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REGULAR ARTICLE

Dual-Band Microstrip Patch Antenna with R-SRR Meta-Surface for 5G-NR Applications

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This paper presents the Dual-band microstrip patch antenna integrated with a rectangular split-ring resonator (R-SRR) metasurface is proposed for 5G-NR Applications. 5G NR applications include mmwave for the short distance line of sight communications. The short distance communications demand the compact devices including compact antennas. A metasurface loaded rectangular patch antenna is designed using an FR4-epoxy (ε_r = 4.4) substrate. In the proposed design, the R-SRR metasurface is placed 1 mm above a rectangular patch antenna to enhance performance. The modified antenna operates at two distinct frequency bands, (22.5-23.7 GHz) and (27.4-28.6 GHz). The metasurface integration in a simple rectangular patch antenna results in improved gain from 2.42 dB to 6.59 dB. Simulations are performed using ANSYS HFSS V 25.0, and key performance parameters, including return loss, radiation pattern, and gain, are analyzed. This antenna design is optimized for 5G networks, ensuring high speed and low-latency communication. As part of this work, the proposed patch antenna was fabricated on an FR4 substrate to initiate the process of experimental validation.

Keywords: Microstrip antenna, FR4-epoxy, R-SRR Metasurface, N257 band, Dual-band, High gain.

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1. INTRODUCTION

The rapid evolution of wireless communication technologies has led to the development of the fifth-generation (5G) networks, which demand high data rates, ultra-low latency, and enhanced spectral efficiency. To support these requirements, the utilization of millimeter-wave (mmWave) frequency bands (above 24 GHz) has become a key focus area in both research and industry. However, designing efficient antennas that operate in these high-frequency bands poses significant challenges due to high path losses and fabrication limitations. Microstrip patch antennas (MPAs) are widely preferred in 5G systems because of their compact size, low profile, and ease of integration with circuits [1]. Despite their advantages, traditional MPAs suffer from narrow bandwidth, limited gain, and high dielectric losses, especially in the mmWave range. These limitations reduce their effectiveness in wideband and high-frequency communication systems [2].

In the recent literature, n257 and n261 are the attractive bands for 5G applications. Many research has been published for targeting 26-29 GHz resonance for short-range communication. In [3], the substrate integrated waveguide (SIW) technique is adopted to enhance the performance. Manish Sharma [4] et al proposed the narrowband antenna for n257 and n261 bands. The antenna is designed upon the low- loss substrate, Rogers Series, for short-range communications. The design element occupies 16 × 20 × 0.8 mm^3 volume and employs circular slotted DGS for performance improvement [5]. Hexagonal-shaped cross-slotted antenna with DGS designed for 5G in [6]. Defected Ground Structures (DGS) present several limitations, including fabrication challenges and unwanted ground-plane radiation leakage. Similarly, advanced antenna technologies such as Substrate Integrated Waveguides (SIW) become increasingly difficult to fabricate at higher frequencies. Moreover, the use of low-loss substrates, although beneficial for performance, significantly increases the overall cost of the antenna. Hence, this paper proposes a simple rectangular patch antenna implemented on a standard substrate, enhanced using a proven superstrate-based improvement technique. Rectangular SRR is used as a superstrate to enhance the gain and impedance matching of a simple rectangular patch antenna in the n261 band. Recent advancements in electromagnetic materials have introduced metamaterials and metasurfaces as promising solutions to enhance antenna performance.

However, integrating metasurfaces into compact antenna design without altering the physical dimensions of the radiating patch remains an open challenge in antenna engineering.

2. ANTENNA STRUCTURE

The antenna proposed in this paper is a dual-band microstrip rectangular patch antenna designed for millimeter-wave 5G-NR applications, the design consists of three primary layers: (1) A rectangular radiating patch, (2) A ground plane, (3) A metasurface layer composed of a rectangular split-ring resonator (R-SRR) unit cell.

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2.1 Microstrip Patch Antenna

The microstrip patch antenna is constructed with FR4 epoxy substrate, which has a relative permittivity of approximately 4.4. A microstrip patch antenna designed for 5G NR application operating at 26 GHz, which covers the 26.5-29.75 GHz (n257) band, offering high gain and a wide bandwidth. Its low-profile structure with optimized impedance matching ensures efficient radiation. The patch is fed using a coaxial probe feed positioned at the optimal impedance- matching points for good performance. The physical structure of the microstrip patch antenna is shown in Fig. 1.

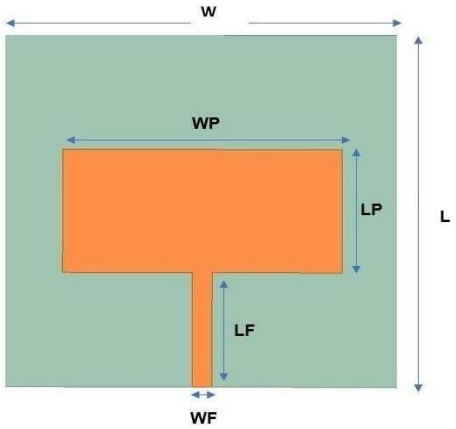


Fig. 1 – Microstrip rectangular patch antenna

Table 1 – Dimension of the microstrip patch antenna

Design Parameters	Values (in mm)
Length (*L*)	6
Width (*W*)	6
Thickness (*T*)	1.6
Patch Width (*WP*)	4.2
Patch Length (*LP*)	2.1
Feed Width (*WF*)	0.3
Feed Length (*LF*)	1.95

2.2 R-SRR Metasurface Integration

To improve the performance, an 8 × 8 array of Rectangular Split-Ring Resonator (R-SRR) unit cells is introduced above the patch. The R-SRR structures are patterned on a thin dielectric layer and placed at a fixed height above the patch. The metasurface used the same dielectric constants and thereby bandwidth and enabling dual-band operation. Each unit cell is placed with a distance that is optimized to obtain the gain. The metasurface alters the surface current distribution and resonance behavior, helping to introduce a second band and widen the response.

The gain of the microstrip patch antenna at higher frequencies improves by shortening the patch length and width compared to standard dimensions. The proposed antenna is designed using calculated parameters, as shown in Fig. 1 and summarized in Table 1. A microstrip line feed excites the antenna, and its dimensions are optimized to achieve a 50 Ω characteristic impedance. This setup ensures efficient power transfer and correct impedance matching. To boost performance even more, an 8 × 8 array of rectangular split-ring resonator (R-SRR) metasurface is placed 1 mm above the patch. The spacing of the unit cells is carefully optimized to enable dual-band operation. This design increases bandwidth, improves gain, and enhances directivity. The metasurface focuses the radiation pattern in the broadside direction. The whole antenna structure, including the metasurface, is modeled and simulated in ANSYS HFSS v25.0. Key performance metrics like S-parameters (S11), gain, bandwidth, directivity, and the stability of the radiation pattern are analyzed to confirm the improvements from integrating the metasurface.

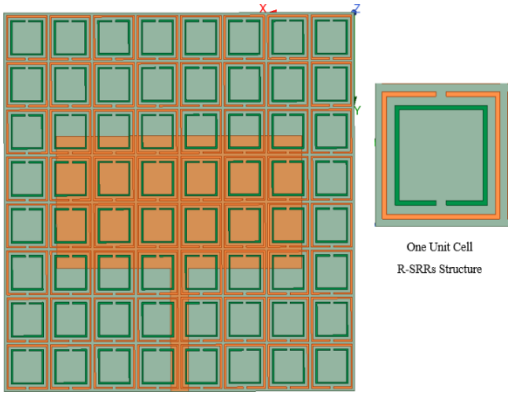


Fig. 2 – R-SRRs metasurface loaded antenna

3. RESULTS AND DISCUSSION

When integrating the Rectangular Split-Resonator (R- SRR) metasurface above the rectangular patch, a noticeable improvement in antenna performance is observed. This includes enhanced bandwidth, gain, and dual-band resonance, while maintaining the original patch size. The effect of the metasurface on the antenna's S-parameter, electric field distribution, and far-field radiation pattern is analyzed and compared in detail below.

3.1 Return Loss

(a) Rectangular Patch Antenna

The return loss of an antenna represents the amount of input energy reflected back from the antenna. It is typically derived from the antenna's reflection coefficient. When the characteristic impedance of the antenna is well matched with that of the feed line, minimal energy is reflected, resulting in a very low return loss.

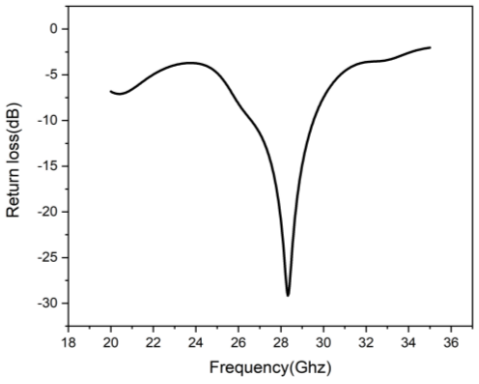


Fig. 3 – Return loss of rectangular patch antenna

The return loss of the rectangular patch antenna shown in Fig. 1. The antenna resonates at 28.4 GHz with the return loss of approximately – 30.5 dB, sufficient for covering the 5G NR n257 band.

(b) Rectangular Patch Antenna with R-SRR Metasurface

The integration of the metasurface modifies the antenna's characteristic impedance, which in turn shifts its resonant frequency, as reflected in the S_{11} response. After incorporating the R-SRR metasurface above the patch, the antenna demonstrates dual-band operation with two distinct resonances at approximately 23.1 GHz and 28 GHz. The corresponding return loss values improve to – 17.9 dB and – 15.5 dB, respectively, both of which indicate good impedance matching.

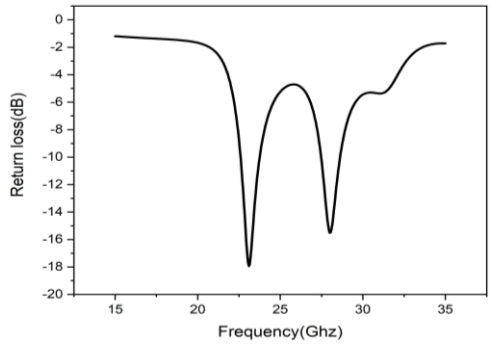


Fig. 4 – Return loss of rectangular patch antenna

3.2 Radiation Pattern

The radiation pattern illustrates the directional radiation characteristics of the antenna. From this pattern, key performance parameters such as directivity, peak gain, and beamwidth can be determined.

(a) Rectangular Patch Antenna

The conventional microstrip patch antenna shows a relatively broad bandwidth with moderate directivity. Some minor side lobes are observed, which can result in reduced efficiency in targeted communication.

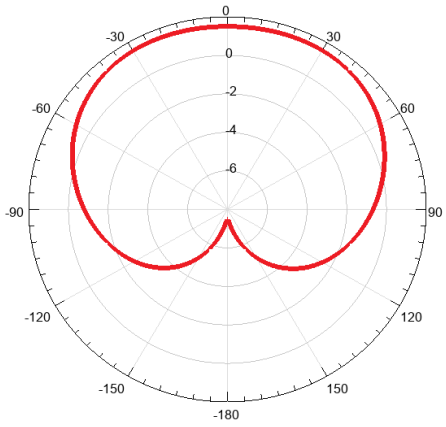


Fig. 5 – Radiation pattern for rectangular patch antenna

(b) Rectangular Patch Antenna with R-SRR Metasurface

After integrating the metasurface, the radiation pattern becomes more focused and directional. The main lobe sharpens in the broadside direction, side lobes are significantly suppressed, and cross-polarization levels are reduced. This results in improved directivity and beam stability, especially beneficial for high-frequency 5G mmWave applications.

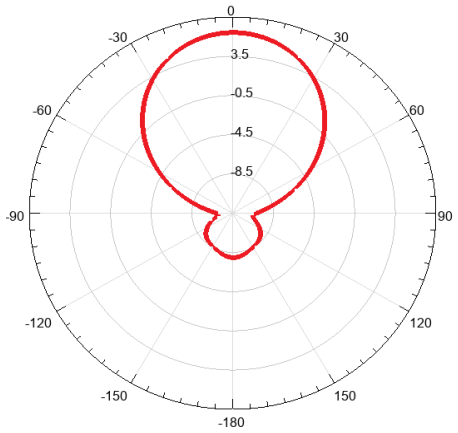


Fig. 6 – Radiation pattern for R-SRR metasurface

4. GAIN

(a) Gain of rectangular patch antenna

The gain indicates the amount of power radiated in a given direction. The Rectangular patch antenna achieves a gain of 2.42 dB at 28.4 GHz.

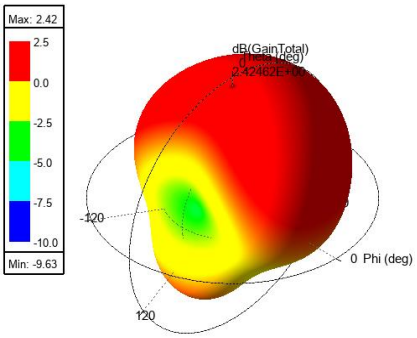


Fig. 7 – Gain of rectangular patch antenna

(b) Gain of Rectangular SRR Metasurface

The gain improves to approximately 6.59 dB, showing an increase of around 4 dB, which is crucial for mmWave 5G applications.

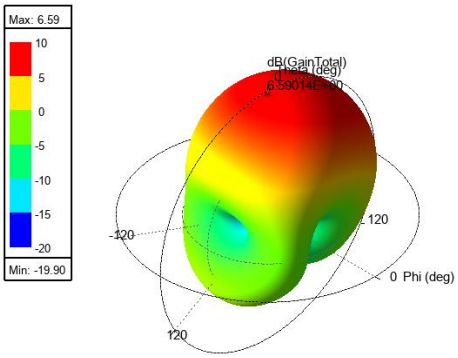


Fig. 8 – Gain of rectangular SRR metasurface

Table 2 – Performance analysis of antenna

Reference No	Resonance Frequency	Material Used	Size	Technology
[3]	n257	FR4	50 mm × 38 mm	–
[4]	n257	Rogers	16 mm × 20 mm	DGS
[5]	n257	FR4	Not mentioned	DGS
[6]	n257	FR4	48 × 36 mm^2	Slot Antenna
[7]	n257	–	Not mentioned	Metasurface supports Dielectric
[8]	n257	Rogers RT5870	60 × 25 × 0.49 mm^3	MTM array
In this work	n257	FR4	6 mm × 6 mm	MTM superstrate

5. CONCLUSION

In this work presents a compact microstrip patch antenna combined with a Rectangular Split-Ring Resonator (R-SRR) metasurface for millimeter-wave 5G-NR applications. The standalone patch antenna is designed to resonate at 28 GHz, effectively covering the n257 band (26.5-29.5 GHz) in the FR2 frequency range. After integrating the R-SRR metasurface, the antenna shows dual-band resonance around 23.1 GHz and 28 GHz. The simulated radiation pattern confirms stable broadside performance with better gain and directivity, achieving a peak gain of 6.59 dB. To prove the design's manufacturability, the patch antenna was made using standard PCB methods on an FR4 substrate. Overall, the proposed metasurface-loaded antenna shows clear benefits in terms of dual-band operation and gain improvement, making it a strong candidate for wideband millimeter-wave 5G-NR applications.

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Дводіапазонна мікросмужкова антена з метаповерхнею на основі R-SRR для застосувань у мережах 5G-NR

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У цій статті представлено двосмугову мікросмужкову антену, інтегровану з метаповерхнею на основі прямокутних розрізних кільцевих резонаторів (R-SRR), призначену для застосувань у мережах 5G-NR. Технологія 5G NR передбачає використання міліметрових хвиль для зв'язку на коротких відстанях у межах прямої видимості. Такі умови зв'язку вимагають використання компактних пристроїв, зокрема й компактних антен. Розроблена антена, що містить метаповерхню, виконана на підкладці з епоксидного склотекстоліту FR4 (діелектрична проникність $\varepsilon_r = 4{,}4$). У запропонованій конструкції метаповерхня R-SRR розміщена на відстані 1 мм над прямокутним випромінювачем для покращення робочих характеристик. Модифікована антена працює у двох окремих частотних діапазонах: 22,5-23,7 ГГц та 27,4-28,6 ГГц. Інтеграція метаповерхні в конструкцію звичайної прямокутної антени дозволила збільшити коефіцієнт підсилення з 2,42 дБ до 6,59 дБ. Моделювання проводилося в середовищі ANSYS HFSS версії 25.0; також було проаналізовано ключові робочі параметри, зокрема зворотні втрати, діаграму спрямованості та коефіцієнт підсилення. Конструкція антени оптимізована для мереж 5G, що забезпечує високу швидкість передачі даних і низьку затримку сигналу. У межах цієї роботи було виготовлено дослідний зразок запропонованої антени на підкладці FR4 для проведення експериментальної перевірки.

Ключові слова: Мікросмужкова антена, Епоксидний матеріал FR4, Метаповерхня типу R-SRR, Діапазон N257, Дводіапазонна, Високий коефіцієнт підсилення.