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ENHANCED ULTRA-WIDE BAND HEXAGONAL PATCH ANTENNA

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ABSTRACT

An enhanced hexagonal shaped planar antenna is presented for ultra-wideband (UWB) applications. In this paper, a hexagonal patch with six circular cuts at its vertices is designed on FR4-substrate with 50 Ω microstrip triangular tapered feed line and a bevelled partial ground plane with five half circular sleeves. The design is investigated using the high-frequency structure simulator (HFSS). The simulated and measured scattering parameter S_{11} (Reflection Coefficient) results show good impedance matching in the frequency range (3 - 27.57 GHz) satisfying return loss (RL = $|S_{11}|$) ≥ 10 dB with a percentage bandwidth (PBW) of 160.75%. High gain and efficiency, radiation pattern similar to the electric dipole in E-plane and good omnidirectionality in the H-plane are achieved.

KEYWORDS

Ultra-Wide Band (UWB), Reflection coefficient, Circular cuts, Sleeves, Bevel, Gain and bandwidth.

1. INTRODUCTION

The most important requirements in modern communication systems are to provide a wide frequency range with very low power consumption. The UWB wireless technology is launched in 2002 by the Federal Communication Commission (FCC) which authorizes the unlicensed use of the frequency band 3.1 to 10.6 GHz with PBW ($\text{PBW} = 100\% * \text{bandwidth}/\text{center frequency}$) of 91.33% and -41.3 dBm/MHz maximally allowed radiated power [1]. Nowadays, the new wireless communication systems in military and civilian applications are searching for an enhanced wideband that covers both the short and long frequency ranges.

Different techniques have been proposed by different researchers to enhance the antenna bandwidth with a low profile and compact size. Rectangular patch with one round cut in its four corners with one ground groove that has a shape composed of triangle and rectangle to get 8.28 GHz bandwidth (3.42 - 11.7 GHz) with a PBW equal to 109.52% is presented in [2]. Three ground plane modifications consisting of two rectangular sleeves, two rectangular slots and one rectangular groove are introduced in [3] to achieve a bandwidth of 19 GHz (3.4 - 22.4 GHz) with a PBW equal to 147.29%. Two trapezoidal patches are etched on both sides of the substrate with a microstrip feed line to increase the PBW to 114.28% [4]. Adding three steps in the lower patch corners of rectangular shape patch and using microstrip feed line are proposed in [5] to increase the bandwidth to (2.33 - 12.4 GHz) with a PBW equal to 136.73%. Adding a rectangular slit and attaching L- and T- shaped stubs on the radiating circular patch with an offset feed achieve a PBW of 127.87% (3.08 to over 14 GHz) [6]. Cutting a bevel in the rectangular patch and etching two rounded inverted L-shaped slots with an open end in the square ground plane achieve a PBW of 129.18% (2.7 - 12.55 GHz) [7]. A triangular patch with one rectangular slot and two slits fed by coplanar feed line with the defected ground are used to increase the PBW to 112.5% (2.8 - 10 GHz) [8].

Hexagonal patch antennas are studied by different researchers and achieve good PBW. Folded hexagon UWB patch antenna with an offset feed at one of its vertices achieves a PBW of 144.33% (2.796 - 17.296 GHz) [9]. Hexagonal patch antenna with two symmetrical slots is etched at the center of the patch with a microstrip feed line to achieve a PBW of 109.09% (2 - 6.8 GHz) [10]. A spanner shape hexagonal patch antenna is designed by defecting the patch with a rectangular shape slot to achieve a PBW of 118.79% (2.95 - 11.58 GHz) [11]. A coplanar waveguide (CPW)-fed hexagonal patch antenna

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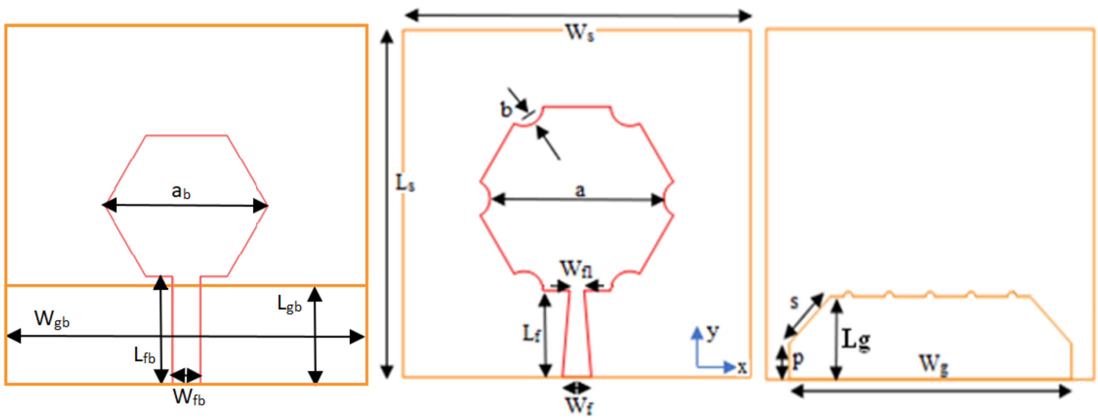
with six small hexagonal elements (fractal elements) is added to its corners to achieve a PBW of 93.33% (4 - 11 GHz) [12]. Different configurations of hexagonal shape patch antennas are introduced in [13] with defected ground planes to reduce the antenna size without affecting the bandwidth. One is composed of the hexagonal patch with L-shape and bevel slots and four rectangular slots in the ground plane to achieve a PBW of 120.43% (2.98 - 12 GHz). While the other consists of the hexagonal patch with one horizontal rectangular slot and bevel slots, one circular slot on the feed line and four rectangular slots in the ground plane to achieve a PBW of 135.2% (2.9 - 15 GHz). A new hexagonal patch antenna is proposed in [14] which consists of small five trapezoidal elements which are added to the center of the patch edges, small six hexagonal slots on each of its corners and another hexagonal slot added at the patch center to achieve a PBW of 126.06% (3.1 - 13.67 GHz). Two hexagonal patch antennas are proposed in [15], one of them achieves the UWB with PBW of 129.55% (3.1 - 14.5 GHz) by etching a rectangular groove and cross slot in the ground plane. The other is designed for the super-wideband antenna (SWB) to achieve a PBW of 154.61% (3.2 - 25 GHz) by adding a deep groove that divides the ground plane into two strips laid symmetrically around the feed and triangular slots at the upper corners of the ground plane.

In this paper, a new enhanced hexagonal UWB microstrip antenna design is proposed and investigated. The antenna shape and dimensions are outlined in Section 2. The proposed antenna consists of a triangular tapered microstrip feed line, a hexagonal radiation patch with six circular cuts at the patch vertices and a bevelled partial ground plane with five half circular sleeves. The simulation results and discussions are presented in Section 3. The experimental verifications are outlined in Section 4. Finally, the conclusion is given in Section 5.

2. Antenna Structure

The proposed antenna with the geometrical parameters is shown in Figure 1, where all dimensions are obtained carefully by parametric analysis (explained in Section 3) in order to achieve the desired bandwidth over the needed frequency range. The antenna dimensions (in mm) are: the substrate is FR4 - epoxy with a thickness h = 1.6, tanδ = 0.02, $\varepsilon_r = 4.4$, width $W_S = 36$ and length $L_S = 36$. A triangular tapered feed line is designed using the equations given in [16] and the length of the triangular tapered feed line is chosen approximately equal to the guided wavelength with $L_f = 9$, $W_f = 3$ and $W_{f1} = 1.5$. The distance between the hexagonal patch and the circular cut edges at the patch middle is a = 18 and six circular cuts at the vertices with a radius b = 2. The partial ground plane length $L_g = 8$ and width $W_g = 31$. The ground bevel has a length s = 7 and is located at a distance p = 3.5 from the lower substrate edge. In order to enhance the design, five half circular sleeves are attached to the ground plane in the bottom layer with a radius $r_s = 0.5$.



(a) (b) (c)

Figure 1. The hexagonal antenna structure; (a) the basic model, (b) the proposed antenna top layer and (c) the proposed antenna bottom layer.

3. Discussion and Parametric Study

The design started with the basic model which consists of a simple hexagonal patch fed by a rectangular microstrip feed line with a partial ground plane as shown in Figure 1.

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(a) (where $L_{gb} = 11$ mm, $W_{gb} = 40$ mm, $L_{fb} = 12$ mm, $W_{fb} = 3$ mm and $a_b = 18$ mm). The achieved PBW for this design is very low with bad impedance matching. The enhancement of the bandwidth is achieved using different means, including changing the length and width of the ground plane, adding sleeves to the partial ground plane, changing the length of the tilted ground plane edge, adding patch circular cuts and adjusting the microstrip feed line shape. The effect of each parameter on the bandwidth (with the scattering parameter $S_{11} \leq$ *- 10 dB)* was performed and optimized to reach the final design. The parametric results in the paper are generated from the final design by varying one parameter at a time and keeping all other parameters constant as listed in Section 2 to show the effect of each parameter alone. The bandwidth enhancement process is as follows:

3.1 Ground Plane Modifications

The ground plane dimensions are important parameters in the design of the UWB antennas since the bandwidth depends strongly on them [17]. The simulation results for the scattering parameters S_{11} using HFSS simulator for L_g equal to 7, 8 and 9 mm are shown in Figure 2. High values of L_g cause narrowband with a lot of rejection bands, while decreasing L_g leads to high bandwidth with lower starting operating frequency. Choosing L_g = 8 mm achieves higher bandwidth, but it still needs to adjust the impedance matching over the different frequency ranges.

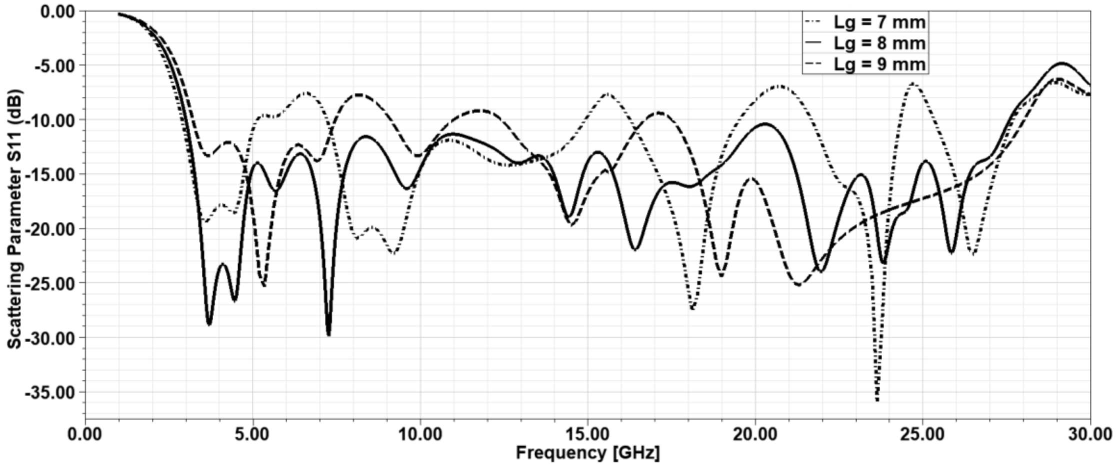


Figure 2. The reflection coefficient when varying the ground length (L_g).

A parametric study is also conducted on the ground plane width (W_g) between (29 - 33) mm, where better impedance matching is achieved with lower starting operating frequency when W_g = 31 mm. The presence of sleeves in the ground plane increases the inductive part of the input impedance and generates additional resonant mode to improve the overall bandwidth [3, 18]. Parametric analysis is performed on the half circular sleeves' parameters to investigate their influence on the antenna performance. The sleeve parameters are the sleeve numbers (N) and their radii (r_s), where r_s is varied between (0 - 1) mm, while N is between (3 - 7). The simulated reflection coefficient for the sleeve number (N) variation shows that using N = 5 achieves lower starting operating point, wider bandwidth and better impedance matching. The reflection coefficient for the sleeve radius variations is shown in Figure 3, where it can be noticed that varying r_s will affect mainly the impedance matching and consequently the covered bandwidth. The optimum value to use for the proposed antenna is r_s = 0.5 mm and N = 5.

Bevelling the ground top corners with symmetrical tilted cuts generate more resonant frequencies and adjust the input impedance imaginary part which leads to wider impedance bandwidth [19]-[20]. Parametric analysis is conducted on the ground cut length (s) between (5 - 9) mm, where the optimum value for s is 7 mm, since below and beyond this value, the impedance matching degrades at different frequency bands.

3.2 Using Triangular Tapered Feed Line

The use of a triangular tapered feed line will enhance the matching between the feeding point and the hexagonal patch to smooth the current path and reduce the incident wave reflection, which achieves wider bandwidth [16]. The reflection coefficient comparison when using rectangular and triangular tapered feed lines and by keeping all dimensions as in Section 2 is shown in Figure 4. It can be observed that higher bandwidth and better impedance matching are obtained when using a triangular tapered feed line.

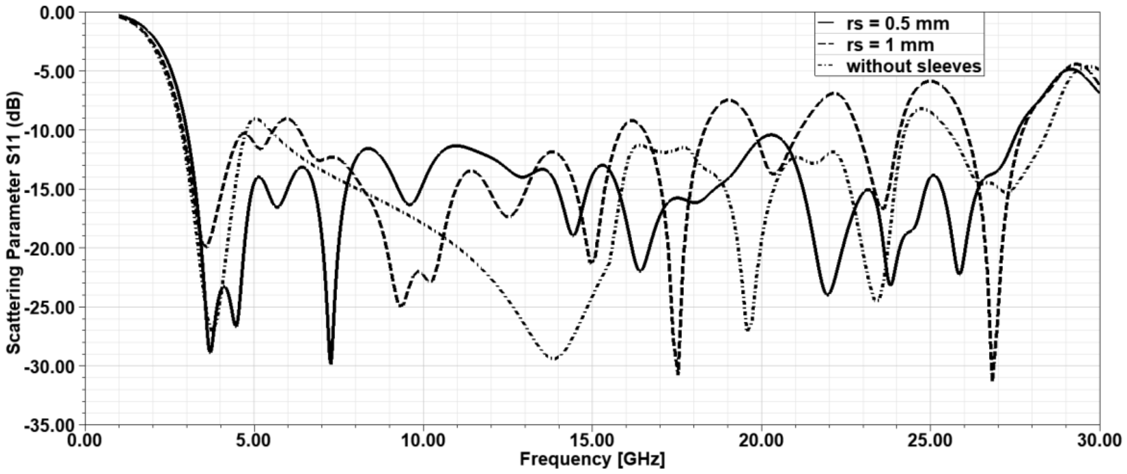


Figure 3. The reflection coefficient when varying the sleeves radius (r_s) using five sleeves.

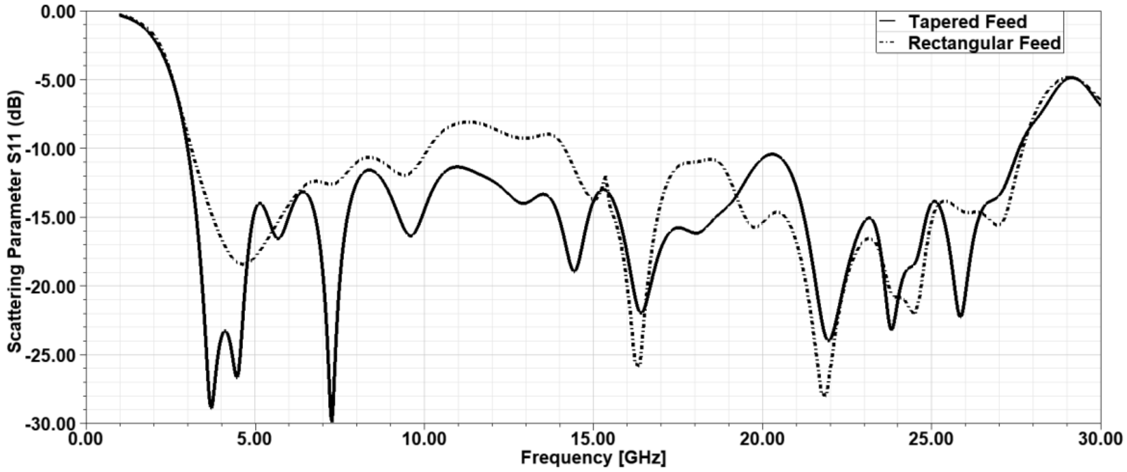


Figure 4. The reflection coefficient to compare between the rectangular and triangular tapered feed lines.

3.3 Incorporating Symmetrical Circular Cuts at the Hexagonal Patch Vertices

Adding cuts in the hexagonal patch leads to perturb the surface current path length which will generate more than one resonant frequency and increase the bandwidth. Parametric analysis is conducted to examine the effect of the circular cuts' parameters on the bandwidth. The important parameters to study are the number of the circular cuts (M) and their radius (b), where M is varied between (0 - 6) and b between (1 - 3) mm. The location of the cuts is varied such as for M = 2 the cuts are on the middle corners and for M = 4 the cuts are in the upper and the lower corners, while for M = 6 the cuts are on every corner. The simulated results for varying the cuts' number M are shown in Figure 5, which confirms that increasing the number of cuts will enhance the impedance matching and the covered bandwidth. The simulated reflection coefficient for radius variation is shown in Figure 6. Varying the cut radius b, the lower operating frequency changes, because the current path on the patch is perturbed. The main noticeable effect of the patch cuts' radius b is at the impedance matching. It is concluded that the optimum value for M=6 and for b = 2 mm. The proposed antenna reflection coefficient *versus* frequency using HFSS software tool before and after all modifications is compared in Figure 7. The achieved bandwidth when RL ≥ 10 dB ranges from 3 till 27.57 GHz with a PBW equal to 160.75% with better impedance matching.

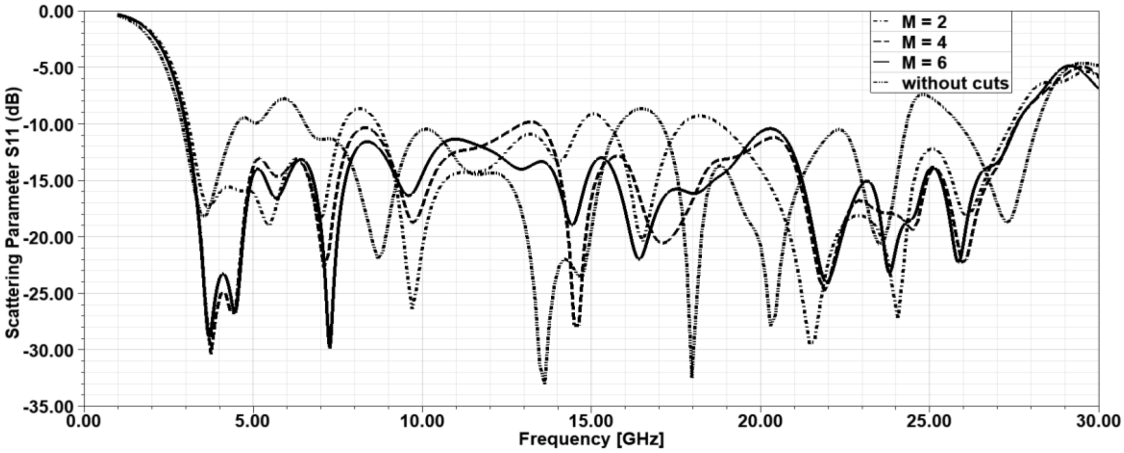


Figure 5. The reflection coefficient when varying the patch circular cut number (M).

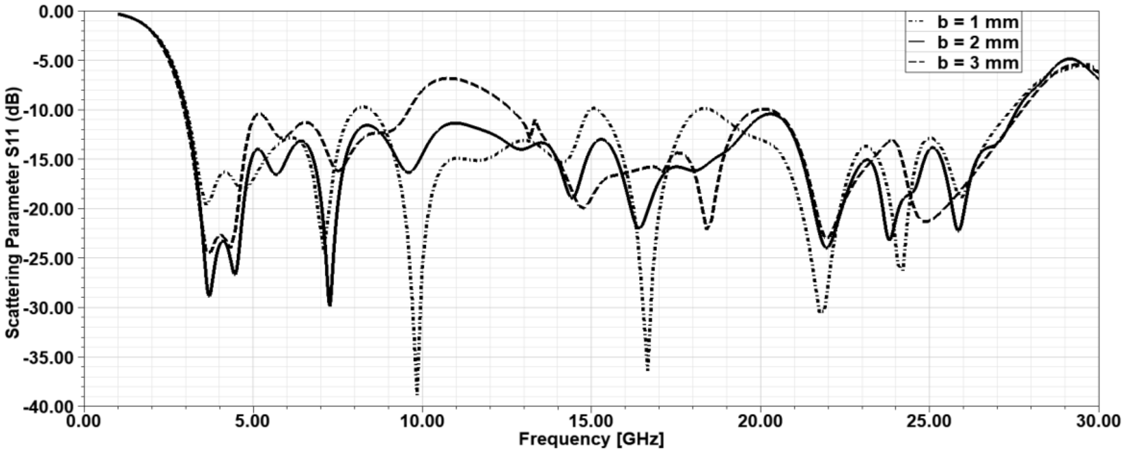


Figure 6. The reflection coefficient when varying the circular patch cut radius (b).

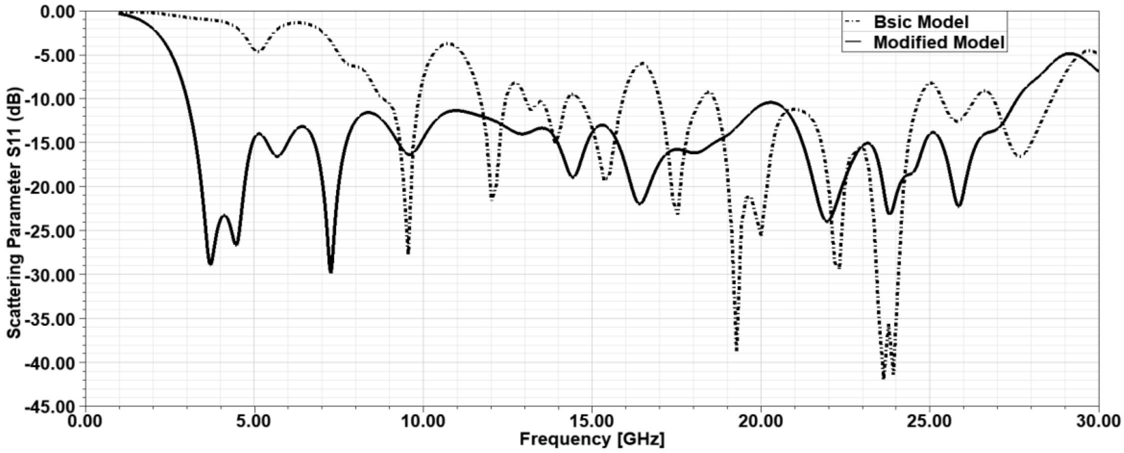


Figure 7. The simulated reflection coefficient for the antenna before and after modifications.

The simulated radiation patterns for the E and H planes at various frequencies 4, 6, 15 and 20 GHz are shown in Figure 8, where the E and H planes are the yz- plane ($\varphi = 90^\circ$ and $0^\circ < \theta < 180^\circ$) and the xz-plane ($\varphi = 0^\circ$ and $0^\circ < \theta < 180^\circ$), respectively. In the E-plane, the antenna exhibits a dipole shape at low-frequency range, but because of the existence of higher-order modes, the number of lobes rises with the increase of frequency. The H-plane shows good omnidirectionality at low-frequency range and becomes less omnidirectional with an increase in frequency. Figure 9 shows the simulated peak realized gain, where the gain has a low value at the start of the desired band and increases as a function of the frequency band and ranges between 5 and greater than 7 dB. The radiation efficiency for the proposed antenna is shown in Figure 10, where it starts at98% and ends with 80%.

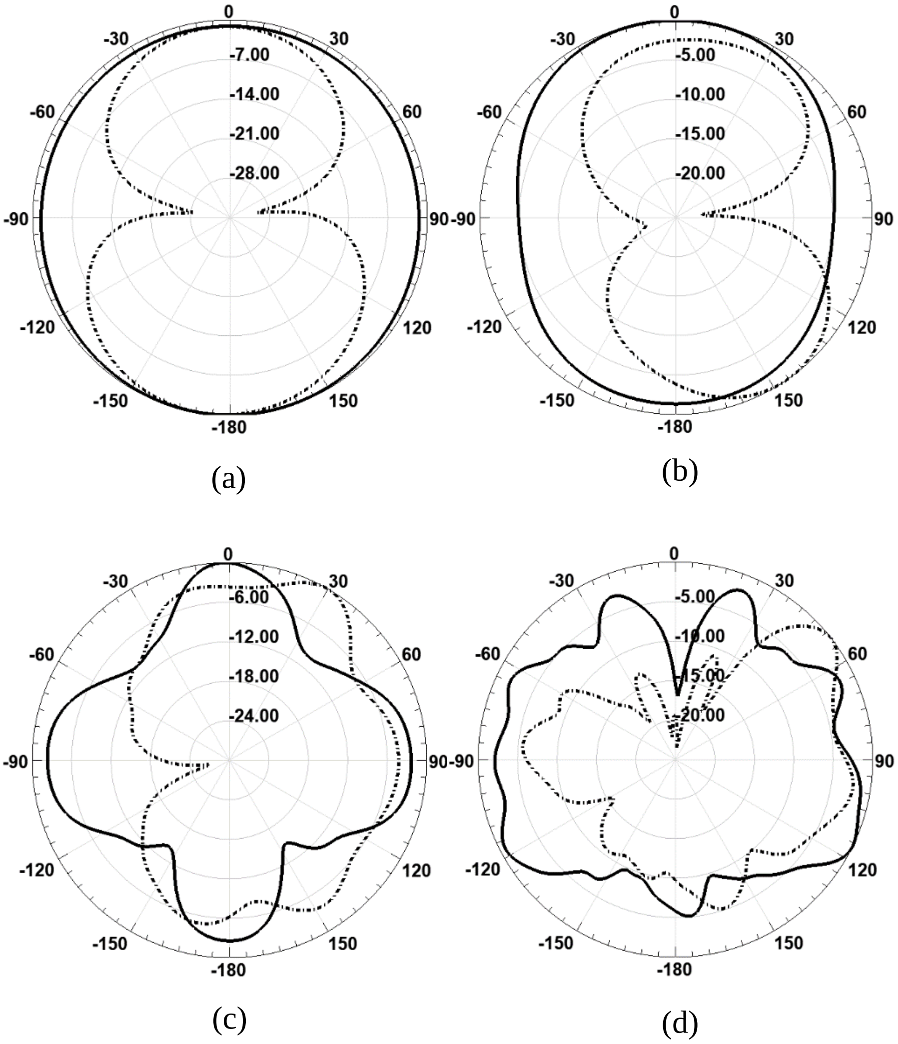


Figure 8. The radiation patterns at:(a) 4 GHz, (b) 6 GHz, (c) 15 GHz and(d) 20 GHz (E--- &H __).

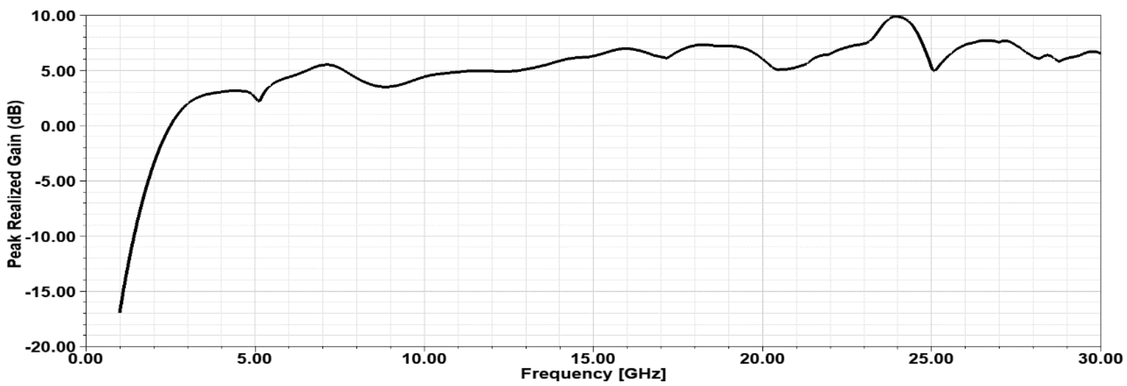


Figure 9. The proposed antenna peak realized gain.

Comparison between different published works and the proposed antenna are shown in Table 1. The proposed antenna achieves a wide impedance bandwidth with simple design compared to other works in [9]-[15]. Although the proposed antenna has a larger substrate area than those in [9], [12]-[13] and [15], the achieved impedance bandwidth is larger.

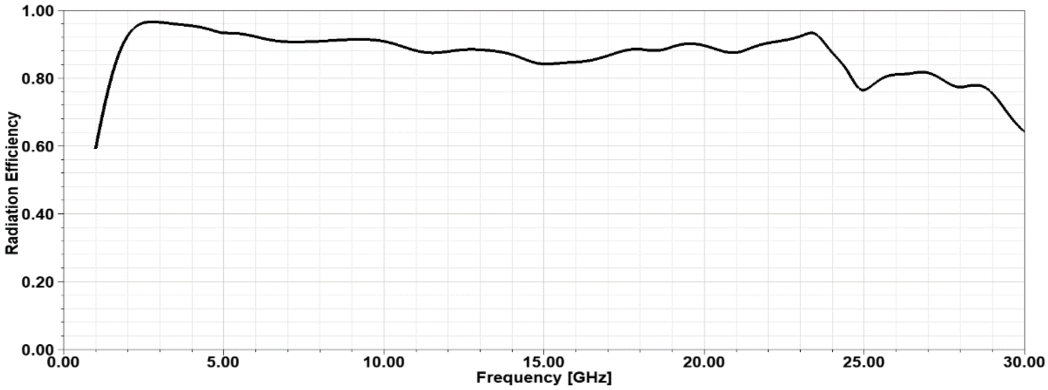


Figure 10. The proposed antenna radiation efficiency.

Table 1. Comparison between the proposed antenna and antennas presented in other published works.

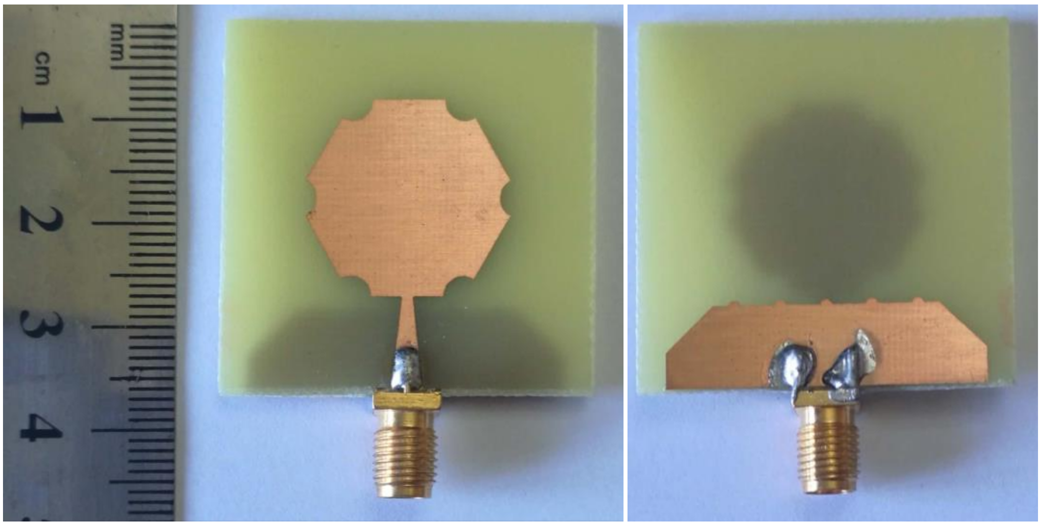
Reference / Parameter	Antenna substrate area (mm^2)	Impedance bandwidth (GHz)	Percentage Bandwidth (PB)
[9]	27 x 24	2.8 - 17.3	144.33 %
[10]	54 x 49	2 - 6.8	109.09%
[11]	31 x 52	2.95 - 11.58	118.79%
[12]	25 x 25	4 - 11	93.33%
[13]	13 x 46.5	2.9 - 15	135.2%
[14]	39 x 36.5	3.1 - 13.67	126.06%
[15]	35.5 x 30.35	(UWB) 3.1 – 14.5 (SWB) 3.2 - 25	(UWB) 129.55% (SWB) 154.61%
Proposed Antenna	**36 x 36**	**3 - 27.57**	**160.57**%

4. EXPERIMENTAL VERIFICATION

The designed antenna is fabricated on an FR4 substrate with a dielectric constant ε_r = 4.4 and a height h = 1.6 mm as shown in Figure 11. The facilities at King Abdullah Design and Development Bureau (KADDB) were utilized to test the fabricated antenna. The reflection coefficient is measured using Agilent N5242A vector network analyzer. The simulated and measured reflection coefficient results for the proposed antenna are shown in Figure 12 and they compare favourably. The difference between the measured and the simulated results are due to different factors which are not considered through the simulation process, such as the accuracy and precision of fabrication techniques used, the SMA connector welding and its effect in the frequency range beyond 18 GHz, as well as the non-homogeneous behaviour of the FR4 substrate with frequency variations.

5. CONCLUSION

A new planar enhanced UWB antenna is designed for UWB applications. The proposed antenna consists of a hexagonal radiation patch with six circular cuts at its vertices, a triangular tapered microstrip feed line and a bevelled partial ground plane with the addition of five half circular sleeves. The design is investigated using electromagnetic simulators HFSS. The simulation results show good impedance matching over (3 - 27.57) GHz for a return loss (RL) ≥ 10 dB. Results of the measurements and simulation compare favourably. Higher gain and efficiency, as well as dipole shape radiation patterns in the E-plane and omni directionality in the H-plane, are obtained.



(a) (b)

Figure 11. The fabricated proposed antenna: (a) patch antenna and (b) ground plane.

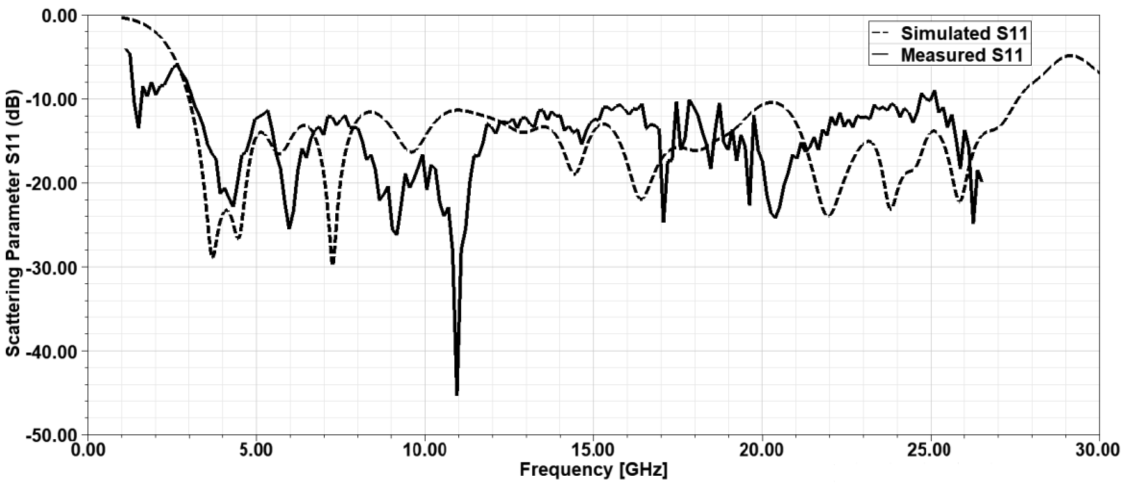


Figure 12. The simulated and measured reflection coefficient curves for the proposed antenna.

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ملخص البحث:

في هذه الورقة ، يُقدم هوائي مسطح محسن سداسي الشكل من أجل تطبيقات النطاق الترددي فائق العلوّ. تم تصميم رقعة سداسية بسِتّ قنوات دائرية عند رؤوسها على مادة أساس من نوع FR4، مع خط تغذية مثلث مستدقّ على شكل شريط صغير مقاومته 50 أوم، ومع سطح أرضي مستوٍ مشطوف جزئياً يحتوي على خمسة أكمام نصف دائرية. وقد تم استقصاء التصميم المقترح باستخدام مُحاكٍ بنيوي للترددات العالية؛ إذ أظهرت النتائج المتعلقة بالمحاكاة والقياس فيما يخصّ معامل التشتت S11 (معامل الانعكاس) مواءمة جيدة للمانعة في النطاق الترددي 3-27.57 جيجاهيرتز، محققة فقد رجوع يساوي أو يزيد على 10 ديسيبل مع نطاق ترددي نسبته 160.75%. وقد تحقق كسب عالٍ وفعالية عالية، إضافة الى نمط إشعاع مماثل لنمط إشعاع هوائي ثنائي الأقطاب في المستوى E، مع إشعاع في جميع الاتجاهات في المستوى H.