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Research Article

Design of Hexagonal-Shaped Artificial Magnetic Conductor for Gain and Directivity Enhancement

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Abstract *–* This study presents the design and evaluation of a hexagon-shaped Artificial Magnetic Conductor (AMC) to enhance the gain and directivity of a microstrip patch antenna. The AMC was positioned under the antenna to assess its impact on various performance parameters. Experimental results demonstrated an improvement in gain and directivity with adding the AMC. Initially, the microstrip patch antenna exhibited a gain of 7.454 dBi and a directivity of 11.22 dBi. After integrating the hexagonal AMC, these values increased to 7.936 dBi for gain and 17.29 dBi for directivity. These findings indicate that a hexagon-shaped AMC can effectively enhance the efficiency of microstrip patch antennas, making it a promising solution for applications that require improved antenna performance.

Keywords – AMC, Microstrip Patch Antenna, Gain, Directivity, Hexagonal Shape.

I. INTRODUCTION

In today's technology, the demand for effective wireless communication is more significant than ever[1]. As technology advances, there is an increasing need for antennas that offer improved performance, specifically in gain and directivity. Microstrip patch antennas are commonly used in various applications due to their low profile and ease of integration[2][3]. However, these antennas often need more performance concerning gain and directivity[4]. Researchers are exploring innovative solutions to tackle these challenges, such as using Artificial Magnetic Conductors (AMCs) to enhance antenna performance. AMCs are specially designed materials that control electromagnetic waves. They possess unique characteristics that allow them to reflect and alter the behavior of these waves[5][6]. When an AMC is placed below a microstrip patch antenna, it can significantly enhance the antenna's performance[6]. This study focuses on designing and evaluating a hexagonal AMC to increase the gain and directivity of a microstrip patch antenna positioned above it.

The hexagonal shape of the AMC is particularly advantageous because it creates a more uniform surface with which electromagnetic waves can interact[7]. This uniformity can enhance reflection properties, which is vital for improving antenna performance[5]. Previous studies have shown that the design and placement of AMC unit cells play a critical role in enhancing antenna performance[8]. This study aims to investigate the potential benefits of integrating a hexagon-shaped AMC with a microstrip patch antenna by optimizing its design. Experimental assessments are essential for demonstrating the theoretical advantages of using Artificial Magnetic Conductors (AMCs) in antenna applications. In this study, the performance metrics of a microstrip patch antenna, including gain and directivity, were thoroughly evaluated before and after the incorporation of a hexagonal AMC. The results provide valuable insights into how the AMC can enhance antenna performance, making it a viable option for various applications, including telecommunications and wireless networks.

The microstrip patch antenna initially had a gain of 7.45 dBi and a directivity of 11.2 dBi. After incorporating the hexagonal AMC, the gain increased to 7.94 dBi, and the directivity rose to 17.3 dBi. This improvement indicates that hexagon-shaped AMCs can significantly enhance the performance of microstrip patch antennas. These enhancements are crucial for applications that require consistent and reliable signal transmission. Improving gain and directivity in antennas is essential for enhancing energy efficiency in communication systems. Higher gain allows for more effective input power conversion into radiated signals, leading to stronger communication lines without additional power. At the same time, enhanced directivity focuses energy transmission in specific directions, which reduces interference and improves signal quality. This combination boosts signal-to-noise ratios, lowers power losses, and enhances overall system performance, making it particularly beneficial for battery-powered devices and long-distance communications.[9]

Integrating AMCs with antennas is not just a theoretical concept; it has practical applications in the real world. For instance, AMCs can enhance performance and reliability in satellite communications, where maintaining strong and clear signals is essential[10]. Additionally, AMCs can help meet the demands of 5G technology by improving antenna characteristics, which are vital for achieving high data rates and low latency[11]. Moreover, using AMCs can contribute to reducing the size of antennas[12]. As devices become smaller and more compact, the need for antennas that perform well in restricted spaces is increasing. AMCs enable smaller antenna designs without compromising performance, which is particularly important in developing modern electronic devices where space is often limited. AMCs can help reduce cross-polarization in antenna systems while enhancing gain and directivity[13]. Cross-polarization can lead to signal degradation and interference in communication systems. By effectively managing the polarization of electromagnetic waves, AMCs can improve the overall performance of the antenna system, ensuring better signal integrity and purity. While utilizing AMC offers numerous advantages, specific challenges need to be addressed. Fabricating precise periodic structures for AMCs can be technically demanding and requires specialized tools and expertise. Additionally, the size and shape of the components in the periodic array significantly influence the performance of AMCs. Any inconsistencies during the manufacturing process can negatively impact the effectiveness of the AMC.

In summary, a significant advancement in antenna technology is the integration of a microstrip patch antenna with a hexagon-shaped AMC. The findings from this research pave the way for further exploration into complex electromagnetic structures, demonstrating that using AMCs to enhance antenna performance is indeed feasible. As the demand for reliable and efficient communication systems continues to grow, developing innovative solutions like AMCs will be crucial in shaping the future of antenna technology. This study highlights the various potential applications of Artificial Magnetic Conductors (AMCs) and contributes valuable information to the existing knowledge on the topic. AMCs can enhance the performance of microstrip patch antennas, helping modern communication systems meet their increasing demands. This improvement ensures the efficiency and reliability of these systems in a rapidly evolving technological landscape.

II. DESIGN OVERVIEW OF HEXAGONAL-PATCH AMC

AMC enhances the performance of microstrip patch antennas by providing a specialized reflecting surface that optimizes the behavior of electromagnetic waves[14]. The hexagonal shape was selected because it allows for more consistent and efficient interaction with incoming electromagnetic waves compared to standard rectangular or square designs[15]. This design facilitates superior phase control and reflection characteristics, essential for improving antenna performance.

In this proposed design for the AMC, both the ground plane and the dielectric substrate are square, measuring 4.42 mm in length and width. The ground plane is constructed from annealed copper with a thickness of 0.035 mm, which ensures excellent conductivity and minimal losses. The dielectric substrate is made from a lossy material from Rogers RO4003C, and it has a thickness of 1.6 mm. This combination of materials provides a robust foundation for the AMC while maintaining the necessary electromagnetic properties. The hexagonal patch has side lengths of 4.22 mm and is made of annealed copper with a thickness of 0.035 mm. This hexagonal shape is designed to resonate at a specific frequency, enabling the AMC to effectively reflect electromagnetic waves to enhance the performance of the microstrip patch antenna positioned above it. Fig. 1, Fig. 2 and Fig. 3 below show the unit cell of AMC, the AMC surface and the phase diagram of the AMC respectively.

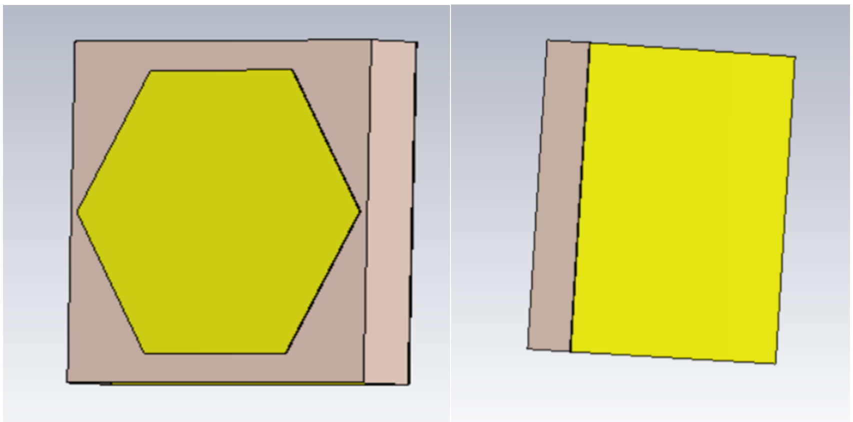

Fig. 1 proposed hexagonal-patch AMC unit cell A) Front view B)Back view

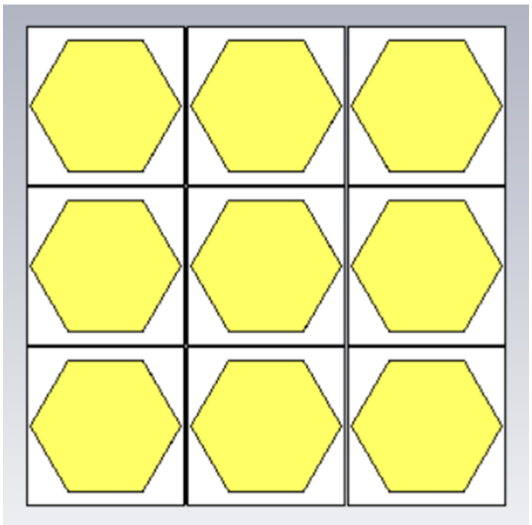

Fig. 2 AMC surface

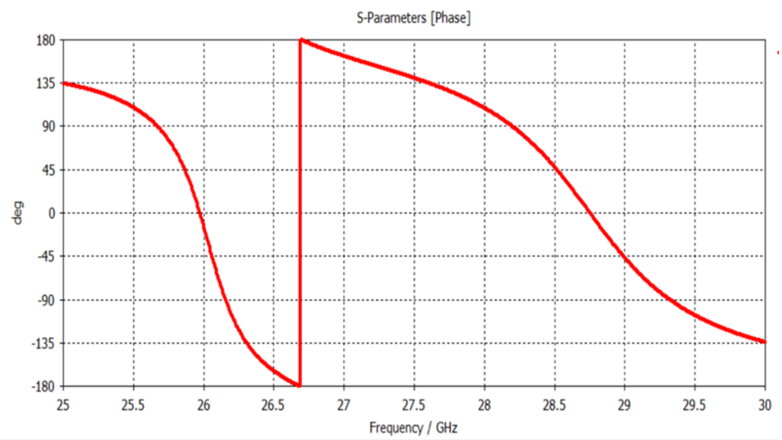

Fig. 3 AMC phase diagram

The arrangement of hexagonal patches on the substrate is crucial because it controls the effective wavelength of the reflected waves. By carefully selecting the size of these hexagonal patches and the overall structure, the AMC can be designed to operate efficiently within the desired frequency range, ensuring optimal performance. This design prioritizes enhancing antenna performance while considering practical factors like ease of production and compatibility with existing antenna systems. The hexagonal shape can be easily produced using standard manufacturing procedures, making it feasible for various telecommunications, satellite communication, and wireless network applications. The parameters of the microstrip patch antenna that we used to test the proposed AMC are shown in Table 1. below.

Table 1. Parameters of the proposed antenna

Description	**Symbol**	**Value (mm)**
Width of the substrate	ws	13.144
Length of the substrate	ls	11.367
Width of the ground	wg	13.144
Length of the ground	lg	11.731
Width of the patch	wp	3.509
Length of the patch	lp	1.965
Width of the feedline	wf	1
Length of the feedline	lf	4.8
Hight of the substrate	hs	1.6
Thickness of the substrate	tg	0.035

The microstrip patch antenna with the proposed AMC is given in Fig. 4.

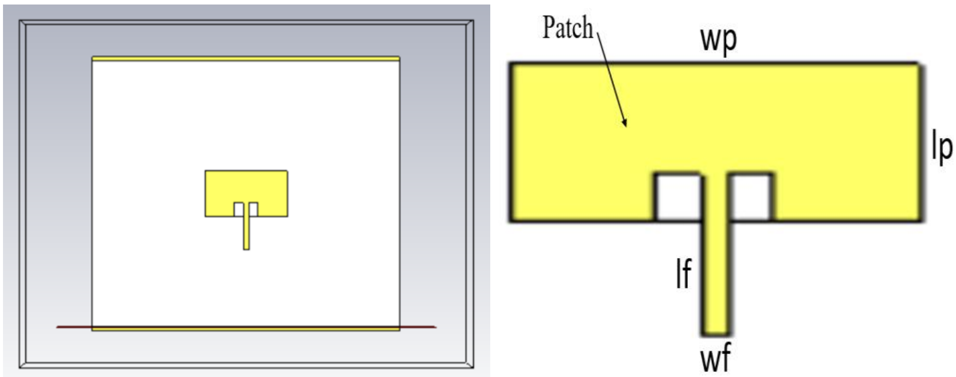

Fig. 4 Microstrip patch antenna

The microstrip patch antenna was placed above the AMC surface, as shown in Fig. 5 below, to observe whether its parameters would increase and how this would affect its overall performance.

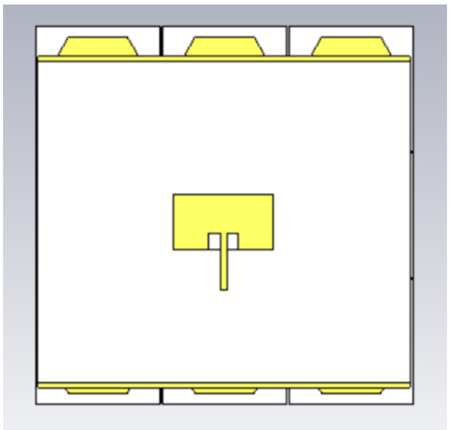

Fig. 5 Microstrip patch antenna with AMC

III. RESULTS

In this section, we present the simulation results for the hexagonal-patch AMC, designed to enhance the performance of microstrip patch antennas. The simulations were conducted using CST simulation software, which allowed us to examine the AMC's reflection properties, gain, directivity, and overall performance.

A. *Gain Improvement:*

The gain of the microstrip patch antenna with a hexagonal-patch AMC was measured and compared to that of a standard microstrip patch antenna without the AMC. The results show a significant increase in gain, with the AMC-equipped antenna achieving a maximum gain of 7.94 dB at a resonant frequency of 26 GHz, as shown in Fig. 6 (a). In contrast, the antenna gain was 7.45 dB before applying AMC, as shown in Fig. 6 (b). This increase in gain can be attributed to the AMC's ability to effectively reflect and redirect electromagnetic waves, thereby enhancing the antenna's effective radiated power.

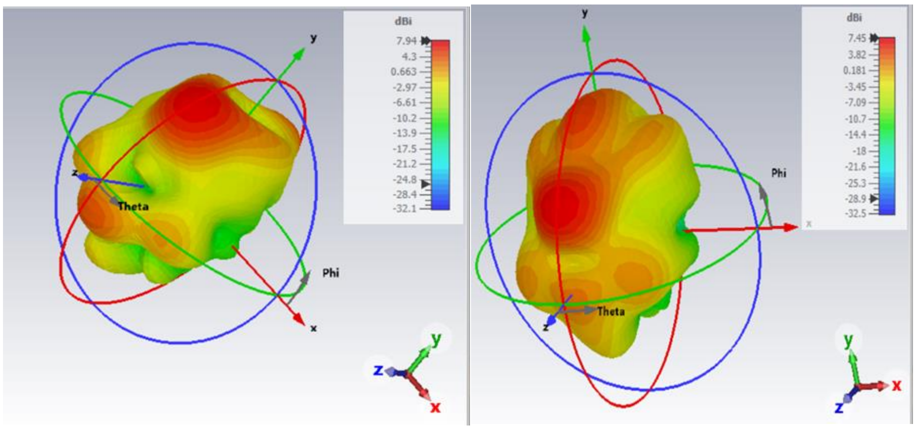

Fig. 6 Gain (a) with AMC (b) without AMC

B. *Directivity:*

The directivity of the antenna system was also assessed. Directivity measures how focused the antenna's radiation pattern is in a specific direction. The hexagonal-patch AMC exhibited a directivity of 17.3 dB, as shown in Fig. 7 (a), which is significantly higher than the typical microstrip patch antenna's directivity of 11.2 dB, as shown in Fig. 7 (b). This enhancement in directivity indicates that the AMC increases gain and improves the antenna's ability to concentrate energy in a particular direction, leading to more efficient signal transmission and reception.

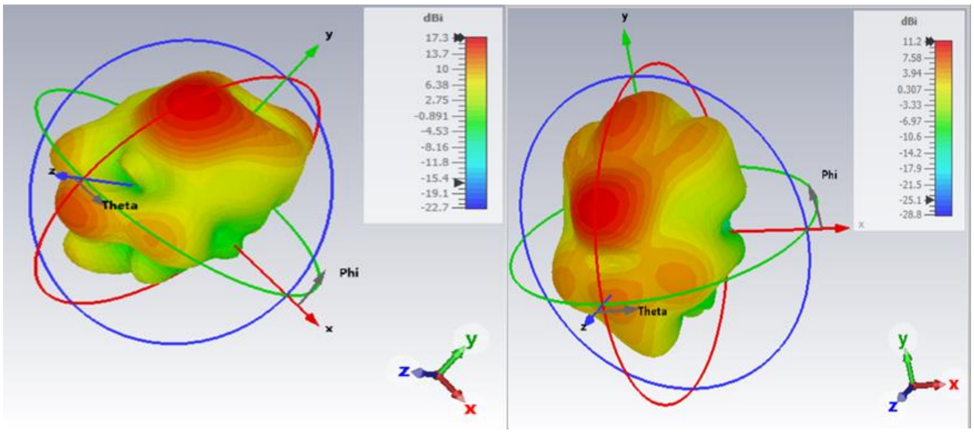

Fig. 7 Directivity (a) with AMC (b) without AMC

C. *Reflection Coefficient:*

The reflection coefficient (S_{11}) of the hexagonal-patch amplitude modulation circuit (AMC) was analyzed at the resonant frequency. The results indicate a notable decrease in the reflection coefficient at this frequency. The regular microstrip patch antenna exhibited a reflection coefficient of -35 dB as shown in Fig. 8 below, whereas the antenna with the AMC showed a reflection value of -32 dB as shown in Fig. 9 below.

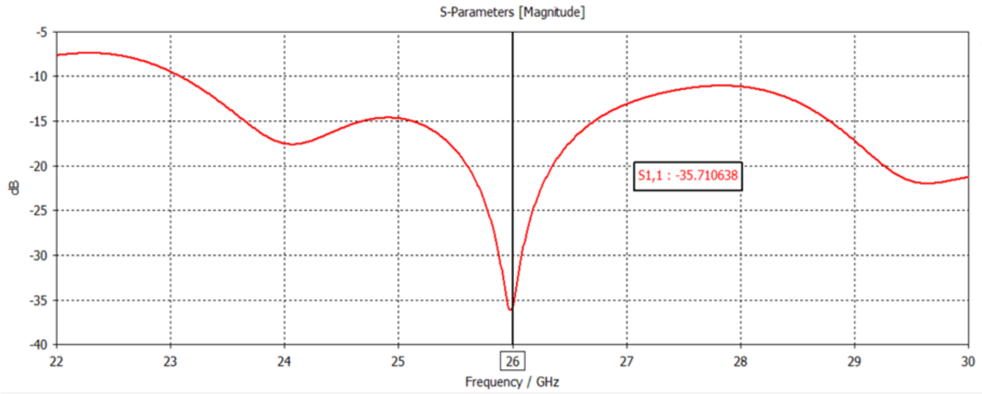

Fig. 8 S_{11} without AMC

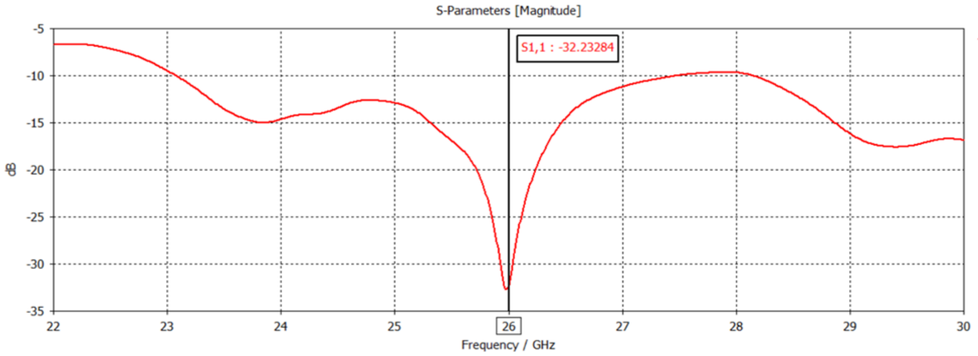

Fig. 9 S_{11} with AMC

IV. DISCUSSION

The simulation results indicate that the hexagonal patch AMC enhances the performance of microstrip patch antennas. The significant improvements in gain, directivity, and reflection coefficient highlight the potential of AMCs in antenna design, especially for applications that require high efficiency and performance. The improvement in gain from 7.45 dB to 7.94 dB when using the hexagonal-patch AMC is significant. This enhancement can be attributed to the AMC's unique characteristics, which allow it to reflect and redirect electromagnetic waves more effectively than a standard metal surface. The AMC's ability to generate a controlled phase shift at the resonant frequency facilitates constructive interference of the radiated waves, resulting in increased radiated power. This gain enhancement is particularly valuable in applications such as wireless communication and satellite systems, where boosting signal strength is essential for reliable operation.

The improvement in directivity from 11.2 dB to 17.3 dB highlights the advantages of using AMCs in antenna designs. This increased directivity indicates that AMCs enhance gain and focus radiated energy in a specific direction. This feature is essential for applications that demand precise beamforming and minimal interference, such as innovative antenna systems and advanced communication networks. The ability to effectively concentrate energy can improve signal quality and coverage, particularly in environments with high levels of electromagnetic interference. The study of the reflection coefficient reveals a decrease from -35 dB to -32 dB when using the AMC. This change indicates improved impedance matching; however, the reduction in S_{11} is not as significant as expected. This suggests that while the AMC enhances the antenna's performance, there is still room for improvement in the design of the AMC structure itself. The AMC's shape, material properties, and periodicity can significantly influence its performance. Future research should optimize these factors for better impedance matching and reflection characteristics.

V. CONCLUSION

In conclusion, using hexagonal-patch AMCs in microstrip patch antennas has proven an effective technique for enhancing antenna performance. The study found significant improvements in key performance indicators such as gain, directivity, and reflection coefficient. Specifically, the gain increased from 7.45 dB to 7.94 dB, while directivity rose from 11.2 dB to 17.3 dB. These enhancements demonstrate the ability of AMCs to optimize antenna radiation properties, making them ideal for use in wireless communication and satellite systems. The results emphasize the significance of AMCs in modern antenna design, opening the way for more efficient and effective communication solutions. Ongoing research and development of AMC structures are essential to track their potential across various applications. AMC structures will contribute to advancements in electromagnetic devices and systems.

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