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**REGULAR ARTICLE**

# A FSS Loaded High Gain Semi-Circle Monopole Antenna for 5G Applications

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In this article, a semi-circle shaped planar monopole antenna is proposed for 5G applications for improved gain. The gain of the proposed antenna is increased by loading the ground plane with a proposed FSS layer. The hexagonal shaped unit cell is proposed to construct the FSS layer. This article presents the composition of architectural equations for creating the band pass hexagonal reflector employing hexagonal geometry and planar monopole radiator. The proposed antenna dimension was in compact size of 20 × 18 mm$^2$. The monopole and FSS substrates both fabricated on FR4-substrate ($\varepsilon_r$ = 4.4) with a height of 1.6 mm. The hexagonal patches are placed with the spacing of 0.6 mm and 14 mm below the main radiator The hexagonal reflector and printed monopole antenna shapes are designed for n77 and n78 NR bands. The ANSYS HFSS software is used to execute the simulations. The prototype is fabricated and the results are validated by measuring the *S* parameter, Gain and Radiation pattern. The results are validated by taking measurements in Anechoic chamber with the aid of VNA with 0.6 mm spacing between the elements. The measured/simulated fractional bandwidth of the antenna is 19.14 %, with a peak gain of 6 dBi and a maximum directivity of 6.2 dBi. The proposed hexagonal FSS structure provides better gain (nearly 6 dB improvement) and impedance matching from3.9 GHz to 5.04 GHz and well suited for 5G applications.

**Keywords:** Semicircular monopole antenna, Hexagonal frequency selective surface reflector, SRR, Wideband.

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## 1. INTRODUCTION

On its evolution over the recent decades, a huge variety of remotely controlled electronic devices, such as cell phones, tablets, and notepads, have gained popularity. The increase of more modern wireless devices, demands high gain and wideband antennas. In recent years, Microstrip Patch antennas have found more advancements [1]. The goal of the modern wireless technology is to attain remarkable data transfer rates (> 10 Gbps), low latency (< 1 ms), denser connections, and increased mobility (> 800 km/h). The introduction of 5G wireless technology [2] helped to realize the solution to some or to the greater extent. The main spectrum for 5G has been classified into three categories by the ITU: Mid-band (sub-6 GHz), high-band (millimeter wave), and low-band (up to 1 GHz) [3]. The millimetre wave band has the highest data speeds and largest capacities, whereas the lower band offers high coverage and the mid-band offers both coverage and capacity. As a result, the sub-6 GHz 50 frequency band is the best option for ready-to-use technology that can be applied right away [4-7]. Well-constructed FSS can function as a spatial filter for the plane waves, and it is applied in broadband communications, radar systems, and high-performance applications. The frequency response of the FSS is affected by the geometrical orientation of the elements, distance across elements, environmental factors and substrate characteristics [8]. FSS has been employed in a variety of applications in the past, including the high frequency spatial filters [9-10], lenses [11], radomes [12-13], reflectors and absorbers [14-17]. FSS are increasingly being employed for systemic health monitoring (SHM) due to a rise in sensor usage [18-19].

In this paper, hexagonal patches are used to construct the FSS. By the application of the FSS, improved gain and directivity are achieved. The modified semi-circle monopole antenna is used as a main radiator [20]. The placement of the patches and their orientation are the key factors to obtain the high gain and directivity.

## 2. MODIFIED SEMI-CIRCLE MOPOLE ANTENNA

The main radiator is a modified semi-circle monopole

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antenna, which resonates at 4 GHz. It includes the circle and semicircle SRR. The layout of the proposed antenna is depicted in Fig. 1. A partial ground structure and offset feed have been implemented to achieve ideal impedance matching across the wideband. The offset feed also provides an omnidirectional pattern at specific frequency points. The antenna is excited with a 50 Ω microstrip line. The monopole is fabricated on FR4-substrate ($\varepsilon_r$ = 4.4) with a height of 1.6 mm. Table 1. Shows the optimized dimensions of the modified semi-circle monopole antenna.

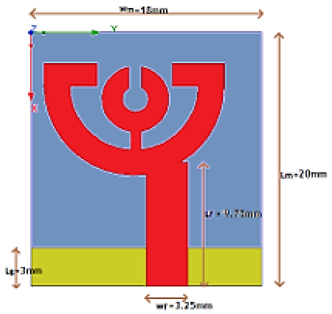


**Fig. 1** – Modified semi-circle monopole antenna

**Table 1** – Dimensions of a modified semi-circle monopole antenna

| Parameters | Dimensions(mm) |
|---|---|
| Width of the patch ($W_m$) | 18 |
| Length of the patch ($L_m$) | 20 |
| Width of the feed ($W_f$) | 3.25 |
| Length of the feed ($L_f$) | 9.75 |
| Length of the ground ($L_g$) | 3 |

The return loss of the monopole is shown in Figure 2. The return loss shows the impedance bandwidth from 3.75 GHz to 4.6 GHz.

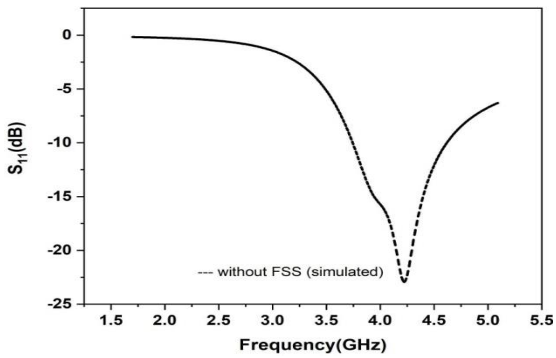



**Fig. 2** – Return loss characteristics of monopole antenna without FSS

## 3. FSS LOADED MODIFIED SEMI-CIRCLE MOPOLE ANTENNA.

FSS reflector surface is designed using the hexagonal patches. The hexagonal lattice eases out a compact arrangement of the FSS elements. Compact designs are often desirable in the antenna systems where space is limited, and a smaller form factor is crucial. Hexagons have inherent symmetry that can aid in achieving uniform directivity. Symmetrical structures are easier to analyze and design that can pave more predictable and controlled radiation patterns. The hexagonal unit cell shown in Figure 3, is designed as per the equation shown in the Equation 1, and the optimized dimensions are given in Table 2.

$$\pi a_e^2 = \frac{3\sqrt{3}}{2} S^2 \tag{1}$$

Where, $S$ – side length of the hexagonal patch, $a$ is the actual radius of the hexagonal structure.

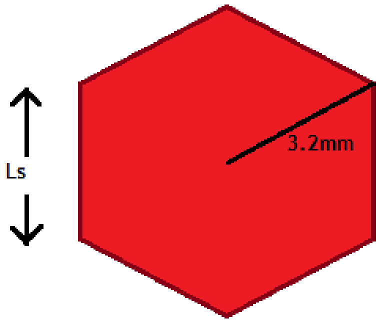



**Fig. 3** – Frequency selective surface unit cell

**Table 2** – Unit cell dimensions

| Parameters | Dimensions(mm) |
|---|---|
| Length of the hexagon ($L_s$) | 4.03 |
| Radius of the cell | 3.2 |

The hexagonal unit cells are placed in the form of an array (3 × 6) with a spacing of 0.6 mm as shown in the Figure 4a, b. The FSS is placed at the back of the radiator. The spacing between the unit cells, the distance between the radiator and FSS are the key factors which influence the radiation characteristics. The impedance matching is also affected by the above mentioned factors.

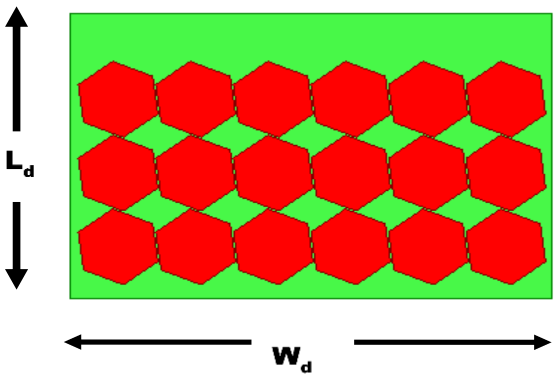



**Fig. 4a** – Frequency selective surface with hexagon array

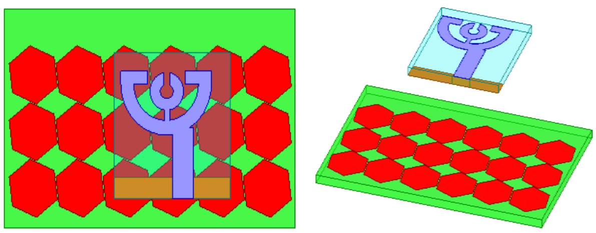


**Fig. 4b** – Modified semi-circle monopole antenna with frequency selective surface

The length and width of the FSS dielectric substrate length and width dimensions are considered as 45 × 30 mm².

### 3.1 Parametric Analysis

The parametric analysis is carried out and the results are presented in Fig 5 & 6. For better performance of directivity and the gain of the antenna optimized by following parametric analysis. The distance between the monopole antenna and the FSS structure were varied from 13 to 24 mm based on quarter wavelength. At the distance of 14 mm, the resonance frequency of the antenna is unaltered and resonates at 4.2 GHZ.

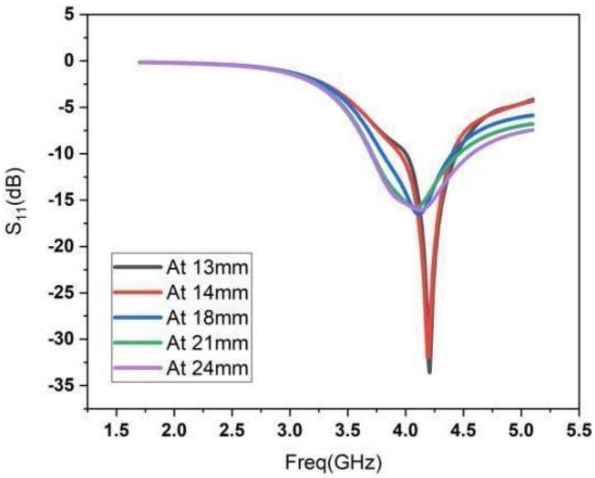



**Fig. 5** – Parametric analysis of distance between antenna to FSS structure

Parametric Analysis by varying the distance between two unit cells of the Frequency Selective Surface. Here, the distance between the two unit cells of the frequency selective surface is varied for different values. For each value of the varying distances, the return loss is measured.

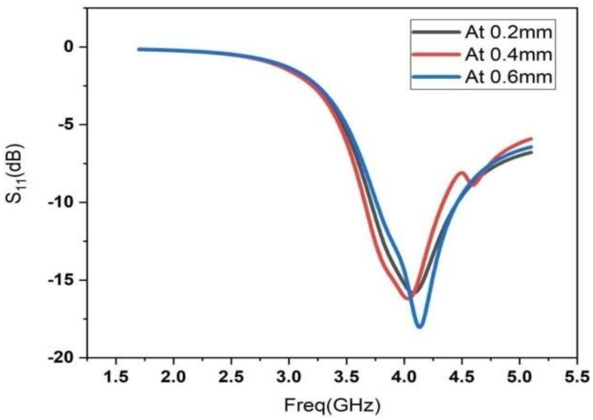
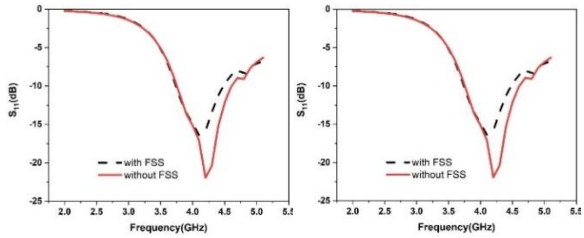



**Fig. 6** – Parametric analysis of space between unit cells of FSS structure

The performance of the FSS is compared with the monopole antenna. When the hexagonal patches are placed with the spacing of 0.6 mm and 14 mm below the main radiator, the impedance matching is good and the resonance frequency remains unaltered. The impedance bandwidth of the FSS loaded antenna is slightly reduced compared to the main radiator. Even though there are reflections at 4.5 GHz to 5 GHz in the FSS loaded monopole antenna, the gain remains positive. Hence the antenna can be used in the specified frequency range. The simulated return loss and the gain of the FSS loaded monopole and simple monopole are compared in the Figure 7a & b.




(a) (b)

**Fig. 7a, b** – $S_{11}$ parameter (return loss) and gain plot of FSS loaded monopole

## 4. RESULT AND DISCUSSION

The designed antenna and FSS structure is fabricated on the FR4 Substrate. The prototypes of both the designed antenna and the FSS structures are shown in Figure 8a. and 8b. Tin coated copper material is used as the conductor and the SMA connectors are used to connect the feedline with the source. Foam material is used to provide spacing between the FSS and main radiator.

(a) (b)

**Fig. 8a** – Front and back view of the modified semi-circle planar mono pole antenna

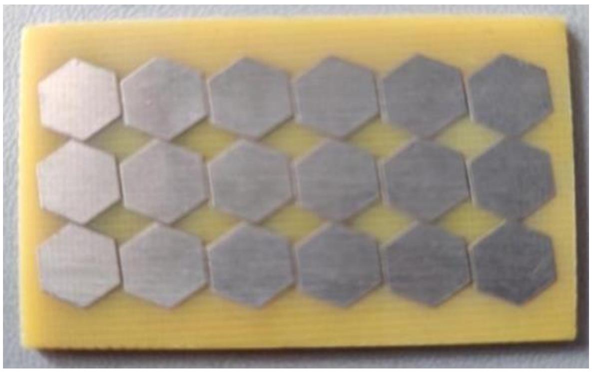


**Fig. 8b** – Frequency Selective Surface (FSS) structure

The measured and simulated results were compared and tabulated in Table 3.

**Table 3** – Comparison of simulated and the measured results

| Title | Parameter | Frequency (GHz) | dB |
|---|---|---|---|
| Measured | $s_{11}$ | 4.5 (3.9-5.04) | – 14.6 |
| Simulated | $s_{11}$ | 4.1 (3.8-4.4) | – 16.4 |

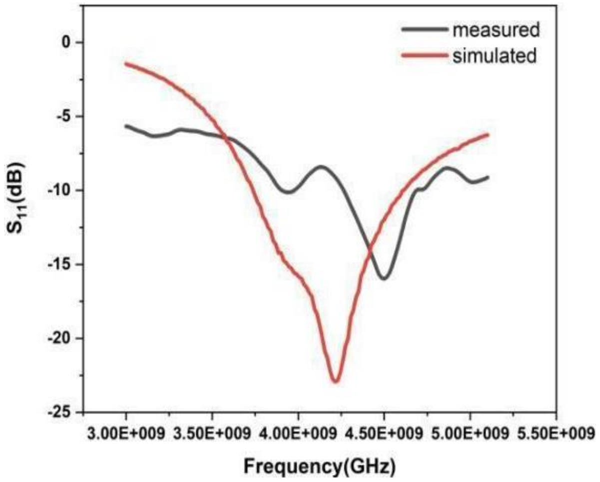



**Fig. 9** – Comparison of simulated and measured return loss

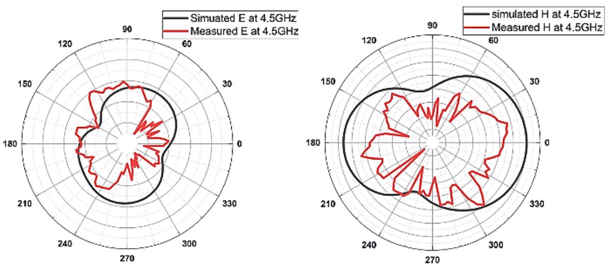



**Fig. 10** – Simulated and measured radiation pattern of *E*-plane and *H*-Plane

The return loss is measured using the Agilent VNA. The comparison of the simulated and the measured return loss is presented in the Figure 9. Due to the inductive coupling of the SMA connector, there is a slight change in the impedance bandwidth of the measured values. This can be overcome by measuring the return loss with industry standard connector. Hence the size of the antenna is comparable with the body of the SMA connector, the change is inevitable. The Figure 10 shows the comparison between the simulated and measured radiation pattern of *E* plane and *H*-Plane at 4.5 GHz, it can be deduced that there is a bidirectional pattern and Omni-directional pattern exists in the *E* and *H* plane.

## 5. CONCLUSION

A modified semi-circle mono-pole antenna is designed for the 4.5 GHZ resonance using a FR4 substrate. The peak/normalized gain of the antenna is 1.6 dB. FSS is designed to improve the performance of the designed monopole antenna. Hexagonal shape patch structures are used as a unit cell element to design the reflector surface. When the FSS is placed at 14mm behind the monopole, the gain of the antenna is improved to 6dB. The results are validated by taking measurements in Anechoic chamber with the aid of VNA with 0.6mm spacing between the elements, the FSS provides better gain and impedance matching from3.9 GHz to 5.04 GHz.

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**Напівкругла монопольна антена з високим коефіцієнтом посилення FSS для додатків 5G**

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У статті пропонується плоска монопольна антена у формі півкола для програм 5G з метою покращеного підсилення. Коефіцієнт підсилення запропонованої антени збільшується шляхом навантаження на площину заземлення шаром FSS. Для побудови шару FSS пропонується елементарна комірка шестикутної форми. У роботі також представлено склад архітектурних рівнянь для створення смугового гексагонального відбивача з використанням гексагональної геометрії та планарного монопольного випромінювача. Розмір запропонованої антени компактний 20 × 18 мм². Підкладки монополя та FSS виготовлені на підкладці FR4 ($\varepsilon_r$ = 4,4) висотою 1,6 мм. Шестикутні накладки розміщені з відстанню 0,6 мм і 14 мм нижче головного випромінювача. Шестикутний рефлектор і друкована форма монопольної антени розроблені для діапазонів n77 і n78 NR. Для виконання моделювання використовується програмне забезпечення ANSYS HFSS. Прототип виготовляється, а результати перевіряються шляхом вимірювання S-параметра, посилення та діаграми спрямованості. Результати перевіряються шляхом проведення вимірювань у безеховій камері за допомогою VNA з відстанню між елементами 0,6 мм. Виміряна/змодельована фракційна смуга пропускання антени становить 19,14 %, з піковим посиленням 6 дБ та максимальною спрямованістю 6,2 дБ. Запропонована гексагональна структура FSS забезпечує краще підсилення (покращення майже на 6 дБ) і узгодження імпедансу від 3,9 до 5,04 ГГц, що ефективно може використовуватись для програм 5G.

**Ключові слова:** Напівкругла монопольна антена, Гексагональний частотно-селективний поверхневий відбивач, SRR, Широкосмуговий.