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A Compact Novel Lamp Slotted WLAN Band Notched UWB Antenna Integrated with Ku Band

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Abstract—A compact novel lamp slotted upper WLAN band rejected ultrawideband (UWB) radiator integrated with Ku and partial K bands is reported. The intended radiator consists of a novel lamp slotted patch structure with a 50 Ω tapered microstrip feed line along with a novel semicircular defected ground structure (SCS-DGS). The size of the suggested radiator is $16 \times 22\,\text{mm}^2$ with an impedance bandwidth ranging from 3.63 to 21.94 GHz to cover UWB integrated with Ku and partial K bands, and a novel via notched element is utilized to notch the upper WLAN band from 5.31 to 6.05 GHz. The proposed antenna has stable radiation patterns, consistent gain, and a peak radiation efficiency of 92.15% except for the notched band which mak it suitable for upper WLAN band notched UWB wireless communication applications.

1. INTRODUCTION

There has been a lot of focus on improving wideband antennas using ultra-wideband (UWB) technology. Planar monopole antennas [1–6] have been designed for UWB (3.1–10.6 GHz) communication systems owing to their large bandwidth, simple construction, and omnidirectional dispersion pattern. However, IEEE 802.11a has limited the usage of the 5.15 to 5.825 GHz frequency spectrum for wireless local area network (WLAN) systems. A band-notch filter is required in UWB systems in order to prevent crossover between UWB and WLAN communications. However, incorporating a filter will make the UWB system more complicated. Therefore, a UWB element with a band elimination characteristic might be a solution to circumvent this problem. There have been reports of a number of antennas exhibiting band-notch characteristics [7–10]. In [7], a simple square shaped UWB element covering 3.7–10.4 GHz of bandwidth with band notched performance accomplished in the span of 5.1–5.9 GHz to notch the WLAN band by utilizing an inverted U-shaped slot etched into the radiator. In [8], the UWB bandwidth of 2.99–10.12 GHz is realised by combining an ellipse and a rectangular structure with a DGS, and the WiMAX (3.12–3.69 GHz) and WLAN (5.18–6.14 GHz) notched bands are realised by etching a U-shaped slot and a parasitic element. A very compact ($16 \times 22\,\text{mm}^2$) tapered fed and defected ground structured UWB antenna integrated with Ku band is reported in [9]. By etching three inverted U-structured slots into an elliptically shaped radiating patch, the reported antenna has been designed to cover frequencies from 3.1 to 18.8 GHz, rejecting C-band (3.7–4.2 GHz), WLAN (5.18–5.85 GHz), and X-band (8–8.4 GHz). A rectangle-shaped UWB antenna with notched corners and four rejection bands is reported in [10]. Notching two inverted U-shaped slots into a patch, a symmetrical split ring resonator and a via yielded four notched bands for WiMAX (3.25–3.55 GHz), C-band (3.7–4.2 GHz), WLAN (5.2–5.9 GHz), and X-band (7–7.8 GHz) on a $24 \times 30\,\text{mm}^2$ sized radiator.

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The intended antenna is a miniature lamp slotted structured patch that utilises a new SCS-DGS and a 50 Ω tapered microstrip feed line. The radiator is etched on an FR-4 substrate with a size of $16 \times 22\,\mathrm{mm}^2$, having an impedance bandwidth spanning from 3.63 to 21.94 GHz to cover the UWB integrated with Ku band (12–18 GHz) and a partial K band (18–21.94 GHz) along with an upper WLAN band ranging from 5.31 to 6.05 GHz which is rejected by utilizing a novel band notched element, via. The suggested antenna is well suited for higher WLAN-notch UWB wireless applications because of its consistent radiation patterns, high gain, and peak radiation efficiency of 92.15%.

2. ANTENNA DESIGN

Figure 1 depicts the geometrical details of the intended microstrip-fed monopole radiator. The intended radiator is printed on an FR-4 substrate having dimensions of width (W_S), length (L_S), a thickness of 1.6 mm, and a relative permittivity of 4.3. The suggested antenna has a novel slotted patch configuration in the form of a lamp and a tapered microstrip feed line with 50 Ω characteristic impedance etched on top of the substrate. To accomplish the necessary UWB assimilation with Ku and partial K band applications, a proprietary SCS-DGS is used on the substrate's underside. To notch the upper WLAN band, a via element is connected in between a rectangular parasitic element, which is deposited on top of an SCS-DGS and the lamp shaped patch structure. The suggested antenna's optimum dimensions are: $W_S = 16$ mm, $L_S = 22$ mm, $W_{F1} = 3$ mm, $W_{F2} = 2$ mm, $L_{F1} = 3$ mm, $L_{F2} = 11$ mm, $R_W = 7$ mm, $R_L = 2$ mm, $R = 0.15$ mm, $R_G = 8$ mm. Figure 2 shows a prototype of the intended radiator.

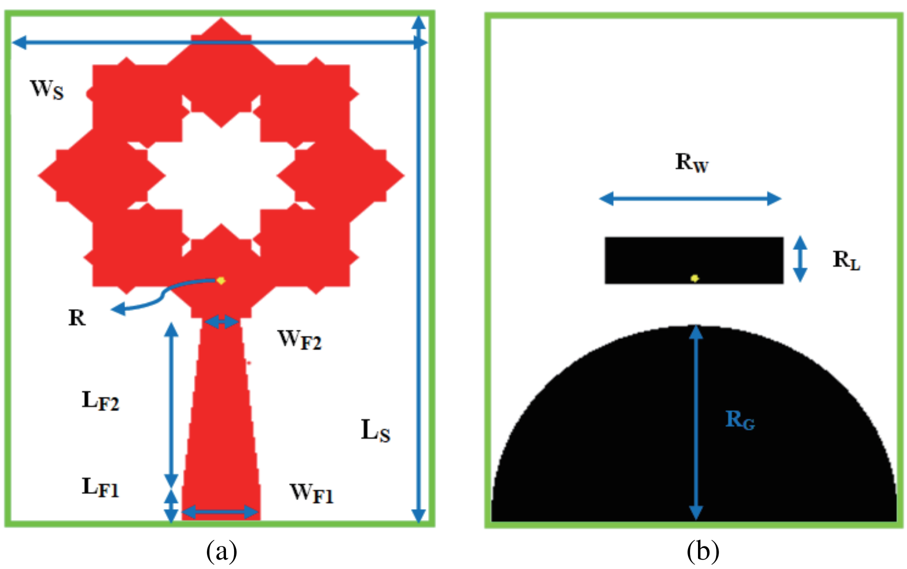


Figure 1. Proposed antenna geometry. (a) Top view. (b) Bottom view.

3. SIMULATION RESULTS AND DISCUSSION

3.1. Basic UWB Antenna Design

3.1.1. Effects of the Tapered Feed

Figure 3 depicts the parametric analysis of the suggested radiator without and with the tapered microstrip line feed designs, and Figure 4 shows the S_{11} parameter plot. Initially, for the radiator structure shown in Figure 3(a), the proposed lamp-shaped slotted radiator without tapered feed can produce three resonant bands at 4.22, 10.04, and 14.68 GHz of resonant frequencies with minimum S_{11} magnitudes of −18.89, −24.18, and −11.44 dB and bandwidths of 3.73–4.98 GHz, 9.10–10.94 GHz, and 14.18–15.28 GHz, respectively, as illustrated in Figure 4. With the tapered line feed [11] as depicted in

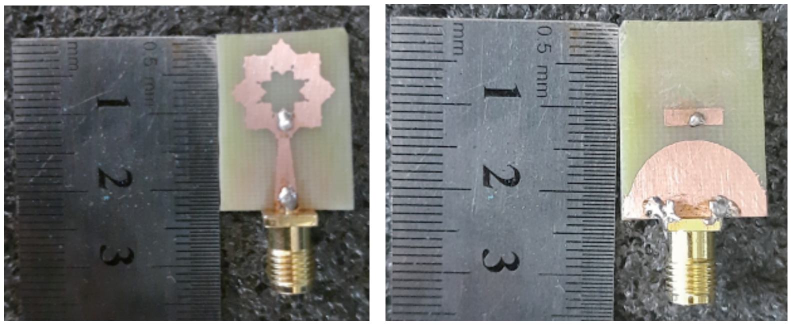
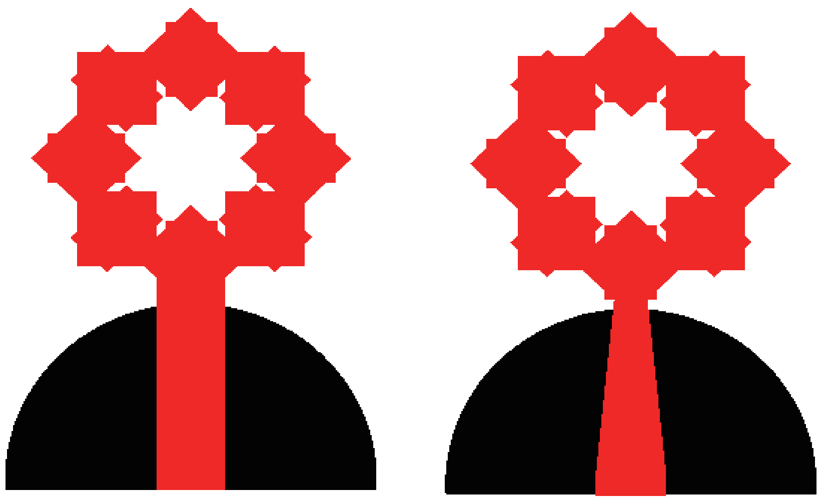


Figure 2. Prototype of the proposed antenna.



(a) (b)

Figure 3. Proposed antenna. (a) Without taper feed. (b) With taper feed.

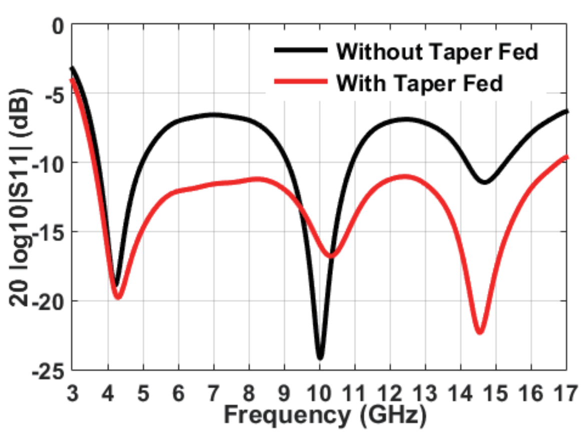


Figure 4. S_{11} magnitude plot for intended radiator with and without the tapered feed.

Figure 3(b), it is noticed that the bandwidth of the intended radiator ranges from 3.60 to 16.84 GHz with peak resonances occurring at 4.3 GHz, 10.34 GHz, and 14.56 GHz with minimum S_{11} magnitudes of −19.78, −16.78, and −22.31 dB, respectively, to cover the entire UWB integrated with the Ku band.

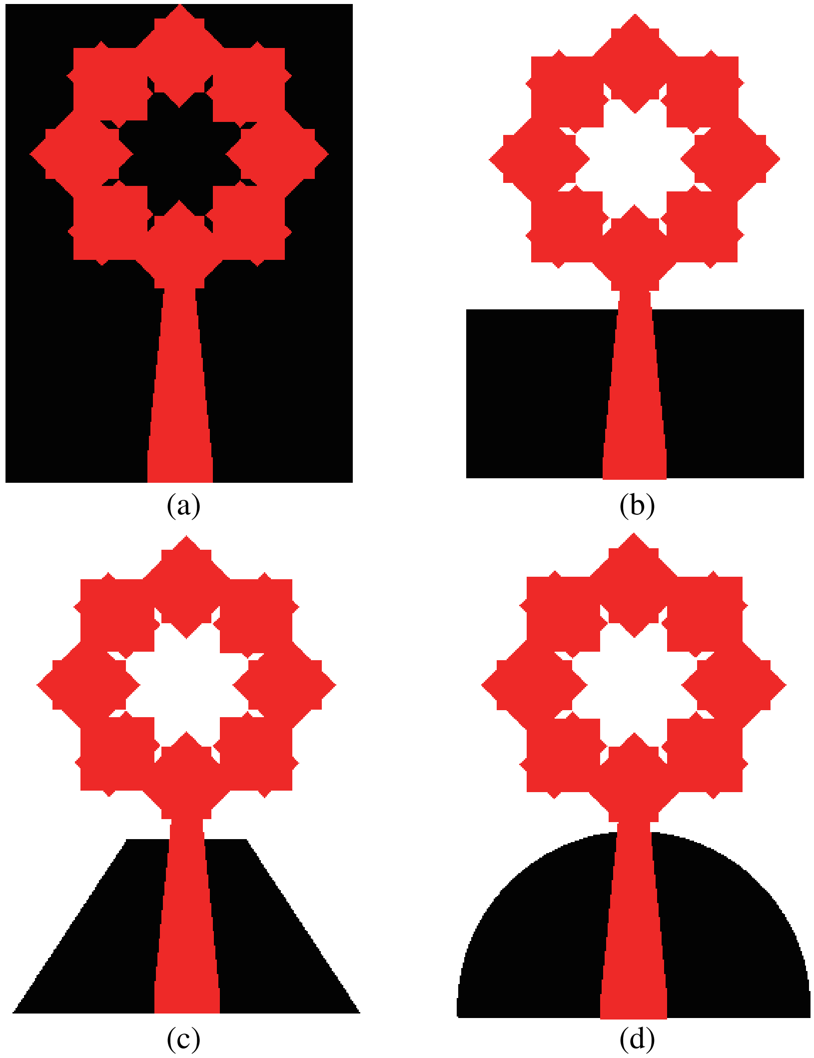


Figure 5. Gradual stages in implementing defected ground structure of proposed antenna. (a) Ant#1, (b) Ant#2, (c) Ant#3, (d) Ant#4.

3.1.2. Effect of SCS-DGS

Figure 5 shows the results of a parametric analysis conducted on the suggested radiator with the ground structure modified at different stages. Initially, as depicted in Figure 5(a), Ant#1 is designed with the complete ground plane structure of the proposed patch, operating over 14.23–14.74 GHz having a narrow bandwidth with minimum S_{11} magnitude of −34.47 dB at 14.46 GHz, as illustrated in Figure 6. In order to broaden the designed antenna's frequency spectrum, the antenna structure Ant#2 is obtained by notching a rectangular defected ground structure as illustrated in Figure 5(b). The radiator, Ant#2, provides a bandwidth of 3.81–9.40 GHz with a resonant frequency at 7.3 GHz having minimum S_{11} magnitude of −22.28 dB as illustrated in Figure 6. For antenna structure Ant#3, two beveled edges are etched to achieve the radiator structure as depicted in Figure 5(c), which covers the bandwidth spans of 3.485.14 GHz, 8–15.8 GHz with minimum S_{11} magnitudes of −19.53 dB and −36.95 dB at the resonant frequencies of 3.98 and 10 GHz, respectively, as depicted in Figure 6. Finally, a semicircular defected ground structure, Ant#4, is notched [12] as shown in Figure 5(d), which covers a bandwidth of 3.62–16.82 GHz with three resonances occurring at 4.3 GHz, 10.34 GHz, and 14.56 GHz with minimum S_{11} magnitudes of −19.78 dB, −16.78 dB, and −22.31 dB, respectively as illustrated in Figure 6.

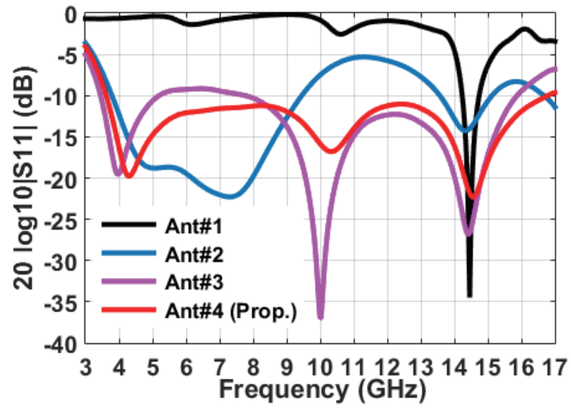


Figure 6. S_{11} magnitude plots for varying ground structures.

3.2. Proposed Antenna Simulation and Measured Results

The intended tapered fed novel lamp slotted radiator with a novel SCS-DGS is designed using Microwave Studio CST Ver.2021 [13]. The suggested antenna's calibrated electrical performance is analysed using an Anritsu MS2037C/2 network analyzer. A little variation occurs between simulated and calibrated values due to manufacturing flaws, uncertainty in relative permittivity values, and imperfect SMA connectors. Figure 7 shows the simulated and measured S_{11} plots of the suggested WLAN band notched UWB radiator that covers a bandwidth of 3.64–21.93 GHz, except for upper WLAN notched band. From Figure 7, it can be seen that the proposed antenna notches the upper WLAN band centred at 5.8 GHz with peak S_{11} value of −2.85 dB by utilizing a via element, which is connected between the proposed patch and the rectangular parasitic element deposited on top of the novel SCS-DGS.

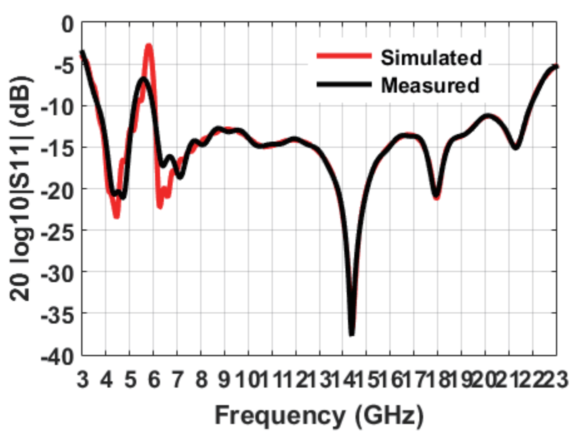
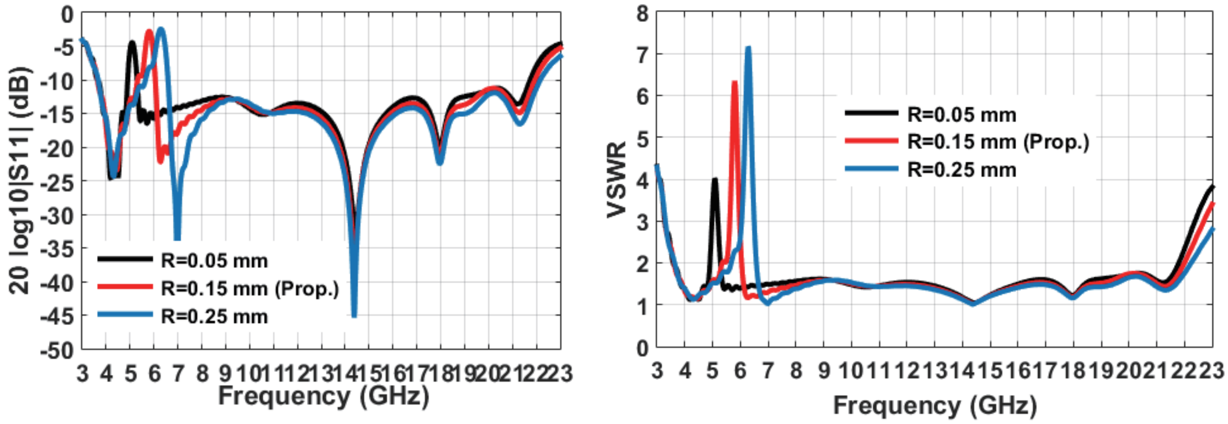


Figure 7. Simulated and measured S_{11} magnitude plots of the intended radiator.

3.3. Parametric study of Via Notched Element

Etching a via hole between the proposed lamp-shaped slotted patch and a rectangular parasitic element positioned on top of the novel SCS-DGS eliminates the WLAN upper band. Vias are used to link the traces on a multilayer circuit board, which often cross at least one ground plane and provide capacitance to a transmission line circuit that is most noticeable at high frequencies [14]. The via is a hollow cylinder with lips which penetrates a ground plane via a circular opening. The microstrip transmission line trace is supported by and dwells on the surface of a dielectric slab, which in turn rests on the ground plane and



(a) (b)

Figure 8. Proposed radiator's (a) S_{11} magnitude plot and (b) VSWR plot for various radius (R) of via.

is connected to the cylinder by lips at its ends. In [15], the procedures for determining the capacitance of a via design are presented. From Figure 8(a), the notched bandwidth ranges from 4.90 to 5.29 GHz, 5.32 to 6.05 GHz, and 5.64 to 6.58 GHz when the via's radius is changed to 0.05, 0.15, and 0.25 mm, respectively. These values correspond to VSWR values of 4.01, 6.34, and 7.15 as depicted in Figure 8(b).

The suggested antenna's max gain is shown in Figure 9. As illustrated by Figure 9, gain drops to −3.25 dBi at 5.8 GHz which represents that the proposed antenna effectively eliminates the WLAN band. The antenna gain is steady in the specified UWB with a fluctuation of less than 2.38 dBi out of the stopband [16]. From Figure 10, the suggested radiator has a peak radiation efficiency of 92.15% at 9 GHz, well within the viable UWB frequency range.

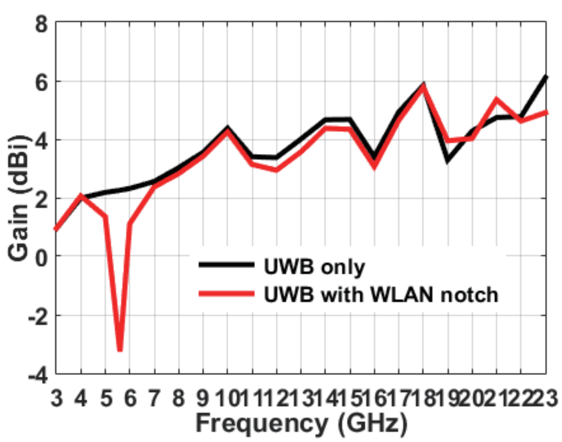


Figure 9. Measured peak gain.

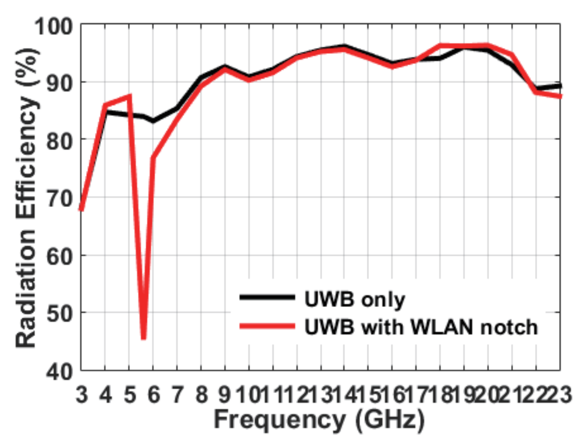


Figure 10. Radiation efficiency of the intended radiator.

Figures 11(a) and (b) show the simulated and calibrated radiation patterns in the y-z plane and x-z plane at 4.44 GHz and 14.4 GHz, respectively. The radiation patterns are similar to dipoles in the y-z plane and almost omnidirectional in the x-z plane [17] making the intended radiator satisfactory for UWB applications.

Figure 12 displays the surface current distributions for the suggested radiator, which helps to elucidate the manner in which the antenna operates. Figures 12(a), (c), and (d) show that for the resonant frequencies of 4.07, 10.26, and 13.57 GHz, respectively, the surface currents are equitably spread

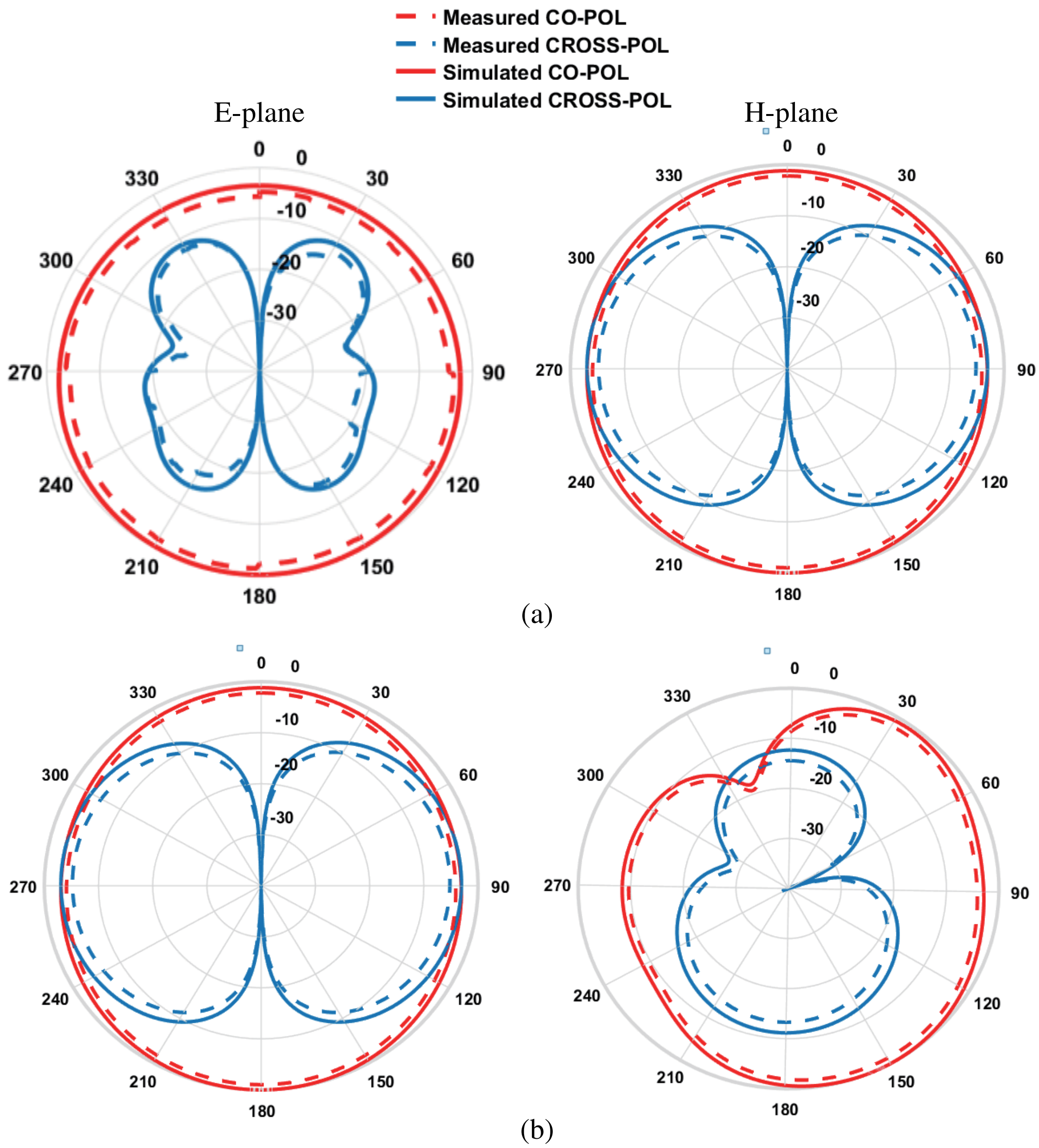
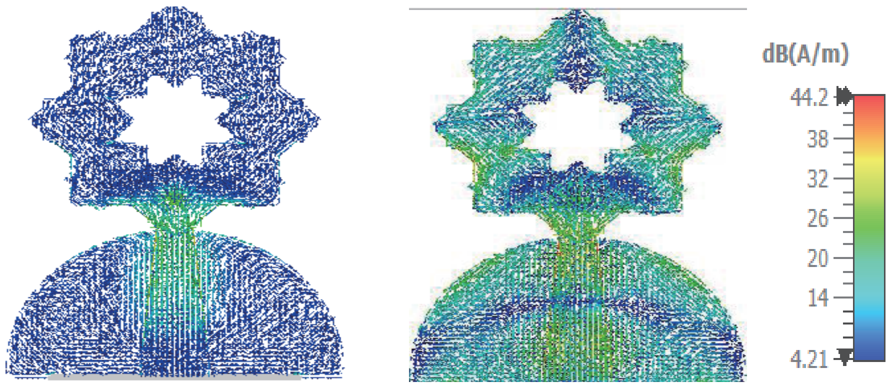


Figure 11. Radiation patterns of intended radiator. (a) 4.44 GHz. (b) 14.4 GHz.

(a) (b)



(c) (d)

Figure 12. Surface current distributions of intended radiator at resonant frequencies (a) 4.44 GHz (c) 6.29 GHz (d) 14.4 GHz and at notch frequency (b) 5.8 GHz.

across the whole surface of the proposed radiator. Figure 12(b) shows that at the notch frequency of 5.8 GHz, surface currents are heavily concentrated around the via element, as shown by the red areas, leading to a restriction on the total amount of radiation that may be emitted. As a result, the suggested antenna significantly mitigates the WLAN interference, making it an excellent choice for wireless UWB applications. Table 1 compares the intended radiator with other antennas that have been described in the literature.

Table 1. Comparison of antenna characteristics of the proposed antenna and those of similar antennas given in recent literature.

Ref.	**Size (mm^2)**	**Area**	**Bandwidth, GHz**	**Patch structure**	**Notch centre frequency, GHz**	**Gain fluctuation, dBi**	**Efficiency, %**	**Applications**
[18]	20.5 × 13.9	$(0.25\lambda_0 \times 0.17\lambda_0)$	3.6–19.08 (136)	Hexagonal	8	3	NR	UWB/X/Ku
[19]	26 × 27	$(0.19\lambda_0 \times 0.20\lambda_0)$	2.19–13.95	Fractal	5.5	5	80.5	UWB/X
[20]	13 × 22	$(0.13\lambda_0 \times 0.21\lambda_0)$	2.9–23.5	Rectangular	5.5	4.2	NR	UWB/X/Ku/ partial K band
[21]	16 × 25	$(0.17\lambda_0 \times 0.26\lambda_0)$	3.1-12.5	Rectangular	5.15	3	NR	UWB
[22]	26 × 16	$(0.27\lambda_0 \times 0.17\lambda_0)$	3.1–10.6	Rectangular	5.25	NR	NR	UWB
[23]	42.5 × 30	$(0.32\lambda_0 \times 0.27\lambda_0)$	3.25–13	Fractal	5.8	6.7	NR	UWB
[24]	24 × 30	$(0.24\lambda_0 \times 0.30\lambda_0)$	2.99–16.62	Fan	5.69	3.1	NR	UWB
Prop.	**16 × 22**	$\mathbf{(0.19\lambda_0 \times 026\lambda_0)}$	**3.63–21.94 (143%)**	**Lamp slotted**	**5.8**	**2.38**	**92.15**	**UWB/ X/Ku/ partial K band**

λ_0 — Wavelength at lower frequency, NR-Not Reported.

4. CONCLUSION

A novel lamp-shaped slotted patch with a tapered microstrip-fed monopole and a novel SCS-DGS UWB radiator integrated with Ku and partial K bands suitable for upper WLAN band notched applications is reported. The intended radiator covers a bandwidth of 3.63–21.94 GHz with $20\log_{10}S_{11} < -10\,\text{dB}$, and a via element is utilized to eliminate the electromagnetic interference with upper WLAN ranging from 5.31 to 6.05 GHz. The intended radiator has stable patterns, gain, and provides a peak radiation efficiency of 92.15%, making it appropriate for upper WLAN notched wireless UWB applications.

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