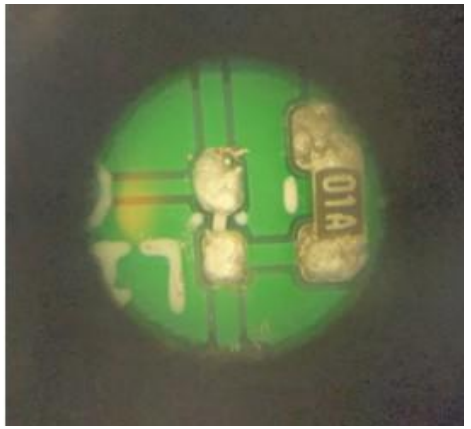
Main PCB: Antenna Array



Test PCB:

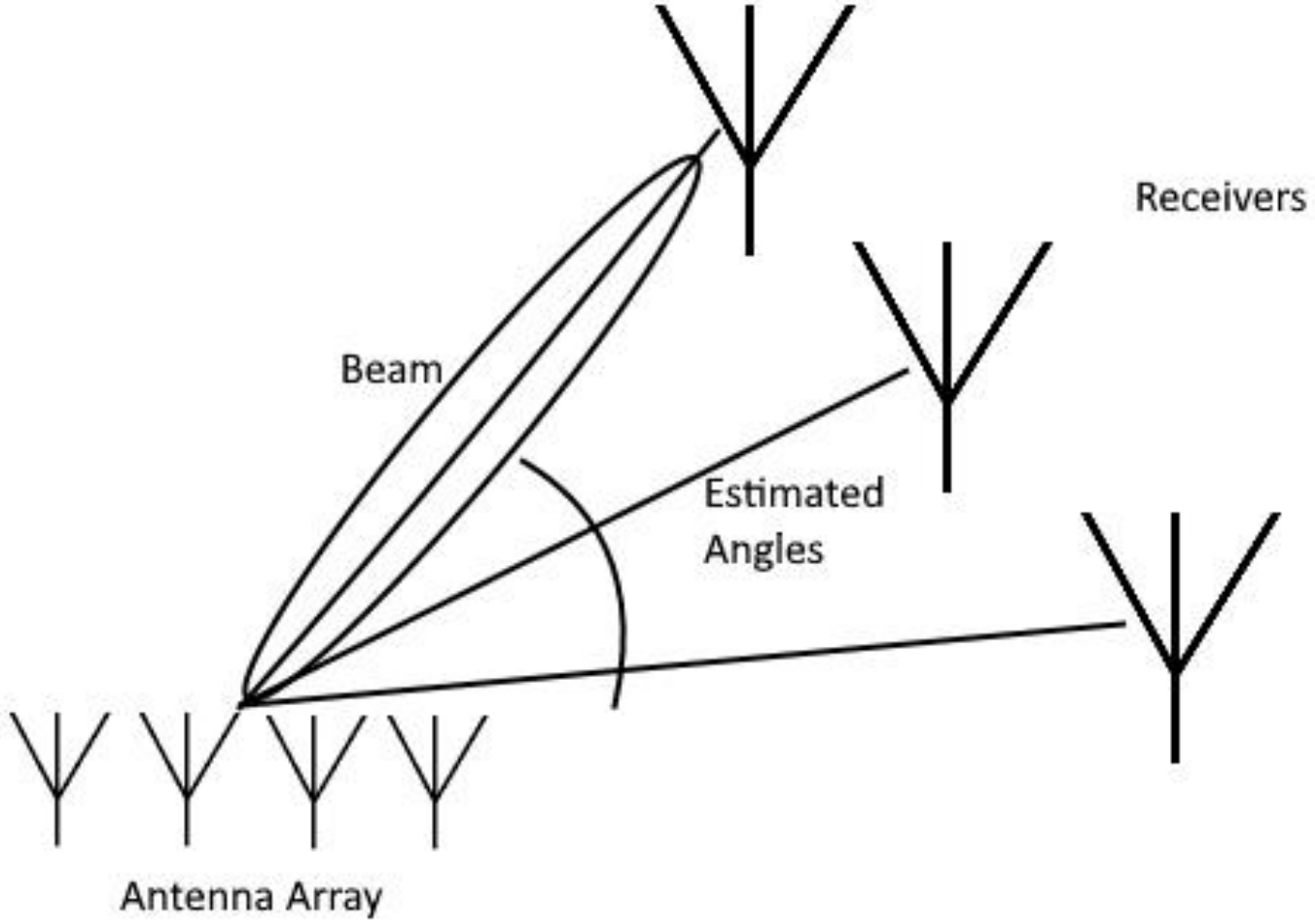


Microscope View:



Final Testing

- Final testing
  - Dr. Arigong's Lab
    - Series of receivers



Presentation Recap

- Project Background
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  - Software Design
  - PCB Design
  - System Design
- System Results
  - Intermediate Testing
  - Hardware Assembly
  - Final Testing

References

- Datasheets:
  - https://www.mouser.com/datasheet/2/256/MAX2750-MAX2752-1512450.pdf
  - https://www.mouser.com/datasheet/2/256/MAX2660-MAX2673-1515397.pdf
  - https://www.mouser.com/datasheet/2/777/GRRF_S_A0010122589_1-2575831.pdf
  - https://www.mouser.com/datasheet/2/238/LNNC_S_A0009494921_1-2551007.pdf

Questions?