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Original Research

Monopole antenna design with flexible frequency selective surface

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ABSTRACT

A flexible monopole antenna combined with a flexible frequency selective surface (FSS) is presented in this work. Initially, the FSS structure is examined by constructing a unit cell of the periodic FSS structure with (3x3) arrays of square loops. On a thickness of 0.13 mm, a fast film with a permittivity of 2.7 is printed, and the substrate of the monopole antenna is FR-4 with a dielectric constant of 4.3. The monopole antenna is then densely and parallelly positioned 26 mm above the FSS structure. After studying the monopole antenna's return loss, efficiency, bandwidth, and antenna gain, the design is included in the FSS framework to obtain a steady frequency response. When the distance between both the antenna and the FSS structure is extended, the frequency response of the antenna is moved, and the return loss is determined to be less than -52 dB. Furthermore, the fractional bandwidth is extended from 62% to 103%, and the gain is increased greatly to 2.4 dB. This design structure demonstrated exceptional wireless communication performance.

Keywords: Index Terms— FSS, monopole antenna, wireless communication, unit cell, FR-4

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1. Introduction

Periodic structures are etched onto a dielectric surface or a set of metallic structures in a vacuum to create frequency-selective surfaces. These forms resonate at certain frequencies based on the length and kind of materials, and the selective surfaces function as bandpass or bandstop philters based on the metallic components [1]. The array of patch elements operates like a bandstop filter, but the array of aperture elements behaves like a bandpass filter [2]. Understanding the operation and use of frequency-selective surfaces requires a multitude of considerations. Figure 1 illustrates the geometrical characteristics of aperture and patch elements (FSS). FSS refers to any surface intended to act as a filter and generally has a periodic and narrowband structure [3]. Without a ground plane, the capacitive and inductive FSS may be constructed on a dielectric substrate. Multiple arrays and material layers can be coupled to generate FSS, also known as resonant structures.

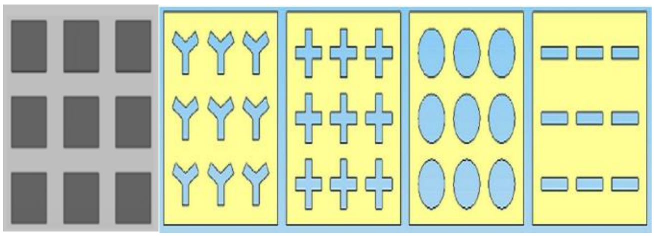


Figure 1. Geometries of aperture and patch elements of FSS [12]

These surfaces may be employed throughout a broad range of the electromagnetic spectrum, from frequencies below ultra-high frequency (UHF) to those in the far infrared [4]. Seven-by-seven FSS structures are built and simulated at 2.4 GHz in [5]. FR4 plate and glass were employed in the fabrication of hybrid materials. Using hybrid materials affects the return loss and transmission signal, resulting in a more compact construction. This design has the problem of covering only one frequency band. Recently, FSSs in substrates or superstrates have been employed to enhance antenna performance, primarily by increasing antenna gain [6, 7]. The FSS resonance of a quadratic loop is altered and its effect on the antenna response is investigated. The FSS superstrate working at 11.4 GHz provides the highest gain. When the gain rises from 1.8 to 6 dB [8] In the Y-shaped monopole antenna, the planar monopole antenna consists of a rectangular notch, the compact meander patch antenna, and the coaxial line-fed monopole with a flawed ground plane; nevertheless, they either occupy an excessive radiation space or have a restricted bandwidth. Debdeep Sarkar demonstrated in 2014 that a unique ultra-wideband (UWB) antenna with a low profile and microstrip feed is in the works. By adding two rectangular resonators with a split ring at the junction of the antenna's feed line and patch, it is possible to suppress X-band frequencies between 7.9 and 8.4 GHz [9]. In recent years, the need for antennas with high gain has made enhancing the gain and directivity a crucial aspect of antenna design. This is due to the substrate dielectric's surface wave losses, which create the patch antenna's weak gain, low directivity, and limited bandwidth. Utilizing a periodic element antenna (FSS) can improve bandwidth, gain, and directivity [10, 11]. Since their inception, antennas with FSS have undergone gradual enhancements, but recent experimental investigations have demonstrated that, while the gain has generally increased, there have been no significant improvements in other parameters such as bandwidth, density return loss, and directivity [13] [14]. Some research focuses solely on the increase of gain to reduce the human body's exposure to radiation [15]. The purpose of this study is to introduce a novel antenna design that simultaneously improves bandwidth, directivity, return loss, and gain.

Frequency-selective surfaces (FSS) play a crucial role in various applications by acting as filters that selectively transmit or reflect specific frequencies. These surfaces consist of periodic structures etched onto dielectric surfaces or metallic structures, which resonate at specific frequencies depending on their geometry and materials used. The FSS can function as either bandpass or bandstop filters, depending on the arrangement of patch or aperture elements. Figure 1 depicts the geometrical properties of aperture and patch elements to highlight the periodic and narrowband nature of FSS. Using capacitive and inductive qualities, FSS structures may be built on dielectric substrates without the necessity for a ground plane. Resonant structures may be made by combining various arrays and material layers, making them applicable throughout a large portion of the electromagnetic spectrum, from ultra-high frequency (UHF) to the far infrared area. FSS technology has recently made strides in improving antenna performance, notably by raising antenna gain. Gain has been significantly increased by modifying the resonance of FSS structures like quadratic loops and examining how they affect antenna response. FSS and the utilization of periodic element antennas present potential benefits over conventional patch antennas in terms of bandwidth, gain, and directivity.

In recent years, the need for antennas with high gain and enhanced directivity has increased due to the need to get over limitations such patch antennas' poor gain, low directivity, and confined bandwidth caused by surface wave losses in the substrate dielectric. In order to overcome these difficulties, the use of frequency-selective surfaces (FSS) into antenna design has shown promise. Research has concentrated on using FSS to gradually enhance the gain and directivity of antennas, with some success. Recent experimental studies, however, have shown that whereas gain has typically increased, other characteristics like bandwidth, return loss, and directivity have not much improved. However, some research has been done specifically to find ways to lower radiation exposure to people. In view of these factors, the goal of this work is to present a unique antenna design that concurrently increases gain, bandwidth, directivity, and return loss. Using a flexible FSS framework and a flexible monopole antenna, this device exhibits exceptional wireless communication performance. resolving the limits brought on by substrate dielectric losses while potentially outperforming traditional patch antennas. It offers a potential option for wireless communication applications because of the large increases in return loss, bandwidth, and gain shown by the experimental findings.

The geometries of the aperture and patch elements of the Frequency-Selective Surfaces (FSS) were investigated in this research, as depicted in Figure 1. Aperture and patch elements are fundamental components of FSS structures that determine their frequency-selective properties. The FSS structures are designed with periodic and narrowband characteristics to act as filters for specific frequencies. When placed in an array, aperture components act like bandpass filters, allowing only certain frequencies to pass through. Patch elements, on the other hand, function as bandstop filters that stop some frequencies from flowing through the structure. The exact geometrical details of these components, such as their size, shape, and arrangement, have a significant impact on the FSS's performance and resonant behavior. For diverse applications in electromagnetic spectrum manipulation, enhancing the design and performance of frequency-selective surfaces requires an understanding of the geometries of aperture and patch components.

Surfaces that choose frequencies By acting as filters that may selectively transmit or reflect certain frequencies, FS) have shown to be adaptable and crucial components in a variety of applications. These surfaces are made by etching periodic patterns onto metallic or dielectric surfaces. In vacuum, metallic constructions. These structures' resonance is governed by their length and the materials they are made of, allowing them to act as either bandpass or bandstop filters depending on how the metallic elements are arranged. While the array of aperture elements operates as a bandpass filter, the array of patch elements functions as a bandstop filter.

Numerous factors need to be taken into account in order to completely understand how frequency-selective surfaces function and are used. The geometrical features of the aperture and patch elements of FSS are shown in Figure 1. Any surface intended to serve as a filter is referred to as an FSS, and it typically has a periodic and narrowband structure. The advantage of capacitive and inductive FSS is that they can be constructed on a dielectric substrate without the need for a ground plane. By coupling multiple arrays and material layers, resonant structures can be generated, resulting in frequency-selective surfaces, also known as resonant structures.

These frequency-selective surfaces find applications across a wide range of the electromagnetic spectrum, spanning from frequencies below ultra-high frequency (UHF) to the far infrared region. Researchers have developed and simulated 7-by-7 FSS structures at 2.4 GHz using hybrid materials such as FR4 plate and glass. By employing hybrid materials, the return loss and transmission signal can be improved, leading to more compact designs. FSSs have also been used in substrates or superstrates to improve the performance of antennas, notably by raising antenna gain. It has been demonstrated that FSS superstrates operating at 11.4 GHz can offer substantial increases by modifying the FSS resonance of quadratic loops and examining their effects on antenna response.

In recent years, efforts have been made to improve gain and directivity in antenna design in response to the need for antennas with high gain. Due to surface wave losses in the substrate dielectric, patch antennas frequently have weak gain, poor directivity, and constrained bandwidth. In order to overcome these restrictions, using frequency-selective surfaces (FSS) in antenna design has showed potential. Increases in bandwidth, gain, and directivity can be made by adding FSS into antenna configurations. Although gain has typically increased, other factors like bandwidth, return loss, and directivity have not much improved.

Researchers want to create a revolutionary antenna design that concurrently improves bandwidth, directivity, return loss, and gain in order to get around these problems. It has been demonstrated that a flexible FSS framework combined with a flexible monopole antenna may provide outstanding wireless communication performance. By overcoming the restrictions imposed by substrate dielectric losses and maybe outperforming conventional patch antennas, this method presents a possible answer for wireless communication applications. Significant improvements in return loss, bandwidth, and gain have been found through experimental research, opening up the possibility of better wireless communication.

The design and performance of frequency-selective surfaces must be optimized, and this requires a thorough understanding of the geometries of aperture and patch components. These components are crucial in deciding how frequency-selective FSS structures are. The shape, size, and arrangement of the geometrical elements significantly affect the FSS's overall performance and resonant behavior. Therefore, understanding the complexities of these geometries is essential for configuring frequency-selective surfaces for particular applications and achieving effective electromagnetic spectrum manipulation.

Frequency-selective surfaces (FSS) act as filters that selectively transmit or reflect specific frequencies.

FSS structures can function as bandpass or bandstop filters based on the arrangement of aperture or patch elements.

Geometrical characteristics of aperture and patch elements influence the performance and resonant behavior of FSS.

Use of FSS in antenna design has shown potential for improving gain, directivity, and bandwidth.

2.Method

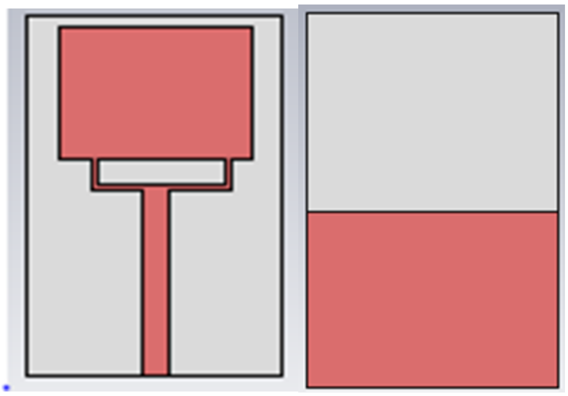
2.1 Design of monopole antenna

The monopole antenna is designed using FR-4 substrate material with a thickness of 0.13 mm and a permittivity of 4.3.

The geometry of the square front and back views of the antenna is carefully planned and examined.

The suggested monopole antenna was created using FR-4 substrate material with a thickness of 0.13 mm and a permittivity of 4.3. The geometry of the square front and back perspectives of the monopole antenna are shown in Figure 2.

Numerous important factors were taken into account when designing the monopole antenna. The antenna was built from FR-4 substrate material, which has a permittivity of 4.3 and a thickness of 0.13 mm. The mono pole antenna's square front and rear views' geometry was meticulously planned out and examined. Figure 2 represented the ground plane and patch elements of the monopole antenna. The performance of the antenna was greatly influenced by its configuration and size. The design sought to ensure effective signal reception with a wide bandwidth by choosing the right substrate material and optimizing the shape. The antenna's compatibility with the eventual integration of the flexible frequency-selective surface (FSS) structure, which significantly boosted the performance, was dependent on these design decisions. the antenna performance characteristics



(a) (b)

Figure 2. Geometry of (a) patch elements as well as (b) Monopole antenna ground plane

Numerous crucial factors were taken into account in the monopole antenna design. It used a FR-4 substrate with a permittivity of 4.3 and a thickness of 0.13 mm. To provide the best possible performance of the antenna, these material characteristics were carefully chosen. The square front and rear views of the monopole antenna were carefully developed and studied to satisfy the requirements.

The patch components and ground plane of the monopole antenna are shown visually in Figure 2. The size and arrangement of these parts had a significant role in the overall performance of the antenna. Effective signal reception was assured by carefully choosing the patch components' sizes and arrangements, and the ground plane was essential for improving the antenna's radiation pattern and impedance.

By choosing the right substrate material and refining the monopole antenna's form, the design sought to achieve a wide bandwidth. This was crucial to ensuring that the antenna could function efficiently across a wide variety of frequencies. By considering these design choices, the antenna could be seamlessly integrated with a flexible frequency-selective surface (FSS) structure, further enhancing its performance characteristics.

2.2 Design of FSS

The FSS layers consist of a substrate and FSS patch layers. The substrate is made of Fast Film with a thickness of 0.13 mm and a dielectric constant of 2.7. The FSS patch is made of Perfect Electromagnetic Conductor (PEC) with a thickness of 0.035 mm. The FSS structure consists of square loops arranged in a periodic (3x3) array. The findings of the S-parameters, which describe reflection and transmission via the FSS, are of primary importance in this instance. The almost equal copular reflections as well as transmissions of both modes are the result of the symmetrical square slots.

The configuration of the FSS layers consisted of substrate as well as FSS patch layers. The substrate for the fast film with a substrate was Fast Film with a thickness of 0.13 mm and a dielectric constant r = 2.7. A Perfect Electromagnetic Conductor (PEC) with a thickness of 0.035 mm was utilised for the FSS patch. The dimensions of the square loops of the FSS construction are depicted in Figures 3 and 4.

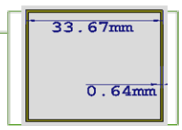


Figure 3. A unit cell of 4.5GHz FSS

Figure 4**.** FSS periodical structure (3x3 array)

The design of the frequency-selective surface (FSS) used in this work considerably improved the performance of the monopole antenna. The FSS layers were composed of a substrate and FSS patch layers, which were meticulously selected for their specific compositions and ratios. The FSS patch was made using a Perfect Electromagnetic Conductor (PEC) with a thickness of 0.035 mm and a Fast Film substrate with a thickness of 0.13 mm and a dielectric constant of 2.7. The FSS structure was built using square loops arranged in a periodic (3x3) array pattern, as seen in Figures 3 and 4. These geometrical features and materials were employed to achieve desired properties including resonance frequency, reflection, and transmission qualities. The simulations and analyses significantly enhanced the performance of the FSS design, particularly for co-polar reflections and transmissions of both modes. The FSS structure considerably enhanced the overall performance and capability of the monopole antenna system.

3. Results and discussion

3.1 Numerical prediction of monopole antenna

The simulation started with a monopole antenna without FSS to demonstrate the findings before integrating FSS. Figure 7 depicts the simulated results of the monopole antenna without FSS.

At the resonance frequency, the antenna obtained a return loss of -23 dB with a bandwidth of 2.7 GHz (62%) and a gain of 2.2 dB.

The surface current in front of a monopole antenna flows along the feed line and evenly through the two branches. As shown in Fig. 5.a, in front of a monopole antenna, the majority of the current flows through the feed line because it is directly connected to the port, whereas on a ground plane, the current assembles on the edges, as shown in Figure 5 (b).

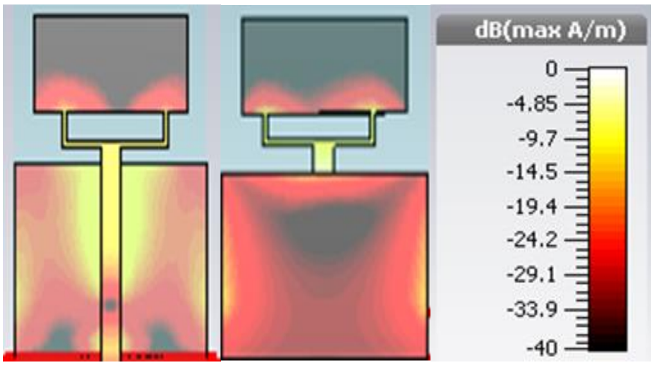
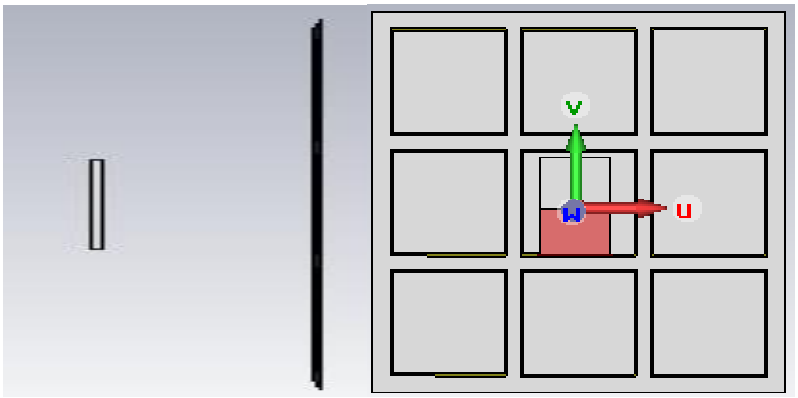


Figure 5: Surface current of the monopole antenna: (a) Front view; (b) distribution back view

3.2 Numerical prediction of monopole antenna with FSS

The monopole antenna was placed at 26 mm above the FSS structure, as presented in Figure 6 (a). Additionally, Figure 6 (b) depicts the monopole antenna with an FSS structure.



(a) (b)

Figure 6. monopole antenna integrated with FSS structure (a) Side and (b) Top view

The numerical prediction of the monopole antenna with the integrated flexible frequency-selective surface (FSS) involved simulating the antenna's performance with and without the FSS structure. The simulation was conducted using Computer Simulation Technology (CST). Initially, the monopole antenna without the FSS

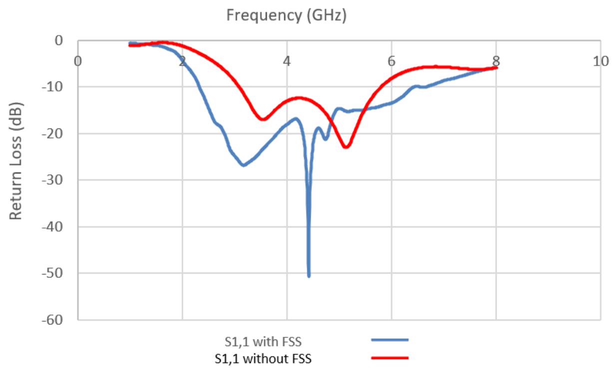


Figure 7. Simulated return loss and individual antenna and integrated structure

Numerous previous investigations were able to improve the antenna parameter to the detriment of other parameters [16]. Table 1 shows the comparison between our experimental investigations and previous studies without FSS and with the integration of FSS.

Table 1. Designed antenna with compared to prior studies before and after FSS article reference

	Gap	Design	Return Loss	BW%	Gain
Our Experimental Results	26mm	Without FSS	-23 dB	62%	2.2 dB
		With FSS	-52 dB	103%	2.4 dB
[10]	19.3mm	Without FSS	-17.1 dB	5.1%	1.81 dB
		With FSS	-10.5 dB	1.7%	5.11 dB
[8]	8mm	Without FSS	-23 dB	6%	1.8 dB
		With FSS	-28 dB	3.6%	6 dB
[11]	25mm	Without FSS	-35 dB	74.3%	4.1 dB
		With FSS	-28 dB	62%	7.5 dB

The surface current of the monopole antenna with FSS is shown in Figure 8. This shows that the current of the monopole flows along the feed line then distributes evenly through the two branches, and the current of FSS antenna flows along the square loop.

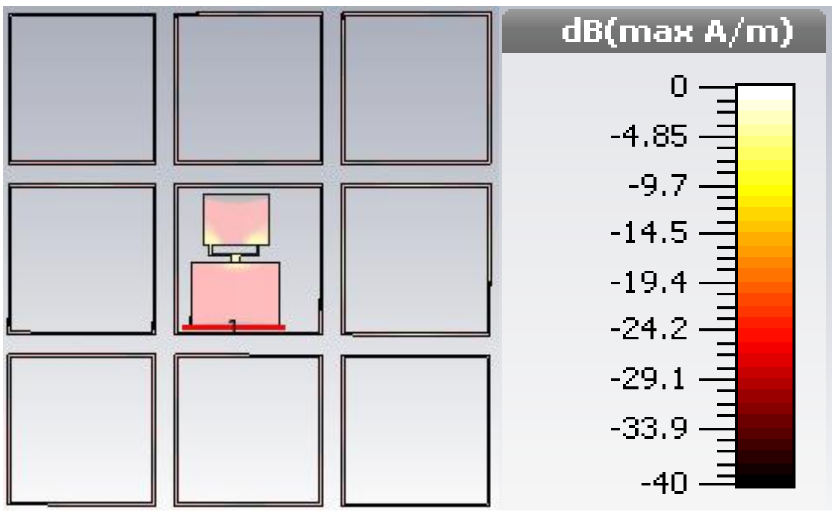
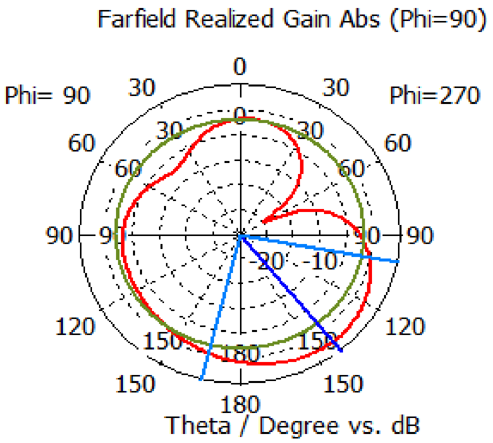
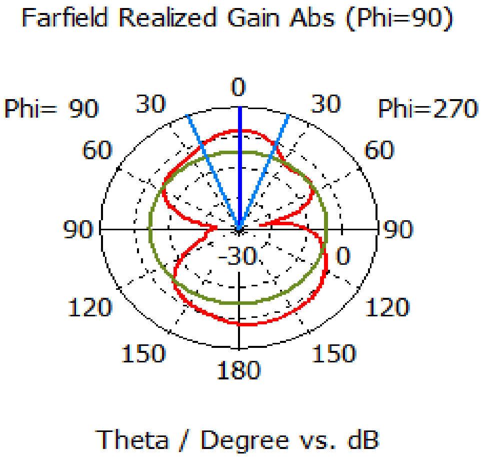


Figure 8. Surface current distribution of the monopole antenna with FSS design: (a) Surface Current of FSS



(a)



(b)

Figure 9. Monopole antenna radiation pattern: (a) with no FSS structure, and (b) with FSS structure

The surface current of the monopole antenna with FSS is shown in Figure 8. This shows that the current of the monopole flows along the feed line then distributes evenly through the two branches, and the current of FSS antenna flows along the square loop.

The performance of the monopole antenna, including return loss, efficiency, bandwidth, and gain, is studied.

The monopole antenna is integrated into the FSS framework, resulting in a steady frequency response.

Varying the distance between the antenna and FSS structure affects the frequency response and return loss.

The proposed design exhibits exceptional wireless communication performance with extended fractional bandwidth and increased gain.

Before beginning the design, the monopole antenna as well as FSS structure at the target frequency are calculated. To model the design, Computer Simulation Technology (CST) was utilized. To improve the antenna's design, fundamental factors such as resonance frequency, return loss, bandwidth, as well as directivity were examined. Once the antenna design procedure was finished, the antenna was constructed. The design incorporates a monopole antenna with a flexible frequency-selective sur-face (FSS). The monopole antenna was built to receive signals with a broad bandwidth. To increase bandwidth and other characteristics, we used FSS antennas, which are regarded as the simplest approach to accomplish this. The FSS structure was then examined using basic square loops to generate unit cells of the FSS periodic structure with (3x3) array square loops arranged face-to-face with monopole antennas.

4. Conclusion

The flexible monopole antenna combined with the flexible frequency-selective surface (FSS) offers improved wireless communication performance.

The design achieves extended fractional bandwidth, increased gain, and steady frequency response.

The integration of FSS with the monopole antenna shows potential for overcoming limitations of conventional patch antennas.

In this work, a monopole antenna with an integrated flexible FSS structure was proposed for wireless communication. The monopole antenna and the FSS structures utilized an FR -4 and Fast Film, respectively. The gain of only 2 dB and the optimal return loss were evaluated as the FSS structure was placed 26 mm in front of the antenna. However, the fractional bandwidth enhances from 62 % without FSS to 103 % with FSS, and the Return Loss enhances from -23 dB to -52 dB. Hence, the proposed antenna potentially serves as a good option for wireless communication.

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Conflicts of Interest

The authors declare no conflict of interest.

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