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REGULAR ARTICLE

Scoop Shaped Patch and Rectangle Defected Ground Antenna for Sub-6 GHz mid Band 5G Communication

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This work describes the construction of a microstrip line patch antenna having rectangular defective ground structure (DGS) to use in 5G mobile communications applications. This de-sign is used to operate at 3.3 GHz, 4.4 GHz, and 5.3 GHz, three different frequency bands. The antenna design, measuring $50.5 \times 41.21 \times 1.6$ mm^3, is positioned on a FR-4 substrate. It operates at impedance bandwidths of 10%, 14%, and 2.3%, with antenna gains of 6.01 dBi, 4.23 dBi, and 4.57 dBi at each of the three bands. The suggested antenna function within C band at frequencies of 0.582 Hz (5.033-5.615 GHz), 0.649 Hz (4.167-4.816 GHz), and 0.076 Hz (3.254-3.330 GHz), with radiation efficiencies of 85 %, 83 %, and 70 %. The findings demonstrate strong directivity, constant high gain, multi bands operating, and advantageous directional radiated patterns. 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 within 5G mobile communications, particularly across the below-6 GHz wavelength band, necessitates the integration of novel electronics with antennas.

Keywords: Defected ground antenna, Semi-circular rectangular radiating elements, Mobile phones, 5G tri-band, DGS, High gain, High directivity.

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1. INTRODUCTION

While several nations are currently deploying 4G cellular networks, researchers in the telecom industry have already begun developing the 5G system. In order to sustain network performance, especially latency, safety, availability, and dependability, future 5G advancements must put user demands first, guaranteeing dependability, good service, energy efficiency, and product cost. Cutting holes in a patch of different forms, such as triangle, rectangle, T, E, and U shapes, is the main method for building a multiband antenna [1-8]. Wearable multiband antennas that can function across many frequency bands are required to adhere to these kinds of communication protocols. 5G will have a big impact on the widespread use of high-speed data transfer rates, large capacity, and consistent gain – all of which have been used in many different domains.

The new 5G radio spectrum includes frequency bands ranging from sub-6 GHz 5G applications to (3.3-4.2 GHz), (3.3-3.8 GHz), and (4.4-5.0 GHz). 5G wireless communications have advanced significantly over the past few decades and are quickly gaining traction due to its amazing benefits, which include minimal latency, massive data capacity, and faster data rates [9-11]. The authors of [12] show that patch antennas with dual- and multiband features can also be made using the U-slot approach. The writer presented a novel plane tiny slots antennae containing C-formed and inverted L-like slots supporting multiple band wireless networking in [13].

There have been reports of triple-band antennas with

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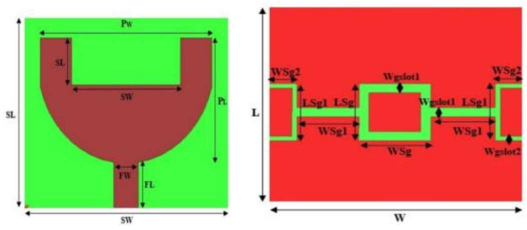
T-, Y-, and triangle-shaped slot arrangements [12, 13].

Microstrip antennas have several advantages, but they also have certain disadvantages. Reduced gain, low power handling capacity, radiated power and bandwidth limitations, and leakage losses at the open border are some of these. Low gain, restricted range, and radiated loss. These problems were resolved by adding slot pairs at the rectangular patch's opposing edges, and the antenna's bandwidth was expanded by changing the patch and ground-plane design [14-15]. In the following paragraphs, the layout of a Y-shaped semi-circle rectangular slotted DGS structured microstrip patch antenna with strip slots. With dimensions of 50.5×41.21 mm^2, the proposed antenna is still small and shows tri-band resonance at 3.3 GHz, 4.4 GHz, and 5.3 GHz. It can have a wider impedance bandwidth and work well at three distinct frequencies with gains of 6.01 dBi, 4.23 dBi, and 4.57 dBi. It is a part of the 5G communication network's low sub-6 GHz frequency band.

2. PROPOSED STRUCTURE DESIGN

Fig. 1 (a) illustrates the suggested $50.5 \times 41.21 \times 16$ mm^3 three-band patch antenna using a slot that is rectangular DGS, where the antenna patch covers one side of the slots while leaving the other side open. For a variety of 5G uses, especially in the below-6 GHz bandwidth band, FR-4, a dielectric substrate with an average thickness of 1.6 mm and a permittivity of 4.4, is utilized to influence its cost, physical robustness, thermal resistance, and adequate electric efficiency. Rectangle DGS layers are placed on the bottom exterior, and semi-circular rectangular radiating elements are arranged horizontally in a scoop-like pattern on the highest layer containing the substrate's substance to produce three-frequency bands. The core rectangular that comprises the DGS shape is located in the middle of the enclosing plane, surrounded by two rectangular halves placed at the borders of the X-axes.

A 6×10 mm^2 microstrip feed line powers the patch of a 41.5×26.71 mm^2 antenna. As illustrated in Fig. 1(b), the DGS structure integration modifies the input impedance and surface current distribution by introducing changes in the functional capacitance as well as inductance. Two half-rectangles on the ground plane's Y-axis borders and a rectangle in the ground plane's center make up the DGS geometry. The antenna pattern is made up of adjacent semi-circular rectangular emitting sections that form scoop shapes on the substrate's top face.



a b

Fig. 1 – The proposed DGS based antenna with dimension (a) Front view (b) Back view having dimensions: $L = 50.5$ mm, $W = 41.21$ mm, $h = 1.6$ mm, $F = 3.5$ mm, $W_{sg} = 12.25$ mm, $W_{sg2} = 6$ mm, $L_{sg} = 6$ mm

3. DESIGN METHODOLOGY

For the recommended configuration, a two-rectangular striped slot patch antenna with a rectangular slit at the top of the patch was carved, resulting in three operating frequencies: 3.3 GHz, 4.4 GHz, and 5.3 GHz. The following expression, where "h" stands for substrate thickness, "PW" for patch width, and "PL" for patch length, was used to determine the substrate layer's length and breadth:

$$L = 6h + PL \;\&\; W = 6h + PH \tag{1}$$

To determine the proportions of the patch, the equs used are

$$PW = \frac{c}{2fr\sqrt{(\varepsilon r+1)/2}} \tag{2}$$

$$PL = \frac{c}{2fr\sqrt{\varepsilon_{ff}}} - 2\Delta L \tag{3}$$

$$\varepsilon_{ff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\{1+12h/PW\}^{0.5} \tag{4}$$

$$\Delta L = 0.412\left[(\varepsilon_{ff}+0.3)\left(\frac{PW}{h}+0.264\right)\Big/(\varepsilon_{ff}-0.258)\left(\frac{PW}{h}+0.8\right)\right] \tag{5}$$

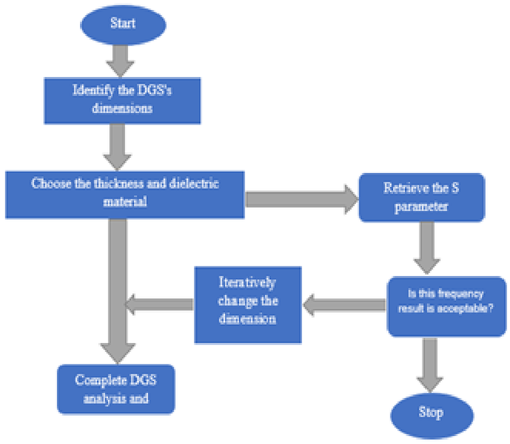
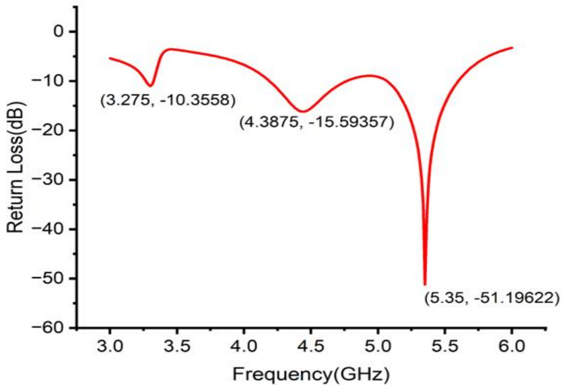


Fig. 2 – Optimization process for DGS design

"c" represents the speed of light, "ΔL" represents the extension duration, "εff" the actual dielectric constant, while "fr" the operational frequency. The procedures outlined in Fig. 2 were used to design the optimized DGS. In order to optimize the size of DGS with respect to the required frequency and lower return loss, a number of trials have been undertaken once the ideal shape has been selected with its starting dimensions. In order to achieve tri band resonance at 3.3, 4.4, and 5.3 GHz, the rectangular shape in the center, measuring 12.25×6 mm, and its half portions on either side have finally been fixed.

4. RESULTS & DISCUSSIONS

Return loss characteristics demonstrate frequency resonances at 3.3 GHz, 4.4 GHz, and 5.3 GHz.



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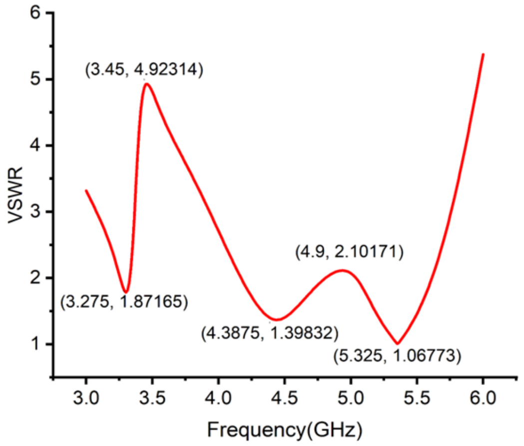

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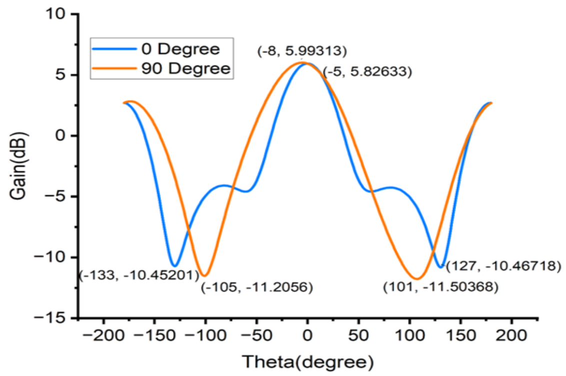
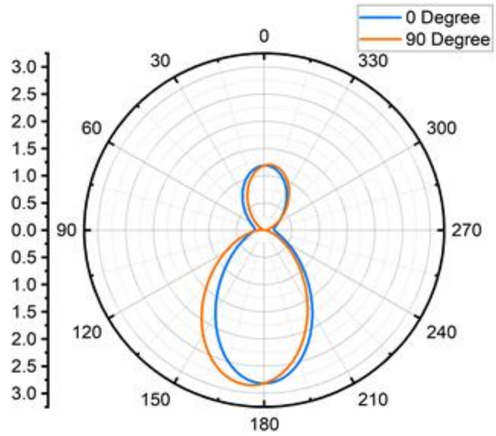


c

Fig. 3 – Simulated results of the designed antenna (a) Reflection coefficient (b) VSWR (c) Gain

Between 3.25 and 3.33 GHz (impedance bandwidth of 76 MHz or 2.3 %), 4.16 and 4.81 GHz (impedance bandwidth of 649 MHz or 14 %), and 5.03 and 5.61 GHz (10.9 %) is the range that can be used. Fig. 3(b) displays VSWR figures for the intended antenna at 3.3 GHz, 4.4 GHz, and 5.3 GHz as 1.78, 1.66, and 1.00. The gain measured at the associated frequency ranges of 3.3 GHz, 4.4 GHz, as well as 5.3 GHz is displayed in Fig. 3 (c), with values of 6.01 dBi, 4.23 dBi, and 4.57 dBi, respectively.



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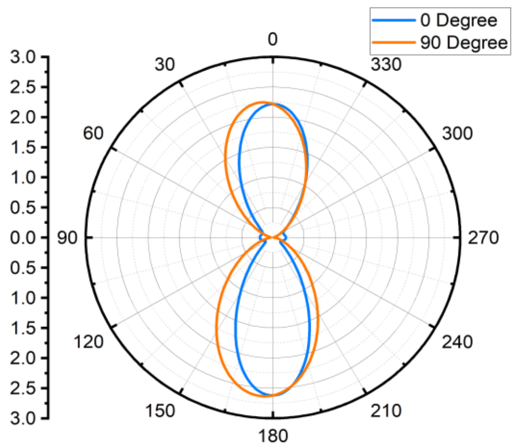

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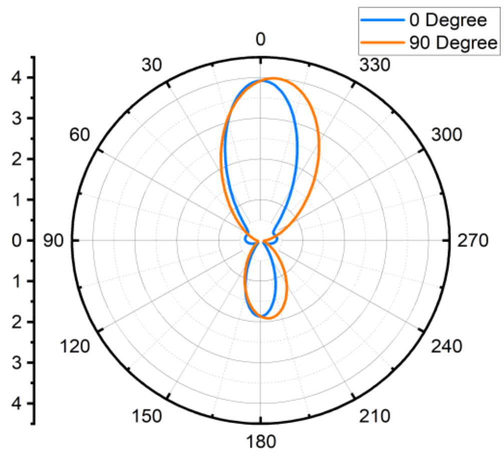

c

Fig. 4 – Radiation pattern of proposesd structure (a) 3.3 GHz (b) 4.4 GHz, and (c) 5.3 GHz

The tri-band antenna's elevation plane (*H*-field) and azimuthal plane (*E*-field) radiation patterns at frequencies of 3.3 GHz, 4.4 GHz, and 5.3 GHz are shown in Fig. 4 the antenna's almost omnidirectional radiation characteristics in the E and H fields. At 3.3 GHz, the surface current density is primarily localized at the margins of the rectangular slot, as seen in Fig. 5 (a). The current density changes at 4.4 GHz and becomes more concentrated near the borders of the Y-shaped slot and the microstrip feed-line, as shown in Fig. 5 (b). The surface current density shows additional redistribution at 5.3 GHz, as seen in Fig. 5 (c), with a significant presence of current along defective ground sections and close to the patch's center.

Table 1 – Simulated outcomes of Antenna at 3 resonant (RES)

Parameters	**RES-1**	**RES-2**	**RES-3**
Resonant Freq. (GHz)	3.3	4.4	5.3
S_{11} (dB)	– 11.03	– 16.18	– 51.19
VSWR	1.81	1.36	1.00
Gain (dB)	4.57	4.23	6.01
Directivity (dBi)	6.49	4.95	7.24
Radiation Efficiency (%)	70	85	83
Impedance BW (MHz)	7.6	6.5	5..2

Table 2 – Comparison of results of this work with related works

Ref	Op.Freq (GHz)	Imp.BW (MHz)	Gain (dB)	Rad.eff. (%)	S_{11} (dB)
[11]	3.45 & 5.9	160 & 220	3.83 & 0.537	59 & 45	– 19 & – 22
[10]	3.5,5.2 &5.8	5.68,3.72 & 6.95	2.56,2.92 & 3.9	85,86 & 87	– 21, – 18 & – 28
[17]	0.8,1.7 & 2.3	9, 29 & 34	2.2, 3.4 & 2.8	37, 42 & 38	– 19, – 20 & – 25
This work	3.3, 4.4 & 5.3	7.6, 6.5, &5.8	4.57, 4.2, & 6.01	70, 85 & 83	– 11, – 16 & – 51

The parameters obtained for our work has been consolidated in table.1 and compared with other similar works in Table 2.

5. CONCLUSION

This multiband patch antenna (MPA), which has dimensions of $50.5 \times 41.21 \times 1.6$ mm^3, is a tri-band, 3.3 GHz, 4.4 GHz, and 5.3 GHz, 5G rectangular slot stripped DGS patch antenna. It is replicated using a FR-4 substrate material. With gains of 6.01 dB, 4.23 dB, and 4.57 dB, directivity of 7.24, 4.95, and 6.49 dBi, and radiation efficiencies of 83 %, 85 %, and 70% at the corresponding frequencies, the antenna design has favorable performance characteristics. 5G and Internet of Things applications are suitable for the suggested antenna.

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Антена з дефектами заземлення у формі кулі та прямокутника для зв'язку 5G середнього діапазону нижче 6 ГГц

Suganthi Santhanam[1], Gunasekaran Thangavel[2], Balamurugan Rajangam[3], V. Diana Earshia[4], M. Ameena Banu[5], Manjunathan Alagarsamy[1]

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У роботі описано конструкцію мікросмужкової патч-антени з прямокутною дефектною структурою заземлення (DGS) для використання в мобільному зв'язку 5G. Ця конструкція використовується для роботи на частотах 3,3 ГГц, 4,4 ГГц та 5,3 ГГц, трьох різних частотних діапазонах. Антена, розміром 50,5 × 41,21 × 1,6 мм^3, розташована на підкладці FR-4. Вона працює з діапазонами імпедансу 10 %, 14 % та 2,3 %, з коефіцієнтами посилення антени 6,01 дБі, 4,23 дБі та 4,57 дБі на кожному з трьох діапазонів. Запропонована антена функціонує в діапазоні C на частотах 0,582 Гц (5,033-5,615 ГГц), 0,649 Гц (4,167-4,816 ГГц) та 0,076 Гц (3,254-3,330 ГГц) з ефективністю випромінювання 85 %, 83 % та 70 %. Результати дослідження демонструють сильну спрямованість, постійно високий коефіцієнт посилення, роботу в кількох діапазонах та вигідні спрямовані діаграми спрямованості. Всеспрямована діаграма передачі антени, значне посилення та ефективне випромінювання роблять її можливим вибором для спектру систем зв'язку 5G у низці ситуацій. Для портативних пристроїв 5G ця запропонована антена може бути корисною. Потреба в конфігураціях антен з активним формуванням променя в мобільному зв'язку 5G, особливо в діапазоні довжин хвиль нижче 6 ГГц, вимагає інтеграції нової електроніки з антенами.

Ключові слова: Дефектна наземна антена, Напівкруглі прямокутні випромінювальні елементи, Мобільні телефони, 5G тридіапазонний зв'язок, DGS, Високий коефіцієнт посилення, Висока спрямованість.