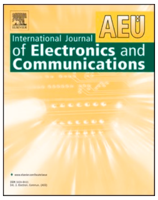
Int. J. Electron. Commun. (AEÜ) 170 (2023) 154841

Contents lists available at ScienceDirect

International Journal of Electronics and Communications

journal homepage: www.elsevier.com/locate/aeue



Regular paper

# Frequency selective surfaces-based miniaturized wideband high-gain monopole antenna for UWB systems

Sania Tariq [a], Qasid Hussain [b,*], Mohammed S. Alzaidi [c], Rania M. Ghoniem [d], Mohammad Alibakhshikenari [e,*], Ayman A. Althuwayb [f], Bal S. Virdee [g], Muhammad Aslam [h]

[a] *Department of Electrical Engineering, COMSATS Uni., Islamabad Campus, Pakistan*
[b] *Department of Information and Communication Engineering, Chungbuk National University, Cheongju 28644, South Korea*
[c] *Department of Electrical Engineering, College of Engineering, Taif University, P.O. Box 11099, Taif 21944, Saudi Arabia*
[d] *Department of Information Tech., College of Computer and Information Sciences, Princess Nourah bint Abdulrahman Uni., P.O. Box 84428, Riyadh 11671, Saudi Arabia*
[e] *Department of Signal Theory and Communications, Universidad Carlos III de Madrid, 28911 Leganés, Madrid, Spain*
[f] *Department of Electrical Engineering, College of Engineering, Jouf University, Sakaka, Aljouf 72388, Saudi Arabia*
[g] *Center for Communications Technology, London Metropolitan University, London N7 8DB, United Kingdom*
[h] *Department of Artificial Intelligence, Sejong University, Seoul, South Korea*

## ARTICLE INFO

*Keywords:*
Frequency Selective Surfaces (FSS)
UWB systems
Monopole antenna
High gain
Wide bandwidth

## ABSTRACT

In the suggested manuscript, an antenna functional over an ultrawide band with a small geometrical configuration and simplified structure is given. The recommended antenna is designed for the Roger 6002, having overall measurements of 40 mm × 30 mm × 1.52 mm. The wideband is obtained after loading stubs and etching slots from the basic antenna design. In order to improve the antenna's performance further, an FSS sheet is designed. The sheet of FSS is placed behind the antenna to reflect the antenna's backward radiation and improve antenna gain. In the results, the gain of the antenna improved from 4.5 dBi to 9.5 dBi. The resultant antenna loaded with FSS is capable of operating over UWB ranging from 3.4 to 9.8 GHz with stable gain throughout the functional bandwidth. The hardware model is manufactured and tested to validate the estimated results achieved from HFSS (High Frequency Structure Simulator). Moreover, the recommended work is differentiated in the form of a table with literature. The compact size, wideband, high gain and stable performance of proposed antenna system over-performs the literature work and makes it protentional candidate for the UWB system requiring high gain.

## 1. Introduction

The current wireless communication devices have compact sizes, a low profile, and offer high functionality [1,2]. For these devices, microstrip patch antennas (MPA) are deployed with reason of their benefits of low profile, light weight, and being easily fabricated and integrated with other components of devices [3]. The microstrip patch antenna also has some demerits, including narrow operational bandwidth and low gain [4,5]. To overcome this issue and the disadvantages of microstrip patch antennas, many techniques are used to improve the bandwidth and gain of the antenna. The improvement of gain and bandwidth is important, as for future and current wireless communication, a high data rate is required to entertain an ocean of users at a time [6,7]. There are huge number of research is done on designing of the wideband antennas, however these antennas alone have the disadvantage of the lower gain [8–10].Table 1

To refine the gain of antenna, in literature numerous techniques and methodologies are discussed. Frequency-selective surfaces (FSS) can be applied to microstrip patch antennas for gain as well as bandwidth improvement of the antenna [9]. The FSS can be placed on top of the antenna as well as on the rear end of the antenna, depending on applications and the nature of work [11,12]. Besides patch antennas, FSS can be implanted in DRA (dielectric resonator antenna) and other types of antennas to improve its performance [13]. Two of the primary essential

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* Corresponding authors.
*E-mail addresses:* saniatariq560@gmail.com (S. Tariq), qasidhussain@chungbuk.ac.kr (Q. Hussain), m.alzaidi@tu.edu.sa (M.S. Alzaidi), rmghoniem@pnu.edu.sa (R.M. Ghoniem), mohammad.alibakhshikenari@uc3m.es (M. Alibakhshikenari), aaalthuwayb@ju.edu.sa (A.A. Althuwayb), b.virdee@londonmet.ac.uk (B.S. Virdee), aslam@sejong.ac.kr (M. Aslam).

https://doi.org/10.1016/j.aeue.2023.154841
Received 17 June 2023; Accepted 26 July 2023

**Table 1**
Comparison with literary works.

| Ref | Antenna Size (mm$^3$) | Overall Size (mm$^3$) | Bandwidth (GHz) | Gain w/o FSS (dBi) | Gain with FSS (dBi) |
|---|---|---|---|---|---|
| [16] | 0.38 × 0.32 × 0.15 | 0.43 × 0.43 × 0.26 | 2.82–19.94 | 4.2 | 7.55 |
| [17] | 0.32 × 0.32 × 0.13 | 0.64 × 0.64 × 0.32 | 2.37–2.56/ 5.15–6.22 | 5.5 | 7.46 |
| [18] | 0.14 × 0.14 × 0.11 | 0.32 × 0.39 × 0.07 | 2.1–9.3 | 5.12 | 8.12 |
| [19] | 0.65 × 0.69 × 0.18 | 0.95 × 0.69 × 0.46 | 3.3–3.5/ 4.9–5.1 | 0.77 | 0.915 |
| [21] | 1.58 × 0.64 × 0.019 | 1.93 × 1.93 × 0.23 | 3.5–6.5 | 8.5 | 12.4 |
| [22] | 0.33 × 0.3 × 0.013 | 0.33 × 0.3 × 0.65 | 5–5.35 | 3.95 | 7.92 |
| [23] | 0.35 × 0.35 × 0.018 | 1.16 × 1.16 × 0.41 | 3.5–5.9 | 3.8 | 7.87 |
| [24] | 0.28 × 0.67 × 0.003 | 0.24 × 0.68 × 0.002 | 1.65–4 | – | 4.45 |
| [25] | 0.37 × 0.42 × 0.015 | 1.53 × 1.25 × 0.46 | 2.79–3.5 | – | 10 |
| [27] | 0.23 × 0.23 × 0.006 | 0.96 × 0.96 × 0.026 | 2.39–2.51 | 5.2 | 9.8 |
| [28] | 0.26 × 0.26 × 0.17 | 1.4 × 1.4 × 0.15 | 3.1–10.6 | 3 | 8.65 |
| [29] | 0.47 × 0.31 × 0.17 | 1.1 × 1.1 × 0.2 | 3.1–6 | 3.85 | 9.7 |
| [30] | 0.12 × 0.18 × 0.019 | 0.48 × 0.48 × 0.36 | 3.6–11.2 | 4.25 | 8.6 |
| Prop. | 0.45 × 0.22 × 0.017 | 0.66 × 0.66 × 0.14 | 3.4 – 9.9 | 4.5 | 9.5 |

*$\lambda_L$ denotes wavelength at the lower cut of frequency.

variables are where the FSS is set up and how much space is maintained between the FSS sheet and antenna, which have been widely investigated in the literature [14,15]. In literature, the number of antennas loaded with FSS is reported for gain enhancement. Some of them are discussed and examined in the review report.

A compact wideband antenna is given in [16]. The antenna loaded with FSS has total measurements of 46 mm × 46 mm × 28.2 mm and operates over a wideband of 2.82–19.94 GHz. The gain is enhanced by 3.3 dBi after loading FSS below the antenna. The demerit of this work is its large volume due to its placement over sand sample boxes. [17] studies a dual-band antenna which works at 2.4 GHz and 5.8 GHz. The antenna has an optimal gain of 5.5 dBi, which is increased by the FSS arrangement to 7.86 dBi. This piece of work has an 81 mm × 81 mm × 40 mm setback with a 0.2 GHz and 0.9 GHz narrow bandwidth. According to [18], there is yet another innovative FSS mechanism placed underneath the antenna. The antenna's strength has been increased from 5.12 dBi to 8.12 dBi, and its broad frequency ranges from 2.1 to 9.3 GHz. Additionally, it is densely sized at 45.8 mm by 55 mm by 10 mm. Although the antenna loaded with FSS has a compact size, a wide band, and a high peak gain, its disadvantage is its complex geometrical configuration.

[19] reports on a dual-band antenna that works across 3.3 and 3.5 GHz and 4.9 and 5.1 GHz. Although the antenna's shape is straightforward, it has a limited bandwidth and a meagre gain of 0.9 dBi after loading FSS. To enhance antenna performance, the FSS structure is positioned above as well as below the antenna [20]. [21] provides a high-gain antenna with a maximum gain of 12.4 dBi after applying FSS. Despite having a high gain, the antenna is big at 166 mm × 85 mm × 20.08 mm. [22] presents a small FSS-placed antenna with overall measurements of 20 mm × 18 mm × 39 mm. A 4 dBi rise in antenna gain (from 3.95 dBi to 7.92 dBi) has been made. The antenna has the benefits of being small and having a high gain, however it only functions between 5 and 4.35 GHz.

Another work having FSS operational over high gain is given in [23]. The antenna offers a top gain of 7.87 dBi and a bandwidth of 3.5–5.9 GHz. The antenna loaded with FSS has an overall measurement of 100 mm × 100 mm × 34.8 mm. The high gain and moderate bandwidth, along with the simple geometrical configuration, are plus points of this work, but the large size is the main demerit of the reported work. Another antenna loaded with an FSS layer provides a moderate gain of 4 dBi and a bandwidth of 1.65–4 GHz, as present in [24]. The antenna has a huge dimensions of 45 mm × 121.5 mm and offers a low gain, as the same gain can be obtained from an antenna without placing an FSS. A high-gain antenna loaded with FSS provides a gain of 10 dBi, as given in [25]. The antenna loaded with FSS offers high gain but has a larger geometry of 165 mm × 135 mm × 49.6 mm with a narrow bandwidth of 2.79–3.5 GHz.

In [26], a dual-band antenna is reported loaded with FSS to improve the gain from 7 dBi to > 9 dBi over the resonating band. The reported work has simplified the geometry of both the antenna and FSS unit cell but operates over a narrow bandwidth and larger measurements. In [27], another narrow band antenna operating over 2.39–2.51 GHz is given for gain improvement from 5.2 dBi to 9.8 dBi. The antenna has a small dimensions (29 mm × 29 mm), which is widely enhanced after loading the FSS structure (120 mm × 120 mm). A wideband and high-gain antenna is reported in [28], which offers a gain of 8.65 dBi and a bandwidth of 3.1–10.6 GHz after loading FSS. Although the antenna affords wideband and high gain, it has complex geometry and a large size of 135 mm × 135 mm × 15 mm after introducing FSS.

In [29], an antenna operating on 3.1–6 GHz and supplying a high point of gain at 9.7 dBi is given for wireless applications. The antenna has a measurements of 45 mm × 30 mm, which increased to 108 mm × 108 mm × 20 mm after the loading of FSS. Although the antenna has good value of gain, it has the disadvantages of compound structure and a big geometry. The small sized antenna with FSS is described in [30]. The antenna with FSS has an overall measurement of 40 mm × 40 mm × 30 mm, offers a wideband of 3.6–11.2 GHz, and has a gain of 8.6 dBi. Besides the lower bands of WLAN, ISM, and 5G sub-6 GHz, FSS is also used to refine the gain and bandwidth of millimeter wave antennas. Like the MPA for the lower frequency spectrum, the FSS can be placed above and below the antenna to refine the gain of millimeter wave applications [31,32].

From the above literature, it is clear that the antenna loaded with FSS is utilized to refine the antenna's outcomes and results in account of gain and bandwidth. The work presented in the literature has certain limitations, either narrow bandwidth, moderate gain, or larger size and complex structure. The antenna investigated in this study offers a good combination of various performance parameters by offering wideband, compact size, simpler geometrical configuration and high peak gain as compared to the work reported in literature. The remaining sections of the paper explain the antenna design technique, the FSS design approach, and how they work to increase the antenna's gain. The hardware prototype is fabricated and tested to validate the software generated results, and finally, the result of the proposed design is compared in the form of a table with already published works to further highlight the achievement of the presented antenna system.

## 2. Designing approach of FSS based high-gain antenna

In this part of the article, the structural mechanism of the antenna and FSS is explained. The individual outcomes of the antenna and FSS are also briefly explained. The examination of these results is performed using the well-known software HFSS (High Frequency Structure Simulator). The outcomes generated by this software are verified by developing a hardware model of the antenna.

### *2.1. Antenna design*

The structure of the recommended wide-band antenna is given in

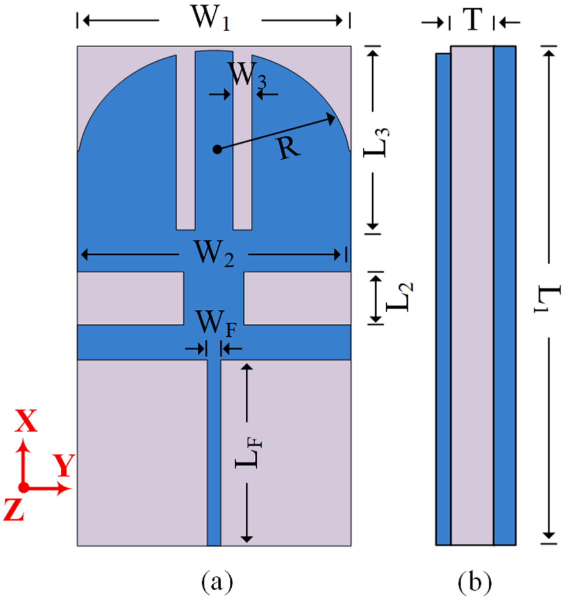


**Fig. 1.** Layout of recommended ultrawideband antenna (a) from top (b) from side. $L_1 = 40$; $L_2 = 4$; $L_3 = 16$; $L_F = 11.5$; $W_1 = 20$; $W_2 = 20$; $W_3 = 4$; $W_F = 1.5$; $T = 1.52$ (units in mm).

Fig. 1. The monopole patch is placed on top of the Roger 6002 substrate material, which has a relative permittivity and loss tangent of 2.34 and 0.0012. The suggested design has a size of $L_1 \times W_1 \times T = 40 \times 20 \times 1.52$ mm$^3$. The given layout of the antenna shows various slots and stubs, which are employed to refine the results of the antenna. Moreover, the backside of the design has a full ground plane, which consists of copper with a thickness of 0.036 mm.

### 2.2. Design methodology

The final shape of the antenna, with consideration of desired results, is obtained after numerous design stages. The different stages involved in the evolution of the antenna, along with $|S_{11}|$ results, are given in Fig. 2.

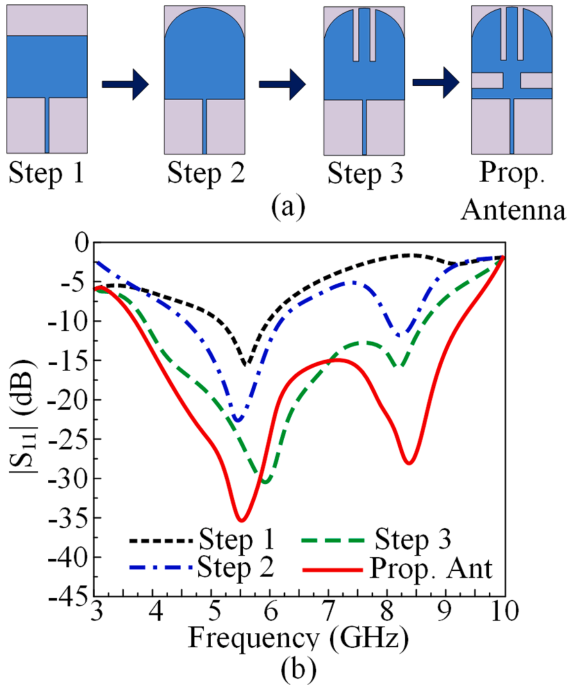


**Fig. 2.** (a) Construction procedure of suggested UWB antenna (b) $|S_{11}|$ parameter of different steps.

*Design Step 1:* Designing a rectangular patch antenna

This is the primary phase in constructing an antenna, as the rectangular patch is constructed. The length and breadth of the patch are calculated by the formulas presented in [33]. The rectangular patch provides resonance along 5.5 GHz, as given in Fig. 2(b).

*Design Step 2:* Semicircular Stub Loading

To refine the bandwidth along with the return loss of the antenna, a semicircular stub is added to the top of the rectangular patch. The resultant design starts resonating at two bands of 5.4 GHz and 8.5 GHz with return losses of −20 dB and −12 dB, respectively.

*Design Step 3:* Two horizontal slot etchings

In this design evolution stage, two horizontal slots are etched as given in Fig. 2(a). The effect of this step can be seen in that the design starts working over 4.1–8.6 GHz.

*Design Step 4:* Two vertical slot etchings

This is the final designing stage, where two vertical slots are etched to further improve the antenna outcomes. The antenna achieved from this step operates from 3.9 to 9.5 GHz with a least return loss of $< -30$ dB at resonant frequency 5.5 GHz and $< -25$ dB at resonant frequency 8.75 GHz.

### 2.3. Results of antenna

The hardware model of the suggested design is manufactured to validate the simulated outcomes. In Fig. 3 (a), the scattering parameter is provided with a comparison between prototype-tested and software-predicted results. This is clear from the given figure: the suggested work is functional over an ultra-wide band ranging from 3.9 to 9.8 GHz. The resemblance between tested and predicted results makes the suggested design more worthy of upcoming 5G communication models. Fig. 3(b) provides the gain curves of the suggested antenna. The antenna provides a moderate value of gain > 3.5 dBi over operational bandwidth. The gain provides peak values around 4 dBi at resonant frequencies.

The preferred antenna's radiation pattern graph is displayed in Fig. 4. This is noteworthy given that the radiation pattern at H-plane is omni-directional across 5.5 GHz and 8.5 GHz. For 5.5 GHz and 8.5 GHz in the situation of E-plane, the radiation pattern is bidirectional and has a four-leaf form, respectively. The minor deformation in the pattern is because of stub insertion and slot etching. Moreover, the resemblance between the tested and predicted radiation patterns is also observed.

### 2.4. Novel FSS design

The recommended FSS unit cell and surface along with s-parameter is illustrated in Fig. 5, which has dimensions of 10 mm × 10 mm and is designed on Rogers 6002, which has a thickness of 1.52 mm. The 5-by-5 array of unit cells is combined together to get the surface. Each unit cell has a circle shaped patch with additional arms on four sides and a cross-sign slot. These insertions of additional patches and etching of slot is done with an initial circular design to get the UWB behavior. The working principle of the FSS is well explained in [35]. The final measurements of the proposed FSS layer is $FSS_X \times FSS_Y$ corresponding to 58 mm × 28 mm. Fig. 5 (b) shows the $|S_{11}|$ and $|S_{12}|$ curves of the recommended FSS. The FSS operates at a broad frequency range of 3–10 GHz.

### 2.5. FSS loaded antenna design

The basic working principle of performance improvement of antennas by using FSS is briefly explained in this portion of the manuscript. The suggested FSS is positioned below the recommended antenna by keeping a space or gap between them ($s = 12$ mm), as given in Fig. 6 (a)

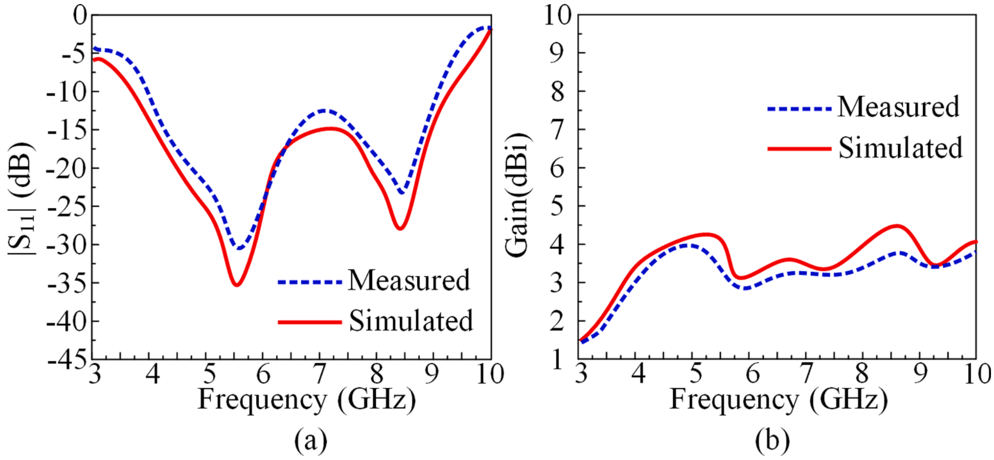


**Fig. 3.** Software predicated and tested (a) S–Parameter (b) Gain.

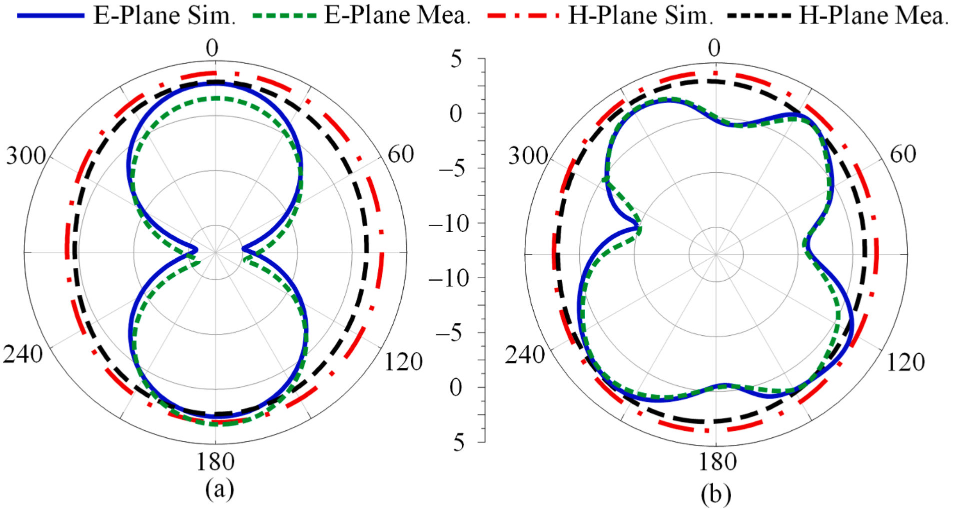


**Fig. 4.** Far filed Pattern of suggested antenna at (a) 5.5 GHz (b) 8.5 GHz.

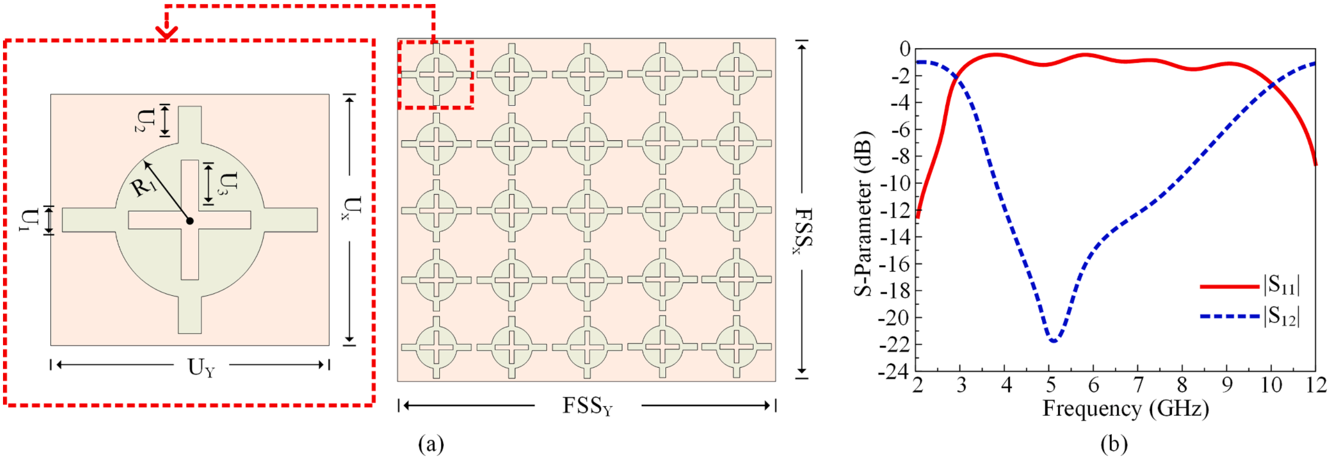
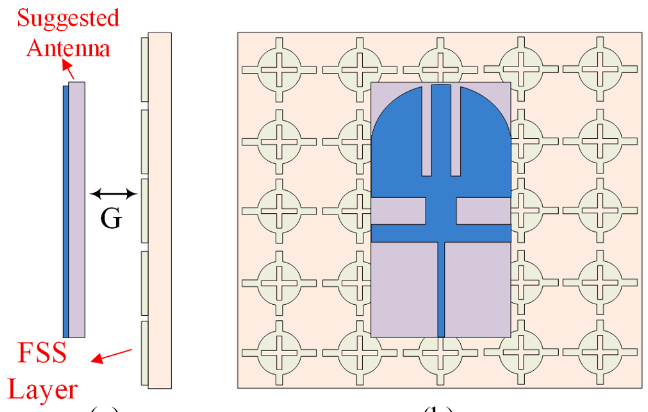


**Fig. 5.** (a) Geometrical configuration of proposed FSS (b) S-parameters of the designed FSS. $FSS_X = 58$; $FSS_Y = 58$; $U_x = 10$; $U_Y = 10$; $U_1 = 1$; $U_2 = 2.3$; $U_3 = 1.5$; $R_1 = 3$ (unit in mm).

and (b). The value of the distance between the antenna and FSS is selected based on the best results and may be calculated by the equations given in [36]. To bounce back the radiation that is leaving from the back side of the antenna, the FSS layer is positioned below the antenna. These reflected waves and radiation from the antenna are in phase, which results in an enhancement of gain.

The outcome and performance of the antenna in concerning S-parameter and gain are examined to verify the functionality of FSS. This



(a) (b)

**Fig. 6.** Frequency selective surface loaded UWB antenna, (G = 12 mm).

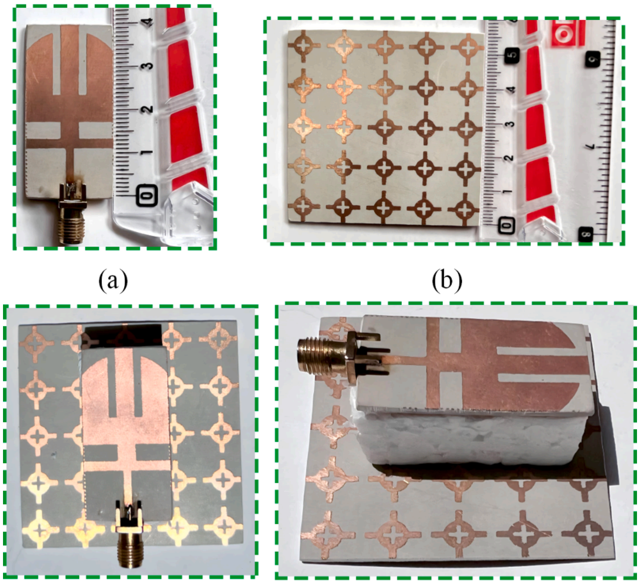
is concluded from Fig. 6 (a) that the bandwidth of UWB packed with FSS is refined and shows an improvement of 1.25 GHz. AS is the only antenna that offers UWB of 3.9–9.5 GHz, while FSS-packed antennas offer 3.4–9.9 GHz. On the other side, the gain is impressively improved from 4 dBi to 9.5 dBi at both resonant frequencies, as referred to in Fig. 7 (b).

## 3. Results and discussion

The outcomes of recommended design packed behind FSS layer will be explained in this portion. The outcomes generated from software tool HFSS are crosschecked with tested results, which are obtained from hardware model. The vector network analyzer (VNA) is utilized for near field measurement while anechoic chamber is utilized for far field measurement. The suggested monopole antenna, novel FSS sheet, top view of antenna placed over FSS sheet and side view of antenna placed over FSS sheet, is given in Fig. 8 (a) – (d).

### 3.1. Reflection coefficient and gain

The estimated and tested S-parameter and gain of the suggested design packed with sheet of FSS are given in Fig. 9. The bandwidth of 3.4–9.9 GHz with two resonances at 5.5 GHz and 8.5 GHz is offered by the recommended design. The recommended design also gives good values of return losses at 5.5 GHz and 8.5 GHz, around $< -40$ dB and $< -30$ dB, respectively. The high value of gain offered by an antenna at functional bandwidth $> 8.25$ dB, with the highest value of 9.5 dBi at resonant frequencies of 5.5 GHz and 8.5 GHz, and the good agreement among estimated and tested results can be seen from the figures, which is an additional advantage of recommended work.



(a) (b)

(c) (d)

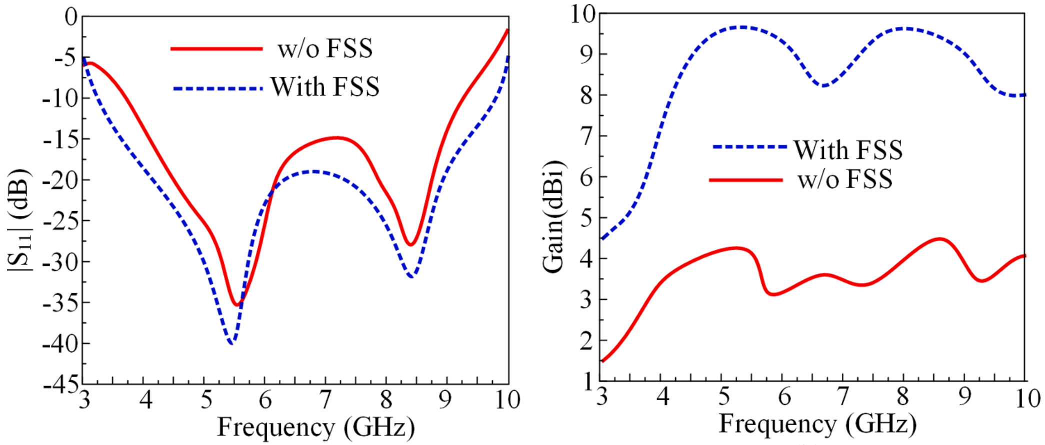
**Fig. 8.** (a) Suggested antenna (b) Suggested Frequency selective surface (c) Top view of antenna loaded on FSS (d) Side view of antenna loaded on FSS.

### 3.2. Radiation pattern

Fig. 10 displays the radiation pattern graph of the suggested antenna at resonance frequencies of 5.5 GHz and 8.5 GHz. This is significant since the radiation pattern at H-plane is omni-directional across 5.5 GHz and 8.5 GHz. For 5.5 GHz and 8.5 GHz, accordingly, the radiation pattern for E-planes is bidirectional and somewhat inclined. Stub insertion and slot etching are to blame for the pattern's deformation. Moreover, the resemblance between the tested and estimated radiation patterns is also observed, which increases the value of the recommended design.

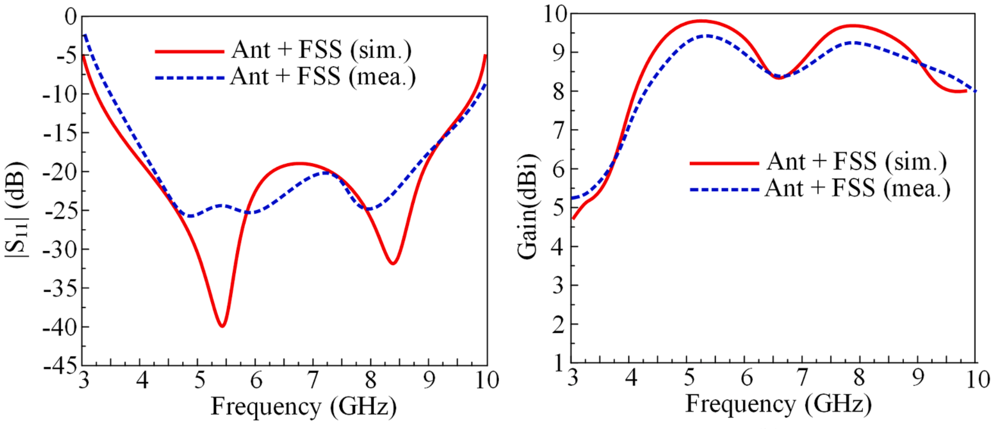
### 3.3. Comparison with literary works

The recommended work is compared with the work already present in the literature. The work presented in [17,19,21–27,29] has the disadvantage of the limited bandwidth along with that except [21] all



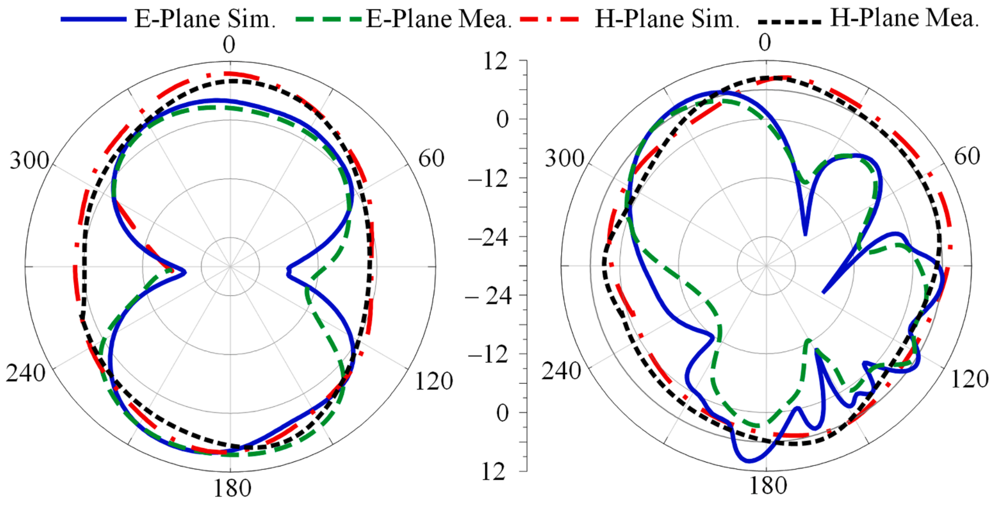
(a) (b)

**Fig. 7.** (a) $|S_{11}|$ curve of suggested antenna with and without FSS (b) Gain curve of suggested antenna with and without FSS.



(a) (b)

**Fig. 9.** Estimated and tested (a) S-parameter and (b) gain of proposed UWB antenna with FSS.



(a) (b)

**Fig. 10.** Radiation pattern of proposed UWB antenna with FSS at (a) 5.5 GHz (b) 8.5 GHz.

the other works have low peak gain value as compared to proposed work. Contrary to them, the reported work in [16,18] and [30] offers compact size but they also have low peak gain value along with complex geometrical structural. On the other hand, [28] offers wideband but its size is almost twice as compared to proposed work. Thus, it can be concluded that the proposed antenna systems offer an overall strong performance by providing wide bandwidth, simple structure, compact size and high peak gain value.

## 4. Conclusions

In this manuscript, an antenna is designed for UWB operation after following various design steps including stub loading and slot etching techniques. The results and outcomes of the antenna are also verified after manufacturing the hardware model. After that, FSS is constructed to work on the same bandwidth as the antenna did. The FSS sheet consists of a 5 × 5 array of unit elements that is compact in size and simple in structure. The gain of the antenna is enhanced by placing the novel FSS behind the UWB antenna so that the backward radiation is bounced back. The hardware model of FSS is also engineered to validate the outcome. A strong resemblance between the tested and estimated results is observed. Last, a comparison table is constructed to provide the value of the suggested design over already presented work in the literature. The outcomes from the studies show that the recommended design is the best applicant for future 5G communication system gadgets.

## Funding

The authors sincerely appreciate the Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP2023R138), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia. Additionally, Dr. Mohammad Alibakhshikenari acknowledges support from the CONEX-Plus programme funded by Universidad Carlos III de Madrid and the European Union’s Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No. 801538. The Article Processing Charge (APC) was afforded by Universidad Carlos III de Madrid (Read & Publish Agreement CRUE-CSIC 2023).

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

No data was used for the research described in the article.

## Acknowledgments

The authors sincerely acknowledge the support from Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP2023R138), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia. Dr. Mohammad Alibakhshikenari acknowledges support from the CONEX-Plus programme funded by Universidad Carlos III de Madrid and the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No. 801538. The Article Processing Charge (APC) was afforded by Universidad Carlos III de Madrid (Read & Publish Agreement CRUE-CSIC 2023).

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## Further reading

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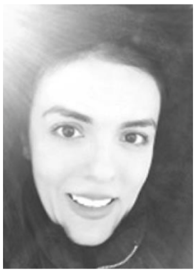
**SANIA TARIQ** received the B.S., and M.S., degrees in Electrical Engineering from Comsats University, Islamabad, Pakistan, in 2018, and 2021 respectively. She is working as an Executive in the wireless Network performance department at Pakistan Telecommunication Company Limited (PTCL) since Nov-2020. Her research interests include electromagnetic theory, reflect arrays, conformal antennas, electromagnetic compatibility, and optimization problems.

**QASID HUSSAIN** received his B.Sc. degree in Electrical Engineering from Sir Syed University Karachi, in 2019. He is currently doing master's in information communication engineering from Chungbuk National University, South Korea, where he is also working as an Assistant researcher with the Radio Communication lab. His research interests include Endfire Antenna, wideband antennas, MIMO antennas.

**MOHAMMED S. ALZAIDI** received the B.Sc. degree in Electrical Engineering from Umm Al-Qura University, Makkah, Saudi Arabia, in 2007, the M.Eng. degree and Ph.D. in Electrical Engineering from Stevens Institute of Technology, Hoboken, NJ, USA in 2014, 2019, respectively. He is currently an Assistant Professor with the Department of Electrical Engineering, Faculty of Engineering, Taif University, Saudi Arabia. He is also the Vice Dean of the Deanship of Scientific Research at Taif University. His research interests include nano molecular communications, wireless communications, signal processing, digital techniques, machine learning, and deep learning.



**RANIA M. GHONIEM** received the Ph.D. degree in integrating artificial intelligence techniques in medical diagnosis from Mansoura University, Egypt. She is with the Department of Information Technology, College of Computer and Information Sciences, Princess Nourah Bint Abdulrahman University, Riyadh, Saudi Arabia. Her research interests include computer-aided diagnostic systems, medical image and sound processing, natural language processing, deep learning, and meta-heuristic optimization methods.

**Mohammad Alibakhshikenari** received the Ph.D. degree (Hons.) with European Label in electronics engineering from the University of Rome "Tor Vergata'', Italy, in February 2020. From May 2018 to December 2018 he was a Ph.D. Visiting Researcher at the Chalmers University of Technology, Gothenburg, Sweden. His training during this Ph.D. research visit included a research stage in the Swedish Company Gap Waves AB in Gothenburg as well. Since July 2021 he is with the Department of Signal Theory and Communications, Universidad Carlos III de Madrid (uc3m), Spain, as a Principal Investigator of the CONEX (CONnecting EXcellence)-Plus Talent Training Program and Marie Skłodowska-Curie Actions. He was also a Lecturer of the electromagnetic fields and electromagnetic laboratory with the Department of Signal Theory and Communications for academic year 2021–2022 and he received the "Teaching Excellent Acknowledgement" Certificate for the course of electromagnetic fields from Vice-Rector of studies of uc3m. From December 2022 to May 2023 he spent three industrial and academic research visits in (i) SARAS Technology Ltd Company in Leeds, England; (ii) Edinburgh Napier University in Edinburgh, Scotland; and (iii) University of Bradford in West Yorkshire, England which were defined by CONEX-Plus Talent Training Program and Marie Skłodowska-Curie Actions as his secondment research visit plans. His research interests include electromagnetic systems, antennas and wave-propagations, metamaterials and metasurfaces, sensors, synthetic aperture radars (SAR), 5G and beyond wireless communications, multiple input multiple output (MIMO) systems, RFID tag antennas, substrate integrated waveguides (SIWs), impedance matching circuits, microwave components, millimeter-waves and terahertz integrated circuits, gap waveguide technology, beamforming matrix, and reconfigurable intelligent surfaces (RIS), which led to achieve more than 4200 citations and H-index above 41 reported by Scopus, Google Scholar, and ResearchGate. He was a recipient of the (i) three years Principal Investigator research grant funded by Universidad Carlos III de Madrid and the European Union's Horizon 2020 Research and Innovation Program under the Marie Skłodowska-Curie Grant started in July 2021, (ii) two years postdoctoral research grant funded by the University of Rome "Tor Vergata'' started in November 2019, (iii) three years Ph.D. Scholarship funded by the University of Rome "Tor Vergata'' started in November 2016, and (iv) two Young Engineer Awards of the 47th and 48th European Microwave Conference were held in Nuremberg, Germany, in 2017, and in Madrid, Spain, in 2018, respectively. In April 2020 his research article entitled "High-Gain Metasurface in Polyimide On-Chip Antenna Based on CRLH-TL for Sub Terahertz Integrated Circuits'' published in Scientific Reports was awarded as the Best Month Paper at the University of Bradford, West Yorkshire, England. He is serving as an Associate Editor for (i) *Radio Science*, and (ii) *IET Journal of Engineering*. He also acts as a referee in several highly reputed journals and international conferences.

**Ayman Abdulhadi Althuwayb** received the B.Sc. degree (Hons.) in electrical engineering (electronics and communications) from Jouf University, Saudi Arabia, in 2011, the M.Sc. degree in electrical engineering from California State University, Fullerton, CA, USA, in 2015, and the Ph.D. degree in electrical engineering from Southern Methodist University, Dallas, TX, USA, in 2018. He is currently an Assistant Professor with the department of electrical engineering at Jouf University, Kingdom of Saudi Arabia. His current research interests include antenna design and propagation, microwaves and millimeter-waves, wireless power transfer, ultrawideband and multiband antennas, filters and other.

**Bal S. Virdee** received the B.Sc. and MPhil degrees in Communications Engineering from the University of Leeds, UK, and his Ph.D. in Electronic Engineering from the University of London, UK. He has worked in industry for various companies including Philips (UK) as an R&D-engineer and Teledyne Defence and Space as a future products developer in RF/microwave communications. He has taught at several academic institutions before joining London Metropolitan University where he is a Senior Professor of Communications Technology in the School of Computing and Digital Media where he is Head the Communications Technology Research Center. His research, in collaboration with industry and academia, is in wireless communications encompassing mobile-phones to satellite-technology. Prof. Virdee has chaired technical sessions at IEEE international conferences and published numerous research papers. He is Executive Member of IET's Technical and Professional Network Committee on RF/Microwave-Technology. He is a Fellow of IET and a Senior-Member of IEEE.

**Muhammad Aslam** received the B.S. degree in electrical engineering from the University of Engineering and Technology (UET), Peshawar, Pakistan, in 2013, and the M.S. and Ph.D. degrees in electrical engineering from Myongji University, Yongin, South Korea, in 2017 and 2021, respectively. He is currently working as a assistant professor in Sejong University, Seoul, South Korea. His research interests include application of Wireless communication systems, AI in power systems, time-series analysis/forecasting, signal analysis, and image processing.