

ENHANCED UWB PRINTED MONOPOLE ANTENNA BASED ON GROUND PLANE MODIFICATIONS

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ABSTRACT

In this paper, a UWB antenna with an enhanced bandwidth is proposed. The enhanced ultra wide band (UWB) antenna consists of a rectangular patch fed by a 50 Ω microstrip feed line and partial ground plane. The bandwidth enhancement is achieved by making three modifications on the partial ground plane; adding two rectangular sleeves, adding one rectangular groove and adding two rectangular slots. The characteristics of this antenna are investigated using high frequency structure simulator (HFSS). The proposed design achieves large bandwidth at return loss $RL \geq 10$ dB of (3.4 - 22.4) GHz (147.29%). Promising peak gain with good impedance matching and omni-directional radiation pattern are obtained.

KEYWORDS

Ultra Wide Band (UWB), Sleeves, Grooves, Slots, Reflection Coefficient, Gain, Bandwidth.

1. INTRODUCTION

Printed circuit antennas are becoming more and more under consideration with a great number of research papers, reports and books to deal with this type of antennas. The rapid growth in the wireless communication systems creates demands for wideband antenna, which should have high gain and large bandwidth covering all frequency ranges used in these systems. In 2002, the Federal Communication Commission (FCC) approved the first report for UWB technology to be operating in the frequency range (3.1 - 10.6) GHz with maximum radiated power of -41.3 dBm/MHz [1]. These UWB patch antennas are designed with different geometries; i.e., triangular [2], circular disc [3] and rectangular [4]. Several methods are used to enhance the antenna bandwidths; in [5] the bandwidth enhancement is achieved by making modifications to the patch and the partial ground plane. Circular shaped slots and a ring are inserted into the patch while diagonal cuts at the top corners of the partial ground plane with two rectangular slots making the bandwidth (2.75 – 20) GHz (151.6%). In [6], modifying the ground plane is achieved with diagonal edges, rectangular slot and T-shape cut added to get -10 dB bandwidth of (2.957 – 11.89) GHz (120.27%). In [7], modifying the rectangular patch is achieved with three steps, single slot besides adding slots to the ground plane to enhance the bandwidth of (6 – 12) GHz (33.3%). In [8], three types of slotted antenna are presented to enhance the bandwidth; T- slotted for patch and feed line, couple a ring and L slots and dual symmetry L slots. In [9], the ground plane is truncated and the patch has round junction and two chamfers to get a bandwidth of (1.79 – 28.02) GHz (175.98%).

Other means are used including the utilization of feeding structure of a trident-shaped strip and a tapered impedance transformer to provide an antenna with a bandwidth of (2.75 – 16.2) GHz (141.95%) [10]. Three round ground grooves are used in [11] to get percentage bandwidth of (2.87 – 50) GHz (178.29%). One round cut in each corner of the patch antenna and one ground groove are used in [12] to get a bandwidth of (3.42 – 11.7) GHz (109.52%). Making triangular shape slots on the top of the partial ground plane in [13] increases the UWB antenna bandwidth to (2.95 – 15.45) GHz 135.87%. Adding a rectangular slot at the top edge of the partial ground plane for a circular patch UWB antenna [14] increases the bandwidth to reach (3.3 – 20) GHz 193%. One may think about increasing the substrate height, but this produces surface wave, which will reduce the antenna efficiency.

In this paper, we introduce a simple design with small size to get a large bandwidth for UWB applica-

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tions. The antenna consists of a microstrip feed line with rectangular patch and a modified partial ground plane as investigated in Section 2. Simulation results, using the HFSS, and discussion are presented in Section 3. Experimental verifications are outlined in Section 4 and finally, the conclusions and references are presented.

2. ANTENNA DESIGN

The antenna parameters for the proposed design are shown in Figure 1. All parameters are optimized to achieve best performance. The antenna dimensions (all lengths in mm) are as follows: the substrate is FR4-epoxy with thickness $h = 1.6$, $\tan(\delta) = 0.02$, $\epsilon_r = 4.4$, width $W_s = 30$ and length $L_s = 40$. The patch length $L_p = 14$ and width $W_p = 15$. The partial ground plane length $L_g = 13$, width $W_g = W_s = 30$. The two ground sleeves length $h_1 = 1.15$, width $W_1 = 1.25$ and are located at $y_1 = 11$ from the antenna edge. The ground groove length $h_2 = 2$, width $W_2 = 1.5$. The two ground slots are located at $y_2 = 7$ from the edge and have width $W_3 = 1.5$ and length $h_3 = 7$. The microstrip feed line is designed for 50Ω impedance with width $W_f = 3.4$ and length $L_f = 14$.

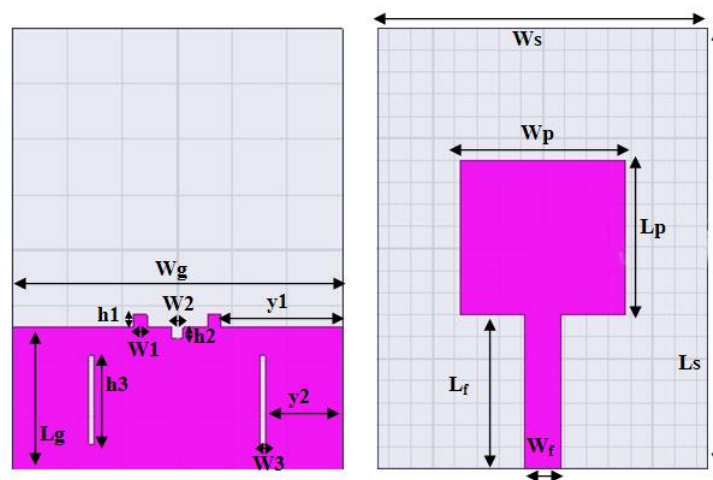


Figure 1. Antenna structure.

The antenna dimensions are obtained through parametric analysis and optimization process in order to achieve stable radiation characteristics over the frequency range of interest. Parametric studies are carried out on groove numbers and dimensions, the ground sleeves and the ground slots dimensions. In simulation, only one antenna parameter was varied each time while others were kept constant.

3. RESULTS AND DISCUSSION

The proposed design started with a simple rectangular patch, microstrip feed line and simple partial ground plane. The simulation of scattering parameter (reflection coefficient) S_{11} (Return Loss (RL) = $-S_{11}$) versus frequency, at $S_{11} \leq -10$ dB, conducted using HFSS software tool, shows low covered bandwidth (3.36 - 9.64) GHz, such that the fractional (percentage) bandwidth is 96.6%. The antenna impedance matching and the covered bandwidth are enhanced by introducing three modifications in the simple antenna ground plane.

The ground modifications were added through three parts:

- 1) Adding sleeves as ground plane extension: these behave as an additional inductive element that generates additional resonant mode, which is used for either dual or multiband operations, or it is combined with the fundamental mode to improve the overall bandwidth [15]. Parametric analysis is carried out on the sleeves dimensions (width, length and location), number and shape. The variation of S_{11} versus frequency when using the ground sleeves is shown in Figure 2. Adding one or three ground sleeves degrades the overall impedance matching and subsequently the covered bandwidth compared to adding two sleeves. Sleeves width W_1 is varied in the range (1.25 - 2.25) mm, as shown in Figure 3, where it can be observed that best performance is obtained when the sleeve width $W_1 = 1.25$ mm. The sleeves length h_1 variation is also studied and varied in the range (1 - 1.3) mm, as shown in Figure 4. It

is found that the resonant frequency values are highly dependent on sleeves length, choosing $h_1 = 1.15$ mm for best impedance matching over the entire covered frequency band. The sleeves location variation from the antenna edge y_1 has a high effect on S_{11} versus frequency as shown in Figure 5, where moving the sleeves towards the antenna edge makes the impedance matching better and yields respectively large bandwidth.

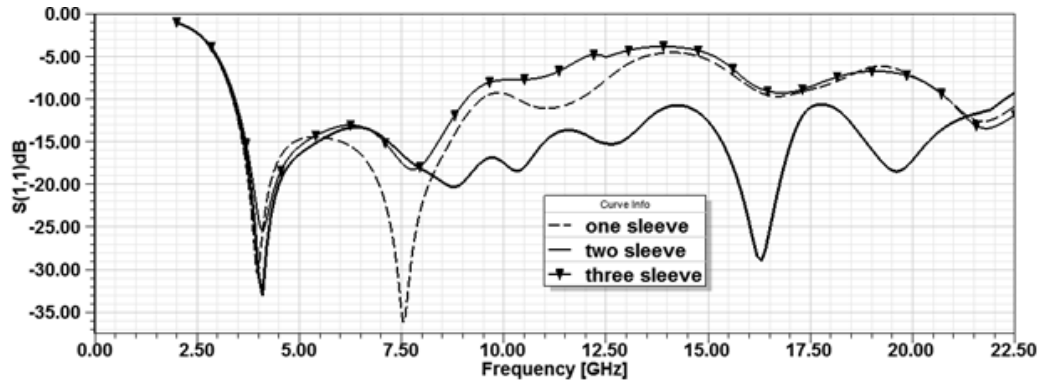


Figure 2. The scattering parameter S_{11} when varying the sleeves number.

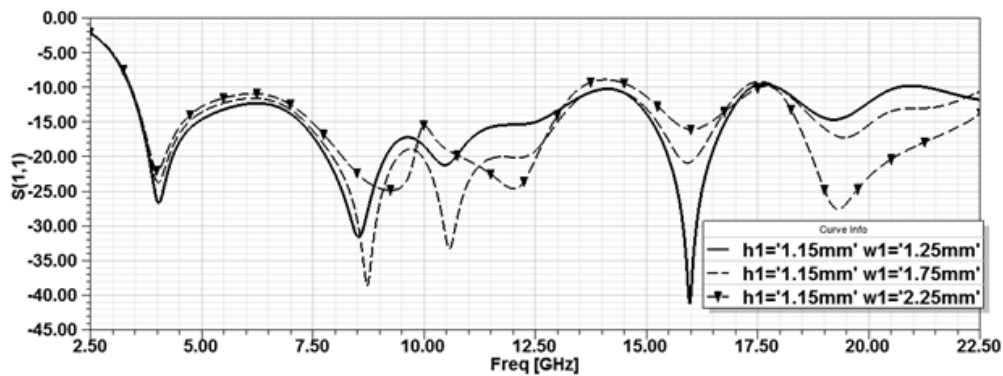


Figure 3. The scattering parameter S_{11} when varying the sleeves width (W_1).

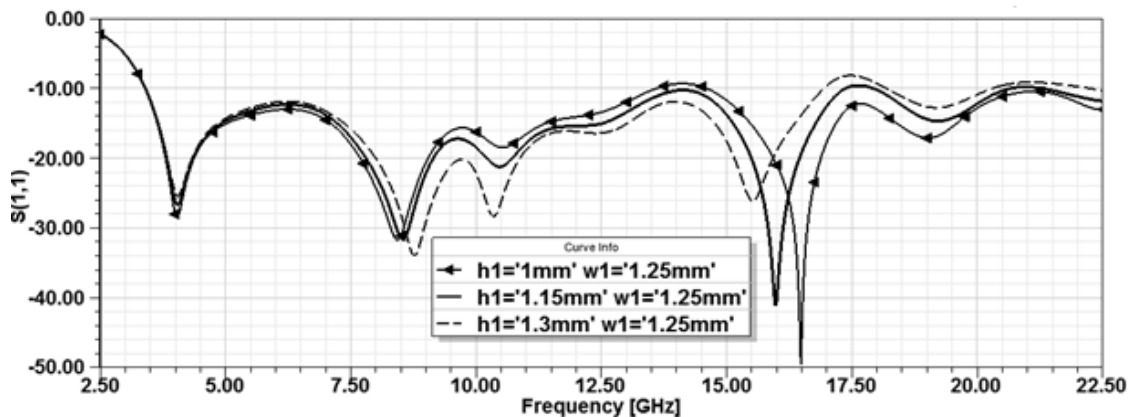


Figure 4. The scattering parameter S_{11} when varying the sleeves length (h_1).

The sleeves shape variation is also studied using different shapes; rectangular, circular and triangular, as shown in Figure 6. Changing the sleeves shape has a high effect on the second resonance frequency values and the impedance matching over the frequency band of interest, such that the best result is obtained when using rectangular shape.

2) Inserting one rectangular groove in the middle of the ground plane. This groove is for adjusting the input impedance imaginary part to get nearly pure resistive impedance [16]. A parametric study is carried out on the groove length and width. The variation of groove length h_2 and width W_2 in the range

(1 – 2) mm and (0.5 – 1.5) mm, respectively, shows approximately minor effects on the impedance matching.

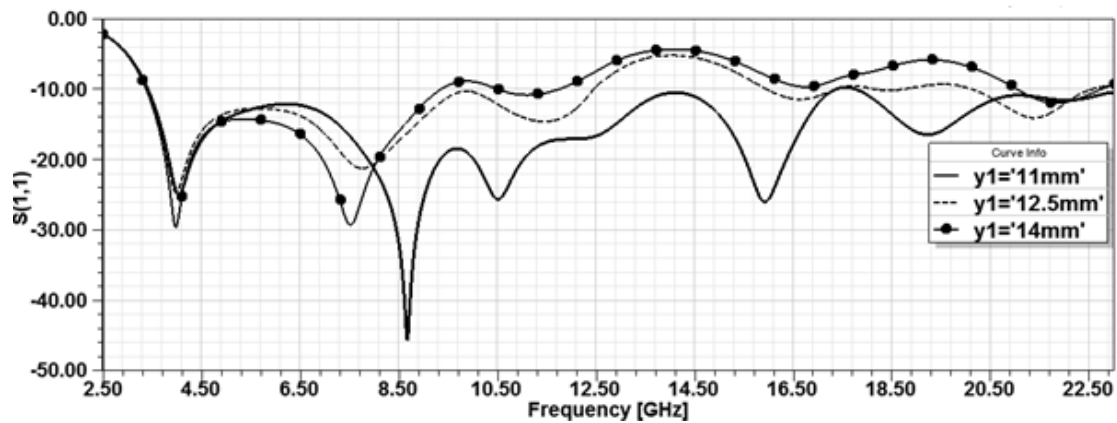


Figure 5. The scattering parameter S11 when varying the sleeves distance (y_1).

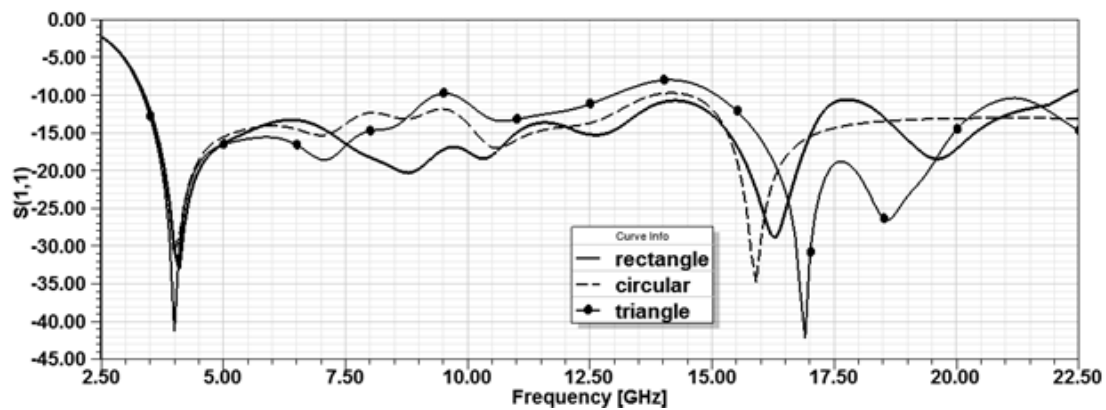


Figure 6. The scattering parameter S11 when varying the sleeves shape.

3) Adding two identical rectangular slots: this technique is used in order to get rid of or moderate the surface current reflection, thus adjusting the antenna impedance and reducing the return loss [17]. Parametric analysis is carried out on its length, width and location. The rectangular slot length h_3 is varied between (5 – 7) mm as shown in Figure 7, where lengthening the slots enhances the impedance matching. The rectangular slot width W_3 variation is also studied between (1.5 – 2.5) mm and no noticeable effect on the impedance matching is shown in Figure 7.

The effect of changing the rectangular slot location y_2 from the antenna edge, (6 – 8) mm, is shown in Figure 8. Return loss curves show minor variations on the impedance matching for the frequency range of interest. Moving the slots either away or closer to the antenna edge makes the impedance matching worse at the lower frequency range and decreases the covered bandwidth in the high frequency range. Better results are achieved when $y_2 = 7$ mm.

The proposed antenna is simulated using HFSS software tool. Comparison between the proposed and simple basic antennas is shown in Figure 9. The bandwidth at $S_{11} \leq -10$ dB starts at 3.4 GHz, while it ends at 22.4GHz, which indicates large useful bandwidth with percentage bandwidth of 147.28%.

The simulated peak gain within the operating band is shown in Figure 10, where it ranges between (2.5 – 6.5) dB within (3.4 – 22.4) GHz. The gain demonstrates moderate values in the low frequency range and increases in the high frequency range.

Radiation patterns for the E-plane and H-plane at different frequencies of 4, 6, 12 and 16 GHz are shown in Figure 11. The radiation pattern plots demonstrate that the antenna actually radiates over the frequency band of interest. The antenna exhibits a dipole-like shape in the E-plane in the low frequency range, while the number of lobes rises with the increase in frequency because of the existence of higher order

modes. The H-plane shows good omni-directional behavior in the low frequency range, while it becomes less omni-directional with an increase in frequency.

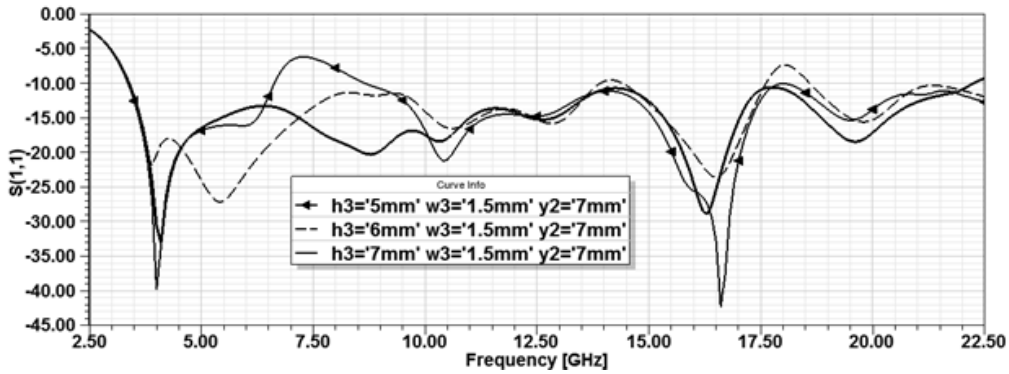


Figure 7. The scattering parameter S11 when varying the slot length (h3).

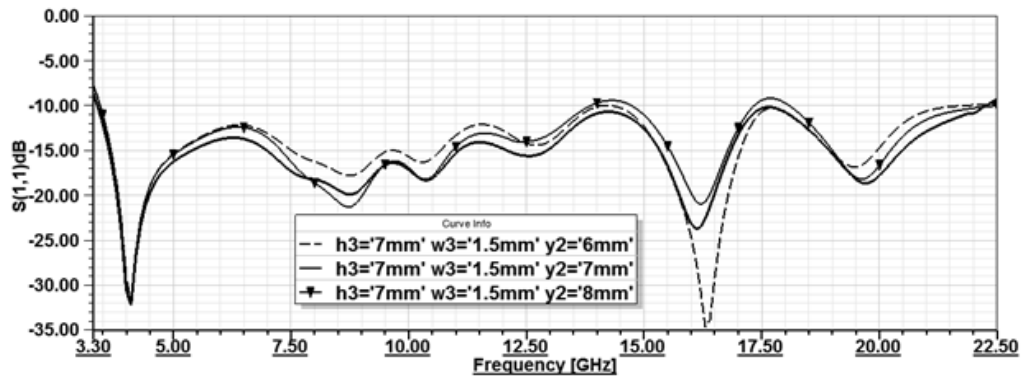


Figure 8. The scattering parameter S11 when varying the slot location (y2).

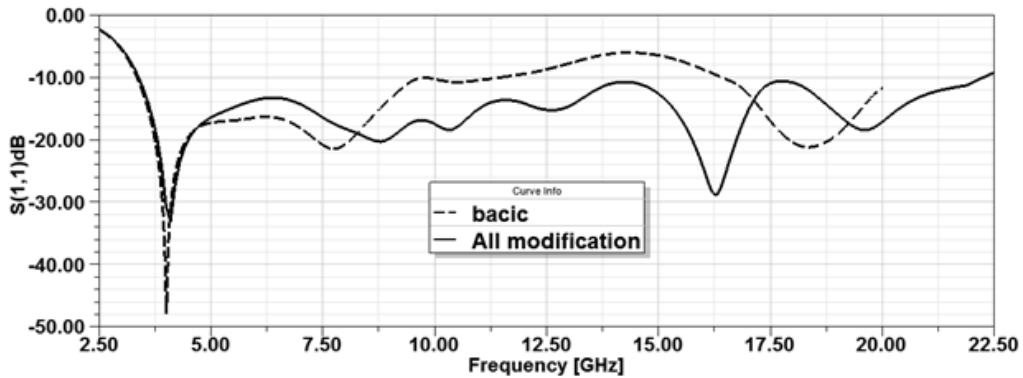


Figure 9. The scattering parameter S11 variation versus frequency.

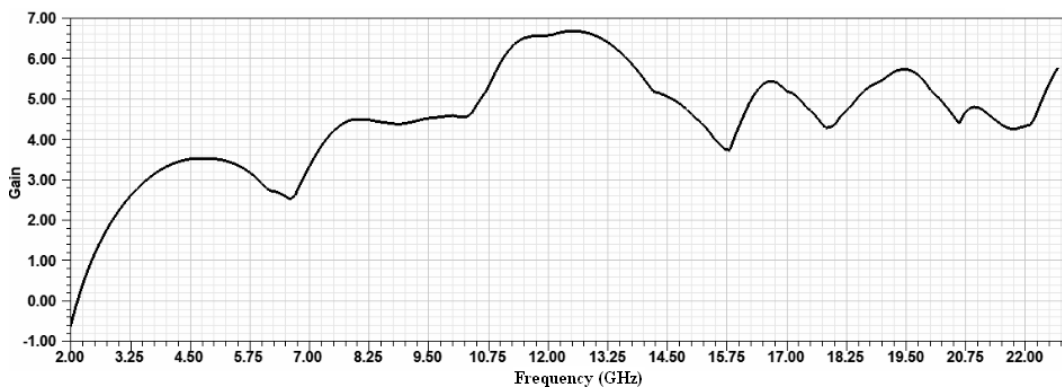


Figure 10. The simulated peak gain (dB).

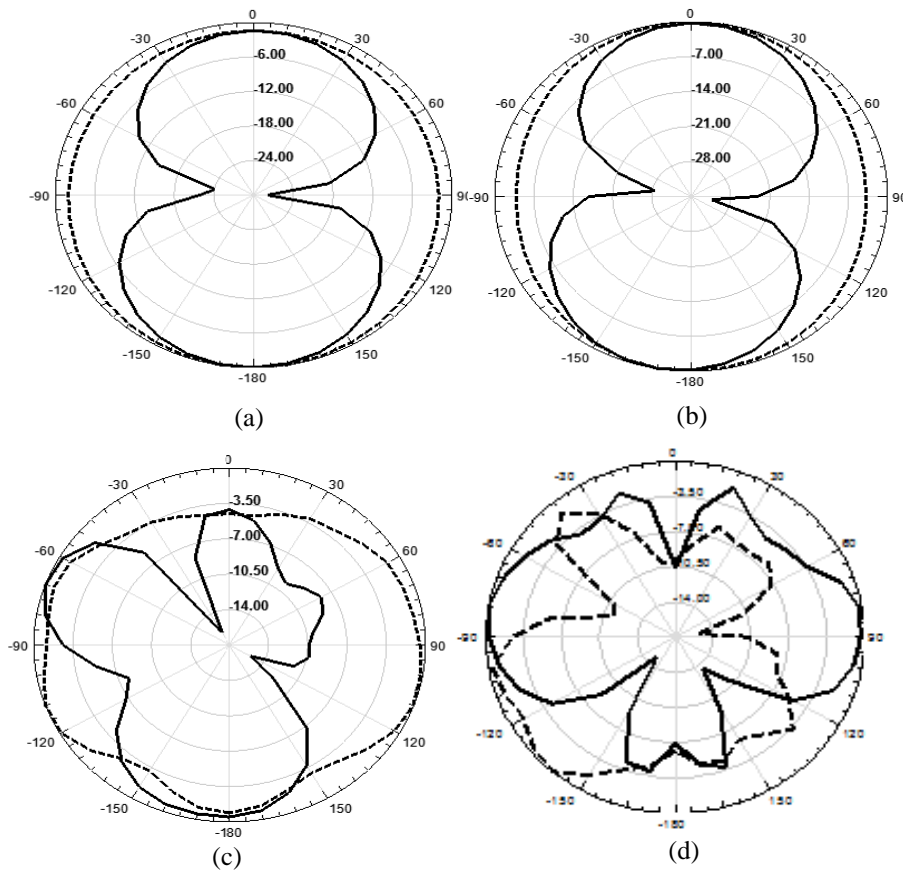


Figure 11. The radiation patterns at: (a) 4 GHz, (b) 6 GHz, (c) 12 GHz and (d) 16 GHz (— E-plane and - - - H-plane).

The proposed antenna simulated radiation efficiency is plotted for the desired frequency range, as shown in Figure 12, which indicates good efficiency ranging between (74 - 94) %. The vector current density distributions at 3.8 GHz and 6.6 GHz is uniformly distributed and nearly flowing along the same direction for the three suggested ground modifications, as shown in Figure 13, which emphasizes the UWB characteristics.

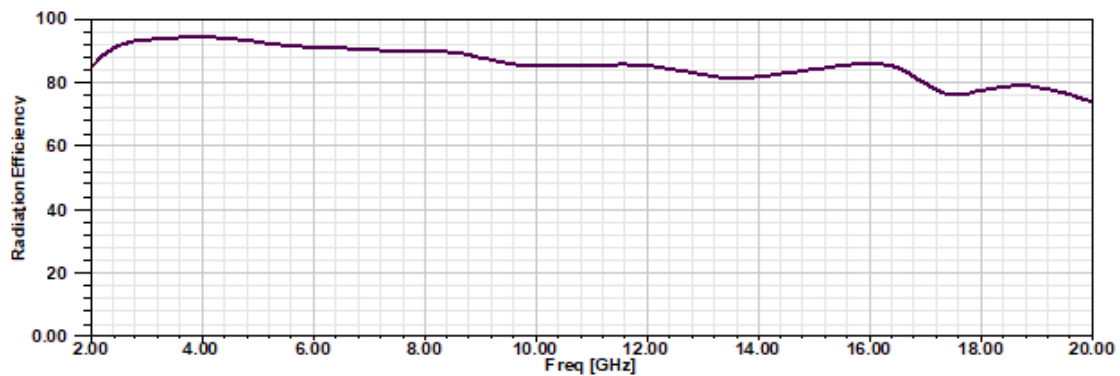


Figure 12. The radiation efficiency for the proposed antenna.

Comparison between the proposed antenna design and those presented in other research papers is shown in Table 1. Our proposed antenna is simpler in design than those antennas given in [2], [5] and [9], has larger bandwidth compared to the antennas presented in [2], [6] and [12] and is smaller in size compared to the antennas given in [5], [6] and [9].

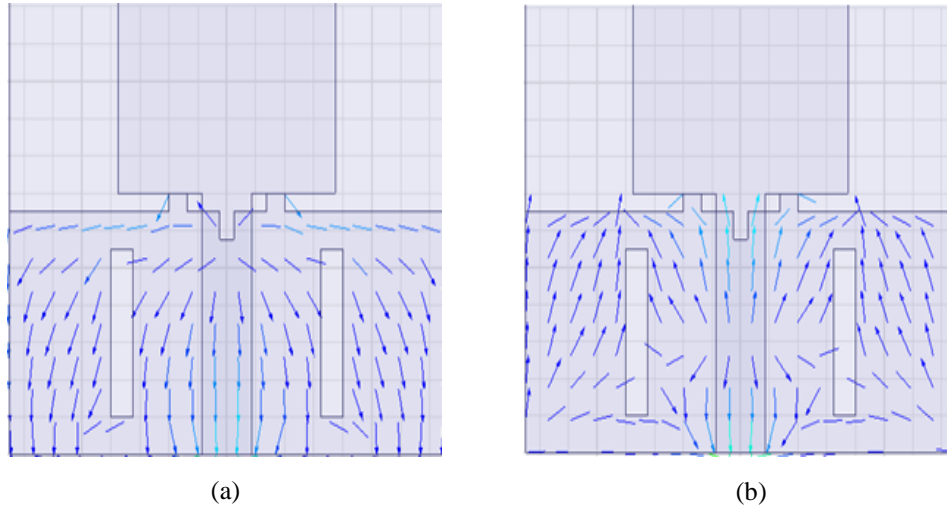


Figure 13. The vector current distribution at the ground plane at (a) 3.8 GHz and (b) 6.6 GHz.

Table 1. Comparison of the proposed antenna with those presented in other research papers.

Reference Antenna	Total Dimensions (L x W) in mm^2	Bandwidth in GHz	Percentage BW %
[2]	18 x 20	3.32 - 9.12	93.25%
[5]	30 x 50	2.75 - 20	151.6 %
[6]	30 x 51	2.96 - 11.89	120.27 %
[9]	60 x 60	1.79 - 28.02	175.98 %
[11]	30 x 40	2.87 - 50	178.29%
[12]	30 x 35	3.42 - 11.7	109.52 %
Proposed Antenna	34 x 36	3.4 - 22.5	147.49%

4. EXPERIMENTAL VERIFICATIONS

The proposed antenna is fabricated on FR4 substrate whose dielectric constant $\epsilon_r = 4.4$ and thickness $h = 1.6$ mm as shown in Figure 14. This antenna is tested at the antenna measurement laboratory at King Abdullah Design and Development Bureau (KADDB). The scattering parameter (reflection coefficient) S11 (Return Loss (RL) = -S11) versus frequency is measured by using Agilent N5242A network analyzer with SAC-26G - 0.5 using 50 Ω cables.

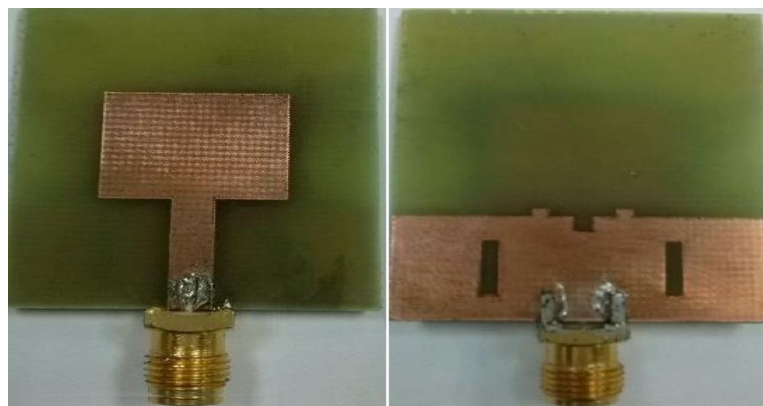


Figure 14. Photos of the fabricated antenna.

The measured S11 agrees with the simulated one in most of the desired frequency range. The measurements confirm the UWB characteristics as predicted in the simulation with a slight shift in the lower edge frequency; besides, they confirm the pass-band characteristics as shown in Figure 15.

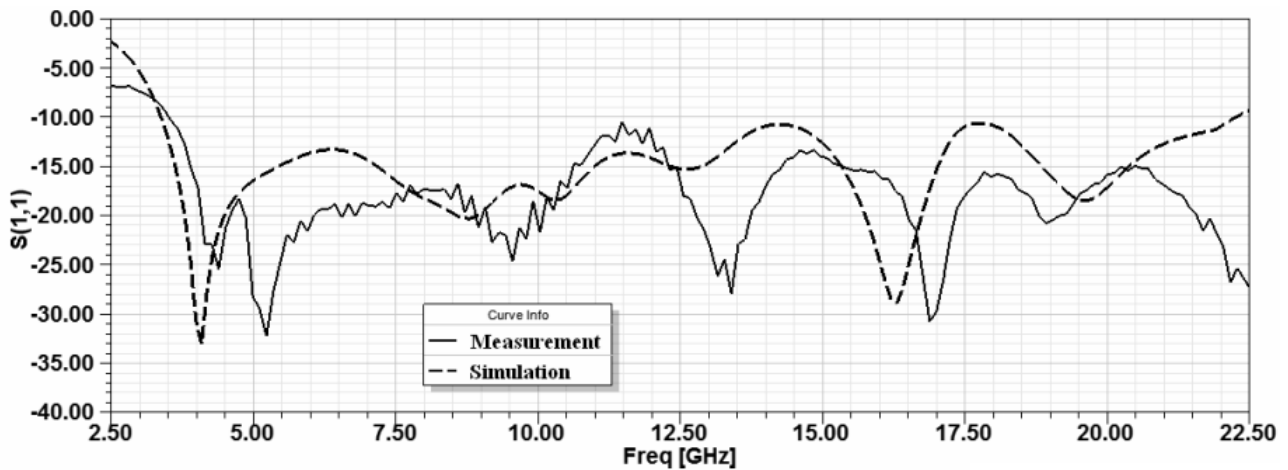


Figure 15. The simulated and measured S11 for proposed antenna.

The discrepancy between the measured and the simulated results are mostly attributed to the tolerance in fabrication and welding the SMA connector, which are not taken into account through simulation. Besides, the dielectric loss tangent of the FR4 substrate is kept constant during simulation, although it is actually a function of frequency.

5. CONCLUSION

UWB antenna is achieved by using rectangular patch antenna; 50Ω microstrip feed line and partial ground plane with ground modifications; adding one rectangular groove, two rectangular sleeves and two rectangular slots. The simulated scattering parameter (reflection coefficient) S11 (Return Loss (RL) = - S11) versus frequency, at $S_{11} \leq -10$ dB using HFSS, shows high bandwidth (3.4 - 22.4) GHz, high gain and dipole-like radiation pattern in E-plane and good omni-directional radiation pattern in H-plane.

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ملخص البحث:

في هذه الورقة، يتم اقتراح هوائي ذي نطاق ترددي فائق العرض بنطاق ترددي محسن. ويتكون الهوائي المحسن من رقعة مستطيلة تُغذى بخط تغذية شريطي ميكروي ممانعته 50 أوم وسطح مستو أرضي جزئي. ويتحقق التحسين في خصائص الهوائي المقترح عبر إجراء ثلاثة تعديلات على السطح المستوي الأرضي الجزئي، هي: إضافة كَمَّين مستطيلين، وإضافة أهدود مستطيل، وإضافة شَقَّين مستطيلين.

تم استقصاء خصائص هذا الهوائي والتحقق منها عبر المحاكاة، وتبين أن الهوائي حقق نطاقاً ترددياً عريضاً جداً عند فقد رجوع يساوي أو يزيد على 10 ديسيبل؛ تراوح من 3.4 جيجا هيرتز إلى 22.4 جيجا هيرتز (147.29%). كما تم الحصول على قيمة عظمى للكسب مع مواءمة جيدة للممانعة ونمط إشعاع في جميع الاتجاهات.



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