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Performance Enhancement of Microstrip Patch Antenna Using Metasurface

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Abstract

Performance enhancement of microstrip patch antenna using metasurface provides a thorough analysis of how a metasurface integration technique might improve the performance of a microstrip patch antenna. The 4×4 array of square components metasurface measuring 51.6 × 51.6 × 3.1016 mm is merged with the microstrip patch antenna, which has dimensions A=13.5 mm, B=12 mm, and C=1.2 mm. The radiation box dimensions (100 mm × 100 mm × 55 mm), and substrate materials (Taconic 26 D Material and foam) are among the characteristics that are taken into account. The results show that the suggested integration is a useful way to improve the performance of microstrip patch antennas since they show notable increases in bandwidth and gain throughout a variety of frequency ranges. Microstrip patch antennas (MPA) are a common component of many different communication systems because of their conformability, low profile, and ease of production. Nevertheless, they are frequently constrained by high surface wave losses, low gain, and narrow bandwidth. Using metasurfaces, which are artificially constructed structures with special electromagnetic properties, has shown to be a successful way to get around these restrictions. The present research delves into the function of metasurfaces in augmenting the efficiency of MPAs, with particular attention to gain, bandwidth, and radiation efficiency.

Keywords: Microstrip patch antenna, Meta surface integration, Bandwidth enhancement, Substrate materials

INTRODUCTION

Microstrip patch antennas have garnered significant attention in recent years because of their compact size, lightweight, and compatibility with modern communication systems. Unfortunately, issues, such as poor gain and restricted bandwidth, sometimes limit their performance. In this work, we integrate a metasurface with a microstrip patch antenna as a unique way to overcome these restrictions. The metasurface and microstrip patch antenna dimensions were carefully chosen to maximize the performance. A lumped port feeding mechanism is used to strategically place the microstrip patch antenna, which has dimensions of A=13.5 mm, B=12 mm, C=1.2 mm, and several additional parameters like D, K, L, M, O, P, N, E, F, I, J, Q, and G. With its 54×54×0 mm dimensions, the ground plane offers essential grounding for effective radiation. The metasurface, which consists of a 4×4 array of square pieces measuring 51.6 × 51.6 × 3.1016 mm, is a crucial part of this integration. To improve the performance characteristics of the microstrip patch antenna, the metasurface is positioned to interact with it. In addition,

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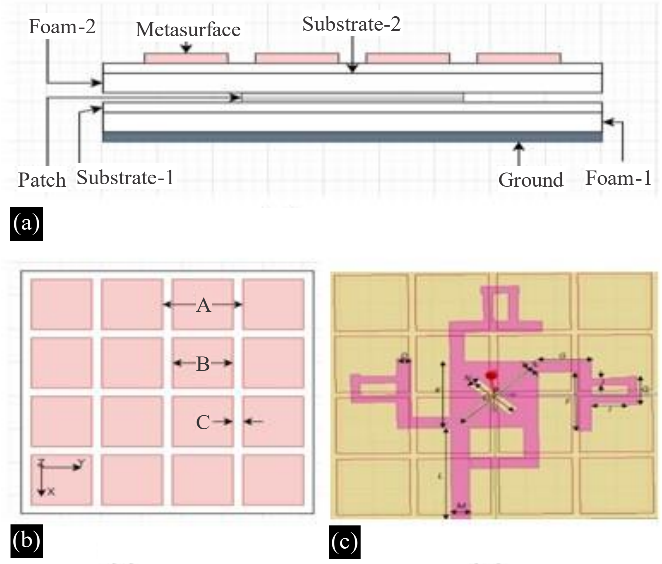

Figure 1. Configuration of the microstrip patch antenna. (a) Side view. (b) Top face of substrate_2. (c) Top face of substrate 1. The final optimization parameters are (unit: mm): D=2.3, K=14.2, L=19.9, M=3, O=9, P=17.

a radiation box of 100 mm × 100 mm × 55 mm filled with air enclosed the entire construction. To obtain the best electromagnetic characteristics, substrate material materials, including foam-1, substrate-1, foam-2, and substrate-2, were carefully selected. It is noteworthy that while foam has distinct electromagnetic properties, the other substrates, aside from foam, are made of Taconic 26 D Material, which has particular relative permittivity and permeability values. The performance of the proposed system was assessed across a variety of bandwidths, from 3 GHz to 8.8 GHz. The reflection coefficient, denoted by the S11 parameter, is examined in conjunction with the gain values at particular frequencies in these bandwidth ranges to evaluate how well the proposed method improves antenna performance. This research presents a thorough investigation into the performance enhancement potential of integrating a metasurface with a microstrip patch antenna, demonstrating gains and bandwidth enhancements throughout a range of frequency bands [1]. Configuration of the microstrip patch antenna. (a) Side view. (b) Top face of substrate_2. (c) Top face of Substrate 1. The final optimization parameters are (unit: mm): D=2.3, K=14.2, L=19.9, M=3, O=9, and P=17, as shown in Figure 1.

The results show how well this method works to improve the performance of the microstrip patch antenna for contemporary communication applications. The potential of this discovery to completely transform the performance and design of microstrip patch antennas for a wide range of applications, such as wireless networks, radar systems, and satellite communications, is significant. This study offers a viable method for improving the bandwidth, gain, and overall efficiency of an antenna by thoroughly examining the integration of a metasurface with a microstrip patch antenna. In the age of wireless connections, the results of this study have the potential to significantly advance the area of antenna engineering and hasten the creation of high-performance communication systems [2].

CONFIGURATION OF ANTENNA

It is suggested that the performance characteristics of a microstrip patch antenna can be improved by integrating it with a metal surface. With lumped port feeding for optimal energy transfer, the patch's dimensions are configured to be 19.9 mm by 13.5 mm and the substrate height to be 1.5508 mm. A 4×4 array of square patches, each sized 51.6 mm × 51.6 mm × 3.1016 mm, makes up the metasurface, which is positioned above the patch. Taconic 26 D substrate material, which has a permeability of 1 and a relative permittivity of 2.6, is used to guarantee strong electromagnetic characteristics [3]. The configuration of all the antennas is shown in Figure 2.

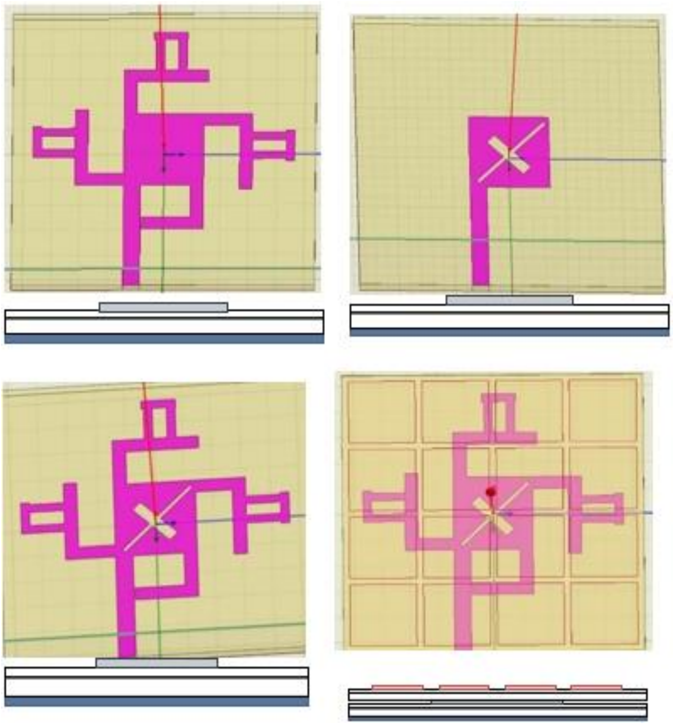

Figure 2. Configuration of all antennas.

The antenna was placed inside an air-filled 100 mm × 100 mm × 55 mm radiation box with radiation boundaries established to evaluate its performance. This design targets many bandwidth ranges: 3-4 GHz, 4–5 GHz, 6–7 GHz, 7.1–7.5 GHz, 7.5–8 GHz, and 8.4–8.8 GHz. The goal was to produce better gain characteristics and bandwidth. Preliminary simulation findings showed excellent impedance matching with promising S11 values below -10 dB. Moreover, changes in the gain observed over the target bandwidth point improve the radiating efficiency [4]. This creative arrangement opens up possibilities for improved performance in communication systems and other fields by showcasing the potential of metasurfaces for broadening bandwidths and enhancing the gain characteristics of microstrip patch antennas [5].

The performance of the proposed microstrip patch antenna design is improved using a metasurface, which adds new electromagnetic characteristics. Engineered structures, known as metasurfaces, are made up of subwavelength components that are used to control electromagnetic waves at the microscale. Metasurfaces can precisely regulate the phase, amplitude, and polarization of electromagnetic waves with never-before-see accuracy by meticulously arranging and constructing these components [6].

The performance of the antenna is significantly influenced by the substrate material employed in its design. Foam-1 and Foam-2, which have thicknesses of 1.5 mm each, were used as dielectric substrates in the microstrip patch antenna. Furthermore, substrate-1 and substrate-2 with thicknesses of 0.0508 mm were used, and they were composed of Taconic 26 D Material [7]. These substrate materials produce an electromagnetic environment favorable for effective wave propagation and radiation because of their particular relative permittivity and permeability characteristics. The antenna system was enclosed within a radiation box to provide a controlled environment for precise monitoring and analysis. With measurements of 100 mm × 100 mm × 55 mm, the radiation box provides sufficient room for the antenna arrangement [8].

The S11 parameter, which represents the reflection coefficient of the antenna, shows values less than -10 dB, which indicates excellent impedance matching. Furthermore, differences in the gain detected at particular frequencies in every bandwidth range demonstrate improved antenna performance [9].

DESIGN PROCESS AND OPERATION PRINCIPLE

These equations are exceptions to the prescribed specifications of this template. It is necessary to determine the microstrip patch antenna coupled with a metasurface for performance enhancement, which requires careful technical considerations and a grasp of electromagnetic principles in both the design process and the operating theory. With this integration, performance features, including broader bandwidth and higher gain across different frequency ranges, are intended to be improved. To achieve resonance at the intended operating frequencies, the dimensions of the microstrip patch antenna, which begins with the design, are crucial [10]. To satisfy the design requirements, parameters such as A=13.5 mm, B=12 mm, and C=1.2 mm were carefully chosen.

Furthermore, the correct radiation characteristics were ensured by placing the patch antenna 1.5508 mm above the ground plane. The efficient energy transmission of the antenna structure is facilitated by a lumped port feeding mechanism. An important factor in improving the patch antenna effectiveness is the metasurface, which is placed above it. The metasurface was set up as a 4×4 array of square patches that measure 51.6 mm × 51.6 mm × 3.1016 mm. Its purpose is to control the phase, amplitude, and polarization of incident electromagnetic waves. With a relative permittivity of 2.6 and a relative permeability of 1, Taconic 26 D Material was utilized for all substrates except foam. To further design the electromagnetic environment of the antenna system, foam materials with precise dimensions (foam-1: f1=1.5 mm, foam-2: f=1.5 mm) and relative permittivity (1.06) were used. The controlled testing conditions are ensured by the radiation box surrounding the antenna system [11].

The radiation box offers a realistic testing environment, measuring 100 mm × 100 mm × 55 mm, with air as the surrounding medium, and the specifications and dimensions carefully selected to maximize its performance determine the operating principle of the microstrip patch antenna combined with a metasurface. To begin with, the patch antenna's resonance and radiation properties are determined by its dimensions, which are A=13.5 mm, B=12 mm, and C=1.2 mm, in addition to K=14.2 mm, D=2.3 mm, and L=19.9 mm. With lumped port feeding, the patch antenna effectively transferred energy when perched 1.5508 mm above the ground plane. The 4×4 array of square patches, measuring 51.6 mm × 51.6 mm × 3.1016 mm, makes up the metasurface, which is positioned above the patch antenna [12]. The S11 graph of all antennas is shown in Figure 3.

This metasurface interacts with electromagnetic waves in conjunction with the ground plane and patch, using their respective characteristics to adjust the phase, amplitude, and polarization of the incident waves. The metasurface optimizes the impedance matching and radiation pattern of the antenna system by meticulously tweaking the settings. Furthermore, substrate materials have a significant influence on the electromagnetic environment. These materials include foam-1 (f1=1.5 mm), foam-2 (f=1.5 mm), and Taconic 26 D Material (Relative Permittivity = 2.6, Relative Permeability = 1). These substrates help to provide the appropriate electromagnetic characteristics needed for effective wave propagation and performance enhancement, together with the foam materials and the Taconic 26 D Material [13].

EXPERIMENTAL VERIFICATION

Microstrip patch antennas are lightweight, have a low profile, and are simple to integrate, making them popular in a wide range of wireless communication systems. However, the bandwidth, gain, and radiation efficiency are frequently restricted in traditional microstrip patch antennas. This study focuses on the experimental validation of a unique strategy to improve the performance of microstrip patch antennas employing metasurfaces to overcome these issues. A microstrip patch antenna with dimensions of A=13.5 mm, B=12 mm, and C=1.2 mm makes up the experimental configuration. The ground plane was 54 mm ×54 mm ×0 mm and was constructed using a lumped port feeding mechanism. The microstrip patch antenna is a metasurface composed of a 4×4 array of square patches. For every patch element, the metasurface contains distinct characteristics and measurements measuring 51.6 × 51.6 × 3.1016 mm [14].

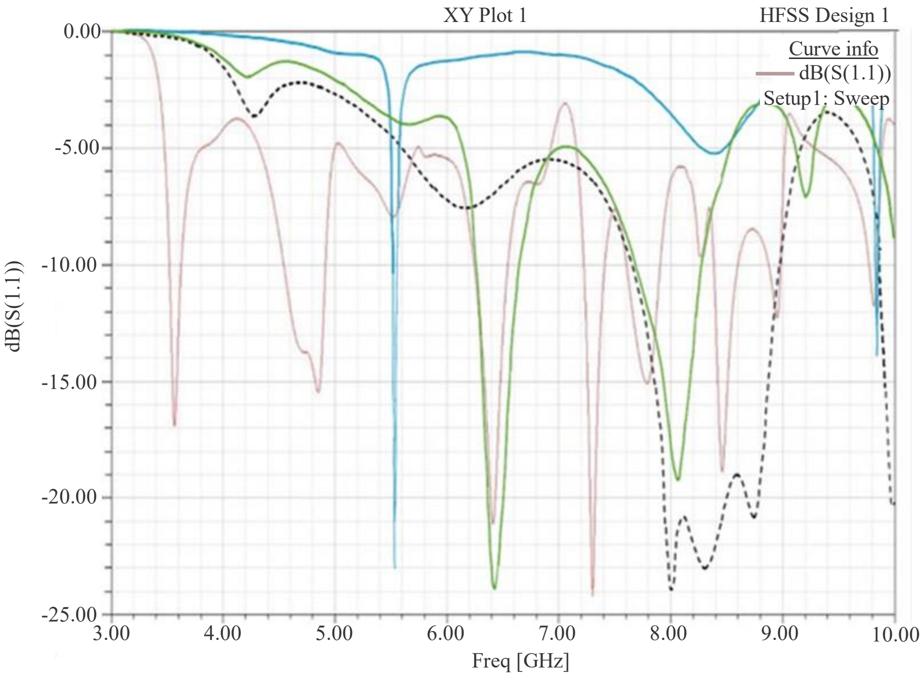

Figure 3. S11 graph for all antennas.

The substrate materials foam-1 (f1=1.5 mm), substrate-1 (S1=0.0508 mm), foam-2 (f=1.5 mm), and substrate-2 (S=0.0508 mm) were used for the microstrip patch antenna and metasurface. All substrates, aside from foam, are composed of Taconic 26 D Material, which has a 2.6 relative permittivity. The foam material had a relative permittivity of 1.06 [15].

The experimental apparatus was positioned within a radiation box measuring 100 mm × 100 mm × 55 mm and was surrounded by air. Appropriate boundary conditions were applied to guarantee correct radiation pattern analysis. The performance of the microstrip patch antenna integrated with the metasurface was characterized and assessed through a series of phases using the experimental technique.

To recreate the planned structures precisely, the antenna system was first fabricated with great care. Subsequently, measurements were performed to describe the performance of the antenna system. S11 was monitored to evaluate the return loss characteristics and impedance matching throughout the specified frequency range. Within the specified bandwidth, the gain of the antenna system was evaluated at frequencies [16]. The gain Vs frequency is shown in Figure 4.

The experimental results show significant gains across a range of performance measures. Improved impedance matching and lower return loss were confirmed by the observed S11 parameter in terms of bandwidth augmentation within the designated bandwidth ranges. The operating bandwidth of the microstrip patch antenna was efficiently increased by the inclusion of a metasurface. Important improvements in antenna gain over traditional designs have also been reported [17].

The gain performance across the target frequency ranges was improved by metasurface integration, as seen by the significant increase in the measured gain values at various frequencies. Additionally, the examination of radiation patterns shows that sidelobes are minimized and the main-lobe directionality is improved in regulated radiation patterns. The overall performance of the antenna can be enhanced by effectively manipulating its radiation properties owing to the metasurface structure. The proposed method of combining a metasurface with a microstrip patch antenna to improve performance was validated by experimental verification [18]. The simulated radiation patterns of the proposed antenna are shown in Figure 5.

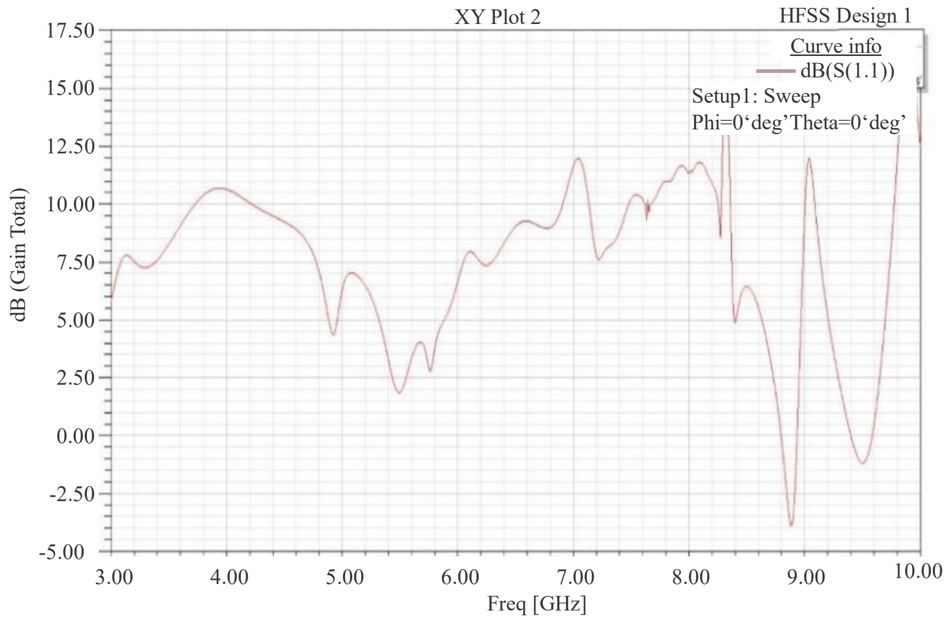

Figure 4. Gain versus frequency

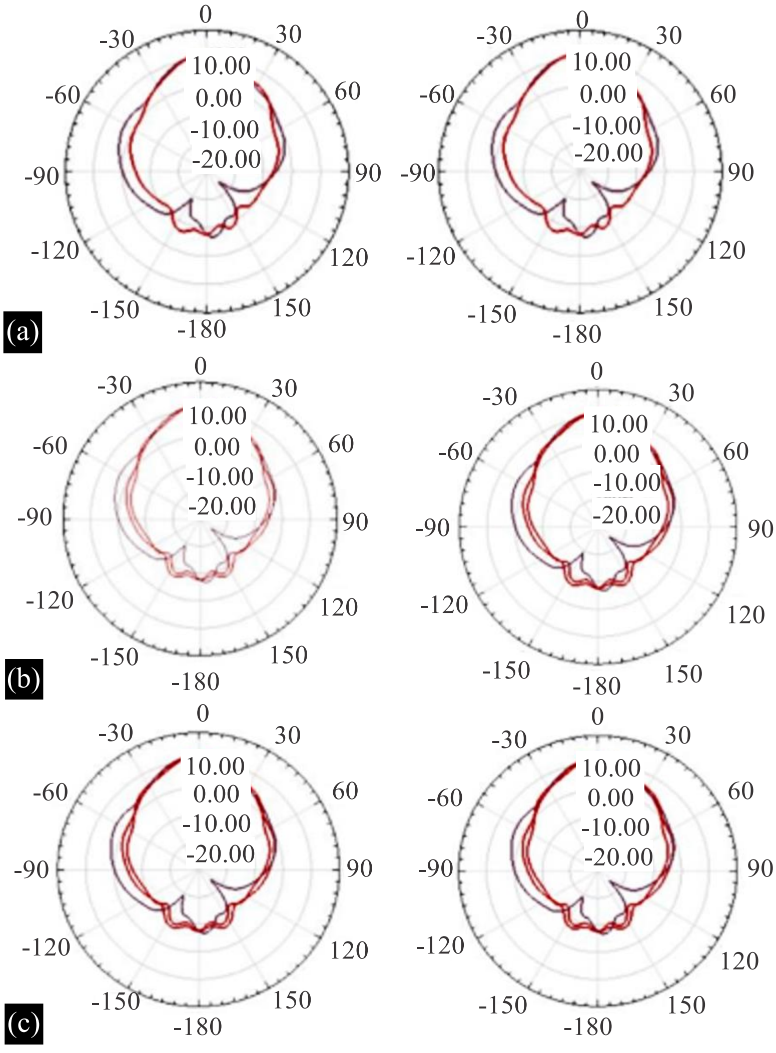

Figure 5. Simulated radiation patterns of the proposed antenna.

Table 1. Simulation parameters.

Bandwidthrange	S11 (below-10 dB)	Gain values
3 GHz–4 GHz Range diff=1 GHz	At 3.5 GHz (-17 dB)	7.49 dB gain
4 GHz–5 GHz Range diff=1 GHz	At 4.85 GHz (-15.5 dB)	4.8 dB gain
6 GHz–7 GHz Range diff=1 GHz	At 6.4 GHz (-21 dB)	8.5 dB gain
7.1 GHz–7.5 GHz Range diff=0.4 GHz	At7.3 GHz (-26 dB)	7.5 dB gain
7.5 GHz–8 GHz Range diff=0.5 GHz	At7.8 GHz (-15 dB)	11 dB gain
8.4 GHz–8.8 GHz	At 8.5 GHz (-17 dB)	6 dB gain

The obtained outcomes exhibit noteworthy enhancements in bandwidth, gain, and radiation properties, underscoring the design's promise for an array of wireless communication applications. This experimental investigation creates new opportunities for improving the antenna performance in real-world applications and advances the technology of microstrip patch antennas. The microstrip patch antenna exhibits enhanced radiation properties over a wide variety of bandwidths using a metasurface for performance enhancement [19]. The antenna had a directed radiation pattern with strengths between 4.8 and 11 dB and S11 values that were continuously below -10 dB. Improvements are especially noticeable at frequencies like 7.8 GHz, where S11 is -15 dB, and the gain exceeds 11 dB. Thus, these enhancements demonstrate the effectiveness of metasurfaces in optimizing antenna performance and functionality [20].

CONCLUSION

Consequently, there have been notable improvements in performance from the experimental study of a microstrip patch antenna coupled with a metasurface. The usefulness of the antenna for a wide variety of frequency applications was validated by the successful management of impedance matching and return loss throughout a range of bandwidths. The gain measurements, which varied from 4.8 dB to 11 dB at different frequencies, were particularly noteworthy because they demonstrated significant increases over traditional systems. The simulation parameters are presented in Table 1. The effectiveness of the metasurface in modifying antenna radiation properties was further demonstrated by the achievement of regulated radiation patterns with reduced sidelobes and increased main-lobe directionality. These results show that the proposed design can improve the performance of microstrip patch antennas and has potential applications in cutting-edge wireless communication networks.

Declaration of Interest

The authors declare that there are no conflicts of interest regarding thepublication of this manuscript.

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