

Executive Summary

This project focuses on designing and implementing a monopulse antenna system capable of accurately determining the angle to a target. The system processes sum (Σ) and difference (Δ) signals of echoed electromagnetic waves to estimate direction in both azimuth and elevation directions.

The design integrates RF components, including a rat-race coupler and an AD9361 transceiver, with FPGA-based digital signal processing. MATLAB and Simulink were used to model and validate the monopulse algorithm before FPGA implementation.

The goal is to achieve accurate angle estimation ($\pm 3^\circ$) while maintaining a compact and cost-effective system suitable for real-world applications.

Background

Monopulse radar systems are used in applications such as:

- Radar tracking
- Aerospace guidance
- Communication systems

Unlike traditional scanning systems, monopulse systems determine direction using a **single pulse**, making them faster and more accurate.

Our system operates at 5.8 GHz, which allows:

- Smaller antenna size
- Better directional control

Key concept:

- When the target is centered $\rightarrow \Delta = 0$
- When off-center $\rightarrow \Delta/\Sigma$ gives angle information

The system consists of:

- 2x2 Patch Antenna array
- Rat-race coupler (comparator, outputs Σ and Δ signals)
- RF front-end (filtering, amplification, base-band processing) using AD9361
- FPGA (ZedBoard) for faster digital signal processing and switching than a microcontroller
- MATLAB/Simulink for modeling and validation
- Signals are processed digitally to compute:
 - Monopulse ratio (Δ/Σ)
 - Angle of arrival

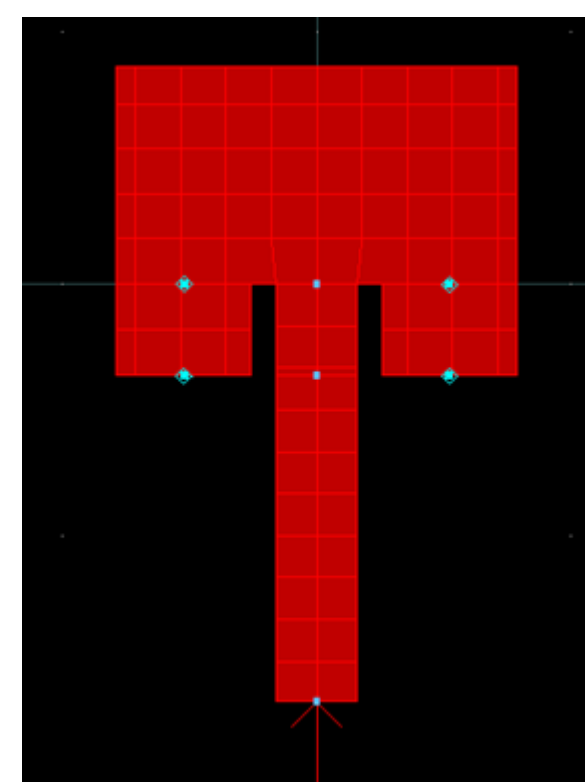
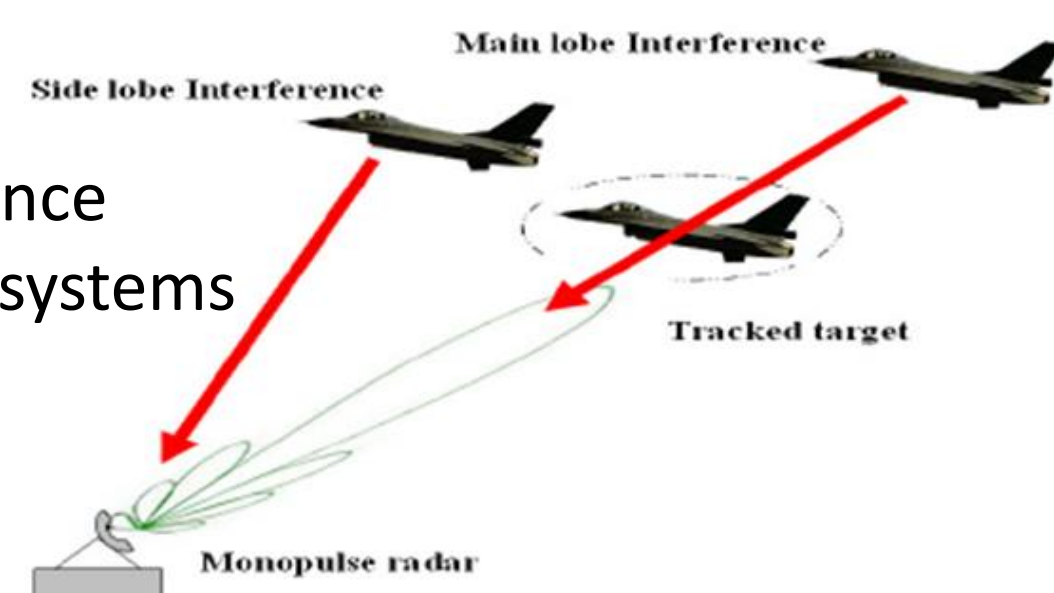
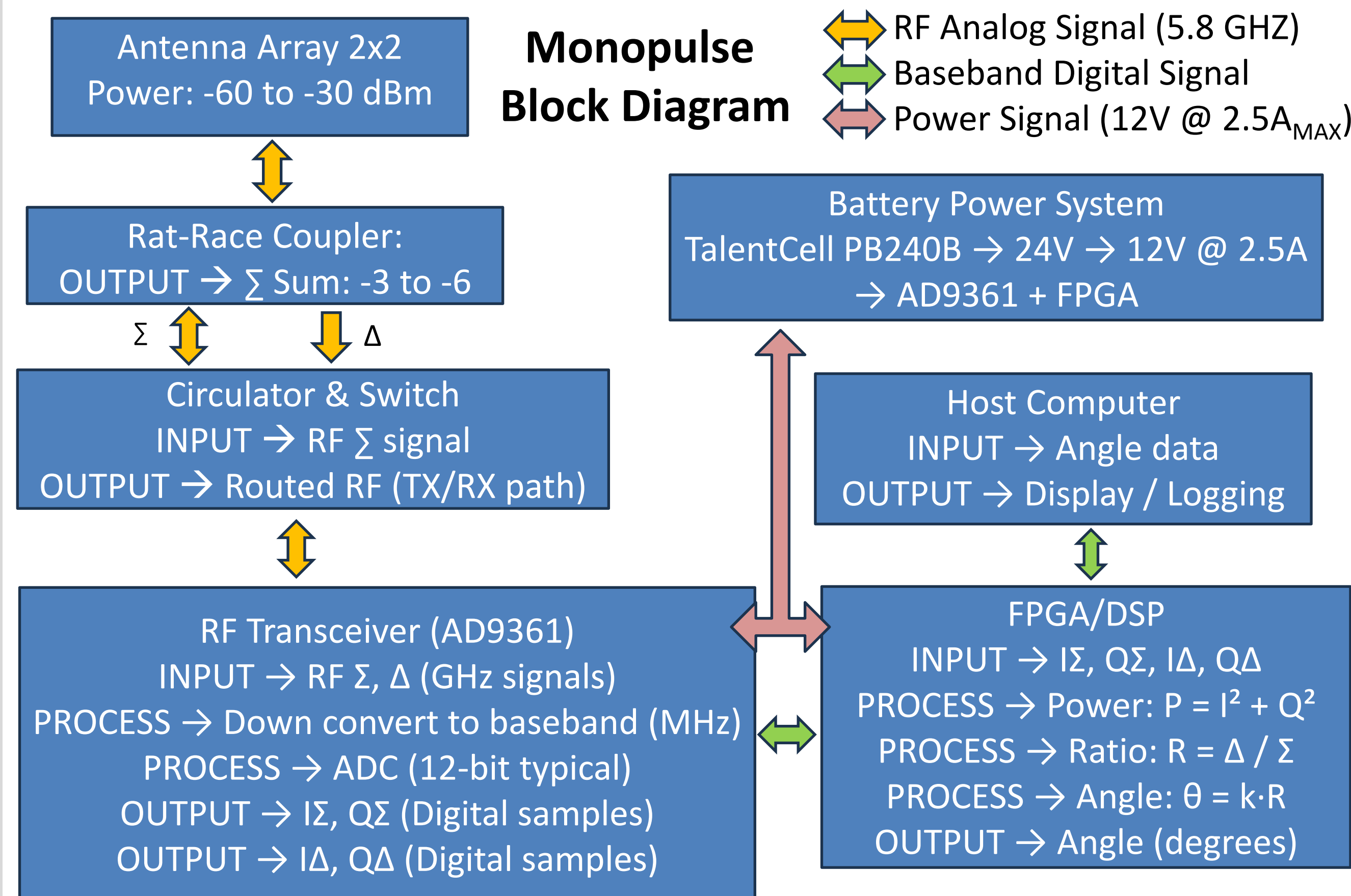


Fig. 1. ADS Single Inset-Fed Microstrip Patch Antenna

Experimental Setup



Experimental Test Plan

Antenna Test Plan:

- Frequency: 5.8 GHz
- Substrate: FR4
- Patch size: $L \approx 11.9\text{mm}$, $W \approx 15.73\text{mm}$
- 2x2 array spacing $\approx \lambda/2$

RF Front-End Test Plan:

- AD9361 used for RF transceiver
- Problem:
- only 2 RX channels
- Solution:
- Circulator $\rightarrow$ share TX/RX
- RF Switch $\rightarrow$ select Δ/Σ

Rat-Race Test Plan:

- Measure and verify port reflections and through-port transmission on e-mag lab VNA
- Verify Σ and Δ port gain given test signals

FPGA Test Plan:

MATLAB:

- Modeled Σ and Δ
- Computed ratio: Δ/Σ
- 4-channel system: A, B, C, D
- Azimuth + Elevation
- Simulink: added delays (FPGA behavior)
- Issue: fixed-point caused precision errors

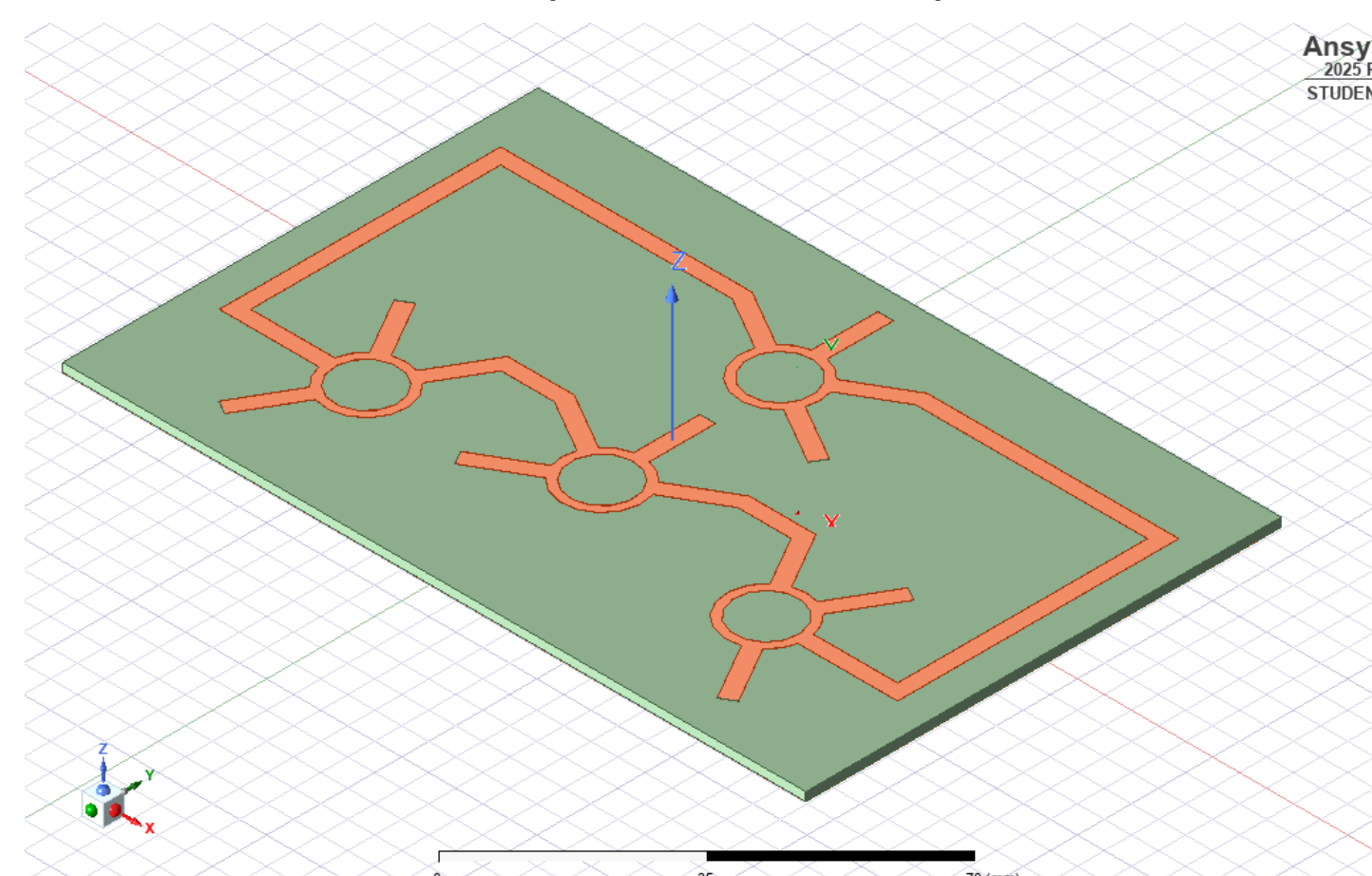


Fig. 2. Rat Race Comparator

Experimental Results

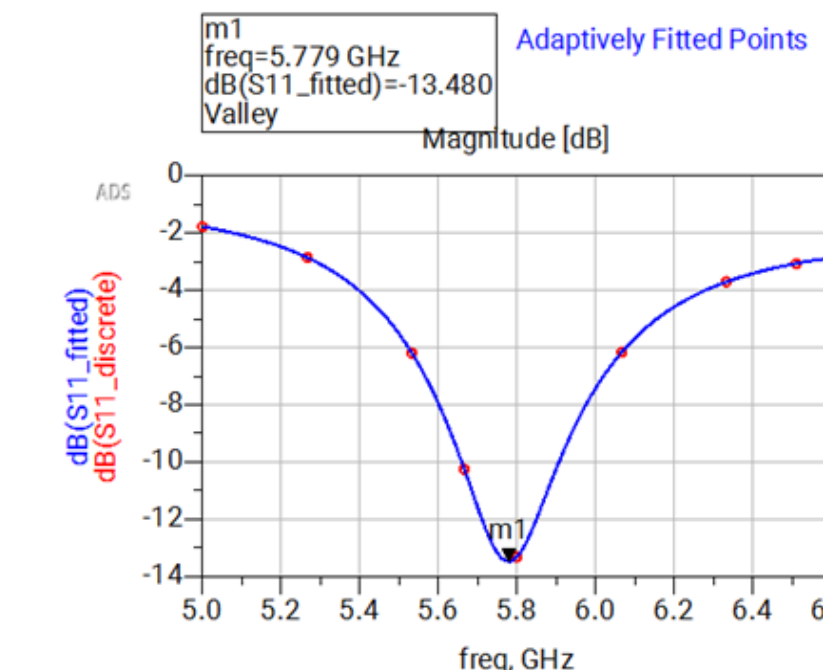


Fig. 3. ADS S11 Resonance at 5.8 GHz

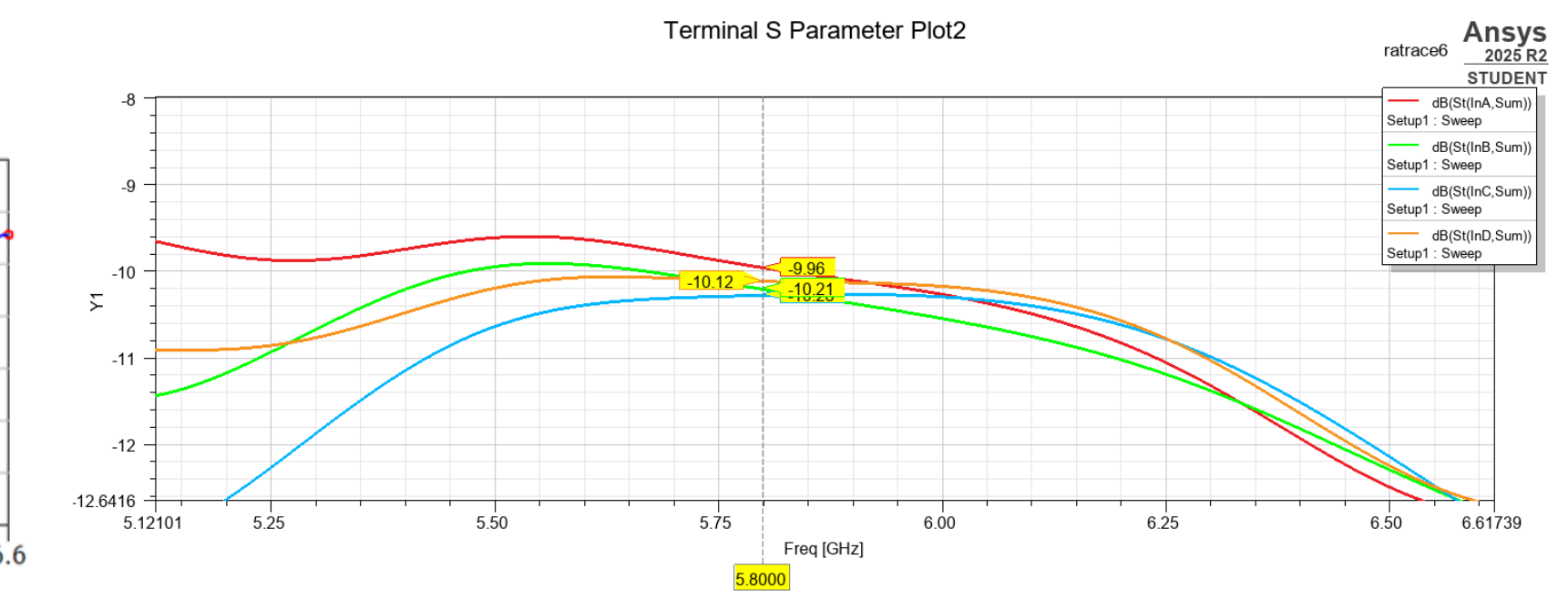


Fig. 4. HFSS Rat Race Comparator, demonstrating $\sim$ even power split at Σ port

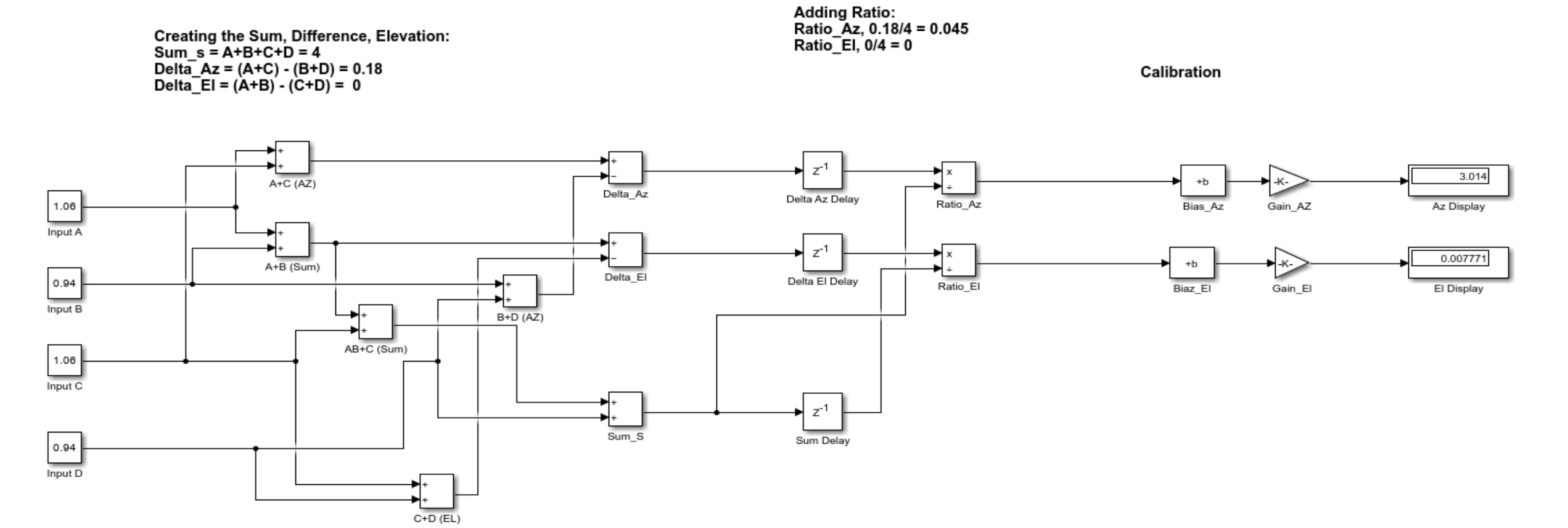


Fig. 5. MATLAB DSP/FPGA (Δ/Σ ratio, 4-channel system, and calibration)

Conclusions

- This project presents the design and system-level architecture of a monopulse antenna system targeting 5.8 GHz. The use of sum (Σ) and difference (Δ) signal processing enables accurate direction estimation, with the monopulse ratio (Δ/Σ) serving as the key parameter for angle determination.
- Simulation and modeling in MATLAB and Simulink validated the functionality of the monopulse algorithm and highlighted important implementation challenges, particularly with fixed-point precision in FPGA-based processing. Hardware design constraints, such as the limited number of receive channels in the AD9361 transceiver, were addressed through the integration of a circulator and RF switch, demonstrating practical engineering trade-offs.
- Overall, the antenna and feed network were validated at the component level, with system-level integration modeled in MATLAB and Simulink. Future work will focus on full hardware testing, system calibration, and improving angle estimation accuracy to achieve the target performance of $\pm 3^\circ$.

References

Antenna

- K. N. Patil and A. D. Jadhav, "2 $\times$ 2 Microstrip Patch Antenna Array for Improving the Power Conversion Efficiency of RF Energy Harvesting," in Proc. IEEE Int. Conf. Communication, Computing and Signal Processing (IICCCS), 2024.
- Y. Albaihani et al., "5.8 GHz Microstrip Patch Antennas for Wireless Power Transfer: A Comprehensive Review of Design, Optimization, Applications, and Future Trends," Electronics, vol. 15, no. 311, 2026.

RF Front-End

- What Are I/Q Signals? Everything RF, www.everythingrf.com/community/what-are-i-q-signals.
- Rothschild, Auro. IQ Demodulator." Auro Rothschild, www.aurothschild.net/posts/IQ-Demodulator/.

FPGA

- FPGA-Based Monopulse Technique Workflow (Part 1). MathWorks, www.mathworks.com/help/dspdl/ug/fpga-based-monopulse-technique-workflow-part-1.html
- MATLAB HDL Coder: Custom FPGA PWM Modulator Implementation. Imperix, imperix.com/doc/help/matlab-hdl-coder.

Monopulse Example

- Elgamel, Sherif A., and John J. Soraghan. Jamming Scenarios for Monopulse Radar. Fractional Fourier Transform Based Monopulse Radar for Combating Jamming Interference, 2010. ResearchGate, https://www.researchgate.net/figure/fig1/AS:296933462691848@1447805862740/Jamming-scenarios-for-Monopulse-radar_Q320.jpg.