A Novel Fractal Patch Antenna Using Defected Ground Structure (DGS) with High Isolation for 5G Applications

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This paper presents a novel compact circular shaped fractal monopole patch antenna (FMPA) with defected ground structure (DGS). The suggested fractal geometry has been created by using an iterated function system (IFS). The primary aim behind the inclusion of this fractal geometry is used to achieve miniaturization and wideband performance. The complete geometry of the prescribed FMPA for 5G applications is constructed by incorporating fractals with square and star with eight segments; in each segment we create a square with a rotation of 45° from one segment to another. The dimension of proposed fractal geometry is 14 × 6 mm². The bottom plane of the antenna consists of defected ground structures (DGS) to acquire better isolation and miniaturization. The proposed structure provides a good performance metrics such as gain, and reflection coefficient. The substrate used in this work is Rogers RO4003C, which has a dielectric constant of 3.55, a high of 0.2 mm, and loss tangent of 0.025. Computer Simulation Technology-Microwave Studio (CST) is used to evaluate this antenna. The suggested antenna operates at 26 GHz with an impedance bandwidth of 0.357 GHz along with maximum reflection coefficient of – 24.426 dB. The prescribed antenna attains a peak gain of 3.83 dB, maximum radiation efficiency of 95.78 % and desired radiation patterns by maintaining its compact size.

Keywords: 5G, Fractal, Patch antenna, Isolation, DGS, IFS.

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1. INTRODUCTION

The Greek word "Frangere," which means "broken or uneven bits," is the source of the English word "fractal." Benoit Man-delbrot, a mathematician, invented it for the first time in 1975. This phrase was used to describe a new class of more complex objects than the clearly defined squares, circles, and triangles that were created by Euclidean geometry. However, was unable to depict other common place phenomena like clouds, blood vessels, and irregular patterns like the seashore [1]. Due to their capabilities and competencies, fractal antennas may operate in multiple bands, have a high gain, and have a low profile. Conventional antennas require a larger space for antenna coupling because they operate on a single frequency band. Fractal geometry has been used successfully in a number of fields [2]. Today, small antennas are used in communication systems. Furthermore, it's necessary to develop new multi-band operating standards. Fractal enables the construction of compact and wideband antennas in restricted spaces because of its space-filling, self-affine, and self-similar properties. The electrical channel length is lengthened when the fractal shape is constructed in a specific tiny area [3-5]. The essential downsizing and wideband phenomena are made possible by the use of fractal geometry in antenna design because of its self-similar and space-filling properties. The space filling property aids in extending the antenna's effective electrical route length in a constrained smaller space. In 5G applications, antenna is designed using a variety of fractal geometries, including the Koch snowflake, Sierpinski triangle, hexagonal form [4-6], Minkowski curve [7-8], Koch curve [9], and a Hilbert curve slot based on fractals [10]. The space filling property contributes to increasing the antenna's effective electrical path length in a given small region.

In this article, the novel fractal geometry is constructed by using a square and star with eight segments; in each segment we create a square of side with a rotation of 45° from one segment to another. This method of fractal structure generation is iterated function system (IFS). The structure of the antenna is shown in Fig. 1. The suggested antenna has excellent gain and bandwidth due to the usage of a defective ground structure (DGS). The major goal is to produce a very small device with broad bandwidth, standard gain, and good efficiency at 26 GHz for 5G applications band. The proposed structure has been created on a substrate with physical dimensions of 14 × 6 × 0.2 mm³. Each antenna structure is designed, simulated, and evaluated using the electromagnetic 3D simulator software: CST Microwave Studio™. The fractal patch antenna is a good contender for upcoming 5G applications due to its sufficient impedance bandwidth, desired unidirectional steady radiation patterns, excellent gain, radiation efficiency, and its minimized size.

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2. FRACTAL ANTENNA DESIGN

This section discusses about the single fractal structure. The substrate being employed is Rogers RO4003C, which has a dielectric constant of 3.55, a high of 0.2 mm, and loss tangent of 0.025. Figure 1 depicts the geometry of the proposed fractal antenna, the partial ground plane with *T*-shaped defect, as shown in Figure 1(a). The structures of basic element antenna, patch antenna with a slot in the form of an eight-segment star and the proposed antenna with self-similar fractal geometry are shown in Figures 1 (b), (c) and (d), respectively. The radiating monopole patch is fed by a microstrip line of 50 Ohm and the intended geometry is analyzed using CST EM simulator.

A list of the suggested antenna's optimum design parameters in shown in Table 1.

Table 1 – The fractal antenna's proposed design characteristics

Parameters	Values (mm)
L_G	12.5
$W_G = W_{SUB}$	6
L_{SUB}	14
X_{sc}	6.4
T_{SUB}	0.2
L_F	7.8
W_F	0.54
$L_{2DGS} = W_{1DGS}$	0.5
L_{1DGS}	5.5
W_{2DGS}	4
R	1.75
$W_{star} = L_{star}$	1.5

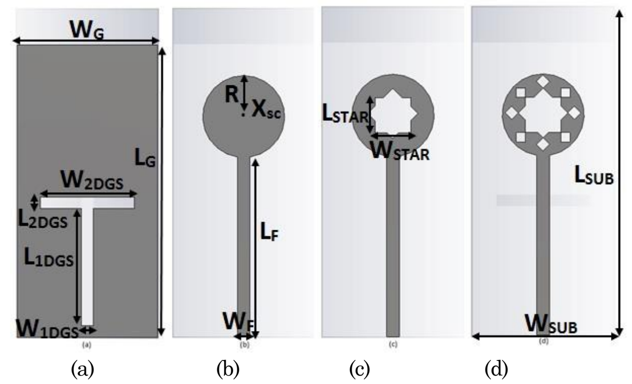

Fig. 1 – The planned antenna's dimensions (a) partial ground plane with DGS, (b) basic element, (c) suggested slotted antenna and (d) the suggested antenna with fractal geometry

3. EVALUATION OF ANTENNA PARAMETERS

Before the suggested antenna is built, it is essential to look into how certain design elements will affect its function in terms of resonance. From the discussion presented in this section, it can be evident that the performance of the suggested antenna is significantly influenced by the size of the slots, ground plane length, DGS, and fractal geometry.

3.1 Impact of Ground Plane Length on the Proposed Antenna's Performance with and without DGS

The effect of the ground plane length on the resonant properties of the proposed antenna with and without DGS has been investigated using a parametric analysis. For a range of ground plane lengths ($L_G = 6$ mm to $L_G = 12.5$ mm), the simulation results (reflection coefficient) are shown in Figure 2.

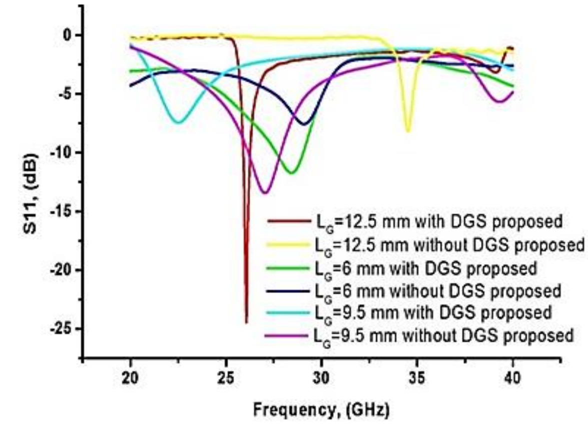

Fig. 2 – The effects of changes in ground plane length on the S11 parameter both with and without DGS

There is a decent change in the resonance response of the suggested antenna in terms of impedance matching and operating band-width when the ground plane length is changed from $L_G = 6$ mm to $L_G = 12.5$ mm. Figure 2 demonstrates that the reflection coefficient lowers to – 24.426 dB at 26 GHz with an approximate – 10 dB impedance bandwidth (25.904 GHz to 26.262 GHz) when the ground structure is defective and the recommended ground plane length L_G is 12.5 mm.

3.2 Impact of Defected Ground Structure (DGS) Size

The results obtained (reflection coefficient) based on changes in the size of the DGS are shown in Figure 3.

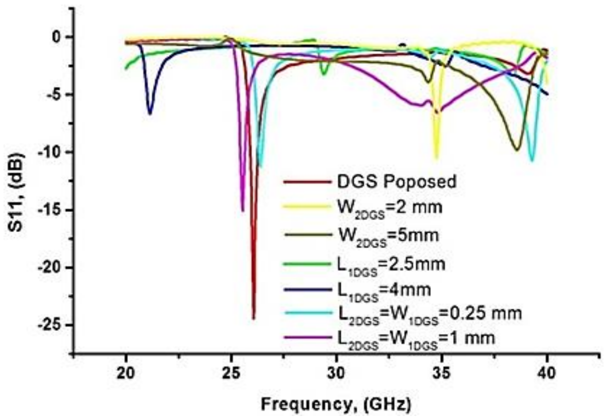

Fig. 3 – Impact of DGS size variations on the S11 parameter

The simulation findings show that the variations in DGS's dimensions ($L_{2DGS} = W_{1DGS} = 0.5$ mm, $L_{1DGS} = 5.5$ mm, and $W_{2DGS} = 4$ mm) produce a reflection coefficient of – 24.426 dB at 26 GHz with an approximate – 10 dB impedance bandwidth of 0.357 GHz from 25.904 GHz to 26.262 GHz.

4. RESULTS AND DISCUSSION

Figure 4 examines the variations in the reflection coefficient as a function of frequency for the basic structural patch antenna with and without a slot shaped like an eight-segment star and with a DGS. The results prove that the suggested antenna's reflection coefficients (Fig. 1(d), red line) present a return loss value of 24.426 dB at 26 GHz and an impedance bandwidth of around 0.357 GHz between 25.904 GHz and 26.262 GHz. In contrast, the patch antenna with slot [Fig. 1(c), blue line] shows a single resonance peak but it's not properly impedance matched and its reflection coefficient is at around – 8 dB and also a poor value is noticed when the patch antenna is utilized without slot [Fig. 1(b), green line]. Figure 5 shows how the proposed fractal antenna's gain varies with frequency (green line)

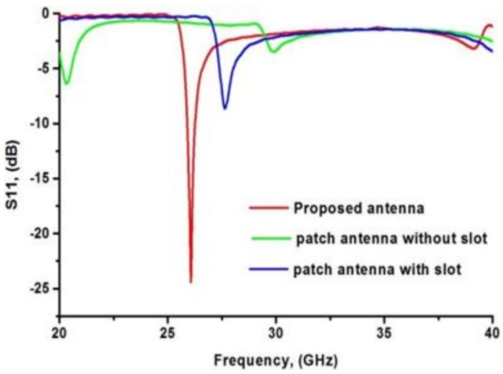

Fig. 4 – Comparison of the proposed antenna's reflection coefficient vs frequencies for different design cases

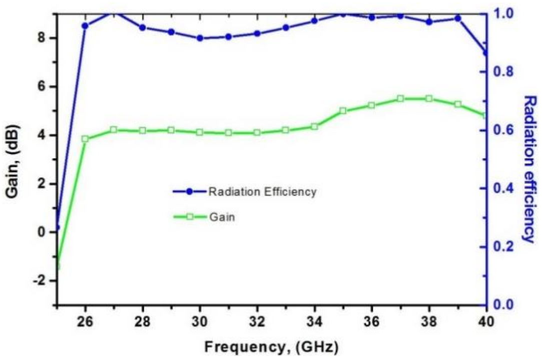

Fig. 5 – Gain and Radiation Efficiency vs frequencies of fractal antenna

(green line). It is clear from the patch antenna with slot that the proposed work has an average gain of 3.83 dB around 26 GHz. The radiation efficiency of the suggested antenna is shown in also indicated in Figure 5 (blue line); at a frequency of 26 GHz, the maximum radiation efficiency is 95.78 %.

The proposed antenna's radiation pattern is shown in Figure 6. The E-Plane (XZ-plane) pattern shown in Figure 6(a) and H-Plane (YZ-plane) pattern as shown in Figure 6(b) show that the developed antenna exhibits a bidirectional radiation pattern for both 26 GHz frequencies. A key requirement for 5G wireless communication applications is that the planned antenna demonstrate stable radiation patterns over the operational band. This requirement is fulfilled by the proposed antenna.

Gain, bandwidth, and return loss parameters for the suggested antenna exhibit good stability at 26 GHz. The suggested antenna has a unique geometry, is less in size, and performs better than current antennas. The proposed antenna's geometrical configuration is distinct when compared to other structures [11-12] for next-generation 5G applications. The performance parameters of the proposed antenna are compared with other referred structures and presented in Table 2. The summarized results in Table 2 suggests the superior performance of the antenna in terms of broader operating bandwidth, high radiation efficiency along with most compact antenna size.

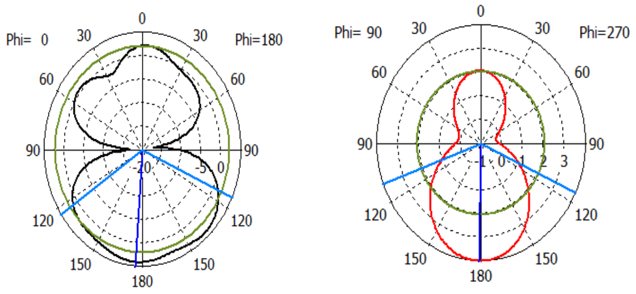

Fig. 6 – The suggested antenna's radiation patterns at 26 GHz (a) *E*-plane (b) *H*-plane

Table 2 – Performance evaluation of developed antenna in comparison to other antenna designs

References	Performance evaluation					
	Size in (mm²) $L_{SUB} \times W_{SUB}$	Center Frequency	Patch Gain (dB)	Impedance bandwidth (GHz)	Level of Reflection coefficient (S11)	Radiation efficiency
[11]	25 × 30	25.2	3	–	–	–
[12]	45 × 40	26.68	7.76	0.12	– 14.5	–
Proposed work	6 × 14	26	3.83	0.357	– 24.426	95.78 %

CONCLUSION

A fractal patch antenna with defected ground plane structure has been designed and simulated. The characteristics parameters of the proposed antenna have been investigated for 26 GHz 5G communication systems. The proposed antenna geometry has been attained by introducing a few slots in the form of an eight-segment star and with self-similar fractal geometry. The suggested geometry has been constructed using Rogers RO4003C substrate, which has a dielectric constant of 3.55, and loss tangent of 0.025. The prescribed T-shaped defect enhances the operating bandwidth of the antenna and the fractal geometry leads to miniaturized dimension of the antenna with improved gain and radiation efficiency. Furthermore, it has been demonstrated that antenna reduction doesn't require a high level of structural complexity. The suggested antenna many attractive features like miniaturized size of 84 mm^2, high radiation efficiency of 95.78 % and resonates at 26 GHz frequency with a huge bandwidth of 357 MHz that is sufficient for 5G applications.

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Нова фрактальна патч-антена, що використовує дефектну структуру землі (DGS) з високою ізоляцією для додатків 5G

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У цьому документі представлено нову компактну фрактальну монопольну патч-антену круглої форми (FMPA) з дефектною структурою землі (DGS). Запропонована фрактальна геометрія була створена за допомогою системи ітерованих функцій (IFS). Основною метою включення цієї фрактальної геометрії є досягнення мініатюризації та широкосмугової продуктивності. Повна геометрія встановленого FMPA для додатків 5G побудована шляхом включення фракталів із квадратом і зіркою з восьми сегментів; у кожному сегменті створюємо квадрат з поворотом на 45° від одного сегмента до іншого. Розмір запропонованої фрактальної геометрії становить 14 × 6 мм^2. Нижня площина антени складається з пошкоджених структур землі (DGS) для отримання кращої ізоляції та мініатюризації. Запропонована структура забезпечує хороші показники продуктивності, такі як посилення та коефіцієнт відбиття. У цій роботі використовується підкладка Rogers RO4003C, яка має діелектричну проникність 3,55, висоту 0,2 мм і тангенс втрати 0,025. Для оцінки цієї антени використовується Технологія комп'ютерного моделювання – мікрохвильова студія (CST). Запропонована антена працює на частоті 26 ГГц із смугою пропускання опору 0,357 ГГц разом із максимальним коефіцієнтом відбиття – 24,426 дБ. Зазначена антена досягає пікового посилення 3,83 дБ, максимальної ефективності випромінювання 95,78% і бажаної діаграми спрямованості завдяки збереженню її компактного розміру.

Ключові слова: 5G, Fractal, Патч-антена, Ізоляція, DGS, IFS.