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An Improved Sierpinski Fractal MIMO Array Antenna with Enhanced Isolation for Next Generation Wireless Applications

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ABSTRACT: In this article, a modified design of a four port microstrip patch antenna array with dual band is presented. Sierpinski carpet fractal geometry is applied here making the proposed antenna array suitable for the next generation MIMO applications. This antenna structure is designed using FR-4 substrate having a relative permittivity of value 4.4 and microstrip feed line technique is used for antenna excitation. After the application of fractal, by placing the array elements efficiently and by optimizing its inter element spacing (D), improved isolation is achieved here. All antenna structure and its array proposed here are designed using ANSYS HFSS. To demonstrate the effectiveness of the fractal geometry on MIMO antenna, all the antenna performance results like return loss, isolation, VSWR, bandwidth, and gain are analyzed. Improved impendance bandwidth and better isolation factor are challenges in the field of MIMO array antenna design. Simulation result illustrates that, this antenna structure resonates at 6.16 GHz and 15.3 GHz with significant impedance bandwidth values of 62.90% and 46.99% respectively. With the improved isolation factor, and a gain of 5 dB to 10 dB over the entire frequency bands, this fractal MIMO array finds suitable applications in different ongoing (2G, 3G and 4G) and upcoming next generation(5G) wireless communications.

Keywords: 5thGeneration, ISM, Isolation, Microstrip Patch Antenna, MIMO Array, Sierpinski Fractal

Abbreviations: MPA, Microstrip Patch Antenna; MIMO, Multiple Input Multiple Output; VSWR, Voltage Standing Wave Ratio; ISM, Industrial Scientific and Medical; Wi-Fi, Wireless-Fidelity

I. INTRODUCTION

The rapid investigations on wireless systems leads high capacity, high speed, ultra-high latency and ultra reliable 5th generation (5G) mobile communication. Major features of 5G communication are large coverage area, low battery consumption, high security, high spectral efficiency, high quality multimedia services, very high data rates which is achievable through Wireless-Fidelity (Wi-Fi) network [1]. Such wireless systems have demand like portability and mobility. Antenna is an integral part of all wireless systems. So there is a need for compact, efficient, multiband and wideband wireless antennas. The Microstrip patch antenna (MPA) is a best candidate to fulfill this need with its multiple features of less volume, light weight dual frequency operation, frequency agility, low fabrication cost and broad bandwidth. MPA contains a conducting patch which is mounted on grounding substrate and fed by microstrip feed line technique [2]. Also, the conducting patch of MPA can be mounted on any other types of surfaces easily to afford highest radiation with negligible side lobes along the direction of perpendicular to the patch. Still, the conventional MPAs suffer severe limitations like narrow bandwidth, low efficiency and lower gain [3]. These limitations of MPA can be solved and major aspects like great compactness, large bandwidth and multiband operation can be accomplished by applying fractal geometry concept in the MPA design [4].

French scientist Benoit B. Mandelbrot used the name "fractal" for the first time and according to him the term fractal is a rough, fragmented (broken) geometric structure which can be sub sectioned repeatedly into multiple alike parts. Individually, these sub sectioned parts are condensed copy of the complete (original) structure. The various types of fractal shapes are available like Sierpinski carpet, Sierpinski gasket, Koch curve, Hilbert curve, Minkowski island, Meander lines etc. When the fractal geometry concept is applied on the patch element, the electrical length of the patch varies and the current start travelling along the long pathway except the conventional (original) patch. This nature of the antenna structure supports it to provide multiband operations [6]. The antenna design applied with Sierpinski carpet geometry structure is found as the most commonly used geometry for various types of antenna designs. Many researchers have worked on development of the MPAs using the carpet geometry with higher gain, multiband operations suitable for various types of wireless applications [7-9]. In [13], Madhu *et al.* designed a Sierpinski carpet fractal multi-band antenna and compared its size and different performance parameters with other available antennas at corresponding resonating frequencies. Although, fractal MPA (FMPA) offer solutions to all problems related to the current antenna requirement for next generation wireless applications, developments in modern technologies like MIMO designs, massive MIMO requires a significant attention towards them [14]. A planar hybrid structure fractal shaped monopole antenna with Multiple Input Multiple Output (MIMO) technology implementation is designed and analyzed for the handheld mobile devices [15]. An improved MU-MIMO of (8×8) with better performance for LTE-A is designed and analyzed [16]. A circular shaped microstrip patch antenna with miniaturized antenna size, better mutual coupling, and large bandwidth is presented for (2×2) MIMO application. Improved (2×2) MIMO antennas for various applications are also presented in [17, 18, 19, 20]. Hence after a rigorous review, this article is focused on the design of a four port MIMO antenna array along with fractal concept to overcome the challenges like operate in dual frequency bands with improved performances of better isolation and higher gain.

This article presents a modest MPA design with an edge-feed for suitable for 2.4 GHz ISM frequency band. The design parameters of the proposed MPA at the required frequency band are calculated using the transmission line parameter equations [3]. Then, the antenna structure is formed with help of design parameters and optimized using ANSYS HFSS to accomplish better performance parameters like exact resonant frequency, higher gain, slender beam-width, wide bandwidth, etc. of the proposed antenna [10, 11]. Latter, the optimized MPA structure is used as the elementary building block and, the Sierpinski carpet geometry is applied to it up to the 3rd iteration. When the Sierpinski carpet geometry is applied the proposed antenna structure resonates at five multiple frequency bands. Eventually, to achieve the suitability of our design in the current as well as upcoming next generation wireless technology, a four port fractal MIMO array is designed and then its corresponding antenna elements are positioned intelligently and optimally for betterment of its isolation and gain factor over all the frequency bands. Several researchers have recommended multiband operations for the use in the future 5G wireless communication technology [12]. The proposed fractal MIMO antenna array structure can operate at two dissimilar frequency bands with wide bandwidth from recommended bands for 5th generation as well as existing 2G, 3G, and 4G wireless mobile communications. We have organized the enduring portion of this paper as follows. Section II provides the design procedures of MPA and its performance at the required ISM (2.4 GHz) frequency band. The section III describes on the design of proposed antenna using fractal geometry and the design of an optimized fractal MIMO antenna array. Section IV describes the antenna simulation results and its discussion. Lastly, the concluding remarks are presented in section V.

II. MPA CONFIGURATION AND ITS PERFORMANCE

We have designed a MPA with edge-feed as it is having simple configuration and easy fabrication method. The selection of operational frequency (f_0) is a major parameter for the design process of any types of antennas. In our work, the operational frequency is taken as 2.4 GHz due to importance of ISM frequency band. The copper material is used for the both the patch and ground element. The dielectric substrate is selected as the FR-4 Epoxy material of relative permittivity (εr) and thickness (h) of 4.4 and 1.6 mm respectively. Considering three design parameters like f0, εr, and h, the MPA dimensions are calculated with help of transmission line parameter equations. The antenna structure is modeled and optimized using ANSYS HFSS for determination of the required optimal results. The complete layout of the proposed MPA and its corresponding optimized designed parameters are shown in Figure 1 and Table 1 respectively. Microstrip line feeding technique is used for excitation for the proposed MPA with the characteristic impedance value of 50 Ω. A matching section is used for the impedance matching of the radiating patch with the used microstrip feed line. Simulation results like return loss (S11 parameter) and radiation pattern for the both co-polarization and cross-polarization are presented in Fig. 3 and Fig. 5 respectively. It can be observed from the Fig. 3 that the proposed MPA shows a return loss (S11 parameter) value of -19.40 dB and an absolute VSWR value of 1.23 with the operational frequency of 2.4 GHz. The Fig. 5 shows that the proposed MPA provides a high gain value of 3.22 dB and 2.87 dB for the both E-plane field and H-plane field respectively. The simulation results for the performance parameters of the proposed MPA are presented in Table 4. By analyzing all the simulation results, it is accomplished that the simulated results and theoretical predictions are in good match.

Table 1: Optimised Design Parameter Values of Edge-Feed Rectangular MPA.

Parameters	Values
L	28.60 mm
W	36.86 mm
Wf2	0.90 mm
Lf2	17.61 mm
H	1.6 mm
Wf1	3.06 mm
Lf1	16.59 mm
ε_r	4.4

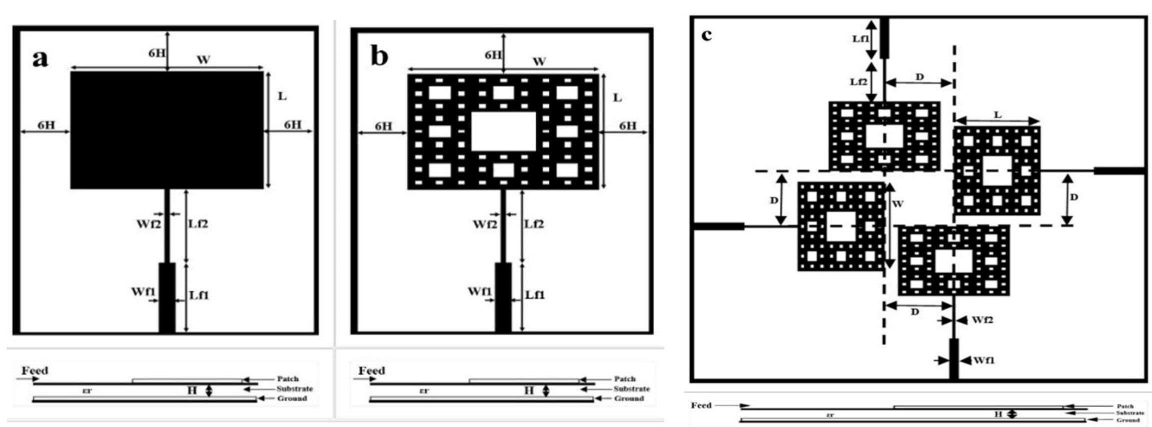

Fig. 1. Top view and side view of rectangular MPAs: (a) Single edge-feed MPA with fractal iteration-0, (b) Single edge-feed MPA with fractal iteration-3, (c) Four port MIMO fractal array.

However, to achieve the multiband property and the wideband/broadband properties in our proposed MPA design, the Sierpinski carpet fractal geometry is applied in to our design and the detailed discussion of this process is presented in the following section.

III. FRACTAL MPA AND MIMO ARRAY

The Various types of fractal structures are inspired from nature. The complex structured natural objects available like trees, leafs, mountain lines, cloud boundaries, sea shores, snowflakes, galaxy etc. are successfully modelled as different fractal geometries [21]. The major intension of the application of fractal geometry in our work is to achieve small sized, higher gain, broadband antennas with multiband property. In this paper, we have used the Sierpinski carpet fractal geometry due to its simplicity nature. This type of fractal geometry is named according to the famous polish mathematician and scientist Waclaw Franciszek Sierpinski, who presented this visibly along with the mathematical modelling and equations in 1916 [5]. This type of fractal geometry is of deterministic in nature that shows similar fractal dimension but with different textures. We have developed the proposed antenna by applying the sierpinski fractal geometry where the patch element structure is sub sectioned into nine numbers of similar smaller squares and consequently dropping the central one. Then sub sectioning of the eight other remaining squares are done into more nine numbers of similar smaller squares and subsequently dropping the central one. To achieve multiple iterations, this process can be continued up to several times. In our work, we have applied the Sierpinski carpet geometry up to the 3rd iteration in to the proposed MPA patch element and its complete layout is shown in Fig. 1. The fractal concept applied proposed antenna structure is efficiently designed and simulated using the ANSYS HFSS and the corresponding result parameters are also analyzed. Fig. 3 presents the return loss (S11 parameter) characteristic of fractal geometry applied proposed MPA (FMPA) in 1 GHz to 20 GHz range of frequency. From the result, it is clear that the FMPA is efficiently resonating at five different resonant frequencies of 1.91 GHz, 7.91 GHz, 8.52 GHz, 13 GHz and 14.9 GHz associated with impedance bandwidth values of 1490 MHz, 200 MHz, 200 MHz, 1130MHz, and 1050 MHz respectively. The proposed FMPA shows gain values of 7.04 dB, -2.79 dB, -0.30 dB, 3.83 dB and 5.90 dB at the corresponding five resonating frequencies respectively. Here, negative gain refers to very small gain of that antenna at that particular frequency. The simulation results proposed FMPA are presented in Table 4. Many researchers from all over the world have recommended different frequency bands that can be efficiently operational for the upcoming 5G wireless mobile communications. Out of those frequency bands our proposed FMPA provides three resonating frequencies with significant gain as the recommended frequencies by the multiple researchers from various countries all over the globe. Our proposed FMPA will be a suitable candidate for the upcoming 5G wireless mobile communication purpose which may be further improved with new technologies like MIMO, massive MIMO concept those are more suitable for this purposes. So to make adaptive our design to MIMO, a four port dual band fractal antenna array is designed and analysed as presented in Fig. 1.

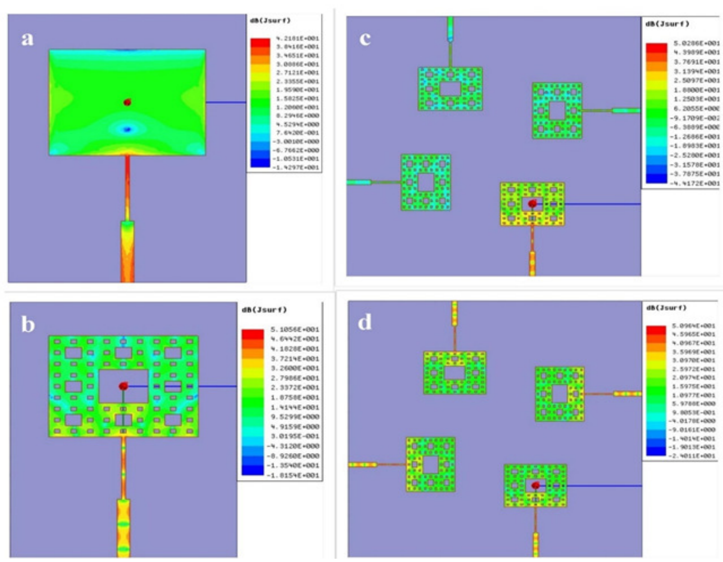

Fig. 2. Surface current distribution of rectangular MPAs: (a) Single MPA with fractal iteration-0, (b) MPA with fractal iteration-3, (c) Four port MIMO fractal array with excitation only at port 1 and (d) Four port MIMO fractal array with excitations at all ports.

The multiple elements of the array are placed in such a way that the isolation factor between them is low as the requirement of 5G communication. The optimized parameters of the array are presented in Table 2. Among all design parameters, the inter-element distance (D) from centre to centre, is analyzed for different values between 0.3λ to 0.9λ to achieve appropriate isolation, gain and antenna surface area. All the MIMO array performances with different values of D are placed in Table 3. D with 46.5 mm and 58.9 mm shows better gain with improved isolation factors. However, with a low surface area of 249 mm^2 with D = 46.5 mm is selected for the purpose. Fig. 3 provides the return loss (S11 characteristics) characteristic for the fractal geometry applied MIMO antenna array in 1 GHz to 20 GHz range of frequency. It is clearly found that the fractal geometry applied MIMO antenna array is efficiently resonating at 6.16 GHz and 15.3 GHz with a high impedance bandwidth of 3880 MHz and 7220 MHz respectively. Thus, by varying and analyzing inter-element distance (D) for different values of λ better impedance bandwidth is achieved.

The fractal geometry applied MIMO antenna array has an E-plane gain of 7.26 dB, 8.48 dB and an H-plane gain of 11.3 dB and 8.06 dB at the two resonating frequency bands respectively. All the performance parameters are given in Table 4. Other performance parameters are discussed in next result analysis and discussion section. Figure 2 shows the surface current distribution of all antennas considered here. It also shows that how current moves on the fractal MIMO array surface with excitation at only port 1 and with excitation at all ports.

Table 2: Optimised Design Parameter Values of Four-Port MIMO Array with Fractal Iteratio-3.

Parameters	Values
L	28.60 mm
W	36.86 mm
Wf2	0.90 mm
Lf2	17.61 mm
H	1.6 mm
Wf1	3.06 mm
Lf1	16.59 mm
D	46.5 mm
ε_r	4.4

IV. RESULT ANALYSIS AND DISCUSSION

We have used ANSYS HFSS for design and simulation of the proposed antenna structures. The ANSYS HFSS, result data are disseminated in to (.txt) files for easy access of results. The corresponding (.txt) files are just imported into the MATLAB software platform and all the result data are efficiently plotted simultaneously allowing in a single effective plot. Then, all the corresponding design files obtained and are exported subsequently in to (.dxf) files which are printed consequently in the AutoCAD to achieve original size of the proposed MPAs. The complete layout of original size of all proposed antennae are presented in Fig. 1. To study the effectiveness of fractal application to MIMO antenna design, a four port antenna array is designed and optimized to operate at dual frequency bands 6.16 GHz and 15.3 GHz with appropriate 10 dB value bandwidth of 3880 MHz and 7220 MHz respectively. The array has a gain of 7.26 dB, 8.48 dB for E-plane and 11.3 dB, 8.06 dB for H-plane for these two bands respectively. All E-plane and H-plane co-polarized and cross-polarized radiation patterns are plotted in Fig. 5 and all the corresponding performance parameters are given in Table 4. Isolation is one of the important factors for any MIMO antenna design. Here, isolation for all ports with respect to port 1 is drawn in Fig. 4. From the figure it can be clearly shown that there is an improvisation in the isolation factor without using any extra concept or structure. It seems to be an acceptable difference between the return loss and isolation values. But this difference can be improved and isolation factor can be improved by using defective ground structure along with appropriate optimization. From the above two resonating bands of MIMO array, the lower band (4.26 GHz to 8.18 GHz) can find an application for the upcoming next 5th generation applications along with other C-band wireless applications like satellite radio communications.

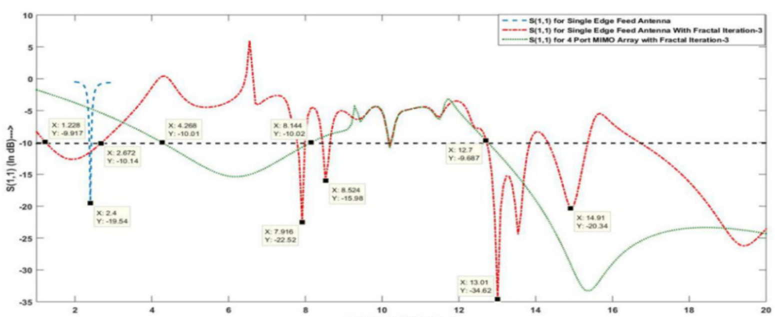

Fig. 3. S (1, 1) vs. frequency plot for proposed MPA: (a) Single edge-feed MPA with fractal iteration-0, (b) Single edge-feed MPA with fractal iteration-3, (c) Four port MIMO fractal array.

Table 3: Selection of Inter Element Spacing (D) of MIMO Fractal Array Based on Simulated Performance Parameters.

Value of D (In mm)	Return Loss Factor	Isolation Factor	Gain at 6.168 GHz		Gain at 15.364 GHZ		Area of the Fractal MIMO Array (In cm^2)
			E-Plane Radiation	H-Plane Radiation	E-Plane Radiation	H-Plane Radiation	
37.2	Good	Good	1.71	0.32	1.20	0.72	220.52
40.3	Good	Good	0.31	-1.58	-2.60	-2.44	229.82
43.4	Good	Good	1.94	2.08	-0.48	0.87	239.32
46.5	Good	Good	7.68	12.23	8.09	8.51	249.00
49.6	Good	Good	-2.97	-1.01	-3.48	-1.74	258.88
52.7	Good	Poor	0.80	4.61	2.14	1.73	268.96
55.8	Good	Good	0.38	-2.81	-0.22	-1.75	279.22
58.9	Good	Poor	12.95	10.93	8.94	9.84	289.68
62.0	Good	Good	-2.08	-2.06	-3.19	-3.12	300.32

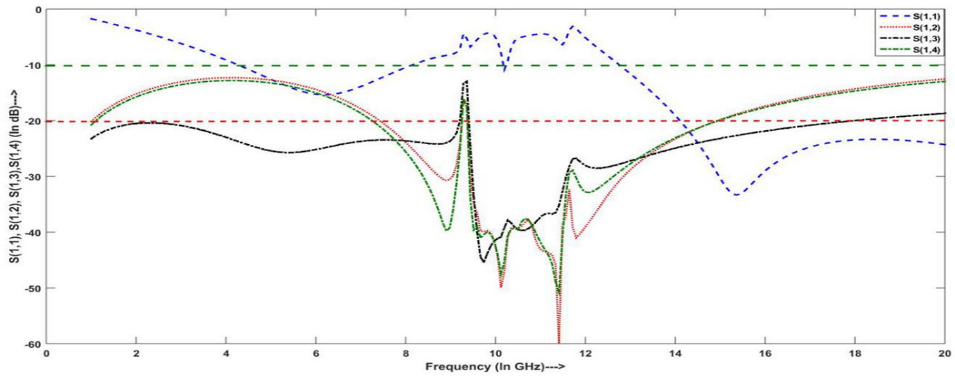

Fig. 4. Isolation curves of MIMO fractal array.

Table 4: Simulated Performance Parameters of Single Rectangular MPA with Edge-Feed for Fractal Iteration-0, Iteration-3 and MIMO fractal array.

Structure Type	**Resonant Frequency f_0 (in GHz)**	**S_{11} (in dB)**	**VSWR (absolute Value)**	**Band-width (In MHz)**	**Band-width %**	**Gain (in dB)**	
						E-Plane	**H-Plane**
Single MPA with Iteration-0	2.40	-19.54	1.23	50	02.08	3.22	2.87
Single MPA with Iteration-3	1.91	-12.65	1.60	1490	78.01	7.04	8.06
	7.91	-22.52	1.16	200	02.52	-2.79	-7.30
	8.52	-15.98	1.37	200	02.34	-0.30	-1.40
	13.0	-34.62	1.03	1130	08.69	3.86	0.89
	14.9	-20.33	1.21	1050	07.04	5.90	3.90
MIMO Fractal Array	6.16	-15.48	1.40	3880	62.90	7.26	11.30
	15.3	-33.32	1.04	7220	46.99	8.48	8.06

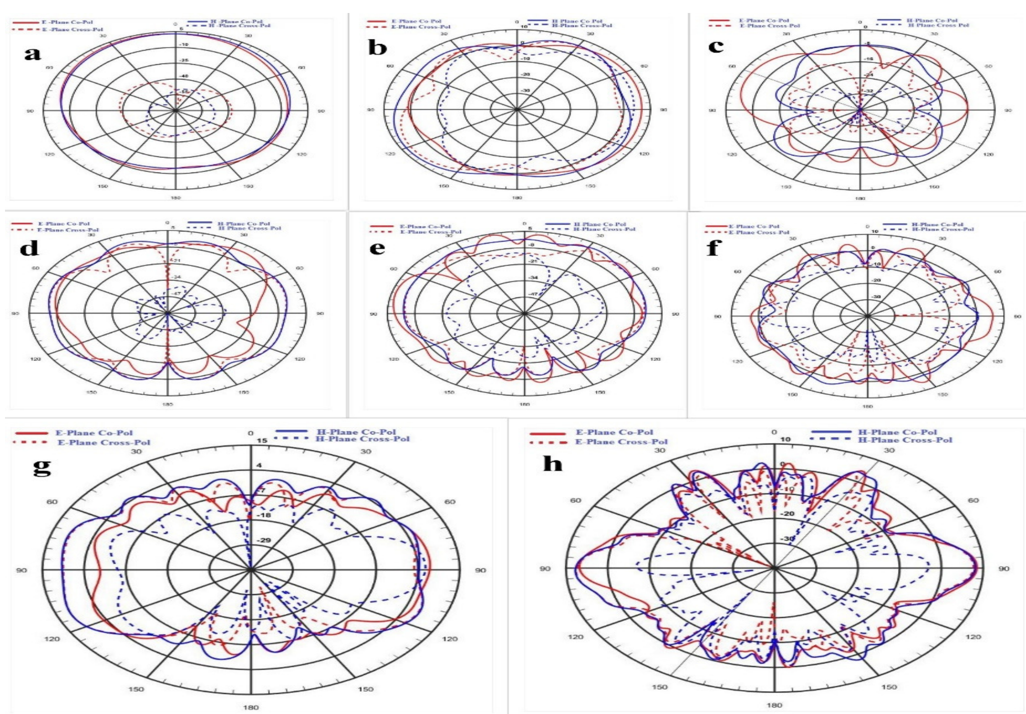

Fig. 5. Simulated radiation patterns (Co and Cross polarization) of MPAs: Single proposed MPA with (a) fractal geometry applied iteration-0 operating at 2.4 GHz, (b) fractal iteration-3 at 1.91 GHz, (c) fractal geometry applied iteration-3 at 7.91 GHz, (d) fractal geometry applied iteration-3 at 8.52 GHz, (e) fractal geometry applied iteration-3 at 13 GHz, (f)fractal geometry applied iteration-3 at 14.9 GHz, MIMO fractal array (g) at 6.16 GHz, and (h) at 15.3 GHz.

The upper band (12.7 GHz to 20 GHz) can be also a suitable test range for 5G mobile communications as the frequency band for 5G is not fixed by International Telecommunication Union (ITU) and other committees, yet. Also this band has limited use and can be the most suitable range for the next generation wireless applications. At last, the gain over frequency graph in Fig. 6 shows that the fractal MIMO array has a gain of 5 dB to 10 dB over the entire two bands. It makes the array more effective for the above applications. Eventually, the results of the proposed work are compared with related works and this comparison is presented in Table 5.

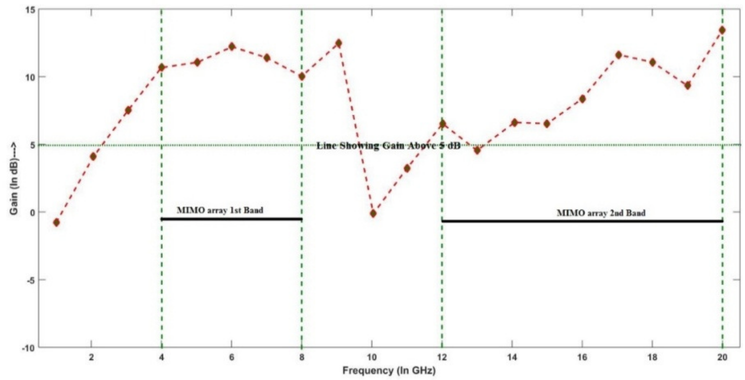

Fig. 6. Gain vs. frequency plot for MIMO fractal array covering its two operating bands.

Table 5: Comparison of proposed work with related works.

References	Resonant Frequency f_0 (in GHz)	S_{11} (in dB)	VSWR (absolute Value)	Band-width (In MHz)	Gain (in dB)
[20]	28	Value not given	Value not given	3.35	13.1
[19]	28	Value not given	Value not given	1500	7.41
[18]	28	Value not given	Value not given	4100	8.3
[17]	2.168	-17.12	1.32	2.214	4.64
Proposed Work	6.16 15.3	-15.48 -33.32	1.40 1.04	3880 7220	7.26(E),11.30(H) 8.06(E),8.48(H)

V. CONCLUSION

A four port fractal MIMO array for next generation wireless communication is successfully designed using HFSS. The usefulness of the implementation of fractal geometry to microstrip patch antenna structure and its corresponding array is investigated too. With application of the Sierpinski carpet fractal geometry, then by placing the array elements efficiently and by optimizing them inter element spacing (D), improved isolation is achieved. The proposed fractal MIMO array is resonating at 6.16 GHz and 15.3 GHz with an impedance bandwidth of 62.90% and 46.99% respectively. It also provides improved isolation factor, and a gain of 5 dB to 10 dB over the entire frequency bands. Improved performances like compact antenna size, better return loss, good VSWR, large bandwidth, high gain, and better isolation factor are achieved successfully here. Hence, this fractal MIMO array finds suitable applications in different ongoing (2G, 3G and 4G) as well as upcoming next generation (5G) wireless communications. To verify the proposed array structure, physical prototype of the array will be fabricated and the measured results will be matched to simulated ones. It can be suggested that, multiple antennas for various applications, could be conveniently substituted by using only one Sierpinski carpet fractal array with enhanced performances suitable for next generation 5G wireless communication systems.

VI. FUTURE SCOPE

Order of MIMO array will be increased and validated to obtain better performances.

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