Design and analysis of a circularly polarized antenna for S-band applications that uses an inclined fractal defective ground structure (IFDGS)

[1]B.Vishnu Vardhan III B.TECH, Department of ECE,
Institute of Aeronautical Engineering, T.S, INDIA
19951a04m7@iare.ac.in

[2]Y.Yuvanth III B.TECH, Department of ECE,
Institute of Aeronautical Engineering, T.S, INDIA
19951a04n4@iare.ac.in

[3]B.Manoj Reddy III B.TECH, Department of ECE,
Institute of Aeronautical Engineering, T.S, INDIA
19951a04n5@iare.ac.in

[4]Y.Vivek III B.TECH, Department of ECE,
Institute of Aeronautical Engineering, T.S, INDIA
19951a04m8@iare.ac.in

[5]Dr. D Srikar, Assistant Professor of ECE,
Institute of Aeronautical Engineering, T.S, INDIA
d.srikar@iare.ac.in

[6]Dr. M V Krishna Rao, Professor of ECE,
Institute of Aeronautical Engineering, T.S, INDIA
mvkrao@iare.ac.in

Abstract :

A circularly polarized microstrip patch antenna is designed in Ansys HFSS software with a circular polarization (CP) single feed square patch with inclined fractal defective ground structure (IFDGS) microstrip antenna is proposed. An angled fractal-shaped slot implanted along the diagonal axis of a ground plane produces CP radiation. An inclined fractal structure is slotted into the ground plane to improve the antenna's performance metrics such as axial ratio bandwidth, return loss bandwidth, and gain. The IFDGS parameter studies are presented to demonstrate how to obtain CP radiation. Fabrication and measurement of the CP antenna with the third iterative IFDGS. The measured findings corroborate the simulations and demonstrate a high level of consistency. With an overall dimension of 41x 41x1.6 mm^3, the suggested antenna achieved CP radiation at 2.61 GHz. It has a 5.53 %, impedance bandwidth at 2.6 GHz centre frequency and a 1.14 %, 3-dB axial ratio (AR) bandwidth at 2.61 GHz centre frequency. The proposed antenna's highest gain was measured to be 3.44 dB. The proposed antenna could be used for S-band wireless communication.

Introduction :

A microstrip antenna is produced on a printed circuit board (PCB) using photolithographic technology. Microstrip antennas are low-profile antennas. A Microstrip or Patch Antenna is a metal patch installed at ground level with a dielectric material in between. These are incredibly small antennas that emit very low radiation. The metal patch is $\lambda/2$ in length. When the antenna is activated, the waves generated within the dielectric are reflected, and energy is radiated from the metal patch's edges, which is very low. Because of their lightweight, compact size, low cost, and easy fabrication, microstrip antennas are extensively employed in satellite and mobile applications.

Circular polarization is a polarization state in which the electromagnetic field of an electromagnetic wave has a constant magnitude at each location and rotates at a constant rate in a plane perpendicular to the wave's direction. The fact that light acts as a two-dimensional transverse wave cause the phenomena of polarization to occur. When the two orthogonal electric field component vectors are of similar magnitude and are 90° out of phase, or one-quarter wavelength apart, circular polarization occurs. Antennas with circular polarization are known as circularly polarised (CP) antennas. CP antennas provide several fundamental advantages over linear polarization antennas due to the properties of circular polarization and are rapidly becoming a crucial technology for a variety of wireless systems, including satellite communications, mobile communications, global navigation satellite systems (GNSS), wireless sensors, radio frequency identification (RFID), wireless power transfer, wireless local area networks (WLAN), wireless personal area networks (WPAN), wireless personal area networks (WPAN), Worldwide Interoperability for Microwave Access (WiMAX) and Direct Broadcasting Service (DBS) television reception systems.

Circularly polarised microstrip antennas are frequently employed in modern communication equipment due to their versatility and ability to reduce the loss caused by antenna misalignment. Because it is the simplest design for obtaining circularly polarised radiation, microstrip antennas with a single feed are often utilized. Circular polarization is made by truncating two opposing edges of a circular patch antenna at 45° to the feed. The truncation divides the field into two orthogonal modes of equal magnitude and phase shift of 90º.

A defective ground structure (DGS) is a defect on a printed microstrip board's ground plane that was purposely produced. It's usually done on the ground plane as an etched design. The Electromagnetic Band Gap (EBG) structure is a simpler version of DGS. In microstrip transmission line and circuit applications, this EBG is a periodic pattern with a band-stop property, whereas the DGS is made up of a single flaw or a small number of defects with periodic/aperiodic topologies. In this model Coaxial feeding is used, often known as probe feed, as a typical method of feeding Microstrip patch antennas. The coaxial connector's inner conductor passes through the dielectric and is attached to the radiating patch, whereas the outer conductor is linked to the ground plane.

The S-band is a designation by the IEEE for a part of the microwave band of the electromagnetic spectrum covering frequencies from 2 to 4GHz. Airport surveillance radar, weather radar, surface ship radar, and several communications satellites, including those used by NASA to communicate with the Space Shuttle and the International Space Station, all use the S-band. The 2.4–2.483 GHz ISM band, which is commonly used for low-power unlicensed microwave devices such as cordless phones, Bluetooth, WiFi, keyless auto locks, and microwave ovens, is also part of the S-band (typically at 2.495 GHz). From 2.483778 to 2.500278 GHz, India's regional satellite navigation network (IRNSS) broadcasts.

Literature Survey :

A dual-band fractal monopole antenna is proposed for use with the Long Term Evolution (LTE) standard. The antenna is built on a perturbed planar Sierpinski fractal shape, with geometrical descriptors calculated through particle swarm optimization (PSO). The improved antenna has good impedance matching in the LTE bands of 700 and 2600 MHz, as well as a size reduction of 24% to a typical quarter-wave resonant monopole. Both models and measurements are used to evaluate the proposed antenna's efficiency [1]. For extending the perimeter of a given shape, fractal geometry uses self-similar or its scaled-down replica. As a result, the current length increases, resulting in miniaturization. Minkowski Island, Koch snowflake, Sierpinski carpet, Sierpinski gasket, crossbar tree, and various polygonal shapes and their hybrids are instances of fractal shapes [2].

A dual-band patch antenna is proposed over Minkowski fractal defective ground structure (DGS) for bandwidth enhancement in GPS applications. The proposed design combines fractal imperfection on the metallic ground plane with truncated dual L-shaped slits cut on diagonal corners of the radiating patch. With better antenna radiation qualities, this approach transfers frequencies to lower bands. Improvements in bandwidth and gain are gained by deploying symmetrical and asymmetrical boundaries to the constructor of the fractal DGS on a metallic ground plane [3]. To minimize the cross-polarized field, a rectangular microstrip patch with an asymmetric-shaped defective ground structure is used. The use of a fractal defective ground structure to decrease the mutual coupling between microstrip antenna elements has been proposed [4].

A new single-feed slotted microstrip antenna in the shape of an arrowhead for CP. By embedding an arrowhead-shaped slot in the first quadrant on the diagonal axis of a square patch, CP radiation and antenna size reduction can be achieved [5]. A new design for a wideband circularly polarised slot antenna is proposed[6]. The planned antenna's CP radiation is achieved by using an inclined coupling slot-loaded feed line on the ground plane. a dual-band small circularly polarized microstrip antenna [7] it suggested antenna achieves CP radiation by utilizing a modified square ring slot in the ground plane.

A compact single-feed circularly polarized stack antenna consisting of a Minkowski-island-based fractal patch with an aperture coupled design [8], this fractal structure is able to generate dual-mode and two orthogonal modes for circular polarization. A circularly polarised Flared-U-type fractal boundary microstrip antenna with a single feed has been presented. Two degenerated orthogonal modes for CP radiation are formed by exchanging the edges of a square path with asymmetrical Flared-U-type fractal curves in two perpendicular orientations. A novel method for designing single-feed CP microstrip antennas is proposed. This single-feed square patch microstrip antenna's CP radiation, on the other hand, is achieved by etching the fractal defective ground structure in the ground plane [9].

Koch fractal geometry is used to create a new circularly polarised antenna design. By displaying two asymmetric Koch fractal geometries on the x- and y-planes of the square patch, CP radiation and antenna size reduction are achieved[10]. A circularly polarised microstrip antenna with two unequal length orthogonal rectangular shaped slots on a circular patch has been developed for mobile satellite applications. Using a mix of DGS and fractal theory, performance characteristics can be improved [11]. A new method for designing single-feed CP microstrip antennas has been developed [12].This single-feed square patch microstrip antenna's CP radiation, on the other hand, is achieved by etching the fractal defective ground structure in the ground plane.

In this work, we propose a single-feed circularly polarised microstrip antenna with an inclined fractal defective ground structure. The CP design is being formed as a result of this inclined fractal slotted DGS along the diagonal axis in the ground plane. To improve the various features of the proposed antenna, an inclined fractal slotted DGS was used. By varying the angle of the inclined fractal slotted DGS, a high-quality CP performance was realized. The operational band's 3-dB axial ratio bandwidth is 30 MHz (2.598 GHz2.628 GHz). The proposed antenna covers the downlink range of the S-band (2.535 GHz 2.655 GHz) application and also falls within the LTE spectrum (1.71 GHz-2.69 GHz). It is most commonly used in satellite communication and mobile WIMAX operations (IEEE 802.16e 2005 standard).

Existing Method :

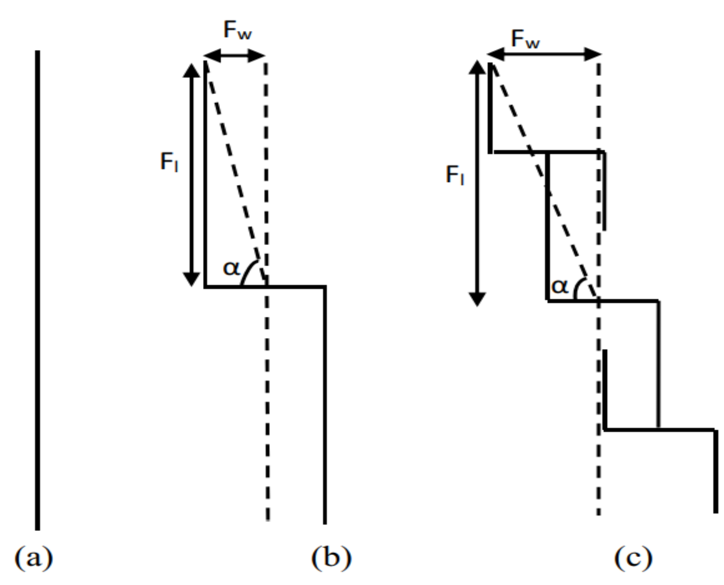

Figure 1. Designed various stages of iteration of the inclined fractal-DGS; (a) zero iteration, (b) first iteration, and (c) second iteration. α (angle) = 74°.

The design of a single coaxial feeding with zero iteration, first iteration, and second iteration inclined fractal slotted defected ground structure square patch antenna. In this work, the ground plane area is 41 mm×41 mm and the square patch area is 24.6 mm×24.6 mm. The antenna is fabricated on an easily available FR4 substrate of the thickness of 1.6 mm ($\varepsilon_r = 4.4$, tan $\delta = 0.02$). In the first and second iterations, asymmetry in the design refers to the fractal slot placed along the diagonal axis in the ground plane, which has variable dimensions. For circularly polarized radiation, this inclined fractal slot generates two orthogonal modes with identical amplitude and 90º phase difference.

The stages of iterations of a fractal design in the ground plane are shown in Figure 1. The zero iteration is a single basis line, as seen in Figure 1(a). The first iterative fractal shape can be made by folding the basis line into an S-shape with two vertical and one horizontal line, as shown in Figure 1(b). The fundamental unit is the initial iterative fractal shape. The second iterative fractal shape evolves from the first iterative fractal shape by folding two vertical lines as shown in Figure 1(c).

Problem Identification :

The circularly polarized microstrip antenna modal is designed on the Ansys HFSS software. The existing method is the perfect antenna but further improvements are needed so, so further IFDGS iteration needs to be adopted as an emerging technique for improving the various parameters of microwave circuits, that is, narrow bandwidth, and cross-polarization. The zero and first iterations even don't have axial ratio bandwidth and 78MHz return loss bandwidth which is very low and for the second iteration, the return loss bandwidth is 129MHz and the Axial ratio bandwidth is also less. So, it will be fully operation used in the S-Band frequency range applications.

Proposed Method :

The design of a single feed third iterative inclined fractal slotted defected ground structure square patch antenna is shown in Figure 2. The ground plane area is 41 mm x 41 mm, and the square patch area is 24.6 mm x 24.6 mm. The proposed antenna is made on an FR4 substrate with a thickness of 1.6 mm ($\varepsilon_r = 4.4$, tan $\delta = 0.02$). Asymmetry in the design refers to the fractal slot implanted along the diagonal axis in the ground plane, which has variable dimensions in the proposed work. For circularly polarized radiation, this inclined fractal slot generates two orthogonal modes with identical amplitude and 90º phase difference.

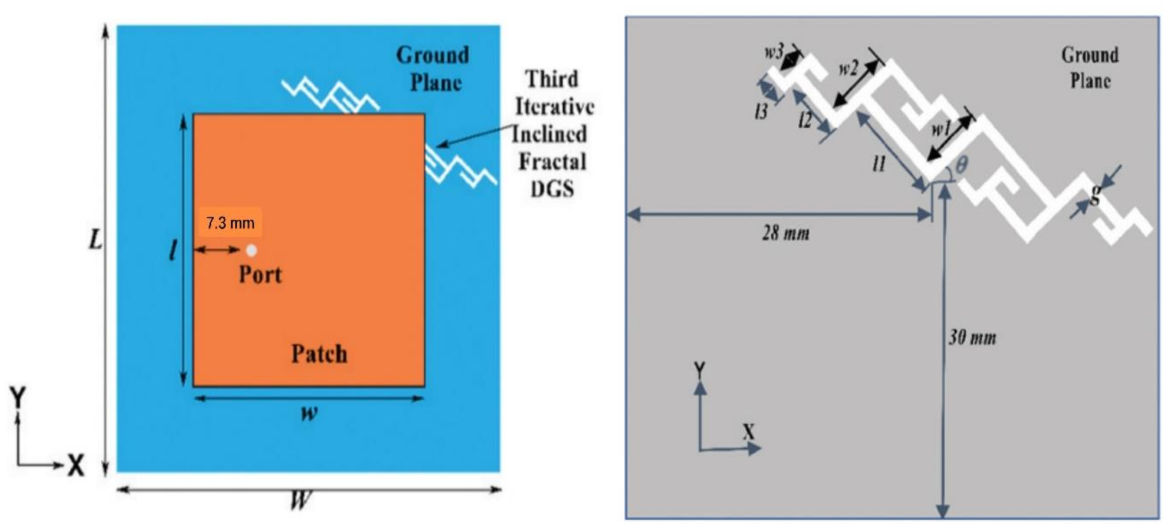

Figure 2. The geometry of the proposed antenna with the third iterative IFDGS; (a) top view,(b) bottom view.

In Figure 3, the proposed antenna's ground layer is etched with the third iterative fractal shape obtained by folding four vertical lines of the second iterative shape. The high-level iterative fractal structure is created in this manner. A 50-coaxial probe is used to feed the proposed circularly polarised IFDGS antenna.

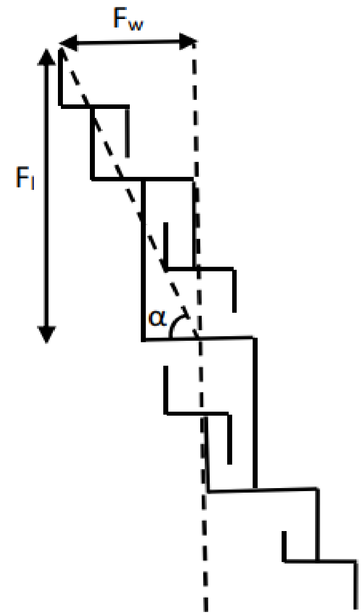

Figure 3. The designed third iteration of the inclined fractal-DGS α (angle) = 74°.

Table 1. Proposed antenna dimensions.

Parameters	Dimensions
Ground Length, L	41 mm
Ground Width, W	41 mm
Patch Length, L	24.6 mm
Patch Width, w	24.6 mm
IFDGS Length, l1	7 mm
IFDGS Width, w1	2.8 mm
IFDGS Length, l2	3 mm
IFDGS Width, w2	2.5 mm
IFDGS Length, l3	2 mm
IFDGS Width, w3	1.4 mm
Slot Width, g	0.4 mm
Angle Of Inclination, θ	49 degree

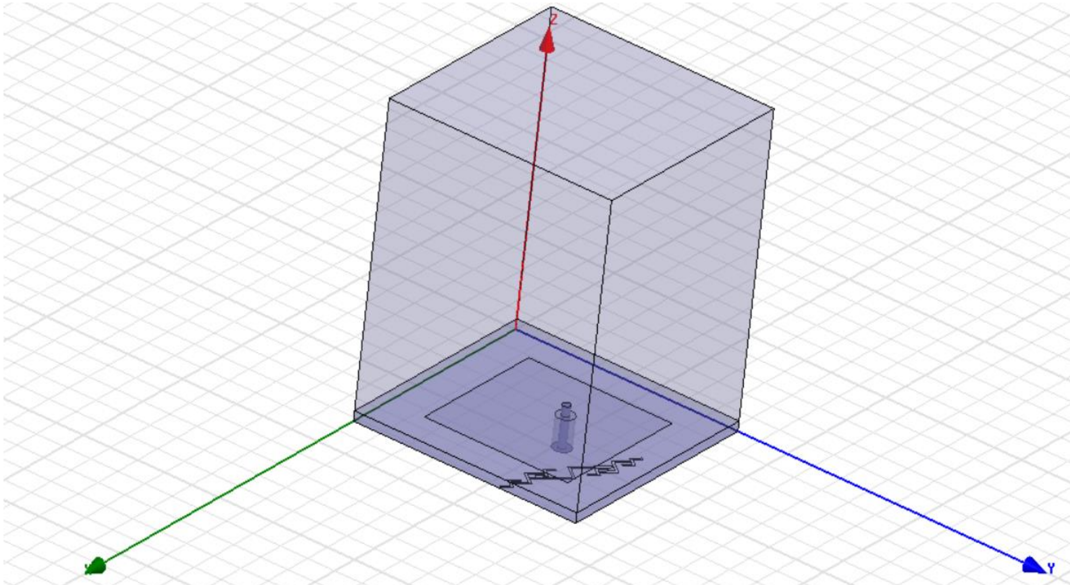

Figure 5a . The Trimetric view of the proposed Antenna

Table 2. Coaxial Feeding dimensions.

Parameter	Material	Radius	Height
Coax Outer	Vaccum	1.6mm	5mm
Coax Inner	pec	0.7mm	5mm
Coax Feed Length	Pec	0.7mm	1.6mm

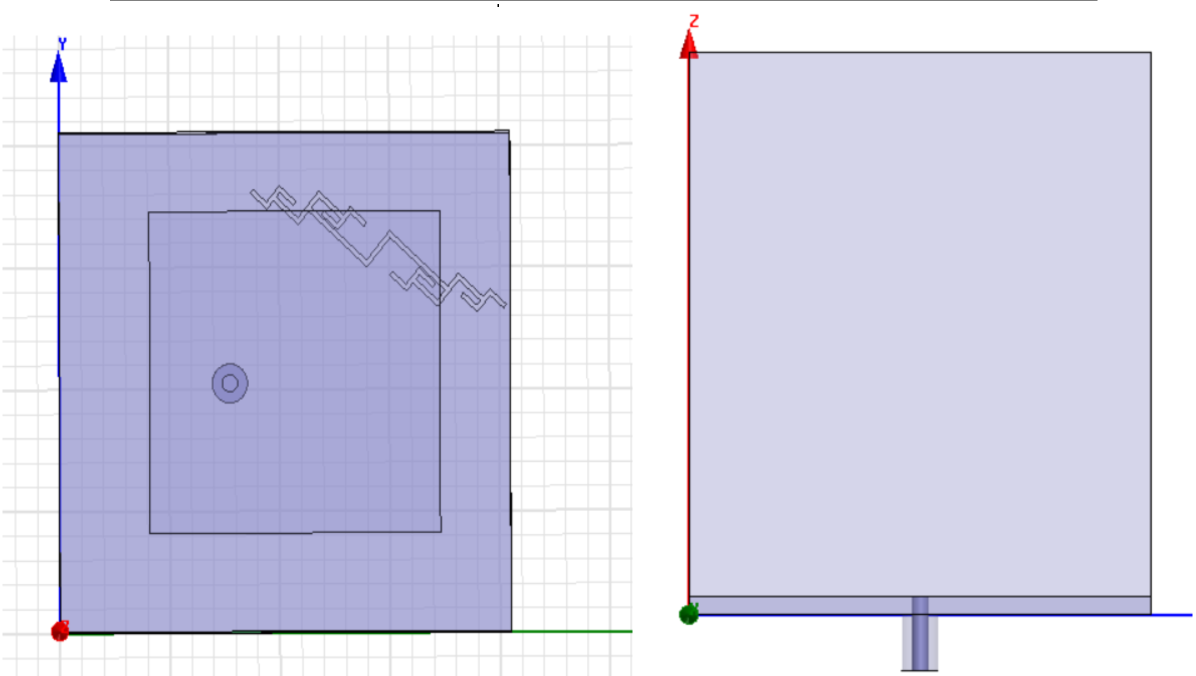

Figure 5.The proposed Antenna (b) Top View, (c) Side View

Flow chart :

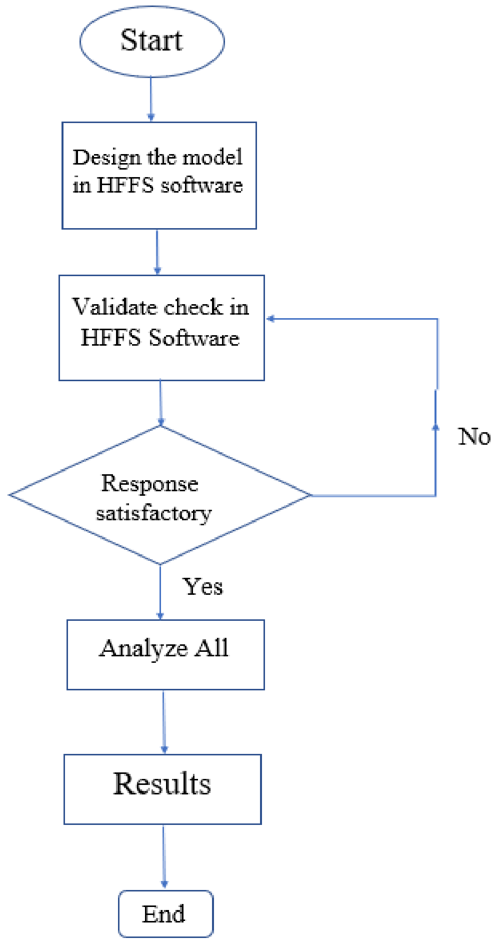

Figure 6. General Flow chart with HFSS Software

The above flow chart Figure 4. illustrates the design of the process of the antenna modal. The modal was designed in HFSS software. The model is first validated-check in HFSS and if the case is satisfactory then Analyze all otherwise repeated till all are satisfied. Then generate results report in HFSS.

Results and Discussions :

The proposed structure is fabricated in a laboratory prototype by a standard photolithography process to validate the simulated results. The electrical performance of the proposed antenna such as return loss, axial ratio, and gain and radiation pattern are accomplished by results in HFSS software.

Table 3. Comparison between iterations of inclined fractal DGS.

Characteristics	Zeroth iteration	First iteration	Second iteration	Third iteration
Return loss bandwidth 144MHz	78 MHz	78 MHz	129 MHz	144 MHz
Axial ratio bandwidth	NA	NA	27 MHz	33 MHz
Gain	3.68 dB	4 dB	3.89dB	3.44 dB

1. Return loss bandwidth

The S-shaped inclined fractal DGS is located on the substrate's lower side, causing reactive lading. The entire electrical length increased with the same area due to the iterations of IFDGS, the miniaturization, and good impedance matching. Table 3 shows how the return loss bandwidth improves with each iteration of inclined fractal DGS antennas. measured S11 of the proposed antenna is shown in Figure 7. The proposed antenna has an impedance bandwidth (S11 < -10 dB) of 67 MHz (from 2.684 GHz to 2.751 GHz) at 2.71 GHz of centre frequency, whereas the impedance bandwidth with IFDGS is expanded to 144 MHz (from 2.529 GHz to 2.673 GHz) at 2.6 GHz of centre frequency, which is wider than the antenna without IFDGS. At 2.6 GHz of centre frequency, it was discovered that the proposed antenna's observed impedance bandwidth (S11 < -10 dB) is about 5.53 % (from 2.529 GHz to 2.673 GHz).

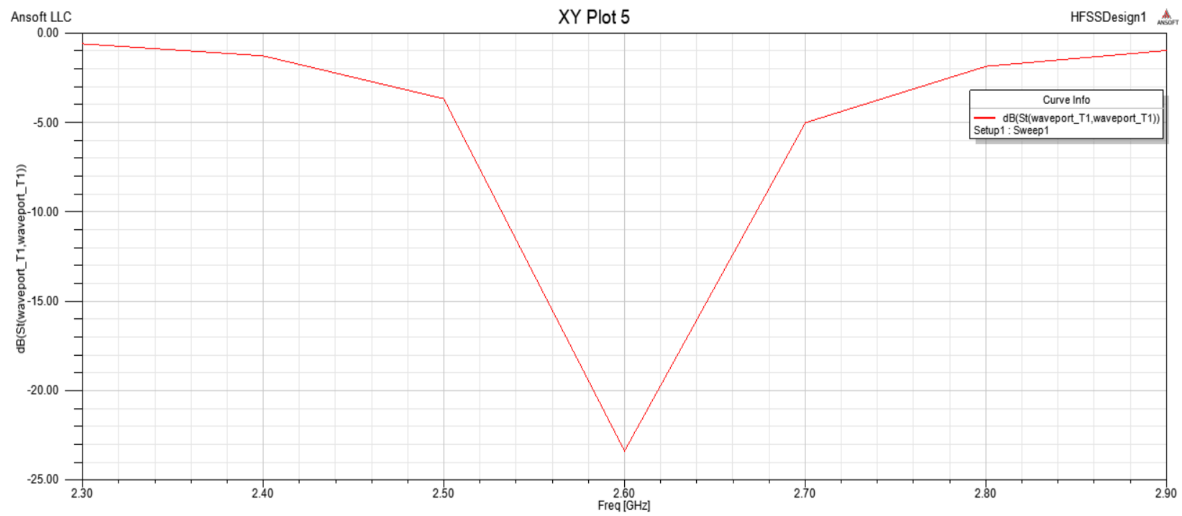

Figure 8. Simulated with the third iterative IFDGS and measured S11 of the CP proposed antenna.

2. Axial ratio bandwidth

The fractal-shaped DGS patch antenna has two orthogonal modes of an electric field with equal magnitude and 90º phase difference for obtaining CP radiation. By feeding the patch at a single spot, these two orthogonal modes with the same magnitude at some resonant frequency are formed. The electric field of one mode can lead by 45º while that of the other can lag by 45º once the suggested inclined fractal slotted DGS is embedded along the diagonal axis of the ground plane, resulting in the 90º phase difference required for circular polarization. As a result of the increased bandwidth of fractal DGS return loss, it also helps to increase the bandwidth of the 3-dB axial ratio in CP.

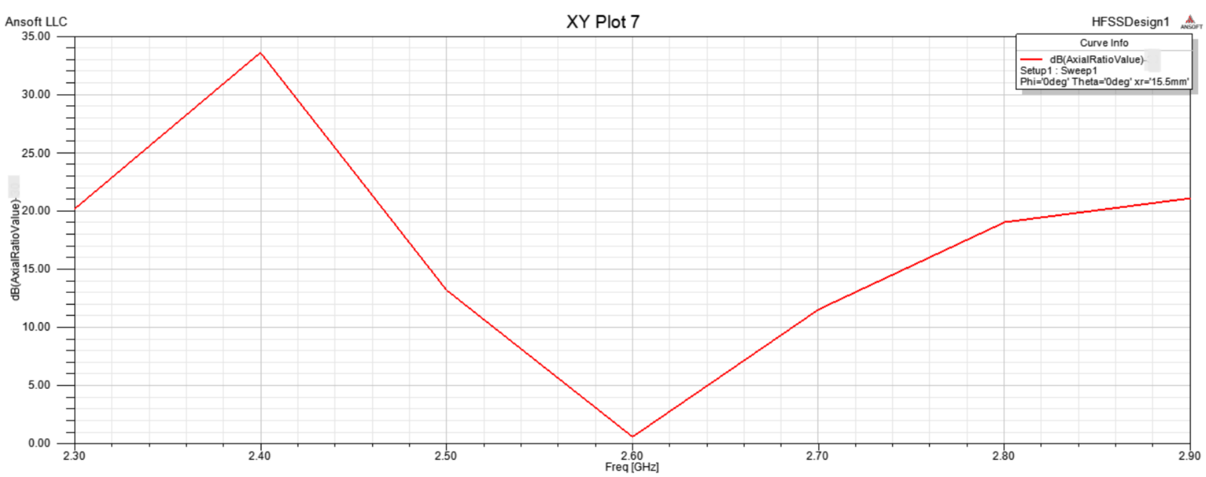

Figure 9. Simulated axial ratio for different iterations of IFDGS.

3. Gain and radiation pattern

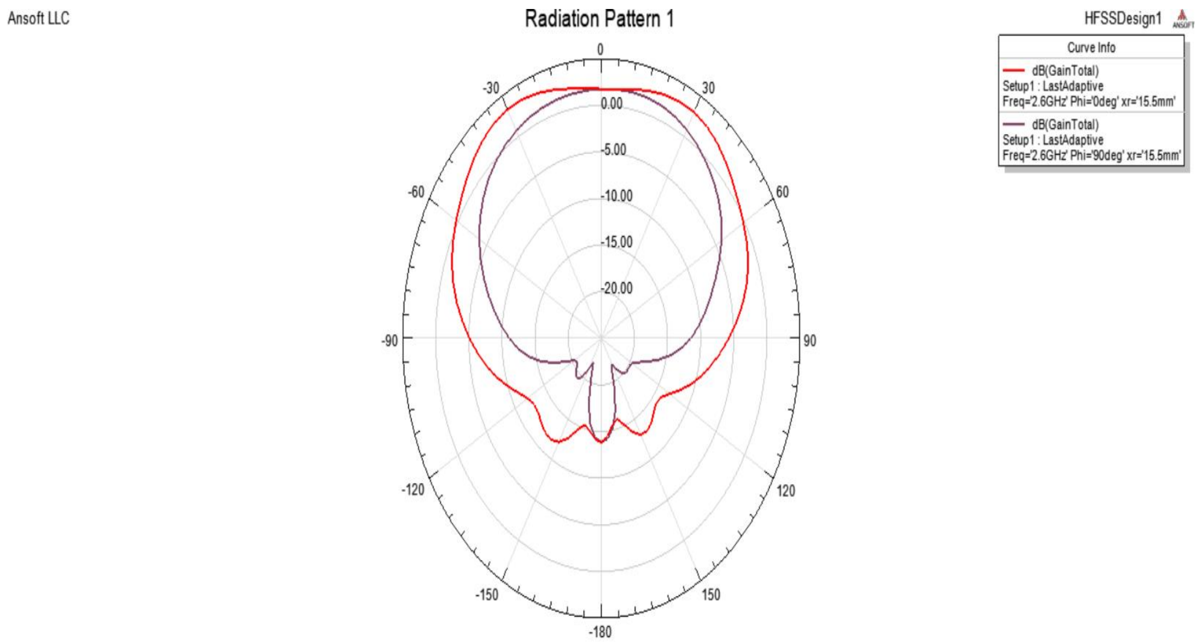

Figure 10. Simulated and measured radiation pattern of the proposed antenna at 2.61 GHz

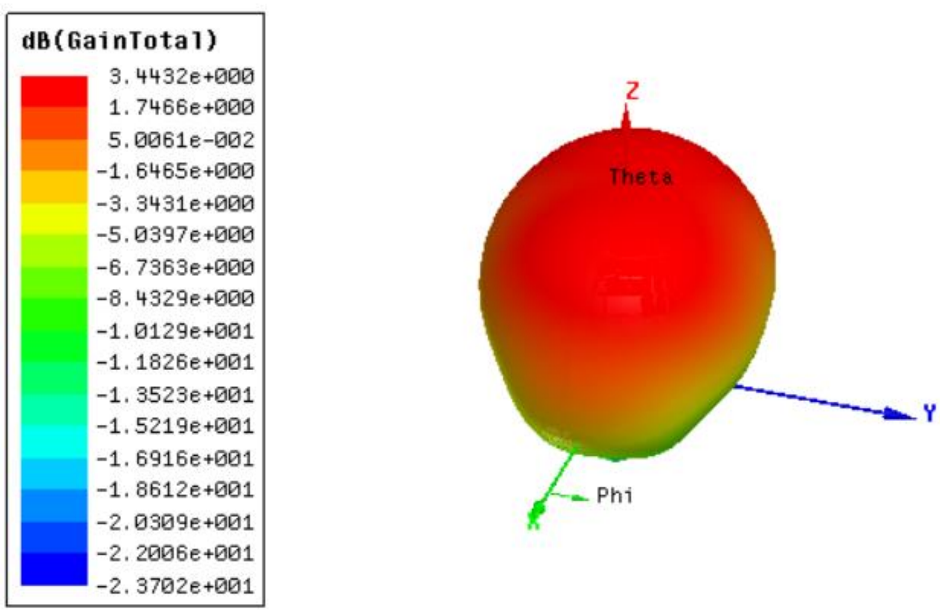

Figure 11. Simulated 3D gain plot of the proposed antenna at 2.61 GHz

The performance of the proposed antenna has been compared with other fractal loaded circularly polarized microstrip antennas as shown in Table 4. It can be seen from the table that the proposed antenna has overall good than the other previous reported work.

Table 4. Comparative study of fractal loaded circularly polarized microstrip antennas.

References	**Antenna Description**	**Overall antenna size (mm^3)**	**Resonant freq(GHz)**	**Dielectric Constant**	**10-dB axial ratio bandwidth (MHz)**	**3-dB axial ratio bandwidth(MHz)**	**Gain (dBi)**
(Hung et al.2012) [8]	Minkowski Island-Based Fractal	57.3 X 57.3 X 3.2	2.4 GHz	4.4	290	30	2-4
(Farswan et al.2015) [10]	Koch Fractal	54 X 54 X 1.6	0.91 GHz	4.4	37	31.5	5.8
(Prajapati et.al. 2015) [11]	Koch Curve Fractal	90 X 90 X 3.149	1.5 GHz	2.5	113	31.5	5.4
(Reddy 2017) [3]	Frared U-Type Fractal	50 X 50 X 3.2	2.3 GHz	2.2	138	42	4-6
(Wei et.al.2016b) [12]	Y-Shaped Fractal	45 X 45 X 3.18	1.575 GHz	10	30	6	2.18
Proposed	S-Shaped IFDGS	41 X 41 X1.6	2.61 GHz	4.4	144	33	3.44

Conclusion and Future Scope :

A circularly polarised microstrip antenna with a single feed has been proposed using IFDGS. On the lower layer of the less expensive FR-4 substrate, an inclined fractal slotted structure is used to create CP radiation. When compared to the second iterative fractal slotted DGS, the antenna performance in the suggested technique of the third iterative fractal slotted DGS is improved. In comparison to other fractals circularly polarized microstrip antennas, this antenna offers good antenna performance. The circularly polarised microstrip antenna is built and measured using the third iterative IFDGS. By adjusting some antenna parameters, the dual impedance bandwidth and 3-dB axial ratio bandwidth may be achieved. All of the simulation's anticipated outcomes are closely matched to measured outcomes. With the LHCP wave at the appropriate axial ratio bandwidth, the proposed antenna analysis has good radiation qualities. This antenna can be used for both mobile WIMAX and satellite connectivity. The Future Scope is to improve the Gain of the antenna, fabricate the antenna design and use this antenna in S-band applications.

References :

[1] Lizzi, L., and A. Massa. 2011. Dual-band printed fractal monopole antenna for LTE applications. IEEE Antennas and Wireless Propagation Letters 10:760–63. doi:10.1109/LAWP.2011.2163051.

[2] Kumar, M., and V. Nath. 2018. Introducing multiband and wideband microstrip patch antennas using fractal geometries: Development in last decade. Wireless Personal Communicable 98:2079–105.

[3] Reddy, B. R. S., and D. Vakula. 2017. Compact dual-band truncated patch antenna with fractal defected ground structure for wireless applications. International Journal of Microwave and Wireless Technologies 9 (1):163–70. doi:10.1017/S1759078715000987.

[4] Kumar, C., and D. Guha. 2015. Asymmetric geometry of defected ground structure for rectangular microstrip: A new approach to reduce its cross-polarized fields. IEEE Transactions on Antennas and Propagation 64:2503–06.

[5] Gautam, A. K., A. Kunwar, and B. K. Kanaujia. 2014. Circularly polarized arrowhead-shape slotted microstrip antenna. IEEE Antennas and Wireless Propagation Letters 13:471–74. doi:10.1109/ LAWP.2014.2309719.

[6] Patil, S., A. K. Singh, B. K. Kanaujia, and R. L. Yadav. 2018a. Design of inclined coupling slot loaded CPW-feed circularly polarized slot antenna for wireless applications. Electromagnetics 38 (4):226–35.

[7] Patil, S., A. K. Singh, B. K. Kanaujia, and R. L. Yadav. 2018b. A compact, dual wide-band circularly polarized, modified square ring slot antenna for C and Ku band applications. International Journal of Microwave and Wireless Technologies 11 (2):182–89. doi:10.1017/S1759078718001368.

[8] Hung, T. F., J. C. Liu, S. S. Bor, and C. C. Chen. 2012. Compact single-feed circularly polarized aperture-coupled stack antenna with minkowski-island-based fractal patch. Microwave and Optical Technology Letters 54 (10):2278–83. doi:10.1002/mop.27090.

[9] Wei, K., J. Y. Li, L. Wang, R. Xu, and Z. J. Xing. 2016. A new technique to design circularly polarized microstrip antenna by fractal defected ground structure. IEEE Transactions on Antennas and Propagation.

[10] Farswan, A., A. K. Gautam, B. K. Kanaujia, and K. Rambabu. 2015. Design of Koch fractal circularly polarized antenna for handheld UHF RFID reader applications. IEEE Transactions on Antennas and Propagation 64 (2):771–75. doi:10.1109/TAP.2015.2505001

[11] Prajapati, P. R., G. G. K. Murty, A. Patnaik, and M. V. Kartikeyan. 2015. Design and testing of a compact circularly polarised microstrip antenna with fractal defected ground structure for L-band applications. IET Microwaves, Antennas & Propagation 9 (11):1179–85. doi:10.1049/ietmap.2014.0596

[12] Wei, K., J. Y. Li, L. Wang, R. Xu, and Z. J. Xing. 2016b. A new technique to design circularly polarized microstrip antenna by fractal defected ground structure. IEEE Transactions on Antennas and Propagation 65:372125.