

Compact Y- Shaped Antenna with partial and meandered ground for WLAN/Wi-MAX Applications

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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 wide bands. It operates at the frequencies of 2.68 GHz, 3.75 GHz and 5.72GHz for WLAN and Wi-MAX applications. The compact antenna has a size of $30 \times 30 \times 1.59 \text{ mm}^3$ and stable radiation patterns are obtained at resonant frequencies.

Keywords: Wi-MAX, UWB, slot, edge feeding.

I. 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 (WiMAX). 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 WiMAX applications.

Complex antenna structures fed by coplanar waveguide are used to generate WLAN and WiMAX 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 WiMAX 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-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 WiMAX and WLAN wide bands. The simulation and experimental results are presented in the manuscript.

II. ANTENNA DESIGN METHODOLOGY

The proposed antenna structure in fig. 1 (a) – (b) is fabricated on 1.59 mm thick FR-4 substrate ($\epsilon_r = 4.3$, $\tan \delta = 0.025$). 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 y_1 , y_2 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 (50Ω) for all states [21-22]. The antenna has a squeezed dimensions of $30 \times 30 \times 1.59 \text{ mm}^3$. The dimensions of the antenna structure is presented in Table I.

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

III. EMPIRICAL FORMULAS FOR WIDEBAND ANTENNA DESIGN AND DESIGN PROCEDURE

(a) Wideband Antenna Design (A-1):

The wide band 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 $h_g \times W_g \text{ mm}^2$ as shown in fig. 3.

It is realized that the radiating patch, partial 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

$$f_L = \frac{14.4}{L_p + L_g + g + R_p + R_g} \text{ GHz} \quad (1)$$

Where, L_p = Length of radiating patch in cm
 L_g = Length of ground plane in cm
 g = 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.

$$R_p = \frac{\text{Area of Patch}}{2\pi L_p \sqrt{\epsilon_{re}}} = \frac{L_p W_p}{2\pi L_p \sqrt{\epsilon_{re}}} \quad (2)$$

$$R_g = \frac{\text{Area of Ground}}{2\pi L_g \sqrt{\epsilon_{re}}} = \frac{L_g W_g}{2\pi L_g \sqrt{\epsilon_{re}}} \quad (3)$$

$$\epsilon_{re} = \frac{\epsilon_r + 1}{2} \quad (4)$$

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 $L_p = 4.84 \text{ cm}$, $L_g = 1.15 \text{ cm}$, $g = 0.05 \text{ cm}$, $R_p = 0.23 \text{ cm}$ and $R_g = 0.02 \text{ cm}$, the value of lower cut off frequency calculated from the Equation 1 is $\approx 2.97 \text{ GHz}$. 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 fig. 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, 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 wide band 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 fig. 2 (b). 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 fig. 5.

(c) Design Step III (Antenna –III):

The wide-band behavior of antenna A-2 is further modified and matched to three wide band resonant modes for WLAN and WiMAX by etching two hook shaped slot on the partial ground plane as shown in fig. 6.

From the parametric study of reflection coefficient for different vertical and horizontal slots are as displayed in fig. 7 (a) – (b) 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 WiMAX [25-26], but these band ranges have values which are quite large than prescribed limit. 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 fig. 8 (a) – (b) 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 fig. 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 fig. 10 (a) – (f). It can 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 fig. 10 (a) – (b). In fig. 10 (c) – (d) 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 fig. 10 (e) – (f).

IV. RESULTS AND DISCUSSIONS

After optimization, the proposed antenna geometry was prototyped on FR-4 substrate. The front and rear view of fabricated antenna design is shown in fig. 11 (a) – (b). 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 fig. 12 and Table II 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 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 fig. 13 (a) – (c). 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 III 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 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.

V. 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 /WiMAX 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 WiMAX. 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 /WiMAX applications.

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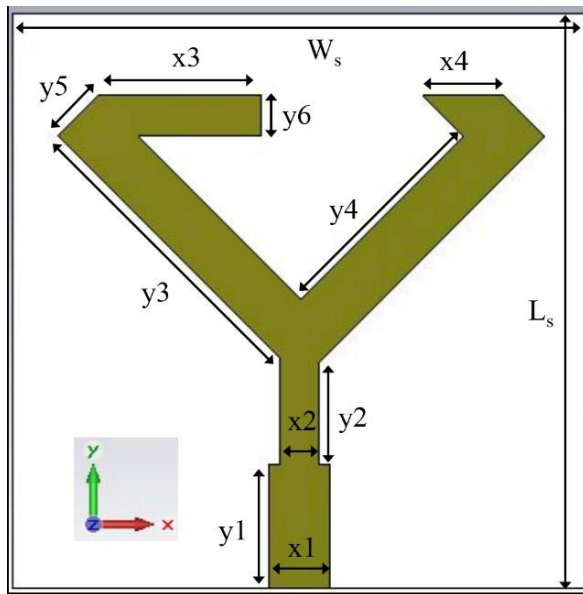


Fig. 1 (a) Proposed antenna geometry – front view

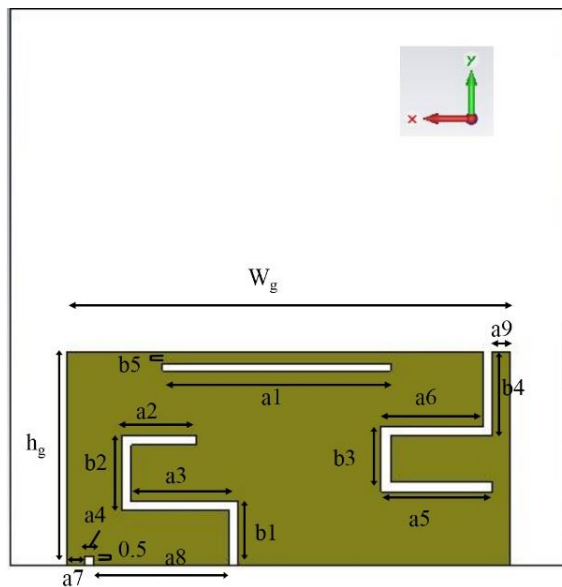


Fig. 1 (b) Proposed antenna geometry – rear view

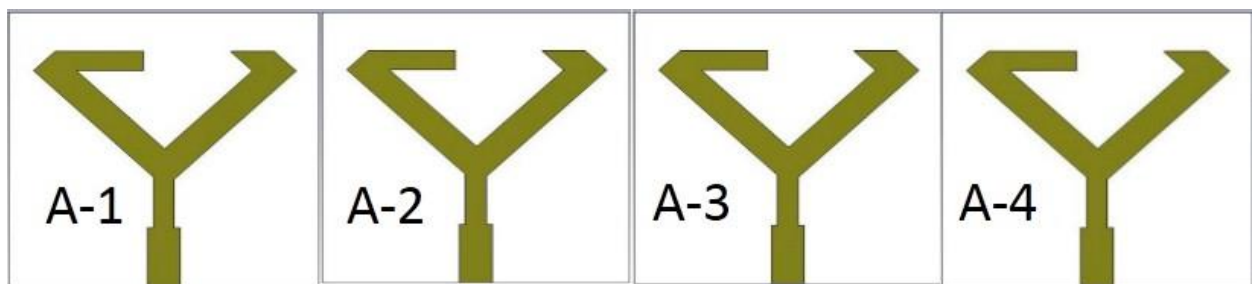


Fig. 2 (a) Evolution steps of proposed design - front side

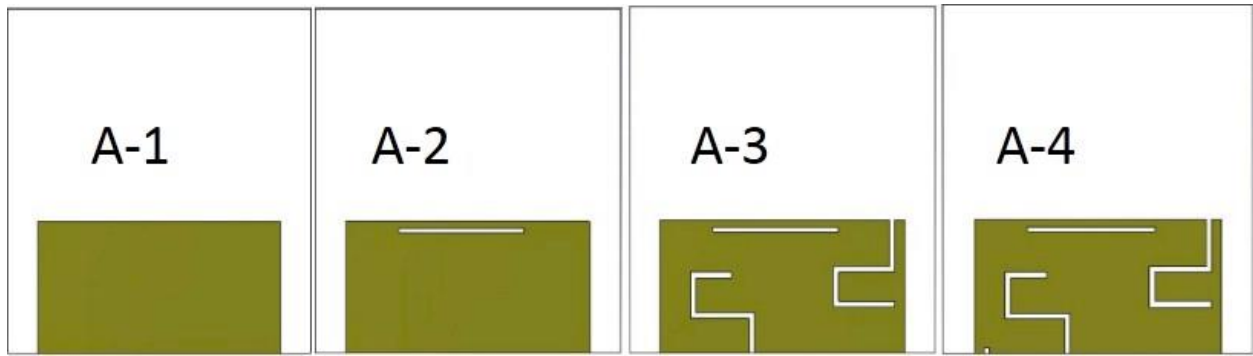


Fig. 2 (b) Evolution steps of proposed design - rear side

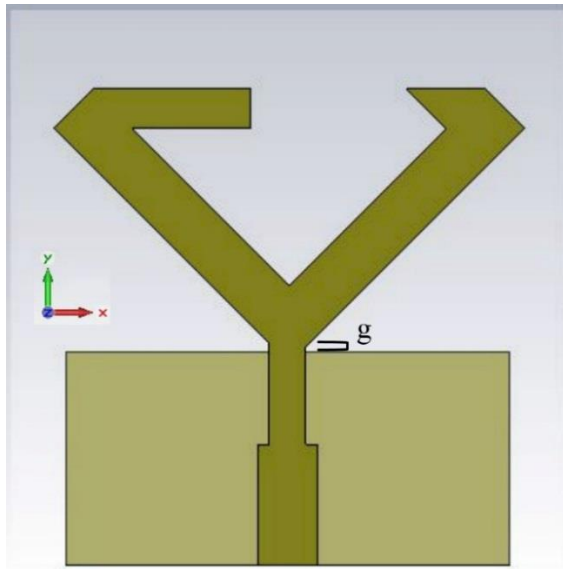


Fig. 3 Proposed antenna A-1

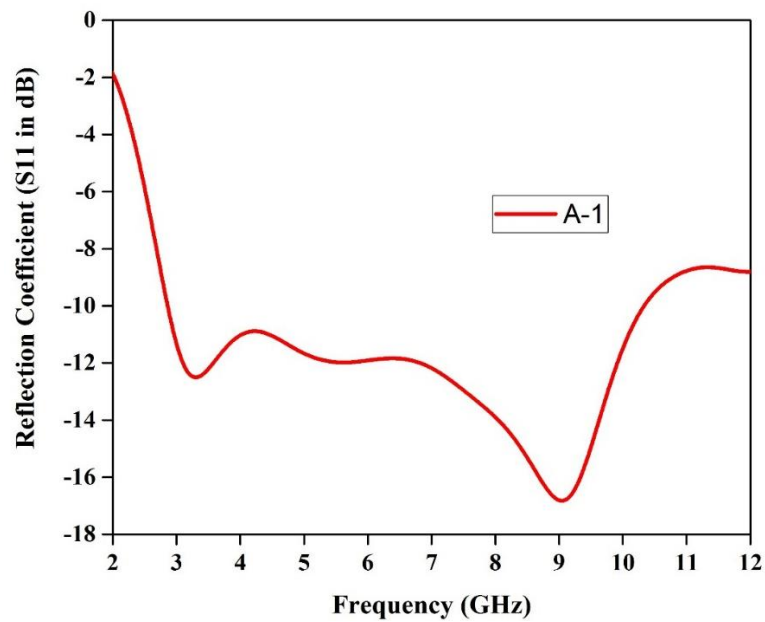


Fig. 4. Simulated reflection coefficient (S11) Vs frequency plot for antenna A-1

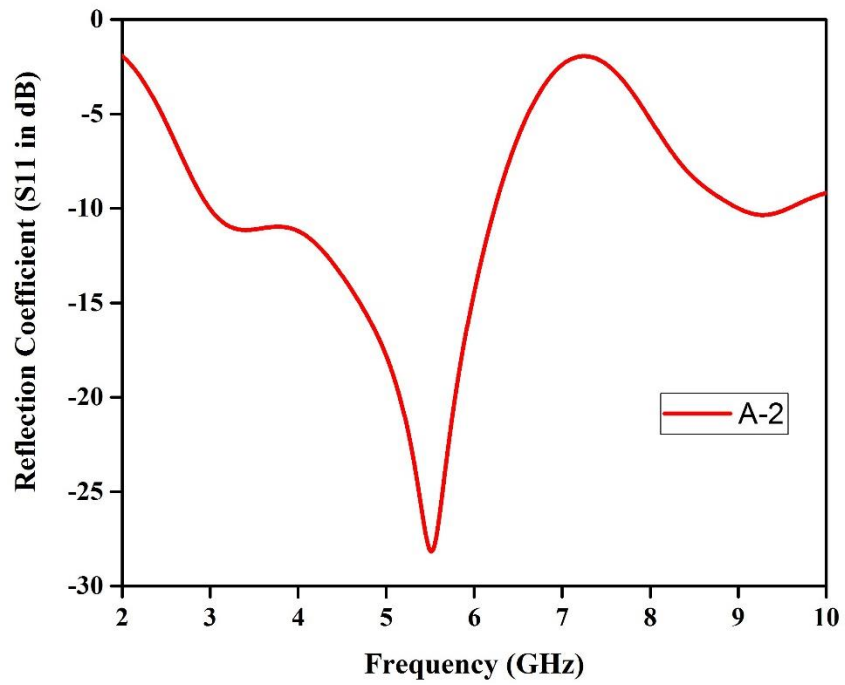


Fig. 5 Simulated reflection coefficient (S11) Vs frequency for A-2

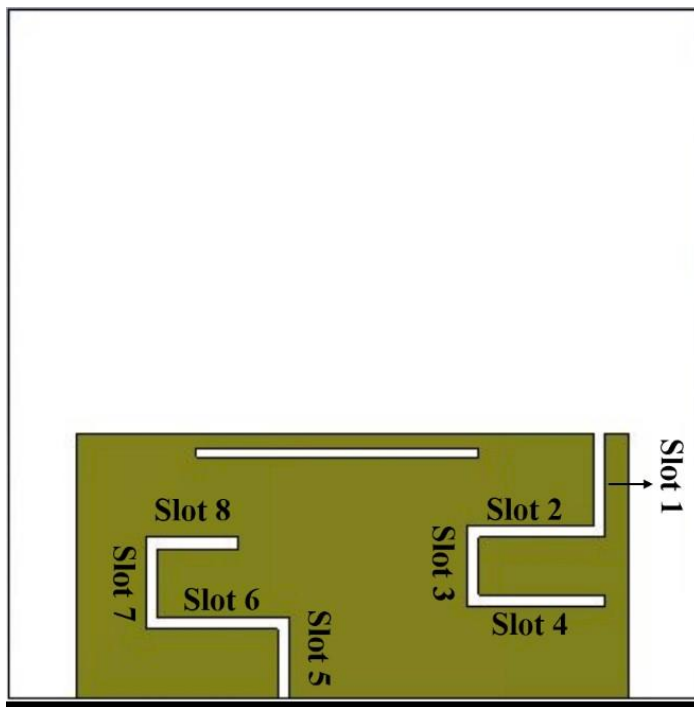


Fig. 6 Ground plane of antenna A-3 with hook shaped slots

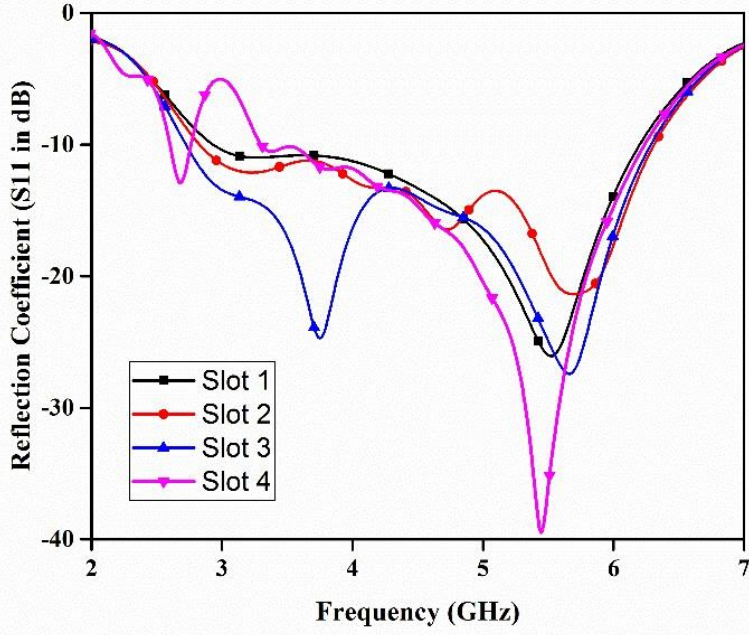


Fig. 7 (a) Simulated reflection coefficient (S11) Vs frequency plot for horizontal and vertical slots (hook shapes) on ground plane of design A - 3

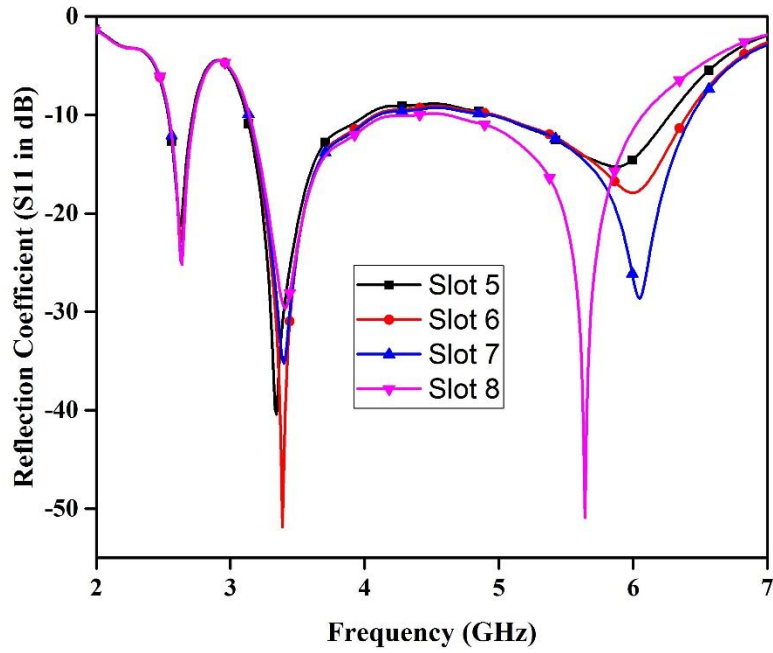


Fig. 7 (b) Simulated reflection coefficient (S11) Vs frequency plot for horizontal and vertical slots (hook shapes) on ground plane of design A - 3

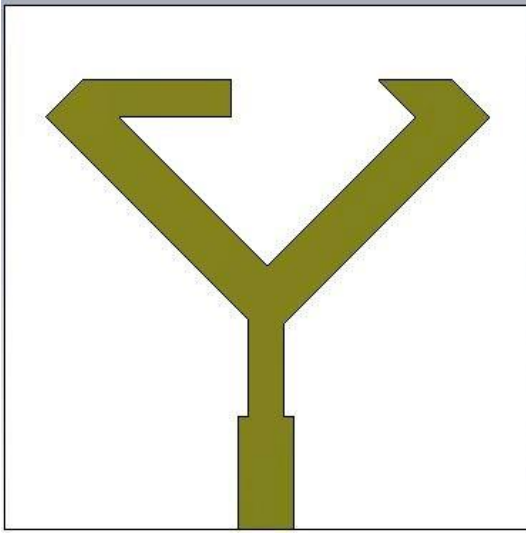


Fig. 8 (a) Final proposed antenna geometry (A-4) - front view

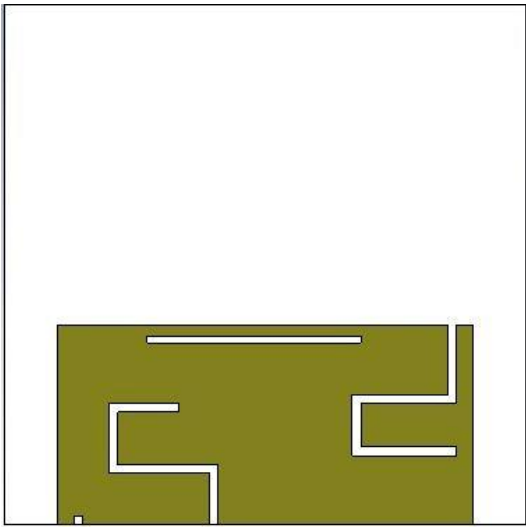


Fig. 8 (b) Final proposed antenna geometry (A-4) – rear view

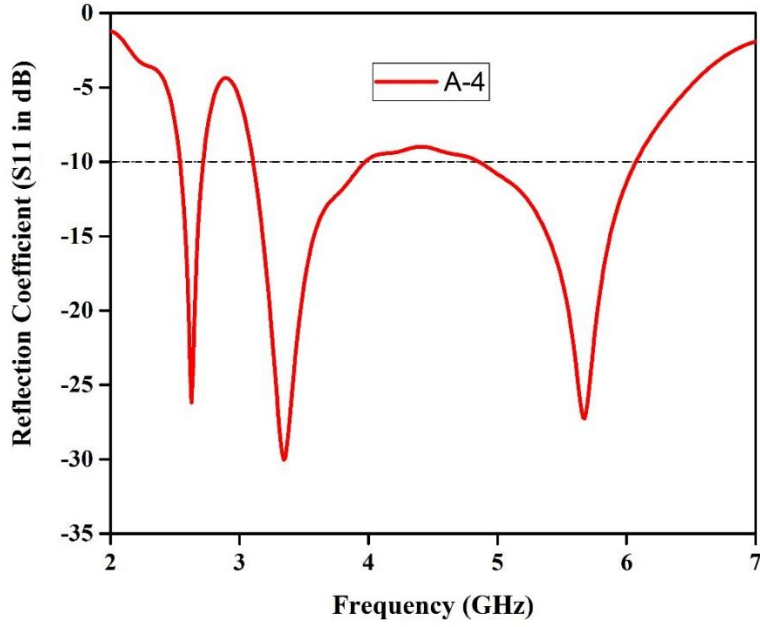


Fig. 9 Simulated reflection coefficient (S11) vs frequency plot for antenna A-4

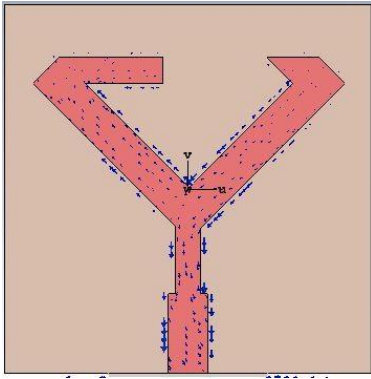


Fig. 10 (a) Surface current distribution on front side at resonant frequency $f = 2.68$ GHz

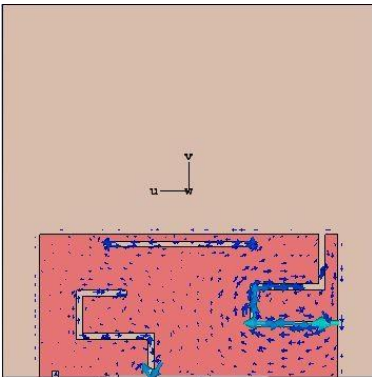


Fig. 10 (b) Surface current distribution on rear side at resonant frequency $f = 2.68$ GHz

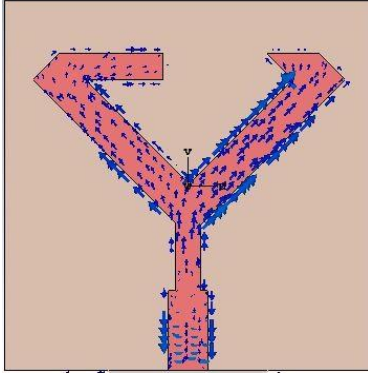


Fig. 10 (c) Surface current distribution on front side at resonant frequency $f = 3.34$ GHz

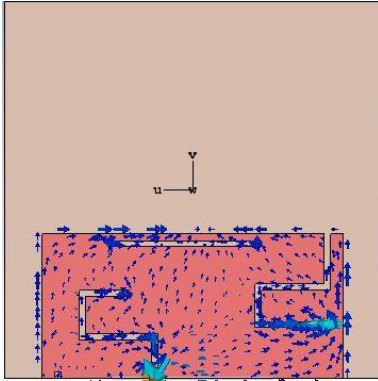


Fig. 10 (d) Surface current distribution on rear side at resonant frequency $f = 3.34$ GHz

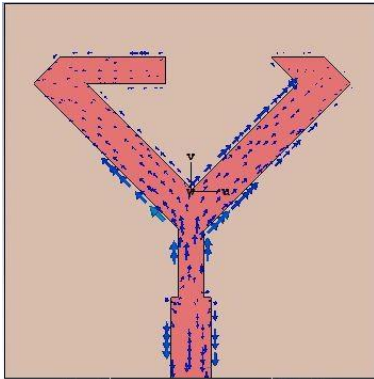


Fig. 10 (e) Surface current distribution on front side at resonant frequency $f = 5.72$ GHz

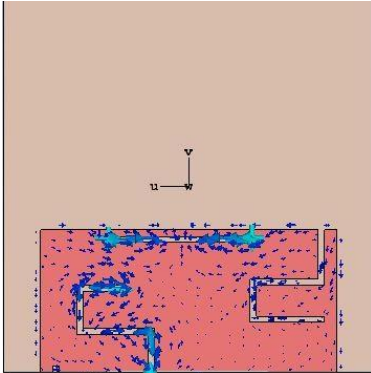


Fig. 10 (f) Surface current distribution on rear side at resonant frequency $f = 5.72$ GHz



Fig. 11 (a) Fabricated Y-shaped antenna – front view



Fig. 11 (b) Fabricated Y-shaped antenna – rear view

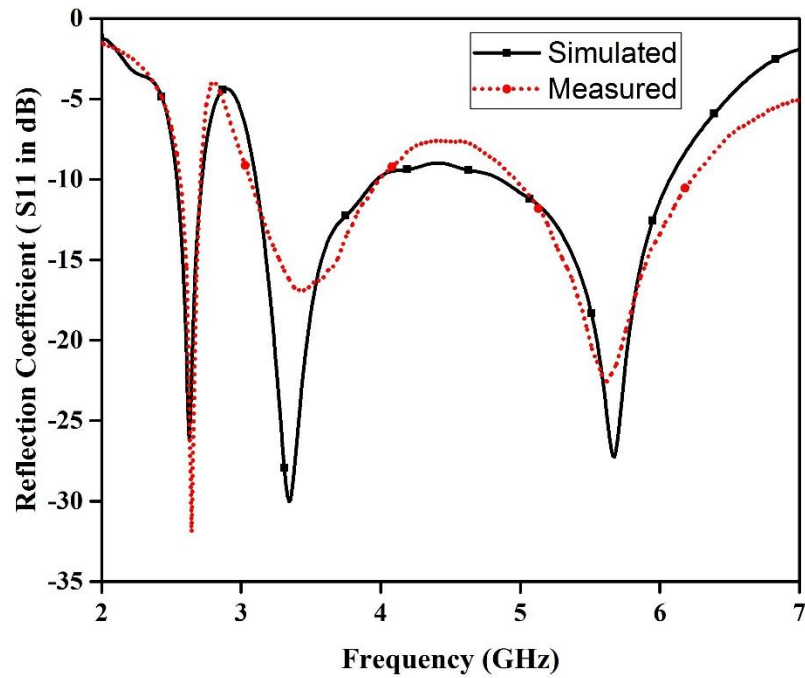


Fig. 12 Simulated and measured reflection coefficients (S11) vs frequency plot of Y-shaped Antenna

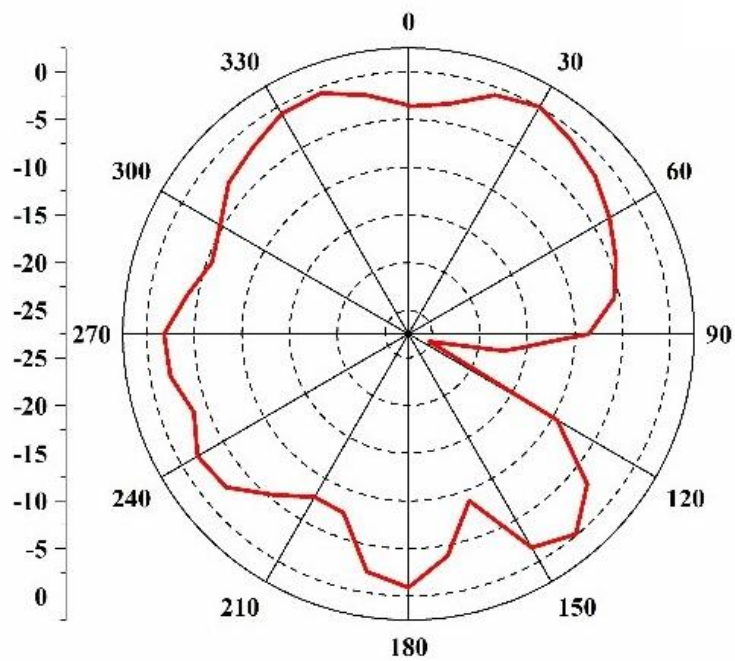


Fig.13 (a) Measured E- field radiation patterns at resonating frequency $f = 2.68$ GHz

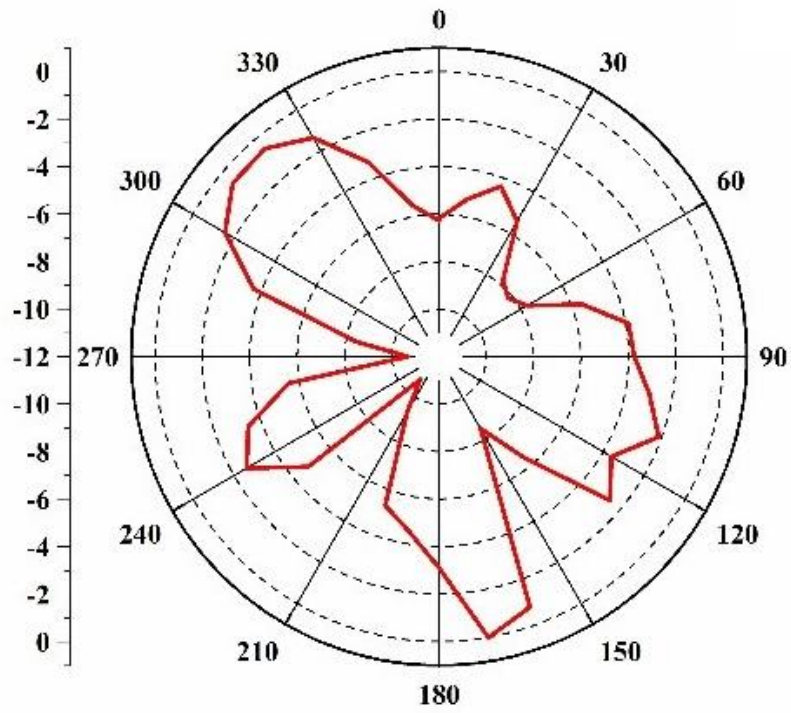


Fig. 13 (b) Measured E- field radiation patterns at resonating frequency $f = 3.75$ GHz

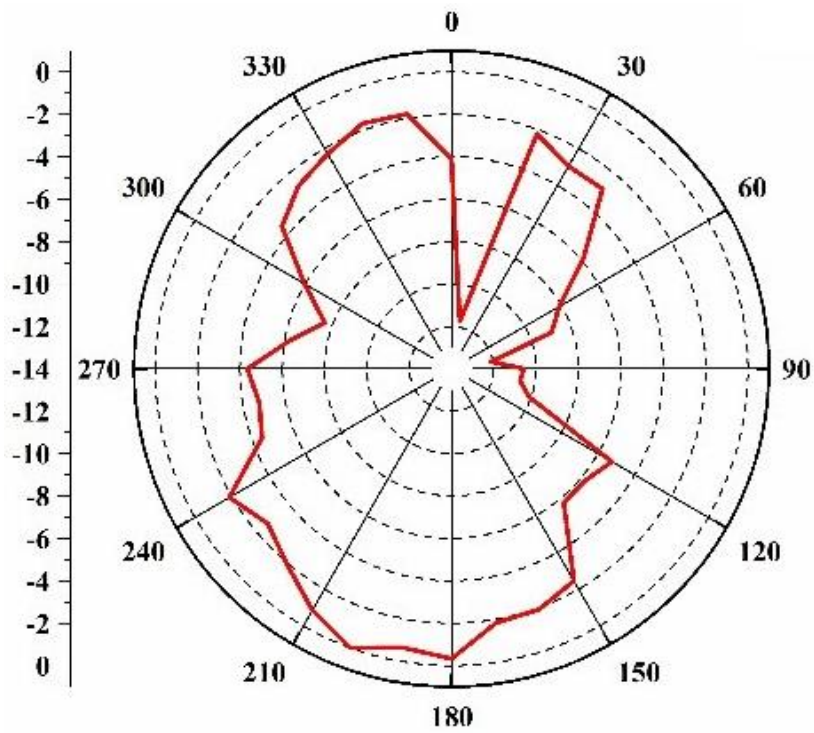


Fig. 13 (c) Measured E- field radiation patterns at resonating frequencies $f = 5.72$ GHz

TABLE I 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

Table II Operating states of antenna

S. No.	Operating Band		BW	
	Simulated	Measured	Simulated	Measured
	GHz		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

TABLE III Comparison of proposed design with reported work

Reported works	Dimensions (mm)	Material	Frequency Bands (GHz)	Resonant Freq. (GHz)	BW (%)
[3]	50×50×1.6	FR-4	2.08 - 2.17	2.12	4.2
			3.47 - 3.54	3.5	2
			5.325 - 5.675	5.6	6.2
[4]	35×45×1.5	Arlon AD255A	2.33 - 2.55	2.4	9.16
			3.40 - 3.56	3.5	7.43
			4.26 - 8.11	5.8	66.4
[6]	35×19×1.6	FR-4	2.38 - 2.5	2.45	4.89
			3.35 - 3.67	3.5	9.14
			4.76 - 6.55	5.5	32.5
[7]	40×54×1.6	FR-4	2 - 2.6	2.4	26
			3.21 - 3.51	3.4	8.9
			3.8 - 6.38	5.8	50.6
[9]	28.1×32×1.6	FR-4	1.5 - 2.2	1.85	40
			4 - 4.3	4.15	7.23
			6 - 7	6.5	15.4
			8.2 - 10.68	9.5	26
[10]	70×44×1.6	FR-4	2.35 - 2.77	2.5	16.4
			5.47 - 6.10	5.8	10.9

[12]	40×50×1.6	FR-4	1.92 - 2.16	2.06	11.2
			3.5 - 3.68	3.56	5.14
			5.16 - 5.36	5.2	3.9
[13]	30×35×1.6	FR-4	2.3 - 2.62	2.46	13
			2.63 - 2.9	2.765	9.74
			3.3 - 4.8	4.05	37
			5 - 8.02	6.51	46.4
[14]	30×65×1.6	FR-4	2.375 - 2.525	2.45	6.1
			3.075 - 3.8	3.5	21.1
			5 - 6.9	5.2,	31.9
				5.8	
[15]	26×36×1.6	$\epsilon_r = 3.5$	2.38 - 2.82	2.6	16.9
			3.32 - 3.88	3.6	15.6
			5.13 - 6.53	5.83	24.01
Proposed Design	25.5×26×1.6	FR-4	2.55 - 2.7	2.68	5.6
			3.06 - 3.98	3.75	26.67
			4.99 - 6.2	5.72	21.53

Brief technical biography:

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Dr. Sanyog Rawat is a Professor in the Department of Electronics and Communication Engineering (ECE) at Manipal University Jaipur. He graduated with a Bachelor of Engineering (B.E.) in Electronics and Communication, Master of Technology (M.Tech) in Microwave Engineering and Ph.D. in the field of Planar Antennas. He has been into teaching and research for more than eighteen years. He has published more than 100 research papers in reputed journals and conferences, and several book chapters. He has supervised five PhDs till date and currently, seven are underway. He has supervised 31 M.Tech dissertations work and nearly 44 UG projects. He has been a member of the Technical Program Committee of many IEEE/Springer conferences, and a reviewer of reputed journals like IEEE/Elsevier/Wiley/Springer. He has also edited the books on proceedings of the International conference on Soft Computing Theories and Applications (SoCTA-2016, 2017), proceedings of International Conference on Smart Systems, Innovations and Computing (SSIC-2017) and International Conference on Engineering Vibrations, Communication, Information Processing (ICoEVCI, 2018) and International Conference for Wireless Communications (ICWC-2021, 2022) for Springer publication. He has extensively travelled to countries like, Japan, Singapore, Malaysia, Vietnam, Indonesia, Thailand, and UAE, to deliver talks, present research papers, or in connection with other research /academic activities. He is a Life Fellow of the Institution of Electronics and Telecommunication Engineers (IETE) India, Life Member of Institution of Engineers (India), Indian Society for Technical Education (ISTE), and Indian Society of Lighting Engineers (ISLE). His current research interests include RF & Microwave devices, Microstrip and Smart Antennas, and Reconfigurable Antennas.

