Ultra Wideband Miniature Microstrip Patch Antenna with Defected Ground Notches

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***Abstract* - The defected ground notches DGN for microstrip patch antenna and its effects on antenna performance have been studied using HFSS simulator. Different patch shapes: square, triangular-rectangular and circular have been supposed. The DGN has been suggested by reducing the length of antenna ground plane and making different shapes of notches at the edges of the proposed ground. The obtained results indicates that the antenna ground of length reduction with three, one and three notches gives respectively an impedance bandwidth from 3.42-17.45 GHz (134% w.r.to centre frequency), 2.33-14.63 GHz (145%) and 3.31-16.13 GHz (131%) for square, triangular-rectangular and circular patches. Also a size reduction of 83.5%, for square and circular patches and 82.5% for triangular-rectangular patch are achieved at resonance frequency of 4.05 GHz and 4.5 GHz respectively compared with those antennas having the same design and operating at the same resonance frequencies but without DGN.**

1. INTRODUCTION

Wireless communications have been developed widely and rapidly in the modern world especially during the last two decades. The development of the personal communication devices will aim to provide image, speech and data communications at any time, and anywhere around the world. This indicates that the communication terminal antennas must meet the requirements of wideband to sufficiently cover the possible operating frequencies. In addition, for miniaturizing the wireless communication system, the antenna must also be small enough to be placed inside the system, low weight, low profile, and low cost. Microstrip patch antennas are widely used to provide and achieve these requirements except the limitation of narrow impedance-bandwidth. Therefore, bandwidth enhancement is currently a popular research area for microstrip antennas in order to transmit and receive more information.

Tugonski, et al.[1] presented a technique which extends the operating bandwidth of the aperture coupled microstrip antenna to over 50%. On the antenna side of the ground plane, a thick slab of Rogers 5880 Duroid is used for the lower substrate, while foam is used for the top substrate. The top patch was etched on a 5 mil thick 5880 Duroid cover layer. Another paper has been published in 2005 by Korean researchers [2] who designed a rectangular slot antenna fed by T-shaped microstrip line for achieving both harmonic suppression and wide bandwidth. Since this proposed antenna consists of the U-shaped conductor line connected ground plane inside the rectangular slot, it is easily fabricated and BW percentage was 52%. Another technique to increase BW was published by Hongyu with partner [3]. It was shown that by using two 180 degrees out of phase excited cylindrical probes, the bandwidth of a patch antenna can be dramatically increased. Based on the proposed differential cylindrical probes (DCP) feed, they were designed a square patch antenna with 104% impedance bandwidth. In 2013 Chattopadhyay et al. [4], proposed and experimentally investigated a wideband microstrip-line-fed hexagonal wide-slot antenna.The hexagonal slot excited by a simple 50 Ω microstrip line with a rotation angle of 0° having 470 MHz bandwidth is considered as a reference antenna. The proposed hexagonal slot is rotated by 30° and excited by a 50 Ω line loaded by a hexagonal tuning stub. The experimental results exhibit matching impedance below a 2:1 VSWR bandwidth of 5165 MHz (2.117–7.282 GHz) covering all the WiMAX and wireless local area network band applications, the percentage impedance bandwidth out 110% at centre frequency of 4699.5 MHz.

The present paper aims to enhance the bandwidth and to miniaturize the antenna size using simple two dimensional structure.

2. ANTENNA DESIGN

Three different antenna designs are investigated. The design configurations for square patch, triangular-rectangular patch and circular patch are illustrated in Fig.1a,b,and c respectively. The ground plane of these antennas is defected by reducing its length L_g and making different shapes of notches at the medium, right and left edges of the defected ground structure as shown in Fig.1. The dimensions of these antennas are listed in Table 1 where $L_p \times W_p$, $L_s \times W_s$ and $L_g \times W_g$ are respectively the dimensions of patch, substrate and ground plane.

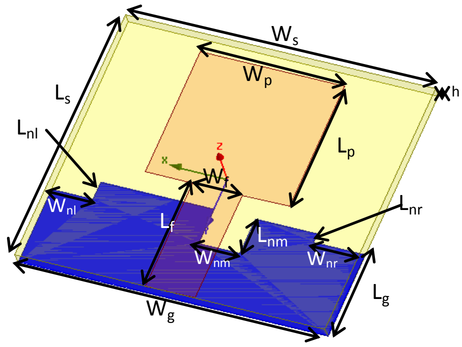


Fig.1a: Design of square patch antenna with three DGNs.

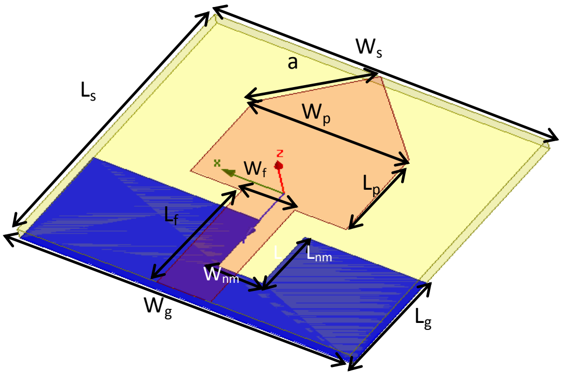


Fig.1b: Design of train.-rect. patch antenna with one DGN.

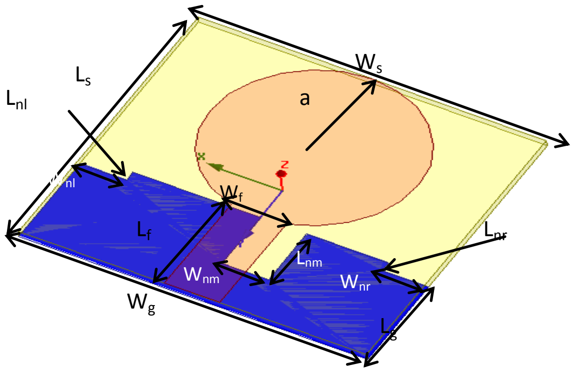


Fig.1c: Design of circular patch antenna with three DGNs.

Table 1: The dimensions of studied antennas in mm.

Patch shape	Patch $L_p \times W_p$	Substrate $L_s \times W_s$	Ground $L_g \times W_g$
Square	14×14	28×30	10.5×30
Train.-rect.	9×14 $a = 10mm$	28×30	10.5×30
Circular	$a = 8mm$	28×30	10.5×30

The dimensions of defected ground notches are given in Table 2 for left notch $L_{nl} \times W_{nl}$, medium notch $L_{nm} \times W_{nm}$ and right notch $L_{nr} \times W_{nr}$. It is noted that the medium notch is shifted to the right side by 4mm for all antenna designs.

The dimensions of strip line feed for all antennas are $L_f \times W_f = 11.5 \times 4.8\ mm^2$. The substrate material is proposed to be Duroid material of dielectric constant ε_r=2.2 and its thickness is 1.57mm.

Table 2: Dimensions of defected ground notches in mm

Antenna patch	Left notch $L_{nl} \times W_{nl}$	Medium notch $L_{nm} \times W_{nm}$	Right notch $L_{nr} \times W_{nr}$
Square	2×4	4×4	1×5
Train.-rect.	-	6×4	-
Circular	1×4	6×4	1×4

3. ANTENNA SIMULATION AND RESULTS

The proposed antenna designs are analysed and simulated using high frequency structure simulator (HFSS), commercial computer software package from Ansoft Technologies, which is based on the finite element method (FEM) technique for arbitrary 3D volumetric passive devices [5]. The characteristics of impedance bandwidth are examined for those three antennas. The return loss, VSWR and radiation patterns of the studied antennas are obtained. Fig.2 shows the return loss S11 characteristics of the square, triangular-rectangular and circular patch antennas for the frequency band of 1-30 GHz. The bandwidth of the square, triangular-rectangular and circular patch antennas are respectively from 3.42-17.45 GHz (percentage of 134% w.r.to centre frequency), 2.33-14.63 GHz (145%) and 3.31-16.13 GHz (131%). The VSWR curves for the studied antennas are plotted in Fig.3.

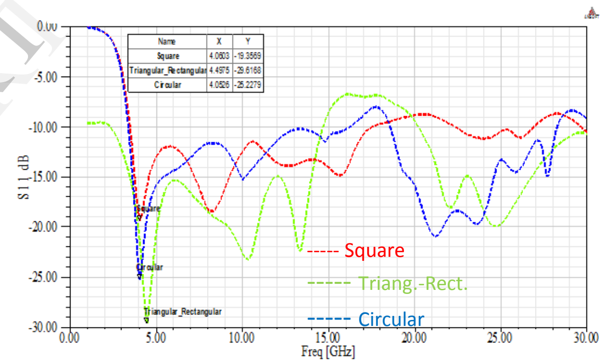


Fig.2: The characteristics of return loss for square, tarin.-rect, and circular patch antennas.

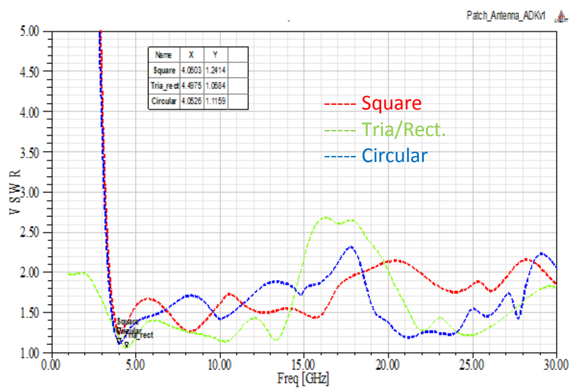


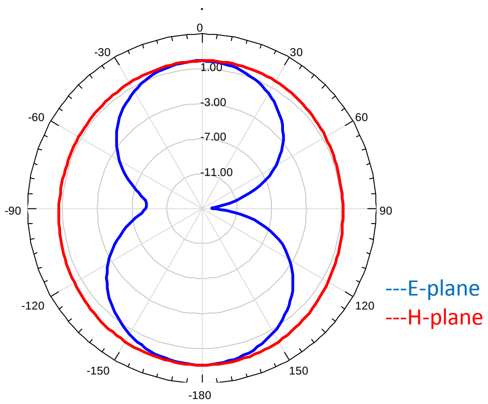
Fig.3: VSWR properties for square, tarin.-rect, and circular patch antennas.

Table 3: Summary of the obtained results

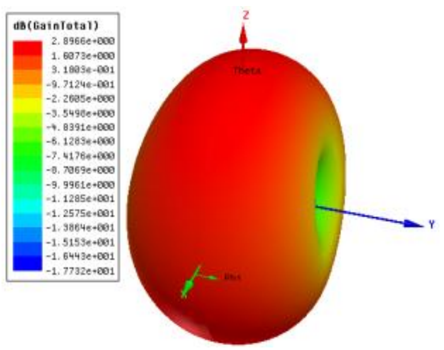
Antenna	f_r GHz	S_{11}	VSWR	BW_r%
Square	4.05	-19.35	1.24	134
Train-rect.	4.5	-29.61	1.06	145
Circular	4.05	-25.22	1.11	131
Hexagonal slot [4]	3.35	-21	1.2	110

Table 3 summarizes the obtained results for the investigated antennas compared with hexagonal slot antenna [4].

The radiation characteristics of the proposed antennas are given in Figs. 4-6. The E- and H-plane patterns of square, traing.-rect. and circular patch antennas are illustrated in Figs.4a, 5a and 6a respectively while Fig.4-6b shows 3D radiation pattern of the studied antennas.

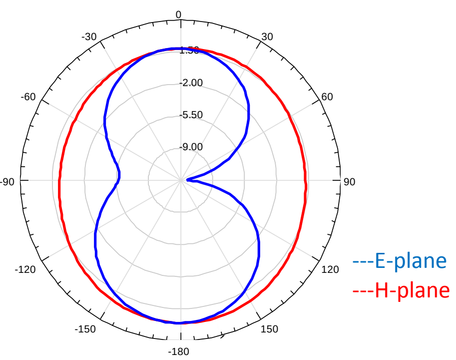


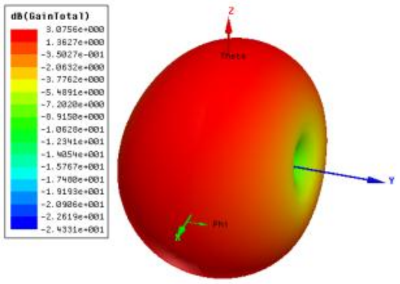
(a)



(b)

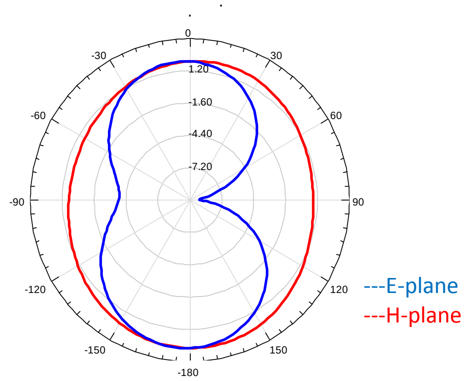
Fig.4: (a) E- and H- plane radiation patterns of square patch antenna with DGNs. (b) 3D gain radiation pattern of square patch antenna with DGNs.



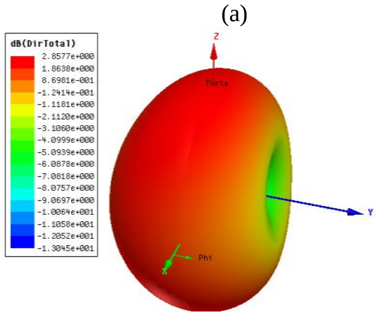


(b)

Fig.5: (a) E- and H- plane radiation patterns of train.-rect. patch antenna with DGN. (b) 3D gain radiation pattern of train.-rect. patch antenna with DGN.



(a)



(b)

Fig.6: (a) E- and H- plane radiation patterns of circular patch antenna with DGNs. b) 3D gain radiation pattern of circular patch antenna with defected ground notches.

Table 4: Comparison between the studied antennas and hexagonal slot antenna [4].

Antenna, size mm^3	f_r GHz	VSWR	BW_r%	Gain dB
Square $28 \times 30 \times 1.57$	4.05	1.24	134%	2.89
Train-rect. $28 \times 30 \times 1.57$	4.5	1.06	145%	3.07
Circular $28 \times 30 \times 1.57$	4.05	1.11	131%	2.85
Hexagonal slot $110 \times 110 \times 1.57$ [4]	3.35	1.2	110%	5.6

It is clear that the studied antennas with defected ground notches behave as omnidirectional antennas, and their gain decreases to about 3dB.

4. RESULTS ANALYSIS

(a) The improvement in bandwidth and reduction in antenna size are achieved as indicated in Table 4 and the antennas properties are compared with those for hexagonal slot antenna [4].

(b) Size reduction

The sizes of the studied antennas with defected ground notches are compared with the sizes of antennas having the same design and same resonance frequency but without defected ground notches (normal ground) as given in Table 5. It is clear that a reduction in antenna size of 83.5% and 82.4% are achieved for square, circular and triangular-rectangular patches respectively.

Table 5: Comparison between sizes of studied antennas and those of antennas having same design and resonance frequency

Antenna	f_r GHz	Ground $L_g \times W_g mm^2$	Substrate $L_s \times W_s mm^2$	Size reduction
Square	4.05	52×98	52×98	-
Square with DGNs	4.05	10.5×30	28×30	83.5%
Train.-rect.	4.5	50.3×94.8	50.3×94.8	-
Train.-rect. with DGN	4.5	10.5×30	28×30	82.5%
Circular	4.05	52×98	52×98	-
Circular with DGNs	4.05	10.5×30	28×30	83.5%

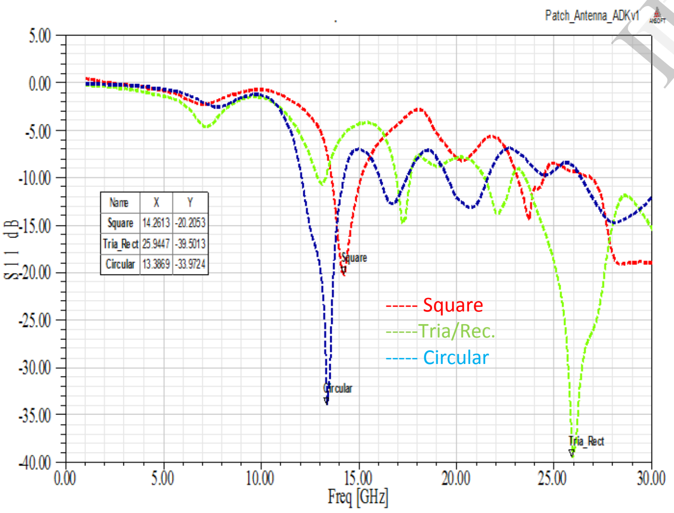


Fig.7: The characteristics of return loss for square, tarin.-rect, and circular patch antennas without DGN.

(c) Resonance frequency

The antenna designs proposed in Fig.1 are again investigated but with normal ground plane (without DGN) and the return loss characteristics is plotted in Fig.7. The obtained resonance frequencies f_{rg} of these antennas are compared with those f_{rDGN} of antennas with DGN as given in Table 6. The relationship of these resonance frequencies may expressed as:

$f_{rDGN} \approx 0.3 f_{rg}$ for square and circular patches, and $f_{rDGN} \approx 0.17 f_{rg}$ for triangular-rectangular patch, where f_{rDGN} is the resonance frequency of antenna with defected ground notch (DGN) while f_{rg} is the resonance frequency of antenna with normal ground (without DGN).

Table 6: Comparison betweeesonance frequencies f_{rg} of antennas without DGN and with those f_{rDGN} of antennas with DGN.

Antenna	f_{rg} GHz without DGN	f_{rDGN} GHz with DGN	Ratio of f_{rDGN}/f_{rg}
Square	14.2	4.05	0.3
Train-rect.	26	4.5	0.17
Circular	13.4	4.05	0.3

4. CONCLUSIONS

Different patch shapes (square, triangular-rectangular and circular) have been proposed. The DGN has been made by reducing the ground length and making different shapes of notches at the edges of the studied ground. Impedance bandwidth enhancement and antenna size miniaturization have been achieved. These antennas are promising to be embedded within Wi-Fi, WLAN, WiMax applications and also, could be used in on-board satellite because of its small size compared with the others.

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BIOGRAPHY

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