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Performance Comparison of Various Configurations of Band Notched UWB Antennas

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Keywords
Slot
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Abstract: This paper presents a study on the efficiency and radiation performance of an Ultra-Wideband (UWB) antenna, emphasizing the effect of introducing slots in both the patch and the ground plane. A key challenge in the current design lies in identifying the optimal slot positions without compromising the antenna's radiation pattern. A critical examination is undertaken to choose slot placement in the radiating structure and in the ground Plane. The dimensional size of the Sierpinski fractal antenna is 14.90 x 14.80 x 1.6 mm^3 which covers the entire UWB frequency ranges from 3 GHz to 11GHz. A band notch is created at 5.2GHz (i.e.) wi-fi band with varying meandered slot length in terms of λ. The substrate material used in the design is RT Duroid 5880 ($\varepsilon_r = 2.2$). The antenna that has been designed features impedance matching (S11 < -10 dB) in the entire operating range and the radiation pattern of measured is in agreement with the simulated one. This proves the antenna’s efficacy in usage for portable devices applications.

1. Introduction

With the rapid evolution of wireless communication technologies, there has been an increasing demand for systems that offer high data rates, low power consumption, and efficient spectrum utilization. Ultra-Wideband (UWB) technology has emerged as a promising solution due to its capability to transmit large amounts of data over short distances while occupying a wide frequency range. The U.S. Federal Communications Commission (FCC) further accelerated interest in UWB systems by allocating an unlicensed frequency spectrum for industrial, scientific, and medical applications in 2002. As a result, significant research has been directed towards the design and optimization of UWB antennas to support reliable communication and meet regulatory requirements. One of the key techniques used in UWB antenna design involves the incorporation of slots, which can be strategically placed to enhance bandwidth, shift resonant frequencies, or suppress interference through band-notching. In particular, meander-line slots have gained attention as effective structures for implementing frequency notches, addressing challenges posed by coexisting narrowband systems.

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Various techniques have been proposed in recent years to achieve band-notched characteristics in Ultra-Wideband (UWB) antennas, particularly to mitigate interference from coexisting wireless systems such as WiMAX, WLAN, and X-band satellite communication. Different types of meander slot configuration in antenna falls under the following category which are, rectangular slot [1,2,3,4,5,6,7,8,9,10], circular slot [11,12,13,14], Shaped slots [15,16,17,18,19,20,21,22], Meander line slot [23,24,25,26].

A hexagonal antenna featuring a meandered S-shaped slot was proposed [1]. The slot is introduced on the patch, while an inverted U-shaped slot has been incorporated into the ground plane to achieve dual band notch characteristics. A C-shaped slot carved into the radiating patch has been utilized to form a notched band aimed at World Wide Interoperability for Microwave Access (WiMAX). Furthermore, a slot shaped like an inverted U embedded in the microstrip feedline has been demonstrated to create a secondary notched band, which effectively mitigates interference from Wireless Local Area Network (WLAN) signals. Moreover, the presence of two inverted L-shaped slots on the microstrip line of the ground plane has facilitated notching in the X-band [2]. High levels of isolation and polarization diversity are accomplished by positioning four microstrip-fed lines at right angles, with a parasitic strip serving as a decoupling mechanism to improve isolation further. Additionally, an alternative method was employed to achieve triple band-notched features by incorporating L-shaped and C-shaped slots into each radiator, in conjunction with the integration of Electromagnetic Band Gap (EBG) structures [3]. The application of an elliptical patch alongside a truncated ground structure has been documented to attain a wide impedance bandwidth. In particular, triple band notching was achieved by etching three inverted U-shaped slots onto an elliptical patch [4]. In a distinct design, two C-shaped slots located on the radiating patch facilitated notched bands within the WiMAX and C-band satellite communication frequencies, whereas a spiral-shaped slot etched on the feedline provided an extra notch for the suppression of WLAN interference [5]. A circularly polarized (CP) MIMO antenna with triple rejection bands has also been proposed for UWB applications. This design incorporates slots beneath the feedline and extends stubs from the ground to achieve a broad axial ratio bandwidth (ARBW) [6]. Furthermore, a patch antenna exhibiting an inverted U-shape with both single and dual band-notched features utilizing split-ring resonators (SRRs) has been presented [7]. A tapered-feed circular monopole antenna with an etched ground plane has demonstrated ultra-wide operating bandwidth. In this configuration, a rectangular slot is etched into the circular radiating patch, with two different SRRs placed symmetrically along the feedline [8]. A compact circular-shaped MIMO antenna covering the UWB spectrum and exhibiting four commonly used band-notched characteristics has been proposed for multi-scenario applications [9]. Another approach introduced a circularly notched rectangular radiating structure integrated with an elliptical resonator and a U-shaped slot to achieve effective multi-band rejection [10].

The advancement of Ultra-Wideband (UWB) antennas has attracted considerable interest owing to their capability to facilitate high data rates across extensive frequency ranges while preserving compact sizes. Various designs have been proposed to improve UWB performance, achieve miniaturization, and integrate band-notched features to reduce interference from overlapping wireless systems. A rectangular slot carved into a semicircular partial ground plane was introduced to attain UWB bandwidth. To incorporate dual-band notch features, a U-shaped slot was etched onto a V-shaped radiating patch, and an inverted U-shaped parasitic resonator was placed adjacent to the feedline [11]. A compact UWB MIMO Vivaldi antenna has been developed featuring a T-slot carved between the Vivaldi elements to improve isolation, while a split-ring resonator integrated into the ground plane facilitates band rejection [12]. A wearable UWB slot antenna constructed on a flexible substrate using ultra-thin liquid crystal polymer (LCP) demonstrated stable performance across varying temperatures and humidity conditions [13]. A circular fractal ring monopole antenna with a dual-band rejection feature was also proposed for UWB applications [14]. Penta-band notching was achieved by integrating two mushroom-type Electromagnetic Band Gap (EBG) structures near the feedline to generate two notched bands, and etching three modified U-shaped slots on the radiating surface to produce three additional notches [15].

Another design utilized a rectangular slot on the radiator and embedded a folded stepped resonator in the ground plane to introduce band rejection characteristics [16]. A single-port UWB antenna has been introduced, featuring three U-shaped slots on the radiating patch, an inverse U-shaped slot on the feedline, and a C-shaped stub positioned next to the feedline to create multiple notch bands [17]. Furthermore, an inverted pi-slot in the radiating element and a pair of double split-ring resonators placed near the feedline were employed to realize dual notch bands in a UWB configuration, while an octagonal patch with a defected ground structure was used to achieve wideband operation [18]. A compact UWB slot antenna design features three L-shaped slots to achieve notched-band characteristics, with the notched frequencies being adjustable through the modification of the slot lengths. Additionally, a stepped slot in the ground plane was implemented to minimize the antenna size while preserving a wide impedance bandwidth [19]. Similarly, a stepper slot on the radiating plane and an L-shaped slot on the ground plane enabled rejection of three interference-prone frequency bands—namely, the C-band, WLAN, and X-band [20].

Further innovations in UWB antenna design have explored various resonator and slot-based techniques to achieve double and triple band-rejection characteristics. H-shaped arcs combined with tiny slots [21], as well as U-shaped and iron-shaped parasitic resonators [22], have been employed as baseline structures for UWB antennas with dual-band notching capabilities. Although effective in generating notches at desired frequencies, these designs often result in larger antenna sizes and compromised radiation performance due to the presence of multiple slots. To address these limitations, a spiral-line Electromagnetic Band Gap (EBG) structure was integrated into a UWB monopole antenna featuring dual fork-shaped slots on the radiating element. This configuration facilitated triple-band notching behavior, while a pair of planar EBG unit cells enabled dual-band rejection [23]. Similarly, a design incorporating triple U-shaped slots on the radiating patch was used to realize triple-band rejection, with meander-line EBG structures placed near the feedline to introduce additional notch characteristics [24]. A simple yet effective coupled meander-line resonator has also been introduced in microstrip patch antennas to suppress mutual coupling and enhance isolation in MIMO configurations [25]. Additionally, a flexible, reconfigurable UWB antenna with dual-band notching was proposed, wherein meander slots etched on both the radiating patch and the ground plane enable dual-band rejection. The use of a PIN diode allows dynamic control and reconfiguration of the notched frequencies, making it suitable for adaptive wireless applications [26]. These approaches demonstrate the versatility of slot and resonator-based techniques in tailoring the frequency response of UWB antennas. They highlight the ongoing efforts to balance compactness, isolation, and radiation efficiency while introducing reconfigurability and multiband rejection features for interference mitigation in complex wireless environments.

In this paper the disadvantages have been overcome by usage of fractal shapes in choice of radiating structure and meander slots for frequency notching. A Sirenkispi fractal antenna with meander slot is evaluated. The slots are placed in radiator and ground plane to compare and identify the best placement, for improved radiation performance. The innovation of the manuscript is i) Minimalized

5G UWB Antenna. ii) Linder Fractal Shape has been used to generate the antenna radiator. It is used for 5G and UWB portal devices applications.

2. Antenna Design

2.1 Design Methodology

Fractal antennas enable miniaturization by extending the effective electrical length of the radiating element within a significantly smaller physical footprint often reducing the occupied area by approximately 1 mm or more compared to conventional designs. The proposed elemental UWB antenna is based on a hybrid Sierpinski–Koch fractal configuration, combining the self-similar geometry of the Sierpinski structure with the iterative edge modifications characteristic of the Koch curve to achieve both compactness and multiband capability. The fractal geometry is generated using the Lindenmayer (L-system) algorithm, implemented in the MATLAB MuPAD toolbox, allowing precise control over the iteration process and scaling parameters. The antenna design incorporates a dumbbell-shaped structure, which inherently improves isolation by increasing the physical separation of current paths. This isolation is further enhanced through the orthogonal orientation of perpendicular segments, which minimizes mutual coupling between elements. A hexagonal molecule-based fractal is applied along the geometry's borders to induce a wideband response. This hexagonal boundary modification introduces multiple current paths of varying lengths, thereby generating several resonances across the operating spectrum. These multiple resonances combine to produce a continuous wide impedance bandwidth characteristic of UWB systems. The edges of the antenna are derived from the first iteration of the hexagonal molecule fractal, balancing bandwidth enhancement with structural simplicity. The stepwise evolution of the antenna geometry from the initial base shape to the final optimized fractal design—is illustrated in Figure 1, along with the corresponding simulated results that validate the effectiveness of the geometry in achieving the desired UWB performance.

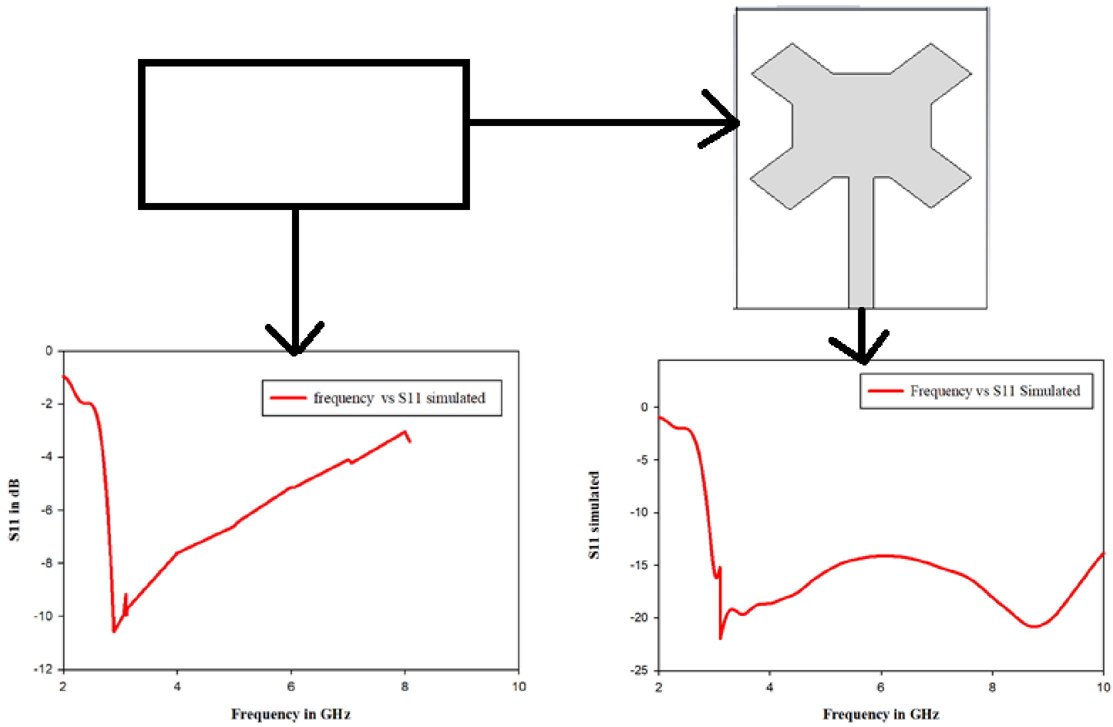
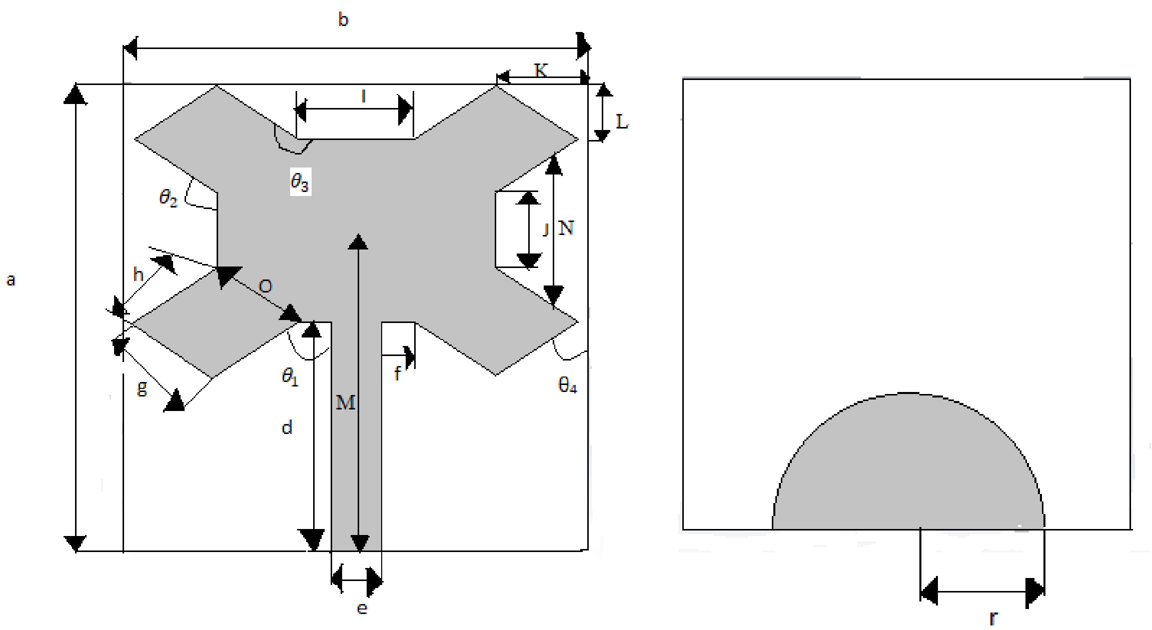


Fig 1: Evolution of the Antenna

The fractal was created using the following algorithm:
Angle θ: 60°
The axiom is: F F F F F
Rule for iterations: F Equals F F + F + FF F F+F
1st generation.
Here, F implies move unit step forward; +implies turn to the left by θ; and −implies turn to the right by θ.

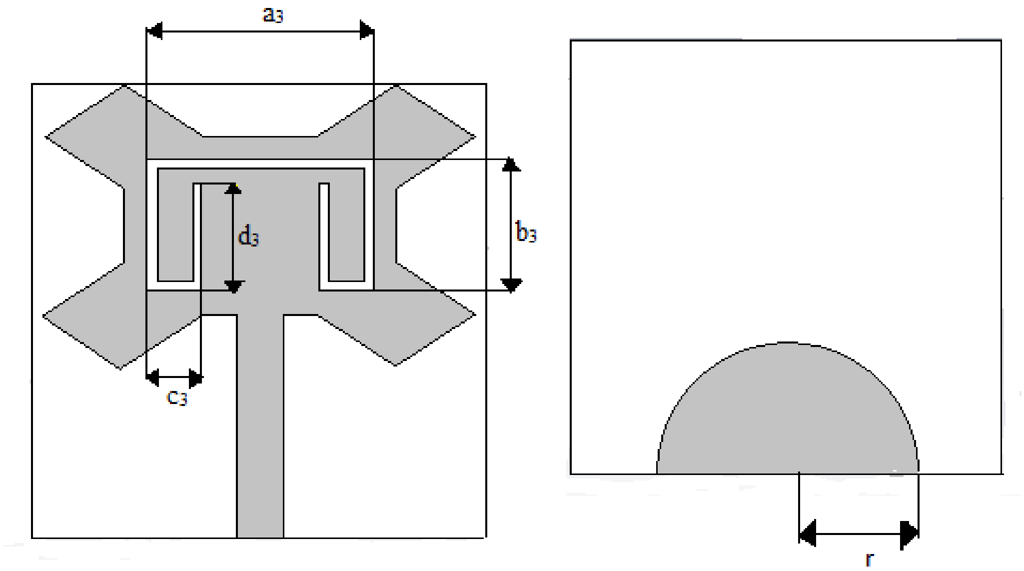
2.2 Proposed Antenna:

The proposed antenna geometry is shown in fig 2. The radiating element is made up of Sierpinski-knopp fractal geometry with different slot configurations in the front and back of the antenna. The ground plane is semi-circular in shape which provides the wide impedance bandwidth. The microstrip antenna system is made of RT Duroid 5880 lossy material on a substrate with relative dielectric constant of $\varepsilon_r = 2.2$ and tan $\delta = 0.0009$. The first configuration illustrated as antenna 1 shows, the antenna with no slots. In antenna 2, the smaller meander slots are placed in the front of the radiating patch to create band notch at a frequency of 5.3 GHz. In antenna 3, a small meander slot is positioned at the rear of the ground plane to generate a notch in the same band. In antenna 4, a larger meander slot is situated at the front of the radiating patch to produce a notch in the same band. All the antenna with slots creates band notch at same frequency. This is done to study the effect of slots on antenna radiation performance and attenuation levels. The antenna size is 14.90 x 14.80 x 1.64mm^3. The photograph of the four fabricated configuration of the proposed slot antenna is illustrated in Figure 3. The final design specifications are detailed in Table 1.

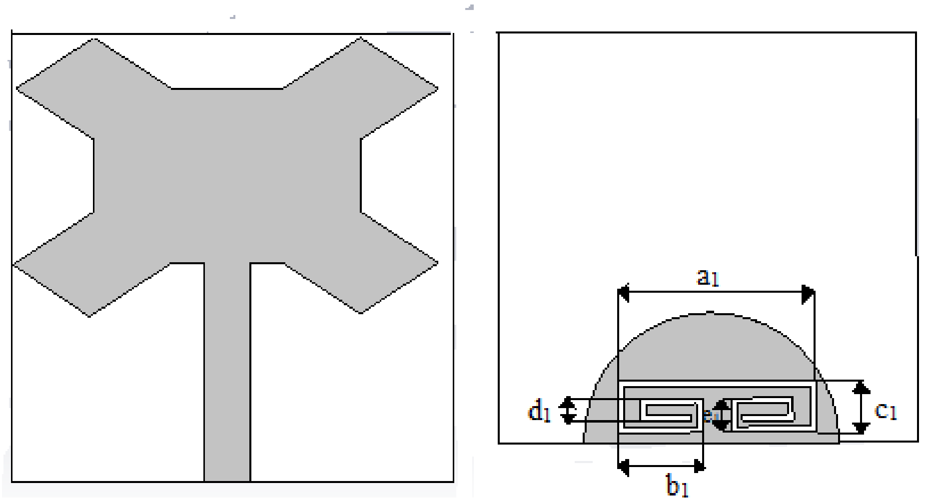


ANTENNA -1

Continue **Fig 2. Geometry of the Antenna design**



ANTENNA -2



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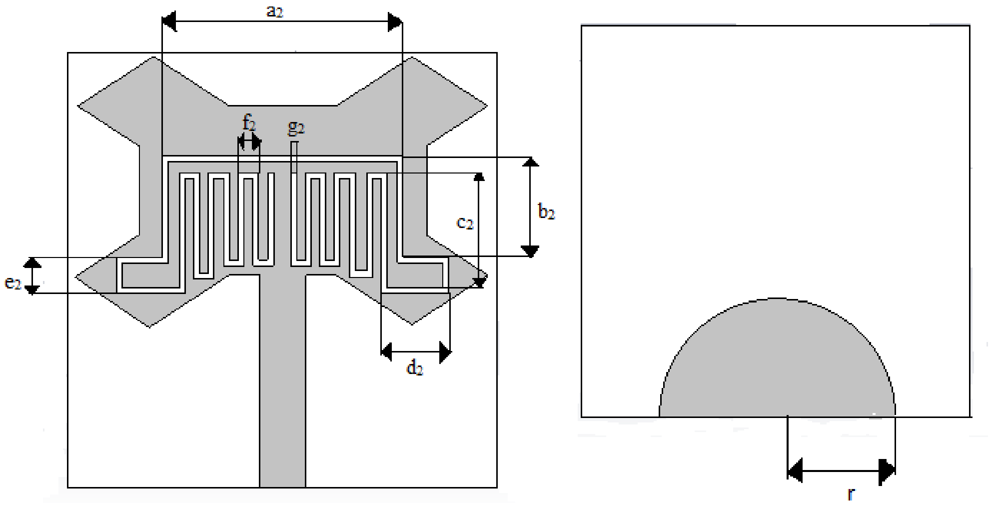
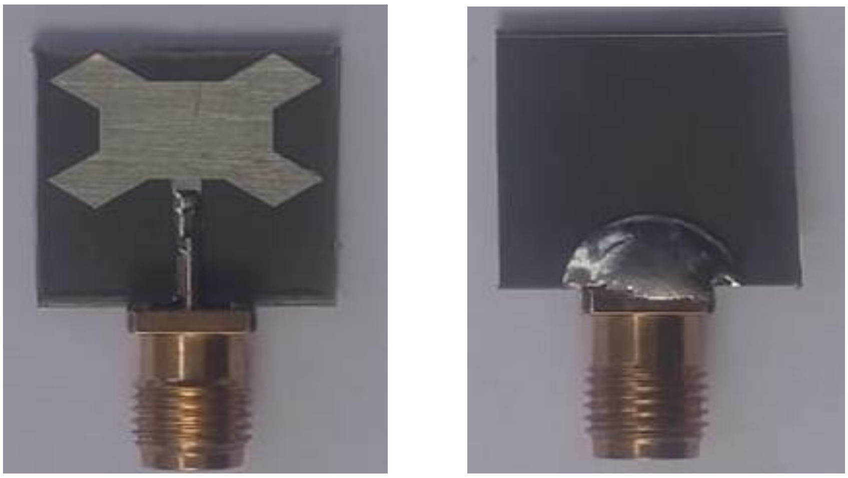
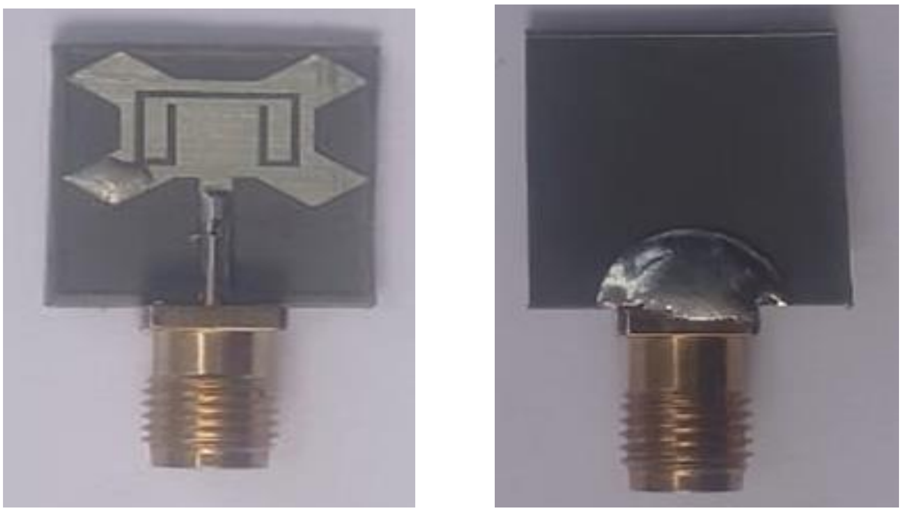


ANTENNA - 4

Fig 2. Geometry of the Antenna design



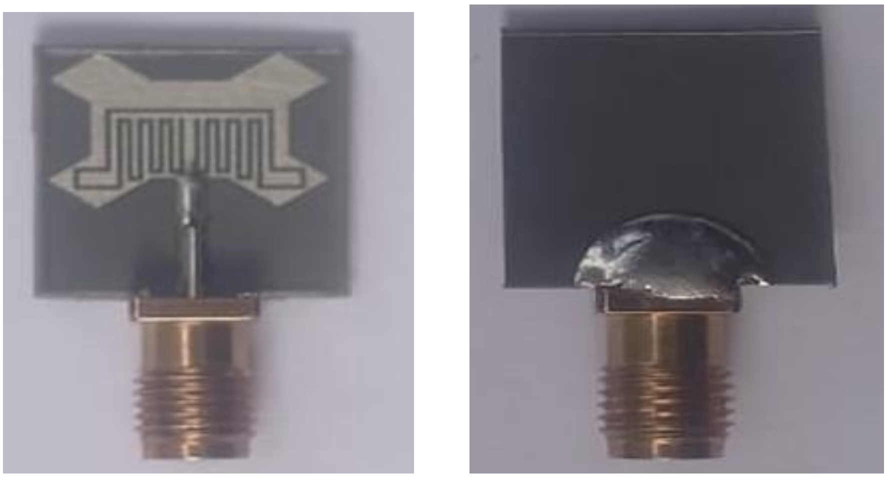
ANTENNA-1



ANTENNA-2

ANTENNA-3

Continue **Fig 3 Photography of the Antenna**



ANTENNA-4
Fig 3 Photography of the Antenna

Table 1: Design values in mm

a	b	c	d	e	F	g	h
14.90	14.80	1.64	1.58	7.33	1.05	3.09	3.12
i	j	θ_1	θ_2	e_1	a_2	b_2	c_2
3.69	2.41	146.81	123.19	1.20	8.30	3.50	3.95
θ_3	θ_4	r	k	a_1	b_1	c_1	d_1
56.82	90	4.50	9.00	7.00	3.00	1.80	0.80
d_2	e_2	f_2	g_2	a_3	b_3	c_3	d_3
2.35	1.25	0.70	0.20	7.45	4.30	1.81	3.55
K	L	M	N	θ_4	O		
2.93	1.78	11.15	4.12	56.81	3.12		

3.Parametric Study:

3.1 Surface Current Plot:

Figure 4 shows the surface current plot at 5.4 GHz. It is observed in Plot (a) that the maximum current is concentrated in the center of the radiator and ground. The slot is placed for electrical length $\frac{\lambda}{4}$ *and* $\frac{\lambda}{2}$ respectively in plot (b, c) and plot (d). It is seen that the notch is close to zero dB when the length is higher when compared to smaller length.

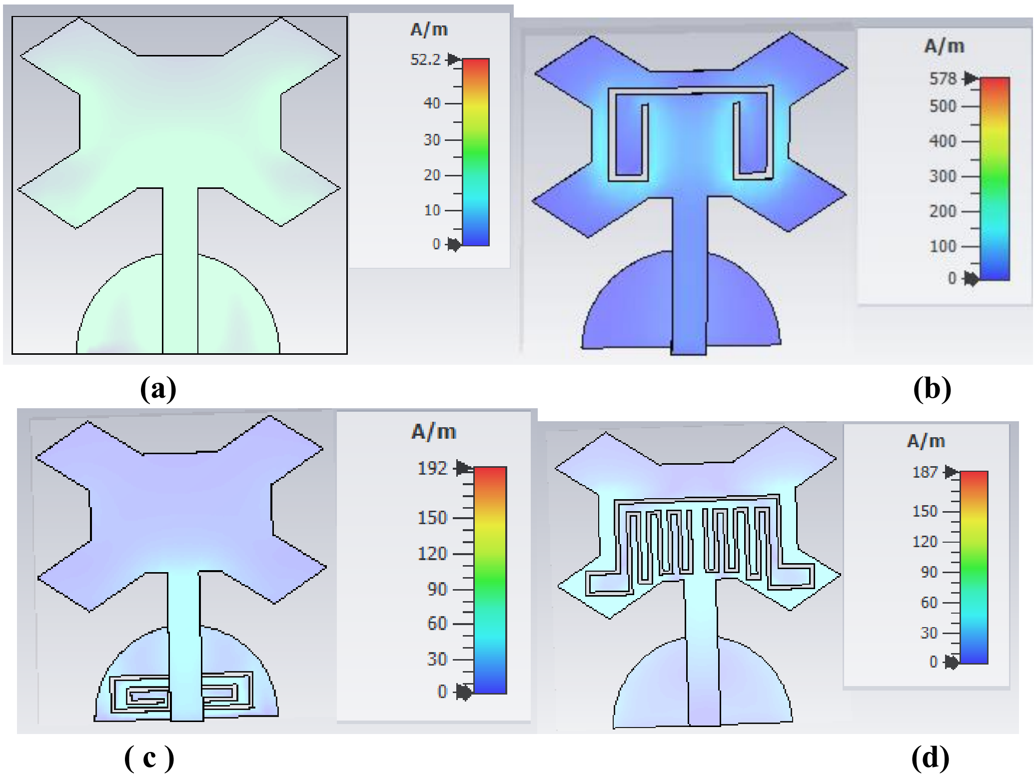


Fig 4: Surface Current Plot (a) Antenna -1 (b) Antenna-2 (c) Antenna-3 (Antenna-4)

3.2 Feed Width Study:

Figure 5 explains that the impedance matching detiorates when feed width decreases and shows good performance with S_{11} below -10dB in plot (a) whereas plot (b,c,d) the performance degrades at high frequency whereas it is below -10dB at low frequency ((i.e) below 5.4 GHz)

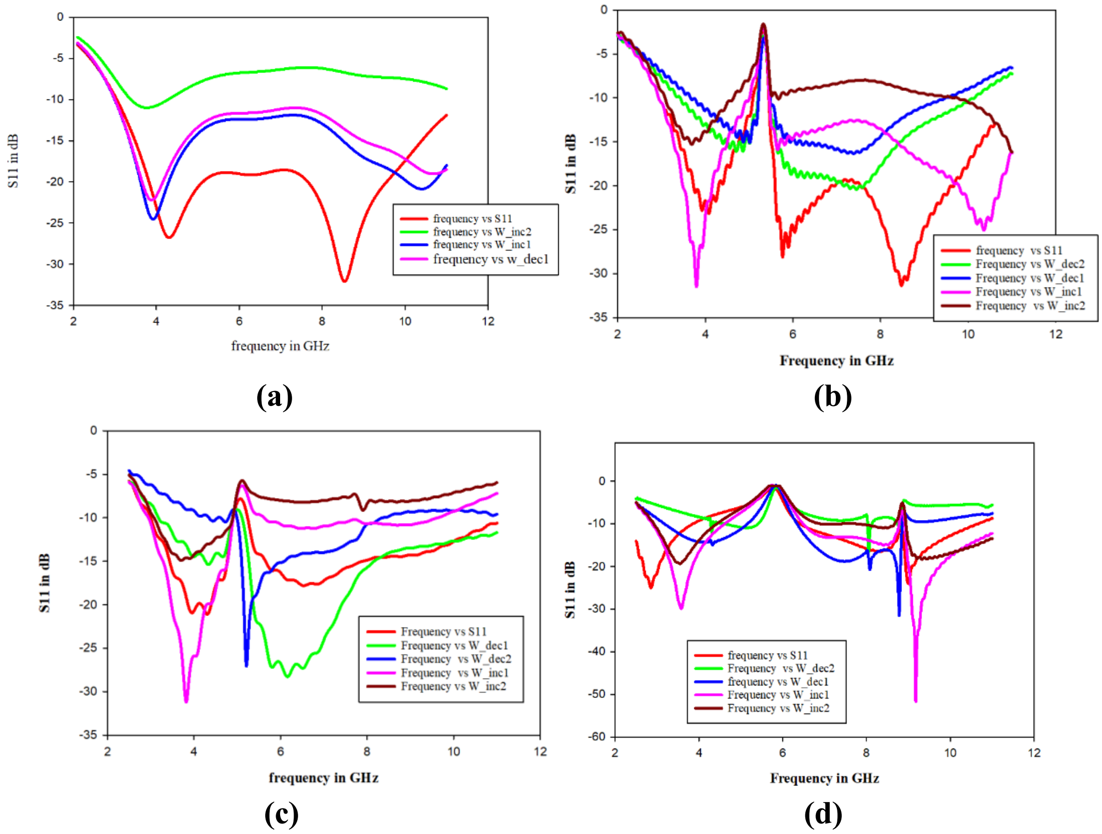
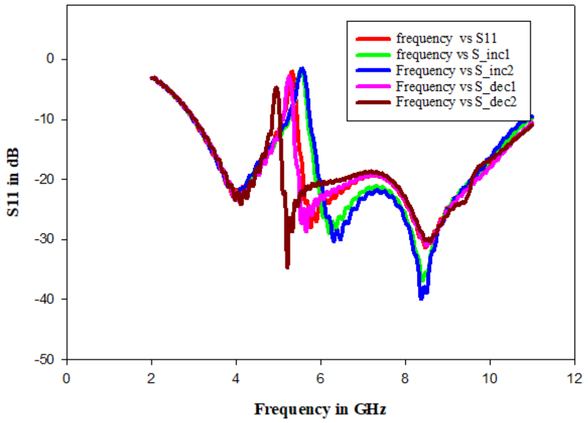


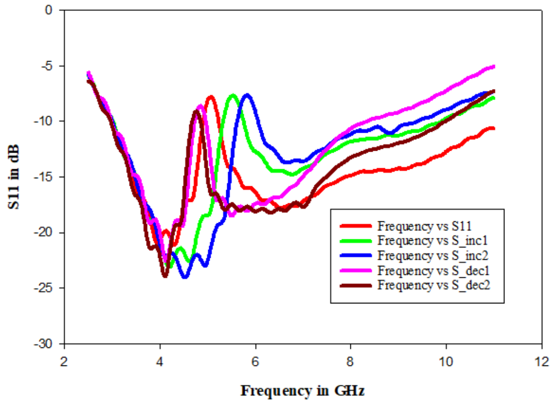
Fig 5: Variation of S_{11} with the width: (a) Antenna-1, (b) Antenna-2, (c) Antenna-3 , (d) Antenna-4

3.3 Slot Width Study:

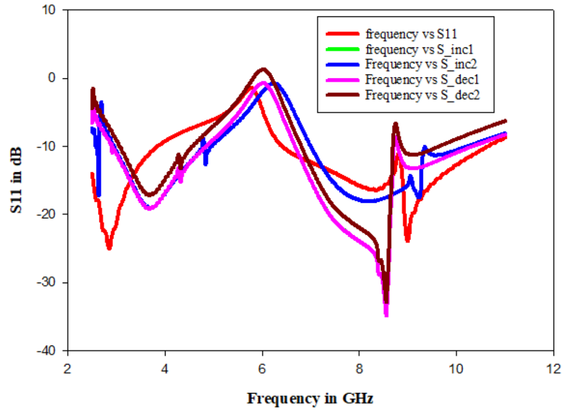
Figure 6 it is observed that the notch band shifts to higher frequency when the slot width increased but remains constant at low operating frequencies.



(a)



(b)



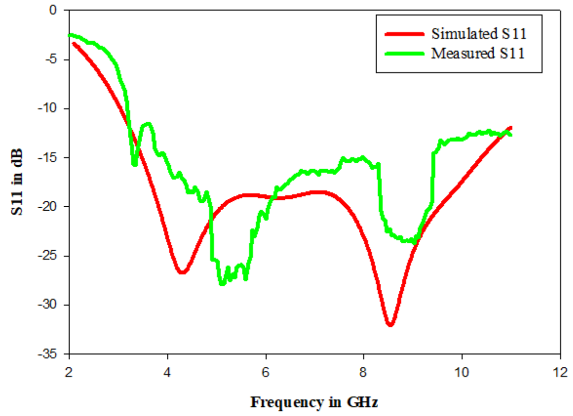
(c)

Fig 6: Variation of S_{11} with the Slot width (a) Antenna-2 (b) Antenna-3 (c) Antenna-4

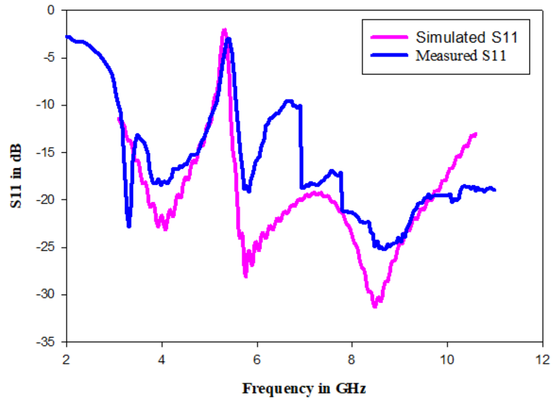
3. Results

3.1. S-Parameters

The measured S-parameter is taken using model network analyser as shown in the fig 7. The results obtained through simulation and measurement are in close alignment. The slight deviation in the results is due to soldering effects, smaller size of antenna and lead placement, fabrication discriminator. In the first plot, the antenna with no slots, the result shows that the antenna operates overall entire UWB range. In the second configuration of the antenna, the band notch is created at the frequency of 5.3 GHz in the UWB band operation. The band notch reaches as close as -2.99 dB showing high attenuation. In the third plot, the band notch is created at the same frequency where the attenuation is slightly lesser comparatively to the second antenna. In the fourth plot, the attenuation is marginally higher than the second antenna due to the largest slot placement in radiating patch.



ANTENNA-1



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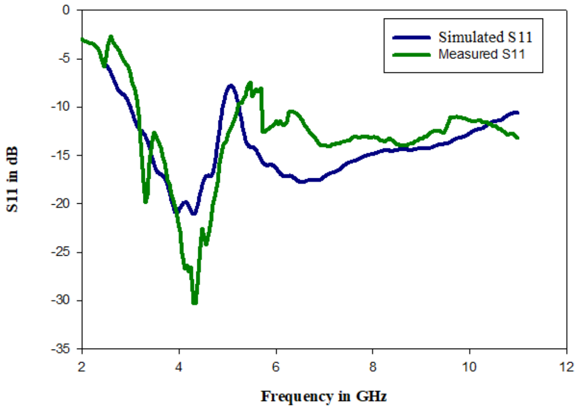

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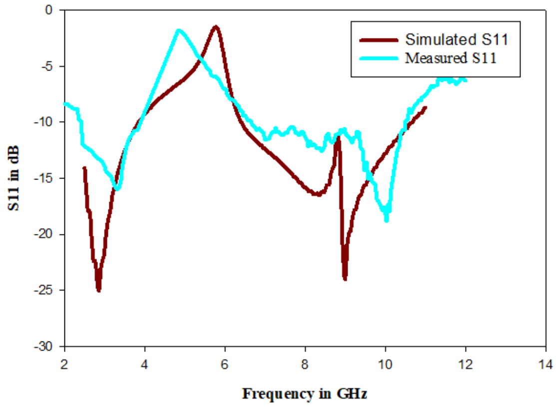
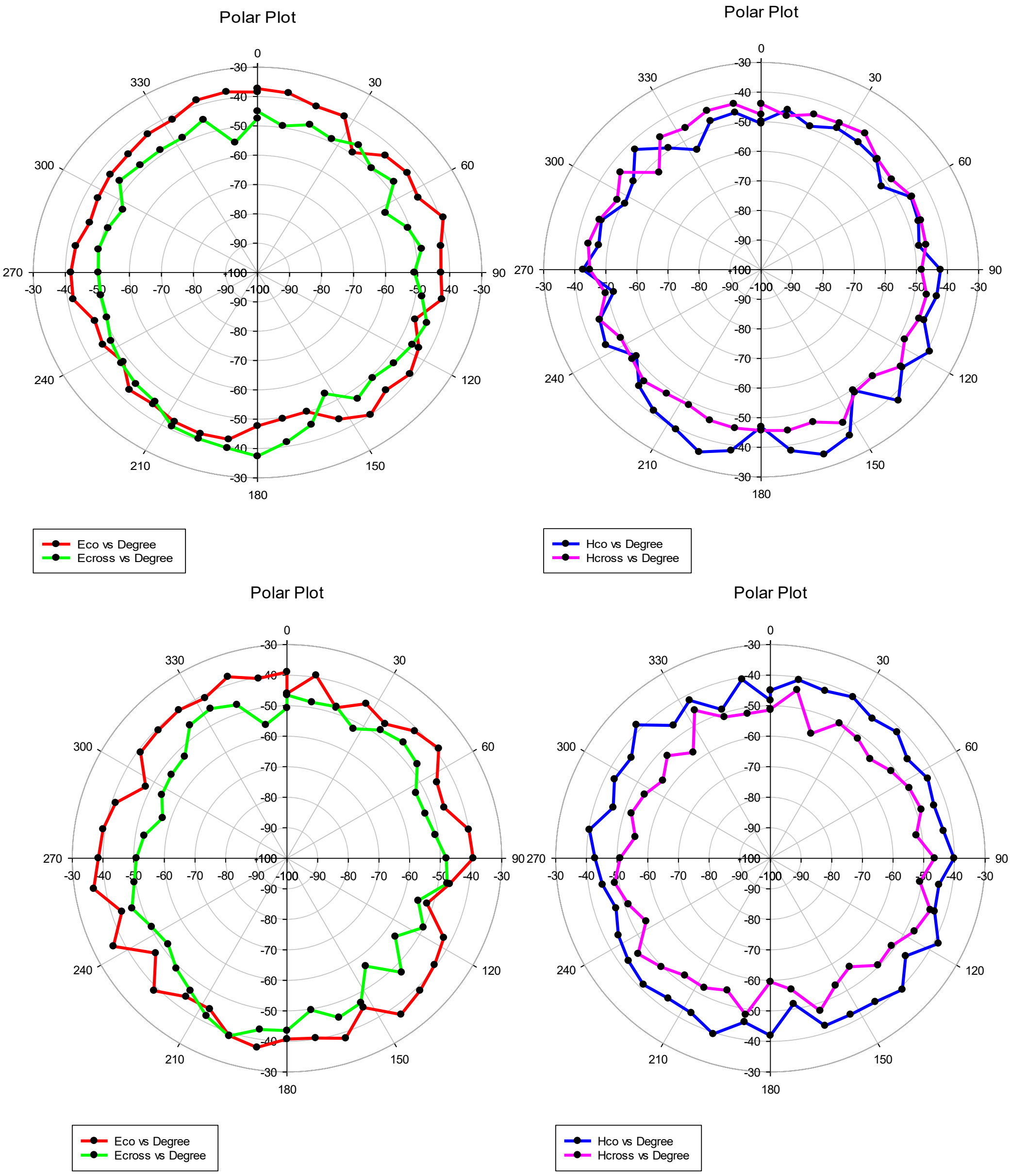


ANTENNA-4

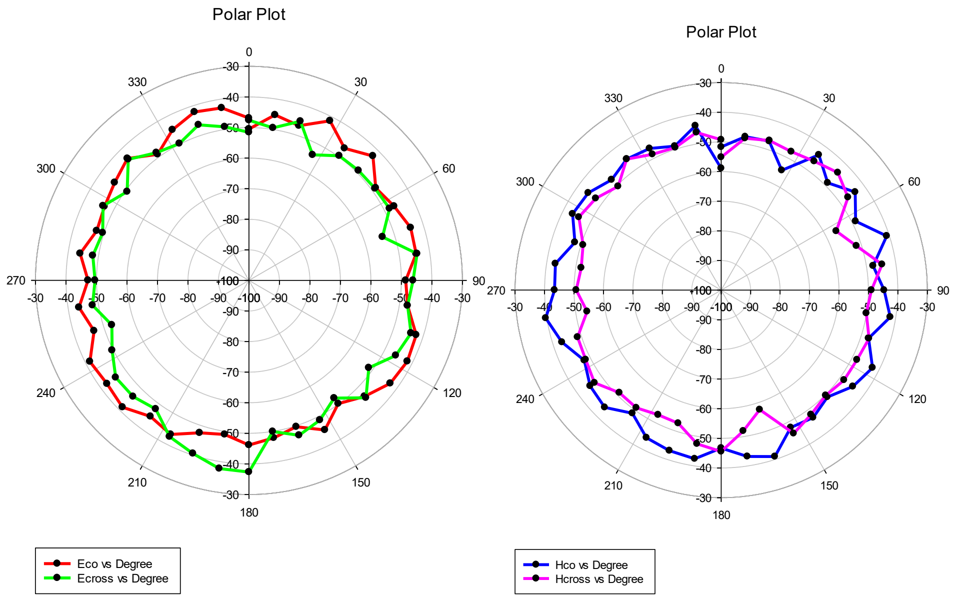
Fig 7: Simulated and Measured S-parameter

3.2. Radiation pattern

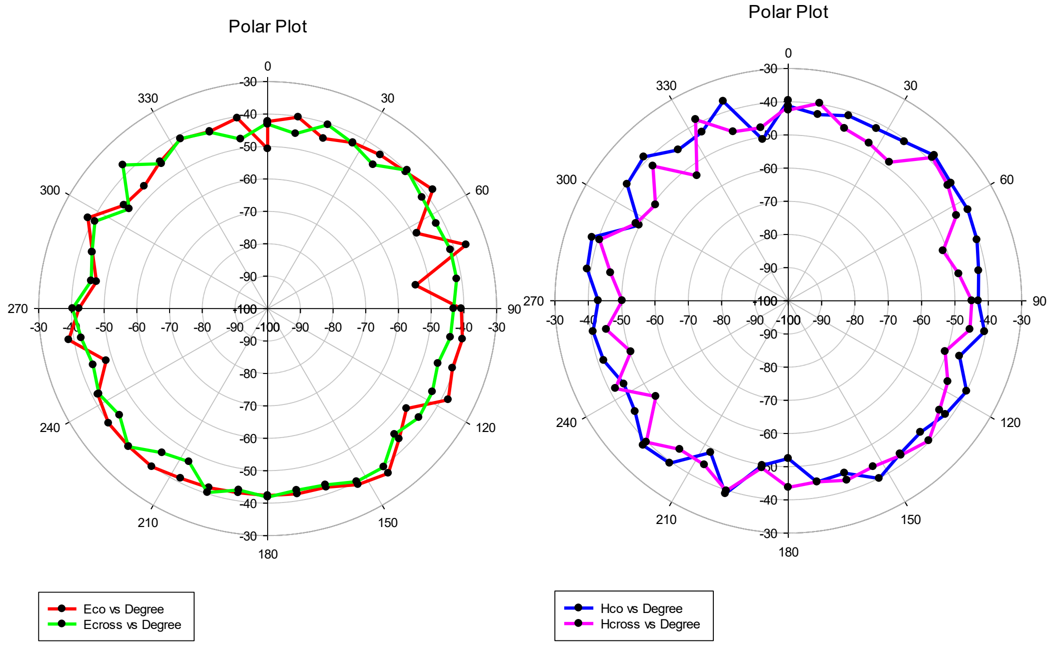
The measured E and H field co and cross polarization radiation pattern of various configurations of the proposed antennas are presented in Fig.8. All the antennas are measured in UWB range of operation, one lower order frequency 3GHz and one higher order frequency 7GHz plot is presented in this paper. It has been noted that the radiation pattern of the antennas is inherently omnidirectional, which is attributed to the monopole configuration of the antenna's design the co and cross polarization component are in similar amplitude. Also due to slot placement there is slight distortion in patterns is observed which is negligible and not much affecting the antenna performance. The antennas were also measured for their gain and efficiency and it is found to be in average range of 5dBi and 60% respectively for the antenna of no slot configuration, while slightly less gain for antenna with slots. The antennas radiation performance suggests that with or without slot placement doesn't affect the antenna efficiency. Also, the Slot placement in ground plane and radiator shows similar performance.



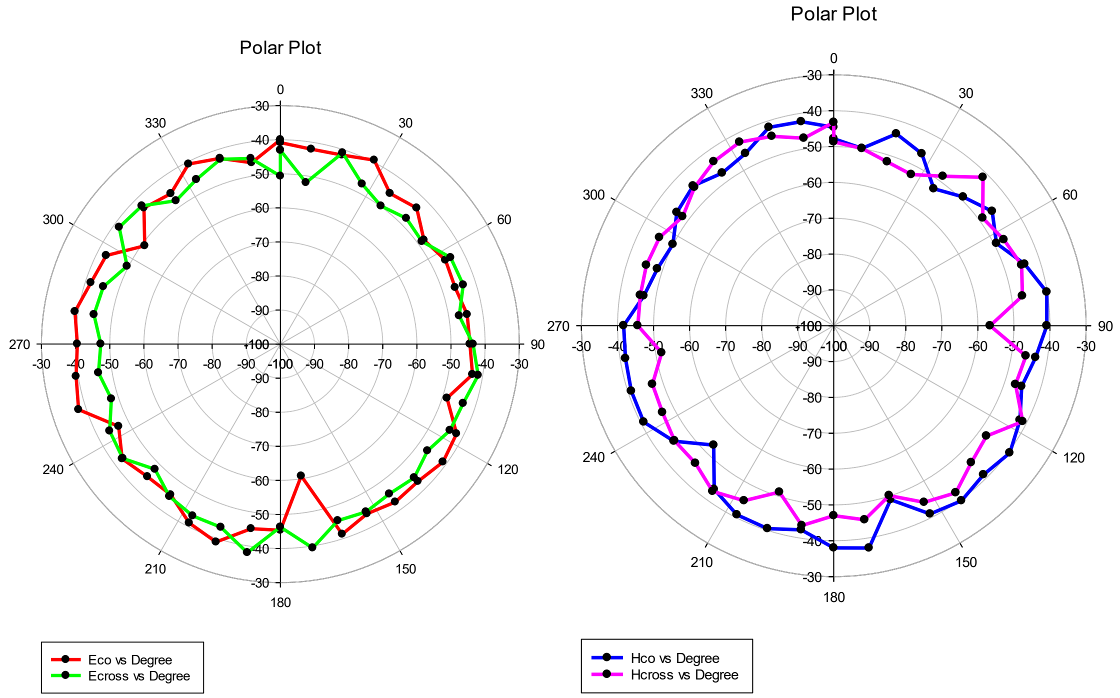
(a)Antenna 1



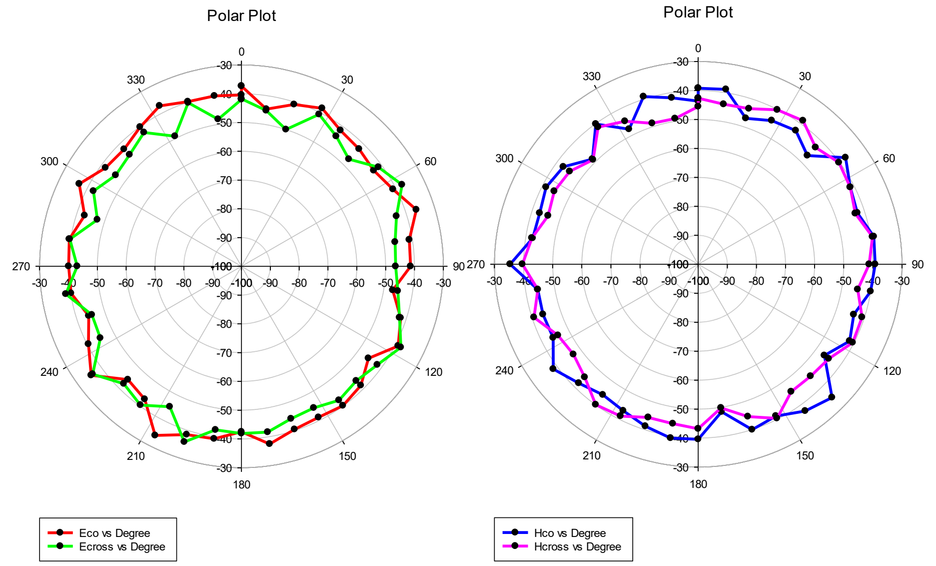
Continue **Fig 8: Radiation pattern of the Antenna at frequency 3 GHz and 7 GHz**



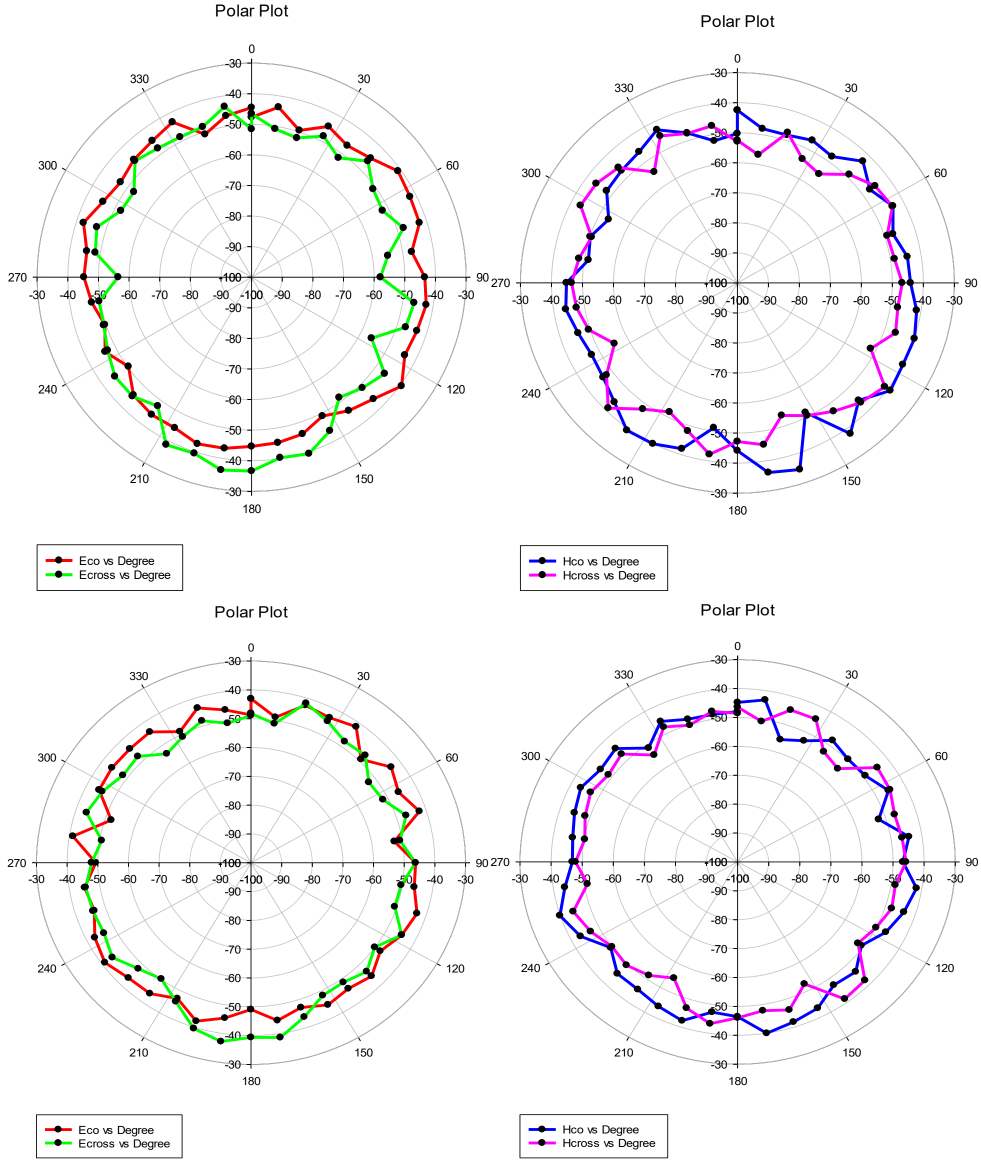
(b) Antenna 2



Continue **Fig 8: Radiation pattern of the Antenna at frequency 3 GHz and 7 GHz**



(c) Antenna 3



(d) Antenna 4

Fig 8: Radiation pattern of the Antenna at frequency 3 GHz and 7 GHz

Table 2 Comparison Performance

Ref no	Technique	Size (mm)	Freq (GHz)	No. of Notches	Gain max dBi
1	Spiral line EBG	31.3 × 34.9 × 16	2.9–10. 5	5	3.1
2	U-shaped slot on radiating patch with inverted U-shape parasitic resonator on the substrate	$0.37\lambda_0 \times 0.30\lambda_0$	4, 8.7, 11.8	2	6.21
3	Meander line EBG	31.3 × 34.9 × 1.6	2.9 to 10.5	4	4.6
4	U Shaped slots and Mushroom type EBG	29.3×37.9 ×1.6	3.0 to 10	5	3.3
5	S-shaped slot	44 × 44 × 1.524	10	2	6.9
6	C-shaped, U-shaped, two inverted L-shaped slot	32×28×1.6	2.08 -12	3	
7	C-slot, L-slot, and adding an H-shaped EBG structure	34×34×1.6	2.5-12	3	2.5 – 5.5
8	Three inverted U- shaped slots	16 x 26	3.1 –18.8	3	
9	Multi-slot UWB aerial with two notched bands	32 × 32	2.8–10.6	2	3–5
10	C-slot shaped and spiral shaped	20 × 20	3.5 –18.9	3	
11	Three U-shaped slots, three inverted U-shaped followed C- shaped stubs	80 × 80 × 1.6	3–14	5	4.8
12	Inverted pi-slot and double SRR	38.7 × 27.1 × 1	3.17-11.61	2	3.5
15	A T-slot with Vivaldi antenna	26 x 24.5	2.5 - 12	2	
16	Three L-shaped slots integrated near the stepped Slots	20.25 × 8	2.65 to 11.05	3	2.88
17	UWB Slot Antenna with Quad Band-Notched	30 × 30 × 0.1.	2.46 to 12.52	4	1.5 - 6
18	Multi-band notched circular polarised antenna	42.7 × 55 × 1.6	3.1 to 10.6	3	
19	Double Band Notch Antenna with Flexible Frequency Tuning	32 x 35	3 - 12	2	5
20	novel circular fractal ring UWB monopole antenna	20 x 30 x 1	2.6 – 11.6	2	Nearly 4
21	New SRR/CSRR antenna	30*24*1.6	3.1- 10.6	2	7.18
22	Circular-Shaped MIMO Antenna	43×36×1.59	1.4-25	4	5.1
23	Printed ultra-wideband antenna by embe frequency Selective Surface	0.29λ × 0.367λ × 0.015λ	2.56–14	2	8.1
24	Compact Self Isolated MIMO UWB Antenna	40 × 21	2.94–11.61	1	4.21
25	Novel dual band-notched UWB antenna	35.5 x 30 x 1.6	2.9–10	2	4.47
26	UWB circular monopole antenna with parasitic resonators	32 x 24 x 1	5.3 – 7.8, 8.4 – 11.5	2	
27	Sierpinski -Knopp Monopole Antenna	14.90 x 14.80 x1.6	3 - 11	1	2.54

4. Discussion/Conclusions

Four antennas were presented in this paper for comparison of radiation performance along with existing literature given in Table 2. It is found the antenna 3 where slot placement in ground plane had better radiation performance to the one placed in radiating element. Also, the larger the slot length in antenna 4 the distorted the radiation performance of the antenna becomes. The simulated and measured S-Parameters are observed to be nearly in exact match. The measured radiation patterns were used for the evaluation of antenna performance. The proposed antenna 3 is suitable for use in portable device application as it provides the best radiation performance which notching the WLAN band effectively

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