URSI GASS 2021, Rome, Italy, 28 August - 4 September 2021

Wideband Small Fractal Antenna with Simple Design Strategy for 5G Sub-6-GHz Wireless Communications

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Abstract

This work offers the design of a fractal geometry based wideband antenna for sub-6-GHz applications. Rogers TMM 4 thermoset microwave material was chosen to design a compact size antenna having an overall dimension of 30 mm × 30 mm × 1.524 mm. The radiator of the presented antenna was extracted from the conventional square patch, afterward fractals were loaded to enhance the bandwidth of the antenna. The antenna covers a measured wide bandwidth of 2.8 GHz ranging 2.97 – 5.77 GHz that is corresponded to 64% practical bandwidth covering complete 5G sub-6-GHz band spectrum allocated globally. Across this band it shows peak gain and radiation efficiency of > 4 dBi and > 90%. Beside this, the presented work offers a low complexity level of the structure and omni-directional radiation pattern. A sample prototype was fabricated and tested to verify various performance parameters of the proposed antenna along with a comparison of proposed work with state-of-the-art-works for similar band, to demonstrate the potential of the presented work.

1 Introduction

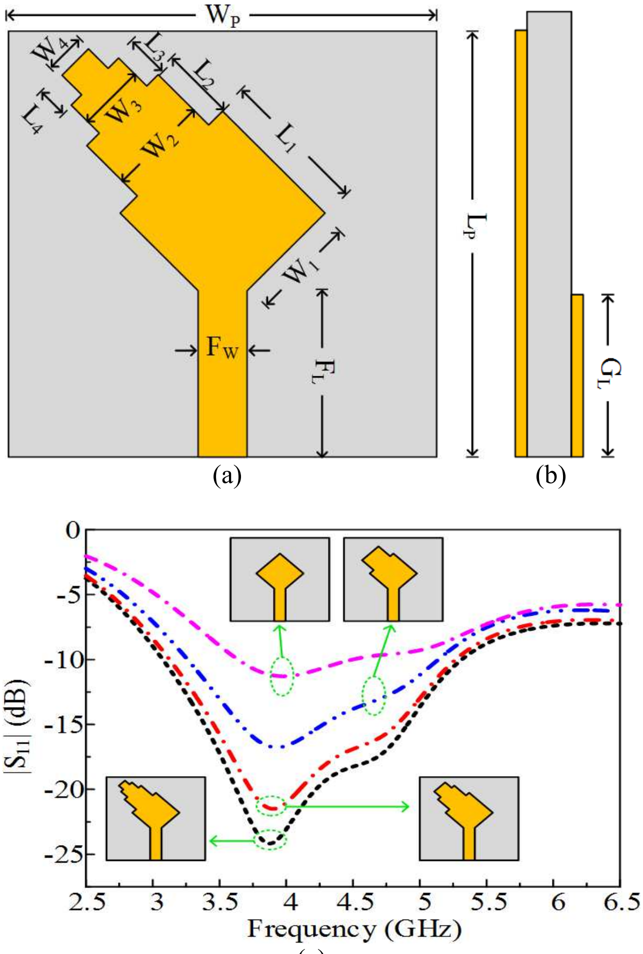
Present decade is revolutionizing the communication system, from the Internet of Things (IoT) to 5th generation of communication (5G) every technology is improving the communication system dramatically. Now researchers are focusing on 6G to move the effective communication one step further [1]. Besides this, with each passing day the communication systems are getting compact because of state-of-the-art technology including Integrated circuit based on nanotechnology [2]. Among various parts of the communication system, antenna is one of the key components that control the overall size of communication device, smaller the size of antenna compact will be the size of device [3]. Researchers adopted various techniques to design compact antennas that are not limited to Defected Ground Structures (DGS) [4], Multi-layer antennas [5], stub loading [6] and Fractal geometries [7].

Fractal geometries were widely studied to design compact, wideband, and high gain antennas [8]. However, most of the geometries adopted/utilized by researcher to design fractal antennas were complex, thus resulting in an overall complex design which significantly increase the fabrication cost along with increased error rate for bulk production. Considering sub-6-GHz band spectrum various techniques including fractal structure was adopted [9-14]. For an instance, in [9] a high gain multi layered wideband antenna was presented having set back of high profile and complex geometrical structure. In [10] monopole antenna having DGS was utilized to achieve wideband, while in [11] defects were introduced in patch to achieve wide operational bandwidth. Contrary to this, in [12] truncation of radiator was utilized to achieve wideband, furthermore, truncated patch loaded with stub was utilized to achieve wideband in [13]. Although the reported works offers compact size, but they had complex structures, moreover, the substrate utilized are either very thin or had high permittivity. Another interesting work was reported in [14] where Polarized Inverted F-Antenna (PIFA) was designed for sub-6-GHz applications, however due to large dimensions the antenna is not suitable for compact devices.

Keeping the considerations, requirements, and limitations of 5G sub-6-GHz systems, a compact yet wideband antenna with moderate gain is still a challenge for researcher around the globe. To overcome this aforementioned challenge a compact antenna having low complexity level is designed in the present paper. The antenna structure was inspired from a conventional patch antenna which is further loaded with fractal patch to achieve a wide operational bandwidth. The antenna offers peak gain and radiation efficiency of more than 4 dBi and 90% while maintaining low profile. Furthermore, the performance parameters have been validate using fabricated prototype and compared with recently reported work for similar applications.

2 Antenna Design and Methodology

The radiator of the presented antenna was engraved on the top side of Roger-TMM4 with relative permittivity of 4.5 and loss tangent of 0.002, as shown in Fig.1(a). Proposed antenna comprises of an overall dimension of 30 mm × 30 mm × 1.524 mm ($L_P \times W_P \times$ H). The rear side of the antenna contain partial ground plane for the propagating element, as depicted in Fig.1(b). All simulation of the presented work were carried out using a finite element based electromagnetic solver High Frequency Structure Simulator (HFSS). The optimized dimensions of the various parameters of the proposed antenna are as follow: $L_1 = W_1 = 10.25$ *mm*; $L_2 = W_2 = 3.88$ *mm*; $L_3 = W_3 = 2.83$ *mm*; $L_4 = W_4 = 2.12$ *mm*; $F_W = 2.5$ *mm*; $F_L = 12.3$ *mm*; $G_L = 11$ *mm*.



(a) (b)

(c)

Figure 1. Geometerical configuration of proposed fractal antenna, (a) top-view, (b) side-view**.** (c) Various antenna design steps and corresponding reflection coefficients graphs.

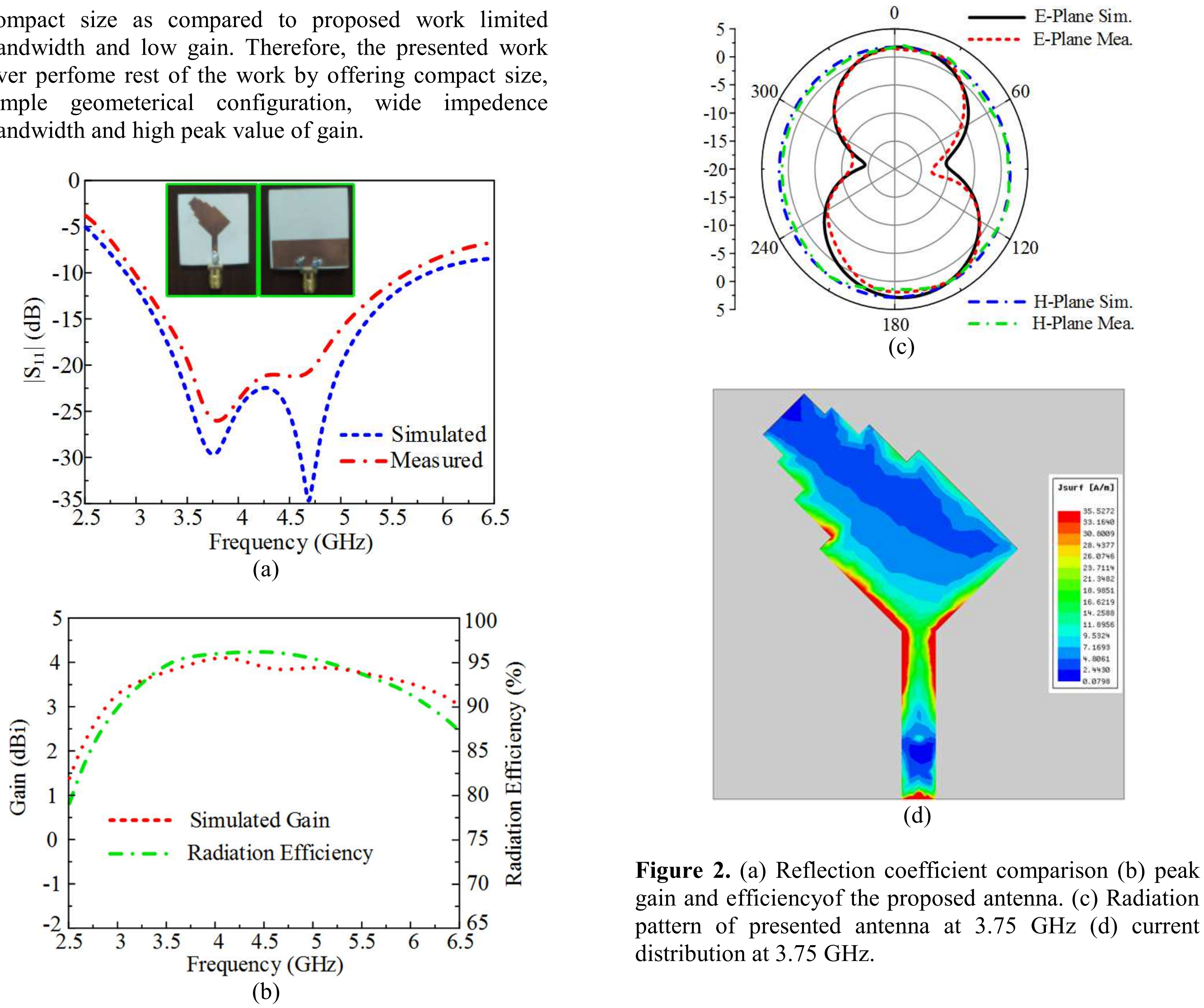
Initially a conventional square shaped quarter wave monopole antenna was designed. The length and width of the radiator can be estimated using the various equations provided in [7]. The resultant antenna shows resonance around 3.8 GHz having an impedance bandwidth of 500 MHz ranging 3.7 – 4.3 GHz, as depicted in Fig 1 (c). Afterwards, three consecutive iterations were performed to enhance the effective length of the radiator which allows more current to flow on the surface thus improves the matching at wide band spectrum. Fig. 1 (c) presents the schematic and corresponding result of each iteration; it could be observed clearly that with each iteration the impedance bandwidth improves having maximum bandwidth with 3rd iteration. A brief explanation on performing various iterations and choosing corresponding dimension was presented in [15]. It was also observed while doing numerical analysis that iterations after 3rd iteration does not have any notable effect on the performance of antenna, therefore the antenna after 3rd iteration was optimized to achieve best possible results.

3 Results and Discussion

To verify various performance parameters including reflection coefficient and radiation pattern, a sample prototype of the proposed work was fabricated using standard chemical etching process. The fabricated prototype was tested using Vector Network Analyzer (VNA) HP-8720D having a frequency range up to 13.5GHz. Furthermore, to measure the radiation pattern of the proposed antenna ETS-Lindgren (EMCO) type broadband horn antenna having model no. 3115 and maximum frequency range of 8 GHz was utilized in an anechoic chamber.

Fig. 2 (a) depicts the comparison among the predicted and measured reflection coefficient along with fabricated prototype of the present work. It could be observed that the proposed antenna offers the simulated impedance bandwidth ($S_{11} < -10$ dB) of 74%, with reference to central frequency of 3.75 GHz. On the other hand, the measured impedance bandwidth of the proposed antenna was observed to be 64% ranging 2.97 GHz to 5.77 GHz, as illustrated in Fig. 2 (a). The proposed antenna offers the simulated gain value of > 3 dBi in operational region having a peak gain of 4.22 dBi across 4.32 GHz, as depicted in Fig. 2 (b). Similarly, it could observed that numerically calculated efficiency is > 90 % in the whole operational region.

Fig. 2 (c) presents the comparsion among simulated and measured radiation pattern of the presented work at the slected frequency of 3.75 GHz. The antenna offers a monopole like bidirectional radiation pattern in principle E-plane ($\Phi = 0^0$), contrary to this an omni-directional radiation pattern was observed in principle H-plane ($\Phi = 90^0$), as depicted in Fig. 2 (c). Overall a strong agreement between simulated and measured results was observed in both planes. Fig. 2 (d) depicts the current distribution graph, it could be observed that a good amount of current is flowing on the whole radiator which could reesults in generation of wideband. Table.1 presents the comparison of the proposed wideband antenna with state-of-the-art. It could be observed that most of the antennas presneted had setbacks of bigger dimesnion, while the antenna having compact size as compared to proposed work limited bandwidth and low gain. Therefore, the presented work over perfome rest of the work by offering compact size, simple geometerical configuration, wide impedence bandwidth and high peak value of gain.



(a)

(b)

(c)

(d)

Figure 2. (a) Reflection coefficient comparison (b) peak gain and efficiencyof the proposed antenna. (c) Radiation pattern of presented antenna at 3.75 GHz (d) current distribution at 3.75 GHz.

Table 1. Comparison of proposed work with literature.

References	**Dimension (mm^2)**	**Design Technique**	**Impedance Bandwidth (GHz)**	**Peak Gain (dBi)**
[9]	85 × 85	Multi-layered Structure	3 – 5	7.8
[10]	44 × 68	Defected Ground Structure	2 – 6	3.08
[11]	20 × 30	Defected Patch Structure	3.85 – 5.55	2.7
[12]	30 × 30	Truncated Corners	2.31 – 4.42	2.97
[13]	25 × 32	Truncated Corners & Stub	2.85 – 5.35	3.75
[14]	50 × 19.7	PIFA	1.5 – 6	2.4
This work	**30 × 30**	**Fractal Geometry**	**2.97 – 5.77**	**4.22**

4 Conclusion

A fractal geometry based compact wideband antenna was presented in this paper. Conventional square shaped antenna was converted into wideband antenna using similar shaped and smaller sized fractals. The resultant antenna offers 64% of measured fractional bandwidth from 2.97 – 5.77 GHz. The gain and efficiency of the proposed antenna were observed to be greater than 3 dBi and 90% over the entire operational frequency band. Moreover, strong agreement between the simulated and measured results was achieved and the proposed design was validated by comparison with state-of-the-art-works, which made it positional nomine for 5G sub-6-GHz applications.

5. Acknowledgments

This work is partially supported by RTI2018-095499-B-C31, Funded by Ministerio de Ciencia, Innovación y Universidades, Gobierno de España (MCIU/AEI/FEDER,UE).

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