Full-wave Validation of a Network-Based RIS Beamshaping Framework

Kavian Zirak(1) , Anish Pradhan(2), Harpreet S. Dhillon(2), and Mohammadreza F. Imani(1)

(1) Arizona State University, Tempe, AZ 85287, USA (kzirak@asu.edu, Mohammadreza.Imani@asu.edu)

(2) Virginia Tech, Blacksburg, VA 24060, USA (pradhananish1@vt.edu, hdhillon@vt.edu)

***Abstract*— Reconfigurable intelligent surfaces (RISs) offer the promise of engineering the wireless propagation environment to alleviate interference, increase data coverage, and improve security. However, most implementations have used simplifying models that ignore coupling between elements. As a result, while the RIS can direct signals toward intended directions, it also results in substantial lobes in other directions that can increase the interference and chance of detection, underlying the primary purpose of using RISs. In this paper, we show that by including the full physical response of RIS as a network in optimization processes, we can control the field both in desired and undesired directions. This idea is validated using a full-wave simulation. These findings provide strong evidence that network-based RIS formulations capture the essential physics of practical implementations, bridging the gap between theory and electromagnetics and supporting the deployment of RISs in real-world wireless systems.**

***Keywords*— RIS, beamforming.**

I. Introduction

RISs have emerged as a promising means to achieve energy-efficient beamforming and interference control [1]. However, they face obstacles to integration into practical settings. One is that they require knowledge of the intended users to redirect signals toward them, while the information about undesired users can be used to reduce the interference. Several works have recently shown the possibility of retrieving directions of signal sources facing the RIS [2]. The second obstacle is that many existing works rely on simplified models that neglect structural scattering and mutual coupling among RIS elements, which may lead to optimistic predictions that cannot be realized in practice [3]. In this case, while the signal may be directed toward the intended users, large sidelobes may be created in other directions. In our recent works, we have introduced physically consistent network-based models that incorporate both coupling and scattering effects [4,5]. These formulations enable systematic design and optimization of RIS configurations while maintaining fidelity to electromagnetic principles. In this manner, we can overcome the second obstacle facing the practical use of RISs.

In this presentation, we focus on validating such an approach through full-wave electromagnetic simulations. Our study provides evidence to complement previous analytical derivations and numerical evaluations, thereby contributing to a deeper understanding of RIS behavior under realistic conditions.

II. Results

We began our study by designing a tunable reflecting element in HFSS that could serve as the unit cell of the RIS. The element consists of a metallic patch printed on a grounded dielectric slab, where a lumped varactor provides the required reconfigurability. The substrate is a low-loss Rogers RO4003 with a thickness of 0.8 mm, chosen to keep the structure compact while supporting resonance near 5.8 GHz. The cell dimensions are summarized in Table I.

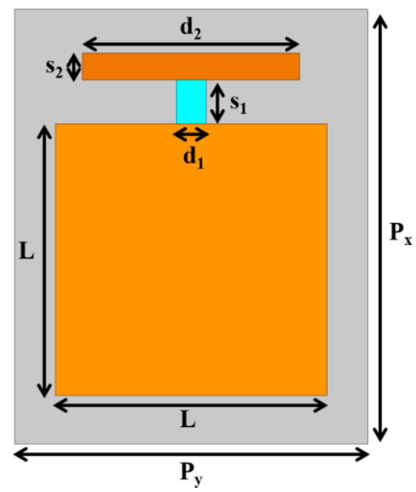

Figure 1:A single unit cell of the proposed RIS. The blue rectangle denotes the placement of lumped RLC or lumped port.

Parameter	Value (in mm)
Px	16
Py	13
L	10
s1	1.6
s2	1
d1	1.1
d2	8

Table I. Geometrical parameters of the unit cell labeled in Fig. 1.

The layout was analyzed under periodic boundary conditions to mimic an infinite array. The simulated complex reflection coefficient as the tuning capacitance was varied is shown in Fig. 2. The computed response indicates that achieving complete control over the phase of the reflected signal, even with the use of varactor diodes, is not possible. Consequently, it is not surprising that while RISs can redirect signals toward desired directions, they also produce significant sidelobes. This insight prompted us to consider an alternative approach: rather than attempting to control the signal in all directions, could we instead focus on managing it in only desired and undesired directions? This approach simplifies the optimization process [5].

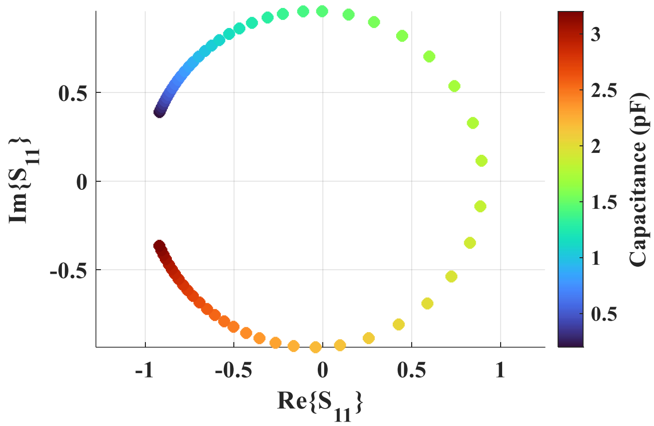

Figure 2: Real and imaginary parts of the simulated S_{11}, the reflection coefficient of the element in Fig. 1.

Once the single-cell behavior was characterized, we used it to build a finite array of 32 such elements in HFSS. First, we simulated this structure with lumped ports replacing varactor diodes. In this manner, the full electromagnetic response of the RIS is derived. The simulated scattering matrix is used in the optimization algorithms described in [4] and [5]. These algorithms help determine the capacitor values for the RIS, enabling it to direct signals toward specific directions while also creating nulls toward directions where unintended users are present. To demonstrate this capability in full-wave simulation, we assumed the 32-element array is illuminated by a normally incident x-polarized plane wave. Fig. 3 shows the case where the RIS is configured to steer the main beam between −25° and −20°, while simultaneously imposing a null between 5° and 10°. Here, the *MATLAB* graph represents the results predicted from the numerical simulation, while the simulation graph represents the one obtained in Ansys HFSS. The two curves exhibit a strong correspondence, reinforcing the notion that incorporating the electromagnetic response of the RIS into the optimization algorithms—rather than relying on simplified models—successfully reduces the disparity between theoretical predictions and full-wave results. Moreover, it is evident that we now have control over both desired and undesired regions.

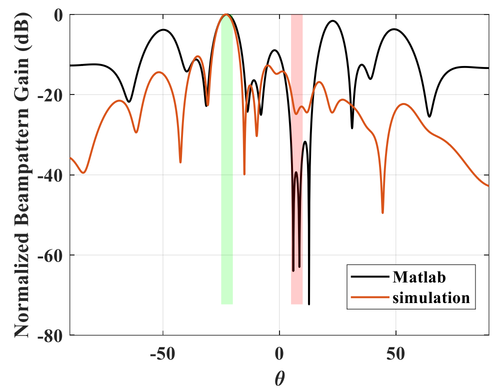

Figure 3: Normalized beampattern for beam steering between −25° and −20° with a null imposed between 5° and 10°. The green box indicates the desired region, while the red box denotes the undesired region.

III. Conclusion

This paper has presented a full-wave validation of a physically consistent network-based formulation for RIS beamforming. Using Ansys HFSS simulations, we confirmed that the proposed model accurately captures the impact of mutual coupling and structural scattering, bridging the gap between theoretical predictions and electromagnetic reality. Future work will extend this validation to larger RIS apertures and additional hardware constraints, further exploring the link between network-theoretic formulations and electromagnetic performance.

IV. Acknowledgement

This material is based upon work supported by the National Science Foundation under Grants ECCS-2030215, CNS-2225511, and ECCS-2333023.

References

[1] E. Basar, M. Di Renzo, J. De Rosny, M. Debbah, M. -S. Alouini and R. Zhang, "Wireless Communications Through Reconfigurable Intelligent Surfaces," in *IEEE Access*, vol. 7, pp. 116753-116773, 2019

[2] I. Alamzadeh and M. F. Imani. "Experimental Demonstration of Sensing Using Hybrid Reconfigurable Intelligent Surfaces." *Sensors* 25, no. 6 (2025): 1811.

[3] G. C. Trichopoulos *et al*., "Design and Evaluation of Reconfigurable Intelligent Surfaces in Real-World Environment," in *IEEE Open Journal of the Communications Society*, vol. 3, pp. 462-474, 2022.

[4] A. Pradhan, M. F. Imani, and H. S. Dhillon. "A Beamshaping Framework for Physically Consistent Reconfigurable Intelligent Surfaces." IEEE International Conference on Communications, 2025.

[5] A. Pradhan, I. Alamzadeh, M. F. Imani, and H. S. Dhillon. "RIS-Aided coexistence in wireless networks using angular information." *Scientific reports* 14, no. 1 (2024): 30659.