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Novel Dual-Band Frequency Selective Surface and its Applications on the Gain Improvements of Compact UWB Monopole Antenna

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ABSTRACT

In this work, a highly directional ultra-wideband (UWB) microstrip patch antenna as a single-element is suggested. The proposed antenna's gain is enhanced with a novel dual-band frequency selective surface (FSS) placed beneath it. The FSS design has a hexagonal structure with meander line inductances and a capacitance-like structure connecting all of the corners to the middle. There is no metallic layer on the other side of the substrate, which shows transmission zeros at 4.95 GHz and 12.7 GHz, and a modified U-shaped monopole antenna is developed. First, the performance characteristics of the antenna and FSS are analyzed from the simulation results, and they are validated experimentally after fabrication, followed by measurement. The compact configuration comprises an antenna loaded with the proposed FSS results S11 less than -10 dB from 3.15 GHz to 22.65 GHz, covering the UWB band together with the X, Ku-band with a bandwidth of 19.5 GHz (151.16% FBW). The antenna's overall physical dimensions would be 38.8 mm×38.8 mm×25.2 mm (0.407λo×0.407λo×0.265λo), with λo denoting the lowest frequency's free-space wavelength. The FSS loading results in a 9.9 dBi maximum gain at 10 GHz. The antenna's small size increases bandwidth, and its high peak gain makes it ideal for use in real-time applications.

Keywords: FSS; HFSS; Monopole antenna; UWB

1. INTRODUCTION

At the beginning of this century, RF and microwave engineers worked on designing UWB (ultra-wideband) systems. In 2002, the Federal Communications Commission (FCC) gave the band from 3 to 10.6 GHz to scientific research and industrial uses without requiring a license. Because of this decision, research has begun in the areas of wireless communication and microwave imaging. Ground Penetrating Radar (GPR), Wireless Local Area Networks (WLAN), Wireless Personal Area Networks (WPAN), Wireless Body Area Networks (WBAN), and Wireless Interoperability for Microwave Access (WiMAX) are all applications that use the unlicensed UWB band. GPR is used in the defence and military sectors to find the location of landmines. It is also used during earthquakes to find people trapped in buildings that have collapsed, and it can be used to test concrete without damaging it.

The UWB system covers a wide range of frequencies, from low to high. This means that the EM (electromagnetic) signal can reach different depths, from deep to shallow. Because of this, the UWB antenna can be used for low-frequency microwave imaging of biological tissue and high-frequency security imaging. Ultra-wideband (UWB) antennas operate in the microwave region's 3.1 GHz–10.6 GHz range of frequencies[1]. The Federal Communications Commission has designated this band as an unlicensed band (FCC). There are a plethora of applications for which UWB antennas are utilised. This includes a fast data rate, low energy consumption demand, small multipath fading, and narrowband signal interference[2]. Due to its various applications, numerous research projects have been performed to enhance the UWB antenna's performance characteristics[3]. Several UWB antennas that are planar and have modest configurations, low-profile designs, and low costs with consistent gain performance and simplicity of manufacture have been discussed in the literature.

One of the fundamental disadvantages of a planar UWB antenna is its inability to attain and maintain high gain throughout the entire operating bandwidth. Since an antenna's gain-bandwidth product is fixed, increasing bandwidth will have to come at the expense of antenna gain. Various UWB monopole antenna structures having simple geometries are proposed in the literature, while complex structures like rectangular[4], circular[5–6], elliptical[7-8], and U-shaped patch antenna have been discussed in[9-10]. The most common and straightforward method to obtain UWB performance is by modifying the ground plane as well as the patch surface. To eliminate the antenna's undesirable ground plane effects and surface current distribution control[11–13], techniques like the slot's introduction in the patch and ground plane, the addition of metallic strips, and the attachment of symmetrical ground stubs are primarily used.

Several approaches have been developed in the literature to acquire an enhanced-bandwidth UWB antenna. Different slot resonators were cut into the printed slot antenna in[14–16] to enhance impedance matching. Miniaturizing the antenna and maintaining the original device's performance characteristics

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(UWB performance) to make the device compact is challenging. Thus, a large amount of work is being conducted in this area. Many researchers have used different types of small UWB antennas, as in[17-19] discusses components with slotted ground planes for multiple-input and multiple-output (MIMO) antennas.

Likewise, a way to increase the current path in the ground plane has been explored through the amalgamation of the meander line[19]. But for many real-time applications such as accurate geo-location, portable devices, and high-accuracy positioning systems[20], a very directed antenna with high gain and a constant radiation pattern is required. Numerous techniques have been described in the literature for increasing gain, such as a gate-like metallic ground plane[21], employing ground-plane EBG devices[20], and a parasitic dielectric resonator antenna[22].

The antenna gain can be boosted even more depending on the application by using differential feeding techniques[23] or multiple layers in an antenna array[24]. The back radiation of an antenna can be redirected in the desired direction using Frequency Selective Surfaces (FSS) beneath the antenna to boost antenna gain. Two-dimensional symmetric unit cells with periodic arrays on a dielectric substrate are known as FSS[26]. In UWB systems, the radiator is an omnidirectional monopole antenna. The maximal gain of a UWB antenna is poor because of its extremely strong back lobe emission. The FSS is utilised as a reflector in the vast majority of applications. Below the antenna, an FSS reflector was used to increase a UWB antenna's directionality and gain while minimizing back lobe radiations[27-28] describes in detail a UWB antenna with a 10 mm reflector that increases the UWB frequency band gain by up to 1.5 dBi. For multi-band operations,[29] suggested a one-layer programmable FSS reflector UWB antenna. To attain the high gain needed in broadband applications,[30–34] recommended an FSS reflector-loaded UWB antenna. Another way to improve gain is by placing multiple FSS beneath the antenna[35-36] proposed two distinct FSS layers for 2–4 dBi gain enhancement[37] proposes and develops a metamaterial FSS reflector antenna for 3–4 dBi gain enhancement. However, the composite FSS-mounted antenna structure's size is doubled. A parasitic patch and a wideband FSS are used to boost an antenna's gain while also expanding the size of the original antenna, as detailed in[38].

A novel dual-band transmission type FSS is proposed in this report, which shows transmission zeros at 4.95 GHz and 12.7 GHz, and a modified monopole antenna (U-shaped) is designed. First, the antenna and the FSS's performance characteristics were investigated from the simulation results and verified experimentally after the fabrication, followed by measurement (the process is detailed in further sections). The compact setup consists of an antenna loaded with the proposed FSS results of S11 less than -10 dB with a range of 3.15 - 22.65 GHz covering the UWB band along with the X, Ku-band with a bandwidth of 19.5 GHz (151.16 % FBW). The FSS loading measures a peak gain of 9.9 dBi at 10 GHz. The design's compactness, broader bandwidth, and high peak antenna gain make it best for real-time applications.

The primary antenna in this article is made up of a metallic A novel ultrawideband (UWB) antenna (115 x 115 mm2) with dual-polarized radiation characteristics proposed[27], along with a UWB stopband FSS that acts as a reflector if it is placed underneath the antenna, and a maximum gain of 9.7 dBi is achieved with an enhancement of 3.5 - 4 dBi after placing the FSS.

Tahir, *et al.,* proposed a simple metallic pattern-based FSS on both sides of the FR-4 substrate (14 mm ×14 mm) for the gain enhancement of the UWB antenna with a minimal transmission coefficient in the 3-12 GHz band[39]. After loading the antenna with FSS, this composite antenna attained a peak gain of 8.9 dBi with a 4 dBi improvement. It is shown that an FSS in the shape of an umbrella can be used to increase the UWB antenna's gain[37]. A compact (35 mm × 30 mm × 0.8 mm) coplanar wave feeding technique using a UWB antenna for the GPR satellite applications is proposed, with a wide impedance bandwidth of 3.05–13.4 GHz covering the entire UWB range. In the FSS layers, the unit cell dimensions are on the order of $\lambda/10$ concerning 3 GHz, which is a substantially smaller quarter-wavelength. Keeping the antenna close to the FSS allows for a gain of 5.5–8.5 dBi while keeping the gain response virtually flat across all bands. In[40] cuts made on both sides of the radiating element reduce the antenna's dimensions by about half, and the addition of two 17.5×17.5 mm2 FSS on the antenna's rear side results in a 3 dBi gain boost. Broadside radiation increases by more than 75 %, and the impedance band is not affected using the proposed antenna with the FSS package.

Hasan, *et al.*, proposed a novel uniplanar UWB band-stop FSS miniaturization for microwave imaging applications[41]. An FSS unit cell with a 0.095×0.095-inch area was introduced, which had been reduced in size by using square loops and cross-dipoles on FR4. It was proposed to use a hexagonal antenna printed on an FR4 substrate with a coplanar waveguide feed, and this was further reinforced by an FSS array of 21.6 mm by 3×3 size. For frequencies between 2.6 and 11.1 GHz, FSS showed transmission magnitudes of less than -10 dB and linear reflection phases. The suggested antenna prototype obtained improved gain, unidirectional radiation, and bandwidth from 3.88 to 10.6GHz. In reference 42, a miniaturised MIMO antenna for UWB is discussed. The antenna consists of a narrow slot on the ground plane and two open L-shaped slotted (LS) antenna elements. A large part of the antenna's isolation comes from its

Table 1. Finalised dimensions of the proposed modified U-shaped monopole antenna

a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}
16 mm	22 mm	7 mm	7.14 mm	1.3 mm	1.6 mm	1.29 mm	0.92 mm	3 mm	4.24 mm	3.3 mm

a_{12}	a_{13}
3.4 mm	3 mm

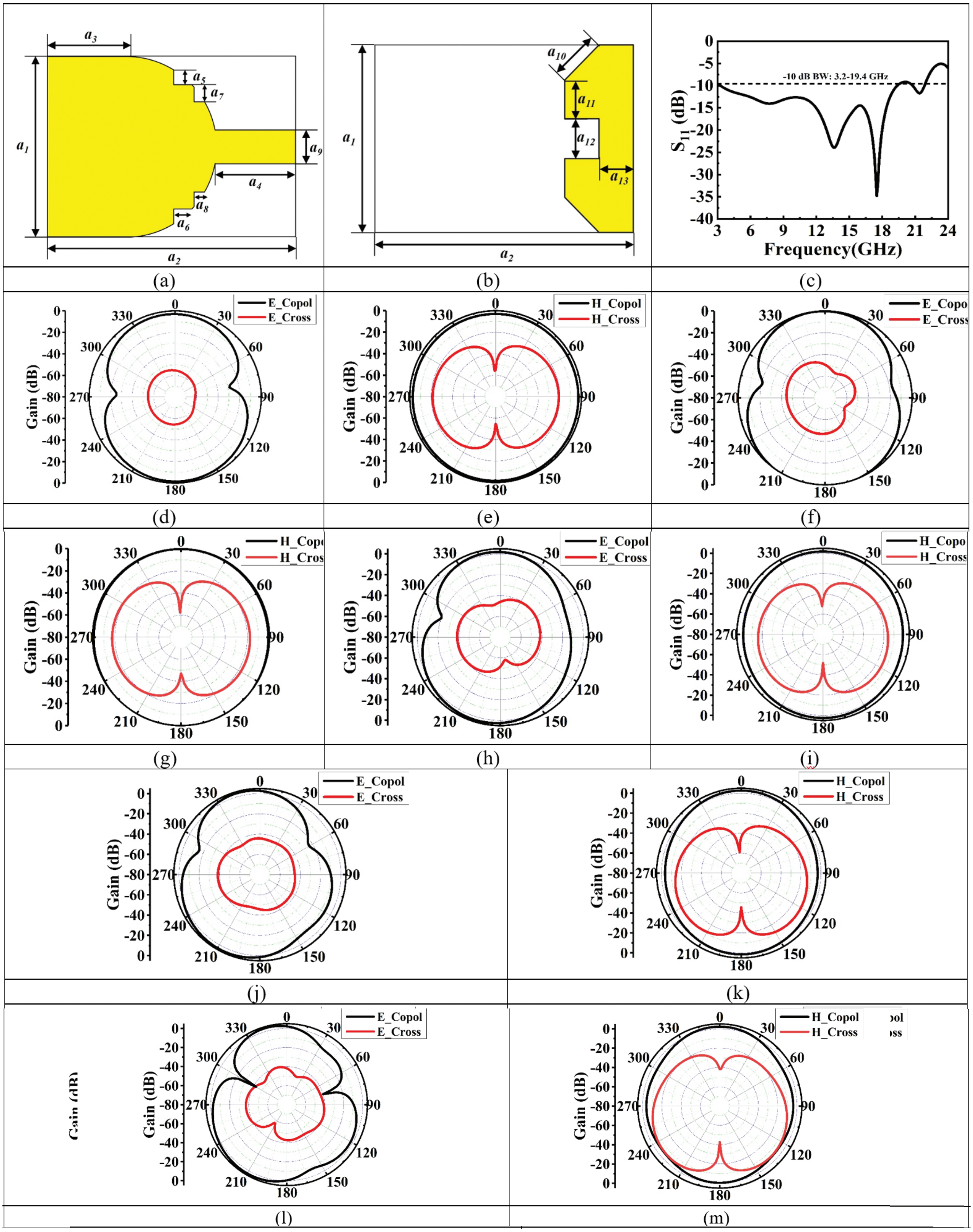
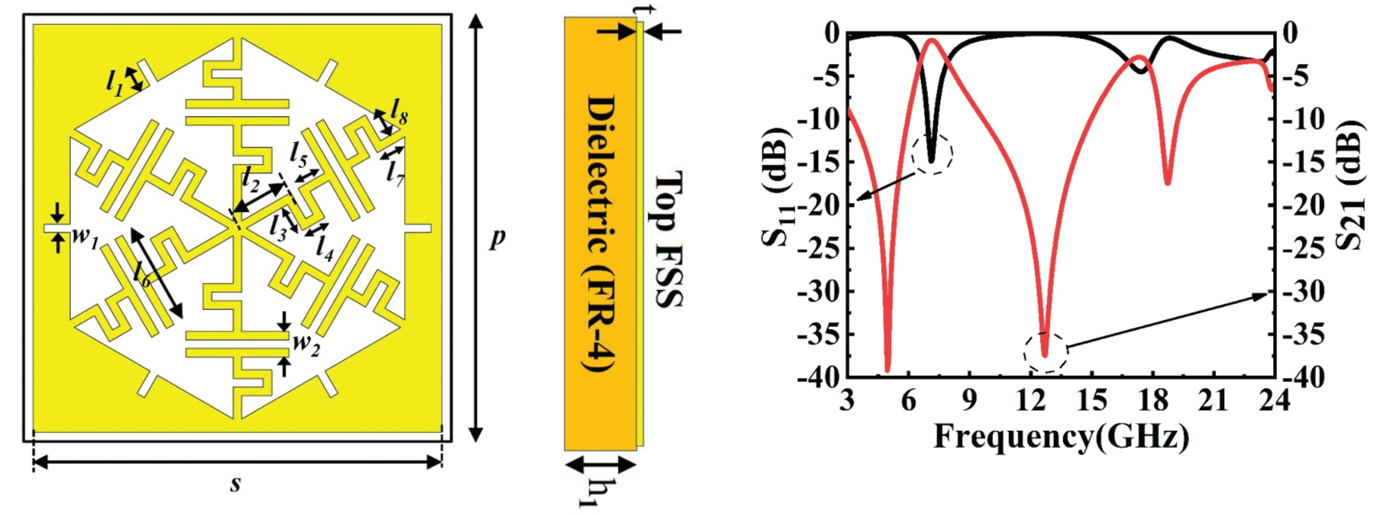


Figure 1. Proposed UWB antenna: (a) top view, (b) bottom view, and (c) Simulated reflectance of the proposed UWB antenna. The simulated radiation pattern of E-plane at (d) 4 GHz, (f) 6 GHz, (h) 8 GHz, (j) 10 GHz, and (l) 12 GHz; H-plane (e) 4 GHz, (g) 6 GHz, (i) 8 GHz, (k) 10 GHz, and (m) 12 GHz, respectively of the proposed antenna.

Table 2. Finalised dimensions of the proposed dual-band transmission type FSS

p	s	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8
7.76 mm	7.6 mm	0.48 mm	1.20 mm	0.56 mm	0.48 mm	0.57 mm	1.92 mm	0.59 mm	0.56 mm

w_1	w_2
0.16 mm	0.48 mm



(a) (b) (c)

Figure 2. The novel proposed a single-layered dual-band FSS: (a) Top view, (b) Side view, and (c) Simulated reflection and transmission response of the proposed FSS.

perpendicularly aligned elements and a small slit designed to reduce mutual interaction between them in the low-frequency range (3–4.5 GHz). The combination of its strong envelope correlation coefficient, low mutual coupling (less than 15 dB), and approximately 3.1–10.6 GHz broad impedance bandwidth make this component ideal for handheld UWB devices (better than 0.02 over the frequency range). Ultrawideband (UWB) antenna gain can be increased with a properly built multi-octave dual-layer Frequency Selective Surface (FSS) reflector[35]. As a result, the UWB antenna's gain can be greatly increased while maintaining a small profile and impedance bandwidth.

2. DESIGN DESCRIPTION AND SIMULATED RESULTS

2.1 Design of UWB Monopole Antenna

The primary antenna in this article is made up of a metallic radiating patch on top of the ground and a dielectric substrate that separates them. The top patch is a combination of a modified U-shaped radiator extended by a rectangular section (a3× a1), as shown in Fig. 1(a). An edge-cut ground plane with a rectangular slit is put on the substrate's other side for increased operating bandwidth. With the physical dimensions of (16×22×1.6 mm3) (0.171λo×0.235λo×0.017λo), the suggested antenna is appropriate for real-time wireless communication applications. The patch is excited using the microstrip feeding method, and its width (a9) is tuned for a 50-ohm impedance. As a dielectric spacer, a commercially available FR-4 dielectric substrate (1.6 mm) having εr = 4.4 (relative permittivity), and tan δ = 0.02 (loss-tangent) is utilised. The finalized dimensions of the antenna for the optimal desired response in the UWB band are given in Table 1. The dimensions are optimised in a Finite Element Method (FEM)-based electromagnetic (EM) solver, ANSYS HFSS, and a wave port is used for the excitation of the proposed prototype. The suggested monopole antenna's simulated reflectance response within the UWB band (Fig. 1(a) and (b)) is depicted in Fig. 1(c). The proposed antenna shows a -10 dB bandwidth response from 3.2–19.4 GHz (143.36 % fractional bandwidth), covering the entire UWB range along with X and Ku-bands. To determine the antenna's radiation efficiency, the radiation plots of the antenna simulated at different frequencies are observed in Fig. 1(d)-(m) over 4 to 12 GHz in steps of 2 GHz.

2.2 Design and Analysis of the FSS Unit-cell

This work proposes a novel frequency selective surface (FSS) with a dual-band, that acts as a band stop filter, as shown in Fig. 2(a). This design consists of a hexagonal structure with all the corners connected to the center using meander line inductances and a capacitance-like structure. The other side of the substrate is not covered with any metallic layer. The dimensions of the unit cell are optimized in the EM solver by applying the periodic boundary conditions in the xy-plane and the floquet port along the z-directions. The dielectric spacer utilized in the design is an FR-4 substrate with εr = 4.4 (relative permittivity) and tan δ = 0.02 (loss-tangent) of thickness 1.6 mm. This design shows bandstop characteristics at two different frequencies with transmission zeros at 4.95 GHz and 12.7 GHz, with S21 (dB) of -39.5 dB and 37.9 dB, respectively, as shown in Fig. 2(c). With the suggested unit cell, the UWB monopole antenna is arranged in the shape of a Fabry Perot cavity to increase its gain. The finalized dimensions are given in Table 2.

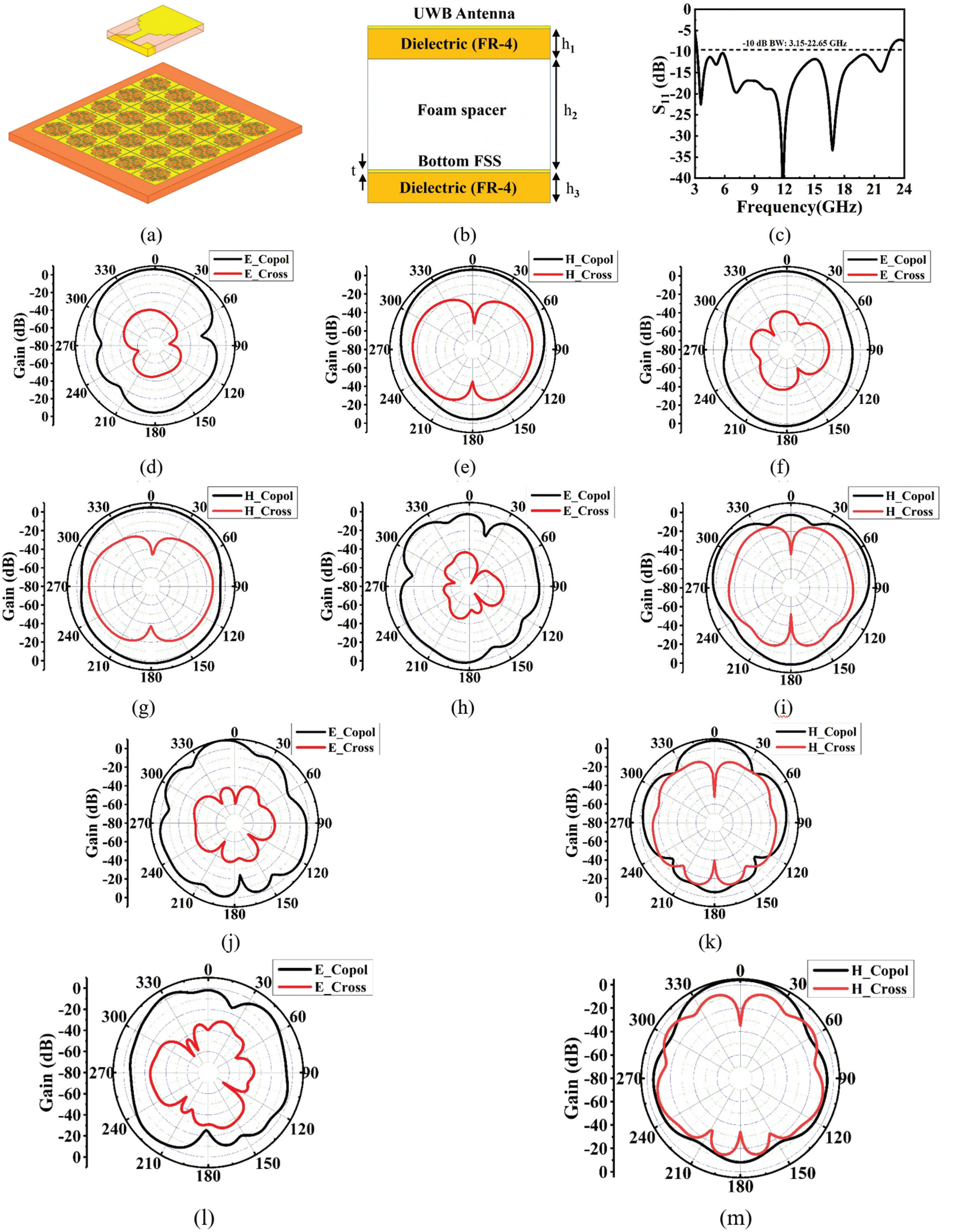


Figure 3. Proposed UWB antenna loaded with the dual-band FSS: (a) 3D view, (b) side view. (c) Simulated reflectance of the proposed UWB antenna after loading with FSS. The Simulated Radiation pattern of E-plane at (d) 4 GHz, (f) 6 GHz, (h) 8 GHz, (j) 10 GHz, and (l) 12 GHz; H-plane (e) 4 GHz, (g) 6 GHz, (i) 8 GHz, (k) 10 GHz, and (m) 12 GHz, respectively of the proposed UWB antenna after loading with FSS.

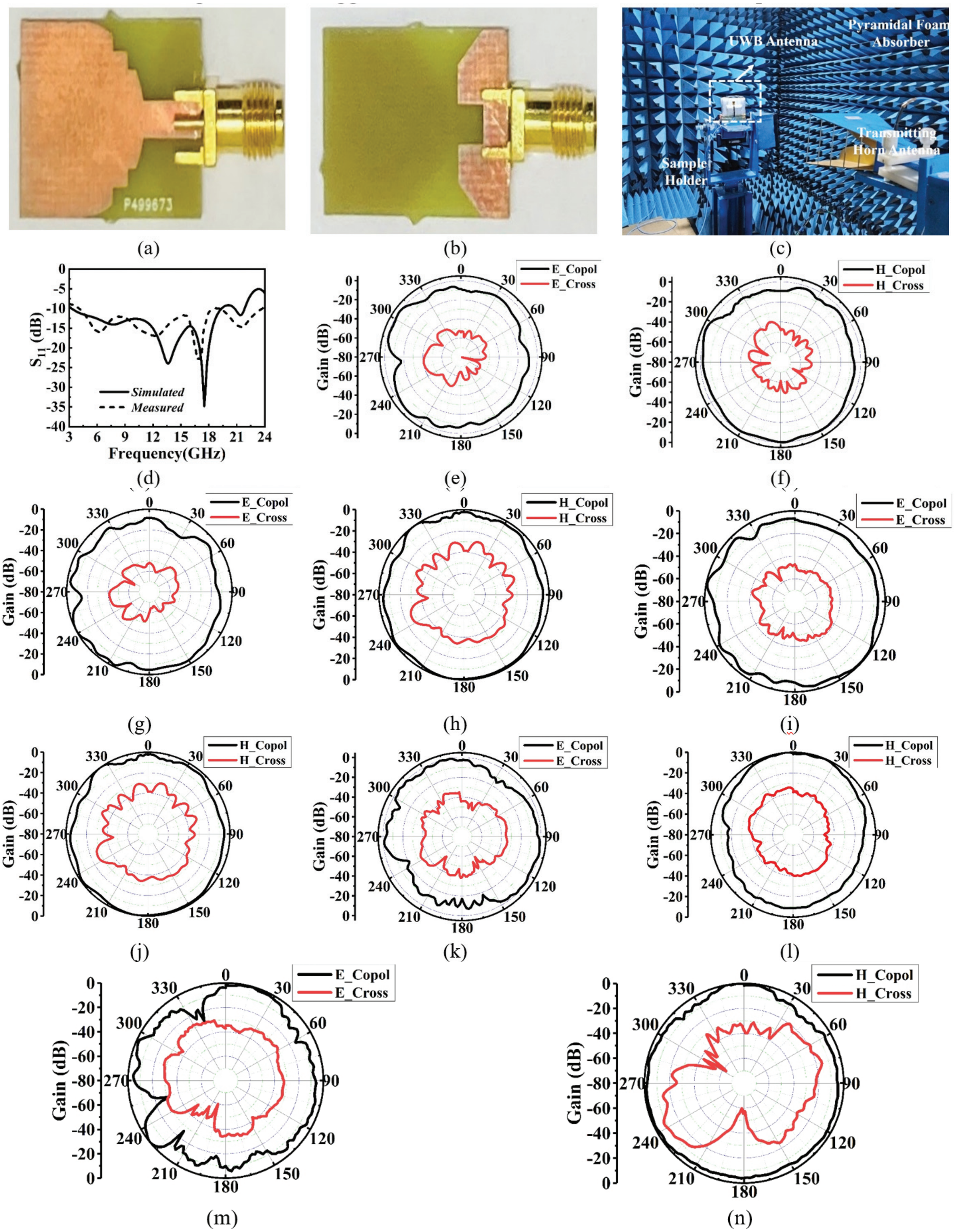


Figure 4. Fabricated prototype UWB monopole antenna (a) top view, (b) bottom view. (c) Measurement setup inside the anechoic chamber. (d) comparison of simulated and measured reflectances of the proposed antenna. The Simulated Radiation pattern of E-plane at (e) 4 GHz, (g) 6 GHz, (i) 8 GHz, (k) 10 GHz, and (l) 12 GHz; H-plane (f) 4 GHz, (h) 6 GHz, (j) 8 GHz, (l) 10 GHz, and (n) 12 GHz, respectively.

The gain enhancement of the proposed FSS-loaded UWB antenna works based on the principle of constructive interference between the forward-directed wave and the reflected backward wave from the FSS. The designed UWB antenna exhibits a wideband return loss BW over 3.2 to 19.4 GHz and has a resonance dip near 7.5, 13.5, and 18 GHz. The operating frequency of the dual-band FSS is strategically designed to obtain its stopband resonances within the operating range of the UWB antenna. The FSS is a spatial filter that shows either bandpass or bandstop characteristics when a plane wave illuminates the surface. The FSS comprised a period arrangement of patches that provides stopband properties, whereas, the periodical arrangement of slot geometry provides bandpass characteristics. For the monopole antenna to have more gain, the FSS must be made with bandstop resonance. At resonance, bandstop FSS reflects the backward wave of the antenna in the broadside direction.

2.3 Design and Analysis of the FSS Loaded with Antenna

The suggested antenna is loaded with FSS, as depicted in Fig. 3(a), for gain enhancement and directivity of the UWB antenna. The foam spacer creates the air gap between the antenna and FSS since the relative permittivity is closer to free space. The height between the UWB antenna and the FSS is required to satisfy the required phase condition of constructive interference. One can recall from the principle of ray theory, that two waves will interfere constructively when the phase difference is an even multiple of 2π. If the FSS provides a phase change of ϕ_{FSS}, then the phase change $\Delta\phi$ between the reflected and forward transmitted wave can be written as Eqn. (1).

$$\Delta\phi = \pi + \phi_{FSS} - \frac{4\pi h_2}{c} f_c - \frac{4\pi}{c} f_c \sqrt{\varepsilon_r}\,(h_1 + h_3) = 2N\pi \quad (1)$$

Here, ε_r is the dielectric constant of the substrate, c is the velocity of the EM wave in free space, and f_c is the center frequency of the UWB antenna's operating range. 'N' is an integer whose minimum value is 1. One can determine the initial value of airspace height (h_2) between the FSS and antenna using the above equation. The height of the air-spacer is optimized, and it is noticed that the suggested antenna performs well with an S_{11} (-10 dB) from 3.15 GHz to 22.65 GHz with 19.5 GHz of bandwidth (151.16 % FBW), as shown in Fig. 3(c). The proposed FSS acts as a bandstop filter over the UWB range, with S_{21} less than -10 dB in most of the UWB range and almost no transmission in the backside direction. This improves the gain and directivity of the UWB antenna. The backside radiation would be reflected, and the height of the air- spacers would be changed to interfere with the front-side radiation in a good way.

The antenna's front-to-back ratio is also enhanced along with the gain and directivity. It is observed that the proposed UWB antenna results in a gain varying from 1.92 to 3.7 dBi with a peak gain of 3.7 dBi, at 10 GHz. After loading the FSS, the gain is enhanced by 2.2 to 9.9 dBi, with a peak gain of 9.9 dBi at 10 GHz (Fig. 6(k)). The proposed antenna's radiation patterns after loading with FSS are investigated at different frequencies over the entire UWB band ranging from 4 GHz to 12 GHz in steps of 2 GHz, as detailed in Fig. 3(d)-(m).

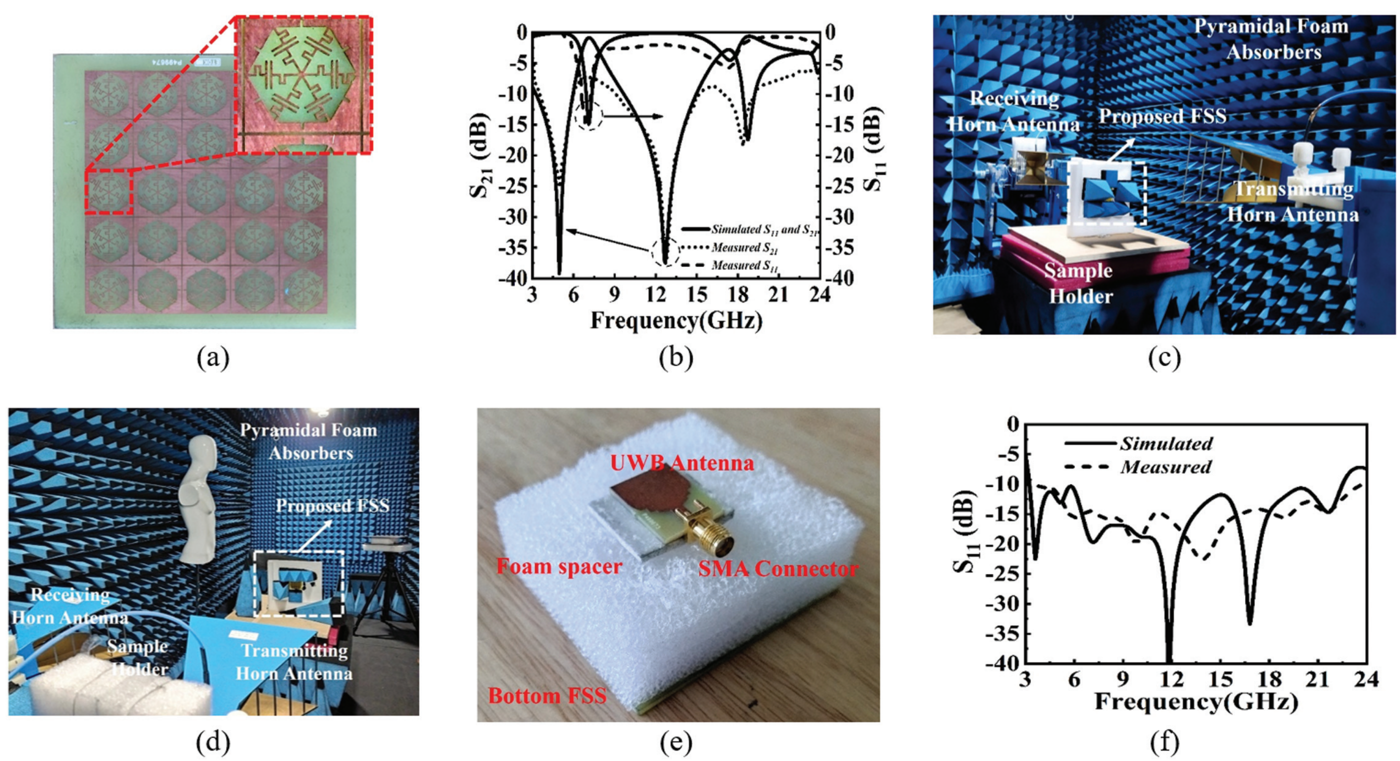


Figure 5. (a) Fabricated FSS prototype, (b) Comparison of measured and simulated reflectances of the proposed antenna, Free-space measurement setup for (c) S21, (d) S11 measurement of the proposed 5X5 array, (e) UWB monopole antenna loaded with the proposed FSS with the foam spacer, and (f) Measured S11 of the antenna after loading with the FSS.

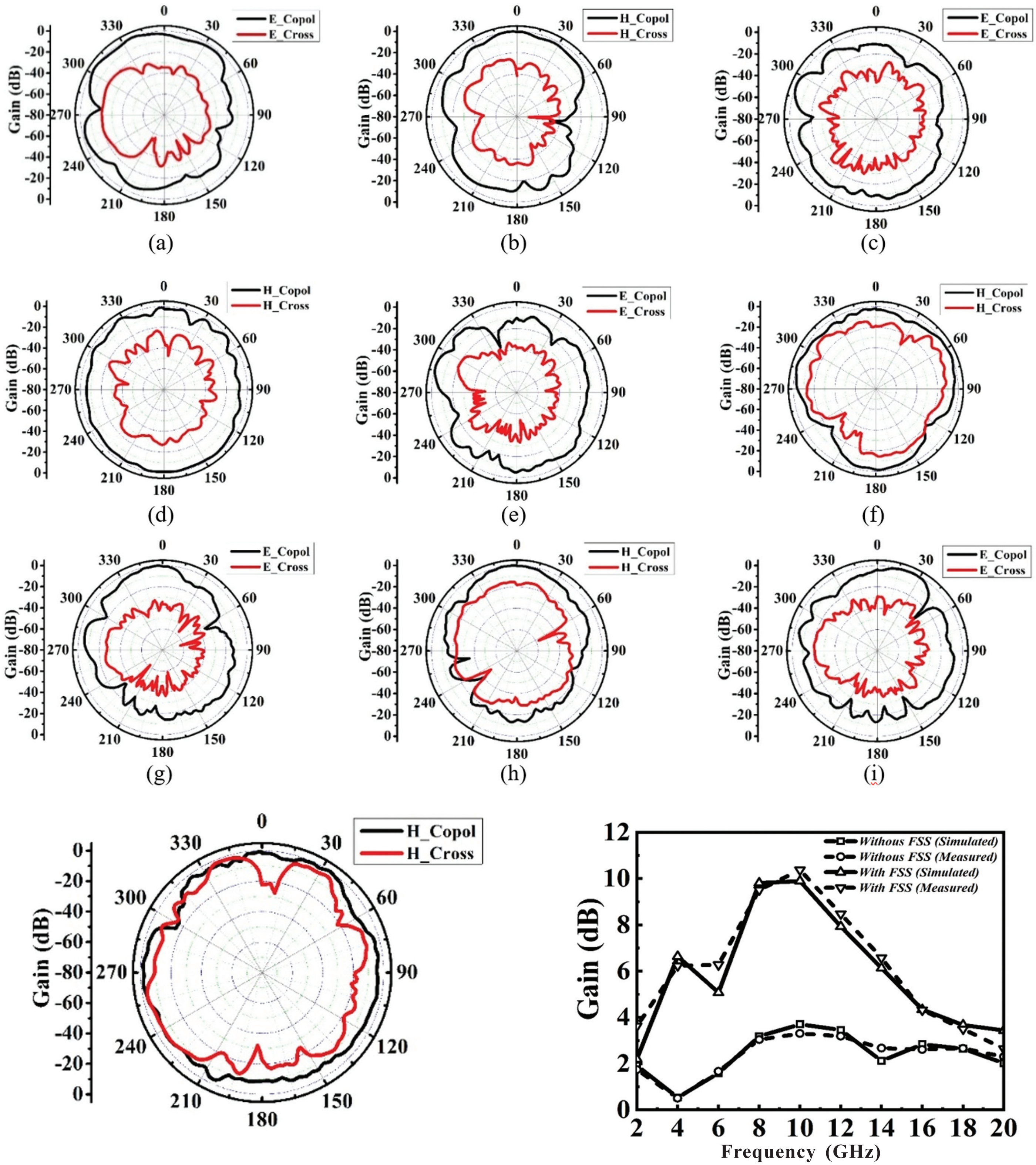


Figure 6. Measured radiation pattern of E-plane at (a) 4 GHz, (c) 6 GHz, (e) 8 GHz, (g) 10 GHz, and (i) 12 GHz; H-plane (b) 4 GHz, (d) 6 GHz, (f) 8 GHz, (h) 10 GHz, and (j) 12 GHz, respectively of the proposed UWB antenna after loading with FSS. (k) Simulated versus measured gains of the UWB monopole antenna with and without FSS.

3. MEASURED RESULTS AND RELATED DISCUSSION

The UWB monopole-type proposed antenna is made with the conventional PCB technique, and the fabricated prototype is shown in Fig. 4(a). A 50-Ω impedance SMA connector is used for the antenna's excitation. The fabricated prototype is connected to the Keysight Power Network Analyser (PNA) N5224B inside the anechoic chamber to measure the characteristic parameters of the antenna, as in Fig. 4(c). The suggested antenna (on the receiver side) is kept in the far-field

Table 3. Performance comparison table with other similar categories of the antennas

Ref	Size of the antenna (mm^2)	FSS unit cell size (mm^2)	Band width (GHz)	No. of FSS layers	Gain (Without FSS)	Gain (With FSS)	Gain enhancement	Approach
27	115 x 115	13.5 ×13.5	3 – 8	1	Around 6	Around 9.7	3.5 - 4	Dual polarised radiator mounted on a backing reflector
39	34 × 26	14 × 14	2.7 – 13.9	1	4.9	8.9	4	Compact uni-layer FSS with UWB antenna.
37	35 × 30	10.8 × 10.8	3 – 13.4	2	2.5 - 5	5.5 – 8.5	2 - 4	Umbrella-shaped UWB antenna with FSS as a reflector
40	17.5 × 14.5	5.4 × 5.4	6.1 – 20.88	2	2 - 4	3.5 – 6.5	3	CPW fed printed UWB antenna with FSS
41	32 × 30	11 × 11	3.8 – 10.6	1	~ 5	~ 8.5	3.5	UWB antenna with FSS
42	32 × 32	-	3.1-10.6	-	1.7-4.2	-	-	Two open L-shaped slots and narrow slots on the ground plane
43	24 × 28	-	2.91-11.4	-	NR	-	-	Y-shaped strips to an annular ring
44	100 × 100	5 ×5	2.29-11.1	1	6.7	11.5	4.8	Mercedes shaped Patch
45	135 × 135	10 ×10	3.1-10.6	1	6.5	9	2.5	Modified circular-shaped Patch
46	84 × 84	6 ×6	3.3-10.5	1	4	8.3	4	Semicircular Shaped antenna with semicircular slot FSS
14	24.5 ×24.5	-	2.95-12.1	-	3.39	-	-	Asymmetrical rectangular patch with the U-shaped open-slot structure
38	Antenna 20 × 27 Antenna + FSS 84 × 84	14 × 14	4.7-14.9	1	4.2	8.7	4.3	Ultra-wide stop band FSS
35	Antenna 63 × 63 Antenna + FSS 119 × 119	17 × 17	3-12	2	6	9.8	3.8	Multioctave FSS reflector
36	30 × 60	22.4 × 6.5	3.2 - 12	2	~5	~9	3 - 4	Slotted ground microstrip antenna with FSS reflector
This work	Antenna 16 ×22 Antenna + FSS 38.8 × 38.8	7.76 × 7.76	3.15 - 22.65	1	3.2	9.9	6.7	Modified U-shaped radiating patch with the slotted ground with a dual-band FSS structure.

zone of the test horn antenna (on the transmitter side). The antenna's input reflectance is measured and compared with the simulated, as shown in Fig. 4(d). A good match is obtained between the simulated and measured results. The radiation patterns of the antenna are illustrated in Fig. 4(e)-(n) and noted at various frequencies within the anechoic chamber (as in the setup of Fig. 4(c)).

The proposed dual-band FSS is fabricated as a 5 × 5 array on the 1.6 mm FR-4 substrate using the PCB technique, as shown in Fig. 5(a). For measuring the reflection transmission properties of the FSS, two different setups have been used, as shown in Fig. 5(c) and Fig. 5(d), respectively. For the measurement of S_{21}, the proposed sample is placed between the two-test horn antennas (one for transmission and one for reception). The path loss between the antennas was calibrated by measuring the S_{21} without any sample. For the reflection coefficient measurement, the proposed prototype is on the opposite side (Fig. 5(d)), which was kept in the far-field method.

Here, the free-space measurement technique is adopted for the measurement. Next, a 22-mm foam spacer is placed between the antenna and FSS, and it is pasted with the help of double-sided adhesive tape, as shown in Fig. 5(e). The antenna's measured reflectance following FSS loading is depicted in Fig. 5(f). Note that better matching of simulated results with measured results is obtained.

For the measurement of gain, the first S21 between the test horn antennas is measured. Then the receiving horn antenna is replaced by the proposed sample (only the antenna for the first time, and the antenna loaded with the FSS), and

S21 is measured. By the standard calibration of the tested horn antennas, the difference between the S21 readings is found. The gain of the monopole antenna would be measured by adding it to the horn antenna's gain at different frequencies. Gain is assessed in two different situations: with and without the FSS of the antenna.

The gain is off by 0.6 dBi compared to the simulation findings (Fig. 6(k)). The simple antenna's gain is improved by 6.2 dBi when the FSS is loaded, leading to a maximum gain of 9.9 dBi. Table 3 provides a side-by-side performance comparison of the proposed antenna and the state-of-the-art.

4. CONCLUSION

An ultra-wideband (UWB) single-element antenna consisting of a U-shaped modified radiating patch and the rectangular slot cut ground on the other side of the substrate is presented in this work. A compact single-layer, dual-band transmission type frequency selective surface (FSS) is designed with better angular stability. All design parameters are optimized for the desired performance. After the inclusion of FSS in the UWB antenna, the gain and bandwidth enhancement are observed. The overall physical dimension size of the antenna loaded with FSS would be 38.8 mm × 38.8 mm × 25.2 mm ($0.407\lambda o \times 0.407\lambda o \times 0.265\lambda o$), where λo corresponds to the lowest frequency of the operational bandwidth. This compacted unit shows a -10 dB S11 bandwidth covering the whole UWB, X, Ku-and some regions of K-band with a 9.9 dB peak gain at 10 GHz. Better matching of simulated results with measured results is obtained. The low-profile nature, low-complexity design, broader bandwidth, and high performance of the FSS-loaded antenna make it suitable for real-time applications like microwave imaging and wireless communications.

REFERENCES

1. Liang, J.C.; Chiu, C.N.; Lin, T.C. & Lee, C.H. An ultra-wideband circularly-polarized Vivaldi antenna with high gain. *IEEE Access*, 2022, **10**, 100446–100455 doi: 10.1109/access.2022.3208375.
2. Aiello, G.R. & Rogerson, G.D. Ultra-wideband wireless systems. *IEEE Microwave Magazine*, 2003, **4**(2), 36-47. doi: 10.1109/MMW.2003.12015972.
3. Deng, C.; Xie, Y.J. & Li, P. CPW-fed planar printed monopole antenna with impedance bandwidth enhanced. *IEEE Antennas and Wireless Propag. Lett.*, 2009, **8**(1), 1394-1397. doi: 10.1109/LAWP.2009.2039743.
4. Amdaouch; I.; Saban, M.; El, Gueri, J.; Chaari, M.Z.; Alejos, A.V.; Alzola, J.R. & Muñoz, A.R. A novel approach of a low-cost UWB microwave imaging system with high resolution based on SAR and a new fast reconstruction algorithm for early-stage breast cancer detection. *J. Imaging,* 2022, **8**(10), 264-279. doi: 10.3390/jimaging8100264
5. Siddiqui, J.Y.; Saha, C. & Antar, Y.M. Compact dual-SRR-loaded UWB monopole antenna with dual frequency and wideband notch characteristics. *IEEE Antennas and Wireless Propag. Lett.*, 2014, **14**(1), 100-103. doi: 10.1109/LAWP.2014.2356135.
6. Vendik, I.B.; Rusakov, A.; Kanjanasit, K.; Hong, J. & Filonov D. Ultra wideband (UWB) planar antenna with single, dual and triple band notched characteristic based on electric ring resonator. *IEEE Antennas and Wireless Propag. Lett.*, 2017, **16**(1), 1597-1600. doi: 10.1109/LAWP.2017.2652978.
7. Liu, J.; Zhong S. & Esselle, K.P. A printed elliptical monopole antenna with modified feeding structure for bandwidth enhancement. *IEEE Transact. Antennas and Propag.*, 2010, **59**(2), 667-70. doi: 10.1109/TAP.2010.2096398.
8. Abbosh, A.M. & Bialkowski, M.E. Design of ultra-wideband planar monopole antennas of circular and elliptical shape. *IEEE Transact. Antennas and Propag.*, 2008, **56**(1), 17-23. doi: 10.1109/TAP.2007.912946.
9. Alsath, M.G. & Kanagasabai, M. Compact UWB monopole antenna for automotive communications. *IEEE Transact. Antennas and Propag.*, 2015, **63**(9), 4204-8. doi: 10.1109/TAP.2015.2447006.
10. Hong, C.Y.; Ling, C.W.; Tarn, I.Y. & Chung, S.J. Design of a planar ultrawideband antenna with a new band-notch structure. *IEEE Transact. Antennas and Propag.*, 2007, **55**(12), 3391-7. doi: 10.1109/TAP.2007.910486.
11. Lu, Y.; Huang, Y.; Chattha, H.T. & Cao, P. Reducing ground-plane effects on UWB monopole antennas. *IEEE Antennas and Wireless Propag. Lett.*, 2011, **10**,147-50. doi: 10.1109/LAWP.2011.2119459.
12. Ojaroudi, M.; Ghobadi, C. & Nourinia, J. Small square monopole antenna with inverted T-shaped notch in the ground plane for UWB application. *IEEE Antennas and Wireless Propag. Lett.*, 2009, **8**(1), 728-31. doi: 10.1109/LAWP.2009.2025972.
13. Xu, K.; Zhu, Z.; Li, H.; Huangfu, J.; Li, C. & Ran, L. A printed single-layer UWB monopole antenna with extended ground plane stubs. *IEEE Antennas and Wireless Propag. Lett.*, 2013, **12**(2), 237-40. doi: 10.1109/LAWP.2013.2247555.
14. Liu, W.; Yin, Y.; Xu, W. & Zuo, S. Compact open-slot antenna with bandwidth enhancement. *IEEE Antennas and Wireless Propag. Lett.*, 2011, **10**(1), 850-3. doi: 10.1109/LAWP.2011.2165197.
15. Sung, Y. Bandwidth enhancement of a microstrip line-fed printed wide-slot antenna with a parasitic center patch *IEEE Antennas and Wireless Propag. Lett.*, 2012, **60**(4), 1712-6. doi: 10.1080/09205071.2012.718857.
16. Xu, K.; Zhu, Z.; Li, H.; Huangfu, J.; Li, C. & Ran, L. A printed single-layer UWB monopole antenna with extended ground plane stubs. *IEEE Antennas and Wireless Propag. Lett.*, 2013, **12**(4), 237-40. doi: 10.1109/LAWP.2013.2247555.
17. Koziel, S. & Bekasiewicz, A. A structure and simulation-driven design of compact CPW-fed UWB antenna *IEEE Antennas and Wireless Propag. Lett.*, 2015, **15**(4), 750-3. doi: 10.1109/LAWP.2015.2471848.
18. Tao, J. & Feng, Q. Compact ultra wideband MIMO

antenna with half-slot structure. *IEEE Antennas and Wirel. Propag*., 2016, **16**(1), 792-5.
doi: 10.1109/LAWP.2016.2604344.

19. Bekasiewicz, A. & Koziel S. Structure and computationally efficient simulation-driven design of compact UWB monopole antenna. *IEEE Antennas and Wireless Propag. Lett.*, 2015, **14**(1), 1282-5.
doi: 10.1109/LAWP.2015.2402282.
20. Fereidoony, F.; Chamaani, S. & Mirtaheri, S.A. UWB monopole antenna with stable radiation pattern and low transient distortion. *IEEE Antennas and Wireless Propag. Lett.*, 2011, **10**(1), 302-5.
doi: 10.1109/LAWP.2011.2141106.
21. Pandey, G.K.; Singh, H.S.; Bharti, P.K. & Meshram, M.K. UWB monopole antenna with enhanced gain and stable radiation pattern using gate like structures. *In IEEE International Conference on Microwave and Photonic*, 2013, **1**-4.
doi: 10.1109/ICMAP.2013.6733504.
22. Ryu, K.S. & Kishk, A.A. UWB dielectric resonator antenna having consistent omnidirectional pattern and low cross-polarisation characteristics. *IEEE Transact. Antennas and Propag.*, 2011, **59**(4), 1403-8.
doi: 10.1109/TAP.2011.2109676.
23. Wang, J. & Yin, Y. Differential-fed UWB microstrip antenna with improved radiation patterns. *Electron. Lett.*, 2014, **50**(20), 1412-4.
doi: 10.1049/el.2014.2126,
24. Hsieh, T.H. & Lee, C.S. Double-layer high-gain micro strip array antenna. *IEEE Transact. Antennas and Propag.*, 2000, **48**(7), 1033-5.
doi: 10.1109/8.876320.
25. Moharamzadeh, E. & Javan, A.M. Triple-band frequency-selective surfaces to enhance gain of X-band triangle slot antenna. *IEEE Antennas and Wireless Propag. Lett.*, 2013, **12**(4), 1145-8.
doi: 10.1109/LAWP.2013.2281074.
26. Kumar, C.; Pasha, M.I. & Guha, D. Defected ground structure integrated microstrip array antenna for improved radiation properties. *IEEE Antennas and Wireless Propag. Lett.*, 2016, **16**(3), 310-2.
doi: 10.1109/LAWP.2016.2574638.
27. Yahya, R.; Nakamura, A.; Itami, M. & Denidni, T.A. A novel UWB FSS-based polarization diversity antenna. *IEEE Antennas and Wireless Propag. Lett.*, 2017, **16**(1), 2525-2228.
doi: 10.1109/LAWP.2017.2730161.
28. Ranga, Y.; Esselle, K.P.; Matekovits, L. & Hay, S.G. Increasing the gain of a semicircular slot UWB antenna using an FSS reflector. *IEEE-APS Topical Conference on Antennas and Propagation in Wireless Commun.*, 2012, 478-481,
doi:10.1109/APWC.2012.6324954.
29. Majidzadeh, M.; Ghobadi, C. & Nourinia, J. Novel single layer reconfigurable frequency selective surface with UWB and multi-band modes of operation. *AEU - Int. J. Electron. Commun.*, 2016, **70**(2), 151-61.
doi:10.1016/j.aeue.2015.10.011
30. Ranga, Y.; Matekovits, L.; Esselle, K.P. & Weily, A.R. Multioctave frequency selective surface reflector for ultrawideband antennas *IEEE Antennas and Wireless Propag. Lett.*, 2011, **10**(1), 219-22.
doi: 10.1109/LAWP.2011.2130509.
31. Hussain, T.; Cao, Q.; Kayani, J.K. & Majid, I. Miniaturisation of frequency selective surfaces using 2.5-D knitted structures: Design and synthesis. *IEEE Transact. Antennas and Propag.*, 2017, **65**(5), 2405-12.
doi: 10.1109/TAP.2017.2673809.
32. Saleem, R.; Bilal, M.; Shabbir, T. & Shafique, M.F. An FSS-employed UWB antenna system for high-gain portable devices. *Microwave and Optical Technol. Lett.*, 2019, **61**(5), 1404-10.
doi: 10.1002/mop.31713
33. Mondal, K.; Sarkar, D.C. & Sarkar, P.P. 5×5 matrix patch type frequency selective surface based miniaturised enhanced gain broadband microstrip antenna for L A N / WiMAX/ISM band applications. *Progress in Electromagn. Res. C*, 2019, **89**(1), 207-19.
doi:10.2528/PIERC18110803.
34. Kundu, S.; Chatterjee, A.; Jana, S.K. & Parui, S.K. High gain dual notch compact UWB antenna with minimal dispersion for ground penetrating radar application. *Radioengineering*, 2018, **27**(4).
doi: 10.13164/re.2018.0990,
35. Ranga, Y.; Matekovits, L.; Esselle, K.P. & Weily, A.R. Multioctave frequency selective surface reflector for ultrawideband antennas. Antennas. *IEEE Antennas and Wireless Propag. Lett.*, 2011, **10**(4), 219-22.
doi: 10.1109/LAWP.2011.2130509.
36. Ram, K. & Kumar, R. Slotted ground microstrip antenna with FSS reflector for high-gain horizontal polarisation. *Electron. Lett.*, 2015, **51**(8), 599-600.
doi: 10.1049/el.2015.0339,
37. Kundu, S.; Chatterjee, A.; Jana, S.K. & Parui, S.K. A compact umbrella-shaped UWB antenna with gain augmentation using frequency selective surface. *Radioengineering*, 2018, **27**(2), 448-54.
doi: 10.13164/re.2018.0448,
38. Das, P. & Mandal, K. Modelling of ultra-wide stop-band frequency-selective surface to enhance the gain of a UWB antenna. *IET Microwaves Antennas and Propag.*, 2019, **13**(3), 269-77.
doi: 10.1049/iet-map.2018.5426,
39. Tahir, F.A.; Arshad, T.; Ullah, S. & Flint, J.A. A novel FSS for gain enhancement of printed antennas in UWB frequency spectrum. *Microwave and Optical Technol. Lett.*, 2017, **59**(10), 2698-704.
doi: 10.1002/mop.30789,
40. Kundu, S. Gain augmentation of a CPW fed printed miniature UWB antenna using frequency selective surface. *Microwave and Optical Technol. Lett.*, 2018, **60**(7), 1820-6.
doi: 10.1002/mop.31246,
41. Abdulhasan, R.A.; Alias, R.; Ramli, K.N.; Seman, F.C. & Abd-Alhameed, R.A. High gain CPW-fed UWB planar monopole antenna-based compact uniplanar frequency

selective surface for microwave imaging. *Int. J. R.F. Microwave in Comput. Aided Eng.*, 2019, **29**(8), e21757. doi: 10.1002/mmce.21757.

42. Ren, J.; Hu, W.; Yin, Y. & Fan, R. Compact printed MIMO antenna for UWB applications. *IEEE Antennas and Wireless Propag. Lett.*, 2014, **13**(1), 1517-20. doi:10.1109/LAWP.2014.2343454.
43. Zhou, Z.L.; Li, L. & Hong, J.S. Compact UWB printed monopole antenna with dual narrow band notches for WiMAX/WLAN bands. *IET Electron. Lett.*, 2011, **47**(20), 1111-2. doi:10.1049/el.2011.2299
44. Al-Gburi.; A.J, Abdullah.; I., Ibrahim.; Z., Zakaria.; B., Ahmad.; N.A., Shairi. & Mohammed, Y.Z. High gain of UWB planar antenna utilising FSS reflector for UWB applications. *Comput. Mater. Contin*. 2022. **70**(1), 1419-1436. doi: 10.32604/cmc.2022.019741
45. Parchin, Ojaroudi.; R.A, Abd-Alhameed. & Ming, Shen. Gain improvement of a UWB antenna using a single-layer FSS. *2019 Photonics & Electromagn. Res. Symposium-Fall (PIERS-Fall)*, 2019, **1**(1), 1735-1739. doi: 10.1109/PIERS-Fall48861.2019.9021920.
46. Din, Iftikhar-Ud.; Sadiq, U.; Syeda, Iffat-Naqvi.; Raza, U.; Shakir, U.; Esraa, M. & Alibakhshikenari, M. *Int. J. Antennas and Propag.*, 2022, (**1**), 1-12. doi: 10.1155/2022/2002552.

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