SONOMA STATE UNIVERSITY | BACHELOR OF SCIENCE ELECTRICAL ENGINEERING

Jam Guard

GPS Anti-Jamming Solution

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Overview

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- Existing Solutions
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- Solution Theory
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- Proposed Solution
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- Tests
- Budget & Schedule
- Supporting Courses
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- Future Work

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Background

- Global Navigation Satellite System (GNSS) was developed by the military in the 1970’s with the first satellite launched in 1978
- GPS is the U.S. owned iteration with 31 Satellites, but others exist (Galileo-E.U, BeiDou-China)
- Operate on multiple frequencies L1 (1575.42 ± 7.5 MHz), L2 (1227.60 ± 5.5 MHz), and L5 (1176.45 ± 6.25MHz)

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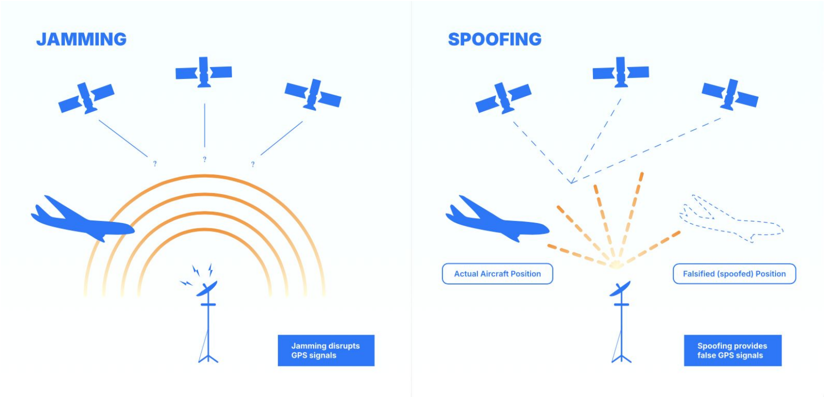
Background (Contd.)

- GPS signals reach Earth at very low power levels (typically -130 dBm)
- Broadband Noise Jammers (most common) overwhelm GPS signal
- Other methods, spoofing and meaconing are more sophisticated forms of signal disruption



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Modern Examples of Jamming

Gulf Region Jamming (Oct 2025)

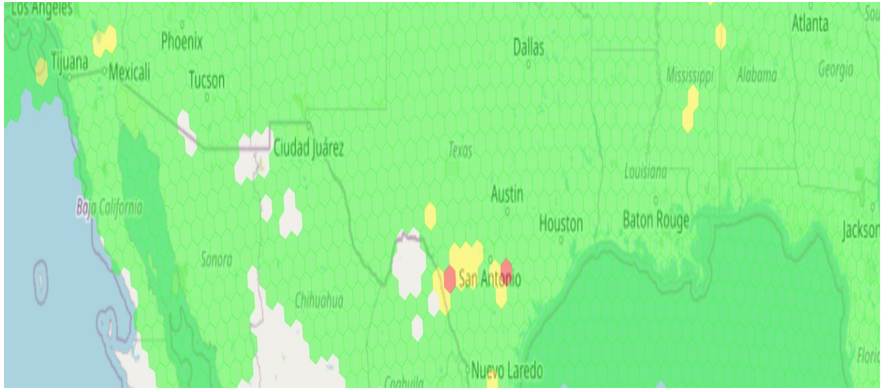
- Mass gps jamming/interference affected over 1000 vessels

Border Gps disruption (Current)

- Border Patrol faces jamming issues at the border, despite advancement in technology

Civil Aviation -Tartu Airport Estonia (2024-25)

- gps jamming resulted in unsafe landing conditions



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Problem Statement

Low-cost wideband jammers can overwhelm GPS signals, preventing receivers from maintaining a reliable position fix. This project focuses on the elimination of jamming interference to ensure a continuously working GPS system. This issue impacts critical users such as transportation, emergency services, defense, and autonomous technologies, where jamming—both accidental and intentional—can disrupt navigation and safety. A robust, low-cost solution is needed to maintain GPS functionality in these environments.

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Existing Solution Methods

Spatial filtering

- Spatial filtering uses multiple elements(antennas) and emphasizes phase control to separate signals based on the direction they come from
- Beamforming directs antenna gain toward GPS signals
- Null-Steering suppresses interference by creating nulls toward the direction of a jammer

Temporal filtering

- Temporal filtering process a signal based off time or frequency of the signal

Pre/Post Correlation

- pre-correlation filtering removes broadband noise and interference from a signal
- post-correlation filtering enhances signal quality by removing jamming effects and any residual noise

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Existing Solutions

- Tualaj 4200 Mini GPS/GNSS Anti-Jam CRPA System
    - $ Quote required/Military Grade

  (CRPA = Controlled Reception Pattern Antenna)

- Anti-jamming device infiniDome GPSdome-SunStone – dual-band GNSS signal protection, compact design
    - $ 2700

- Orolia GPSdome 1.02B Anti-Jammer
    - $ Quote required- only non-ITAR

      (ITAR= International Traffic of Arms Regulation)

Tualaj 4200 mini

Orolia GPSdome

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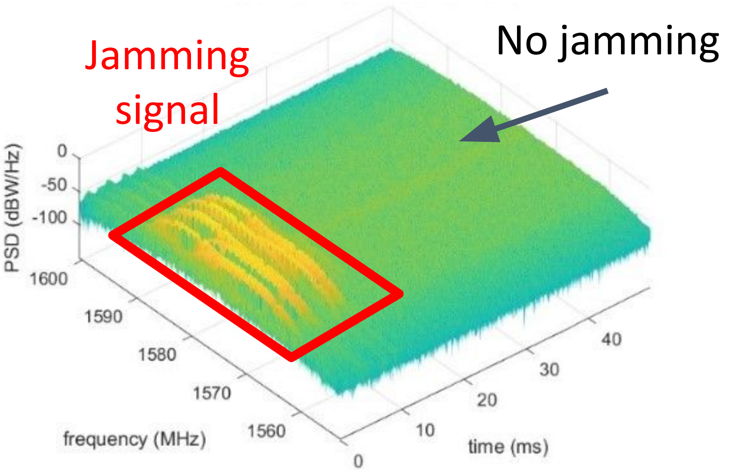
Value Proposition

Jam Guard helps GPS-reliant systems operate reliably in jamming environments by suppressing interfering RF signals, allowing receivers to maintain functionality, unlike conventional systems that lose accuracy or fail under interference.



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Marketing Requirements

MR 1 Device shall reliably detect GPS broadband jamming

MR 2 Device shall integrate easily with existing GPS receivers

MR 3 Device shall maintain usable GPS under broadband jamming

MR 4 Device shall be compact and portable

MR 5 Device shall operate efficiently using a battery

MR 6 Device shall be easy to install and operate

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Engineering Requirements

ER 1.1 Device must detect jamming with ≥ 95% probability at Jamming Signal Ratio ≥ 10 dB

ER 1.2 Device must trigger jamming alert in < 500 ms

ER 2.1 Device must support GPS L1 (1,575.42 MHz ± 7.5 MHz)

ER 2.2 Device must have a return loss > 10 dB

ER 3 Device must provide ≥ 20 dB null-forming suppression at 1,575.42 ± 15.34 MHz

ER 4 Device's PCB footprint must ≤ 15×15 cm and must weigh less than 600 g

ER 5 Device must consume average current ≤ 200 mA and maximum current ≤ 300 mA

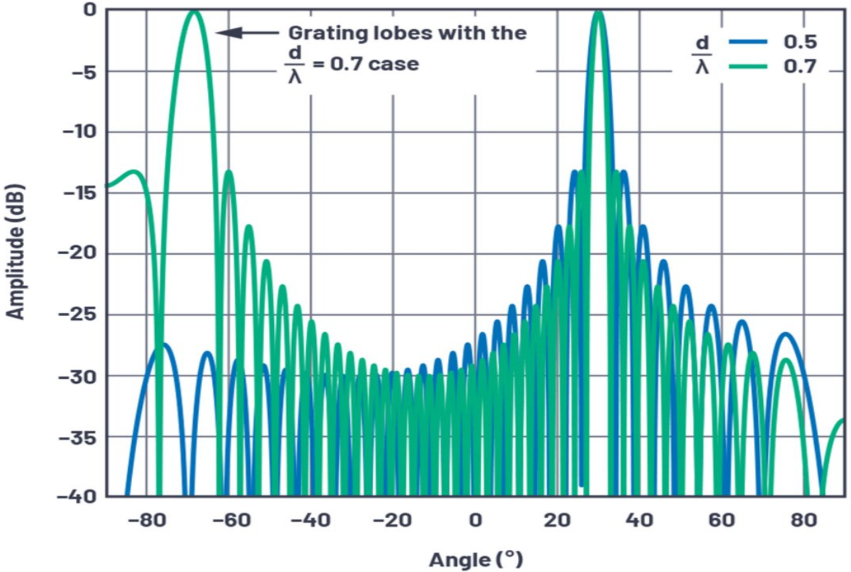
ER 6.1 Device must utilize a u.Fl connector for antenna connection

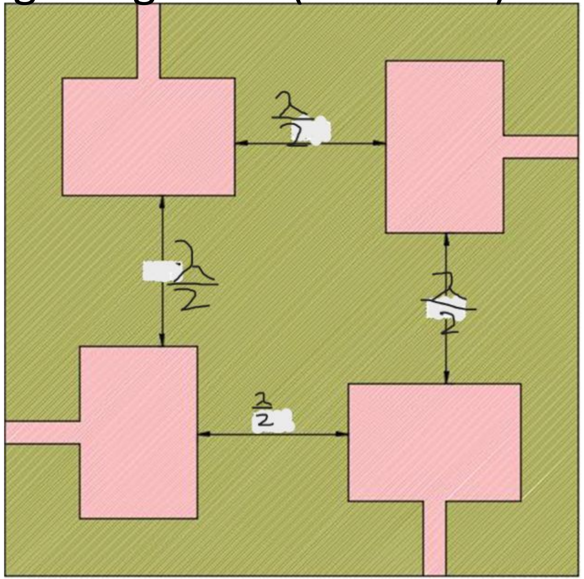
ER 6.2 Device must be operational after ≤ 100 µs from turning on

Solution Theory (Array)

Phased Antenna Array

- Electronic Antenna Array movement through Phase Shifter
- Changes lobe size/direction based off Phase and Magnitude
- Elements Separated by .5λ(Standard) to prevent grating lobes (9.525 cm)

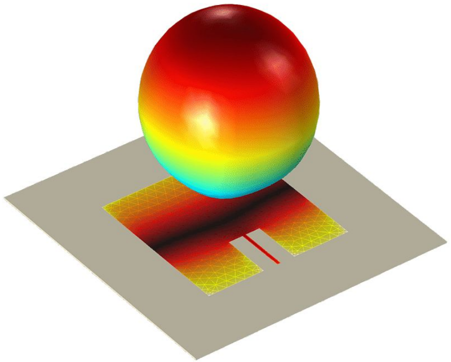


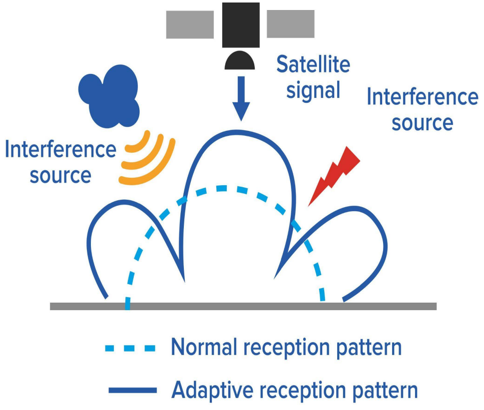


Radiation Pattern

- **A radiation pattern shows how an antenna sends energy into space**
  It tells us **where the signal is strong or weak**
- **Main Lobe**
  Direction which has the **highest signal power**
- **Sidelobes**
  Smaller, unwanted radiation in other directions
- **Nulls**
  Directions where **signal is minimized or cancelled**

- **Why it matters**
  Determines **coverage, interference, and signal quality**

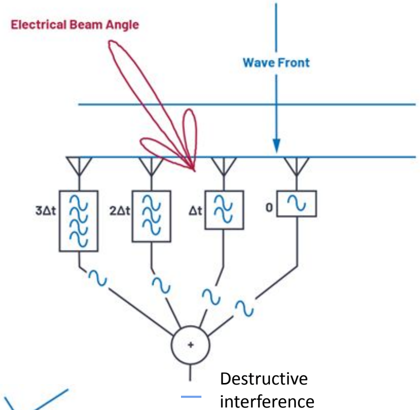


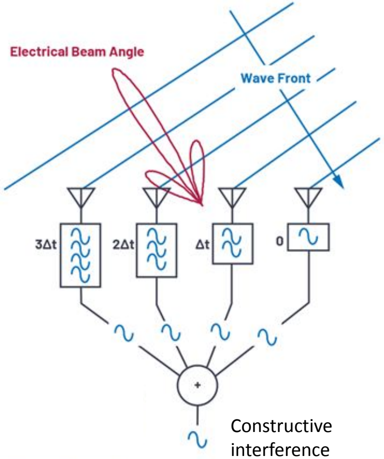


Phased Array

- **A phased array uses multiple antennas working together**
- **Each element transmits the same signal with a slight phase shift**
- **These phase shifts control the radiation pattern**
  Constructive interference
  Signals **add up** in a desired direction (main beam)
- **Destructive interference**
  Signals **cancel out** in other directions (nulls)

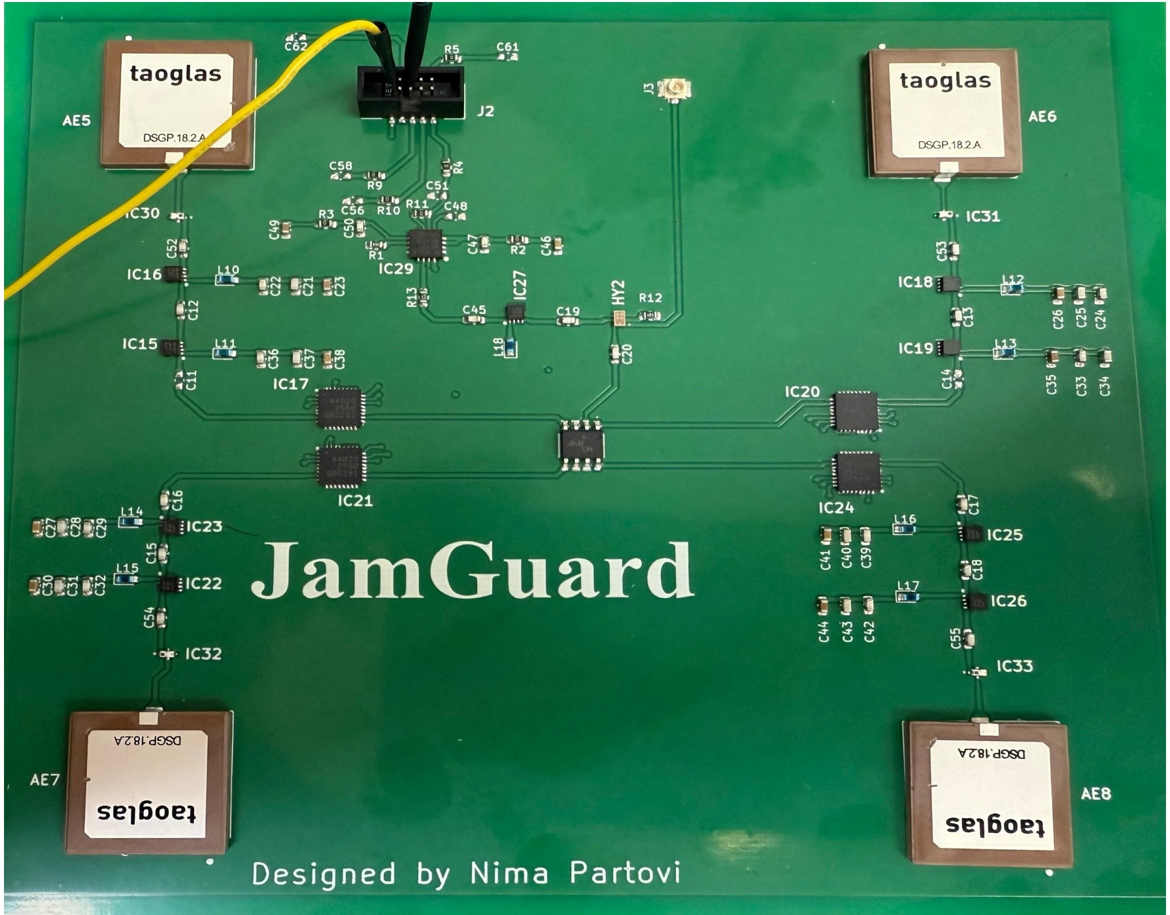
- **Result**
  We can **steer the beam electronically** (no moving parts)





Proposed Solution

- Replace the current antenna on a GPS system with Jam Guard
- Integrate a null forming system into the system to block/reduce jammer signal before getting to the GPS receiver



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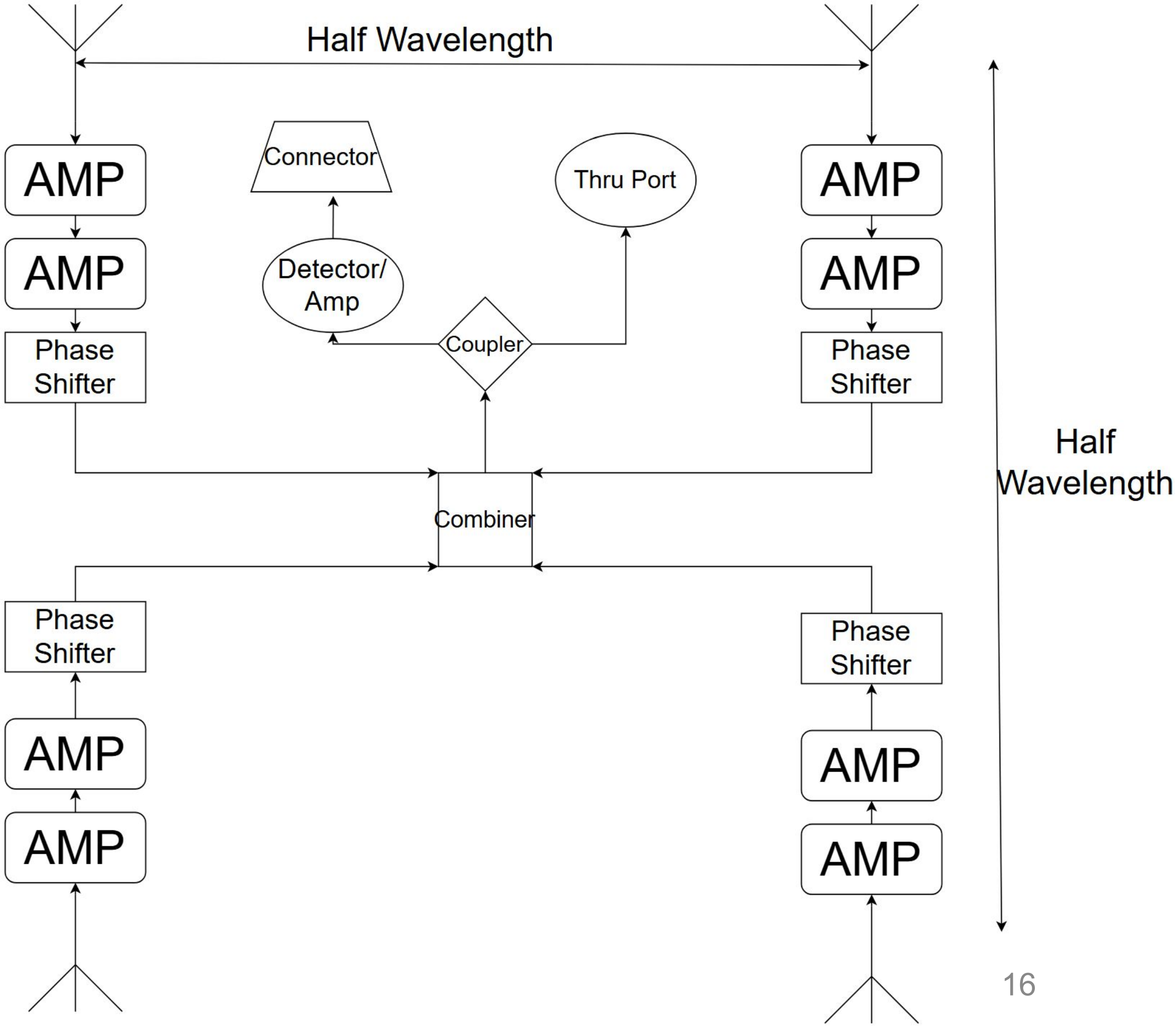
PCB layout (Block Diagram)

$$c = f\lambda$$

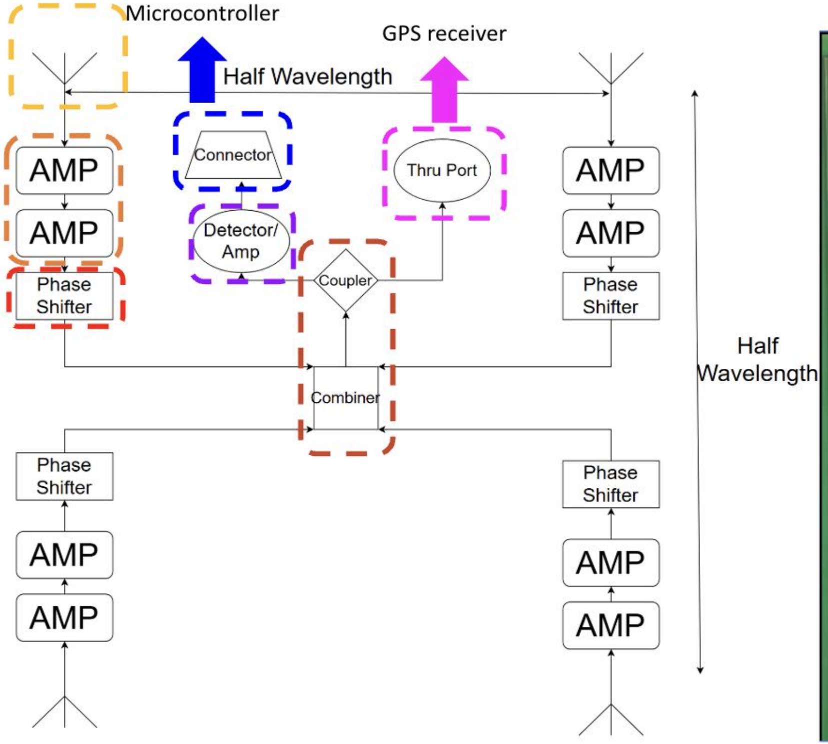
C = 3* 10^8 m/s

f = 15.7542 * 10^8 s^-1

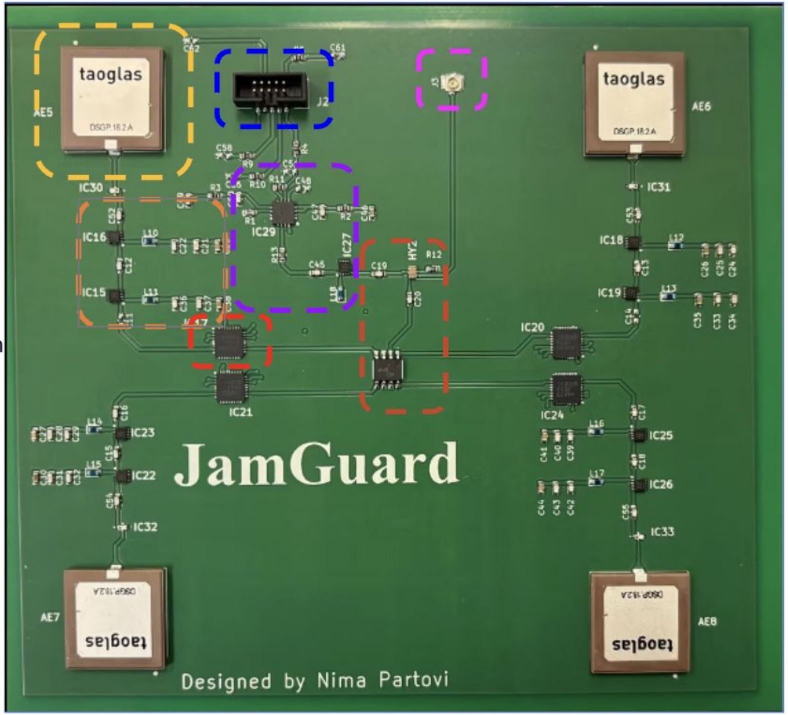
λ = 19.5 cm



PCB layout



System block diagram



Fabricated **Jam Guard** PCB

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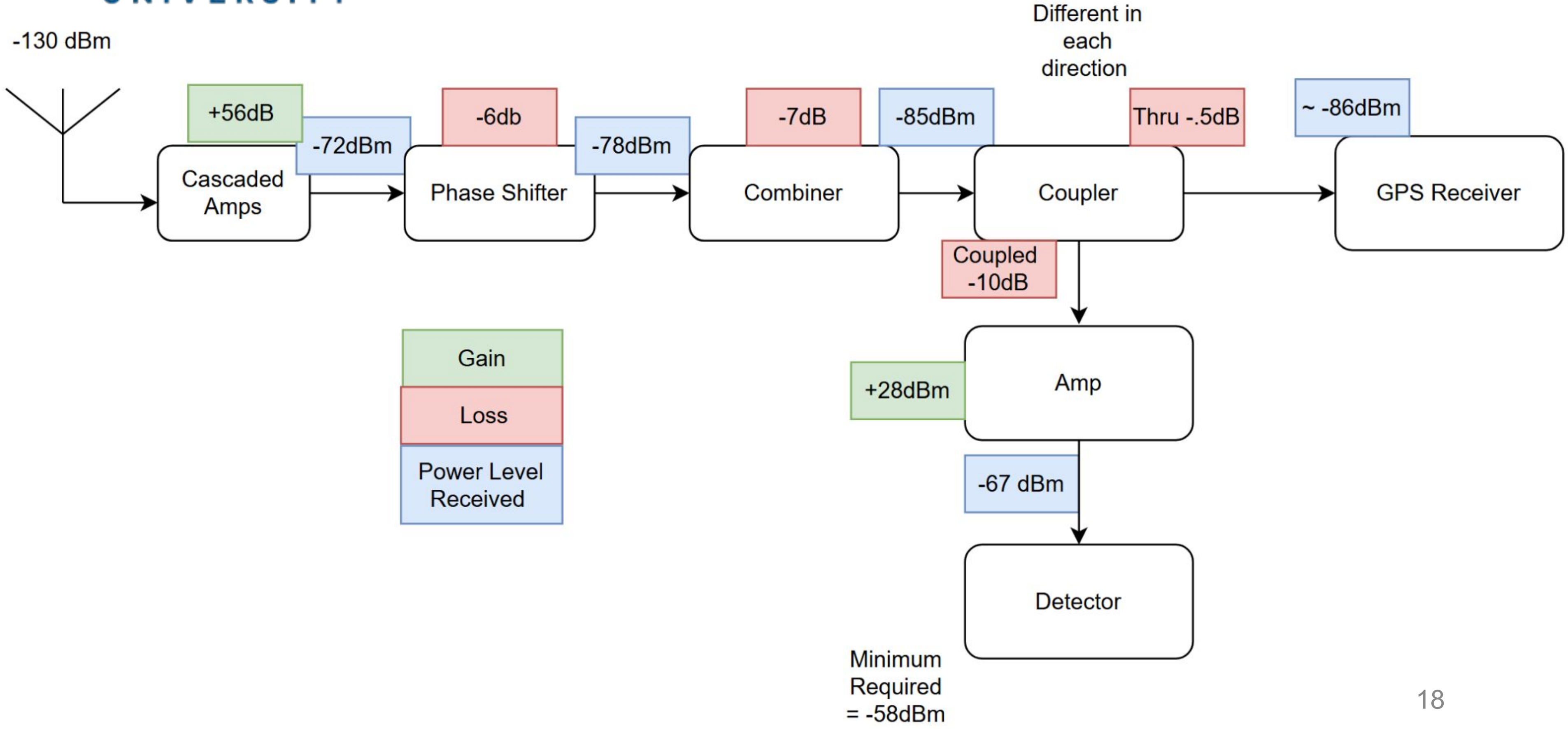
Link Budget



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Noise Figure

$$F_{total} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3} + \frac{F_5 - 1}{G_1 G_2 G_3 G_4} + \frac{F_6 - 1}{G_1 G_2 G_3 G_4 G_5}$$

1. Filter
2. Amp 1
3. Amp 2
4. Phase shifter
5. Combiner
6. Coupler

F(total) = ~1.6

NF = ~2.15 dB

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Algorithm Development

Beamforming & Null Steering Research

- Compute phase shifts for each antenna element
- Radiation pattern modeled using array factor:

$$\mathrm{AF}(\theta, \phi) = \sum_{m=0}^{1} \sum_{n=0}^{1} e^{j[kd(m \sin\theta \cos\phi + n \sin\theta \sin\phi) + \phi_{m,n}]}$$

Null Depth & Null Width Experiments

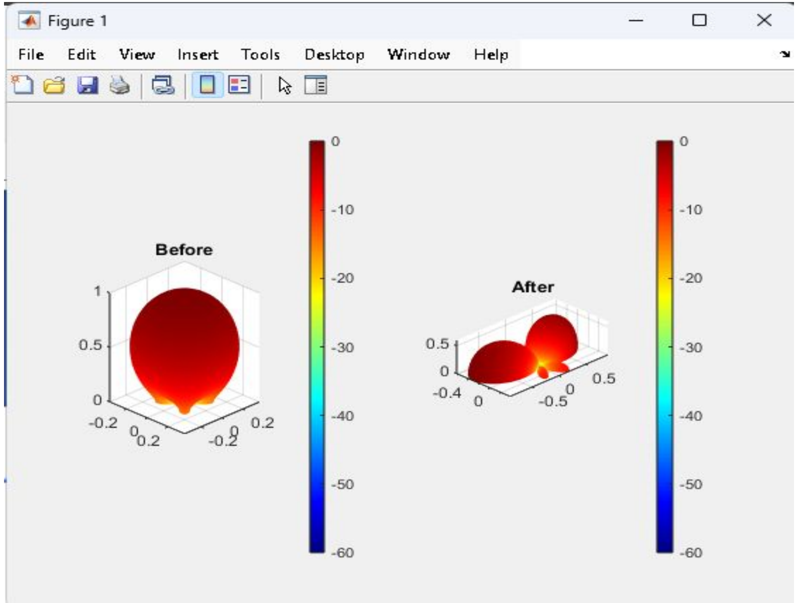
- Studied null depth vs phase resolution (5° steps)
- Identified limits of scan-based approaches

Identified Limitations of Scan-Based Approaches

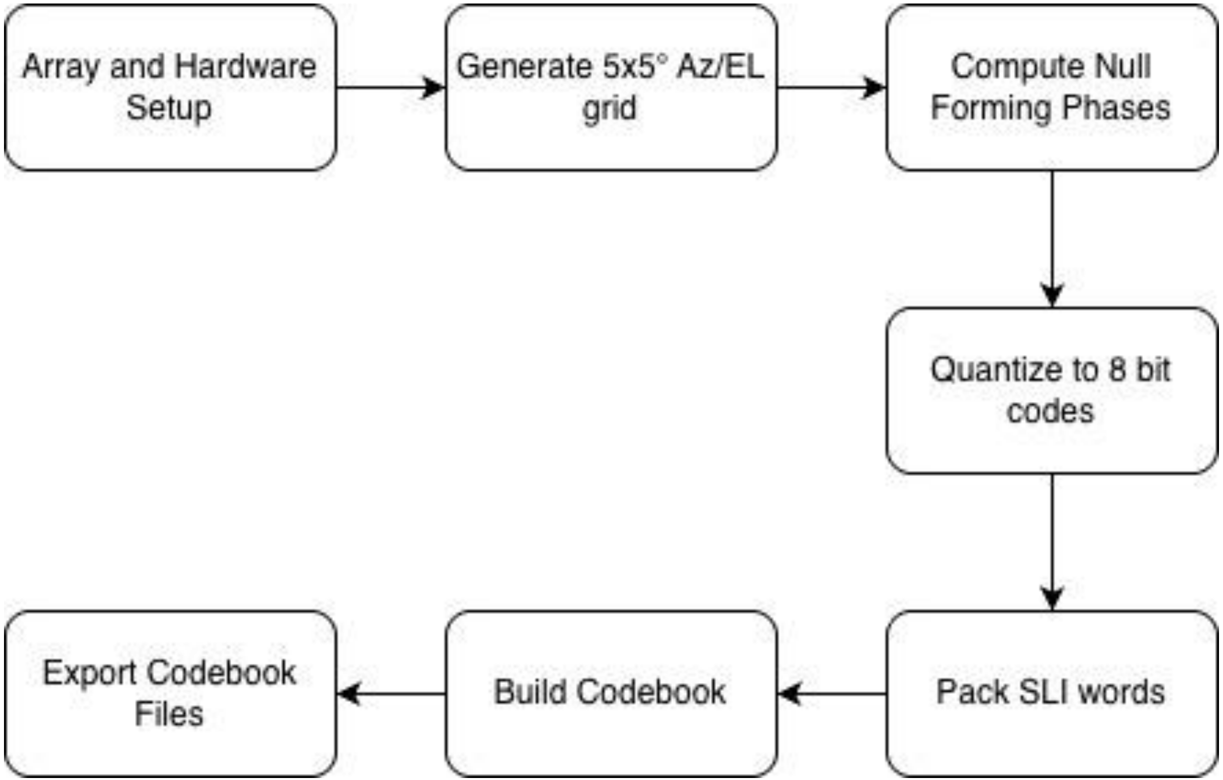
- Transitioned to **codebook-based null steering**
- Precomputed phase values for fast real-time response

Steering away from Jammer

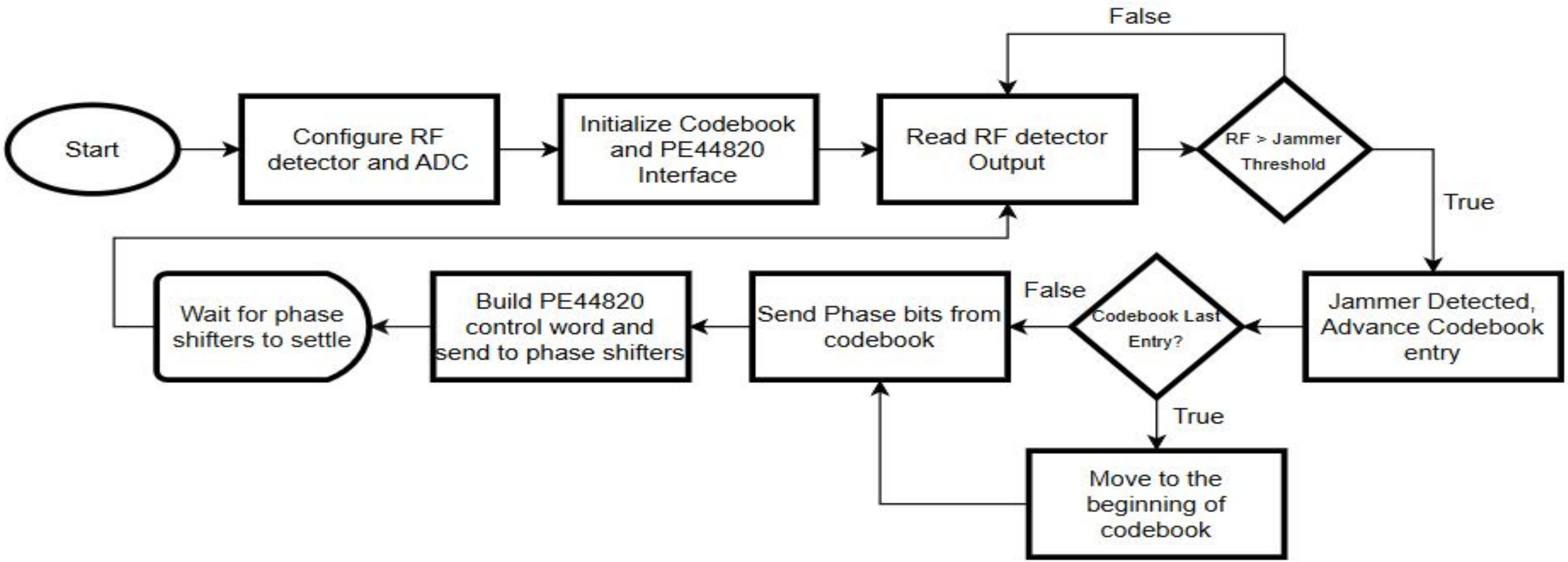
- Developed a **2×2 phased-array system** for directional null steering
- Generated a **3D radiation pattern** to visualize beam shape and null formation
- Built a **5° × 5° azimuth/elevation codebook** for predefined jammer directions
- Computed phase shifts to place a **null at jammer direction**
- Quantized phases into **8-bit PE44820 hardware control codes**
- Exported a **lookup-table codebook** for real-time SI based control



Software Design



Software Flowchart



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Design Matrix - Microcontroller

	Weight	PIC18F47K42	STM32 NUCLEO-L432KC	ESP8266 Node-MCU	ESP32 WROOM-32E	PYNQ -Z2
Cost	0.175	0.24	0.18	0.31	0.25	0.02
Size	0.075	0.26	0.30	0.12	0.28	0.14
Clock Speed	0.100	0.12	0.18	0.22	0.26	0.22
Software Compatibility	0.100	0.18	0.22	0.20	0.24	0.16
Power Consumption	0.200	**0.32**	0.28	0.08	0.14	0.08
Processing Speed	0.100	0.14	0.22	0.18	0.26	0.20
Availability/ Familiarity	0.300	**0.36**	0.22	0.18	0.22	0.10
Score		0.27	0.24	0.18	0.24	0.13

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Design Matrix - Power Detector

	Weights	AD8318	ADL5513	ADL5902	LTC5507ES6
Cost	0.047	0.25	0.17	0.17	0.42
Freq. Coverage	0.193	**0.28**	0.22	0.28	0.22
Dynamic Range	0.279	**0.31**	0.31	0.25	0.12
Bandwidth	0.240	0.25	0.25	0.19	0.31
Accuracy	0.144	0.27	0.27	0.33	0.13
Power Consumption	0.097	0.21	0.21	0.15	0.36
Score		0.27	0.26	0.24	0.23

Main Challenges

1. Developing Search Algorithm

2. PCB development including Selecting hardware/hardware cost/delivery and PCB fabrication

3. Performing RF based tests

Key Risks and Mitigation Plans

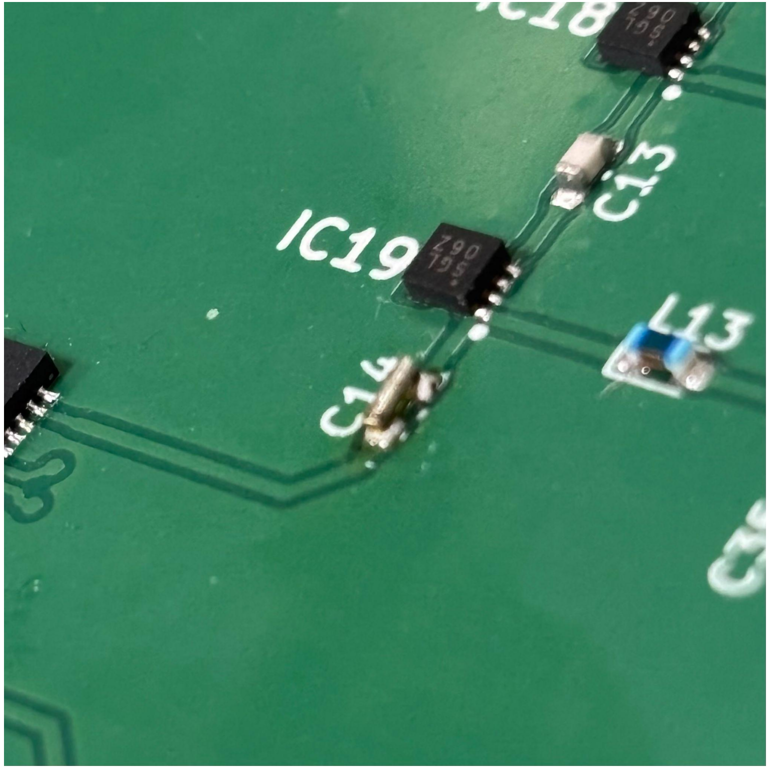
Risk	Status	Mitigation Plan
System requires multiple iterations beyond available time	Occurred, Not Resolved	Work with best iteration and proceed with testing
Specific RF hardware unavailable	Did not occur	Identified compatible components and validated them prior to integration
PCB wear and tear	Occurred, Resolved	Planned ahead and ordered multiple PCB boards and soldered missing components

PCB Fabrication - Missing Components

Problem: Upon inspection of the board, we noticed missing components near the phase shifter on 2 different antenna paths

Solution Plan: Soldered a tiny piece of resistor wire to complete the connection

Result: Successfully soldered on the resistor wire and made the connection, confirmed by continuity test



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Summary of Tests Conducted

Test Number	Test Objective	Related ER(s)	Status	Notes
Pre-Test	Obtain GPS signal	N/A	Completed	Successful Lock-on
FT-1	Measure Jam Guard return loss	ER2.2	Completed	Obtained -13 dB return loss
FT-2	Jam Guard GPS Lock-on	ER2.1 ER6.1	Completed	Sucessful Lock-on
FT-3	Measure Size and Weight	ER4	Completed	Meets the defined specs

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Summary of Tests Conducted

Test Number	Test Objective	Related ER	Status	Notes
FT-4	Measure Current Draw	ER5	Completed	Measured within spec (182 mA)
FT-5	Measuring InitializationTime	ER6.2	Completed	Measured within spec

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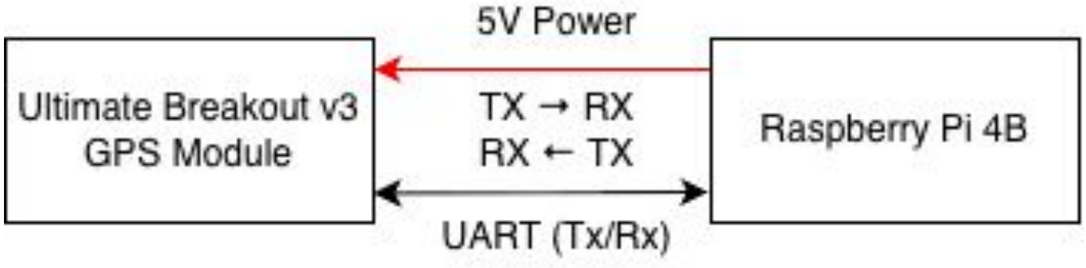
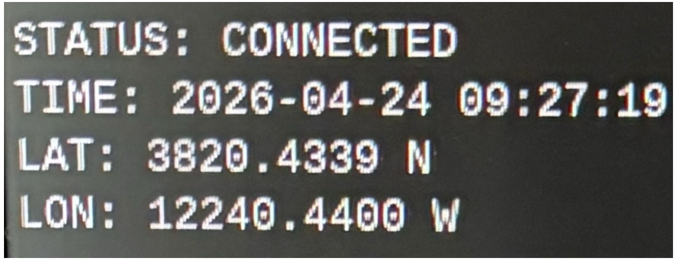
Pre-Test GPS Reciever Board

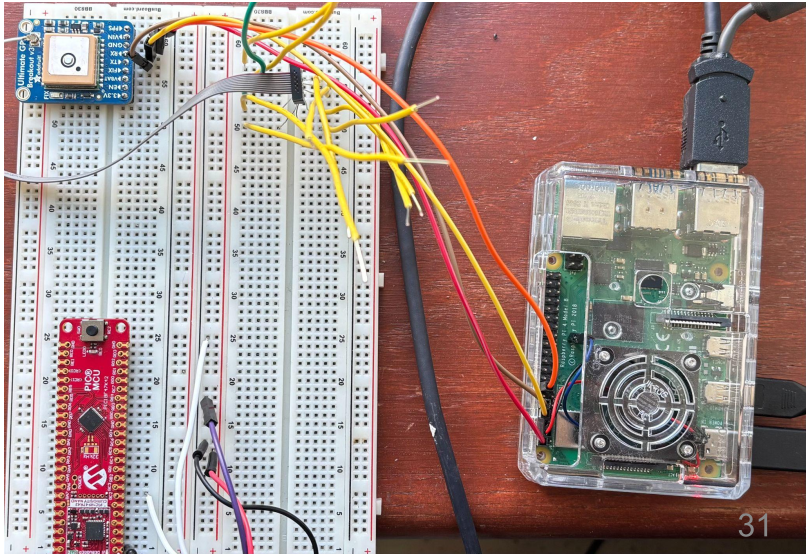


<u>Objective:</u> Confirm the Adafruit GPS receiver can maintain a consistent lock on

<u>Procedure:</u> Connect the GPS module to RPI via UART (Universal Asynchronous Receiver/Transmitter) and run python program to read data from the module

<u>Conclusion:</u> Ultimate GPS Breakout v3 GPS receiver functions properly with accurate longitude and latitude to our location after GPS lock on



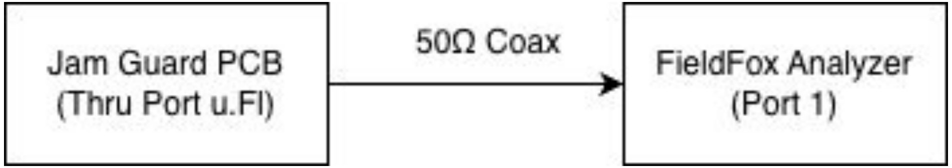


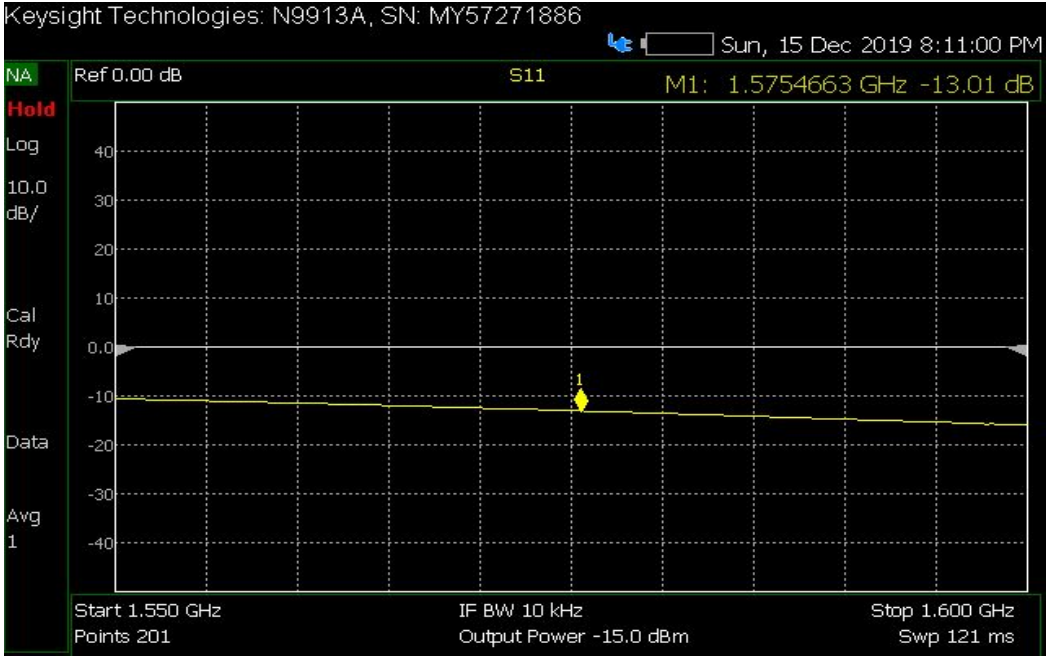
FT-1 Measuring Return Loss

<u>Objective:</u> To confirm the RF return loss of Jam Guard is less than 10 dB (ER2.2)

<u>Procedure:</u> Use the RF Demo kit to calibrate the cable. Connect the calibrated cable to the thru port on Jam Guard. Measure S11 to see the return loss

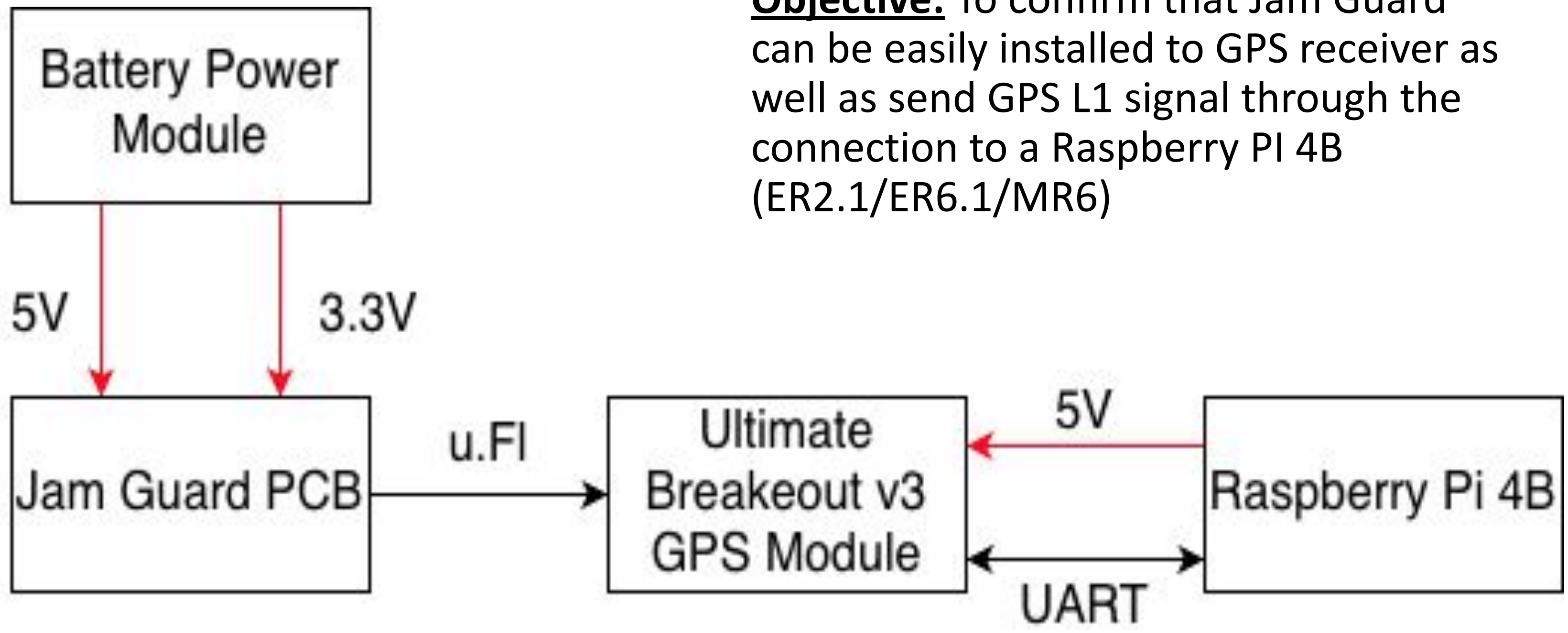
<u>Conclusion:</u> Jam Guard meets the requirement for less than 10 dB return loss





FT-2 Jam Guard GPS Lock-on

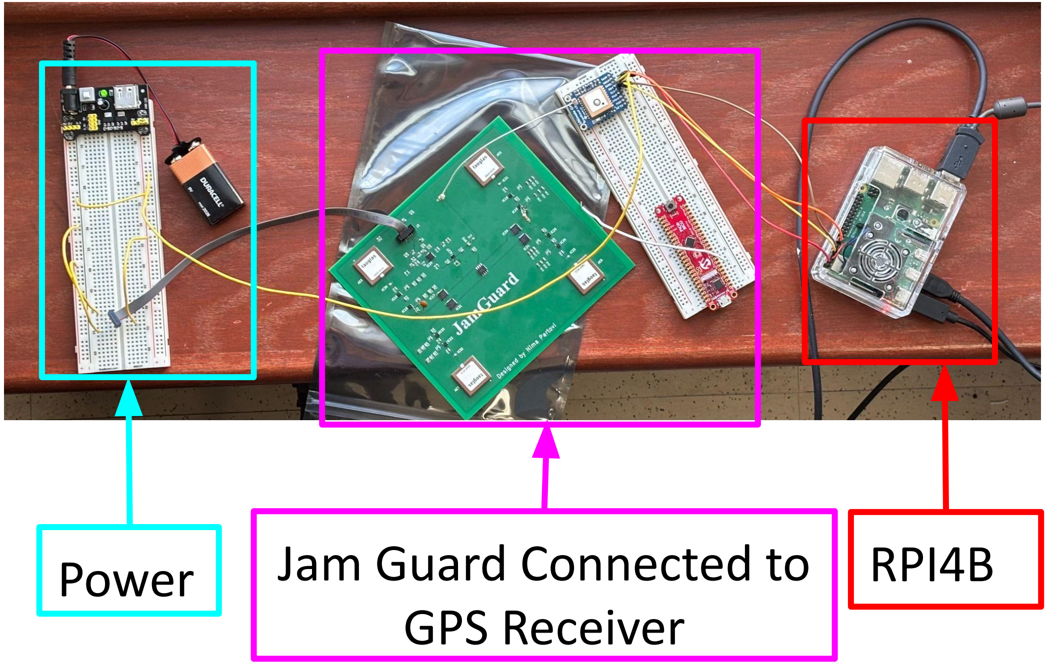
Objective: To confirm that Jam Guard can be easily installed to GPS receiver as well as send GPS L1 signal through the connection to a Raspberry PI 4B (ER2.1/ER6.1/MR6)



FT-2 Jam Guard GPS Lock-on

Procedure: Connect the PCB to 5V and 3.3V power. Connect the board to the GPS module via u.Fl cable. Power on the board and monitor response from the RPI

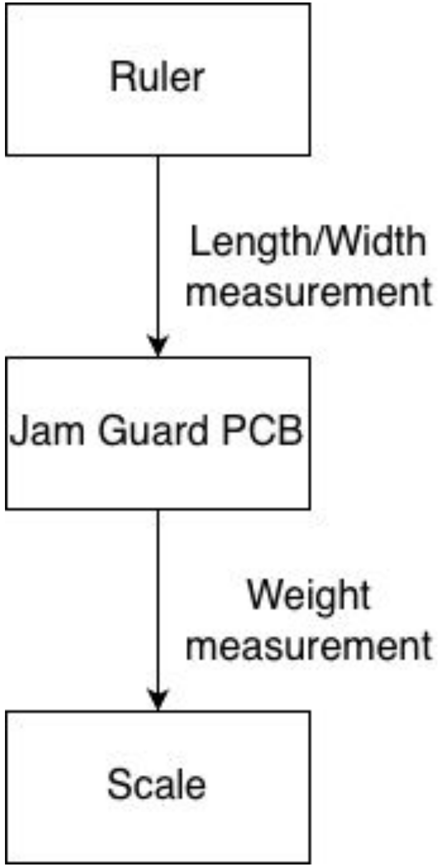
Conclusion: We confirmed that our PCB is able to receive GPS L1 and transmit it though the GPS module to the RPI



FT-3 Measuring Size and Weight

Objective: Determine if the Jam Guard PCB fits within 15x15 cm with weight of 600g (ER4/MR4)

Procedure: Measure the edges of the board and weigh it on a scale



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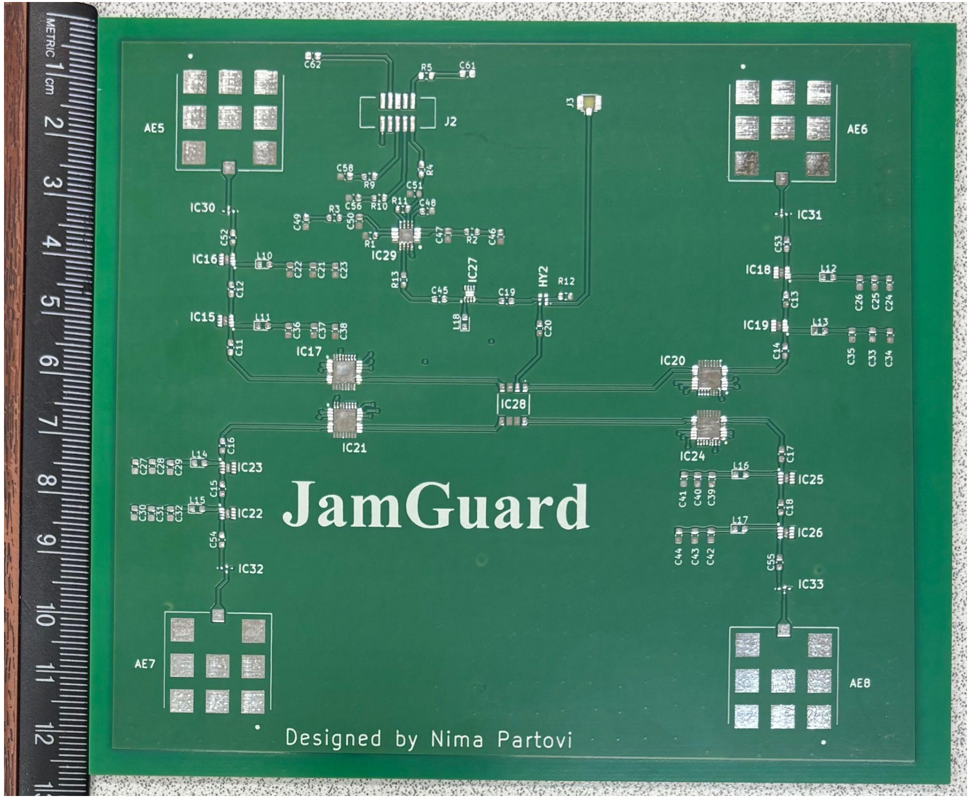
FT-3 Measuring Size and Weight



Length ≈ 12.7 cm // Width ≈ 14.4 cm

Weight = 80g

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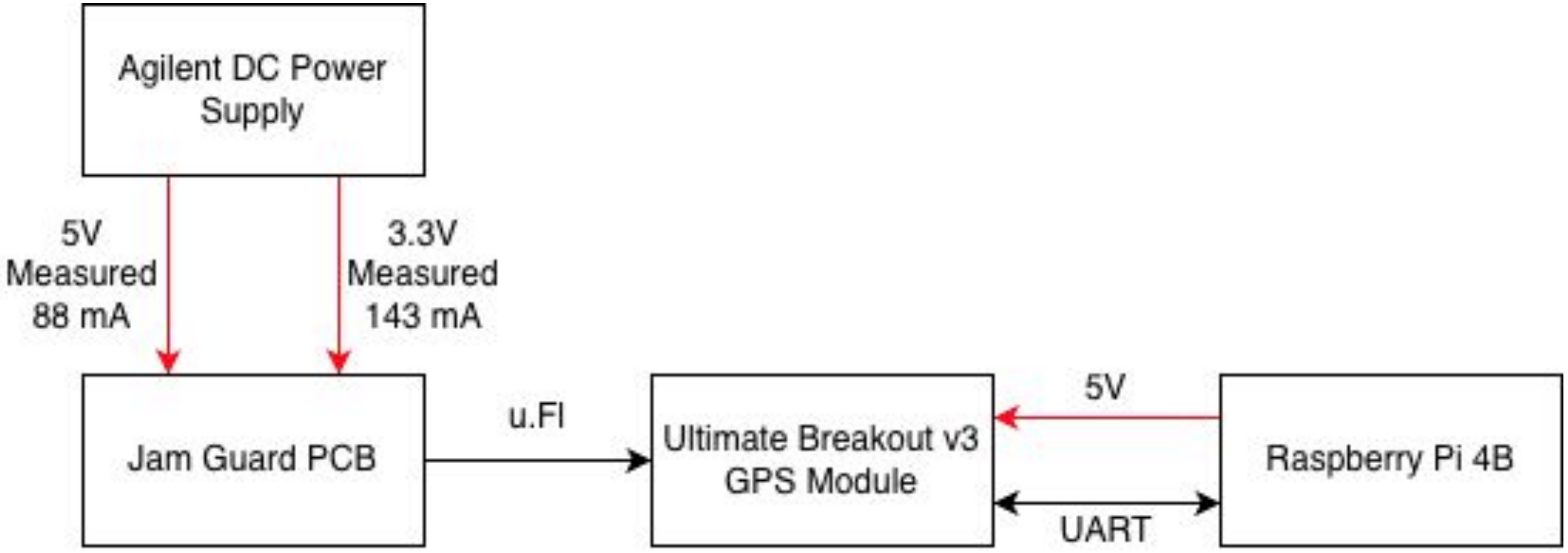
FT-3 Measuring Size and Weight

Conclusion: The Jam Guard PCB fits within the defined specs of length, width and weight.

FT-4 Measuring Current Draw



Objective: Measure the total current being consumed by our device (ER5/MR5)

Procedure: Power Jam Guard using a bench supply (5V and 3.3V) and observe the current measurement shown on the supply

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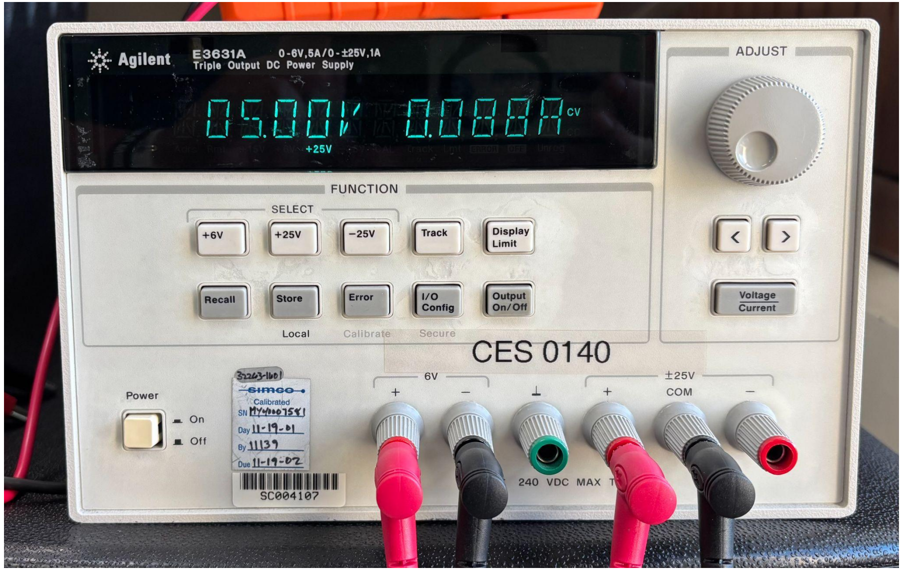
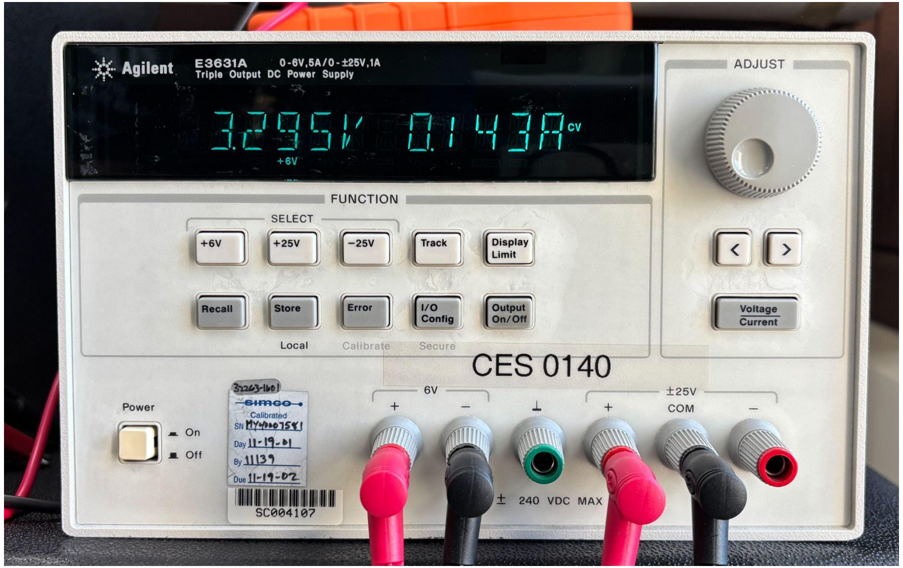
FT-4 Measuring Current Draw





P(5V) = 5 x 0.088 = 0.44 W

P(3.3V) = 3.3 x 0.143 = 0.47W

P(tot) = 0.44 + 0.47 = 0.91W

I(eq) = (0.91/5) = 182 mA

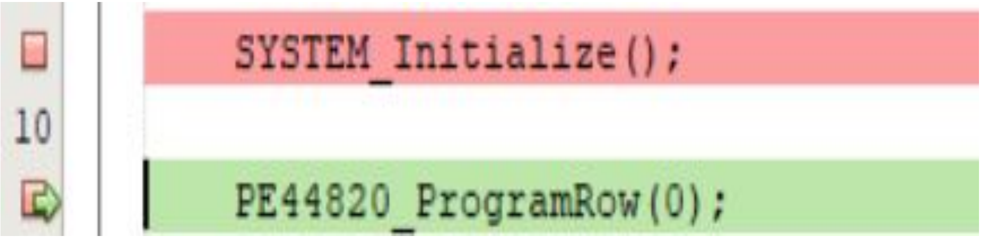
Conclusion: Jam Guard comfortably sits within the specs and met the requirement

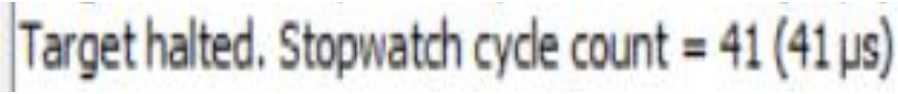
FT-5 Measuring Initialization Time

Objective: To confirm the initialization time of the PIC is under 100µS (ER6.2)

Procedure: Run the code and measure the time between initialization and the first codebook row

Conclusion: Microcontroller is ready to scan under 41us which meets the requirement





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Budget

Component	Quantity	Price
Parts	2 Sets	$319
(Phase Shifter)	4	($13 each)
(Antenna)	4	($11 each)
Assembly	2	Free(due to purchase size)
GPS Receiver		$120(already owned)
Raspberry Pi	1	$120
PCB	5	$336
MISC		$30-40
Taxes/Tariffs/Fees		$246
Total		**~$1060**

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Schedule

Initial Research/Concepts	PCB/Code Development	Testing/Optimization	Documentation
Ideal: September 2025 **Actual: Mid November 2025**	**Ideal: Early February 2026** **Actual: Mid March 2026**	**Ideal: Early April 2026** **Actual: Ongoing**	**Ideal: Ongoing** **Actual: Ongoing**
Develop understanding of fundamentals and begin to start developing first blocks (conceptual layout/early code)	Get finalized forms of both PCB and Code for first implementation	Complete robust testing for use-cases and applications of JamGuard	Complete documentation of project
Key Issue: Dunning-Kruger	Key Issue: Lack of KiCAD experience	Key Issue: Late Dev of PCB and manufacturing/exporting issues	

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Supporting Courses

Past/Current:

EE 282 - Engineering Modeling Lab
EE310 - Introduction to Microcontrollers
EE 430 - Electromagnetics Theory and Applications
EE 444 - Introduction to RF Communications
EE 444L - Introduction to RF Communications
EE 470 - Introduction to Internet Of Things

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Demonstration Video

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Future Work

Board Improvements:

- Add onboard voltage regulators
- Idealize component spacing and fix missed board issues
- Correct Connector
- Achieve true 50Ω across RF chain

Future Testing:

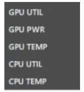
- Implement “jammer” signal
- Increase compatibility testing
- Test null-forming code

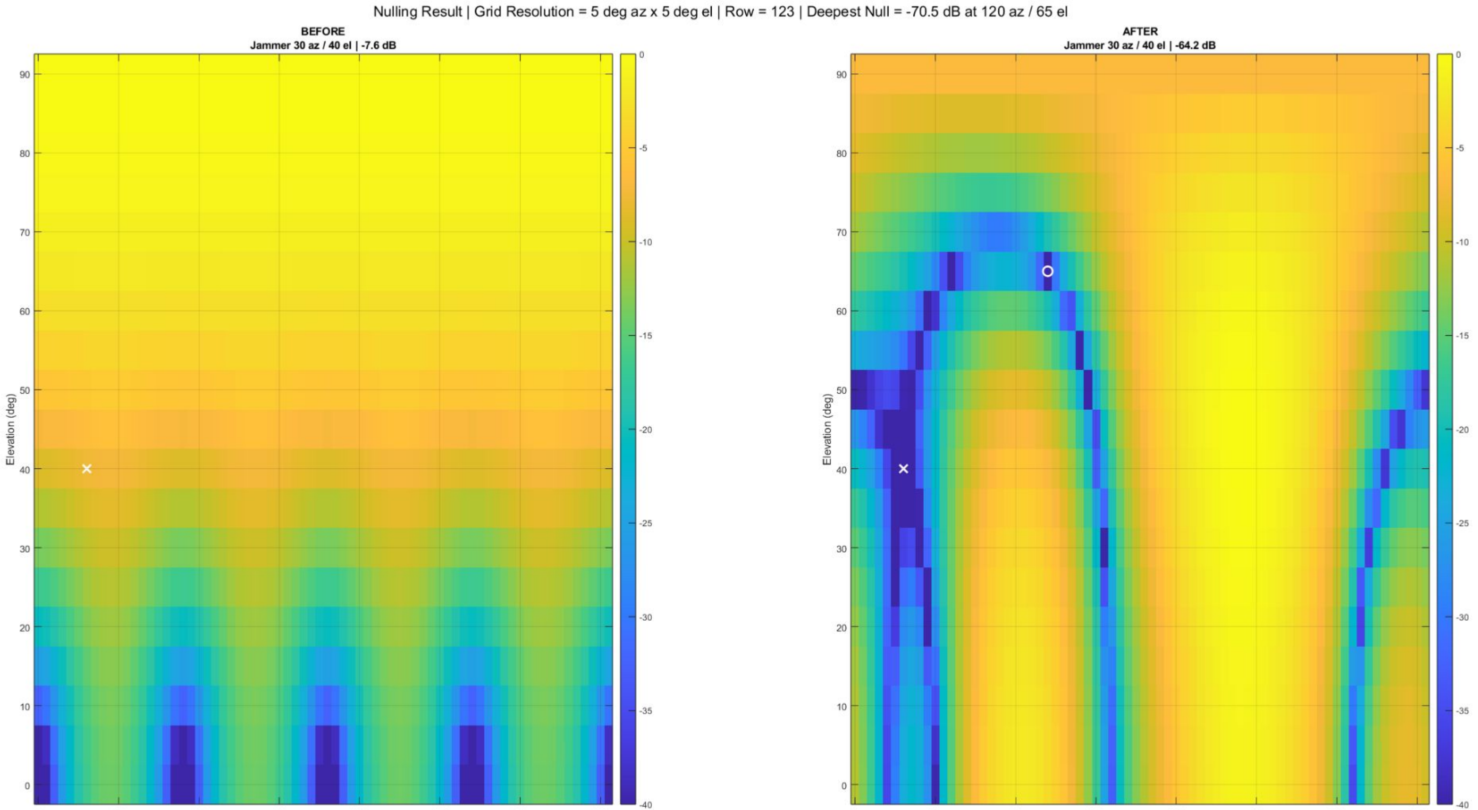
Questions/Comments

We want to acknowledge funding from the Center for Environmental Inquiry (CEI) at Sonoma State University: **The Norwick Memorial Fund**

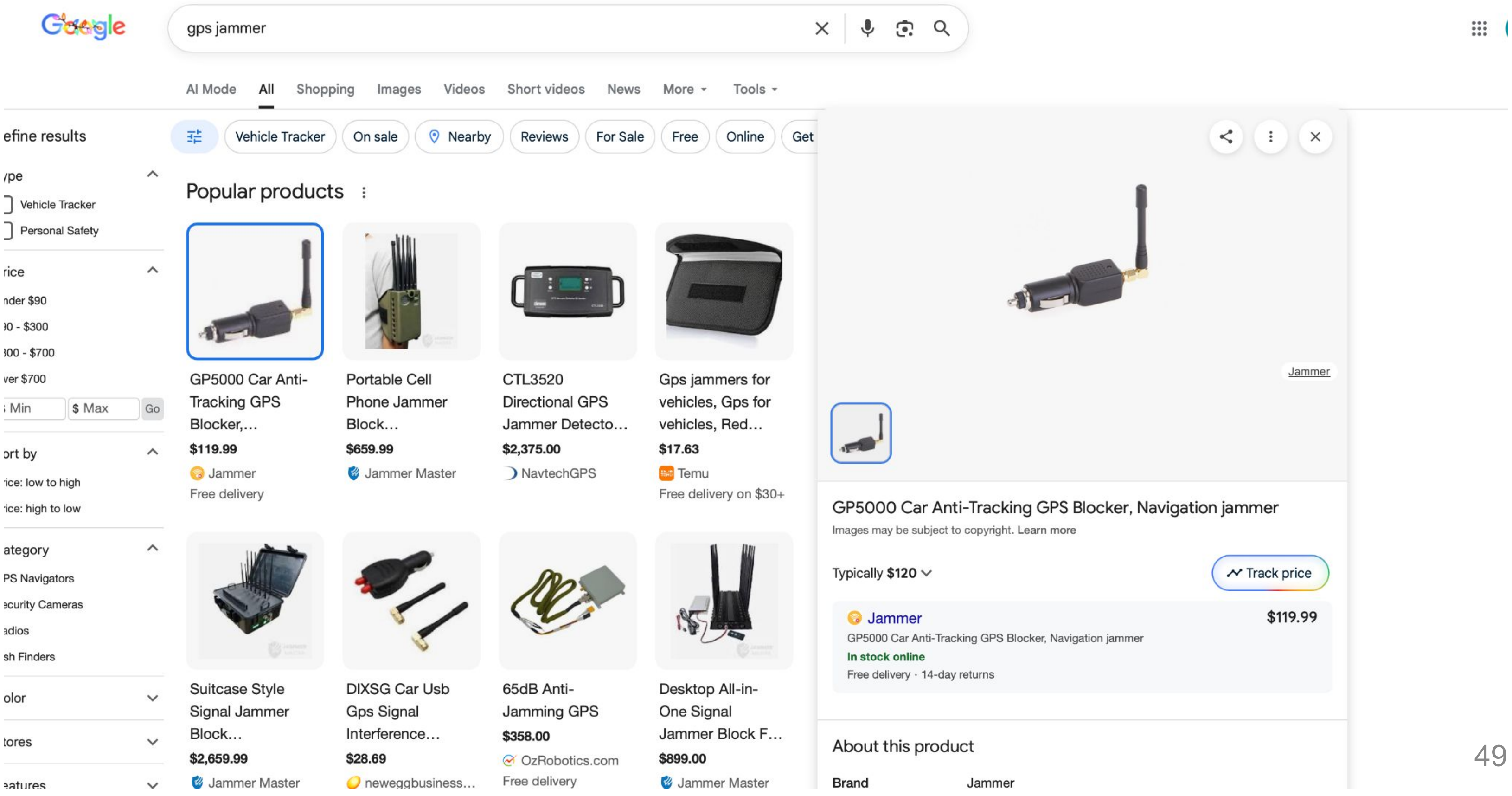
Supporting Slides

Null Depth Example





Supporting Slides - Existing Problems



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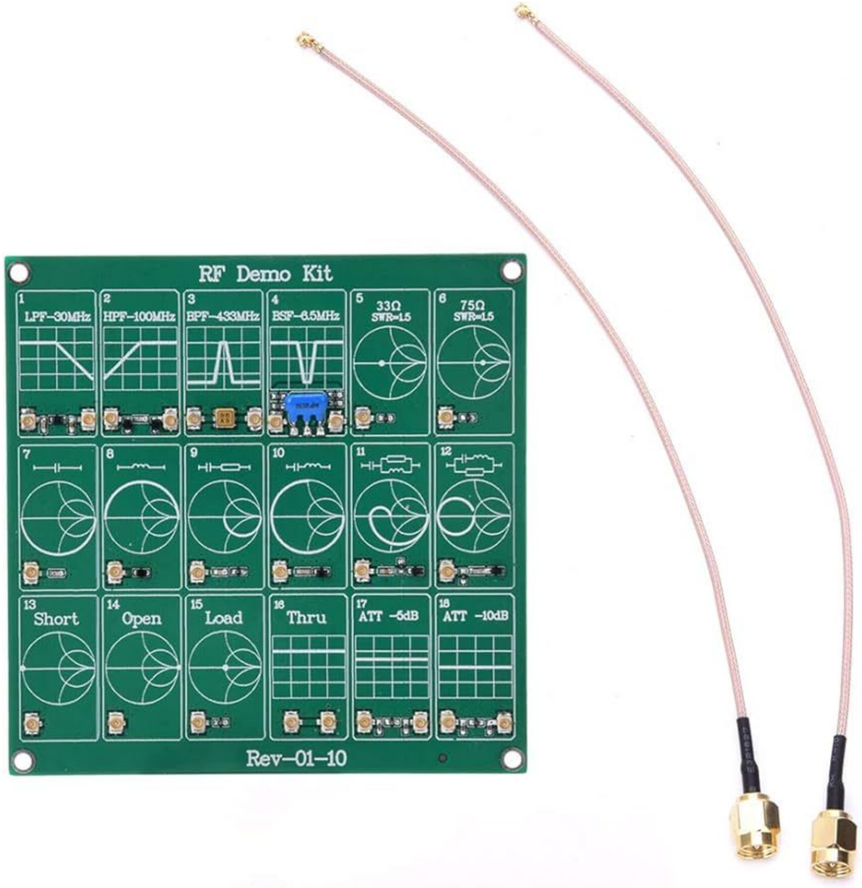
Supporting Slides - RF Demo Kit



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Part Cost

PCBWay

PCBWay Bom Quotation, Product No.:T-5D2W911214A

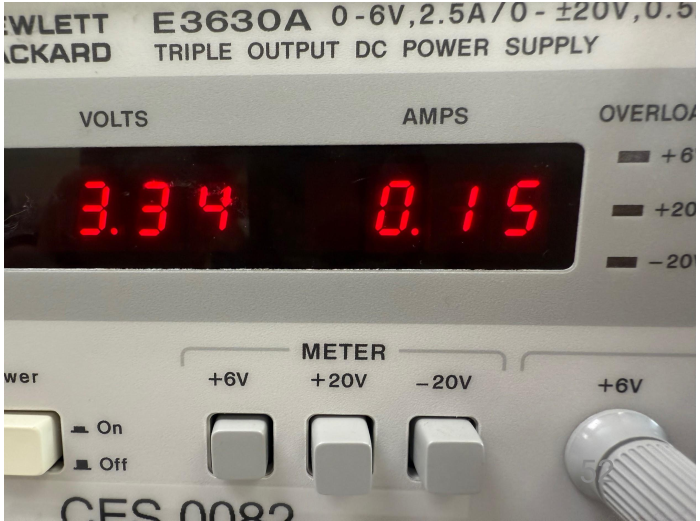
Item #	*Designator	*Qty	Description / Value	*Unit Price(2 units)	*Total	*Delivery Time	*Actual Purchase Mfg Part #	*PCBWay Note
1	AE5,AE6,AE7,.	4	Antenna_Chip	$11.677	$93.416	7-10 Workdays		
2	C12,C13,C15,(	23	100 pF	$0.011	$0.506			
3	C21,C25,C28,(	8	1200 pF	$0.071	$1.136			
4	C23,C26,C27,(	8	1 uF	$0.071	$1.136			
5	C46,C49	2	.1 uF	$0.060	$0.240			
6	HY2	1	DC1722J5010AHF	$3.303	$6.606	7-10 Workdays		
7	IC15,IC16,IC18	9	SGL0622Z	$0.839	$15.102			
8	IC17,IC20,IC21	4	PE44820B-X	$13.811	$110.488			
9	IC28	1	BP4P1+	$7.094	$14.188			
10	IC29	1	AD8318	$15.483	$30.966		AD8318ACPZ-REEL7	Original part is not available, substitute we will supply is AD8318ACPZ-REEL7 (LFCSP-16(4x4) ,pls confirm ok?
11	IC30,IC31,IC32	4	DPX162500DT-8014A1	$0.968	$7.744	7-10 Workdays		
12	J2	1	Conn_02x05_Odd_Even	$1.223	$2.446			
13	J3	1	Conn_Coaxial	$0.408	$0.816			
14	L10,L11,L12,L1	9	68 nH	$0.123	$2.214		LQW18AN68NG00D	Original part is not available, substitute we will supply is LQW18AN68NG00

Supporting Slides-Power Calculation

Expected Current 3.3V rail
9- SGL6022Z Amps - 9 mA each

4-PE44820 Phase Shifters - 20 uA each

Actual Current
3.3 V rail
- 150 mA



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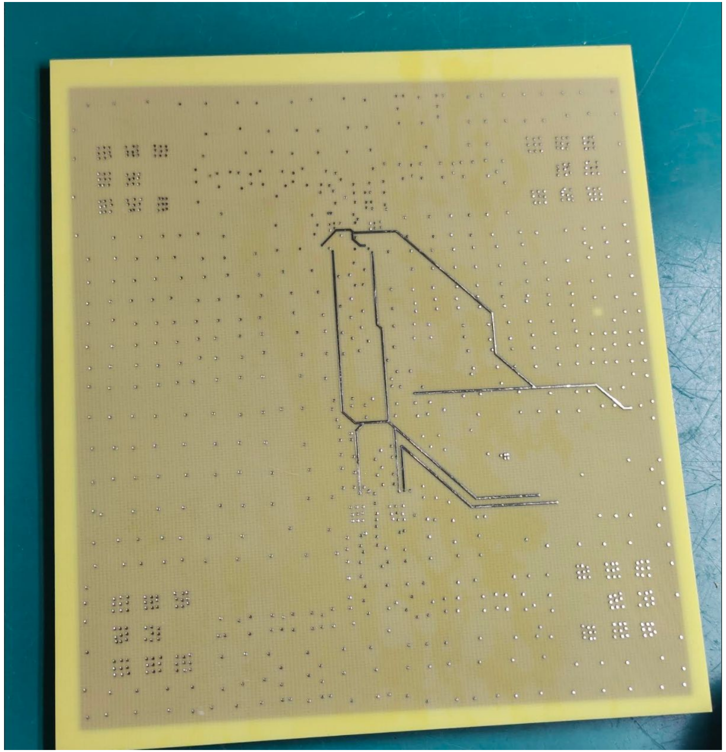
Supporting Slides-Manufacturing Troubles



Here it is! Same idea, soldermask on back, if not specified should be full coverage

Extra FT- Worst case Scan time

Objective: Figure out the worst case scan time

```
best_row = ScanCodebookBestRow();
scan_done = true;
```

Target halted. Stopwatch cycle count = 3822 (3.822 ms)

Result: Worst case scan time is 3.822 ms

Conclusion: Some delays for RF settling increased the scan time

Noise Figure

$$F_{total} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3} + \frac{F_5 - 1}{G_1 G_2 G_3 G_4} + \frac{F_6 - 1}{G_1 G_2 G_3 G_4 G_5}$$

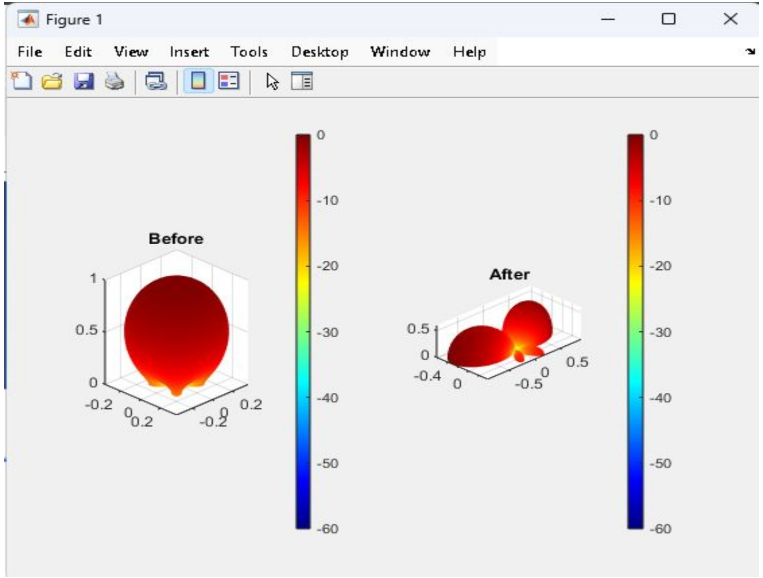
1. Filter
2. Amp 1
3. Amp 2
4. Phase shifter
5. Combiner
6. Coupler

F(total) = ~1.6

NF = ~2.15 dB

Simulation V3

- **Implemented full 2D array simulation with 3D pattern visualization**
- **Built 5° × 5° lookup-table (codebook) for fast null steering**
  – Each entry stores phase settings for a specific jammer direction
- **Demonstrated before-and-after null patterns using codebook**
  Achieved strong jammer suppression with phase-only control
- **Realistic constraints applied:**
  – Phase shifter step size
  – Array spacing (0.5λ)
  – Expected null width based on resolution



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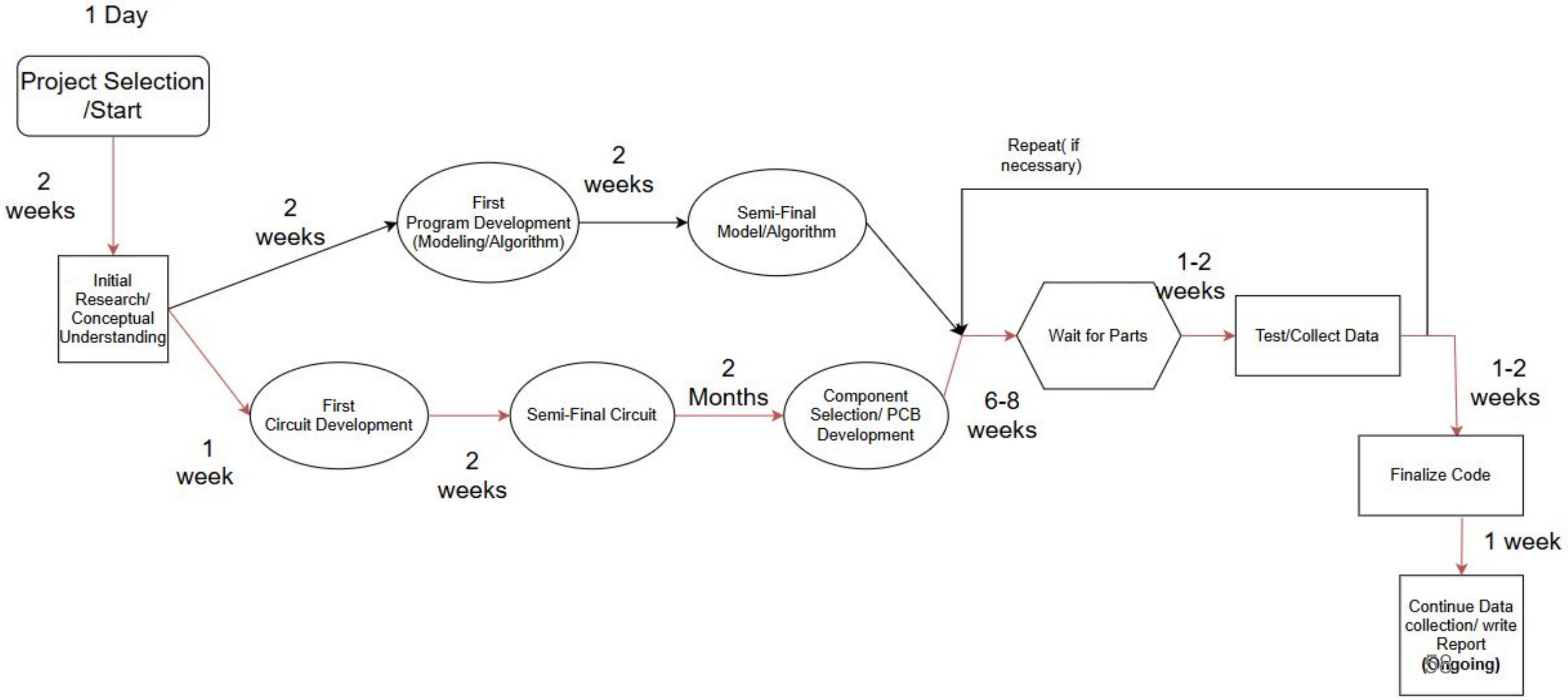
List of Components

1	Reference	Qty	Value	Manufacturer_Name	Manufacturer_Part_Number
2	AE5,AE6,AE7,AE8	4	Antenna_Chip	Taoglas Limited	DSGP.1575.18.2.A.02
3	C11,C12,C13,C14,C15,C16,C17,C18,C19,C20,C22	23	100 pF	Murata	GRM1885C1H101JA01D
4	C21,C25,C28,C31,C34,C37,C40,C43	8	1200 pF	Murata	GRM1885C1H122JA01D
5	C23,C26,C27,C30,C35,C38,C41,C44	8	1 uF	Murata	GRM188R71E105KA12D
6	C46,C49	2	.1 uF	Murata	GRM188R71C104KA01D
7	HY2	1	DC1722J5010AHF	ANAREN	DC1722J5010AHF
8	IC15,IC16,IC18,IC19,IC22,IC23,IC25,IC26,IC27	9	SGL0622Z	Qorvo	SGL0622Z
9	IC17,IC20,IC21,IC24	4	PE44820B-X	Peregrine Semiconductor	PE44820B-X
10	IC28	1	BP4P1+	Mini-Circuits	BP4P1+
11	IC29	1	AD8318	Analog Devices	AD8318ACPZ
12	IC30,IC31,IC32,IC33	4	DPX162500DT-8014A1	TDK	DPX162500DT-8014A1
13	J2	1	Conn_02x05_Odd_Eve	CNC Tech	3221-10-0300-00
14	J3	1	Conn_Coaxial	HiRose Electric	U.FL-R-SMT-1
15	L10,L11,L12,L13,L14,L15,L16,L17,L18	9	68 nH	Murata	LL1608-FSL68NJ
16	R1	1	499	Yageo	RC0603FR-07499RL
17	R2,R3,R4,R5,R6,R7,R9,R10,R11	9	0	Yageo	RC0603JR-070RL
18	R12	1	49.9	Yageo	RC0603FR-0749R9L
19	R13	1	52.3	Yageo	RC0603FR-0752R3L

Critical Path



Likelihood → Consequences ↓	Rare (1)	Unlikely (2)	Possible (3)	Likely (4)	Certain (5)
Catastrophic (5)	Jamming Test damages Hardware (5)	Complete PCB Failure (10)	Testing Environment Unavailable (15)	Specific RF Hardware Unavailable (20)	System Requires Multiple Iterations Beyond Available Time (25)
Major (4)	Algorithm Produces Unstable Outputs (4)	RF Interference Degrades Testing Results (8)	Algorithm Failure (12)	PCB Fabrication Issues (16)	Multiple Debug Phases Slow Integration (20)
Moderate (3)	Soldering Components Onto PCB (3)	Incompatibility between software and hardware (6)	Learning RF Measurement Tools (9)	Continued Algorithm Development (12)	Calibration Drift Over Time (15)
Minor (2)	Hardware Wear and Tear (2)	Tooling or Scripting Errors (4)	Substitute Components (6)	Setting Up Testing Plans (8)	More Testing Than Anticipated (10)
Negligible (1)	Formatting Issues (1)	Communication Issues in Group (2)	Project Organization (3)	Meetings With Advisors (4)	Time Spent Testing (5)

where :

m,n : antenna index in the x- and y-directions

k : wave number ($2\pi/\lambda$) where λ is the wavelength

d : distance between two adjacent antennas

θ : elevation angle

ϕ : azimuth angle

$\phi_{m,n}$: phase shifter phase for antenna at (m,n)

References

- IEEE Guide for