An Octogonal Ring Monopole Antenna for ISM & UWB Applications

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Abstract—The proposed work reports a monopole antenna for ISM & UWB frequency applications. A octagonal ring patch with truncated corners and a T-shaped printed line loaded with a circular ring is placed over the low-loss dielectric material with a dielectric permittivity of 2.7 and a loss tangent value of 0.134. To realize the proposed antenna, a simple octagonal patch monopole antenna is modified in 6 evolutionary stages. The dimension of the presented antenna is 50 X 40 X 1.6 mm^3. Etching the central portion of the patch and truncated corners of the patch plays a crucial part in enhancing the bandwidth. The simple microstrip feed to the octagonal radiator provides a good impedance matching at both the ISM (2.29 – 2.47 GHz) and UWB (3.05 - 12 GHz) bands. The gain of 4.92 dB and 1.36 dB at 2.45 and 5.8 GHz frequencies respectively are observed. The S_{11}, VSWR, radiation pattern at E and H planes, surface current distribution, and radiation efficiency are obtained and realized using the HFSS tool.

Keywords—Monopole Antenna, ISM band; Ultra-wideband (UWB); Truncated Corners; Octogonal ring; Surface current distribution.

I.INTRODUCTION

UWB (ultra-wideband) band antennas and ISM (industrial, scientific, and medical) band antennas are crucial parts of contemporary wireless communication networks. Radio frequencies between 902 MHz and 2.4 GHz are collectively referred to as the ISM band and are only permitted for use in industrial, scientific, and medical uses. For low-power wireless transmission systems like Bluetooth, Wi-Fi, and Zigbee, ISM band antennas are frequently used. These antennas are perfect for use in a variety of consumer electronics products, including cell phones, laptops, and home automation systems because they are highly efficient, small, and affordable. On the other hand, rapid growth in network users and advanced developments in communication systems demand high data rate transition, both in terms of fixed and portable systems [1]. Ultra-wideband (UWB) technology is considered one of the most promising solutions for advanced wireless communication systems due to its exceptional immunity to multipath interference and the ability to provide high-speed data rates [2]. As per Federal Communication Commission, U.S. 2002, the unlicensed ultra-wideband (UWB) applications were assigned a range of frequencies from 3.1 to 10.6 GHz [3]. UWB has a variety of applications, including radar systems, high-speed short-range WLAN systems, military communication systems, etc. [4]. A single antenna to cover both ISM and UWB frequencies can offer significant advantages in terms of versatility, cost-effectiveness, space-saving, improved performance, and reduced interference in modern wireless communication systems.Research is being done at ISM and UWB frequency bands that are listed in the open literature. The authors in [5] presented a broadband antenna with a dual semicircular slot structure which obtained 86.9% impedance bandwidth. The UWB antenna with dual feed, three metallization layers with slot, and two dielectric layers are introduced. It has an impedance bandwidth of 8 GHz [6]. In [7] a broadband antenna with a rotational symmetry dipole structure with an impedance bandwidth of 140.6% is reported. A slot antenna with CPW feeding achieved an impedance bandwidth of 111.2 % is presented in [8]. [9-15] reports various monopole antennas operating at UWB frequency and it is observed that there is a trade-off between the dimensions and performance characteristics of the antenna. The proposed radiating structure resembles a simple octagonal ring. Therefore, the proposed antenna shall hereafter be referred to as a octagonal -ring monopole antenna (OR-MA). Ansys HFSS 2022 was used to design and carry out simulations.Further, this communication is ordered as follows: section II explains the evaluation and geometry of the OR-MA antenna. Section III analyses the results. Section IV concludes the proposed work and gives future directions.

I.OR-MA DESIGN AND ITS GEOMETRY

A. Evolution of OR-MA Antenna

The proposed antenna is realized in six evolutionary stages as shown in Figs. 1(a)–(d). Initially, a square patch monopole antenna of 50 X 40 mm^2 is designed using the equation of [16,17]. In stage II a portion of the conducting patch is etched from the center to form a square ring of 4 mm thickness. A T-shaped printed line is formed in the center of the square ring as shown in Fig. 1 (c) considered as a stage III. A disk encircled by a circular ring of 0.5 mm thickness with a gap of 1.5mm is loaded on the T-shaped printed line in stage IV. The top left and bottom right corners of the square ring are truncated in stage V and further in stage VI top right and bottom left corners are also truncated to enhance the bandwidth.

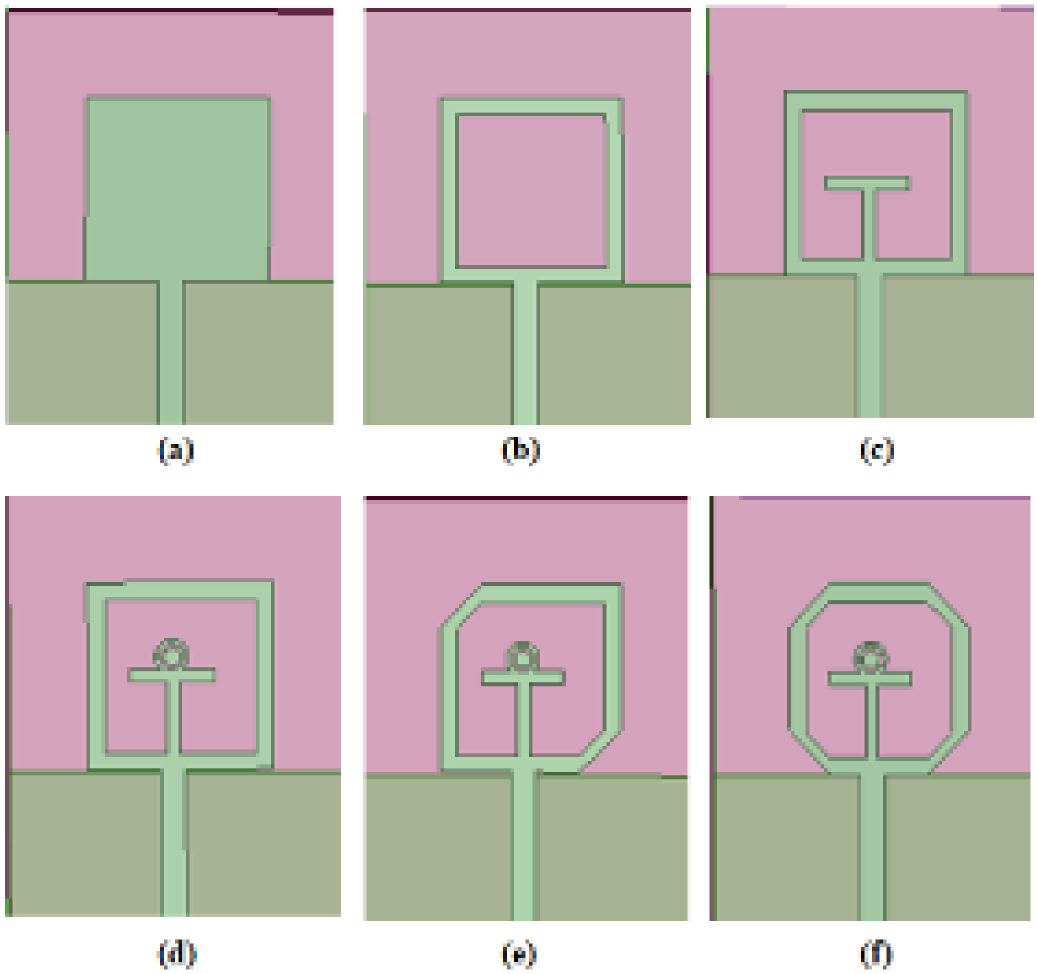
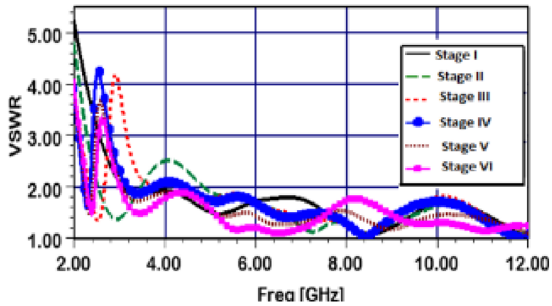


Fig1.Evolutionary stages of SR-MA Antenna (a) Stage I simple square patch monopole antenna (b) Stage II Square ring monopole antenna (c) Stage III Square ring monopole antenna with T-shaped printed line (d) Stage IV Square ring monopole antenna with T shaped printed line loaded with disk encircled by a circular ring. (e) Stage V Square ring monopole antenna with T-shaped printed line loaded with disk encircled by a circular ring and orthogonally truncated corners. (f) Stage VI Octagonal ring monopole antenna with T-shaped printed line loaded with disk.

B.Analysis of evolutionary stages of OR-MA Antenna

Plot. 1. S_{11} Comparison of evolutionary stages of OR-MA Antenna



Plot. 2. VSWR comparison of evolutionary stages of OR-MA Antenna

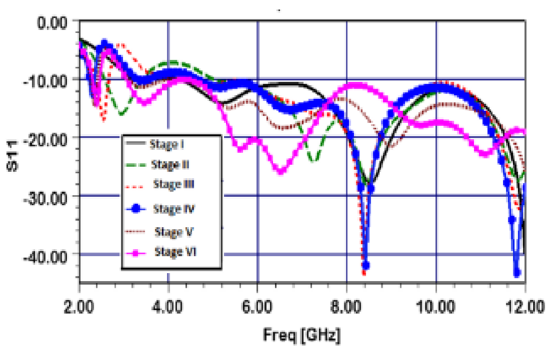
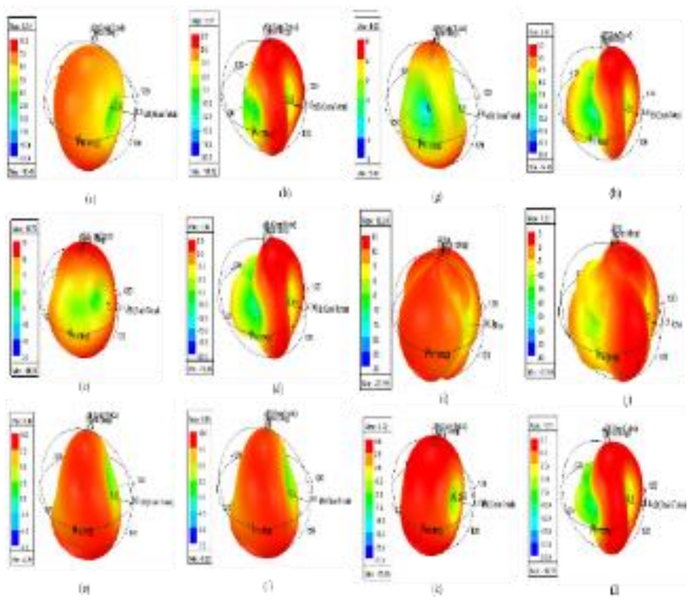


Fig. 2. Gains of evolutionary stages I to VI at 2.45 and 5.8 GHz respectively



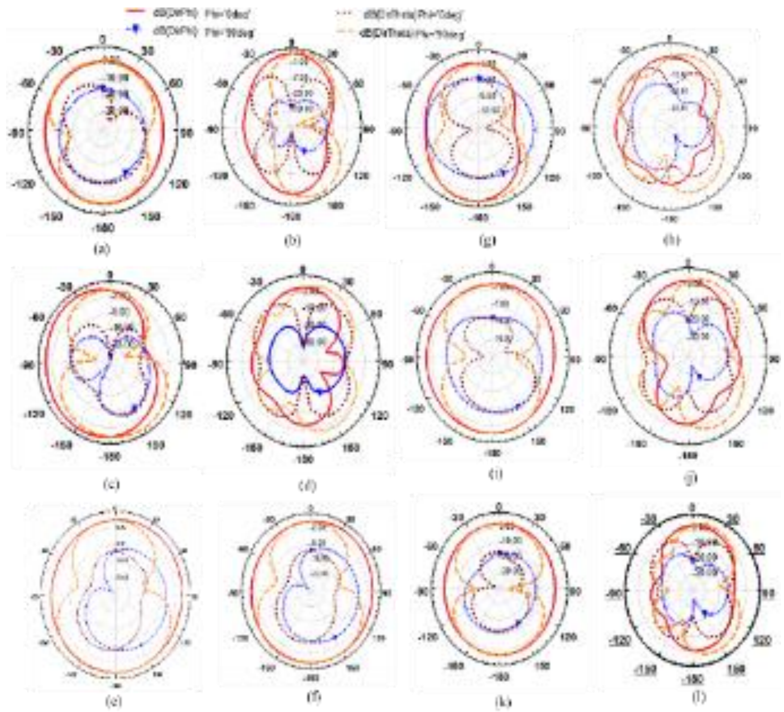


Fig. 3. Cross and co-polarization plots of evolutionary stages I to VI at 2.45 and 5.8 GHz respectively.

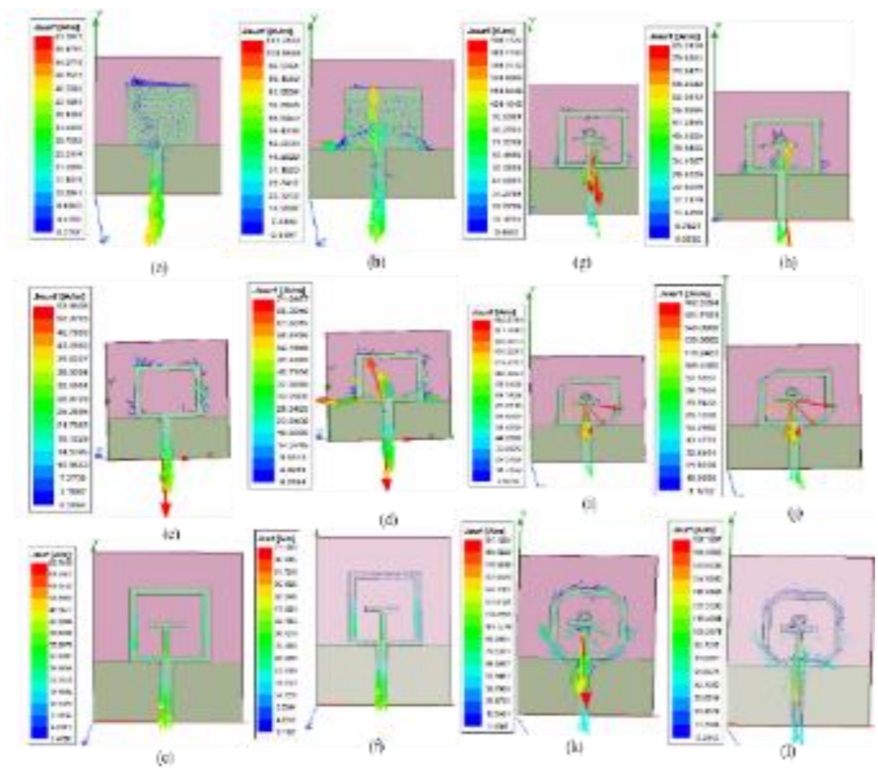


Fig. 4. Surface current distribution of evolutionary stages I to VI at 2.45 and 5.8 GHz respectively.

TABLE I. COMPARISION OF EVOLUTIONARY STAGES

Parameters	Stage (I)	Stage (II)	Stage (III)	Stage (IV)	Stage (V)	Stage (VI)
Frequency Range (GHz)	3.30-3.85, 4.11-12	2.57-3.44, 4.98-12	2.37-2.68, 4.62-12	2.23-2.36, 3.24-3.62, 4.57-12	2.26-2.42, 3.2-12	2.31-2.48. 3.05-12
Bandwidth (GHz)	8.44	7.89	7.69	7.94	8.96	9.12
No. of Bands	2	2	2	3	2	2
VSWR	< 2	< 2	< 2	< 2	< 2	< 2
Gain (dB) at 2.45 GHz	NA	NA	8.05	NA	10.69	4.75
Gain (dB)at 5.8GHz	1.17	1.36	1.01	0.80	1.25	1.51

From plots 1 and 2 it is evident that the modifications made at each evolutionary stage resulted in the shift of operating frequency. In the stage, I, a simple square patch monopole antenna is designed and obtained a total impedance bandwidth of 8.44 GHz in two bands with a gain of 1.17 dB at 5.8 GHz frequency. In stage II the change in resonating modes can be noted as shown in Figs. 4. (c) and (d), the shift in lower frequency is noted due to the etching of the square slot in the central portion of the patch. The impedance bandwidth of 7.89 GHz and gain of 1.36 dB at 5.8 GHz frequency is obtained. The intended operating frequency at 2.45 GHz is realized in stage III by placing a T-shaped printed line in the center of the square ring patch, however, it couldn't cover the complete UWB band. The total impedance bandwidth obtained in the two bands is 7.69 GHz with a gain of 8.05 and 1.01 dB at 2.45 and 5.8 GHz frequencies respectively. Further, in stage IV the T-shaped printed line is loaded with a disk encircled by a square ring, which enabled multiple resonating modes and resulted in tri-band characteristics with an impedance bandwidth of 7.94 GHz. The desired ISM band of 2.45 GHz is achieved, in stage V by truncating the top left and bottom right corners of the square ring, and further in stage VI to obtain the complete UWB band along with the ISM band, top right and bottom left corners are also truncated which resulted in an octagonal ring with impedance bandwidth of 9.12 GHz, with a gain of 4.75 and 1.51 dB at 2.45 and 5.8 GHz respectively.

B.Geometry of OR-MA

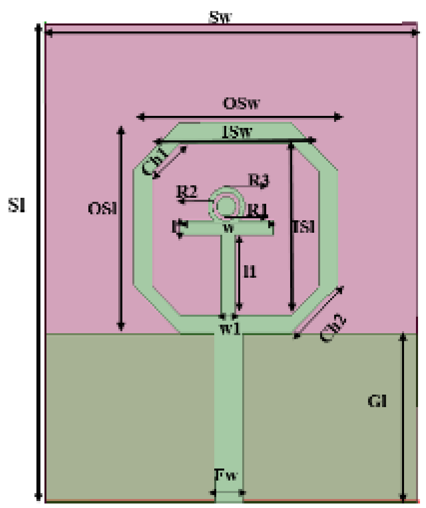


Fig. 5. Geometry of SR-MA Antenna

TABLE II. GEOMETRIC VALUES OF THE CONSTRUCTED ANTENNA

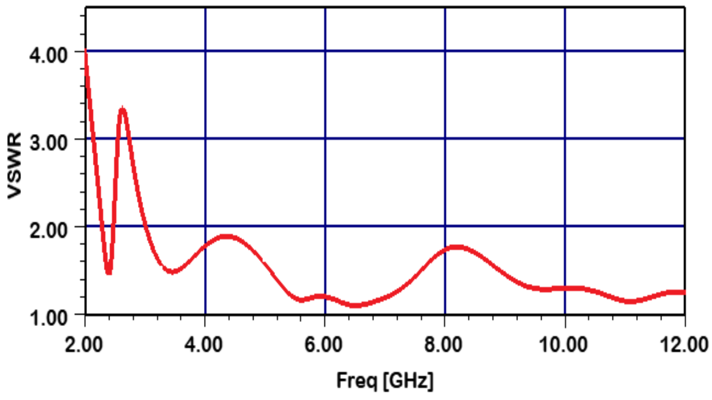
Parameters	Dimensions(mm)
Sl	50
Sw	40
Gl	17.5
OSl	22
OSw	22
ISl	18
ISw	18
Ch1	3
Ch2	5
I	1.5
Il	10
W	10
W1	1.5
Fw	3
R1	1
R2	2.5
R3	3

The dimension of the OR-MA antenna is 50 X 40 X 1.6 mm^3. The radiating structure is constructed on dielectric material with a dielectric permittivity of 2.7 and a loss tangent value of 0.134. The partial ground structure (PGS) is designed at the back of the substrate material to achieve enhanced bandwidth. Fig.5 depicts the radiating patch and partial ground structure of the OR-MA. An antenna is fed by 50 microstrip lines. The final structure of the proposed antenna arrives in six evolutionary stages as mentioned in section II b. The detailed geometry values are listed in Table II.

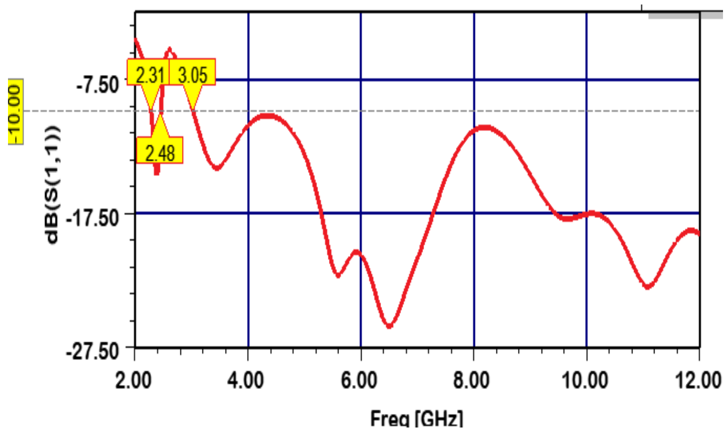
II.RESULTS ANALYSIS

The performance characteristics of the OR-MA antenna constructed on a low-loss dielectric material are analyzed concerning S_{11}, bandwidth, VSWR, and radiation efficiency plots along with the surface current distribution, radiation pattern, and gain at 2.45 GHz and 5.8 GHz. From plots 3 and 4 it is observed that the OR-MA antenna is resonating at two bands, the lower band from 2.31 to 2.48 GHz and the second band in the range of 3.05 to 12 GHz. The overall bandwidth obtained concerning <-10 dB return loss is 9. 12 GHz. The proposed OR-MA antenna covers both the intended ISM (2.45 GHz) and UWB (3.1 to 10.6 GHz). The gain of 4.72 dB and 1.51 dB at 2.45 GHz and 5.8 GHz are obtained and presented in plots 5 and 6 respectively.

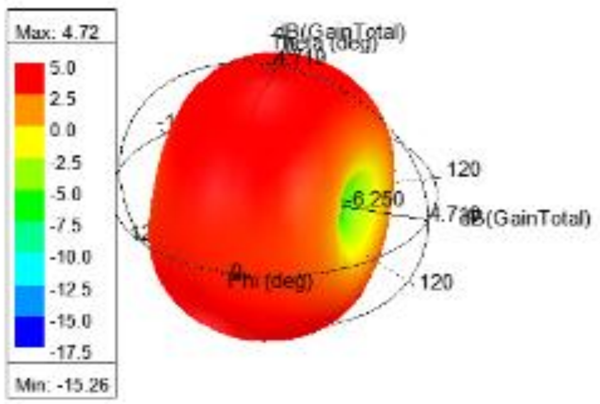
Plot. 3. S_{11} of OR-MA Antenna



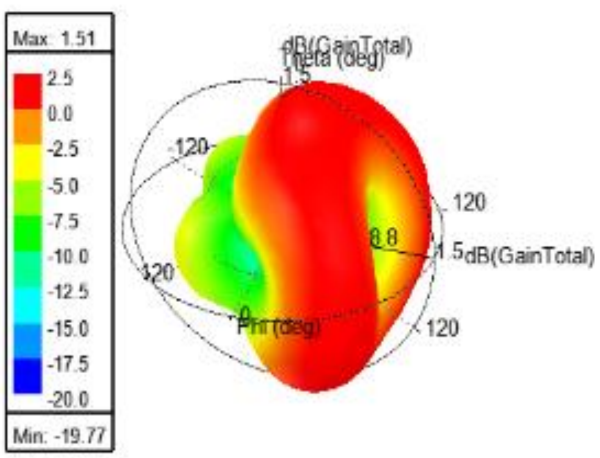
Plot 4. VSWR of OR-MA Antenna



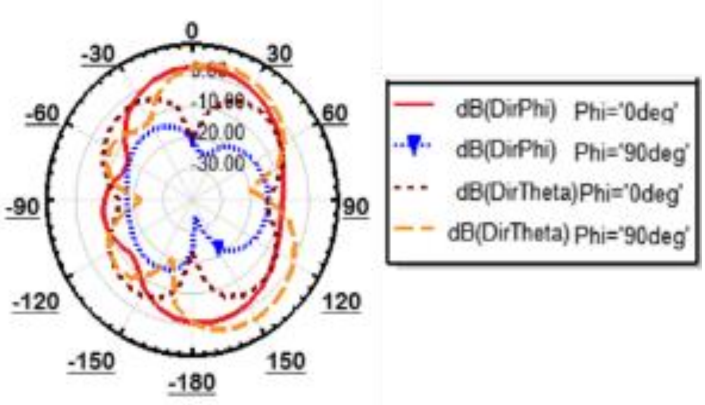
Plot. 5. Gain of OR-MA Antenna at 2.45 GHz



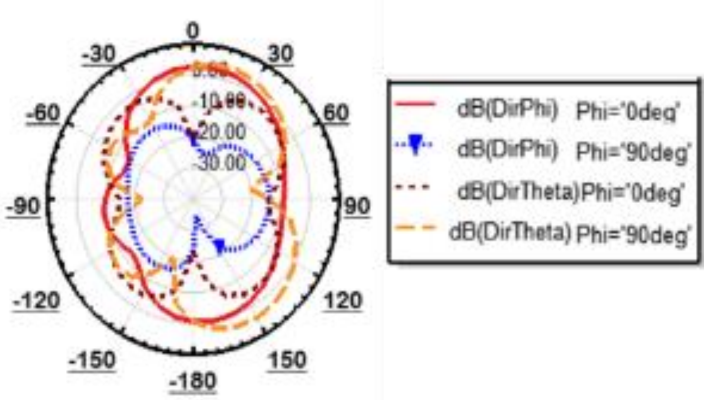
Plot. 6. Gain of OR-MA Antenna at 5.8 GHz



Plot. 7. Radiation Pattern of OR-MA Antenna at 2.45 GHz



Plot. 8. Radiation Pattern of OR-MA Antenna at 5.8 GHz



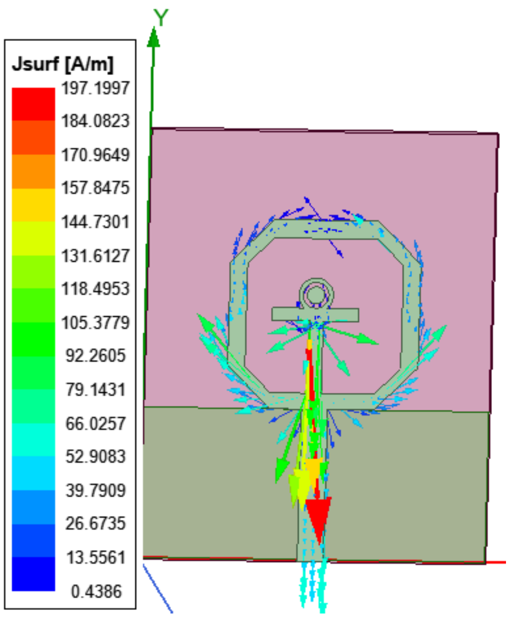


Fig.6. Surface current distribution of OR-MA antenna at 2.45 GHz

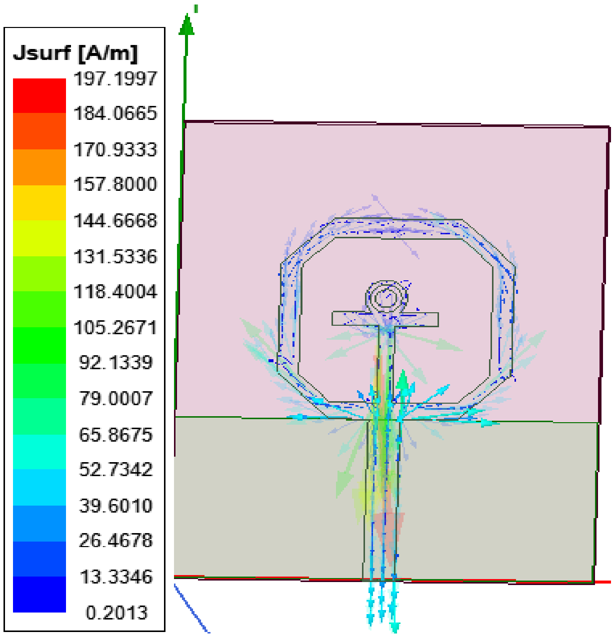
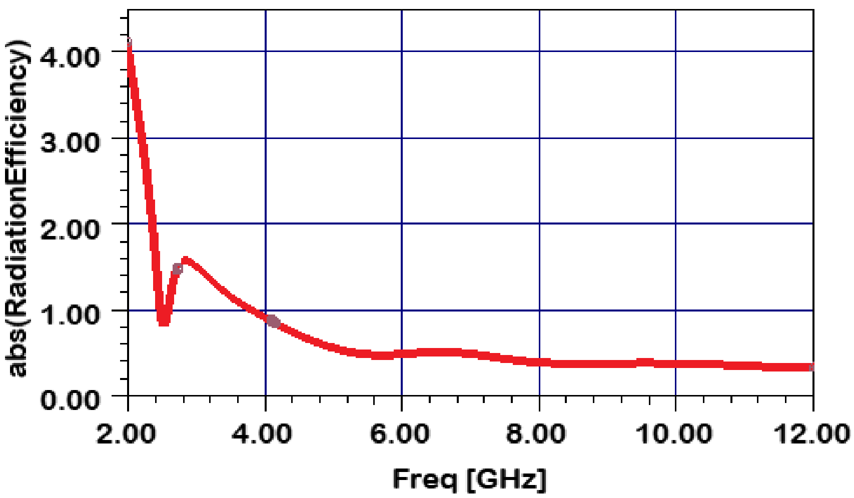


Fig.7. Surface current distribution of OR-MA antenna at 5.8 GHz



Plot.9. Radiation Efficiency of OR-MA Antenna

The cross and co-polarization of the antenna at 2.45 GHz and 5.8 GHz are shown in plots 7 and 8 respectively. Similarly, the surface current distribution at 2.45 GHz and 5.8 GHz are shown in Figs. 6 and 7. And it is observed that the maximum current is at the feed and T-shaped printed line. The radiation efficiency versus frequency is shown in plot.9. The proposed OR-MA antenna designed for ISM and UWB band is compared with the state of artworks reported in the literature and tabulated in Table III. The comparison and analysis showed that the OR-MA antenna was a significantly small structure with a wide bandwidth of 9.12 GHz.

TABLE III. COMPARISON WITH STATE –OF-ART WORKS

Reference	Size (mm^3)	No. of Bands	Bandwidth (GHz)	Max. Gain (dBi)	Max. Radiation Efficiency (%)
[5]	101×64×1.52	1	5.58	7.3 dBic	-
[6]	66 x80x1	1	8	1.6 dBic	80-85
[7]	60x40x1	1	8.74	4.8 dBi	-
[8]	50 x 50 x 0.8	1	4	5.3 dBic	-
OR-MA antenna	50 x 40 x 1.6	2	9.12	6.7 dBi	97

II. CONCLUSIONS AND FUTURE DIRECTIONS

A octagonal -ring monopole antenna (OR-MA) for ISM and UWB applications is proposed and designed. The OR-MA is analyzed on low-loss dielectric materials. A simple ring patch on the top of the dielectric material partial ground structure (PGS) on the lower side ensures ease of fabrication and prototyping. It has a smaller size compared to the works reported. It has a very wide bandwidth of 130%. A maximum gain of 6.7 dBi and radiation efficiency of 97% is obtained at 2.45 GHz. Further methods can be implemented to improve the radiation efficiency at all the operating frequencies while retaining wideband characteristics. The concept of frequency reconfigurability can be applied to switch between ISM and UWB bands.

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