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Fractal Geometry based Chakra-shaped Microstrip Patch Antenna array for Vehicular Communications under 5G Environments

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Abstract: In this paper, fractal geometry based two printed antenna structures are proposed for vehicular communication in 5G wireless communication networks. Initially, a 48×39 mm² single element fractal patch antenna is designed and tested which shows dual band resonance at around 28.1 GHz and 32.5 GHz. In order to improve different antenna characteristic descriptors such as bandwidth, reflection coefficient, voltage standing wave ratio (VSWR), and gain, number of fractal radiating elements have been increased to four and constructed an array of patches such that it can be used for multiple applications in the field of vehicular communications. For better performance, the antenna is replicated in the form of a 2×2 patch array such that the performance can be increased by at least 20%. The proposed array model is fabricated on a Rogers RT duroid 5880tm material of size 115×82 mm² and tested using Agilent Technologies N5247A VNA. The measured results confirm the validity of the designed model for intended applications. The proposed array antenna operates at distinct quintuple bands in the frequency range of 25–36 GHz for vehicular communication within the proposed lower fifth generation (5G) channel. The proposed array configuration shows a good peak gain of 6.72dB within the operating bands.

Keywords: Microstrip patch antenna, fractal geometry, 5G, multi-patch array, vehicular communications.

1. Introduction:

Traditionally from 1st generation to 4th generation, there was an impact on the hardware advancements only, but as per the latest technology of 5G, there is a direct impact on software [1]. With the advancements of software, the level of computational capacity has increased which provides a scope of automobile communication. This provides the technology to be self-configure, self-healing and self-analysis. Location information can be accessed very easily as the technology has very good self-informative system available in itself [2]. This all is achieved as the technology has a direct impact on software accessing and development. Using cooperative localization, device-to-device communication is enabled to its highest position where multiple applications are entitled to it [3]. Internet of things (IoT) is another field in which the impact is directly observed as the sensors are intact with the 5G communication, where the latency can be reduced and the active time of the device can be improved. The range of communication can be increased with the milli-meter technology incorporated using 5G [4]. Health and medical sciences are another areas where the impact of 5G is directly seen as the high frequency can be used to scan the organs and give a better understanding of the health of the patient [5]. Vehicular communication is another area where the impact is seen as a vehicle to everything is largely exposed to the technology which includes communication using Vehicle to Vehicle (V-V), vehicle to infrastructure (V-I), vehicle to pedestrian (V-P), and vehicle to the user (v-u) [6]. This has brought the automobile industry to its highest technology-based movable vehicles. The communication unit is set up at different vehicles, roadside units, and other objects which are needed to provide the information. These units are to be

in contact and should provide the information continuously [7]. The information regarding the roads, the way the curves are ahead, weather information, and other necessary information are stored in the cloud which can be accessed by the vehicle to provide the information to the user [8]. As the information is endless and continuous which is very much needed for the user to understand the vehicle and the road better, there is an emergency need of having a proper end-to-end connection. Wireless communication comes to existence as it provides information via wireless connectivity [9].

In this era, it is very much clear that the technology surrounded with 5G has an impact on the luxury, safety, security, and comfort of the individual [10]. Society is benefited from this technology which makes it as an essential commodity for day to day life. Table 1 provides the information regarding the proposed Spectrum under 5G.

Table 1: Proposed spectrum under 5G for various countries [1]

Countries	Channel-1	Channel-2	Channel-3	Channel-4
US Proposed Spectrum	24.25 to 27.5 GHz	31.8 to 33.4 GHz	37 to 40.5 GHz	40.5 to 42.5 GHz
EUROPE Proposed Spectrum	27.5 to 29.5 GHz	37 to 40.5 GHz	47.2 to 50.2 GHz	50.4 to 52.6 GHz
SOUTH KOREA Proposed Spectrum	28.4 to 32.4GHz	41.25 to 43.75GHz	59.3 to 71 GHz	-----
CHINA Proposed Spectrum	31.75 to 33.54GHz	45 to 47GHz	59 to 64GHz	-----

At these frequencies, there is a very much need for an antenna that should have a good gain, multi-band, highly directive with compact in size.

The best antenna for the fulfillment of this is a microstrip patch antenna, which can be used for very high frequencies, but the drawback of the antenna is, it possesses low gain, low bandwidth which will have an impact directly on the performance of the antenna. There are many ways to overcome these drawbacks such as fractal geometry which provides self-similarity and improves the performance of the antenna. The alternate is to design a multi-patch that increases the antenna dimensions yet can be used for multiple applications. The antenna patch can be implemented using fractal designs like Sierpinski carpet, Minkowski island, snowflake [7], these designs are based on fractal geometry which is an endless, self-similar design [11]. Over the years these shapes are used in the design of antennae at frequencies not greater than 10Giga Hertz (GHz).

In this paper fractal geometry based single and multi-patch antenna are presented. The antennas are simulated and measured at futuristic 5G frequencies for vehicular applications, where the size of the single patch is 39mm × 48mm × 0.55mm and 2×2 array antenna is 82mm × 115mm × 0.55mm. The antennas are tested under frequency range of 25GHz to 35GHz. The advantage of 2×2 array antenna are its miniaturized dimensions achieved by using fractal geometry, antenna resonates at multiple bands with enhanced operating bandwidths, a maximum gain of 6.72dB with Voltage Standing Wave Ratio (vswr) of 0.715 and reflection coefficient of −27.71dB at the frequency of 32.8GHz. The antennas are simulated using High Frequency Structure Simulator (HFSS) v15 and measured using N5247A Vector Network Analyzer (VNA).

2. Related Works:

In this section, the latest research works carried out by various researchers in the domain of vehicular communications, fractal antennas, and 5G communications are presented. The focus is majorly on the parameters of the antenna and the behavior of the antenna at futuristic frequencies. The authors [12] proposed a Hexagonal shaped ultra-wide bandwidth Fractal dipole antenna for frequency range 0.5 to 12GHz. The simulation is carried out to focus on the gain of the antenna which was around 6.9dBi for various angles of penetration. The proposed fractal module is very tiny in its size and shape which can be used for vehicular communications. A minimum reflection coefficient of 29.19dB was achieved and the VSWR was in the range of 4dB. In the next analysis, the author [13] proposed a triangular-shaped fractal geometry antenna for UWB applications. The self-complementary principle is applied at the first iteration of the planner triangular monopole antenna for its enhancement. Through this principle, it is observed that the reflection coefficient is reduced to below 10dB for a frequency range of 4 to 11GHz. The triangle patch is compared with single and multiple patches in which the performance level was enhanced up to 30%. The idea of studying this antenna leads us to design antenna both single and multi-layer patch. One of the key features of the antenna is to design such that it can be used for multiple applications. The author [14] proposed Fractal based Hexagonal wide slot antenna for super wide-band applications. The proposed antenna achieves a ratio impedance bandwidth 15:19 for a frequency range of 3 to 30GHz for $VSWR \leq 2$. The achieved bandwidth is double when compared with the required bandwidth of SWB operation. For bandwidth enhancement, even at lower frequencies, the author proposed a hexagonal tuning stub loaded at microstrip feed line which is a very good idea for the compact antennas which can be placed on a vehicle.

The latest requirements of the antenna are to make it wearable and conformal which can be placed on the human body for providing the required information. The author [15] proposed a wearable Fractal monopole antenna embedded with a reflector for better antenna performance and SAR reduction. The proposed antenna shows improved bandwidth of 130MHz in the free space and 128MHz when mounted on a flat homogeneous phantom at an operating frequency of 2.36 to 2.50GHz. The bandwidth of the antenna is the most important feature for any application and the author [16] had proposed about Fractal antenna with a modified hexagonal shape with multiband notch characteristics for UWB applications. The antenna is fabricated using FR4 Epoxy which leads to obtaining a bandwidth of 2.36GHz in the frequency range of 9.8GHz to 15GHz with S_{11} is less than -10 dB over the entire UWB range. The author mentioned that these improved features provide several applications in the field of telecommunication and vehicular communications. The above-related work has provided a lot of understanding regarding the design of the proposed work to make it useful for multiband applications in vehicular communications under 5G environments. The slots have been introduced in the design to achieve wide-band and to achieve multiband characteristics with wide impedance. The antenna is also designed using a single patch and multi-patch design which is described in the next section.

3. Antenna Design

3.1 Microstrip Patch Antenna with Single Patch:

The single element patch antenna is designed using a self-similar pattern with the same dimensions as the rectangular patch of $39\text{mm} \times 48\text{mm}$. The antenna is designed using the Rogers RT duroid 5880tm, with a relative permittivity of 2.2. The patch is of circular shape and internally made of seven iterations, with each iteration radius is reduced by 1mm as shown in Figure 1. The single element fractal antenna resonates at dual band due to the suggested antenna geometry.

Figure 1: Microstrip patch antenna with a single patch

3.2 Microstrip Patch Antenna with 2×2 Patch:

The antenna is configured using the same single patch structure with the extension of 2×2 , the antennas are arranged in the matrix form with two rows and two columns. The feed lines are drawn row-wise and connected in a column to match the impedance between the four single patch antennas. The antenna substrate is measured at $82 \times 115\text{ mm}$ with a $2 \times 30\text{ mm}$ of the feed line. The antenna is designed using the Rogers RT duroid 5880tm, with a relative permittivity of 2.2.

Figure 2: Microstrip patch antenna with 2×2 array

Table 2: Dimension of single patch and multi-patch antennas(dimensions in mm)

L1	L2	L3	L4	L5	L6	L7	L8	L9	R1
21	8	4	5.5	7	8.5	39	7	82	10
W1	W2	W3	W4	W5	W6	W7	W8	W9	R2
44	52	1.6	115	90	8	50	33	25	9

The antenna dimensions are calculated as per the circular patch with radius of r , and the mathematical formulation is as follows:

$$R = Qr / \omega r C \quad (1)$$

$$L_1 = 1/\omega r^2 C_1 \quad (2)$$

$$C_1 = \frac{LW\epsilon_0\epsilon_e}{2h} \cos^2(\pi x_0/L) \quad (3)$$

in which L = Patch length, W = Patch width, x_0 = feed point location, h = substrate thickness.

$$Q_r = \frac{c\sqrt{\epsilon_e}}{fh} \quad (4)$$

where f = frequency of the designed antenna, c = light velocity, ϵ_e = effective permittivity of medium.

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + \frac{12h}{W}\right)^{-1/2} \quad (5)$$

4. Design Evolution of the proposed 2×2 patch antenna

In the proposed design, 5 inner circles are loaded in the circular patch each decreasing continuously by a factor of 1mm and three stages are implemented where the antenna is first designed using a single patch, then the antenna is designed using a 1×2 patch format and finally the antenna is designed using 2×2 patch as shown in the figure 3.

Figure 3:(A) Single patch antenna (B) 1×2 patch antenna (C) 2×2 patch antenna

The iterations and number of circular cross sections are mentioned in Table 3 with the impedances of fractal antenna is shown in Figure 4.

Table 3: Comparison of number of slots for the designed antenna

Iterations	Chakra Shape
Nth Stage	$6 \times 2^{(n-1)}$ Circular Slots
1 st Stage(single patch)	$6 \times 2^0 = 6 \times 1 = 6$
2 nd Stage(1×2 patch)	$6 \times 2^1 = 6 \times 2 = 12$
3 rd Stage(2×2 patch)	$6 \times 2^2 = 6 \times 4 = 24$

Fig4: Circuit Diagram of Designed Antenna

The equivalent input impedance of the chakra shaped fractal antenna with single, 1×2 and 2×2 patch are provided in equation 6, as for single patch there are 6 circular slots, for 1×2 patch there are 12 circular slots and 24 for 2×2 patch respectively [8] .

$$Z_{\text{total}} = \frac{1}{\frac{1}{Z_p} + \frac{1}{Z_q} + \frac{1}{Z_r}} = \frac{1}{\frac{6}{Z_{sp}} + \frac{12}{Z_{sq}} + \frac{24}{Z_{sr}}} \quad (6)$$

Where Z_p , Z_q and Z_r are the equivalent impedance of similar circular slots loaded on to the antenna of different stages and can be calculated as

$$Z_p = \frac{1}{\frac{1}{Z_{sp1}} + \dots + \frac{1}{Z_{sp6}}} = \frac{Z_{sp}}{6}; Z_{sp} = Z_{sp1} \dots = Z_{sp6}; (1^{st} \text{ stage with six circular slots}) \quad (7)$$

$$Z_q = \frac{1}{\frac{1}{Z_{sq1}} + \dots + \frac{1}{Z_{sq12}}} = \frac{Z_{sq}}{12}; Z_{sq} = Z_{sq1} \dots = Z_{sq12}; (2^{nd} \text{ stage with twelve circular slots}) \quad (8)$$

$$Z_r = \frac{1}{\frac{1}{Z_{sr1}} + \dots + \frac{1}{Z_{sr24}}} = \frac{Z_{sr}}{24}; Z_{sr} = Z_{sr1} \dots = Z_{sr24}; (3^{rd} \text{ stage with twenty four slots}) \quad (9)$$

The antenna performance parameters can be calculated using total input impedance for all the three stages combining as (Z_{total})

$$\text{Reflection Coefficient, } \Gamma = \left(\frac{Z_{total} - Z_0}{Z_{total} + Z_0} \right) \quad (10)$$

4.1. Parametric study of S_{11} parameter for different antenna configurations

The parametric investigations are performed to observe the variations of reflection coefficients for different design evolution stages. Figure 5 provides the parametric study of S_{11} for all the designed antenna structures, single patch, 1×2 patch and 2×2 patch configurations. It can be observed that as the numbers of elements are increased, the reflection coefficient are reduced and number of resonating points have increased. So, with the suggested 2×2 patch array configuration, the antenna resonates at multiple bands with enhanced operating bandwidths.

Figure 5: Parametric study of S_{11} for single patch antenna, 1×2 patch antenna and 2×2 patch antenna

The design and analysis execution flowchart of the proposed 2×2 multi-patch antenna models is presented in Figure 6.

Figure 6: Detailed design and analysis flow chart of the designed antennas

5. Results and Discussion

5.1. Simulation

The simulation studies are performed using HFSS EM solver, with the operating frequency from 25GHz to 36GHz and the analysis has been carried out on single patch and multi-patch antenna separately. Figure 7 shows the surface current all over the patch, the electrical field is strong throughout the antenna and provides good stability, and radiates maximum energy which is received at the port. Maximum current distribution is available at the center of the proposed multi-patch antenna with high magnitude at the edges of the patch for the resonating frequency of 32.8GHz.

Figure 7: Surface Current on a single patch antenna at 31.35GHz and multi-patch antenna at 32.8GHz

The antenna design is simulated for the frequency ranging from 25GHz to 36GHz and for the process of calculating the bandwidth, the first step is to find out the S_{11} of both the antennas. Figure 8 represents the reflection coefficient vs. frequency characteristics of the single patch and multi-patch antennas. It is evident from the portrayed figure that the suggested multi-patch antenna provides better performance and multiple resonating frequencies compared to the single patch antenna structure. As observed in Figure 8 (a), the single patch antenna provides dual band resonant characteristics as per observation below -10 dB level of S_{11} parameter. However, very good reflection coefficient is observed at higher resonance with a highest attained value of -18 dB at the resonant frequency of 31.6GHz, As per Figure 8(b), the multi-patch antenna provides penta band operation considering $S_{11} \leq -10$ dB with significant bandwidths at each operating bands of 27.1GHz, 28.5GHz, 30.1GHz, 32.8GHz and 34.8GHz with the reflection coefficients of -20.01 , -18.36 , -14.96 , -27.71 and -24.19 respectively . The best value of reflection coefficient is recorded as -27.71 dB at the frequency of 32.8GHz in the operating frequency.

Figure 8a: Reflection coefficient of single patch antenna

Figure 8b: Reflection coefficient of 2×2 multi-patch antenna

The VSWR values are shown in Figure 9. As indicated in Figure 9 (a), VSWR of the single patch antenna is computed the values are within the maximum applicable limit of 4 in vehicular communication for the resonating points. The minimum VSWR for single patch antenna is observed at 31.6GHz with a value of 1.08. On the other hand, due to the incorporated feed geometry, the proposed multi-patch antenna shows improvement in impedance matching and as a result minimum VSWR of 0.423 is obtained at 34.75 GHz. The acceptable VSWR confirms that well impedance matching the designed structures and ensure low mismatch losses associated with the suggested designed antenna models such that these antenna models can be used practically.

Figure 9: VSWR of single patch and 2×2 antennas

Figure 10 provides the radiation pattern of 2×2 antenna at operating bands of 27.1GHz, 28.5GHz, 30.1GHz, 32.8GHz and 34.8GHz for both E-plane and H-plane of multi-patch antenna.

Figure 10: Radiation Patterns for E-plane represented in black and H-plane represented in red color of multi-patch antenna at a) 27.1GHz b) 28.5GHz c)30.1GHz d)32.8GHz e) 34.8GHz

At 27.1GHz, 7.63dB gain is achieved with the theta ranging from -20 degrees to $+20$ degrees with the phi value of 90 degrees, and at 28.5GHz, 9.43dB gain is achieved with the theta ranging from -40 degrees to $+40$ degrees with phi value of 0 degrees. At 32.8GHz, 9.17dB gain is achieved with the theta ranging from -30 degrees to $+30$ degrees with the phi value of 0 degrees and at 34.8GHz, 5.27dB gain is achieved with the theta ranging from -30 degrees to $+30$ degrees with the phi value of 0 degrees. The achieved values implies that thee radiation pattern is best suitable for vehicular communication as it is spread out in forward directions and for moving vehicles the radiation should be towards the target with at least 20 degrees[17] and the proposed design is suitable with a range of at least 40 degrees overall .

Figure 11 provides the details about total gain with the primary sweep of frequency at theta and phi at zero degrees. The gain of the single patch antenna reaches the maximum gain of 8.2dB, and for

most of the frequency range, the gain is greater than or equal to 3dB. The range starts from 25GHz and stays greater than 3dB till 34.5 GHz. The gain of the multi-patch antenna reaches the maximum gain of 6.72dB at resonating frequency of 32.8GHz and 6.69dB at 28.5GHz respectively.

Figure 11: Total Gain of single patch and 2x2 antennas

5.2. Fabrication and Measured results:

The process for fabrication starts with exporting both patch and ground separately in the form of dxf files by keeping z axis as zero and dip trace software is used to combine both the patch and ground as single entity and then exported with an extension used is grb. This file is then opened in eagle software which is used to interface the single-sided CNC machine for fabrication which consist the precision of 95% efficiency and the material used for fabrication is Rogers RT duroid 5880tm. The time required for fabrication depends on the layers of antenna and the structure of patch. The proposed antenna took around 60 minutes for fabrication. Then the fabricated antenna models are connected with an SMA connector. The prototypes of the fabricated antennas are shown in Figure 12.

Figure 12: Fabrication of a) single patch b) multi-patch antenna

The antenna after fabrication is tested under an experimental confined laboratory with a highly précised Vector Network Analyzer of Agilent Technologies N5247A with a range of 1GHz to 50GHz with both 1dB and 2dB sweep which is very much helpful for the futuristic frequencies. Figure 13 provides the snapshot of the measurement set up of antennas connected with VNA. The simulated and measured values are compared to provide information regarding the deviation of obtained results. The comparisons of measured and simulated S_{11} parameters for the single patch antenna and proposed array antenna are shown in Figures 14 and 15, respectively. The detailed results are summarized in Table 4. The measured and simulated S_{11} results are almost similar and the array antenna with multi-patch elements possesses better results compared to the single patch and the performance has improved in reflection coefficient, number of operating bands, and bandwidth.

Figure 13: Testing of a) Single patch antenna b) multi-patch antenna

Figure 14: Comparison of measured and simulated S_{11} of the single patch

Figure 15: Comparison of measured and simulated S_{11} of proposed multi-patch antenna

Table 4: Results of the single patch and multi-patch antenna.

Simulated S_{11} (Single Patch)				Measured S_{11} (Single Patch)			
f_L (GHz)	f_H (GHz)	f_c (GHz)	BW(MHz)	f_L (GHz)	f_H (GHz)	f_c (GHz)	BW(MHz)
29.35	32.65	31.35	3300	25	26.7	25.3	1700
				31.1	32.15	31.6	1050
Total Simulated Bandwidth			3.3GHz	Total Measured Bandwidth			2.75 GHz
Simulated S_{11} (Multi-Patch)				Measured S_{11} (Mult- Patch)			
f_L (GHz)	f_H (GHz)	f_c (GHz)	BW(GHz)	f_L (GHz)	f_H (GHz)	f_c (GHz)	BW(GHz)
26.35	27.25	27.1	0.9	26.3	27.25	27.05	0.95
27.95	28.65	28.5	0.7	28	28.7	28.4	0.7
29.8	30.25	30.1	0.45	29.9	30.3	30.05	0.4
31.95	33	32.8	1.05	31.9	32.95	32.55	1.05
33.9	35.45	34.8	1.55	33.95	35.25	34.7	1.3
Total Simulated Bandwidth			4.65GHz	Total Measured Bandwidth			4.4GHz

The table 4 provides the comparison between the simulated and measured S_{11} for both the single patch and multi-patch antenna. It can be concluded that due to the suggested array configuration, the antenna operates at more number of distinct operating bands with enhanced impedance bandwidths. In fact, the number of resonating frequencies has increased from two to five which makes the proposed array configuration suitable for multiple applications at the lower band spectrum of the upcoming 5G technology.

Table 5 provides a detailed comparison between the proposed antennas and work carried out by various researchers under fractal antennas, 5G and multiband applications. The 2×2 antenna achieved penta bands in the frequency ranging 25GHz to 36GHz, and a combined simulated bandwidth of 4650MHz with a peak gain of 6.72dB. The proposed design is able to achieve higher bandwidths compare to other models but unable to enhance the total gain of the antenna but the gain is in acceptable range. This comparison clearly indicates that the proposed antenna performance is better in the area of bandwidth and good standing wave ratio compare to the antennas provided as reference.

Table 5: Comparison between the proposed design model and other antennas design

Reference	Antenna Dimension	Substrate used	Operating band (GHz)	Bandwidth (MHz)	Peak Gain (dB)	Minimum VSWR
S. Patil et al., [12]	$140 \times 88 \times 3.3$	Rogers RT/duroid 5880tm	0.5GHz-1.1GHz, 3.6GHz-3.95GHz, 5.25GHz-5.85GHz, 7.35GHz-8.1GHz, 9.65GHz-10.25GHz 11.03GHz-12GHz	2400MHz	6.9dB	1.4
Fadhel et al., [13]	$32 \times 36 \times 1.6$	Rogers RT/duroid 5880tm	4.0GHz-4.65GHz, 5.67GHz-6.1GHz, 10.35GHz-11.0GHz	1200MHz	7.32dB	1.21
S Das et al., [14]	$26 \times 30 \times 1.53$	FR4_Epoxy	3GHz-8GHz, 8.92GHz-10.65GHz, 18GHz-22GHz, 28.5GHz-30GHz	1600MHz	9.56dB	1.22
N. T. Atanasov et al., [15]	$120 \times 120 \times 4.3$	Rogers RT/duroid 5880tm	2.36GHz-2.50GHz	130MHz	10.68dB	0.98
J. B. Benavides et al., [16]	$150 \times 150 \times 4$	Rogers RT/duroid 5880tm	9.8GHz-10.36GHz 13.6GHz-15GHz	2360MHz	8.35dB	1.01
Zhu et al., [17]	$42 \times 33 \times 1.58$	FR4_Epoxy	24.5GHz-26.32GHz, 28.1GHz-19.36GHz, 31.2GHz-32.13GHz.	3300MHz	7.45dB	1.21
S. Velan et al[18]	$64.4 \times 53.7 \times 3.94$	Rogers RT/duroid 5880tm	28GHz-29.17GHz, 31.3GHz-32.5GHz	1200MHz	8.16dB	0.87
X. Zhu et al.,[19]	$59.9 \times 59.9 \times 3.7$	Electromagnetic band gap (EBG) structure	18.5GHz-19.28GHz, 22.3GHz-22.95GHz, 23.6GHz-24.3GHz	1890MHz	6.12dB	1.01
S. Agneessens et.al.,[20]	$40 \times 40 \times 0.503$	non-conductive textile material	24.6GHz-25.32GHz, 26.8GHz-27.35GHz	3500MHz	6.54dB	0.75
Proposed Design-single patch	$39 \times 48 \times 0.52$	Rogers RT/duroid 5880tm	29.35GHz-32.65	3300MHz	5.6dB	1.08
Proposed Design:multi-patch antenna	$82 \times 115 \times 0.52$	Rogers RT/duroid 5880tm	26.35GHz-27.25GHz, 27.95GHz-28.65GHz, 29.8GHz-30.25GHz, 31.95GHz-33GHz, 33.9GHz-35GHz.	4650MHz	6.72dB	0.423

Conclusion: A single patch and 2×2 patch fractal geometry based chakra-shaped microstrip patch antenna for vehicular communications is investigated and discussed in this paper. The 2×2 patch covers five operating bands in the range of 25GHz to 36GHz. The gain of the antenna reaches the maximum gain of 6.72dB at resonating frequency of 32.8GHz and 6.69dB at 28.5GHz respectively. The reflection coefficients of – 20.01, –18.36, –14.96, –27.71 and –24.19 respectively achieved at operating bands of 27.1GHz, 28.5GHz, 30.1GHz, 32.8GHz and 34.8GHz. Maximum current distribution is achieved at the center of the proposed multi-patch array antenna with high magnitude at the edges of the patch for the resonating frequency of 32.8GHz. A good agreement between the experimental and simulated results justifies the suitability of proposed antenna for vehicular communications as it needs multi band antennas for its communication with good peak gain and better bandwidth. The proposed antenna has enhanced the overall bandwidth to 4650MHz in the 5G proposed lower band spectrums for vehicular communications.

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Conflict of Interest

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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