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REGULAR ARTICLE

Theta-Shaped Microstrip Patch Antenna with DGS for Dual NR Mid Band 5G Deployment Applications

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The design and installation of an improved defective ground structure (DGS) slotting theta-shaped patch antenna (TSPA) for 5G Sub-6 GHz applications are presented in this work. An FR-4 substrate ($\varepsilon_r = 4.3$, tan $\delta = 0.025$), which has a copper layer on the two sides, is used to manufacture the suggested antenna. The antenna works at two frequencies of 4.13 GHz and 5.12 GHz, including the n77 (3.3-4.2 GHz) and n79 (4.4-5 GHz) bands. Its small dimensions are $35 \times 34 \times 1.6$ mm^3 ($0.39\lambda \times 0.37\lambda \times 0.02\lambda$). It has an enhanced reflection coefficient of – 30 dB at both frequencies and a broader bandwidth of 130 MHz at 4.13 GHz and 400 MHz at 5.12 GHz. The benefits and efficacy of the suggested design for the intended applications are highlighted by a careful comparison with similar published studies. The results shed light on how 5G wireless communication networks should be optimized. The antenna's omnidirectional transmission pattern, significant gain, and effective radiation make it a feasible choice for the spectrum of 5G communication systems in a number of situations. For 5G portable devices, this suggested antenna may be helpful. The need for active beam forming antenna configurations in 5G telecommunications, especially in the sub-6 GHz frequency range, necessitates the integration of novel electronics with antennas.

Keywords: Microstrip patch antenna, Defected ground, Circular slotted theta-shaped radiating elements, Mobile phones, 5G tri-band, DGS, High gain, High directivity.

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1. INTRODUCTION

The technology transformation of the past century has drastically altered humanity and worldwide con-nected-ness. Our everyday lives have been greatly impacted by this technology revolution, and mobile communication is an essential part of it. The fundamental performance requirements of wireless communication, such as high data flow, broad connection, and low latency between devices, can be successfully met by sub-6 GHz technology. Numerous wireless technologies, including Wi-Fi, WiMAX, 3G, 4G, and the potential of 5G net-works, rely on this technology [1]. Robots, cloud computing, augmented and virtual reality, high-definition live broadcasting, astronomy, space travel, the internet of things (IoT), smart houses, effective transportation [2], and remote medical and educational services. Large data speeds, many connections, incredibly low latency, higher dependability, and a larger geographic area of availability with improved mobility are the main bene-fits of sub-6 GHz 5G that enable it to provide so many services [3]. Even though mm-wave 5G employs fast-frequency spectrum as well as enables extremely high data rates, the 5G technology operating less than 6 GHz is thought to have been more feasible and easily deployable due to its higher reach and deployment capacities [4].

In wireless technology, antennas are essential for

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creating communication links. Patch antennas can now operate in several bands, have a broader bandwidth, reduced return loss, and are more compact thanks to de-sign advancements in recent years. Due to their multi-band support, affordability, portability, durability, and ability to accurately adjust radiation patterns, planar antennas have been utilized in Wireless LAN, WMAN, along with the next generation of wireless alongside 5G use cases [5]. Numerous researchers argue that array antenna is among the greatest ways to achieve optimal equalization of impedance and increase gain [6]. The software for HFSS uses the finite element method, also known as FEM, to develop an IA adaptable CPW-powered transparent antenna with WLAN in addition below-6 GHz workloads [7]. AgHT-8 conducting material, which has an electric size of $0.48\lambda \times 0.64\lambda$, is combined with a lightweight, transparent PET inside the antenna. Specialists created a $40 \times 30 \times 1.6$ mm^3 planar antennas featuring a bandwidth of 0.72 GHz in addition to a successful gain of 2.5 dB considering 5G applications. The reflecting accuracy is – 31.15 dB under a resonant rate of 3.83 GHz [8].

Another FR-4-based $32.4 \times 27.9 \times 1.6$ mm^3 plane antenna is reported in [9]. Its entire bandwidth is 0.019 GHz. Its reflecting coefficient is – 26.5 dB and its greatest gain is 4.2 dB at 3.5 GHz. Defective Ground Structures (DGS) as a popular method due to its adaptability and architectural autonomy. The application of WiMAX with sub-6 GHz has been covered in numerous important studies. A compact dual-band 5G network antenna [9] explains how to utilize sub-6 GHz. Circular polarization plus a ring-shaped slot antenna construct-ed from FR-4 substrates are suggested [10].

2. PROPOSED STRUCTURE DESIGN

Antenna-1 uses a novel modified DGS technique with a special theta-shaped patch antenna. The modified DGS approach can be used to increase a theta-shaped patch antenna's bandwidth and return loss. The simulated form is shown in Figs. 1 (a) and (b), whereas the structure with optimized dimensions is shown in Figs. 1 (c) and (d).

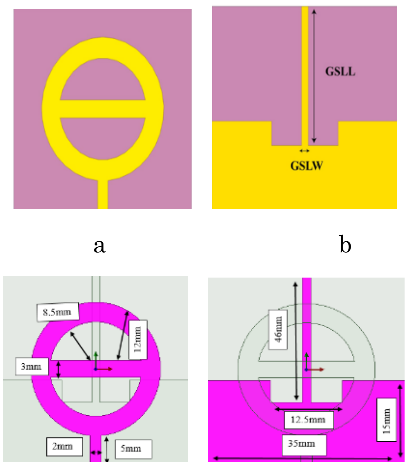

Fig. 1 – The proposed DGS based antenna with dimension (a) Front view (b) Back view

The theta slotted patch antenna's radiation performance characteristics were estimated using a DGS and the CST Studio suite 2020. FR-4 (lossy) substance, with an apparent permittivity of 4.3 alongside is 1.6 mm thick, was used in the construction of the antenna. The circularly slotted theta-like patch, feed cable, in addition to grounding plane are made using metal (average thickness of 0.035, annealing) and a DGS.

The usage of modified DGS on the ground plane and circular slotted unique theta forms enables the element to function in multiple modes upon the area that radiates in separate bands. The microstrip patch technique further improves impedance matching. The antenna evaluation procedure is shown in Fig. 2. The solid ground plane was swapped out for a partial ground plane and the circle for a ring in order to enhance the output. A vertical stub and a ground plane design modification were made to further enhance the outcome. Additionally, a horizontal line was added to the front side design. Fig. 3 shows the finished design.

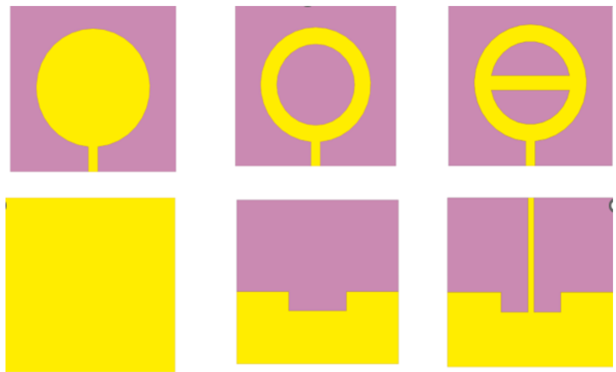

Fig. 2 – Evaluation procedure for DGS design

The circular patch was designed to have a theta shape using Eqs. (1-3). This formula includes a logarithmic function F, the substrate material's relative permittivity ε, and the resonanting duration f in GHz.

The design consideration of antenna is expressed as

$$R_e = R\left(1+\frac{2h}{\pi\varepsilon_r R}\left\{\ln\left(\frac{\pi R}{2h}\right)+1.7726\right\}\right)^{\frac{1}{2}} \tag{1}$$

In this case, R is the rings radius and R_e is the effective circular patch radius.

$$R=\frac{F}{\sqrt{1+\dfrac{2h}{\pi l F\left[\ln\left(\frac{F_r}{}2h\right)+1.7726\right]}}} \tag{2}$$

Where:

$$F=\frac{8.791\times10^{9}}{f\sqrt{\varepsilon}} \tag{3}$$

3. RESULTS & DISCUSSIONS

The complete electromagnetic simulation was performed using CST Studio Suite 2020 in order to ascertain the constructed antenna's reflection coefficient. Fig. 3 displays the reflection coefficient plot for the recommended antenna with enhanced DGS. At resonant 4.13 GHz and 5.12 GHz, the simulated $|S_{11}|$ values are – 35.64 dB and – 32.69 dB, respectively. These resonant frequencies have a bandwidth of 400 MHz (5.05-5.45) and 130 MHz (4.11-4.35).

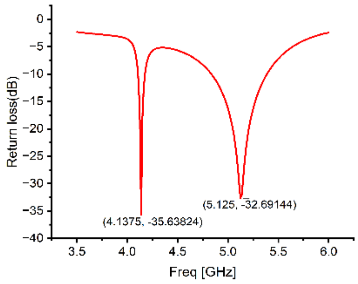

Fig. 3 – Reflection coefficient of theta shaped antenna

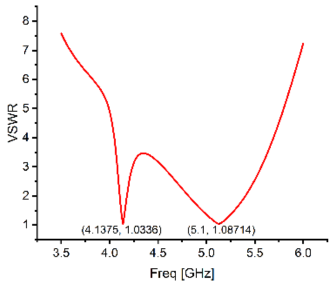

Fig. 4 – The VSWR plot of theta shaped antenna

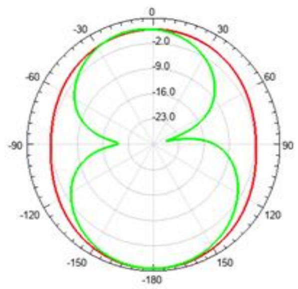

Fig. 5 – Gain of the theta shaped antenna

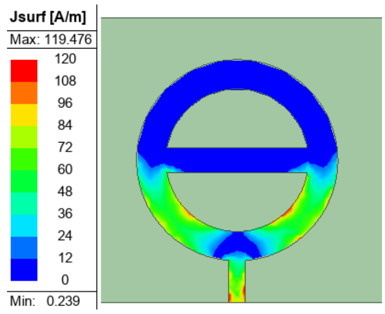

Fig. 6 – Current distribution proposed antenna

The suggested antenna's simulated VSWR values fall between 1 and 1.1 as in Fig. 4 which is satisfactory. Ultimately, the results demonstrate that the recommended antenna can be used in both desired frequency bands. The impedance mismatch between the antenna along with feed systems is measured by the VSWR the amount of voltage over standing waves ratio is known as VSWR. The simulated 3D gain of the proposed antenna over 4.13 GHz and 5.12 GHz is displayed in Fig. 5. At 5.12 GHz and 4.13 GHz, the structure's gain is 1.88 dBi and 0.05 dBi, respectively. It is discovered that the gain in the 4.13 GHz frequency range is between 1.87 and 1.01 dBi. Although the gain started out negatively, it rose when frequency climbed. For the frequency band at the resonance frequency of 5.12 GHz, gain ranges from 2.36 to 1.51 dBi. The starting gain in this frequency range was sufficient, yet as the frequency range rose, the gain dropped and eventually settled at 1.51 dBi. Figure 6 displays the outermost current distribution of the suggested antenna at 4.13 GHz. The surface current distribution must be used to determine which antenna components are necessary on the multiple band frequencies. The lower portion of the theta-shaped patch and the feed line have higher levels of current density, either the center portion of the patch along with the DGS line. The obtained characteristics are compared with various literary works in Table 1.

Table 1 – Comparison with literature results for the proposed work

Ref	Operating Frequency (GHz)	Antenna Size (mm²)	Substrate	Bandwidth (MHz)	Return Loss (dB)
[10]	3.3 & 4.5	$0.4\lambda \times 0.34\lambda$	FR-4	340 & 410	– 22 & – 23
[11]	4.53 & 4.97	$0.85\lambda \times 0.85\lambda$	RO5880	200 & 50	– 14 & – 28
[12]	5.65	$0.58\lambda \times 0.61\lambda$	Arlon	135	– 12.5
[13]	3.51	$0.42\lambda \times 0.42\lambda$	Rogers	69.2	– 54.08
[14]	3.4 & 5.9	$0.4\lambda \times 0.41\lambda$	FR-4	356 & 443	– 19.36 & – 22.9
[15]	4.0 & 4.9	$0.56\lambda \times 0.45\lambda$	FR-4	130 & 890	– 18.82 & – 19.91
This work	4.13 & 5.12	$0.48\lambda \times 0.41\lambda$	FR-4	130 & 400	– 35.64 & – 32.69

4. CONCLUSION

A unique defected grounded system with slotted theta-formed antenna patch targeting sub-6 GHz 5G services is presented in this research. The traditional one-band patches antenna is outperformed by a microstrip powered patch antenna utilizing the FR-4. The main technique to increase the antenna's performance is to use a single line in the DGS. We additionally modeled the compact (35×30 mm²) and easy-to-construct proposed DGS-powered two-band TSPA to verify its operation. The suggested antenna provides an excellent return loss of more than – 30 dB at both 4.13 GHz and 5.12 GHz for Sub-6 GHz, and its narrow spectrum width exceeds 130 MHz in addition 400 MH. Models using the CST Studio Suite 2020 program demonstrate the benefits and efficacy of the suggested design according to the intended uses. The results provide insight into potential two-band patched antennas, considered essential in scenarios demanding broad frequency bands and reliable operational qualities, could be further maximized in 5G networks.

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Тета-подібна мікросмужкова патч-антена з DGS для розгортання 5G середнього діапазону з подвійним NR

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Робота присвячена проектуванню та встановленню вдосконаленої щілинної тета-подібної патч-антени (TSPA) з дефектною заземлювальною структурою (DGS) для застосувань 5G Sub-6 GHz. Для виготовлення запропонованої антени використовується підкладка FR-4 (ε_r = 4.3, tan δ = 0.025), яка має мідний шар з двох боків. Антена працює на двох частотах: 4,13 ГГц та 5,12 ГГц, включаючи діапазони n77 (3,3-4,2 ГГц) та n79 (4,4-5 ГГц). Її малі розміри становлять 35 × 34 × 1,6 мм3 (0,39 × 0,37 × 0,02 Ω). Вона має покращений коефіцієнт відбиття –30 дБ на обох частотах та ширшу смугу пропускання 130 МГц на частоті 4,13 ГГц та 400 МГц на частоті 5,12 ГГц. Переваги та ефективність запропонованої конструкції для цільових застосувань підкреслюються ретельним порівнянням з аналогічними опублікованими дослідженнями. Результати проливають світло на те, як слід оптимізувати бездротові комунікаційні мережі 5G. Всеспрямована діаграма спрямованості антени, значний коефіцієнт посилення та ефективне випромінювання роблять її можливим вибором для спектру комунікаційних систем 5G у низці ситуацій. Для портативних пристроїв 5G ця запропонована антена може бути корисною. Потреба в активних конфігураціях антен з формуванням променя в телекомунікаціях 5G, особливо в діапазоні частот нижче 6 ГГц, вимагає інтеграції нової електроніки з антенами.

Ключові слова: Мікросмужкова патч-антена, Дефектна земля, Круглі тета-подібні випромінювальні елементи з прорізами, Мобільні телефони, Тридіапазонний 5G, DGS, Високий коефіцієнт посилення, Висока спрямованість.