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Communication

A Simple Design of Compact Size UWB Microstrip Antennas with Improved Performance

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Abstract: A compact size ultra-wideband (UWB) microstrip antenna with improved performance is proposed in this communication. In this article, the design of the antenna, which is based on the interaction between the circular patch and the rectangular slot cutting in the metal ground plane, as a result the required starting frequency can be achieved due the coupling between the metal ground plane and patch. UWB microstrip antenna is studied and designed using computer simulation. For verification of simulation results, the antenna is fabricated and measured. The simulation and measured results as reflection coefficient and radiation pattern are presented. Its measured results indicate that the proposed antennas achieve UWB from 1.49 GHz up to 18 GHz with improved the radiation pattern performance in the upper frequency range(up to 10 GHz). Proposed antenna achieve many wireless services including wireless local area (WLAN 2.5 or 5.6 GHz), GSM (1.71-1.88 GHz), PCS (1.93-1.99 GHz), Multiband GNNs, UWB (3.1-10.6 GHz), and for see through wall and concrete application.

Keywords: Circular Patch R_p, Metal Ground Plane, Rectangular Slot, UWB, Radiation Pattern Uniformity

1. Introduction

A different UWB antenna has been studied because of its superior performance characteristics; those include a more compact size, lower profile, and simple structure, which lead to lower cost, easy fabrication and convenient integration with monolithic RF circuits [1]. Many researchers have been reported to achieve the developments of many different wireless communications standards, as the global positioning system (GPS), worldwide interoperability for microwave access (WiMAX), and wireless area network (WLAN). The main problem about UWB antenna is the radiation pattern degradation in the upper of the UWB frequency range as well as compact size. Different UWB antennas has been designed to solve the main problems, such as electromagnetic band gap (EBG) ground [2] and gate-like [3], [4] structures in the same plane as the radiating elements, and stacked patches [6] and dielectric resonators above them [5]. An optimal microstrip-fed monopole antenna with two F-shaped slot radiators have been proposed for compact size, good tri-band operating bandwidth, and stable radiation patterns [7].

Design of WLAN/LTE/UWB antenna by introducing a ground – cooperative radiating structure (GCRS) into the metal ground plane of a defected hexagonal monopole antenna (HMA) improve the performance of planar ultra-wideband monopole antennas to have stable omnidirectional radiation patterns, much more compact size, and boarder bandwidth [8]. An arc shaped slot is etched into the radiating patch of a standard compact elliptically shaped UWB monopole antenna, which produces broadside realized gain values, above 2.13 dBi over the entire UWB frequency range as well as improves the radiation pattern performances in the upper frequency range and compact size 0.342 λ_o x0.231 λ_o where λ_o indicates the free space wavelength [9].

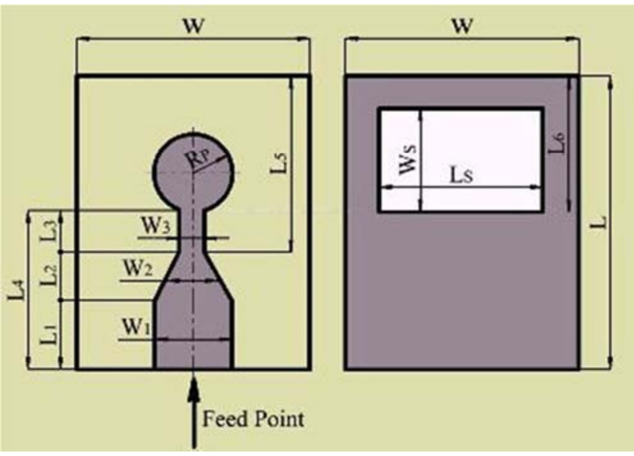
In this communication, a simple UWB microstrip antenna is shown in figure 1. The antenna consists of circular patch in front of rectangular slot cutting in metal ground plane. Figure 1a illustrates the top side of board materials; a circular patch of radius Rp is positioned at the terminal microstrip feeding line to match a 50Ω standard source. Figure 1b illustrates the bottom side of board materials, the metallic ground plane is designed with a rectangular slot of dimensions Ls and Ws. Circular patch operates as an exciter and modified ground plane as a radiator. It will be demonstrated that a rectangular slot effectively tunes the mutual coupling between the circular patch and the ground plane over a very large frequency range to achieve UWB impedance matching as well as improve the stability of the radiation patterns at the higher portion of the UWB frequency range.

2. Basic Design Rules

a) A circular patch excites a modified ground plane with rectangular slot as a radiator. A rectangular slot effectively tunes the mutual coupling between the circular patch and the ground plane over a very large frequency range to achieve UWB impedance matching.
b) We use tapered transmission line to improve the impedance bandwidth with respect to the – 10 dB criterion, the requirement is a transition between the input impedance of radiator and a 50Ω standard source.

3. Parametric Studies and Optimization

The operating principle of the antenna is studied by using the CST 2015 software in two cases. The parametric antenna has been optimized to achieve good performance, impedance matching S11 and enhancement uniform far field radiation gain pattern.

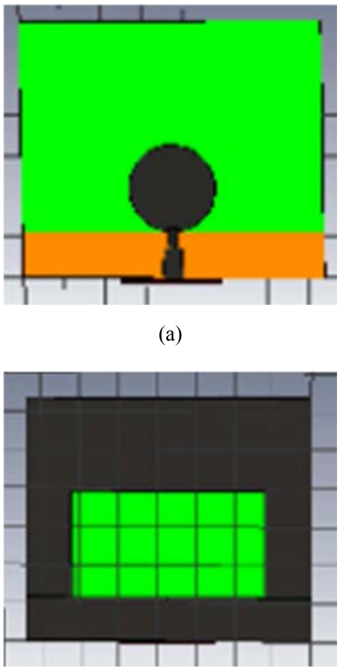


(a) (b)

Figure 1. Design Layout of the Proposed Antennas. (a) Top View. (b) Metal Ground Plane.

3.1. Case-1

Figure 2 illustrates the shape of proposed antennas in case-1. In this case as illustrated in Figure 2b the bottom side of board material is designed to achieve approximately infinite metallic ground plane. Table 1 illustrates the optimized dimensions of the proposed antenna using a substrate of $\in_r$ = 2.2, and thickness = 1.57mm. To illustrate the effect of the modified metal ground plane cutting by rectangular slot on the resonating property of the antenna, the simulations were carried out in four optimized construction. Figure 3 indicates the simulation results for different antenna description. As can be seen in table-2 the impedance matching bandwidth with different area of metal ground plane depends on the tuning between the dimensions of rectangular slot and patch radius Rp.



(a)

(b)

***Figure 2.** Proposed Antennas in case-1. (a)Top View. (b) Metal Ground Plane.*

***Table 1.** Antenna Description.*

Metal ground plane area 44×41mm²

W×L	Rp	Ls	Ws	ε_r	W1	W2
44×41mm²	6mm	31	16	2.2	4.77	4.2
W3	L1	L2	L3	L4	L5	L6
2.5	4	2	4	10	35	31

Metal ground plane area 54×48mm²

W×L	Rp	Ls	Ws	ε_r	W1	W2
54×48mm²	8	38	20	2.2	4.77	4.2
W3	L1	L2	L3	L4	L5	L6
2	4	2	4	10	42	38

Metal ground plane area 64×56mm²

W×L	Rp	Ls	Ws	ε_r	W1	W2
64×56mm²	9	45	24	2.2	4.77	4.2
W3	L1	L2	L3	L4	L5	L6
2	4	2	4	10	49	45

Metal ground plane area 74×63mm²

W×L	Rp	Ls	Ws	ε_r	W1	W2
74×63mm²	11	50	27	2.2	4.77	4.2
W3	L1	L2	L3	L4	L5	L6
2	4	3.5	4	10	55.5	52

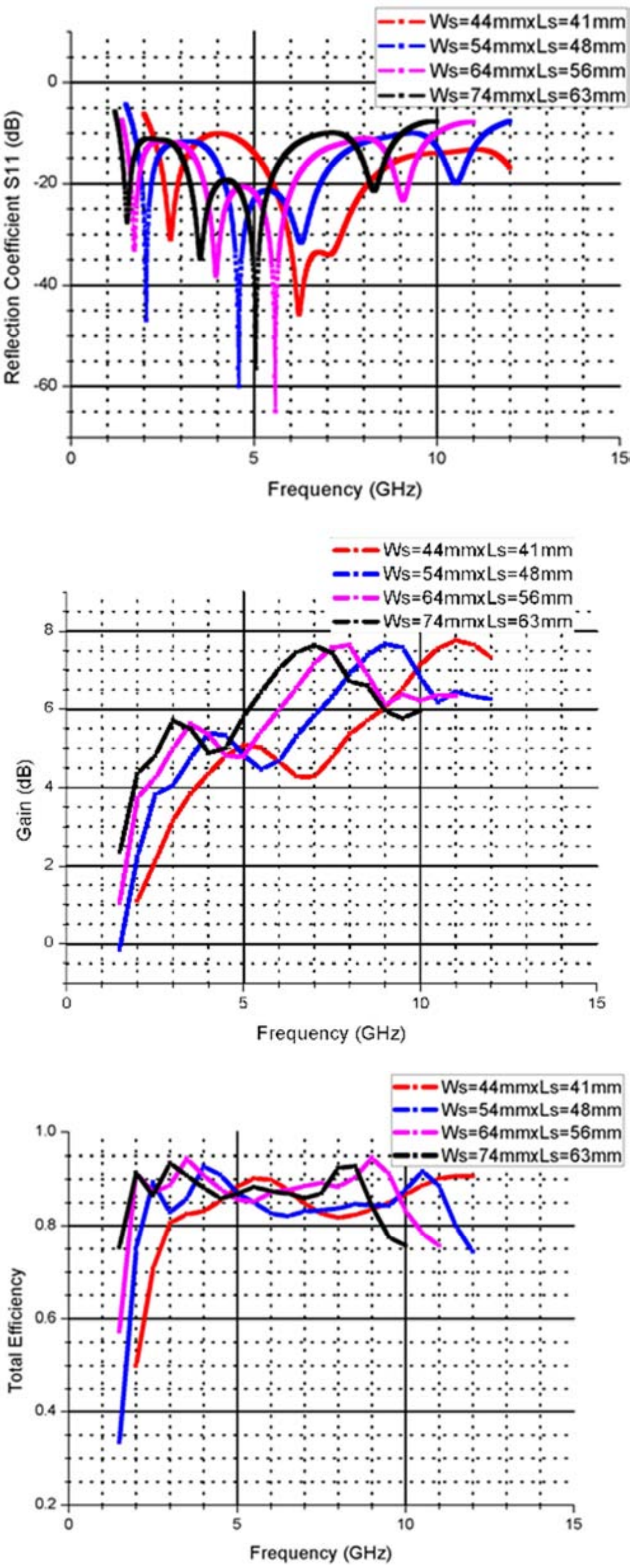


Figure 3. *Simulated Results of Proposed Antennas (case-1).*

Table 2. *Simulated Results of Case-1.*

Antenna Description	Operating Frequency(GHz)	Max Gain (dB) over Frequency
W=44mm-L=41mm Ls=31mm-Ws=16mm	2.2 up to 12	7.75
W=54mm-L=48mm Ls=38mm-Ws=20mm	1.7 up to 11.4	7.75
W=64mm-L=56mm Ls=45mm-Ws=24mm	1.5 up to 10	7.75
W=74mm-L=63mm Ls=50mm-Ws=27mm	1.3 up to 9	7.75

With these results, we propose to set the starting frequency of proposed antennas using the following steps:

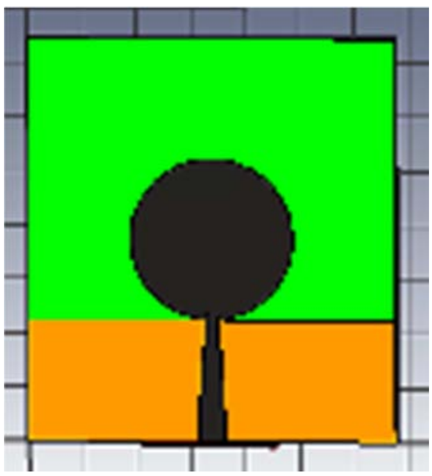
1. Bandwidth is one of the key issues of proposed antenna, since the bandwidth can be tuned by adjusting the slot dimensions. As a result, it can be achieved the starting frequency according to the slot dimensions.
2. The starting frequency can be approximately calculated by:

$$f_{st} = \frac{c}{2(Ls+Ws)\sqrt{\varepsilon_r}}$$

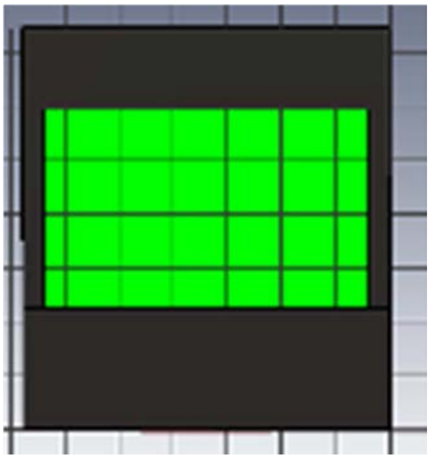
And Ls = 0.7 W, Ws = 0.35 W, L6 = 0.7 W, and Rp = 0.21 Ls
Since,
a) c is the velocity of light.
b) Ls, Ws are the slot dimensions.
c) $\boldsymbol{\varepsilon_r}$ is the relative permittivity.

3.2. Case-2

Figure 4 illustrates the construction of proposed antennas (case-2) with reduced substrate dimensions. In this case as illustrated in Figure 4b the bottom side of board material is designed with reduced metallic ground plane area. Table 3 illustrates the optimized dimensions of the proposed antenna using a substrate of $\in_r$ = 2.2, and thickness = 1.57mm. To illustrate the effect of reduced modified metal ground plane cutting by rectangular slot on the resonating property of the antenna, the simulations were carried out in four optimized construction. Figure 5 indicates the simulation results for different antenna description. Table-4 illustrates the simulation results.



(a)



(b)

Figure 4. *Proposed Antennas with Reduced Substrate Dimensions. (a) Top View. (b) Metal Ground Plane.*

Table 3. *Antenna Description.*

Metal ground plane area 21.6×27.66mm²

W×L	Rp	Ls	Ws	ε_r	W1	W2
21.6×27.66mm²	5mm	20.5	11.4	2.2	4.77	2.8
W3	L1	L2	L3	L4	L5	L6
2.699	4	1	4	9	22.66	18.66

Metal ground plane area 29.5×37mm²

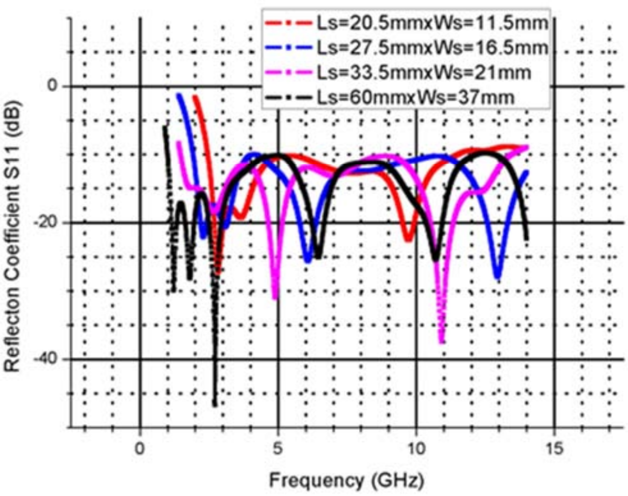
W×L	Rp	Ls	Ws	ε_r	W1	W2
29.5×37mm²	7mm	27.6	16.7	2.2	4.77	4.2
W3	L1	L2	L3	L4	L5	L6
2.699	4	3	4	11	30	26

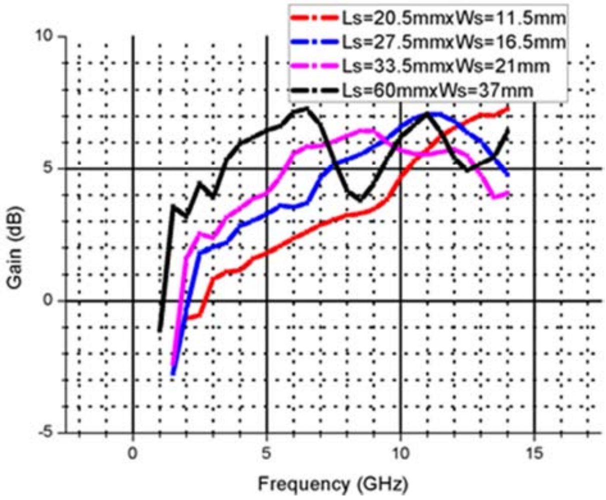
Metal ground plane area 36×45mm²

W×L	Rp	Ls	Ws	ε_r	W1	W2
36×45mm²	9mm	33.5	21	2.2	4.77	4.2
W3	L1	L2	L3	L4	L5	L6
2.699	4	3	4	11	44.5	34

Metal ground plane area 68×74.5mm²

W×L	Rp	Ls	Ws	ε_r	W1	W2
68×74.5mm²	15mm	60	37	2.2	4.77	3.2
W3	L1	L2	L3	L4	L5	L6
2.3999	5	12.5	5	22.5	57	52





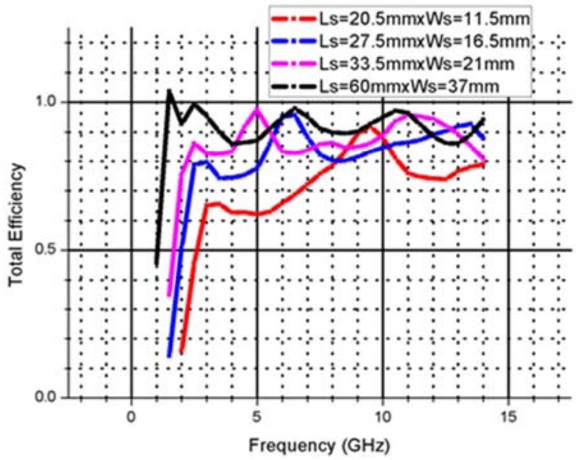


Figure 5. *Simulated Results of Proposed Antenna with Reduced Size (case-2).*

Table 4. *Simulated Results of Case-2.*

Antenna Description	Operating Frequency(GHz)	Max Gain (dB) over Frequency
W=22mm-L=27mm Ls=21mm-Ws=11.5mm	2.45 up to 11.5	7
W=30mm-L=37mm Ls=28mm-Ws=17mm	1.94 up to 14	7
W=36mm-L=45mm Ls=34mm-Ws=21mm	1.5 up to 14	7
W=68mm-L=74.5mm Ls=60mm-Ws=37mm	1 up to 14	7

With these results, the starting frequency can be approximately calculated as in case-1.

4. Practical Result and Discussion

To validate the basic design rule, a prototype of the proposed antenna with dimensions given in table-3 of R_P=9mm is designed and fabricated as shown in Figure 6. Manufacturing and measurement of reflection coefficient S11 parameters were carried out in National Telecommunication Institute and radiation pattern was measured in the antenna lab (operating frequency from 1GHz up to 10GHz) in the microwave engineering department, Faculty of Engineering, Ain Shams University. Figures 7 shows the reflection coefficient S11 which indicates that the proposed antenna achieves good impedance matching with starting frequency 1.49GHz up to 18GHz. Figure 8 illustrate better radiation pattern up to 10GHz.

Figure 6. *Photograph of the Proposed Antenna.*

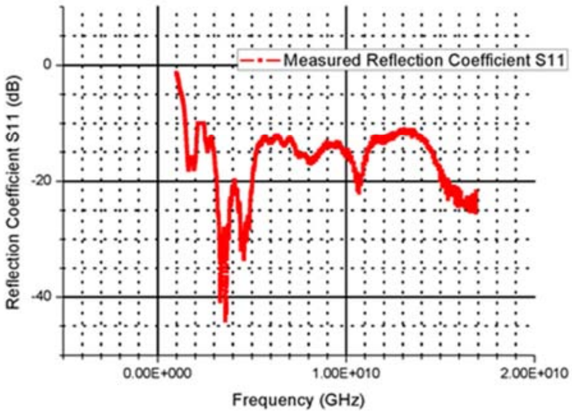
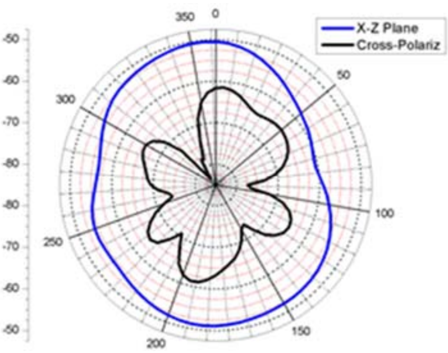
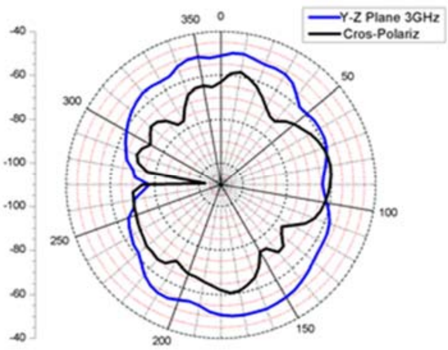


Figure 7. *Measured Reflection Coefficient S11.*

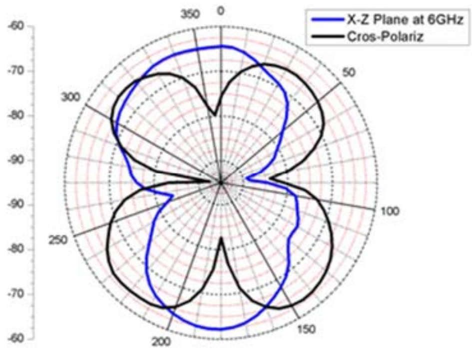


X-Z Plane

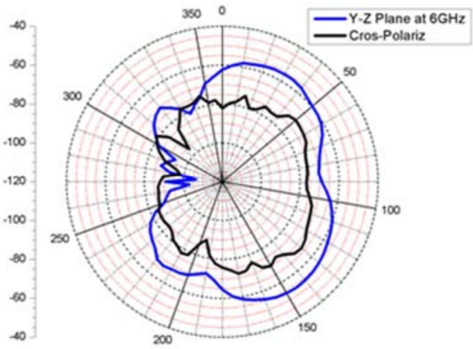


Y-Z Plane

(a)

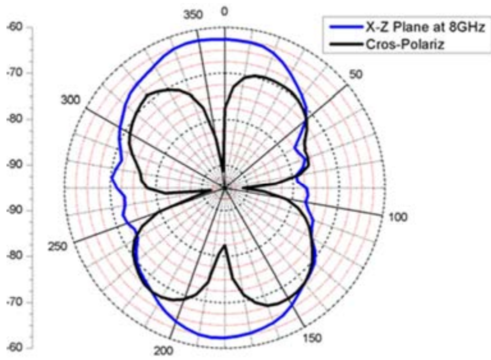


X-Z Plane

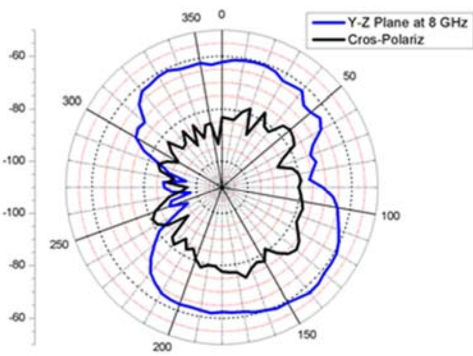


Y-Z Plane

(b)

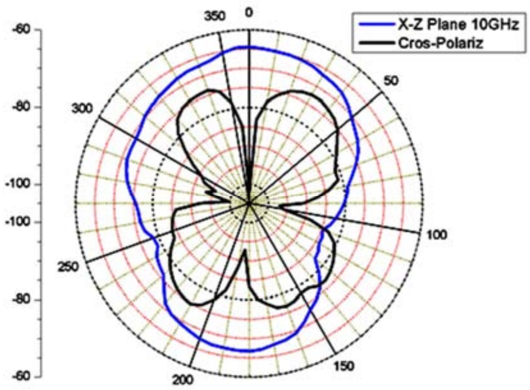


X-Z Plane

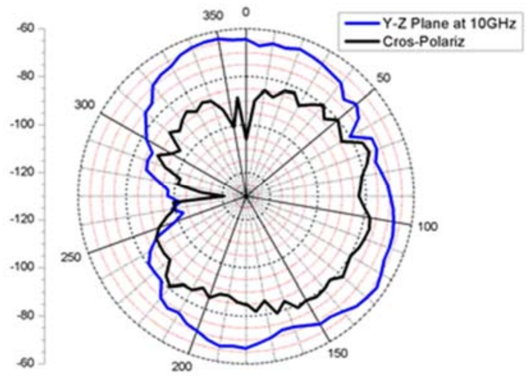


Y-Z Plane

(c)



X-Z Plane



Y-Z Plane
(d)

Figure 8. *Measured Radiation Pattern. (a) at 3 GHz. (b) at 6 GHz. (c) at 8 GHz. (d) at 10 GHz.*

Table-5 illustrates the comparison between the proposed antennas with the UWB antennas reported in [8], [9], [10], [11], [12]. As can be seen, the proposed antenna provide a broaden impedance matching bandwidth with improved the realized gain values, and the lower edge frequency than reported in [8], [9], [10], [11], [12].

Table 5. *Comparison of UWB Antennas.*

Antenna description	Bandwidth (GHz)	Max Gain (dB)	Size (mm²/λ_o^2)
Proposed Antennas	1.49-18 (168%)	7.2	0.178x0.22 λ_o^2
Hexagonal Monopole[8]	2.38-11.8 (133%)	5.6	0.21x0.25 λ_o^2
arc shaped slot[9]	2.7-10.8 (102%)	6	0.22x0.32 λ_o^2
Integrated antenna[10]	3.2-10.9 (109%)	5.1	0.54x0.65 λ_o^2
Spanner Monopole[11]	2.95-11.8 (129%)	7	0.3x0.51 λ_o^2
CPW-fed slot antenna[12]	3.1-11.1 (113%)	5	0.27x0.27 λ_o^2

Since λ_o is the free space wavelength.

5. Conclusion

In this article, the operating principle of the antenna is studied in two cases to discuss the effect of metal ground plane area on antenna performance. As can be seen in case -2, the antenna exhibit reasonable performance over the entire frequency range with compact size but in case-1 the realized gain is enhanced in the lower portion of the UWB frequency range with slightly enhancement in that upper portion than in case -2. We present the design process to fabricate metal ground plane cutting by rectangular slot as a radiator with a circular patch as exciter, and testing of antenna with improved broadside – realized gain values above 3 dB over the entire UWB frequency range, as well as lowered the lower edge of the impedance bandwidth. By tuning the dimensions of the rectangular slot and circular patch radius, a broaden impedance matching was achieved with improved radiation pattern uniformity as well as compact size. The simulation and measured results indicate good performance than the UWB antenna reported in [8], [9], [10], [11], [12]. As a result the proposed antenna achieve the developments of many different wireless communications standards, as the global positioning system (GPS), worldwide interoperability for microwave access (WiMAX), and wireless area network (WLAN).

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