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Designing and optimizing RIS unit cell with CST for mm-waves

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Abstract: Wireless communication is being modernized with reconfigurable intelligent surface (RIS) antennas, which enhance signal coverage, capacity, and energy efficiency. This project depicts the Rogers RT Duroid 5880 substrate design and simulation for a 28 GHz RIS antenna. Phase stability with varactor integration was detected in initial probations using a 'P' shaped unit cell without warning. The design was polished to an 'R' shape, and a stripline was added to boost phase response and delegate for dynamic phase modification. For electromagnetic simulations, CST software was utilized; however, MATLAB conceivable accurate phase visualization, hence rout CST's downsides. The resulting design shows amplified system efficiency, beamforming, and variability. However, because of analytical limitations, simulating a 32 by 32 RIS array caused difficulties. In the face of this, the discoveries highlight how RIS antennas can improve wireless communication performance, especially in knotted settings.

Keywords: Phase control, Rogers RT 5880, beamforming, reconfigurable intelligent surface (RIS).

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1. Introduction

Advances in smart antenna systems and reconfigurable intelligent surfaces (RIS) have led to fundamental developments in wireless communication systems. Signal coverage, capacity, and energy efficiency can all be fortified with RIS, which are meta-surfaces formed of configurable elements (ALRikabi et al., 2024; Dai et al., 2020; Naaz et al., 2024; Tang et al., 2020; Yildirim et al., 2021). By stewardship of the electromagnetic waves that navigate through them, these surfaces help to enhance many aspects of wireless networks, including power efficiency, spectrum utilization, and multipath interference (Fara et al., 2022; Huang et al., 2021). By strictly controlling radiation patterns, the incorporation of RIS with smart antenna arrays offers a qualified way to dynamically adjust beam shape and signal transmission (Hong, 2023; Pei et al., 2021; Zeng et al., 2020). To make adaptive systems that adjust to changing environmental factors and connection requirements and open the door for improvements in next-generation networks, such as 5G and 6G. This technology has divergence for automated systems, smart cities, and IoT ecosystems, among other smart settings (Gao et al., 2024; Kim et al., 2024; Zhao et al., 2024). Reconfigurable intelligent surface (RIS) incorporation into wireless communication systems has attracted a lot of attention, uncovering the technology's possible advantages as well as faults. The debate on multi-hop RIS-empowered terahertz communications, which introduces a hybrid beamforming design advanced by dusky reinforcement learning (DRL), is a remarkable addition to this object. By increasing signal propagation and coverage, this research offers a new method of routing in THz networks, resulting in a 50% rise in coverage over conventional approaches (Ahmed et al., 2024; Huang et al., 2021). The utilization of DRL in RI-assisted THz networks to handle problematic routing difficulties highlights the technology's possibility to encourage the increase of arriving wireless communication devices (Yuan et al., 2022).

Concerning multiple-input multiple-output (MIMO) devices, the research on MIMO transmission through RIS supplies a thorough scanning of how RIS might ameliorate communication that is energy efficient. In addition to addressing functional implementation challenges, this research provides a design for phase tunable RIS elements that declaration multi-frequency modulation (Tang et al., 2020). The recommended system's effectiveness and viability are bolstered by experimental validation, which closes the knowledge gap between abstract ideas and practical implementations.

The evaluation of RIS technology's potency to authorize vehicular networks sheds light on how RIS can strengthen signals, reduce interference, and superfast privacy to improve vehicle-to-everything (V2X) communication (Hu, 2024; Naaz et al., 2024). It examines cutting-edge technology like artificial intelligence and mobile edge computing, but it also attracts attention to a lack of empirical data from real-world vehicular networks, demonstrating the necessity for more examination and verification.

The study on RIS-based wireless communications concentrates on antenna design and prototyping and addresses real-world deployment challenges. The study presents a 256-programmable-element RIS system and shows notable gains in antenna gain and power consumption (Dai et al., 2020). The results of the experiments confirm that RIS technology could improve wireless communication performance by bridging theoretical and practical factors.

Another significant contribution is the prototype of RIS with continuous control of the reflection phase, which explores how RIS can improve signal quality through phase regulation (Fara et al., 2022). Although the study shows promising results, it primarily emphasizes prototype implementation without thorough performance evaluation.

The paper details the design and simulation of a 32 by 32 RIS array using Rogers RT 5880 substrate at 28 GHz, adapting the design from a 'P' shape to an 'R' shape with an added stripline to improve phase control. Electromagnetic simulations with CST and phase visualization with MATLAB revealed enhancements in tunability and beamforming, despite computational challenges with the large array. The results demonstrate RIS technology's potential to advance wireless communication performance in complex environments.

Figure 1 represents the flow chart to follow through the design process:

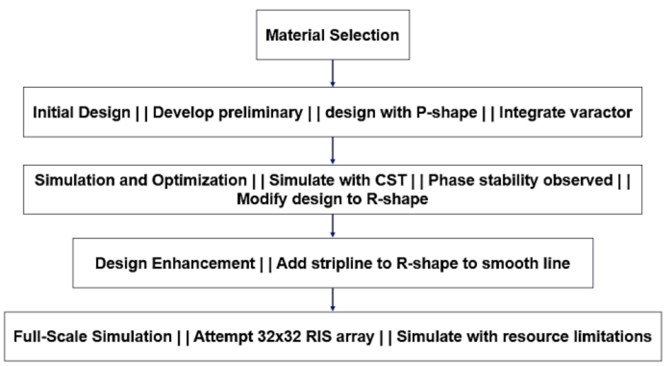

Figure 1. Flow chart of the work process.

2. Materials and methods

To design a RIS antenna with Rogers RT 5880 at 28 GHz, we selected the substrate for its favorable dielectric properties. We began with a preliminary design using electromagnetic simulations, focusing on the arrangement of passive elements. Initial experiments with a 'P' shaped unit cell in Figure 2 and figure

3 integrated varactor revealed unexpected phase stability, prompting a shift to an 'R' shape for improved dynamic phase control. To boost the RIS antenna design, more studies will inspect this phase equilibrium and attempt other configurations.

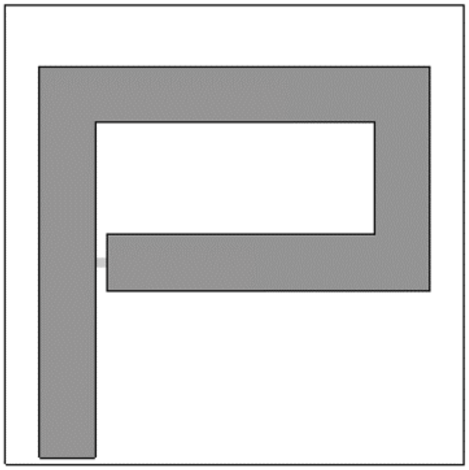

Figure 2. P-shape of the unit cell RIS.

By reforming the RIS antenna unit cell into a 'R' form, shown in figure 4 and figure 5 we were able to use the varactor to present the essential phase alterations. To enhance performance, we inserted a stripline inside the 'R' shape to address the non-smooth line issue. This alteration raises the RIS antenna design's overall success, phase control, and structural integrity.

CST software, a tremendous tool for electromagnetic simulation and analysis, was applied for the complete simulation procedure. As a simulation result, we were able to accurately simulate and raise the RIS antenna design. We imported data from a horn antenna with an acquirer of 15 dB for the far-field seeking. This authenticated that the design adhered to the obligatory requirements and performance standards by giving us an authoritative benchmark to measure the effectiveness of our RIS antenna.

We can exactly tune the resonance frequency to the appropriate locations with the R-shaped cell, which gives it a significant advantage over the P-shaped or other designs. We can get more control over the operational frequency range as a result. Furthermore, the R-shaped cell offers a smoother phase response across a range of frequency bands, which is critical for enhancing the RIS antenna's overall efficiency and tunability. For the intended application, the R-shape is more suitable, as the P-shaped design does not offer the same degree of control or smoothness in the phase response as shown in figure 6 and figure 7.

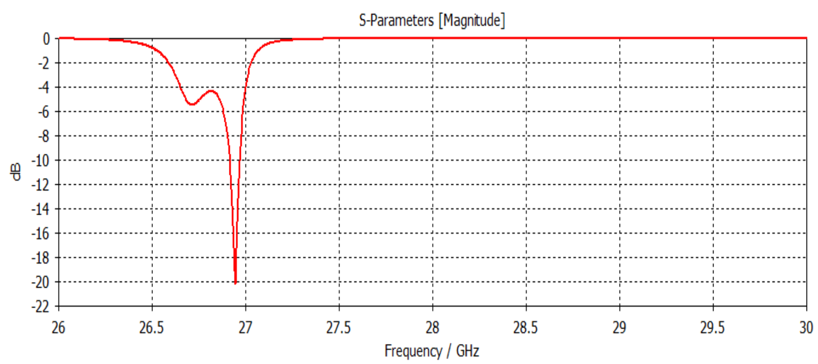

Figure 3. S11 magnitude for P-shape of the unit cell.

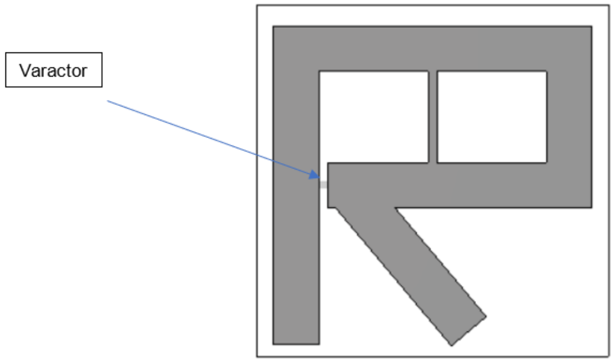

Figure 4. R-shape of the unit cell for whole structure.

Figure 5. R-shape of the unit cell with the radiation pattern of the beam at a distance.

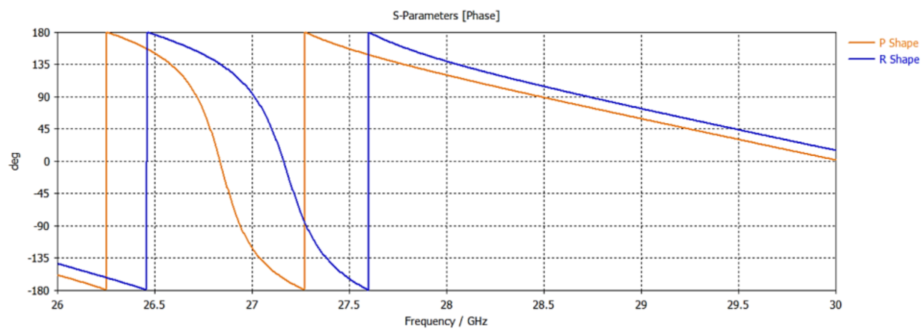

Figure 6. The phase of R and P shapes.

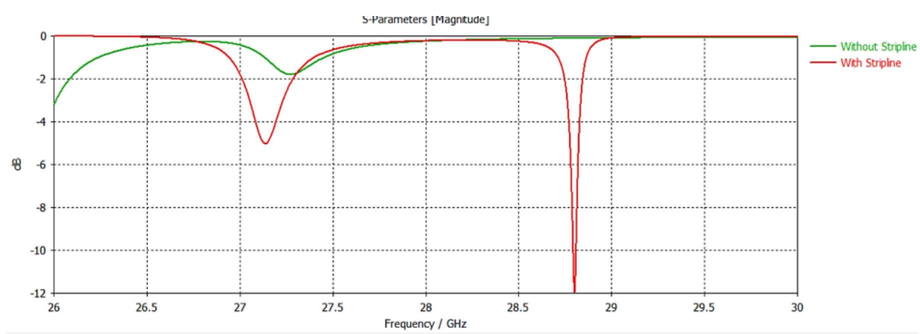

Figure 7. Magnitude S-parameters for R-shape of the unit cell with and without stripline.

Our RIS antenna design is now much more tunable thanks to the addition of a stripline and the switch to the R-shape. Although computational limitations prevent our laptop's 32 GB RAM from fully simulating the 32 × 32 array, the unit cell study reveals encouraging gains in phase-shifting power over traditional designs. More specifically, the addition of the stripline provides more accurate control over beam steering by smoothing the phase response over a range of varactor values. These preliminary findings, derived from CST simulations, point to improved tunability and the possibility of achieving excellent performance at 28 GHz with the Rogers RT5880 substrate. A varactor (SMV2019-079LF from Skyworks Solutions) operating at this frequency has a capacitance range of 0.1 to 5 pF as shown in figure 8.

We struggled to clearly visualize the phase response during our simulation process using CST software. Because CST's phase span is limited to –180° to 180°, it was difficult to obtain a clear, continuous phase image for our design as shown in figure 9. We used MATLAB to plot the design's phase response with numerous varactor settings to bypass this issue as shown in figure 10.

We were able to create intricate, continuous phase charts with MATLAB that reliably depicted the phase changes over the whole varactor value range. This approach provided a clear understanding of how the phase changed with several varactor settings, enabling us to precisely modify and optimize the design of the RIS antenna. Improving the phase representation with MATLAB was essential for adjusting the design parameters and achieving the intended performance.

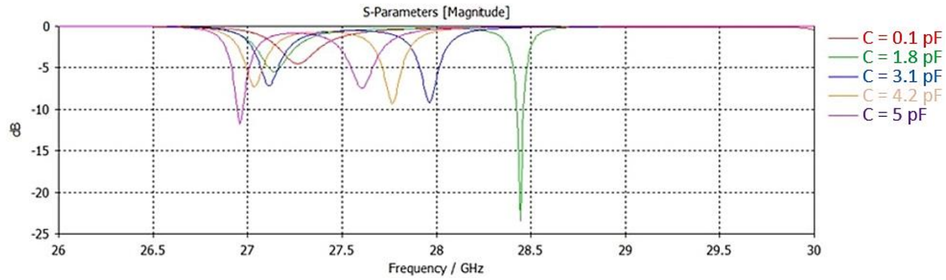

Figure 8. Magnitude S-parameters for the R-shape unit cell with the beam's radiation pattern.

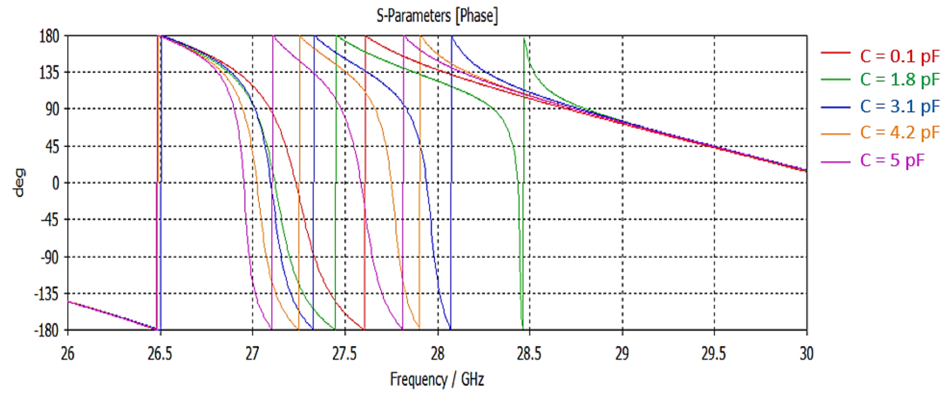

Figure 9. Phase angle of the S-parameters for the R-shape unit cell with the beam's radiation pattern.

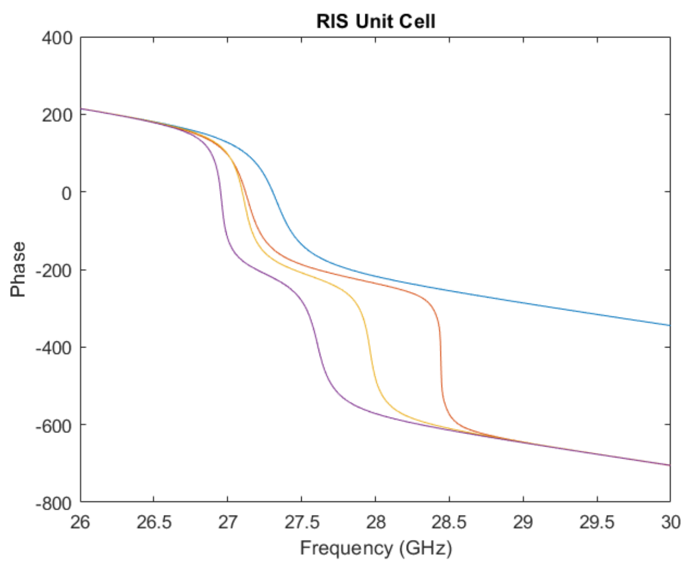

Figure 10. Phase angle of the S-parameters for the R-shaped unit cell, obtained using MATLAB, with the beam's radiation pattern.

In our continuous endeavors to enhance the RIS antenna blueprint, we expanded our methodology to generate a complete 32 × 32 RIS array as shown in figure 11. With many reconfigurable elements available, this extensive array design seeks to optimize the advantages of RIS technology, thereby improving signal manipulation and coverage to a great extent.

But modeling this large 32 × 32 array presented considerable difficulties. The sheer size and complexity of the array required computational resources beyond our current capabilities. The high-performance demands for accurately simulating such a large array in CST software made it impractical to proceed with full-scale simulations on our existing hardware.

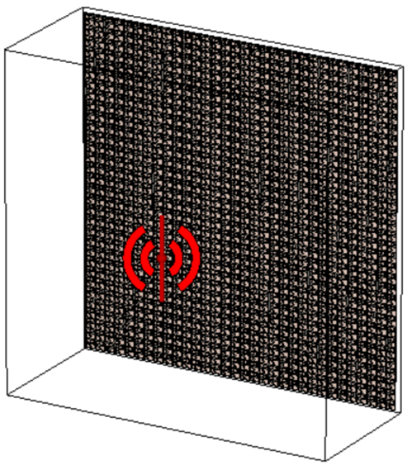

Figure 11. Reflectarray of the R-shaped unit cell with the beam's radiation pattern position.

In contrast, Wu et al.'s study adopts a different strategy, concentrating more on the RIS's signal processing components to increase network capacity, coverage, and energy efficiency (Wu et al., 2021). Although the goal of both projects is to maximize wireless communication, Wu's research focuses more on network-level performance enhancements via intelligent reflecting surfaces than on the actual construction of unit cells. Additionally, a more thorough examination of material characteristics and signal reflection angles was part of their work, which made it possible to implement IRS on a larger scale with less computational difficulty. On the other hand, the current effort places more emphasis on the antenna's physical design and optimization, stressing its performance at 28 GHz through specific design changes that improve the RIS antenna's overall efficiency.

Table 1. Comparative study between related work and the proposed design.

Aspect	Previous Work	Proposed Design
Unit Cell Design	Traditional shapes (e.g., square, rectangular)	Initial *P*-shape, refined to *R*-shape with added stripline
Phase Control	Limited phase tunability	Improved phase control with varactor integration and stripline
Antenna Array Configuration	Smaller arrays, unspecified configurations	Full unit cell–based design
Beamforming Capabilities	Basic beamforming with standard techniques	Enhanced beamforming with dynamic phase modification

3. Conclusions

Reconfigurable intelligent surface (RIS) antennas offer transformative potential in wireless communication systems by dynamically controlling the phase, amplitude, and polarization of electromagnetic waves. Our design process involved selecting the Rogers RT5880 substrate, initially experimenting with a *P*-shape, and later transitioning to an *R*-shape with an added stripline for improved phase control and structural integrity. This iterative approach, combined with simulations using CST software and MATLAB for enhanced phase visualization, has demonstrated significant improvements in tunability and performance. Despite challenges, including computational limitations for a 32 × 32 array, our advancements highlight the promising capabilities of RIS technology in enhancing signal strength, coverage, and network efficiency, particularly in complex environments.

Conflict of interest

The authors have no conflict of interest to declare.

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