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REGULAR ARTICLE

Compact Circular Petal Fractal Antenna with Defected Ground Plane Structure for Sub-6 GHz 5G and X-Band Radar Applications

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This paper presents the design, fabrication and experimental evaluation of a fractal-structured design to target dual-band operation for Sub-6 GHz 5G and X-radar frequency bands. The suggested prototype is fabricated on a FR-4 substrate with a defective partial ground structure (DPGS). Commercial EM simulation software (CST Microwave Studio simulation) was used to optimize the antenna performance attributes, such as directional gain, S_{11}. The simulated antenna resonates at 3.3 GHz, 7.3 GHz and 9.2 GHz which corresponds to the Sub-6 GHz and X-band frequency bands. The antenna was made to resonate three times, an approximate level of 3.3 GHz and another at 7.3 GHz and 9.2 GHz, covering the Sub-6 GHz 5G frequency range and X-band radar frequencies respectively. The measurements are confirmed by experimental measurements when tested using an Anritsu Vector Network Analyzer (MS2037C). The proposed antenna achieved gains of 3.9 dBi at Sub-6 GHz and 4.8 dBi and 5.7 dBi at X-band. The Close match between both the simulated results and experimental outcomes proves the validity and strength of the designed antenna. From the results, the paper confirms that the proposed compact fractal antenna is a perfect one for practical modern wireless communication and radar systems.

Keywords: Fractal antenna, Sub-6 GHz 5G, Dual band, Return loss.

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1. INTRODUCTION

Increase in wireless communication systems and their contributions in the areas of next generation communication systems (5G), Smart device ecosystems (IoT), and radar operations have necessitated constant development of more compact, efficient and multiband antenna designs. Antenna designers are now being asked to meet the needs of emerging technologies and cover several frequency bands in an antenna with small size and with low cost of production [1]. The unique geometric nature of fractal antennas, including self-similarity characteristics and space-filling properties has led to great interest in fractal antenna designs over the last few years [2]. These characteristics enable these antennas to be small yet multi band or broad band capable and thus fractal antennas find significant use in recent wireless applications where size is of high priority, just like in the case of wireless phones [3]. The different fractal geometries, Koch, Sierpinski, Minkowski and Cantor have all been used in greater electrical length of the radiating elements and have led to better bandwidth a multiband functionality that does not necessarily add to the size of an antenna [4]. Moreover, the inclusion of defected ground structures (DGS) into antennas has also found to be a strong scheme to attain wide bandwidth, surface waves and radiation features [5]. Specifically, Sub-6 GHz spectrum range are of atmost importance in 5G communication since they provide a balance between coverage and capacity, whereas X-band frequency has been broadly applied in radar and sat-com systems [6]. A few researchers have designed compact, multiband and fractal antennas to be used in wireless communications such as 5G, WLAN and IoT. This was first suggested by Chakraborty et al. [7] with a compact dual-band microstrip antenna specifically designed to serve as an IEEE 802.11a WLAN application. An efficient design of microstrip patch antenna specialized to support 5G applications was introduced by Xu et al. [8], who underlined its efficiency in addressing the bandwidth requirements of contemporary communications systems. Wang et al. [9] presented a new multiband fractal antenna wireless device application where the advantage of fractal geometries in terms of achieving wide bandwidth and multiband was demonstrated. In terms of sub-6 GHz spectrum based 5G deployments, Kadu et al. [10] came up with a miniature dual-band antenna with enhanced perfor-

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mance and its applicability to modern mobile communication systems.

2. METHODOLOGY

The research methodology adopted in the research work come up with the proposed compact fractal-structured antenna that can be useful for sub-6GHz, 5G applications. As shown in Figs. 1 and 2. This was done by establishing the design goals and needs in terms of target frequency bands of the 5G Sub-6GHz and radar X-band communication. Performance characteristics like small size, dual-band performance, stability of radiation patterns, excellent impedance matching, high radiation efficiency, and high gain were found to be important objectives. The choice of substrate material was FR-4 because it is readily available and has generally accepted dielectric properties and can be used to make prototypes. The original antenna shape was based on the monopole topology which is characterized by simple geometry and easy packaging into small devices. Fractal geometries such as hexagonal or fish-tail were incorporated into the design to secure dual-band characteristics in a smaller footprint by extending the electrical path length without expanding the physical area. The ground plane was diligently realized in the form of a Fractal partial ground structure (FPGS) with both increasing the bandwidth and enhancing the impedance match using systematic parametric studies.

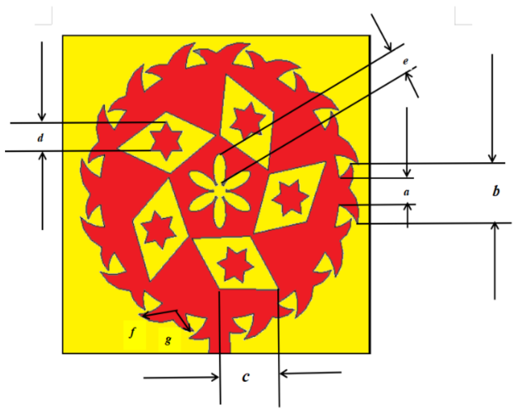
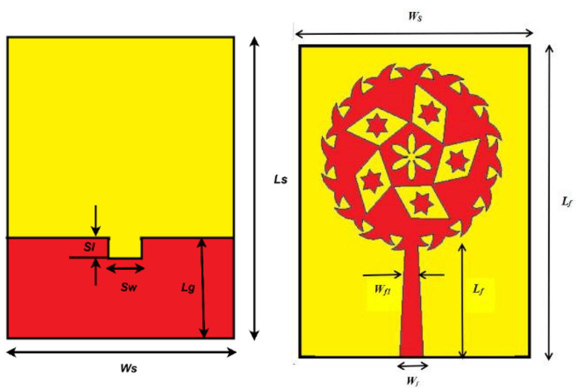


Fig.1 – Proposed antenna's Radiating patch



a b

Fig. 2 – Proposed prototype (a) front and (b) rear views

Return loss was measured on an Anritsu Vector Network Analyzer (MS2037C), gain and radiation patterns measured in an anechoic chamber using the conventional test set-ups. The results of the experiment were subsequently compared with the simulated results to verify the performance of the design with regards to the stated objectives. Lastly, the antenna was found to be usable in the Sub-6 GHz 5G, as well as X-band radar, which ends the methodology with a definite indication of the antenna to be suitable in practice. The dimensions of the structure in mm are depicted in Table 1.

Table 1 – Proposed Antenna dimensions

Parameter	Dimension (mm)	Parameter	Dimension (mm)
W_s	28	a	2.5
L_s	40	b	4.6
W_f	2.95	c	4.8
W_{f1}	14	d	1.6
L_f	14.6	e	2
L_g	13.3	f	1.6
S_w	2	g	1
S_l	4	r	9.6

3. FABRICATION OF THE DESIGNED PROTOTYPE AND ITS RESULTS VALIDATION

CST Microwave Studio was used to obtain simulation results which were also experimentally verified with Anritsu Vector Network Analyzer (MS2037C) measurements. The antenna was made to resonate three times, an approximate level of 3.3 GHz and another at 7.3 GHz and 9.2 GHz, covering the Sub-6 GHz 5G frequency range and X-band radar frequencies respectively. Simulated S_{11} values, as well as measured S_{11} values, indicated that the return losses were below – 10 dB at the targeted frequencies, which indicates impedance match of commendable effect and efficient radiation. The measured bandwidth at the two resonant frequencies was sufficient to meet the required operating conditions of the targeted applications. Minor differences between simulations and measurements reported were explained by resisting tolerances and losses in connectors in the test. This was also supported by VSWR analysis with VSWR value consistently less than 2 throughout the operating bands meaning there is excellent impedance match, as well as minimal signal reflection. The test was performed by means of an Anritsu MS2037C Vector Network Analyzer (VNA) system as demonstrated in the above figure with the fabricated antenna prototype connected to an ordinary coaxial cable. The antenna was positioned within an anechoic chamber to assure that the environment is free of interference, giving precise and reliable measurement results. Fig. 3 illustrates the fabricated prototype for the proposed antenna and from Fig. 4, the simulated results are indicated by the red solid line and measured indicates with yellow colored dash line. It can be observed that three large resonance dips will be detected, namely the first ear 3.3 GHz at Sub-6 GHz 5G uses, the second and third one at 7.3 GHz and 9.2 GHz for X-band applications.

a b

Fig. 3 – Fabricated model (a) Front view (b) Back view

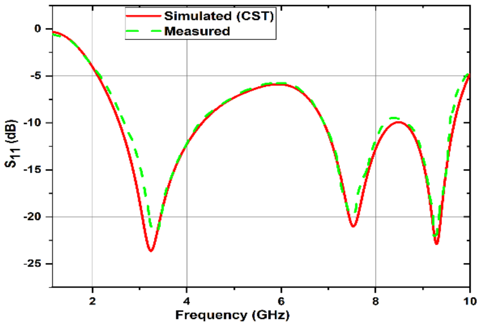


Fig. 4 – Obtained Simulated and measured S_{11}

Using the frequency range of 3.2 GHz to 9 GHz, Fig. 5 shows the suggested compact fractal-structured antenna's gain and radiation efficiency performance. Here, red colored spectrum indicates radiation efficiency and black colored spectrum illustrates gain of the proposed antenna's.

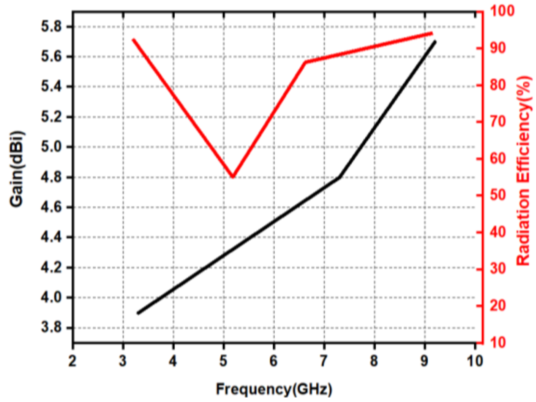


Fig. 5 – Obtained Gain and radiation efficiency plots of the proposed antenna

4. CONCLUSION

In the proposed research, a dual-band fractal-structured antenna was proposed and simulated using commercially available software, manufactured, and validated with experiments. The actual measurements were closely in agreement with the simulations which confirmed the presence of dual resonance at around 3.64 GHz and 8.49 GHz and 9.24 GHz with the return loss below –10 dB. The proposed antenna had a directional gain of 3.9 dBi at Sub-6 GHz and 4.8 dBi and 5.7 dBi at X-band. These results make the antenna suitable for 5G applications as well as X-band Radar applications.

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Компактна кругла пелюсткова фрактальна антена з дефектною структурою заземленої площини для радіолокаційних застосувань 5G та X-діапазону в діапазоні менше 6 ГГц

G. Yaminisasi[1], P. Pardhasaradhi[1], M. Valathuru[2], N. Prasad[3], G.V. Ganesh[1], G. Srinivas[1]

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Представлено проєктування, виготовлення та експериментальну оцінку фрактально-структурованої конструкції для дводіапазонної роботи в діапазонах частот 5G нижче 6 ГГц та радіолокаційного діапазону X. Запропонований прототип виготовлено на підкладці FR-4 з дефектною частково заземленою структурою (DPGS). Для оптимізації характеристик продуктивності антени, таких як спрямоване підсилення S_{11}, було використано комерційне програмне забезпечення для електромагнітного моделювання (моделювання CST Microwave Studio). Антена резонувала тричі, приблизно на рівні 3,3 ГГц та ще раз на рівні 7,3 ГГц та 9,2 ГГц, охоплюючи діапазон частот 5G нижче 6 ГГц та радіолокаційні частоти діапазону X відповідно. Вимірювання підтверджено експериментальними вимірюваннями під час тестування за допомогою векторного мережевого аналізатора Anritsu (MS2037C). Запропонована антена досягла коефіцієнта посилення 3,9 дБі в діапазоні менше 6 ГГц та 4,8 дБі та 5,7 дБі в діапазоні X. Близька відповідність між результатами моделювання та експериментальними даними доводить достовірність та потужність розробленої антени. Згідно з результатами, у статті підтверджується, що запропонована компактна фрактальна антена є ідеальною для практичних сучасних систем бездротового зв'язку та радіолокації.

Ключові слова: Фрактальна антена, Sub-6 GHz 5G, Дводіапазонна, Втрати відбиття.