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Compact Y-shaped antenna with partial and meandered ground for WLAN/Wi-MAX applications

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Wi-MAX;
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Abstract. A broadband compact Y shaped monopole antenna with band-notched characteristics is designed and investigated. The antenna structure is based on the defected ground with slit resonating structures. The ground plane is loaded with two hook shaped slots on the opposite edges along its width. One horizontal slot and one vertical slot are also etched on the ground plane to improve the impedance matching for the design to resonate in Wi-MAX and WLAN widebands. It operates at the frequencies of 2.68 GHz, 3.75 GHz and 5.72 GHz for WLAN and Wi-MAX applications. The compact antenna has a size of $30 \times 30 \times 1.59$ mm^3 and stable radiation patterns are obtained at resonant frequencies.

1. Introduction

The development in wireless communication is taking place widely and rapidly, particularly in short range radio links such as WLAN (Wireless Local Area Network) and worldwide interoperability for microwave access (Wi-MAX). By word development we mean, different wireless standards is extending or overlapping. It leads to the designing of such antenna, which are wideband, capable of communicating in different allocated frequency bands i.e., multiband, and of compact size with good performances. In literature several antenna configurations [1–20] have been done for both WLAN and Wi-MAX applications.

Complex antenna structures fed by coplanar waveguide are used to generate WLAN and Wi-MAX band. The design is based on radiating element with stubs and slots which are loaded on the ground plane. The parasitic elements are also used to generate the requisite bands. Different layouts are utilized for the design of required antennas like the stubs and slots are loaded on the radiating ring antennas [3,4], a modified bow tie antenna [5] and composite right and left metamaterial [10] based antenna produce dual or triple band for Wi-MAX and WLAN. Large size, complex design geometries etc., are the basic disadvantages of such structures. The present design is attempted to overcome such disadvantages. The proposed design is a Y-

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shaped monopole antenna designed on a commercially available material FR-4 with modified ground structure having compact size. Actually modified ground is the Defected Ground Structure (DGS), where the defects (slots) are intentionally extrude on the ground plane of the microstrip patch antenna to enhance the bandwidth, gain and suppress the higher order modes, cross polarization to improve the radiation characteristics of the patch. Two hook-shaped slots are etched on the ground plane on opposite edges along its width, as well as one horizontal and vertical slot, to improve impedance matching for the design to resonate in Wi-MAX and WLAN widebands. The simulation and experimental results are presented in the manuscript.

2. Antenna design methodology

The proposed antenna structure in Figures 1(a) and 1(b) is fabricated on 1.59 mm thick FR-4 substrate ($\varepsilon_r = 4.3$, $\tan\delta = 0.025$). The antenna is composed of a Y-shaped radiating patch with partial ground plane. The partial ground plane is loaded with two hook shaped slots on the opposite edges along its width. Also, one horizontal slot of width 0.4 mm and one vertical slot of 0.5 mm width and length are etched on the lower edge of the ground plane. A single microstrip feed line of two sections of lengths $y1$, $y2$ mm with widths 3.2 and 2 mm respectively is used to feed the radiating patch. The microstrip feed line with two fragments lead to have good impedance matching (50 Ω) for all states [21,22]. The antenna has a squeezed dimensions of $30 \times 30 \times 1.59$ mm^3. The dimensions of the antenna structure is presented in Table 1.

The evolution process of antenna design to achieve the triple-band operation for WLAN/Wi-MAX by four design prototypes (A-1 to A-4) is presented in Figure 2(a) and 2(b). The step by step design configuration are explained in the next sub-sections.

3. Empirical formulas for wideband antenna design and design procedure

(a) **Wideband antenna design (A-1):**
The wideband antenna structure devising a gap amid the patch (radiating element) and partial ground plane makes a coupling capacitance. This coupling capacitance is responsible for the wide band behavior of the antenna structure. So the ground plane is a vital part of radiating configuration and current distribution on it affects the antenna behavior. In present antenna, radiating patch is of Y-shaped with one horizontal arm is more elongated and rectangular partial ground plane of size $h_g \times W_g$ mm^2 as shown in Figure 3.

It is realized that the radiating patch, partial

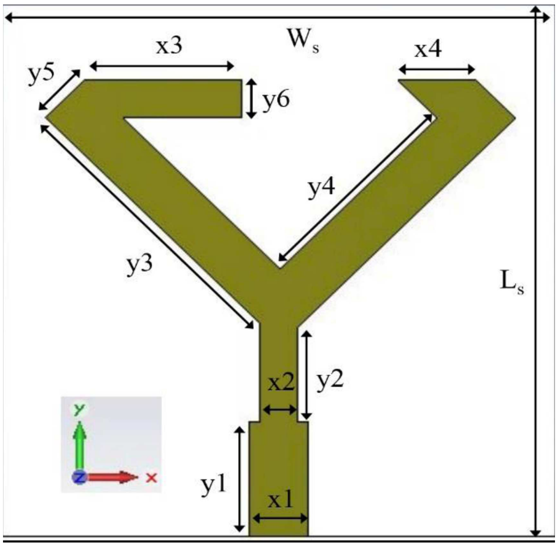

Figure 1a. Proposed antenna geometry - front view.

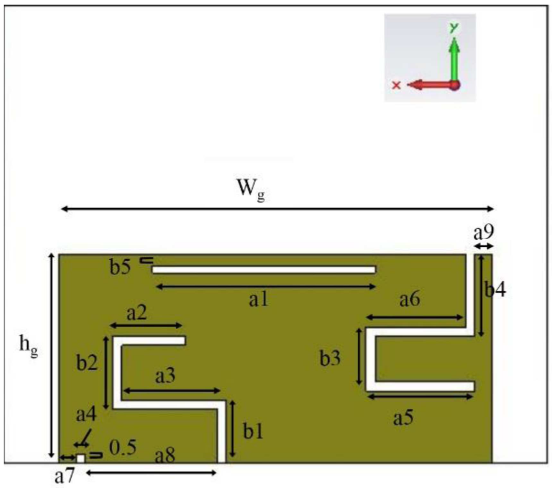

Figure 1b. Proposed antenna geometry-rear view.

Table 1. Parameters of proposed design.

Parameters	L_s	W_s	h_g	W_g	$x1$	$x2$	$x3$	$x4$	$y1$	$y2$	$y3$	$y4$	$y5$	$y6$
Value (mm)	30	30	11.5	24	3.2	2	9	4.24	6.5	5.47	16.45	12	3	2.12
Parameters	$a1$	$a2$	$a3$	$a4$	$a5$	$a6$	$a7$	$a8$	$a9$	$b1$	$b2$	$b3$	$b4$	$b5$
Value (mm)	12.4	3	5.75	0.5	6	5.5	1	7.25	1	3.5	4	3.5	4.5	0.6

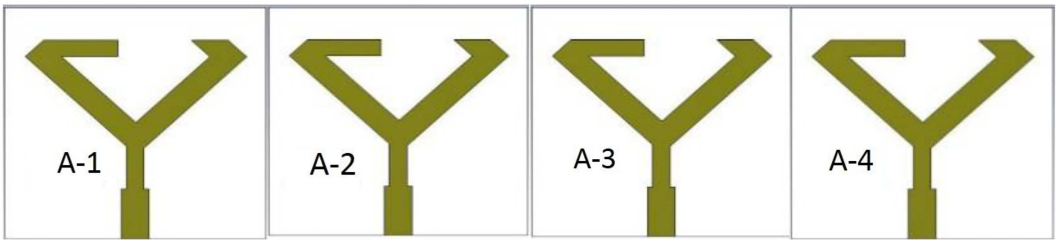

Figure 2a. Evolution steps of proposed design - front side.

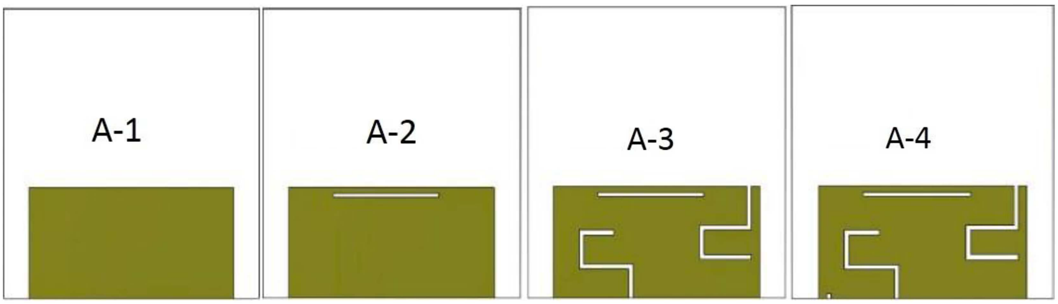

Figure 2b. Evolution steps of proposed design - rear side.

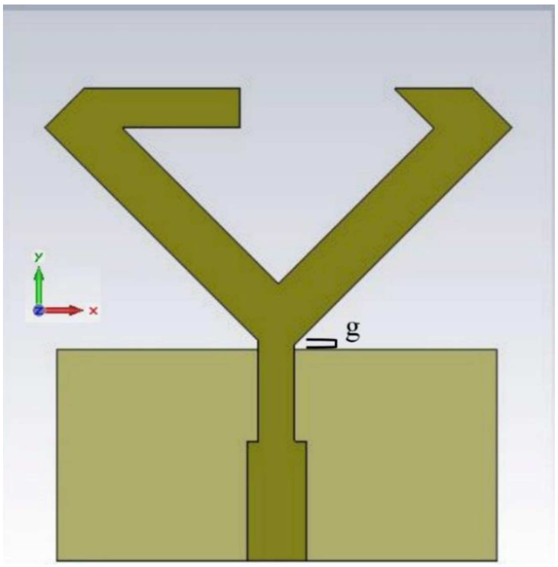

Figure 3. Proposed antenna A-1.

ground plane and gap (g) forms an equivalent dipole antenna. The fundamental resonant frequency of the design is calculated by using the length of antenna. The wideband response of antenna is attributed to the overlapping of closely spaced multiple resonances (harmonics of fundamental resonance). The radiation patterns of the monopole antenna in general resembles with that of a dipole antenna and therefore planar printed monopole antenna can be considered as printed dipole antenna [23].

The lower cut off frequency of antenna is estimated by associating its area equal to that of an equivalent cylindrical monopole antenna of same length and radius, as given:

$$f_L = \frac{14.4}{L_P + L_g + g + R_P + R_g} \text{ GHz}, \tag{1}$$

where L_p is the length of radiating patch in cm; L_g the length of ground plane in cm; g the gap between patch and ground plane in cm.

The R_p and R_g are the radii of cylindrical dipole equivalent to the radiating patch and ground plane respectively as given below:

$$R_P = \frac{Area\ of\ Patch}{2\pi L_P\sqrt{\varepsilon_{re}}} = \frac{L_P W_P}{2\pi L_P\sqrt{\varepsilon_{re}}}, \tag{2}$$

$$R_g = \frac{Area\ of\ Ground}{2\pi L_g\sqrt{\varepsilon_{re}}} = \frac{L_g W_g}{2\pi L_g\sqrt{\varepsilon_{re}}}, \tag{3}$$

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2}, \tag{4}$$

where, ε_r is the dielectric constant of substrate and ε_{re} is the approximate effective dielectric constant of the composite dielectric (air-substrate).

For L_p = 4.84 cm, L_g = 1.15 cm, g = 0.05 cm, R_p = 0.23 cm and R_g = 0.02 cm, the value of lower cut off frequency calculated from the Eq. (1) is $\approx$ 2.97 GHz. The dimensions of the patch and ground plane are optimized for the almost UWB frequency range from 2.85 – 10.34 GHz as shown in Figure 4.

(b) **Design Step II (Antenna A-2):**
It is well known fact that the loading of slot on the ground plane increases the current path,

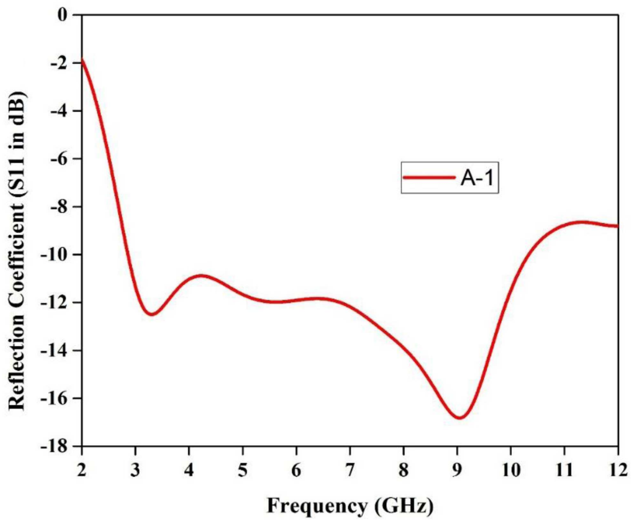

Figure 4. Simulated reflection coefficient (S11) vs frequency plot for antenna A-1.

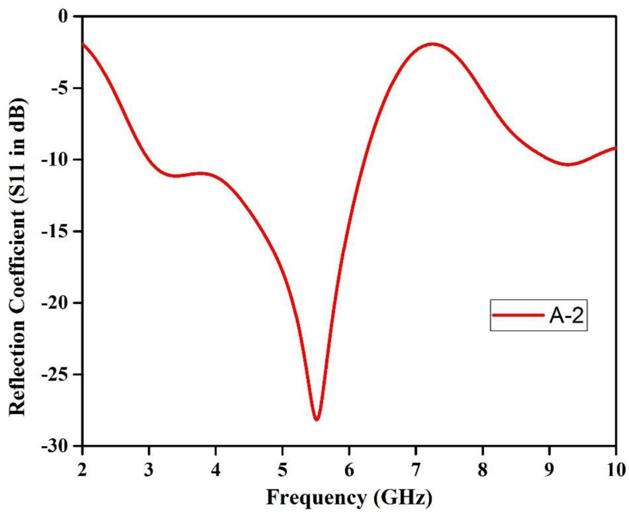

Figure 5. Simulated reflection coefficient (S11) vs frequency for A-2.

which results in modification of inductance and capacitance and ultimately the antenna impedance. Thus matching between antenna impedance and microstrip feed line is increased and hence the coupling of energy for radiation [24].

Here the UWB antenna A-1 is modified into a single resonant wideband antenna structure by etching a slot of 0.5 mm length and 12.4 mm width on the upper edge of ground plane width as shown in Figure 2b. The modified antenna structure is labeled as antenna A-2, while keeping other dimensions unchanged. The antenna A-2 has resonating frequency 2.98–6.24 GHz with 5.51 GHz resonant frequency is impedance matched to −28 dB as shown in Figure 5.

(c) **Design Step III (Antenna –III):**
The wide-band behavior of antenna A-2 is further

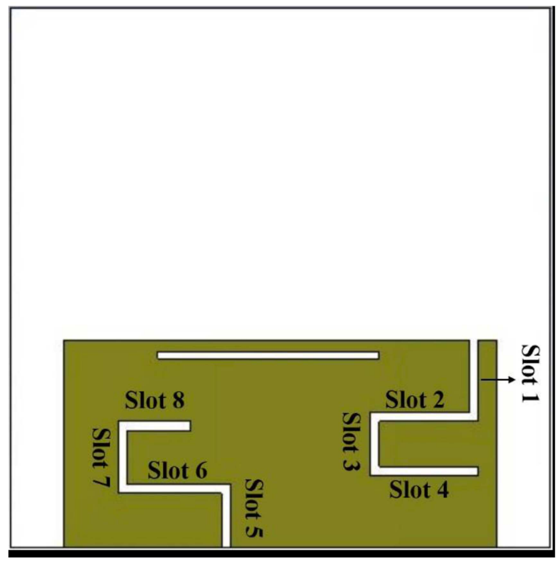

Figure 6. Ground plane of antenna A-3 with hook shaped slots.

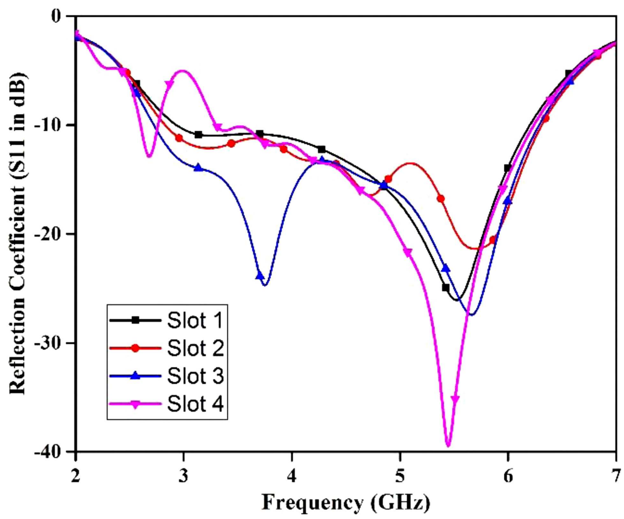

Figure 7a. Simulated reflection coefficient (S11) vs frequency plot for horizontal and vertical slots (hook shapes) on ground plane of design A-3.

modified and matched to three wideband resonant modes for WLAN and Wi-MAX by etching two hook shaped slot on the partial ground plane as shown in Figure 6.

From the parametric study of reflection coefficient for different vertical and horizontal slots are as displayed in Figure 7a and 7b respectively. The three resonating bands are 2.54–2.74 GHz, 3.13–4.4 GHz and 4.6–6.1 GHz observed with 2.64, 3.40 and 5.64 GHz resonant frequencies respectively.

(d) **Design step IV (Antenna–IV):**
Although, the simulated resonant frequencies includes the prescribed frequency bands for WLAN and Wi-MAX [25,26], but these band ranges have values which are quite large than prescribed limit.

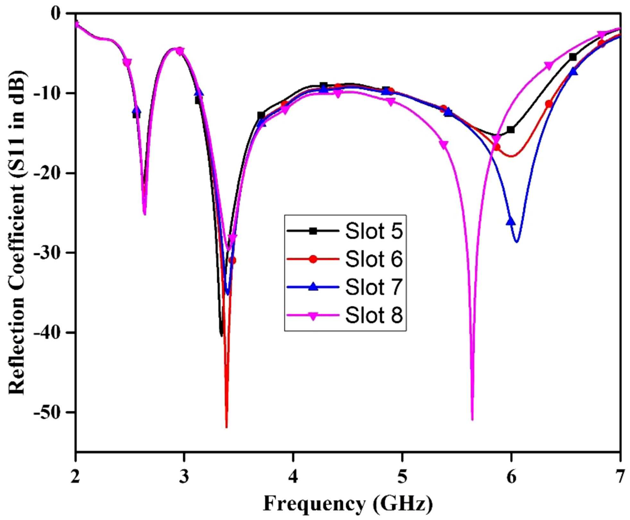

Figure 7b. Simulated reflection coefficient (S11) vs frequency plot for horizontal and vertical slots (hook shapes) on ground plane of design A-3.

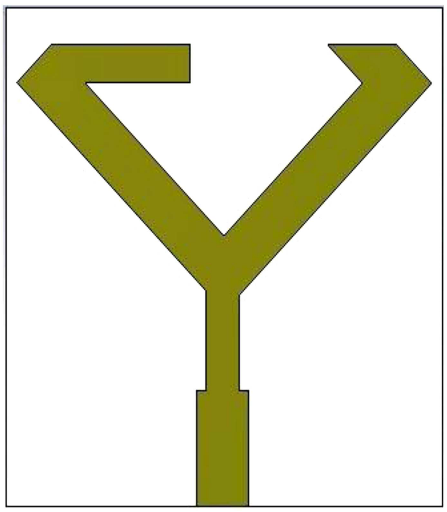

Figure 8a. Final proposed antenna geometry (A-4)–front view.

To squeeze the frequency bands more close to the prescribed values, a square slot of dimension 0.5 mm is etched on the lower edge of the ground plane as shown in Figures 8a and 8b and design is labeled as antenna A-4.

The antenna A-4 resonating in 2.54–2.72 GHz, 3.1–3.94 GHz and 4.86–6.1 GHz with resonant frequencies 2.63, 3.34, and 5.67 GHz as depicted in Figure 9 for S11 plot. The squeeze in frequency bands are also observed.

To understand the working mechanism and relationship among resonant [27,28] frequency and antenna parameters, the simulated surface current distribution for resonant frequencies i.e, 2.63, 3.34, and 5.67 GHz are visualized by CST simulation software and plotted in Figures 10a–10f. It can

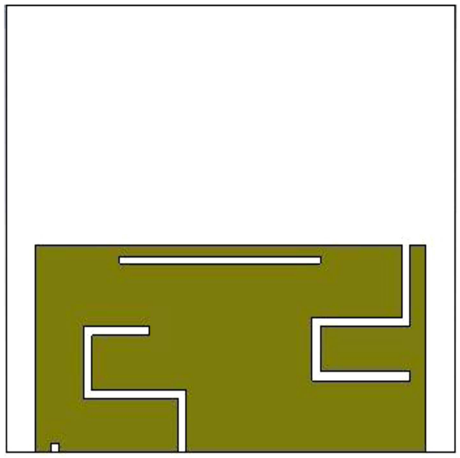

Figure 8b. Final proposed antenna geometry (A-4)–rear view.

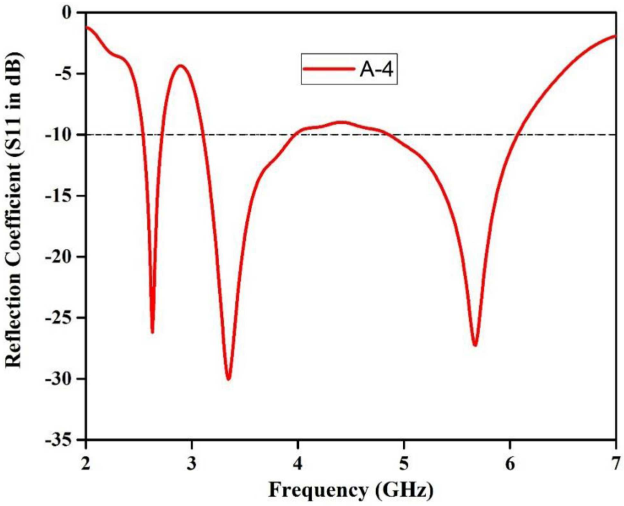

Figure 9. Simulated reflection coefficient (S11) vs frequency plot for antenna A-4.

be clearly seen that at different resonant frequencies, the current has different distribution on the antenna.

At 2.63 GHz, the current is more concentrated on the hook from the upper outline than the bottom line as shown in Figures 10a and 10b. In Figures 10c and 10d for 3.34 GHz resonant frequency, the surface current is more distributed on the short arm length than longer arm of radiating patch and on both the hook shaped slots on the ground plane with much concentrated near to the bottom line hook. While at 5.67 GHz, surface current is distributed on both the arms of radiating patch, on the ground plane it is more concentrated around the horizontal slot and bottom line hook as evident from Figures 10e and 10f.

4. Results and discussions

After optimization, the proposed antenna geometry

Table 2. Operating states of antenna.

	Operating band		BW	
S. no.	Simulated (GHz)	Measured (GHz)	Simulated (GHz)	Measured (GHz)
1	2.52 – 2.71	2.55 – 2.70	0.19	0.15
2	3.11 – 4	3.06 – 3.98	0.89	0.92
3	4.84 – 6.05	4.99 – 6.2	1.21	1.21

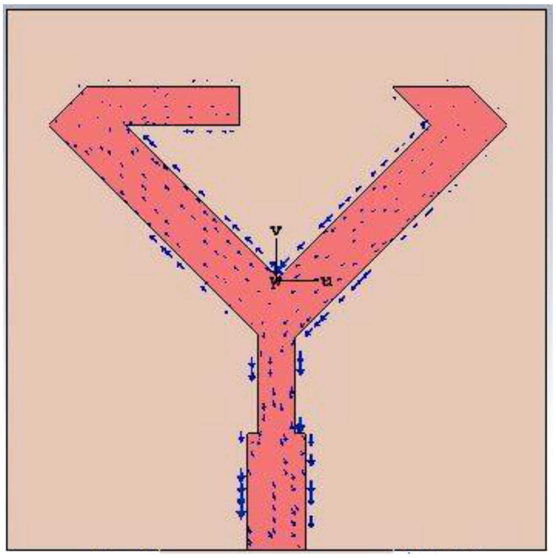

Figure 10a. Surface current distribution on front side at resonant frequency $f = 2.68$ GHz.

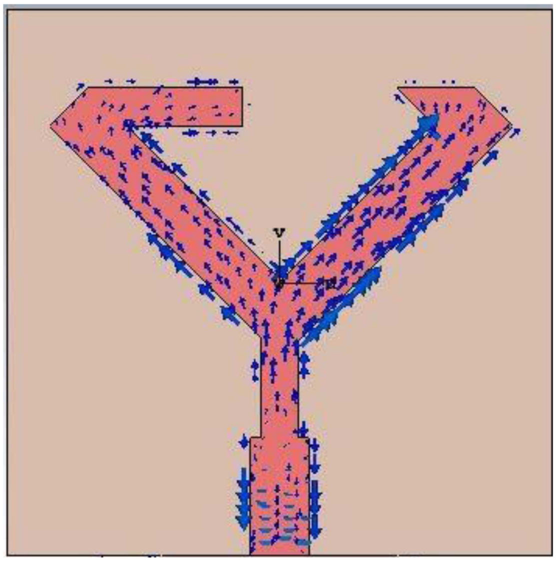

Figure 10c. Surface current distribution on front side at resonant frequency $f = 3.34$ GHz.

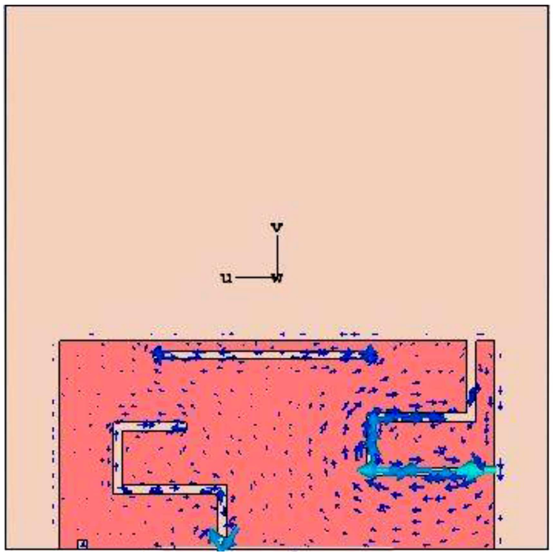

Figure 10b. Surface current distribution on rear side at resonant frequency $f = 2.68$ GHz.

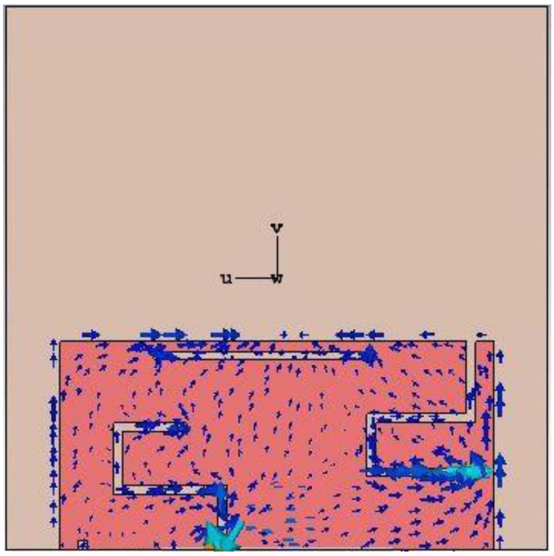

Figure 10d. Surface current distribution on rear side at resonant frequency $f = 3.34$ GHz.

was prototyped on FR-4 substrate. The front and rear view of fabricated antenna design is shown in Figure 11a and 11b. The antenna is measured with Agilent N5234A vector network analyzer.

The simulated and measured reflection coefficient versus frequency for the operating states of antenna is presented in Figure 12 and Table 2 respectively. The measured operating bands of final designs are 2.55 – 2.70, 3.06 – 3.98 and 4.99 – 6.2 GHz, covering the Wi-MAX and WLAN bands successfully. Satisfactory

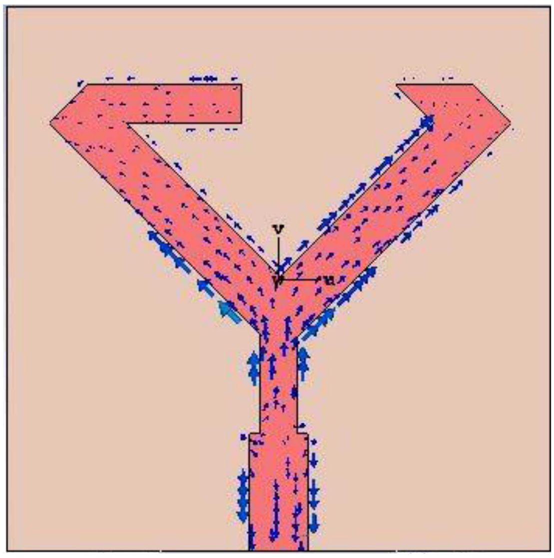

Figure 10e. Surface current distribution on front side at resonant frequency $f = 5.72$ GHz.

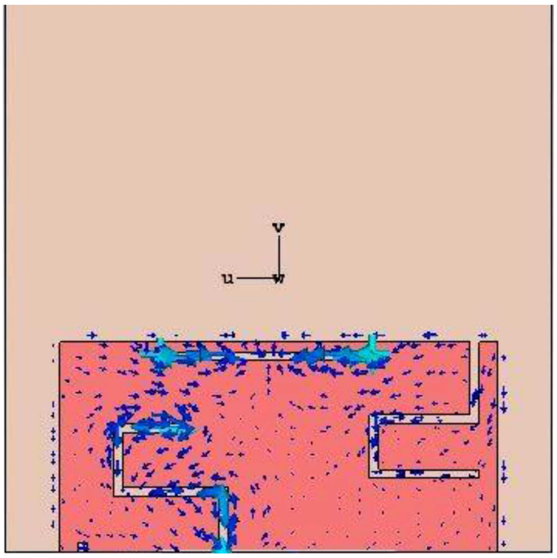

Figure 10f. Surface current distribution on rear side at resonant frequency $f = 5.72$ GHz.

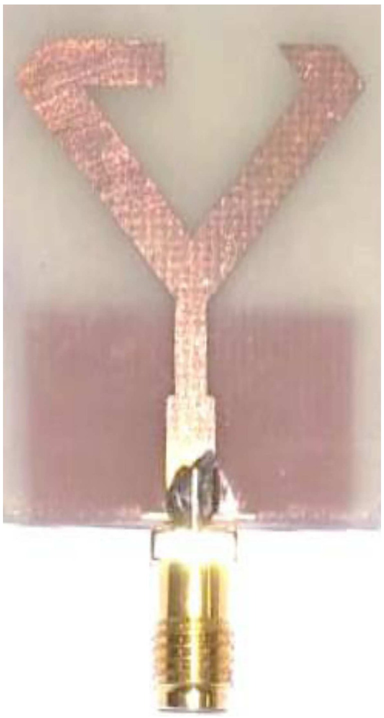

Figure 11a. Fabricated Y-shaped antenna–front view.

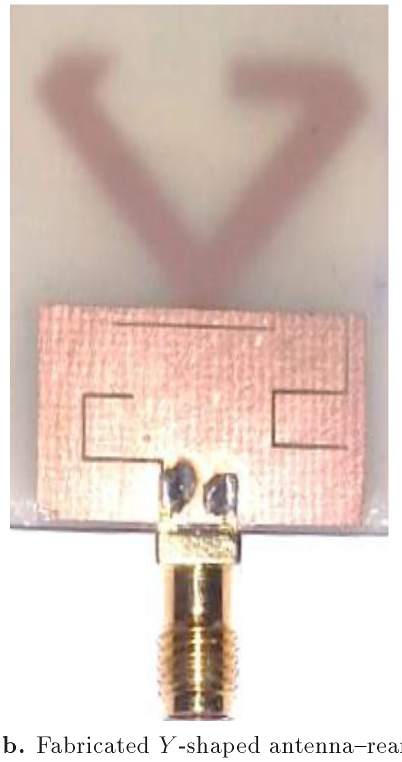

Figure 11b. Fabricated Y-shaped antenna–rear view.

agreement between simulated and measured results are observed with minor discrepancies, which are probably due to error in fabrication process, measurement environment, feed wires and substrate losses.

The radiation pattern and gain of the suggested antenna were measured in anechoic chamber. The measured normalized E-field radiation pattern for resonating frequencies 2.68, 3.75 and 5.72 GHz as shown in Figure 13a–13c. It is observed that E-field radiation pattern is omnidirectional at 2.68 GHz and bidirectional at 3.75 and 5.72 GHz. The peak antenna gains for frequencies are 0.5 dBi at 2.68 GHz, 1.08 dBi for 3.75 GHz and 2.4 dBi for 5.72 GHz respectively.

Table 3 presents the comparison of proposed antenna design with previously reported work. The designs are single fed either by microstrip line or coaxial probe or coplanar waveguide (CPW). The multi-band resonant behavior of all designs attributes to strips, slots and stubs with disadvantages like large physical size [3,7,10,12,14], narrowband at low frequency [3,6], expensive [4,15], complex structure [6,12–14], not

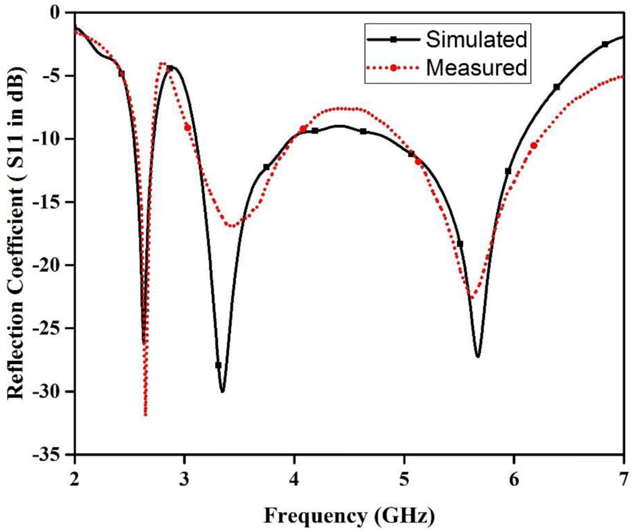

Figure 12. Simulated and measured reflection coefficients (S11) vs frequency plot of Y-shaped antenna.

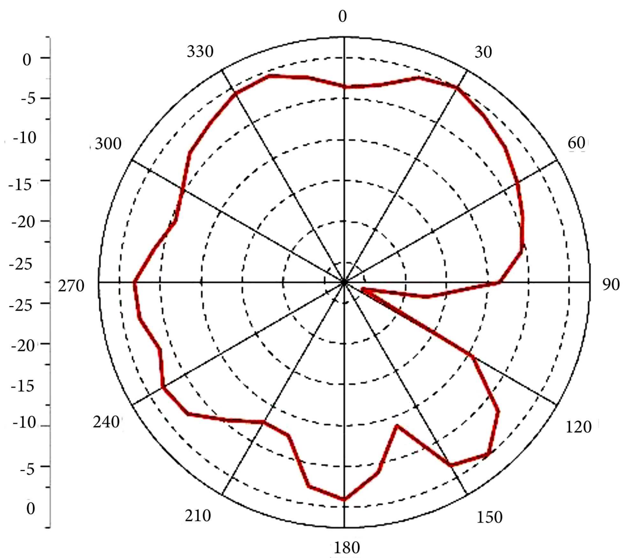

Figure 13a. Measured E- field radiation patterns at resonating frequencey $f = 2.68$ GHz.

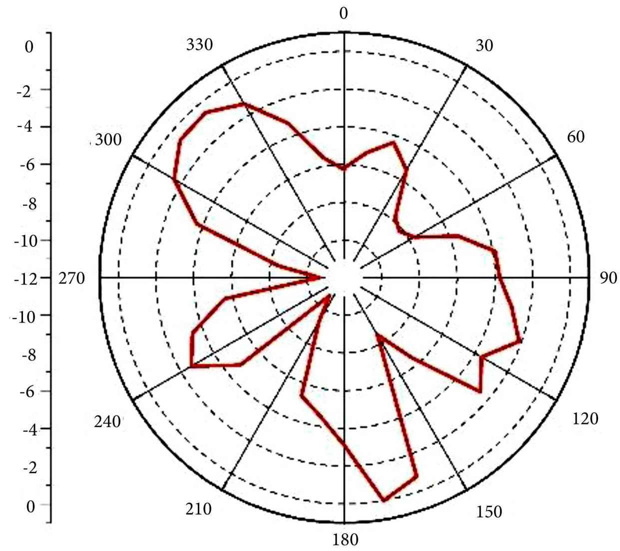

Figure 13b. Measured E- field radiation patterns at resonating frequency $f = 3.75$ GHz.

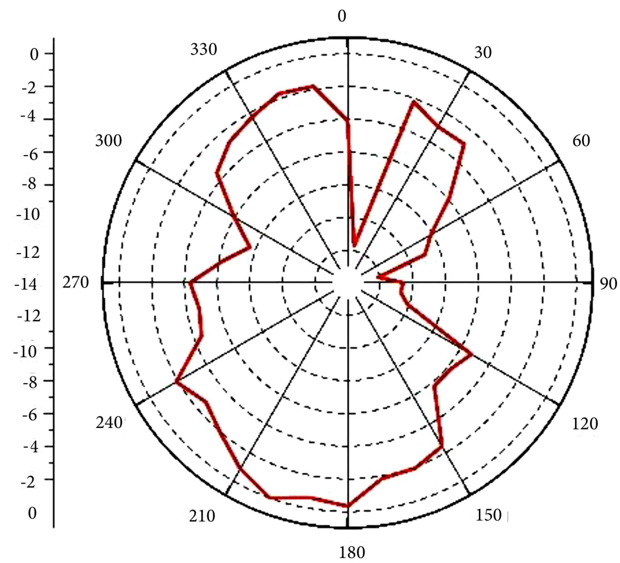

Figure 13c. Measured E- field radiation patterns at resonating frequenceies $f = 5.72$ GHz.

very stable radiation pattern [15] and moderate volume [4,6,9,13,15]. The presented antenna is relatively compact in size, simple structure and multiple resonating bands with reasonable impedance bandwidth (IBW) in comparison to other reported design.

5. Conclusion

In this paper, the stepwise realization of microstrip fed Y-shaped monopole with defected ground structure is successfully proposed, simulated and measured for WLAN/Wi-MAX operation with three resonant bands. The proposed antenna has impedance bandwidth for VSWR $<$ 2 lies in the range of 2 – 6 GHZ with two bands for WLAN and one for Wi-MAX. The good agreement between the simulated and experimental performance of the antenna in free space validates the design concept and method. The simple geometry, compact size, wideband, multi-band functionality and stable radiation pattern makes the antenna design suitable for WLAN/Wi-MAX applications.

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Table 3. Comparison of proposed design with reported work.

Reported works	Dimensions (mm)	Material	Frequency bands (GHz)	Resonant freq. (GHz)	BW (%)
[3]	$50 \times 50 \times 1.6$	FR-4	2.08 – 2.17 3.47 – 3.54 5.325 – 5.675	2.12 3.5 5.6	4.2 2 6.2
[4]	$35 \times 45 \times 1.5$	Arlon AD255A	2.33 – 2.55 3.40 – 3.56 4.26 – 8.11	2.4 3.5 5.8	9.16 7.43 66.4
[6]	$35 \times 19 \times 1.6$	FR-4	2.38 – 2.5 3.35 – 3.67 4.76 – 6.55	2.45 3.5 5.5	4.89 9.14 32.5
[7]	$40 \times 54 \times 1.6$	FR-4	2 – 2.6 3.21 – 3.51 3.8 – 6.38	2.4 3.4 5.8	26 8.9 50.6
[9]	$28.1 \times 32 \times 1.6$	FR-4	1.5 – 2.2 4 – 4.3 6 – 7 8.2 – 10.68	1.85 4.15 6.5 9.5	40 7.23 15.4 26
[10]	$70 \times 44 \times 1.6$	FR-4	2.35 – 2.77 5.47 – 6.10	2.5 5.8	16.4 10.9
[12]	$40 \times 50 \times 1.6$	FR-4	1.92 – 2.16 3.5 – 3.68 5.16 – 5.36	2.06 3.56 5.2	11.2 5.14 3.9
[13]	$30 \times 35 \times 1.6$	FR-4	2.3 – 2.62 2.63 – 2.9 3.3 – 4.8 5 – 8.02	2.46 2.765 4.05 6.51	13 9.74 37 46.4
[14]	$30 \times 65 \times 1.6$	FR-4	2.375 – 2.525 3.075 – 3.8 5 – 6.9	2.45 3.5 5.2, 5.8	6.1 21.1 31.9
[15]	$26 \times 36 \times 1.6$	$\varepsilon_r = 3.5$	2.38 – 2.82 3.32 – 3.88 5.13 – 6.53	2.6 3.6 5.83	16.9 15.6 24.01
Proposed design	$25.5 \times 26 \times 1.6$	FR-4	2.55 – 2.7 3.06 – 3.98 4.99 – 6.2	2.68 3.75 5.72	5.6 26.67 21.53

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