IRO Journal on Sustainable Wireless Systems (ISSN: 2582-3167)
www.irojournals.com/irosws/

Development of Reflectarray Antenna with Twin Cut Resonator for High Gain X Band Applications

Sivasankari N.[1], Abishek K.[2], Jerry Abraham J.[3]

Electronics and Communication Engineering, Mepco Schenk Engineering College, Anna University, Sivakasi, India

E-mail: [1]sivasankari2015@mepcoeng.ac.in, [2]abi9578017625_bec26@mepcoeng.ac.in, [3]abrahamjjerry_bec26@mepcoeng.ac.in

Abstract

This paper presents a high-gain reflect array antenna design that utilizes a double-cut ring structure to enhance performance in terms of gain and bandwidth. Reflect array antennas are recognized for their lightweight, low-profile characteristics and capability to achieve high directivity. However, their performance is often constrained by the phase shift range and accuracy of the reflecting elements. To overcome these limitations, the proposed design incorporates an innovative double-cut ring element structure, which improves phase control across a broad frequency range, resulting in enhanced beam-steering capabilities and increased gain. The double-cut ring structure is optimized to achieve a substantial phase shift range, contributing to the antenna's high-gain performance by facilitating precise phase correction throughout the array. The proposed structure illustrates the effectiveness of the double-cut ring configuration as a viable solution for improving the gain and operational bandwidth of reflect array antennas. The maximum gain achieved is 44.5 dBi at 10 GHz, and the Voltage Standing Wave Ratio (VSWR) plot indicates a value of 1.04 at the resonant frequency of 10 GHz.

Keywords: High-Gain Reflect Array Antenna, Double-Cut Ring Structure, Phase Control, Beam-Steering, Bandwidth Improvement, VSWR.

1. Introduction

Reflectarray antennas (RAAs) represent an innovative class of antennas developed by Luyen et al. [1] that merge the advantages of parabolic reflectors and phased arrays. These antennas deliver high gain and beam-steering capabilities in a lightweight, planar

DOI: https://doi.org/10.36548/jsws.2025.2.006
Received: 30.03.2025, received in revised form: 01.05.2025, accepted: 18.05.2025, published: 30.05.2025

configuration, rendering them ideal for applications where space and weight are critical. Unlike conventional parabolic reflectors, which necessitate large and bulky structures, reflectarray antennas employ an array of reflecting elements arranged on a flat surface to focus signals from a feed source, such as a horn antenna. This is accomplished by introducing precise phase shifts across the elements, enabling directional beam control without the need for physical movement of the antenna. Reflectarray antennas have attracted significant attention in high-frequency applications, particularly in satellite communications, radar systems, and other domains that require high directivity and compactness.

Despite their numerous advantages, reflectarray antennas encounter challenges related to phase control and bandwidth. Achieving accurate phase shifts over a wide frequency range is essential [3] for ensuring consistent performance, especially in dynamic environments where beam steering and high gain are imperative. The limited phase shift range of conventional reflectarray designs often constrains their effectiveness, particularly in applications requiring wideband performance. Moreover, the bandwidth of these antennas must be optimized to satisfy the stringent requirements of modern communication systems, where a broader operating bandwidth is crucial for accommodating a wide spectrum of frequencies. Reflectarrays can be implemented as single-layer (Chaharmir et al. [2], Atlasbaf), three-layer (Encinar et al. [7]), or multi-layer configurations (Zornoza et al. [3]).

Extensive literature has demonstrated the performance of these layers in various orientations, including polarization in the required direction as shown by Hasani et al. [4] and mirror-based polarizations by Zornoza et al. [3]. Enhancements in phase shift control have been discussed by Salti [6] and the Minkowski structure phase shift design by Ozturk et al. [8].

Recent advancements have concentrated on addressing these challenges by introducing novel designs such as the double-cut ring structure [4], [5], which significantly improves phase control and bandwidth. The double-cut ring resonator structure offers a broader phase shift range and enhanced operational bandwidth, rendering reflectarray antennas more suitable for high-performance applications in the X-band and beyond. This paper presents the development of a reflectarray antenna utilizing the twin-cut resonator design, optimized for high-gain performance in X-band applications. The proposed design achieves enhanced gain, improved phase control, and wider bandwidth, addressing the limitations of traditional reflectarray antennas and enhancing their effectiveness for modern high-frequency applications. Optimizations with multi-layer configurations are discussed in Robustillo et al. [10].

2. Proposed Work

The antenna design follows a systematic approach using the ANSYS HFSS software. Key steps include the creation of a reflect array with twin cut resonators, excitation assignment, and simulation.

Step 1: The antenna has been designed with the following specifications:

- Operating Frequency: 10 GHz. It has been designed with Arlon substrate with a dielectric constant of 2.1 and a height of 1.2 mm for compatibility with X-band frequencies for satellite applications.
- The patch width is designed according to Equation 1.

$$Width = \frac{c}{2f_0\sqrt{\frac{\varepsilon_R+1}{2}}} \tag{1}$$

Where the dielectric constant; the effective dielectric constant is calculated as per Equation 2.

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{W}\right)}}\right] \tag{2}$$

The effective dielectric constant is calculated with ϵ_R=2.1 a substrate height of 1.2 mm; The patch physical length is calculated as per equation 3 as follows:

$$L = \frac{c}{2f_r\sqrt{\epsilon_{reff}}} - 0.824h\left(\frac{(\epsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{reff}-0.258)(\frac{W}{h}+0.8)}\right) \tag{3}$$

L = 9.56665 mm; Effective Length increased from each side is Leff=1.08219 cm.

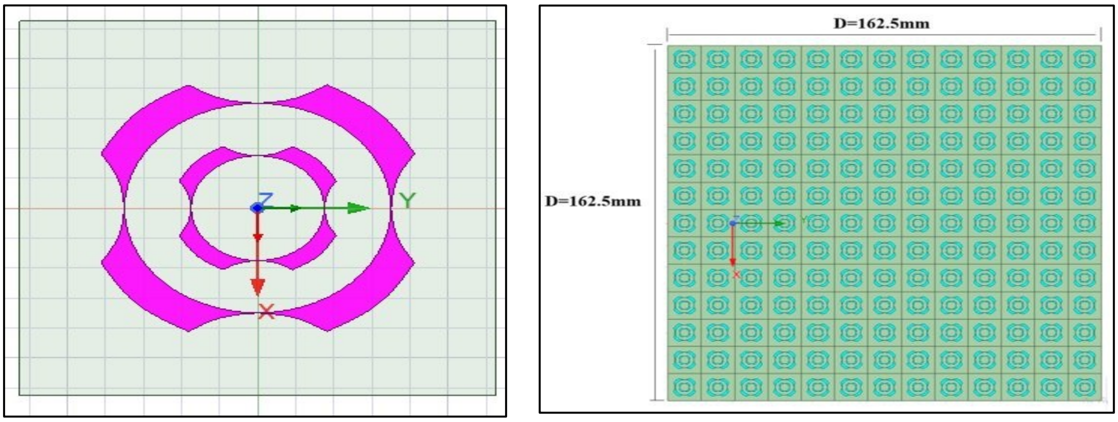

Figure 1. Antenna Array Formation

The twin-cut resonator is a variant of the split-ring resonator (SRR), where the resonating elements are modified by cutting two small segments from a circular ring, forming the "twin cut" shape. The primary reason for choosing this configuration is the enhanced ability to control the phase shift, which is crucial for achieving high directivity and efficient beamforming in reflectarray antennas. Approximately (162.5/13) =12.5 mm is allotted for a single cell of the twin-cut resonator, with a width of 9.5 mm and an effective length of 3.16 mm. First, two concentric circles are formed with a certain width. The diameter of the outer circle is set at 8 mm. For the 1mm gap width, the next circle has been created. At the top, left, right, and bottom corners, one arc has been cut in both the inner and outer circles. The exact structure dimensions are given in Table 1 and the reflectarray formation from the twin-cut structure is shown in Figure 1.

Table 1. Twin Cut Resonator Structure

Parameter	**Radius**
Outer circle radius (outer)	8 mm
Inner circle radius (outer)	6 mm
Inner circle radius (outer)	4 mm
Inner circle radius (inner)	3 mm

Excitation (Feed) Set Up:

The antenna design employs a horn antenna as the feed, positioned 148 mm from the reflectarray surface depicted in Figure 2.

Unlike single feed structure by Nayeri et al. [9] Radiation boundaries and Floquet ports are assigned for excitation as shown in Figure 3.

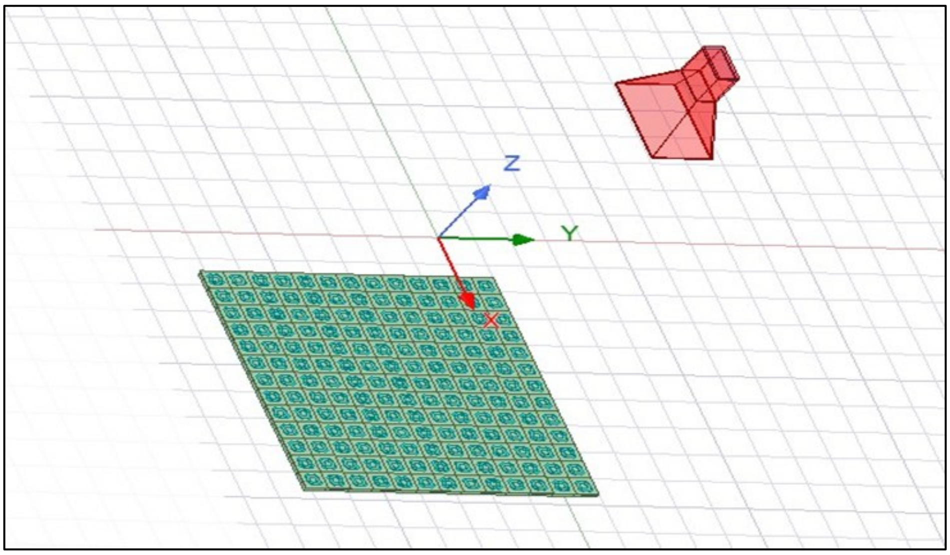

Figure 2. Reflectarray Antenna

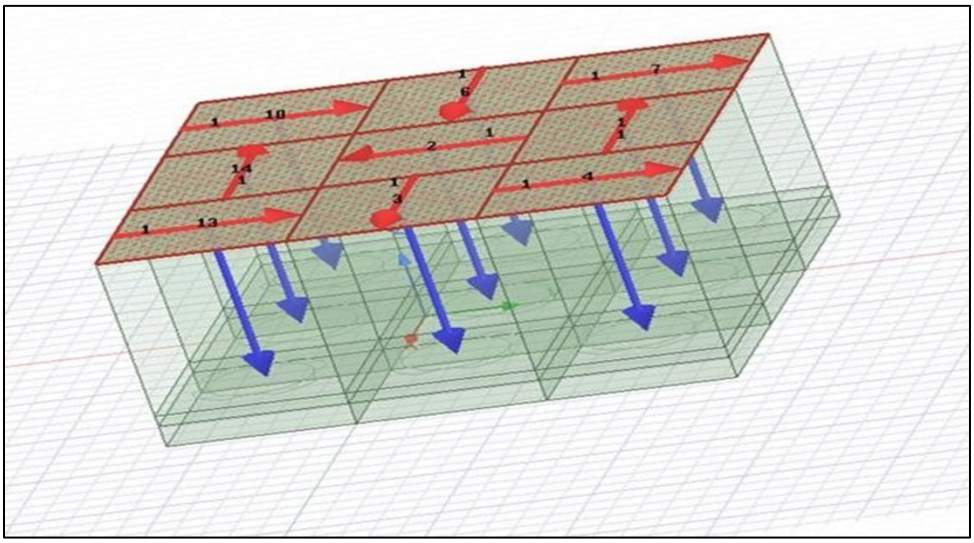

Figure 3. Floquet Port Assignment

Then the antenna is analyzed for 8-12 GHz frequency. This is discussed in section 3.

3. Results and Discussion

3.1 Return Loss (S11)

The return loss plot shows significant dips at 10 GHz, indicating optimal impedance matching, as shown in Figure 4.

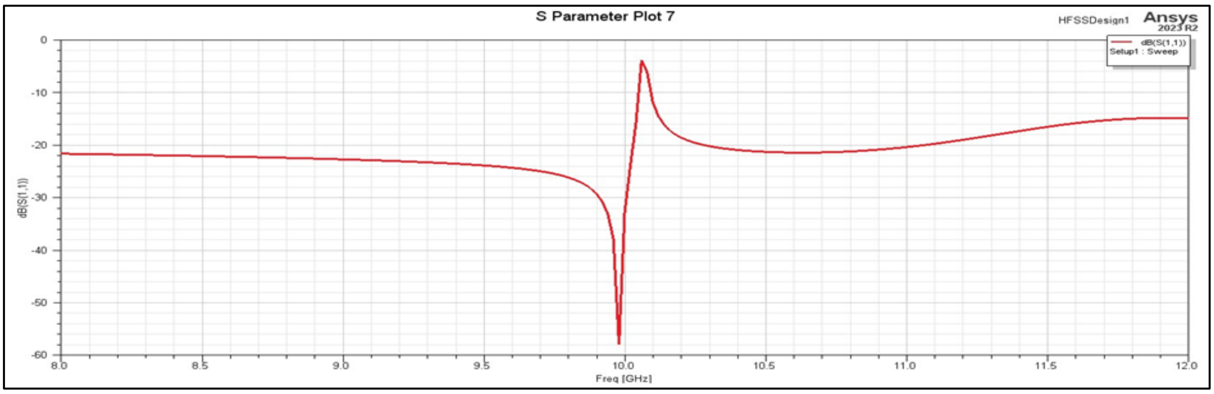

Figure 4. Return Loss Plot

3.2 VSWR

The VSWR plot demonstrates values below 1.5 at the resonant frequency of 10 GHz as shown in Figure 5, confirming efficient power transfer.

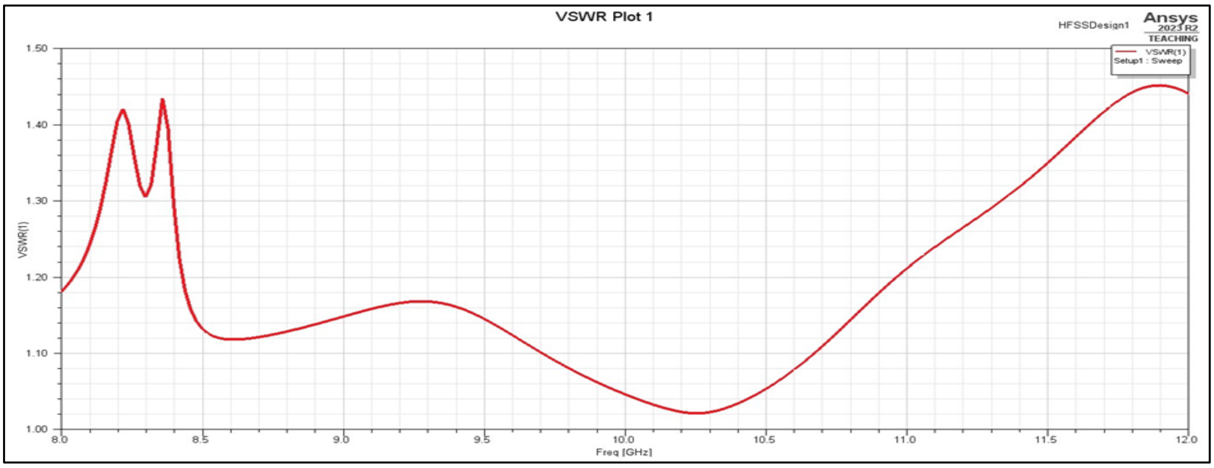

Figure 5. VSWR Plot

3.3 Gain and Radiation Pattern

The 3D gain plot indicates a maximum gain of 44.5 dBi at 10 GHz, with strong directional radiation. Side lobes are minimal, showcasing excellent beam shaping with minimal side radiation, as shown in Figure 6.

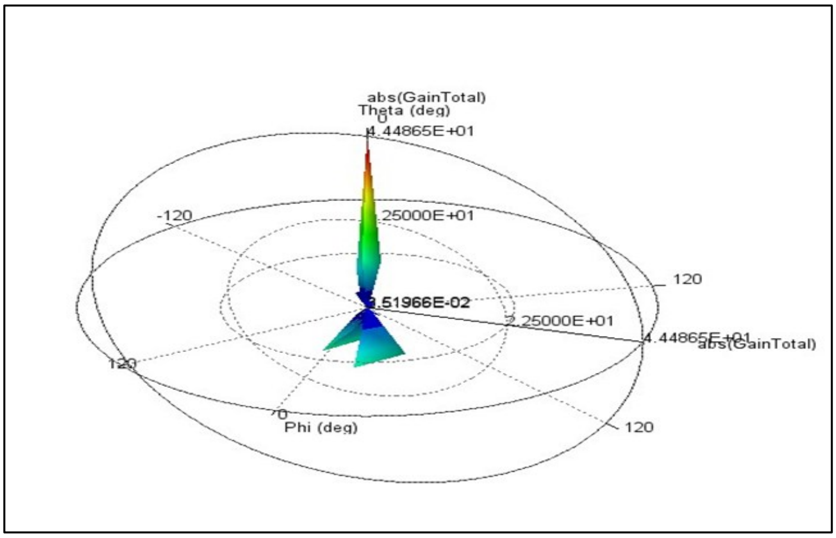

Figure 6. 3D Radiation

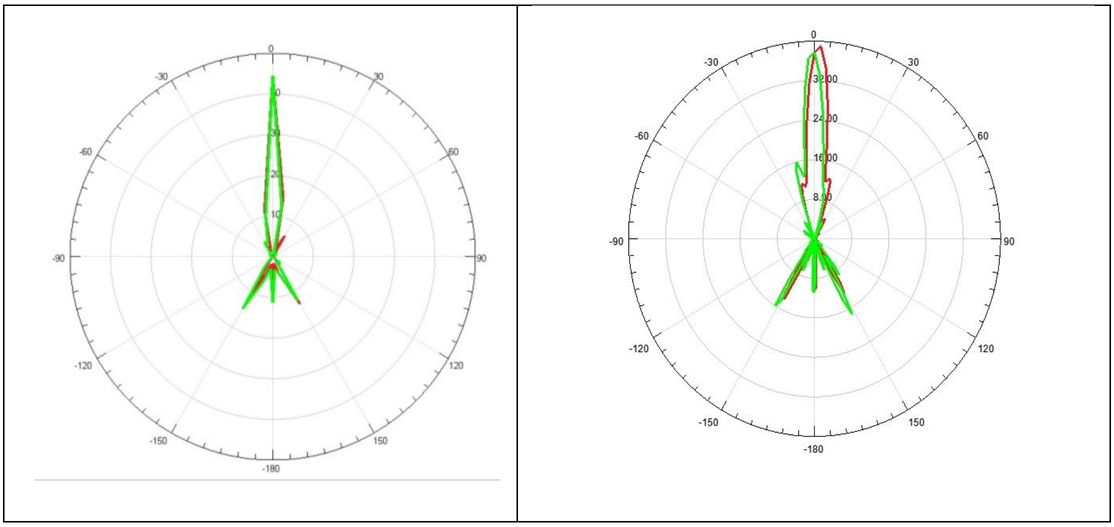

Figure 7. 2D Gain Plot

The design and optimization of the reflectarray antenna with a twin-cut resonator structure involves several key steps aimed at achieving high performance in terms of gain, bandwidth, and efficiency. By changing the above parameters, an optimized reflectarray can be designed. The key innovation in the proposed design is the use of a twin-cut resonator. This structure is chosen because it can provide a smooth and wide range of phase shifts across the operating frequency band, thus improving the antenna's performance in terms of both bandwidth and gain. Additionally, it can also be used to make phase changes at the required frequency.

Applications

This type of twin cut resonator is primarily integrated with substrate-integrated wave structures. It can be combined with a dielectric resonator to create multiple reflectarrays from a single structure. This design is suitable for implementation at millimeter-wave frequencies.

4. Conclusion

The design of a high-gain reflectarray antenna utilizing a twin-cut resonator structure has been successfully demonstrated. This proposed design exhibits significant enhancements in gain and phase control, positioning it as a viable candidate for X-band applications such as satellite communications and radar systems. By incorporating the twin-cut ring resonator, the antenna surpasses conventional reflectarrays, offering a broader phase shift range and improved beam-steering performance. Simulation results confirm that the reflectarray antenna achieves a maximum gain of 44.5 dBi at 10 GHz. Additionally, return loss and VSWR analysis validate the impedance matching and effective power transfer of the antenna, resulting in minimal signal loss. The selection of Arlon as the substrate material contributes to the high efficiency of the design without sacrificing structural compactness. Optimization techniques, including parametric sweeps and mesh refinement, have been employed to enhance the antenna's performance. The application of Floquet port boundary conditions facilitated accurate simulation of the periodic reflectarray structure. Despite trade-offs among gain, efficiency, and material selection, the presented design effectively balances these factors to achieve exceptional performance. Overall, the twin-cut resonator-based reflectarray antenna presents a promising solution for contemporary high-frequency applications, offering a lightweight, high-gain alternative to traditional parabolic reflectors. Future research may focus on further optimizing phase shift control and exploring additional materials to enhance performance while maintaining cost-effectiveness.

References

[1] Luyen, Hung, Zhe Yang, Meng Gao, John H. Booske, and Nader Behdad. "A wideband, single-layer reflectarray exploiting a polarization rotating unit cell." IEEE Transactions on Antennas and Propagation 67, no. 2 (2018): 872-883.

[2] Chaharmir, Mohammad Reza, Jafar Shaker, Nicolas Gagnon, and David Lee. "Design of broadband, single layer dual-band large reflectarray using multi open loop elements." IEEE Transactions on Antennas and Propagation 58, no. 9 (2010): 2875-2883.

[3] Zornoza, J. Agustín, Ralf Leberer, Jose A. Encinar, and Wolfgang Menzel. "Folded multilayer microstrip reflectarray with shaped pattern." IEEE Transactions on Antennas and Propagation 54, no. 2 (2006): 510-518.

[4] Hasani, H., M. Kamyab, and A. Mirkamali. "Low cross-polarization reflectarray antenna." IEEE Transactions on Antennas and Propagation 59, no. 5 (2011): 1752-1756.

[5] Malfajani, R. Shamsaee, and Zahra Atlasbaf. "Design and implementation of a dual-band single layer reflectarray in X and K bands." IEEE Transactions on Antennas and Propagation 62, no. 8 (2014): 4425-4431.

[6] Salti, Hassan, Raphaël Gillard, Renaud Loison, and Laurent Le Coq. "A reflectarray antenna based on multiscale phase-shifting cell concept." IEEE Antennas and Wireless Propagation Letters 8 (2008): 363-366.

[7] Encinar, Jose A., and J. Agustin Zornoza. "Broadband design of three-layer printed reflectarrays." IEEE Transactions on Antennas and Propagation 51, no. 7 (2003): 1662-1664.

[8] Ozturk, Ender, and Birsen Saka. "Multilayer Minkowski reflectarray antenna with improved phase performance." IEEE Transactions on Antennas and Propagation 69, no. 12 (2021): 8961-8966.

[9] Nayeri, Payam, Fan Yang, and Atef Z. Elsherbeni. "Design and experiment of a single-feed quad-beam reflectarray antenna." IEEE transactions on antennas and propagation 60, no. 2 (2011): 1166-1171.

[10] Robustillo, Pedro, Juan Zapata, Jose A. Encinar, and Jesus Rubio. "ANN characterization of multi-layer reflectarray elements for contoured-beam space antennas in the Ku-band." IEEE Transactions on Antennas and Propagation 60, no. 7 (2012): 3205-3214.