Analysis and Reflection on a Four-Element Antenna Array System With 15 Reconfigurable Radiation Patterns

Angelica M. Gutierrez
School of Electrical Engineering & Computer Science
Washington State University
Richland, WA 99301, USA
angelica.gutierrez@wsu.edu

***Abstract*—This report summarizes and reflects on the paper A Four-Element Antenna Array System With 15 Reconfigurable Radiation Patterns [1]. The study introduces a compact planar antenna array capable of generating 15 distinct radiation patterns in the azimuthal plane. Each element consists of two printed Yagi–Uda antennas that radiate into separate sectors, providing high isolation and directional control. A reconfigurable feeding structure, composed of four independent networks with integrated PIN diodes and a one-to-four power divider, enables on-demand beam selection while maintaining operation at a fixed frequency of 5.8 GHz. The system achieves approximately 9 dBi gain per element, a 44° half-power beamwidth, and −16 dB sidelobes, with strong agreement between measured and simulated results. In addition to summarizing the work, this report discusses the key electromagnetic concepts reinforced through the study and how they relate to my graduate research and professional development in RF system design.**

***Index Terms*—Reconfigurable antennas, Yagi−Uda, PIN diodes, beam steering, 6G.**

I. Introduction

Reconfigurable antennas are a growing field in electromagnetics, offering the ability to adapt their frequency, polarization, or radiation pattern in response to changing operational demands. This flexibility improves link reliability, minimizes interference, and enables communication systems to maintain performance across diverse environments. Among these technologies, pattern-reconfigurable antennas stand out for their ability to electronically steer or reshape radiation beams—enhancing the signal-to-noise ratio and overcoming multipath fading without mechanical movement [1].

To place the design discussed in this report into a broader context, I performed background research on practical uses of reconfigurable antennas in both communication and defense systems. In next-generation wireless research, electromagnetically reconfigurable antennas (ERAs) are considered central to 6G networks, supporting intelligent beam steering, frequency agility, and polarization control for massive multiple-input multiple-output (MIMO) and integrated sensing applications [2].

In the defense sector, Lockheed Martin's GPS Spatial Temporal Anti-Jam Receiver (GSTAR) provides a real-world example of beam-steering and nulling in action, using adaptive electronic control to maintain assured GPS operation in contested environments, as illustrated in Fig. 1. The GSTAR system integrates controlled beam direction with mission equipment and is deployed across both manned and unmanned platforms, as shown in Fig. 2, highlighting its relevance to modern defense applications [3]. These examples show how reconfigurable antennas have evolved from experimental concepts into practical solutions that enable high-performance, resilient communication across multiple domains.

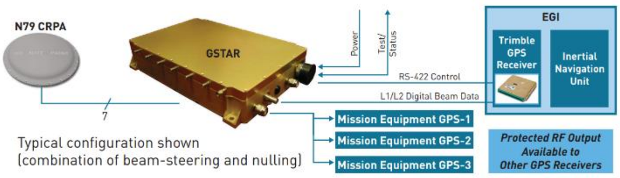

Fig. 1. Typical configuration of the Lockheed Martin GSTAR anti-jam GPS receiver showing beam-steering and nulling system connections.

Fig. 2. GSTAR deployment across manned and unmanned applications.

Building on these same principles, the paper *A Four-Element Antenna Array System With 15 Reconfigurable Radiation Patterns* [1] presents a compact, electronically controlled antenna array that uses PIN diodes to achieve beam reconfiguration. The system consists of four printed Yagi–Uda radiating units arranged in a cross-like layout, each radiating into a different sector of the azimuthal plane. A reconfigurable feeding network, composed of four diode-controlled branches connected to a one-to-four power divider, selectively distributes excitation signals among the elements. By switching the diode states, the array produces 15 distinct radiation patterns while maintaining a constant 5.8 GHz operating frequency.

This design demonstrates how PIN diodes (small, fast, and reliable semiconductor switches) can replace complex mechanical steering mechanisms in modern RF systems. It highlights how electromagnetic theory, circuit modeling, and practical fabrication converge to achieve adaptive functionality. The ideas presented in this paper directly reinforce topics I have studied in my graduate electromagnetics and antenna courses, including radiation-pattern synthesis, impedance matching, and array-feeding techniques, while connecting them to current 6G communication and defense-grade beam-forming technologies such as Lockheed Martin's GSTAR [3].

II. PATTERN RECONFIGURABLE ANTENNA SYSTEM

The reconfigurable antenna array presented by Patriotis et al. [1] is divided into three primary functional blocks that together enable beam control across multiple azimuthal directions. As illustrated in Fig. 3, the compact design occupies an area of 133 mm × 133 mm and is fabricated on a 0.79 mm-thick Rogers RT5870 substrate with dielectric constant $\varepsilon_r = 2.33$ and loss tangent $tan\delta = 0.0012$. The four identical radiating units are arranged in a cross-like configuration, each facing a distinct 90° sector of the azimuthal plane.

- Block 1 consists of four radiating units (1a–1d) that generate the directional beams.
- Block 2 includes four reconfigurable feeding networks (2a–2d), which determine the active sector by controlling two integrated PIN diodes per branch.
- Block 3 serves as the one-to-four power divider, distributing the excitation signal evenly to the radiating units (Block 1) and through the reconfigurable feeding network (Block 2).

Through the coordinated operation of these three subsystems, the antenna array achieves 15 distinct reconfigurable radiation patterns at a fixed 5.8 GHz operating frequency, enabling full 360° azimuthal coverage with strong sector isolation and minimal mutual coupling.

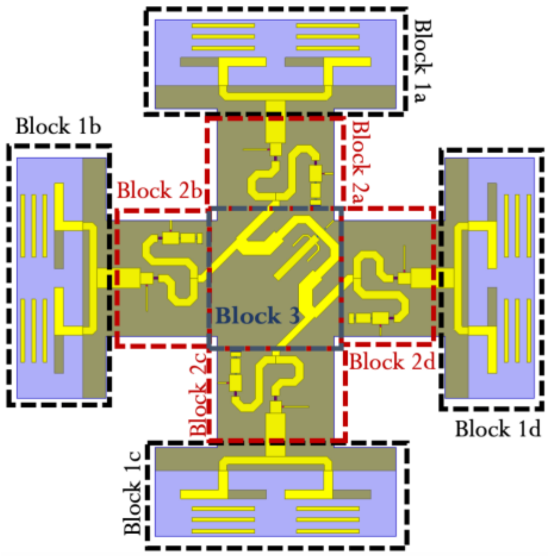

Fig. 3. The proposed antenna system with 15 reconfigurable radiation patterns over four different sectors in the azimuthal plane.

A. *BLOCK 1 – Two-Element Radiating Unit*

Each radiating unit consists of two printed Yagi–Uda dipole elements arranged in an antipodal configuration to minimize the overall footprint while maintaining balanced excitation. Each dipole is approximately $0.5\lambda_g$ long at 5.8 GHz, providing good impedance matching between the feed and the radiating structure.

The array is positioned $0.15\lambda_g$ above a conducting ground plane that functions as a reflector, improving forward radiation and minimizing back-lobes. In front of each dipole are three parasitic directors, each 16 mm long and separated by 1.9 mm, which enhance directivity and produce the end-fire radiation characteristic of Yagi–Uda designs.

Although the detailed geometry is illustrated in Fig. 4, the essential takeaway is that the spacing between the dipoles, directors, and ground plane enables high isolation between adjacent beams while keeping the structure compact. Simulation results reported by the authors indicate a maximum gain of 9 dBi, 44° half-power beamwidth (HPBW), and −16 dB sidelobe level, confirming strong beam confinement and minimal sector coupling. These characteristics allow each direction to be selectively activated by the reconfigurable feeding network.

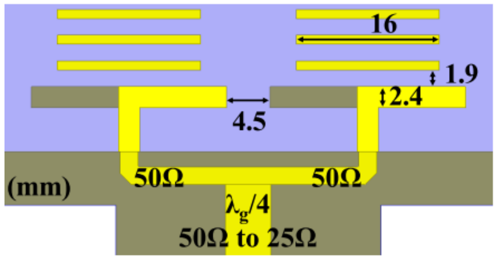

Fig. 4. Design of the two-element radiating unit (Block 1) showing dipole elements, directors, and feed structure.

B. *BLOCK 2 – Reconfigurable Feeding Network*

The reconfigurable feeding network forms the active core of the antenna system, allowing electronic control over which radiating unit transmits at a given time. Each network includes a single input port and two output branches: one connected to the antenna element and the other terminated with a 50 Ω matched load.

Two PIN diodes, labeled d_L and d_R, determine the routing of the RF signal. They are mounted on parallel 50 Ω microstrip transmission lines, TL_Left and TL_Right, each with an electrical length of 180° at 5.8 GHz. The diodes (Skyworks SMP1321-040LF) act as semiconductor RF switches, when one is ON (forward-biased), current flows through its branch toward the antenna or load, while the other diode in the OFF state behaves as a virtual open circuit at the input.

This selective biasing mechanism directs RF power only to the desired active path, isolating the remaining inactive units. The authors modeled the PIN diodes using their data sheet-based S-parameters to account for junction capacitance, forward resistance, and other parasitic effects, improving simulation realism.

Surface-current distributions, shown in Fig. 5(b), illustrate the network's two operating states:

- State 1: d_L *(ON)*, d_R *(OFF)* – the current flows toward the antenna port, activating the corresponding beam.
- State 2: d_L *(OFF)*, d_R *(ON)* – the current is directed into the 50 Ω termination, suppressing radiation while preserving impedance matching.

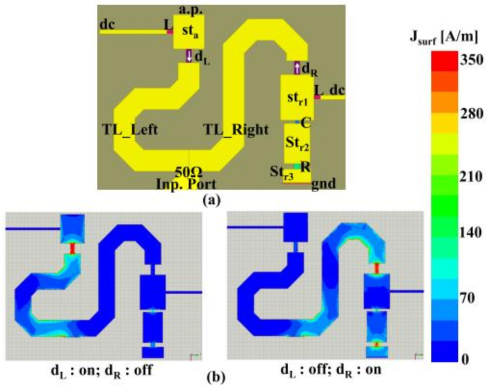

Fig. 5. (a) Design of the reconfigurable feeding network (Block 2). **(b)** Surface-current distribution for the two diode states, illustrating power routing between the antenna and load paths.

Each diode is forward-biased at 10 mA at 3V through 27 nH RF-choke inductors and high-impedance bias lines that prevent DC interference with the RF path. The left branch connects to the antenna through a 3 mm × 3.2 mm matching section (st_a), whereas the right branch terminates at the load through a sequence of matching sections 3.2 mm × 4.3 mm (st_{r1}), 2.5 mm × 3.8 mm (st_{r2}), and 2.5 mm × 1.3 mm (st_{r3}) and a 9.9 pF DC-block capacitor (L).

The measured S-parameter performance demonstrates excellent switching behavior. In the d_L *ON* d_R *OFF* state, both S_{11} and S_{22} remain below -10 dB from 3.3 − 6 GHz, while $S_{21\,|\,12}$ at 5.8 GHz reach −0.75 dB. When d_L *OFF* d_R *ON* is applied, the input port stays well matched from 4.4 − 6.3 GHz, achieving isolation above 10.8 dB due to deliberate output mismatch.

These results confirm that the PIN-diode feeding network effectively routes RF energy, maintains good matching, and enables 15 unique beam states when implemented across all four array branches.

C. BLOCK 3 – Power Splitter

The final stage is a one-to-four power splitter that distributes the input RF signal uniformly to the four reconfigurable feeding networks. Center placement ensures phase balance and consistent excitation across all radiating units (see Fig. 6).

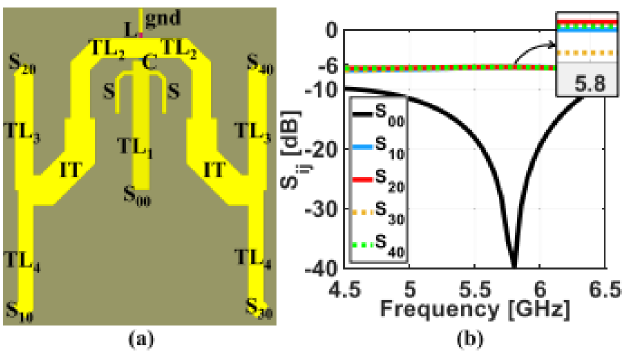

Fig. 6. (a) One-to-four power divider (Block 3) layout with TL, stub, and matching sections; **(b)** corresponding S-parameters showing ≈ -6.38 dB transmission at 5.8 GHz and good match over 4.5 − 6.5 GHz.

The splitter starts with a 50 Ω, 155° line (T_{L1}) that is divided into two 50 Ω, 142° lines (T_{L2}) connected in parallel. Each branch is matched by a quarter-wavelength impedance transformer (35 Ω, 90°) that feeds the output lines (T_{L3}) at 55 Ω and 155° and (T_{L4}) at 63 Ω and 148°. Two 80 Ω, 25° stubs (S) provide fine impedance trimming over bandwidth. A 9.9 pF DC-block capacitor (C) protects the RF input from the diode-bias network, and a 27 nH RF-choke inductor (L) at the center node supplies a common DC return for the PIN-diode networks. In practice, T_{L3} sections are made slightly wider to compensate for stronger coupling introduced by the quarter-wave transformer region.

The splitter response in Fig. 6(b) shows broadband operation from 4.5 − 6.5 GHz with near-equal transmission to all four ports. At the design frequency 5.8 GHz, the transmission magnitude is about −6.38 dB, consistent with an ideal one-to-four split and modest divider loss. This performance underpins uniform drive to each Block 2 network and supports stable beam formation across all 15 states.

III. Prototype Model And Measurements

The complete antenna prototype was fabricated by integrating the three functional blocks: the radiating units, reconfigurable feeding networks, and one-to-four power splitter onto a single Rogers RT5870 substrate. The assembled design is shown in Fig. 7, with four active PIN diodes connecting the radiating units and four additional diodes providing load terminations. By selectively biasing these switches, the array can generate 15 distinct radiation states, each corresponding to a unique binary combination of active sectors.

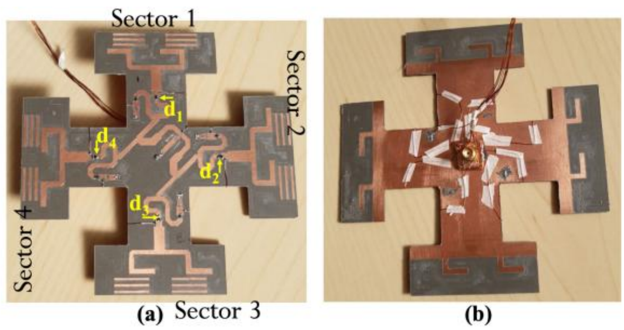

Fig. 7. Fabricated prototype of the four-element antenna array showing **(a)** top view with integrated PIN-diode biasing and **(b)** bottom view with DC wiring.

During experimental testing, the diodes were manually biased through DC wires, although the authors note that a microcontroller could be implemented for automated control in future designs. Because the feeding network is coplanar with the radiating structure, the overall system maintains impedance consistency and minimizes unwanted coupling among the elements.

The measured input-reflection coefficients for all 15 configurations show strong agreement with simulation, maintaining good impedance matching between 5 GHz and 6 GHz and a well-defined resonance at 5.8 GHz. The corresponding radiation patterns, presented in Fig. 8, confirm that the antenna accurately forms directional beams for one, two, or three simultaneously active sectors. In each case, the measured and simulated beams align closely, demonstrating reliable isolation between inactive sectors and stable pattern reconfiguration.

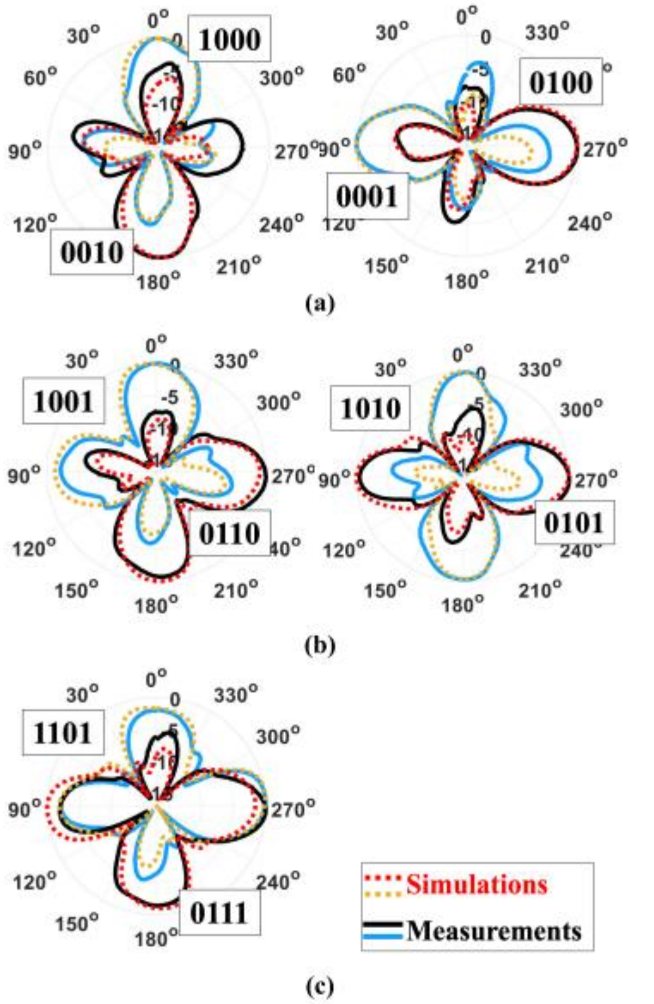

Fig. 8. *Simulated and measured reconfigurable radiation patterns of the proposed four-element antenna array at 5.8 GHz for different activation cases:* ***(a)*** *one active sector,* ***(b)*** *two active sectors, and* ***(c)*** *three active sectors. The close agreement between simulation (dotted lines) and measurement (solid lines) confirms accurate beam steering and strong sector isolation.*

At the design frequency, the array achieves a measured gain of approximately 9 dBi and a cross-polarization discrimination greater than 18 dB. Depending on the number of active radiating elements, the measured efficiency varies between 62% and 86%, consistent with simulated predictions. These results validate that the prototype achieves precise beam steering and stable operation using a compact, electronically reconfigurable structure.

IV. Conclusion And Reflection

This paper demonstrates a compact four-element, pattern-reconfigurable antenna array capable of producing 15 distinct beams at a fixed 5.8 GHz. Using a PIN-diode-based feeding network, a one-to-four power divider, and printed Yagi–Uda radiating elements, the system achieves approximately 9 dBi gain, stable impedance matching, and strong isolation between active and inactive sectors. The close agreement between measured and simulated results validates the design's efficiency, confirming that agile beam control and directional selectivity can be achieved without altering the operating frequency or compromising performance.

Analyzing this work strengthened several technical concepts I have studied throughout my master's program at Washington State University. The integration of reconfigurable feeds, impedance matching, and beam-steering networks reinforced what I practiced in my FDTD simulations, particularly in modeling Gaussian excitations, implementing absorbing boundary conditions, and extracting S-parameters for patch-antenna validation. The systematic verification between simulated and measured results parallels the engineering discipline I have developed across course lectures in electromagnetics, propagation, and link-budget analysis.

Although my current profession is not centered on RF system design, I work as an Electrical Engineer supporting the Hanford Site, where I help sustain and modernize the electrical infrastructure of the historic 222-S Laboratory, originally constructed in the 1950s. Our mission focuses on upgrading the lab's electrical systems, many of which now integrate or interface with RF and digital communication components to ensure safe, reliable, and compliant operation. The knowledge gained from studying reconfigurable antenna systems enhances my ability to evaluate installation environments, identify potential interference, and verify that electrical and RF systems are installed optimally and free of obstructions. In this way, the theoretical understanding from my graduate studies directly informs my practical engineering work, bridging the gap between RF theory and real-world system reliability.

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