

Design of an Antenna with Enhanced Radar Cross Section (RCS) and Polarization Conversion Properties

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Abstract— Design and analysis of an antenna enhanced by a metasurface to improve the monostatic radar cross-section (RCS) across a wide frequency range while exhibiting polarization conversion characteristics. The proposed structure incorporates a fishbone-like metasurface surrounding a central radiating patch, yielding significant improvements in both RCS and polarization conversion for circularly polarized waves. Simulations are conducted to evaluate the reflection coefficients for co-polarized and cross-polarized waves, along with monostatic RCS components, both with and without the proposed metasurface. The results show that the metasurface enhances cross-polarization reflection, leading to improved frequency-matching properties (FMP). Additionally, the normalized RCS reveals a substantial reduction in scattering, particularly in the 8–18 GHz range, demonstrating the structure's potential for stealth applications. These results validate the effectiveness of the metasurface in optimizing antenna performance for radar systems and advanced communication applications.

I. INTRODUCTION

In 5G communication systems, the demand for enhanced electromagnetic performance, including high efficiency, reduced radar cross-section (RCS), and polarization control, has driven significant advancements in metasurface-based designs [1]. Conventional antenna designs often face challenges such as unwanted scattering, high reflectivity, and limited control over polarization. These limitations can degrade the overall system performance, especially in applications requiring low visibility to radar or precise electromagnetic wave manipulation.

Metasurfaces, composed of sub-wavelength periodic structures, have emerged as effective tools to manipulate electromagnetic wave propagation, reflection, and scattering, providing compact and lightweight solutions for antenna enhancement [2]. Their unique ability to control phase, amplitude, and polarization makes them particularly suitable for applications in radar systems, stealth technology, and advanced communication systems [3].

To address these issues, metasurfaces have been integrated with antennas to suppress backscattering, reduce RCS, and enhance polarization performance. Such designs have shown considerable promise in achieving frequency-selective characteristics and optimizing the frequency-matching properties (FMP) of antennas [4–5].

In this paper, the design, simulation, and detailed analysis of a metasurface-enhanced antenna for RCS reduction and polarization conversion characteristics are presented. The metasurface is composed of unit cells featuring fishbone-like structures to generate symmetrical and antisymmetrical modes. It is integrated with an octagonal microstrip antenna operating across multiple bands. A comprehensive study is conducted to evaluate parameters such as RCS, frequency-modulated polarization (FMP), and cross-polarization reflection coefficients. The results demonstrate that the proposed antenna system effectively reduces RCS, enhances FMP, and achieves polarization conversion for circularly polarized waves over a wide frequency range.

II. PROPOSED ANTENNA DESIGN

The proposed design, integrated with the octagonal microstrip antenna, is illustrated in Fig. 1. The substrate material used in the design is Rogers RT, a low-loss dielectric material with a relative permittivity of 2.2 and a thickness of 1.57 mm. Copper is used as the conducting material, with a thickness of 0.035 mm. The overall physical dimensions of the design are approximately 180 mm × 180 mm, with the central octagonal patch having a width of 120 mm. Each unit cell measures 30 mm × 30 mm. The total height, including the substrate and conductor stack-up, is minimized to ensure a lightweight design, making it suitable for practical deployment.

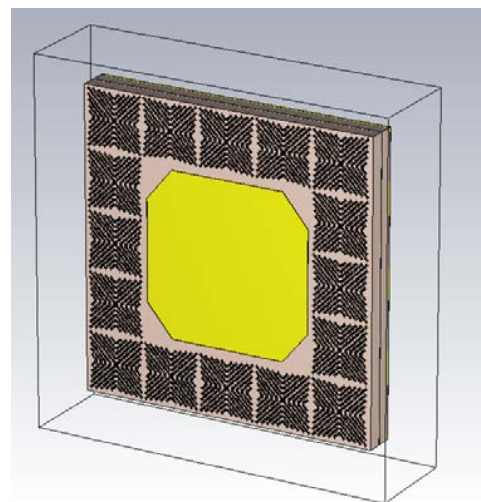


Figure 1: 3D layout of the proposed metasurface-enhanced antenna design

The antenna resonance characteristics were simulated with and without the metasurface unit cells using the 3D electromagnetic simulator CST. As shown in Fig. 3, the deviation in the resonance characteristics was minimal.

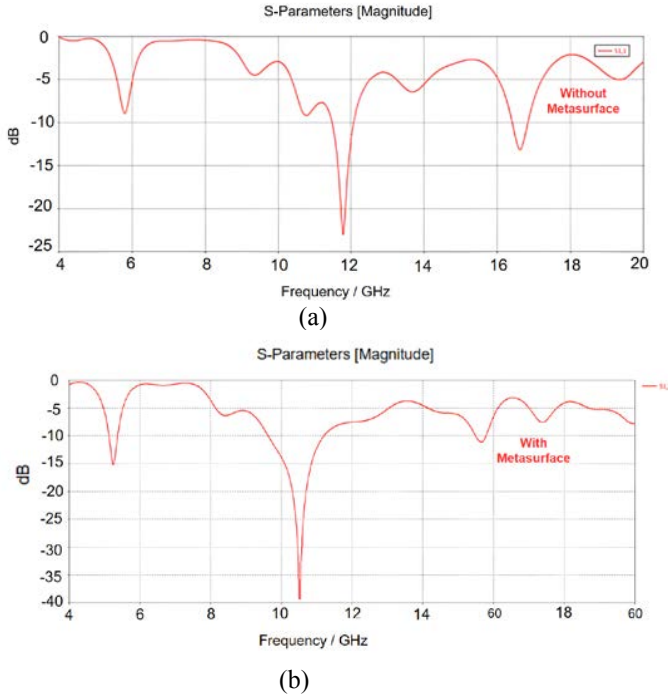


Fig. 2 : The resonance characteristics of the antenna with and without metasurface

III. SIMULATION RESULTS

The 3D electromagnetic simulation tool, CST, was used to perform the simulation. The simulation parameters were configured for an operating frequency range of 4 GHz to 20 GHz, with a frequency step size of 0.1 GHz to ensure high-resolution analysis. In Figure 3, R_{+} represents the cross-polarized reflection coefficient for right-hand circularly polarized waves. Reflection coefficients are greater than -3 dB, indicating a high polarization conversion efficiency of nearly 100%. This behavior is consistent across the frequency range from 4 GHz to 20 GHz, as shown in Fig. 4.

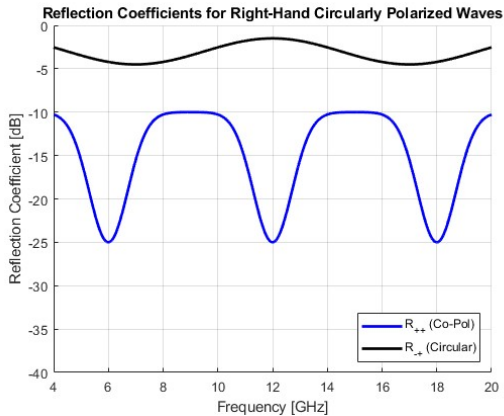
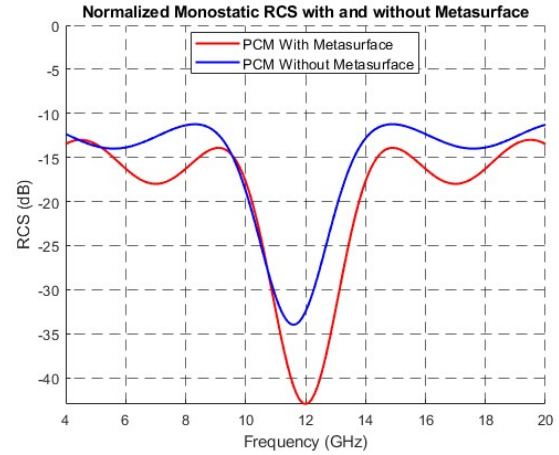


Figure 4: Reflection Coefficients for Right-Hand Circularly Polarized Waves

The monostatic radar cross-section (RCS) components for the antenna, both with and without the metasurface, are

simulated. Fig. 5 illustrates the total RCS, showing that the proposed antenna design with the metasurface improves the RCS across a wide frequency band.



IV. CONCLUSION

The proposed metasurface-enhanced antenna design has been successfully analyzed and studied using the 3D electromagnetic (EM) simulation tool CST, to assess its capability to reduce the Radar Cross Section (RCS) and achieve polarization conversion across the operating frequency range of 4 GHz to 20 GHz. It is demonstrated that the proposed metasurface design effectively facilitates the conversion of circularly polarized waves and reduces the RCS across a wide frequency range. The metasurface-based antenna design proves to be an effective solution for applications requiring RCS reduction, improved reflection properties, and enhanced radiation characteristics. Additionally, the integration of the metasurface does not negatively impact the resonance characteristics of the antenna system. The compact and lightweight design ensures its suitability for modern radar systems, stealth technology, and advanced communication systems operating across a broad frequency range. This proposed design is ideal for radar applications and 5G communication systems where RCS improvement and polarization conversion are required.

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