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Metasurface-Based Circular Polarization Conversion for a Patch Antenna at 5.8 GHz

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***Abstract*—This paper presents the design of a circularly polarized antenna system operating at 5.8 GHz. The objective is achieved by designing a linearly polarized patch antenna integrated with a metasurface, which functions as a polarization converter. The considered metasurface converts part of the incident wave on it into the orthogonally polarized scattered field. The combination of the patch antenna and the metasurface resulted in circular polarization with a realized gain of 5.1 dBi. The distance between the antenna and the metasurface was optimized to provide the required phase shift for the effective realization of circular polarization.**

***Index Terms*—antenna, circular polarization, metasurface.**

I. INTRODUCTION

CIRCULARLY polarized (CP) antennas play a crucial role in modern wireless communication systems, including satellite communication, radar, and navigation, due to their ability to mitigate polarization mismatch and multipath interference [1-5]. Various techniques have been proposed to achieve circular polarization, such as multi-feed networks [2], truncated patches [3], and proximity-fed structures [4]. Multi-feed and hybrid feed techniques have been investigated for wideband CP operation, where orthogonal modes are excited with precise phase control [2]. Additionally, proximity-fed structures have demonstrated polarization agility by dynamically switching between left-handed and right-handed CP states [4]. However, these methods often introduce design complexity, increased profile, or narrow bandwidth limitations.

Recently, metasurfaces have emerged as 2D structures which can improve antenna performance by manipulating electromagnetic waves [6,7]. Metasurface-engineered 2D electromagnetic structures have emerged as an effective solution for polarization manipulation and antenna performance enhancement [5]. Several studies have explored metasurface-based CP antennas. Metasurfaces have been used to enhance bandwidth and improve polarization purity by suppressing unwanted modes [5].

This work presents the design of a metasurface-integrated patch antenna operating at 5.8 GHz. The metasurface acts as a polarization converter, transforming part of the transmitted LP wave into its orthogonal counterpart to achieve CP radiation. The optimal spacing between the patch antenna and the metasurface is carefully adjusted to ensure the required phase shift for efficient polarization conversion. The proposed antenna achieves a realized gain of 5.1 dBi while maintaining a compact structure.

By leveraging metasurfaces for polarization conversion, this study demonstrates a simple and efficient approach to CP antenna design, offering a low-profile alternative to conventional CP configurations.

II. Design and Principle of Operation

The primary patch antenna is designed to operate at 5.8 GHz with coaxial feed as shown in Fig.1. Figure 2 illustrates the radiation pattern of the antenna for E and H planes with realized gain of 6.3 dBi. To convert the LP to CP, a metasurface consisting of periodically arranged unit cells with engineered structural geometries is positioned above the antenna. The unit cell exhibits asymmetry for y-polarized waves. Consequently, the induced current from the y-polarized incident wave creates a net electric dipole in the x direction, producing an x-polarized wave [8]. Therefore, it converts part of the incident energy with cross-polarization generating two orthogonal waves necessary to create circular polarization. By optimizing the geometry and dimensions of the unit cell, the cross-polarized transmitted wave will have a 90-degree phase difference relative to the co-polarized transmitted wave. Fabrication feasibility has also been considered for designing the unit cell. Simple geometry reduces manufacturing complexity and loss. Additionally, to make the integration of the metasurface with the patch antenna easier, we focused on design of single layer and low profile unit cells.

Figure 3 shows the unit cell of the proposed matasurface with the periodicity of $0.17\lambda_0 \times 0.11\lambda_0$ at the operation frequency. It consists of two split-ring resonators on a dielectric substrate, namely Rogers RO4350B with the dielectric constant of 3.66, loss tangent of 0.0037 and thickness of 1.5 mm. Figure 4 illustrates the amplitude and phase of the co- and cross-polarized transmitted wave through the metasurface. It reveals that at the operation frequency of 5.8GHz, the transmitted wave with x and y polarization has the same amplitude with almost 90 degrees phase shift enabling to convert linear polarization of the patch antenna to circular polarization.

The distance between the patch antenna and the metasurface also should be optimized. Even if the unit cell provides a perfect 90-degree phase shift between co- and cross-polarized waves, when it interacts with the radiation pattern of the patch antenna, the effective phase difference between the antenna radiation and the metasurface-converted radiation can be altered.

Furthermore, the axial ratio (AR) is very sensitive to small changes from the perfect phase conditions. Therefore, the

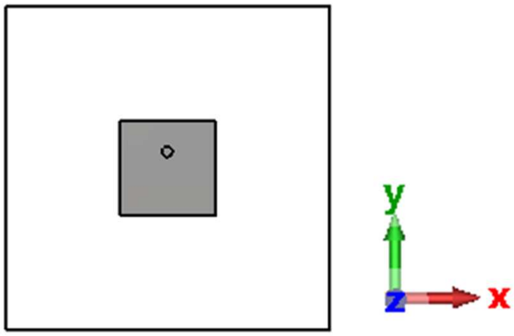
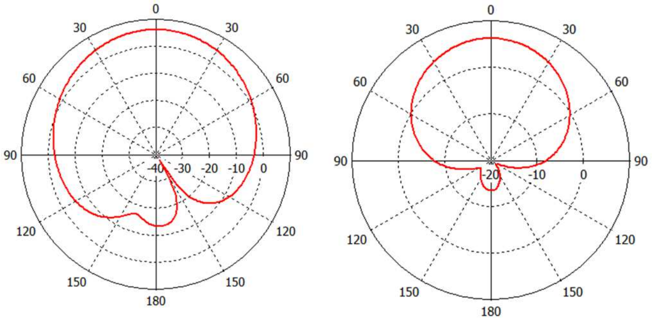


Fig. 1. Structure of the rectangular patch antenna.



(a) (b)

Fig. 2. Radiation pattern of the antenna for (a) E-plane and (b) H-plane for co-linear polarization.

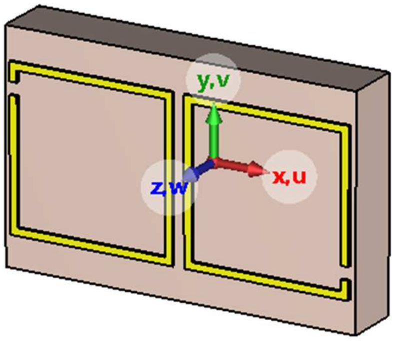
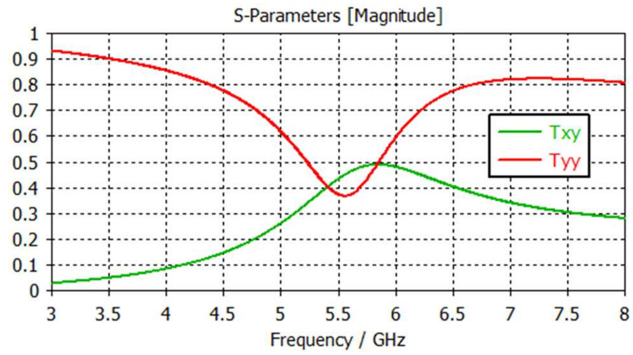
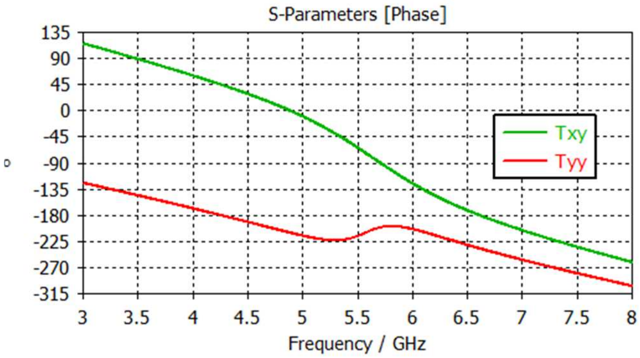


Fig. 3. Structure of the unit cell of the metasurface.



(a)



(b)

Fig. 4. Amplitude and phase of the transmission coefficient of the metasurface for co- and cross-polarization.

The distance between the patch and the metasurface has a significant effect on how the fields combine, affecting polarization purity. Thus, optimal spacing ensures minimum AR and pure circular polarization.

III. RESULTS AND DISCUSSION

Figure 5 depicts the combination of the patch antenna with the metasurface consisting of 7×7 proposed unit cells. The distance between the patch and the metasurface is optimized to obtain 90-degree phase shift between orthogonal polarizations. It is observed that a separation of 18.5mm provided the optimal phase relationship between the co- and cross-polarized components, resulting in effective circular polarization at 5.8 GHz.

Simulation results shown in Fig. 6 demonstrated that when the metasurface is introduced, the antenna's polarization is converted into circular polarization, with a realized gain of 5.1 dBi. The observed reduction in gain compared to the original patch realized gain is attributed to the partial reflection and energy absorption in the metasurface.

The AR, which determines polarization purity, is analyzed, showing a good performance compared to recent studies. Figure 7 demonstrated an AR below 3 dB within -21 to 80 degrees around the broadside direction, indicating effective circular polarization in the desired radiation direction.

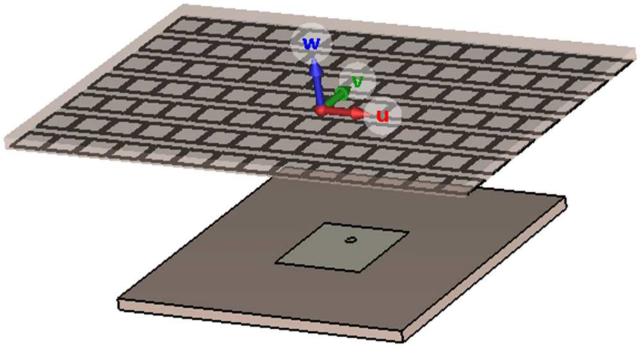
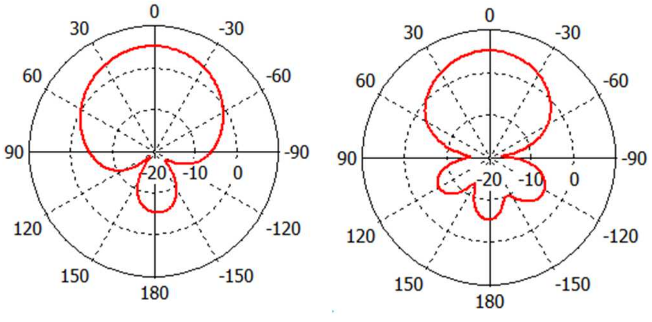


Fig. 5. Structure of the patch antenna integrated with the metasurface.



(a) (b)

Fig. 6. Radiation pattern of the antenna integrated with the metasurface for (a) E-plane and (b) H-plane for right-handed circular polarization.

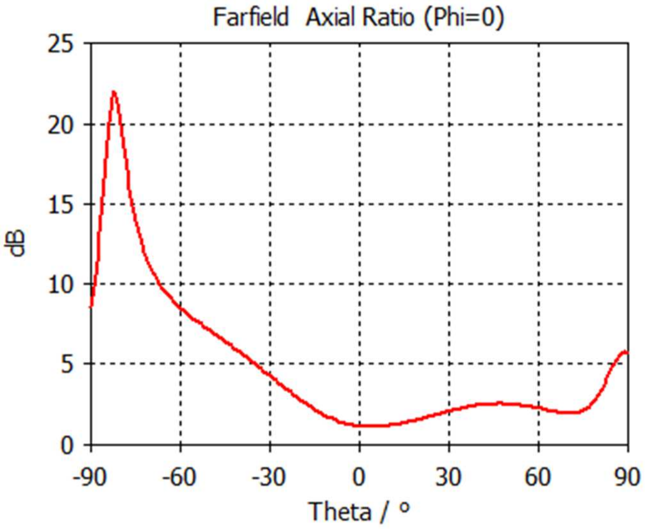


Fig. 7. Axial ratio of the structure for near broadside angles.

In this work, the structure has been optimized to achieve sufficiently low AR in the vicinity of 5.8 GHz, and due to the resonant nature of both the patch antenna and the metasurface, it has a narrow bandwidth (around ±80 MHz). Nevertheless, within this operational range, the design achieves robust circular polarization suitable for most wireless communication needs. By using multi-layer metasurfaces**,** periodic changes to the unit cell geometry, or more broadband patch designs, we can improve the bandwidth**.**

IV. CONCLUSION

In conclusion, a metasurface has been designed and integrated on top of a rectangular patch antenna to convert the polarization of the radiated field from linear to circular. Efficient polarization conversion has been obtained at 5.8GHz with the proposed approach. The simulation results illustrate 5.1 dBi realized gain for right-handed circular polarization. The optimization of the separation between the antenna and metasurface proved essential in achieving a proper phase shift for circular polarization. The designed structure exhibits superior AR performance within -21 to 80 degrees around broadside compared to other reported structures, making it a practical and effective solution for wireless communication systems.

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