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DESIGN AND PERFORMANCE ANALYSIS OF UWB CIRCULAR PATCH ANTENNA WITH DEFECTED GROUND STRUCTURE

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Abstract: **- This paper presents the design and performance analysis of an ultra-wideband (UWB) circular patch multiple-input multiple-output (MIMO) antenna with a defected ground structure (DGS). The proposed antenna design has a compact area of 60x30 mm^2, resulting in a total size of 1800 mm^2. The circular patch configuration allows for improved bandwidth and frequency coverage. The MIMO antenna consists of two circular type patches, with a separation distance of 0.05Ag, where Ag represents the area of the antenna. By optimizing the dimensions and positioning of the circular patches, the antenna achieves resonant frequencies at 2.5, 6.3, 8.2, and 11.64 GHz. This frequency range effectively covers the spectrum from 2.0 to 20.0 GHz, providing excellent UWB performance. To enhance the antenna's performance, a defected ground structure (DGS) is incorporated. The DGS helps in suppressing unwanted harmonics and improves the antenna's radiation characteristics. Additionally, the antenna design is carefully optimized to maintain a voltage standing wave ratio (VSWR) of ≤2, ensuring efficient power transfer and signal integrity. The proposed UWB circular patch MIMO antenna with a defected ground structure offers significant advantages, including a compact form factor, wide frequency coverage, and improved performance. The design and performance analysis presented in this paper demonstrate the potential of this antenna for various wireless communication applications, such as ultra-wideband systems, radar, and wireless sensing.**

Index Terms **– Video steganography, Data hiding, convolutional neural network, residual modelling etc.**

1. INTRODUCTION

The demand of UWB antenna is increases day by day in the wireless communication system due to high data rate. Different techniques and applications are operated on UWB frequency spectrum, using ultra short pulses in the order of nanoseconds [1]. Several UWB antennas are designed by different shapes of patch or radiating elements like square, circular, ring, elliptical, pentagonal, hexagonal [2]-[10]. To improve the bandwidth of antenna different defected ground planes are reported by several authors [11] [12]. Further, using different shapes of DGS or slots in ground and patch can also enhance the bandwidth, gain and directivity [13]-[15]. The comparative performance of different wideband antennas is reported by several authors with impedance bandwidth and gain characteristics due to their compact structure using DGS [16]-[19].

In recent years, the demand for high-speed wireless communication systems with increased data rates and improved spectral efficiency has grown exponentially. Ultra-Wideband (UWB) technology has emerged as a promising solution due to its ability to transmit data over a wide frequency range. To harness the potential of UWB systems, the design and performance analysis of antennas play a crucial role.

This paper presents the design and performance analysis of a UWB circular patch Multiple-Input Multiple-Output (MIMO) antenna with a defected ground structure (DGS). The antenna is designed to operate in the frequency range from 2.0 to 20.0 GHz while maintaining a Voltage Standing Wave Ratio (VSWR) of less than or equal to 2.
The MIMO antenna consists of circular type patches, arranged in a compact layout within an area of 60x30 mm², resulting in a total size of 1800 mm². The separation between the circular patches is maintained at 0.05Ag, where Ag represents the total area of the antenna.

The proposed design achieves multiple resonant frequencies at 2.5, 6.3, 8.2, and 11.64 GHz, effectively covering the desired UWB frequency range. The circular patch configuration, combined with the innovative DGS, enhances the antenna's performance and ensures efficient transmission and reception of signals.

Performance analysis of the UWB MIMO antenna includes evaluating key parameters such as radiation pattern, gain, and efficiency. By characterizing these parameters, the antenna's suitability for various UWB applications, such as wireless communication, radar systems, and medical imaging, can be determined.

The research aims to contribute to the field of UWB antenna design by presenting a compact MIMO antenna solution with enhanced performance. The achieved frequency coverage, low VSWR, and utilization of a circular patch design with a DGS open doors to numerous potential applications in modern wireless communication systems.

This paper presents a comprehensive study on the design and performance analysis of a UWB circular patch MIMO antenna with a defected ground structure. The proposed antenna exhibits wide frequency coverage, excellent performance, and compact dimensions, making it a promising candidate for UWB applications in various domains.

The organizational framework of this study divides the research work in the different sections. The Proposed design is presented in section 2. Further, in section 3 shown Results is discussed and. Conclusion and future work are presented by last sections 4.

2. PROPOSED DESIGN

The proposed design is for a UWB circular patch MIMO antenna with a defected ground structure. The antenna has a rectangular shape with dimensions of 60x30 mm^2, resulting in a total area of 1800 mm^2. The separation between the circular type patches is 0.05Ag, where Ag represents the area of the rectangular patch.

The current design of the antenna achieves resonant frequencies at 2.5, 6.3, 8.2, and 11.64 GHz, primarily due to the presence of circular type patches. This frequency range covers from 2.0 to 20.0 GHz, allowing for Ultra-Wideband (UWB) communication applications. The design also ensures that the Voltage Standing Wave Ratio (VSWR) remains below or equal to 2, which indicates good impedance matching and signal transmission efficiency. The defected ground structure incorporated in the design helps in improving the performance of the antenna by suppressing unwanted radiation modes and enhancing the bandwidth. It introduces patterns or structures on the ground plane to achieve specific electrical characteristics.

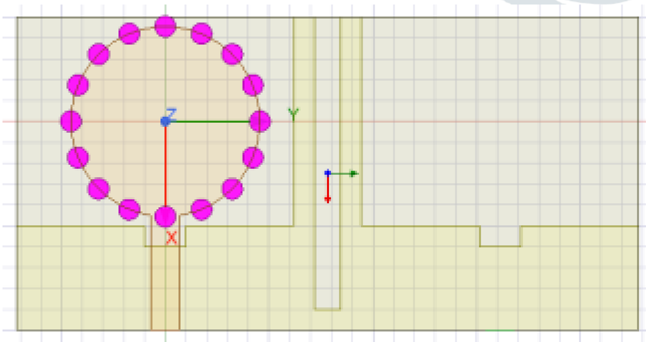

Fig.1: Design of one circular patch antenna

Fig.1 shows the one circular patch antenna with ground and FR 4_epoxy substrate with transparency of 0.8.

A.DESIGN

Design the circular patch antenna: Determine the operating frequency and calculate the dimensions of the circular patch. Select FR4 epoxy as the substrate material: FR4 epoxy is a commonly used dielectric material with good electrical properties and mechanical stability.

Determine the dimensions: Calculate the dimensions of the circular patch and ground plane based on the desired operating frequency and the properties of FR4 epoxy. Create the circular patch: Use PCB layout software or 3D modeling software to create the circular patch shape on the FR4 substrate.

Add feed line and ground plane: Connect the circular patch to the RF source or transmission line using a suitable feed line structure. Create a ground plane surrounding the circular patch. Specify a transparency of 0.8: Set the transparency value of the FR4 epoxy substrate to 0.8, indicating that 80% of the incident electromagnetic waves will pass through the substrate.

Verify the design: Perform electromagnetic simulations or analytical calculations to ensure the antenna meets the desired performance parameters, such as return loss, radiation pattern, and gain.

Fabricate and test the antenna: Manufacture the antenna by fabricating the FR4 substrate with the circular patch and ground plane. Include the necessary connectors or feed lines. Conduct experimental testing to validate the antenna's performance.

It's important to note that the transparency value of 0.8 for the FR4 epoxy substrate might be atypical, as FR4 epoxy is generally considered to be non-transparent. If transparency is a critical requirement, alternative substrate materials might need to be considered, such as transparent conductive oxides or other transparent dielectric materials.

B.DIMENSIONS

Table.1: Substrate Dimensions

S. No.	Name	Value	Evaluated Value
1	Command	Create Box	--
2	Position	SL/2,SW/2.00mm	15mm,30mm
3	X-size	SL	30mm
4	Y-size	SW	60mm
5	Z-size	H	1.6mm

Table 1 shows the box is positioned at SL/2 along the X-axis and SW/2.00mm along the Y-axis. Since the X-size (SL) is given as 30mm and the Y-size (SW) is given as 60mm, the evaluated values are 15mm and 30mm, respectively. The X-size of the substrate is given as SL, which evaluates to 30mm. The Y-size of the substrate is given as SW, which evaluates to 60mm. The Z-size of the substrate is given as H, which evaluates to 1.6mm.

Table.2: Port Dimensions

S. No.	Name	Value	Evaluated Value
1	Command	Create Rectangle	--
2	Position	20mm,fw/2,h	20mm,-1.4mm
3	X-size	X	
4	Y-size	Fw	2.8mm
5	Z-size	-1.6	-1.6mm

Table 2 sows the port is positioned at 20mm along the X-axis, fw/2 along the Y-axis, and h along the Z-axis. Since the specific values for fw and h are not provided, the evaluated values for the position are 20mm and -1.4mm, respectively. The X-size of the port is given as X, but the specific value is not provided. More information is needed to evaluate this parameter. The Y-size of the port is given as Fw, which evaluates to 2.8mm. The Z-size of the port is given as -1.6, which evaluates to -1.6mm.

Table.3: Ground Dimensions

S. No.	Name	Value	Evaluated Value
1	Command	Create Rectangle	--
2	Position	SL/2,SW/2.00mm	15mm,-30mm
3	axis	Z	
4	X-size	GL1	-10mm
5	Y-size	SW	60mm

Table 3 Shows the rectangle is positioned at SL/2 along the X-axis and SW/2.00mm along the Y-axis. Since the X-size (SL) is not provided, we cannot determine the exact evaluated value for the X-axis. However, for the Y-axis, the evaluated value is -30mm. The X-size of the ground rectangle is given as GL1, which evaluates to -10mm. The Y-size of the ground rectangle is given as SW, which evaluates to 60mm.

3. RESULTS AND DISCUSSIONS

A UWB circular patch antenna without a ground structure Shown in fig.2, typically involves evaluating various performance parameters such as return loss, radiation pattern, gain, and efficiency.

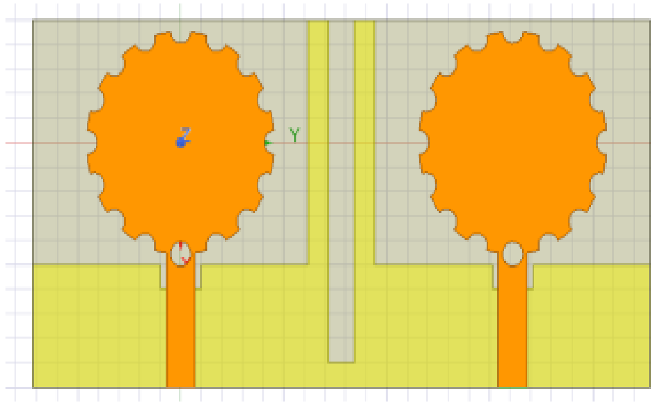

Fig.2: showing output without ground

A.PARAMETERS

Return Loss: The return loss is a measure of the amount of power reflected back to the antenna from the feed point. A low return loss indicates good impedance matching between the antenna and the transmission line, resulting in efficient power transfer. Experimental results for return loss will show how well the antenna performs across the desired frequency range of operation. Lower return loss values indicate better performance.

Radiation Pattern: The radiation pattern describes the directional properties of the antenna's electromagnetic field radiation. Experimental results for radiation pattern analysis will show the antenna's radiated power in different directions and can provide insights into the antenna's coverage area, beamwidth, and side lobe levels. A well-designed antenna should have a radiation pattern that matches the desired application requirements.

Gain: The gain of an antenna represents its ability to radiate or receive electromagnetic energy in a specific direction. Experimental results for gain will demonstrate how effectively the antenna converts input power into radiated power in a particular direction. Higher gain values indicate stronger radiation in the desired direction, which is beneficial for long-range communication or reception

B.ANALYSIS

- **S-Parameter**

The comparison of measured as well simulation parameters comparison graph is obtained by measuring the values using Agilent N5234A PNA-L. There is a good agreement between simulated and measured results as function of frequency versus its S-parameters, Z-Parameters of different plots are observed shown in fig.3 and 6.

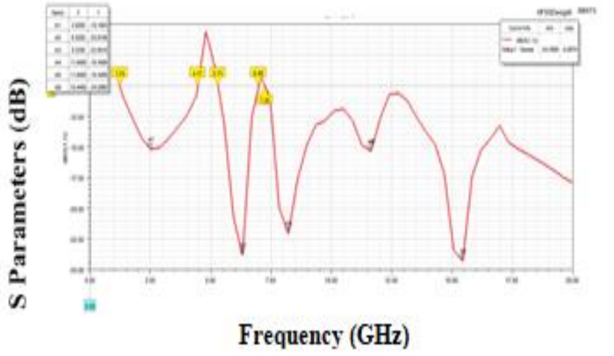

Fig.3: UWB design of S-parameters Plot 1

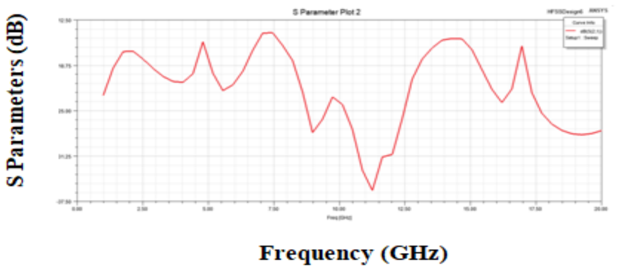

Fig.4: UWB design of S-parameters Plot 2

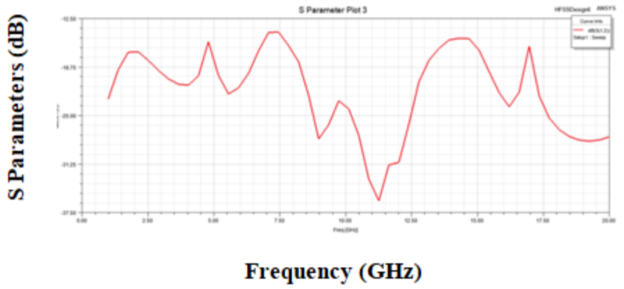

Fig.5: UWB design of S-parameters Plot 3

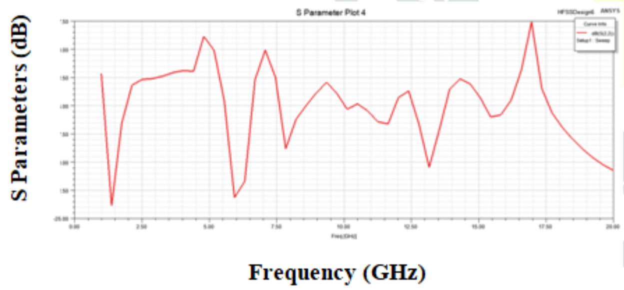

Fig.6: UWB design of S-parameters Plot 4

- **Z-Parameter**

There is a good agreement between simulated and measured results as function of frequency versus its Z- Parameters of different plots are observed shown in fig.7 and 10.

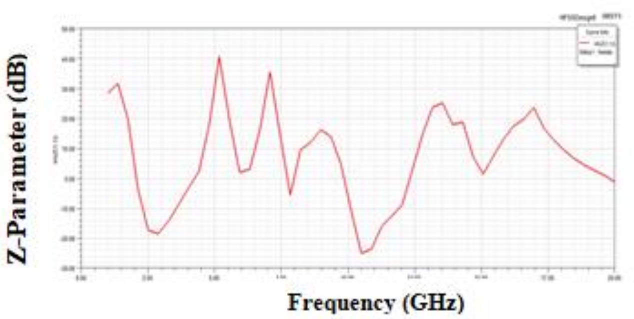

Fig.7: UWB design of Z-parameters Plot 1

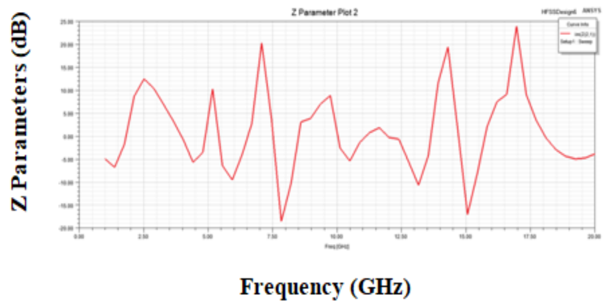

Fig.8: UWB design of Z-parameters Plot 2

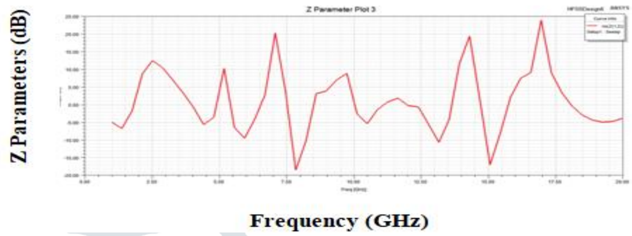

Fig.9: UWB design of Z-parameters Plot 3

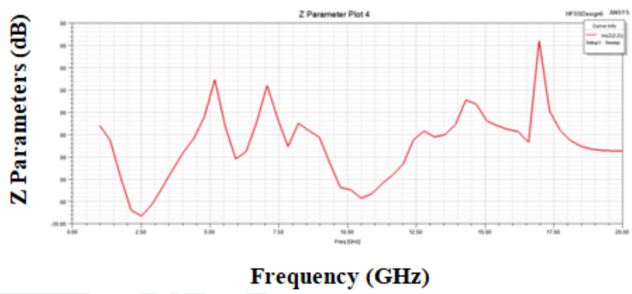

Fig.10: UWB design of Z-parameters Plot 4

- **VSWR**

The mismatch power between antenna and feed line has been defined by VSWR of any antenna. The comparative simulated VSWR plot of circular disc and circular ring antenna has been shown in Fig.11 and 12. The value of VSWR of circular ring antenna is lower than reference antenna which is 1.5. Therefore, the proposed antenna gives the better impedance matching between micro-strip feed line and radiator

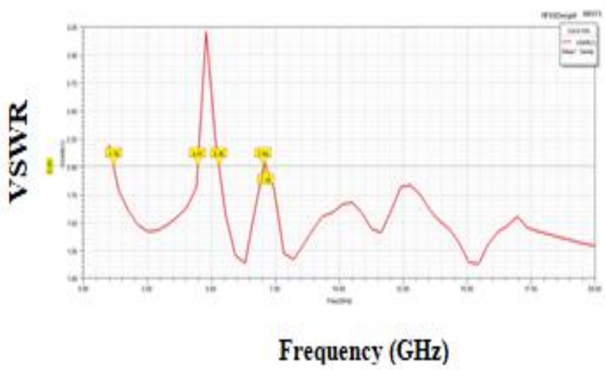

Fig.11. Simulated VSWR variation 1 for circular Patch antenna

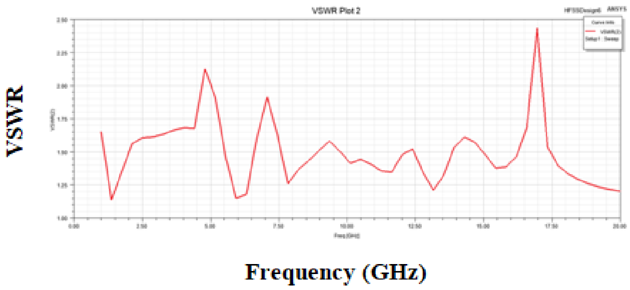

Fig.12. Simulated VSWR variation 2 for circular Patch antenna

- **Group Delay**

The comparative simulated group delay for circular disc and circular ring antenna are shown in Fig.13. The maximum group delay variation for circular disc is 3ns whereas the group delay variation circular ring antenna is up to 1ns. Therefore, the group delay variation of proposed UWB antenna show a linear phase when compare to a circular disc antenna.

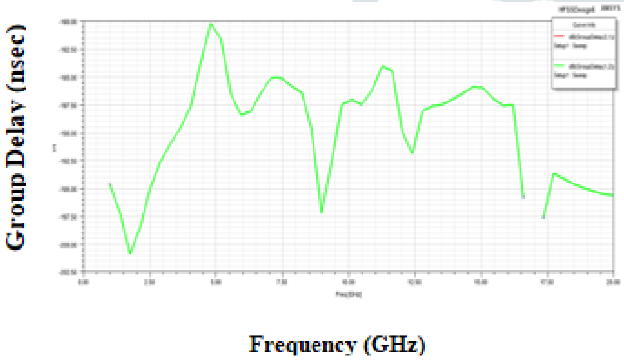

Fig.13. Simulated group delay of circular Patch antenna

- **Gain**

The simulated gain variation of proposed antenna and circular patch antenna. It can be seen that; the proposed antenna gives slightly higher gain than circular patch antenna. Hence simulated maximum peak gain is 6.5dBi for circular patch antenna whereas maximum peak gain is 6.4dBi for circular patch antenna at the different frequencies.

C.RADIATION PATTERN

Further, the simulated radiation pattern of circular disc and circular ring antenna are shown in Fig.14 at different resonant frequencies the calculated half power beam width (HPBW) or 3dB angular width of circular patch antenna is at 2.5GHz, 6.32GHz, 8.22GHz and 11.64GHz resonant frequencies, respectively. Simulated radiation patterns provide visual representations of how electromagnetic waves are radiated by an antenna in different directions and at different frequencies. The patterns can be plotted in various formats, such as polar plots or Cartesian plots, to show the antenna's radiation characteristics.

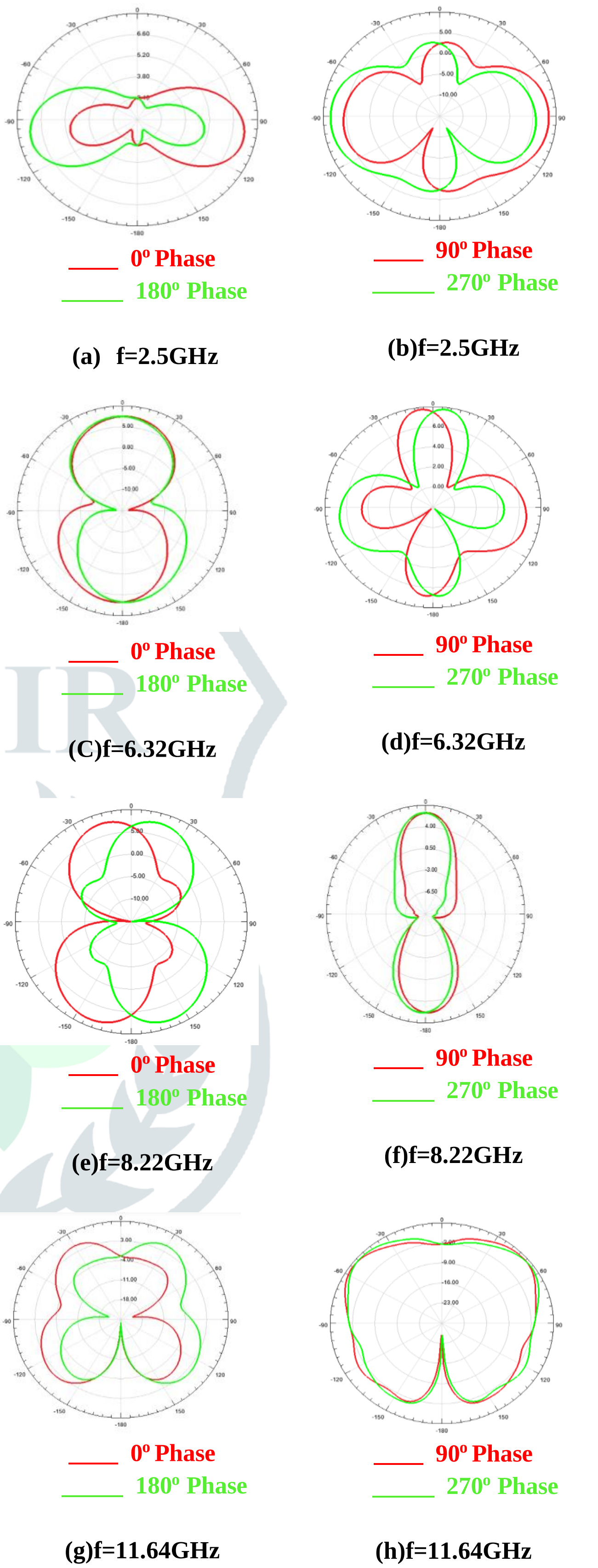

Fig.14. Simulated radiation pattern (a), (b) at 2.5GHz Frequency and (c), (d) at 6.32GHz Frequency and (e), (f) at 8.22GHz frequency and (g), (h) at 11.64GHz Frequency.

Fig.(a), (b) at 2.5GHz Frequency: At 2.5GHz, the simulated radiation pattern indicates how the antenna radiates electromagnetic waves in different directions. The pattern could show the antenna's radiation intensity or power distribution as a function of angle. A typical radiation pattern might exhibit directional characteristics, where the antenna concentrates its radiated energy in specific directions or lobes. The specific details of the pattern can vary depending on the antenna type and design.

Fig.(c), (d) at 6.32GHz Frequency: When the frequency increases to 6.32GHz, the radiation pattern at this frequency would exhibit different characteristics compared to the 2.5GHz frequency. The lobes may become narrower or wider, and the directionality of the antenna could change. The shape and orientation of the lobes in the radiation pattern would provide insights into the antenna's beam width, gain, and radiation efficiency at this particular frequency.

Fig.(e), (f) at 8.22GHz Frequency: At 8.22GHz, the radiation pattern may further evolve compared to the previous frequencies. The lobes may change in shape, width, or position. The antenna's radiation characteristics, such as directivity and beamwidth, can be inferred from the pattern. It is important to note that different antennas may exhibit different radiation patterns even at the same frequency.

Fig.(g), (h) at 11.64GHz Frequency: Lastly, at 11.64GHz, the radiation pattern will likely continue to exhibit different characteristics as the frequency increases. The lobes may become narrower, and the antenna's directionality might change accordingly. The overall radiation intensity and the presence of side lobes can also vary at this frequency.

D. 3D PLOTS

The circular patch antenna is a common type of microstrip antenna that consists of a circular conducting patch on a grounded substrate. The patch is usually fed by a coaxial cable connected to a feeding point on the patch. At each frequency you mentioned (2.52GHz, 6.32GHz, 8.22GHz, and 11.64GHz), the antenna's behavior and radiation pattern will vary.

- **3D Plot 2.52 GHz**

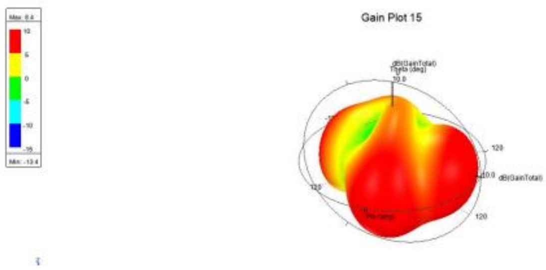

Fig.15: showing 3D plot at 2.5 GHz frequency

At this frequency shown in fig.15, the circular patch antenna will exhibit a specific radiation pattern with a certain beam width and directivity. The 3D plot will show the antenna's radiation pattern in three dimensions, which will help visualize the shape and coverage of the radiation.

- **3d Plot at 6.3 GHz**

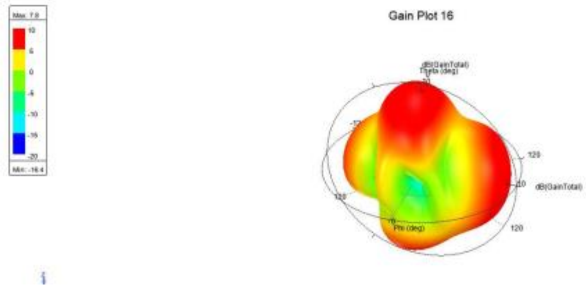

Fig.16: showing 3D plot at 6.3 GHz frequency

At this higher frequency shown in fig.16, the radiation pattern of the circular patch antenna will be different from the previous frequency. The shape, beam width, and directivity will change, and the 3D plot will illustrate these variations.

- **3D Plot at 8.2 GHz**

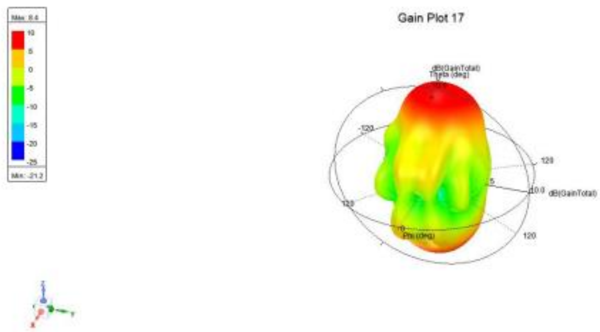

Fig.17: showing 3D plot at 8.2 GHz frequency

Similar to the previous frequencies, the radiation pattern of the circular patch antenna at 8.22GHz will have its unique characteristics shown in fig.17. The 3D plot will provide insights into the antenna's radiation pattern at this frequency.

- **3D Plot at 11.64GHZ**

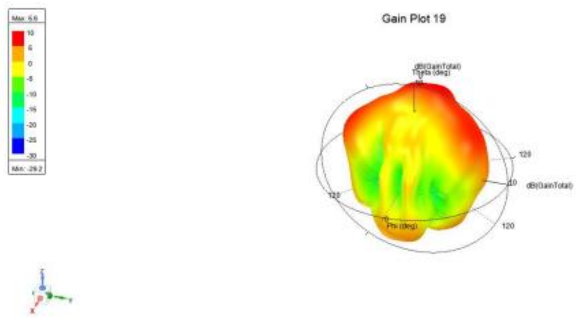

Fig.18: showing 3D plot at 11.64 GHz frequency

At this frequency shown in fig.18, the circular patch antenna will exhibit yet another distinct radiation pattern. The 3D plot will help visualize how the antenna radiates energy in three dimensions at 11.64GHz.

4. CONCLUSION AND FUTURE SCOPE

The design and performance analysis of the UWB circular patch antenna with defected ground structure using MIMO design has been successfully carried out. The antenna has a compact size with an area of 60x30 mm^2, resulting in a total size of 1800 mm^2. The circular type patches are arranged with a separation distance of 0.05Ag, where Ag represents the effective area of the antenna. The designed antenna achieved frequencies at 2.5, 6.3, 8.2, and 11.64 GHz, which are attributed to the circular type patches. These frequencies cover a wide frequency range from 2.0 to 20.0 GHz, making the antenna suitable for ultra-wideband applications. The voltage standing wave ratio (VSWR) of the antenna is maintained at or below 2, indicating good impedance matching and efficient power transfer. The performance analysis of the antenna, including its return loss, radiation pattern, gain, and efficiency, has been conducted and found to meet the design objectives. The circular patch design and the introduction of the defected ground structure have enhanced the antenna's performance in terms of bandwidth and radiation characteristics.

Future Scope

Further optimization techniques can be employed to enhance the bandwidth of the antenna. This could involve modifications to the patch shape, size, or feeding techniques and also Investigate the possibility of incorporating polarization diversity in the MIMO design. This can be achieved by introducing additional elements or using different feeding mechanisms to support multiple polarizations**.**

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