Bandwidth Enhancement of Star-Shaped Fractal Antenna in X-band

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***Abstract*—A small star-shaped fractal antenna is presented in this research paper. The antenna is designed using a microstrip feedline and FR4 substrate material. High Frequency Structural Simulator (HFSS version 15) is used to design the proposed antenna. The design consists of three iterations with partial ground in final iteration. The bandwidth has been enhanced by increasing iterations, further bandwidth enhancement has been obtained by using partial ground. The design is analysed for important antenna parameters such as return loss, gain and bandwidth. The impedance bandwidth of 8.865-11.96 GHz (30%) has been achieved at a resonant frequency of 10.29 GHz. The present design mainly focuses on the X band applications such as satellite communications, military, RADAR and weather forecast.**

Keywords: Fractal Antenna, Partial Ground and Impedance Bandwidth.

I. Introduction

The present communication system requires a compact and low profile antenna with wideband operating characteristics to meet the demand of high data rate and small size. Designing such antennas is a challenge and very complicated task for antenna designers; however to obtain the above requirements various techniques have been mentioned in previous papers which include dual feed, stacked substrates, parasitic patches, slots, shorting pin and fractal geometries [1-5]. Fractals follow properties of self-similarity and space-filling which are the main reasons to inspire researchers to take fractal geometries as a substitute to fulfill the above-said requirements. Implementation of fractal geometry in microstrip patch antenna is a favorable option to obtain multiband/ broadband antenna with compact size. Several fractal geometries were incorporated in previous literature such as Sierpinski carpet, Koch snowflake, Sierpinski triangle, Minkowski curve, Fibonacci word and Hilbert curve along with some novel geometries [6-20]. Additionally, few researchers have offered ideas related to designing star shape fractal antenna with combination of geometries such as star-Sierpinski, truncated star, star-hexagon, octagon-star, ring-star, circle-square, rotating squares etc. As Bhomia et al. presented X band star shape fractal antenna using FR4 substrate and probe feed method. In this design, Sierpinski carpet shape slots are cut from a basic star shape patch to increase bandwidth to 26.9% [21]. Then, Swathi et al. anticipated a fractal antenna of star shape truncated patch along with CPW feed and DGS (defected ground structure). In antenna design, Fr4 substrate is used and dimensions of design are optimized using ANN tool in MATLAB; thus achieved bandwidth of frequency region 2.2-6.3 GHz [22]. Furthermore, Dhakad and Singhal suggested star-shaped fractal antenna design using FR4 substrate material along with partial ground plane; it is observed that bandwidth of frequency region 2-6 GHz is obtained with symmetrical radiation pattern, high gain and compact size [23]. Rao et al. proposed star shaped fractal antenna using RO 4003 substrate ($\varepsilon r = 3.55$) and observed multiband behavior in the frequency region of 4.5-17 GHz [24]. Jain and Binod reported a star shape fractal patch using FR4 substrate and a layer of metamaterial prepared by cross-shaped slots on the ground plane. It is observed that bandwidth of frequency region 3-14 GHz along with the maximum gain of 15.8533 dB is obtained [25]. Singh and Sharma presented a comparison of multifractal antenna with star-shaped fractal antenna using FR4 substrate and partial ground plane where star-shaped fractal antenna provides more bandwidth in final iteration as compared to multi fractal antenna [26]. Also, Khade et al. designed star shaped fractal antenna with improved line feed and semi-elliptical ground plane with addition of notch and then provides bandwidth of 2.36-2.77 GHz [27]. Sharma and Gangwar proposed star shaped fractal antenna with dumbbell shaped DGS and

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dumbbell shaped microstrip feed line designed on FR4 substrate which provides triple band characteristics at resonant frequencies (2.25, 3.61 and 5.16) GHz [28]. Malallah et al. reported a star shaped fractal antenna with semi-circular slot at the center of patch and using FR4 substrate. It is perceived that dual-band resonance is obtained at frequencies of (1.3308 and 2.6992) GHz [29]. Pandav et al. designed a monopole antenna based on star-shaped fractal patch and FR4 substrate. It is observed that maximum gain of 3.5 dBi is achieved at frequency 4.4 GHz alongwith wide bandwidth of frequency region 1.87 GHz-4.78 GHz having omnidirectional radiation properties [30]. It is observed from the above literature that few star-shaped fractal antennas have been designed with different geometrical combinations which increase complexity of design. Also previous star shape fractal antennas are operating in different frequency bands. Merely in [22], star shaped antenna is designed in X band having a percentage bandwidth of 26.9%. With the motivation to design X band antenna having simple star-shaped fractal geometry and broad bandwidth, antenna design is presented in this paper using microstrip feed line and FR4 substrate. The third iteration is considered as the main radiator along with partial ground plane. The simulation results present a broad bandwidth of 8.865-11.96 GHz. This broadband antenna is useful for X-band application areas. Thus the designed antenna has required advantages of broadband, compact size and simple structure. The next contents of the paper are antenna geometry and design, simulation results, and conclusion in last.

II. Antenna Geometry and Design

The foremost necessity of the anticipated antenna is to design a wideband/broadband antenna which can support a high data rate in order to inspire the current communication. Thus a star-shaped fractal antenna is proposed for X- band uses such as weather forecasting, defense, satellite communication and RADAR. The reported antenna is intended for three iterations (iteration 0 to iteration 2). The proposed antenna is designed using FR4 substrate having size (75x75x3) mm3 where substrate height of 3mm is taken after parametric analysis. However, substrate height is considered 1.575 mm before the final design. This structure is designed with HFSS simulator. To achieve broadband, partial ground is used in this design. The dimensions of ground plane are considered as 75x5 mm2 using parametric analysis. The microstrip feedline is applied to deliver input signal to antenna. A similar feed point is used in all iterations. The feedline dimensions are 18.7x6.5 mm2. Optimal values of antenna parameters are used to obtain broad bandwidth by parametric analysis. In order to design iteration 0, two triangles with an angular difference of 600 are joined to make a star shape and then the position of this star is rotated by angle -450. Furthermore, to design iteration 1, one more star is taken with lesser dimensions than the star designed in iteration 0. Then the second star is subtracted from first star. Thus patch metal is reduced in size and perimeter of patch is greater than before. This is the main requirement of fractal antenna design. Likewise, six more symmetrical stars of smaller size are taken and are subtracted from iteration 1 to design iteration 2. The next iterations didn't provide favorable results so iteration 2 is considered as the final iteration. Moreover, to increase bandwidth in X band, partial ground is used in iteration 2. Table 1 depicts dimensions of designed antenna. Fig. 1(a)-(d) represents different iterations of proposed antenna. It is characterized as self-correlated star- formed iterations (iteration 0 to iteration 2) to present final fractal antenna design. The black part signifies copper material and the white part implies removed copper from patch and ground plane. This design is found suitable for X band application areas.

III. Simulation Results

The fractal structure is simulated in frequency range (8-12) GHz using HFSS simulator. Then, the designed antenna is analyzed to examine performance of specific parameters which are termed as return loss, bandwidth and gain. The pa-rameter return loss signifies matching impedance amid feed position and antenna. The acceptable value of return loss is -10 dB at required resonant frequency. Ta-ble 2 represents simulation results of the designed antenna.

Table 1: Line Dimensions of Proposed Antenna

Parameters	Line Dimensions (mm)
WS	75
LS	75
Wg	75
Lg	5
Wf	6.5
Lf	18.7
h	3
r1	35.5
r2	20.3
r3	18.4
r4	10.4
r5	7.2
r6	3.94
s1	20.4
s2	10.6
s3	4.08

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Table 2: Represents Simulation Results of Intended Antenna

Iteration	Resonant Frequency (GHz)			S11 (dB)	Bandwidth Ratio	Gain (db)	
	FL	FC	FU		(FU- FL)		
0th iteration	8.08	8.14	8.2	-11.7896	118.7 MHz	1.015:1	0.175
	8.4411	8.58	8.7	-22.5014	338.9 MHz	1.03:1	0.286
	9.1559	9.38	9.46	-12.0662	304.1 MHz	1.03:1	6.5
	9.7911	9.95	10.1514	-36.66	360.3 MHz	1.04:1	4.18
1st iteration	9.81	10.14	10.6759	-17.2288	865.9 MHz	1.26:1	3.2
	10.739	10.89	11	-11.2468	260.3 MHz	1.024:1	6.253
2nd iteration	10.236	11.29	11.66	-27.0728	1.424 GHz	1.14:1	4.304

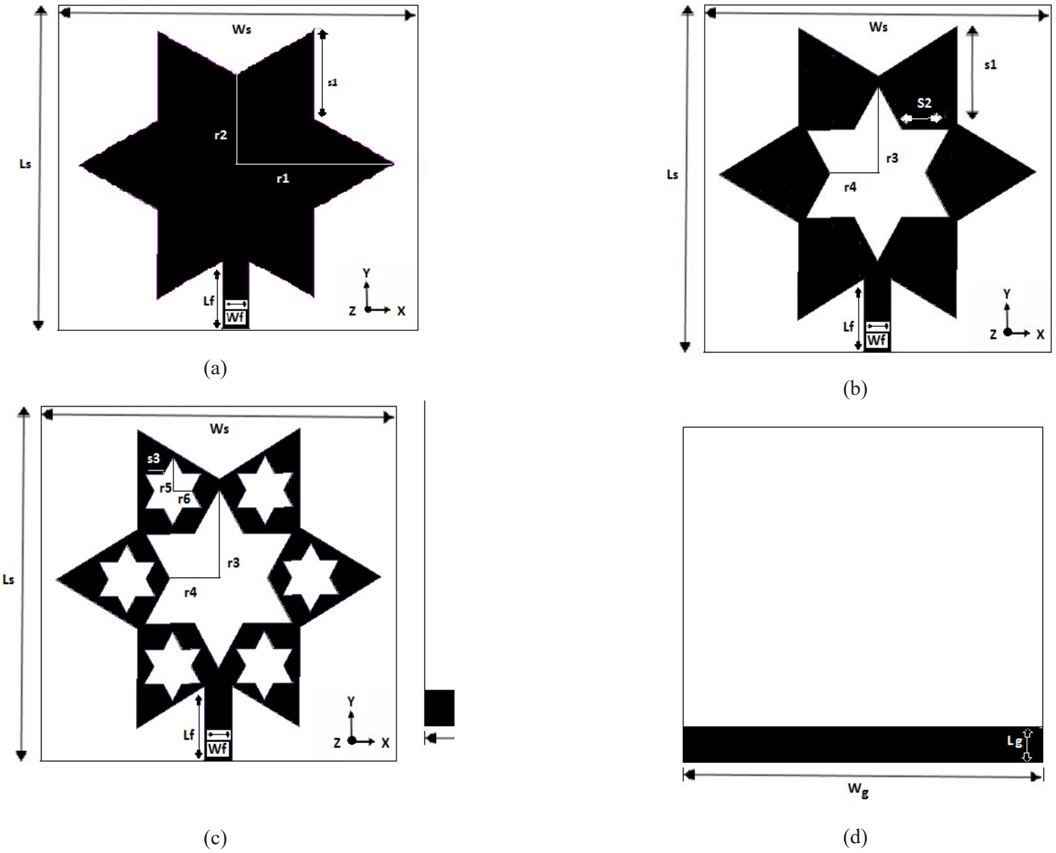

Fig. 1: Represents (a) Iteration 0 (b) Iteration 1 (c) Iteration 2 and (d) Partial Ground Plane

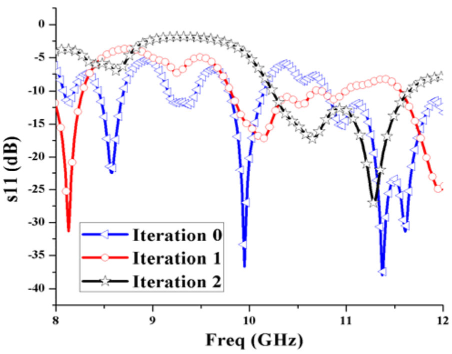

Fig. 2: Represents S11 of the Designed Antenna From Iteration 0 to Iteration 2.

A. Variation of Partial Ground Length Dimension (Lg)

To achieve the enhanced parameter values as impedance matching and broader bandwidth, parametric analysis of ground length dimension is performed in this part. To obtain improved results, Lg is enlarged with a step size of 5mm by taking first value as 5mm and ending value 75mm, the deviations of Lg have described in figure 3.

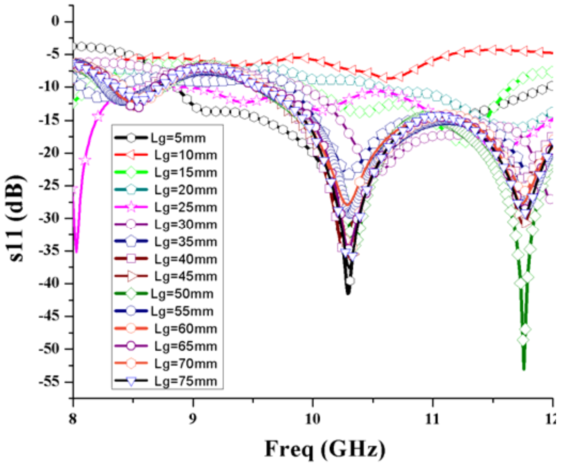

Fig. 3: Represents S11 of Iteration 2 with Different Values of Partial Ground

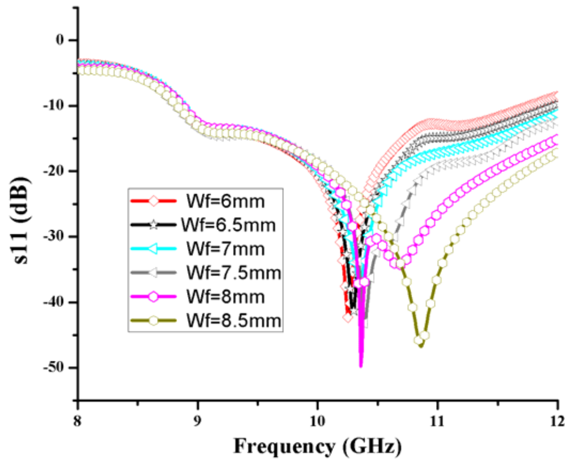

Fig. 4: Represents S11 of Iteration 2 with Different Values of Feed Width

Table 3: Comparison of Results of Antenna Geometry Without and With DGS

Antenna design	Resonant Frequency (GHz)			Return Loss	Bandwidth (GHz)	Bandwidth Ratio
	FL	FC	FU	(dB)	(FU- FL)	
2nd iteration (basic geometry)	10.236	11.29	11.66	-27.0728	1.424 GHz	1.139
Antenna with defected ground plane	8.865	10.29	11.96	-41.4	3.1 GHz	1.35

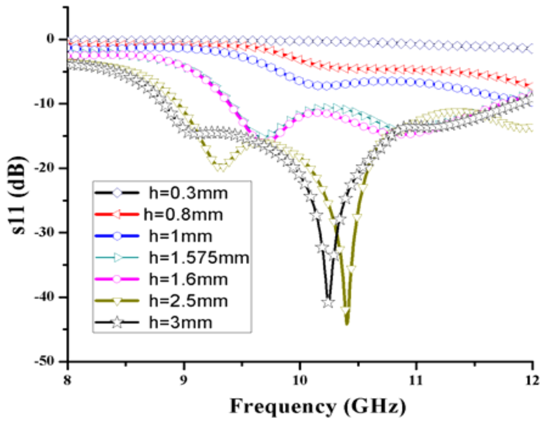

Fig. 5: Represents S11 of Iteration 2 with Different Values of Substrate Height

B. Variation of Feed Width (WF)

The width of microstrip feed line is changed from 6mm to 8mm with gap of 0.5 mm to achieve an ideal wide impedance bandwidth. As it is apparent from figure 4 that for the feed width of 6mm and 6.5mm, bandwidth exists in X band and for other values of feed width, bandwidth extends X band region. Thus, it is observed that bandwidth of 3.095 GHz is obtained with feed width of 6.5mm which is greater than the bandwidth of 2.89 GHz; obtained with feed width of 6mm. Thus feed width of 6.5mm is considered optimum for the design of proposed antenna.

C. Substrate Height Variation (h)

Along with changes in feed width, substrate height is also varied and simulated to obtain the finest results. The antenna is analyzed for various values of substrate heights (which are available in the market) 0.3mm, 0.8mm, 1mm, 1.575mm, 1.6mm, 2.5mm, 3mm and 3.6 mm as shown in figure 5. It is observed that (-10 dB) band width is found only for substrate heights 1.575mm, 1.6mm and 3mm. The highest bandwidth of 3.095 GHz is obtained with a substrate height of 3mm. Thus substrate height of 3mm is considered as the final height.

D. 2D Radiation pattern and Gain

It is a graphical illustration of radiation properties concerning angular coordinates. Figure 6 shows radiation patterns of simulated design at cut-off frequencies of impedance bandwidth. There are two primary planes, called E-plane and H-plane, are taken. The simulated radiation patterns are observed at cut off frequencies 8.865 GHz and 11.96 GHz and are represented in figure 6 (a) and 6 (b).

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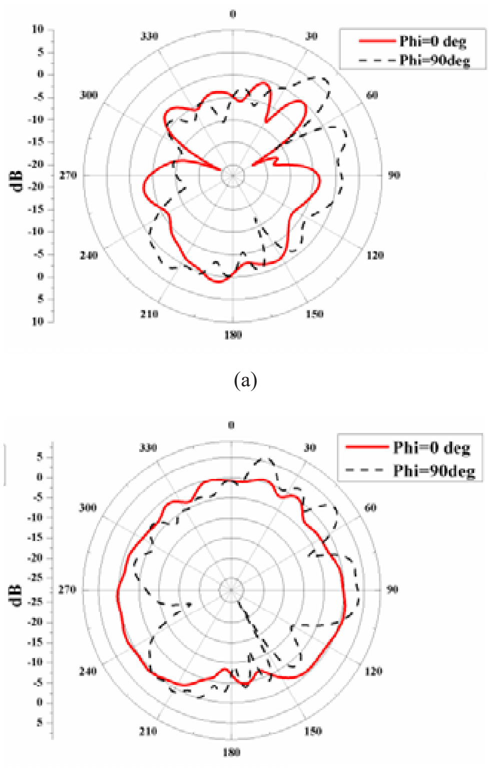

(a)

(b)

Fig. 6: E Plane (phi=90^0)/H Plane (phi=0^0) Radiation Patterns of Intended Antenna Design at Frequencies (a) 8.865 GHz (b) 11.96 GHz

It is observed from the figure that E/H plane represents nearly directional patterns at lower cut-off frequency 8.865 GHz and almost omnidirectional patterns at upper cut-off frequency 11.96 GHz along with some distortions. Figure 7 shows simu-lated gain versus frequency plot for the designed antenna. It is examined from the plot that highest gain of 4.957 dB is offered by proposed antenna. Further-more, it is observed that the value of gain varies in X band region.

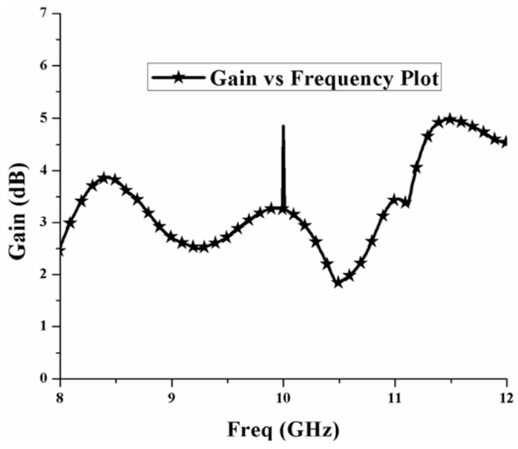

Fig. 7: Gain w.r.t. Frequency Plot for Proposed Antenna

IV. Conclusion

A star-shaped fractal antenna is designed using HFSS where partial ground plane is used. It is excited through microstrip line feed and partial ground plane. The fractal antenna is useful because it provides a compact size antenna with wideband characteristics. The achievement of proposed antenna is optimized by using parametric analysis on various important antenna parameters termed ground length, feed width and substrate height. Thus, the optimized fractal antenna provides broad impedance bandwidth between frequency region 8.865-11.96 GHz. Thus bandwidth of 30% has been obtained relative to the center frequency of 10.29 GHz. A wideband antenna with small size can be used in portable devices. This proposed antenna can be employed in X band application areas including weather forecast, microwave communication, SATCOM, military and RADAR.

References

[01] Werner, D.H. & Ganguly, S. : An Overview of Fractal Antenna Engineering Research. IEEE Antennas Propag Mag. 45, 38–57 (2003)

[02] Kumar, A., Gupta, N., Gautam, P.C.: Gain and Bandwidth Enhancement Techniques in Microstrip Patch Antennas - A Review. IJCA. 148 (7), 9-14 (2016)

[03] Gupta, N., Saxena, J., Bhatia, K.S.: Design of Wideband Flower-Shaped Microstrip Patch Antenna for Portable Applications. Wireless Pers Commun, 109, 17–30 (2019)

[04] Gupta, N., Saxena, J., Bhatia, K.S., Kumar, R.: A Compact CPW Fed Planar Stacked Circle Patch Antenna for Wideband Applications. Wireless Pers Commun. 116 (4), 3247-3260 (2020)

[05] Balanis, C.A.: Antenna Theory:Analysis and Design. Wiley, Hoboken, NJ, USA. (2005)

[06] Kumar, M., Nath, V.: Introducing Multiband and Wideband Microstrip Patch Antennas Using Fractal Geometries: Development in Last Decade. Wireless Pers Commun. 98, (2) 2079–2105 (2018)

[07] Gupta, N., Saxena, J., Bhatia, K.S.: Optimized Metamaterial-Loaded Fractal Antenna using Modified Hybrid BF-PSO Algoritham. Neural comput and applic, 32, 7153- 7169 (2019)

[08] Kumar, A., Pharwaha, A.P.S.: Development of a Modified Hilbert Curve Fractal Antenna for Multiband Applications. IETE J. Res., 1-10 (2020)

[09] Anand, R., Chawla, P.: A Novel Dual-Wideband Inscribed Hexagonal Fractal Slotted Microstrip Antenna for C- and X-band Applications. International journal of RF and Microwave Computer-Aided Engineering. 30 (9), e22277 (2020)

[10] Garg, R.K., Nair, M.V.D., Singhal, S., Tomar, R.: A New Type of Compact Ultra Wideband Planar Fractal Antenna with WLAN Band Rejection. Microwave and Optical Technology Letters. 62 (7), 2537-2545 (2020)

[11] Sharma, N., Bhatia, S.S. Ultra-Wideband Fractal Antenna using Rhombus Shaped Patch with Stub Loaded Defected Ground Plane: Design and measurement. AEU-International Journal of Electronics and Communications. 131, 153604 (2021)

[12] Kumar, A., Pharwaha, A.P.S.: On the Design of Novel Half T-Square Strip Fractal Antenna. IJE (2021)

[13] Singhal, S.: Asymmetrically CPW Fed Square Sierpinski Carpet Ultra Wideband Terahertz Antenna. Optik. 242, 167056 (2021)

[14] Kola, K.S., Chatterjee, A.: A High-Gain and Low Cross-Polarized Printed Fractal Antenna for X-Band Wireless Application. International Journal of Communication Systems. 34 (10), e4807 (2021)

[15] Ohi, M.A.R., Hasan, Z., Faruquee, S.F.B., Kawsar, A.A.M., Ahmed, A.: Wideband Minkowski Fractal Antenna using Complementary Split Ring Resonator in Modified Ground Plane for 5G Wireless Communications. Engineering Reports. e12388 (2021)

[16] Nallapaneni, S., Muthusamy, P.: Design of Multiband Fractal Antenna Loaded with Parasitic Elements for Gain Enhancement. International Journal of RF and Microwave Computer-Aided Engineering. 31 (6), e22622 (2021)

[17] Sohi, A.K., Kaur, A.: Computational Analysis of a Dual-Port Semi-Circular Patch Antenna Combined with Koch Curve Fractals for Ultra-Wideband Systems. Engineering Reports. e12378 (2021)

[18] Zou, Q., Jiang, S.: A Compact Flexible Fractal Ultra-Wideband Antenna with Band Notch Characteristic. Microwave and Optical Technology Letters. 63 (3), 895-901 (2021)

[19] Kattimani, B., Patil, R.R.: Bandwidth Enhancement of Microstrip Antenna using Fractal Geometry for S-Band Applications. SN Computer science. 2 (4), (2021)

[20] Sairam, M.V.S., Harini, R.M.V.: Performance Analysis of an Extended Sierpinski Gasket Fractal Antenna for Millimeter-wave Femtocells Applications. Wireless Pers Commun. 1-32 (2021).

[21] Bhomia, Y., Dutta, B.R., Rathore, DVS.: Star Shape Wideband Fractal Antenna Design for X Band Microwave Application. IJECCE. 4 (4), 1306-1311 (2013)

[22] Swathi, A., Pavithra, J.J., Divya, S., Indhumathi, V., Suganthi, S., Raghavan, S.: A Novel ANN Optimized CPW Fed Truncated Star Shaped Fractal Antenna for Wireless Applications. IJMA. 2 (2), 77-84 (2013)

[23] Dhakad, M., Dr. Singhal, P.K.: Design of a Novel Wideband Star Shaped Iterated Fractal Antenna for Various Wireless Applications. IJSRD. 3 (6), 241-244 (2015)

[24] Rao, N., Malik, A., Kumar, R., Goel, S., Kumar, D.: Novel Star-shaped Fractal Antenna for Multiband Applications. IJMWT. 9 (2), 419-425 (2015)

[25] Jain, S., Binod, B.: Metamaterial Inspired Star Shape Fractal Antenna for Gain Enhancement. Engineering and Technology Journal. 1 (2), 45-51 (2016).

[26] Singh, M., Sharma, N.: Comparison of Multi-Fractal Antenna with Star Shaped Fractal Antenna for Wireless Applications. IJCA. 133 (14) 35-37 (2016).

[27] Khade, S., Bhagat, M., Khatri, S., Tompe, S., Khatri, S.: Design of Star Shaped Fractal Antenna for Wireless Applications. JETIR. 5 (5), 155-160 (2018)

[28] Sharma, S., Gangwar, S.P.: A Compact Star Shaped Fractal Antenna for Multiband Applications. Lecture Notes in Electrical Engineering, 587, 199-208 (2020)

[29] Malallah, R., Shaaban, R.M., Al-Tumah, W. A. G.: A Dual Band Star-Shaped Fractal Slot Antenna: Design and Measurement. AEU- International Journal of Electronics and Communications. 127, 153473 (2020).

[30] Pandav, S., Das, T.K., Samyuktha, K.R., Behera, S.K., Sadhukhan, G., Mohanty, M.: Design of Star-Shaped Fractal Antenna for Wideband Applications. IEEE SCEECS , Bhopal, India (2020).

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