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# DESIGN AND SIMULATION OF THE RADAR CROSS-SECTION REDUCTION ANTENNA OPERATING IN THE 28 GHZ-BAND OF 5G

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## ABSTRACT

The main idea of this work is to design and simulate a microstrip antenna with reducing Radar Cross-Section (RCS) accomplished in 28 GHz-band for 5G. The design is based on a combination of Frequency Selective Surfaces (FSSs) and a microstrip antenna. In particular, the RCS reduction can be realized by using the FSS in the place of the metal ground. The resonant frequency can be at the 28 GHz band. The reflection coefficient of the proposed structure is better (about 31 dB) than nearly 21 dB for the reference antenna. The RCS value decreases significantly in the frequency ranges of 24-32 GHz. Additionally, the radiation performances are mostly maintained. In the paper, the simulation results are performed using the software program CST Microwave Studio.

*Keywords:* Microstrip antenna, Frequency Selective Surfaces (FSSs), Radar Cross Section (RCS), 5G wireless applications, 28 GHz, reflection coefficient.

## 1. INTRODUCTION

Antennas play an important role in telecommunications equipment. They are used in modern wireless communication [1], radar [2], and satellite communication [3]. In recent years, antennas have also been used in modern stealth technology for military applications. To improve modern stealth technology, reducing Radar Cross Section (RCS) has been researched especially in the military. The radar cross section, being a far-field parameter, is used to characterize the scattering properties of a radar target [1]. In designing low-observable or stealth platforms, the RCS needs to be minimized. In general, the RCS of a target is a function of the polarization of the angle of incidence, the incident wave, the angle of observation, the electrical properties of the target, the frequency of operation, and the geometry of the target [1]. The RCS value of conventional antennas is very large, so the signals from such antennas are easily detected by conventional radar systems. Thus, the research on RCS reduction for antennas is meaningful. To achieve the stealth effect, the materials are often coated on the surfaces of aircraft, reducing their RCS. In other words, RCS is a parameter measuring object detectability. The lower the RCS, the harder it is for radar systems to detect an object. There are many proposed technical solutions to reduce the RCS, such as Radar Absorber Material (RAM) [4], Artificial Magnetic Conductor (AMC) [5], and Electromagnetic Band Gap (EBG) structure [6].

In addition, another technique that is also applied to RCS reduction is the use of Frequency Selective Surface (FSS) [7-9]. The detectability can be reduced using state-of-the-art metamaterials and modern plasma technology. FSS can be embedded in the aircraft structure to create a design with low RCS. The FSS is a periodical structure. In this case, the

FSS is semitransparent to electromagnetic waves in the operating frequency range, whereas the signals outside that frequency range are reflected. The FSS structures resonate at a designed frequency and attain spectral selectivity [10]. The FSS technology has been widely used to design high-performance radomes, antennas, radar-absorbing structures, reflectors, and so on. FSSs with various geometries have been applied in different practical applications due to their filtering properties.

The microstrip antenna is a kind of traditional antenna, which is used in many fields such as communication systems [11], medical applications [12], mobile services [13,14], and radar systems in missiles [15,16]. The microstrip antenna needs a ground plane, acting as a reflector to enhance the radiation gain. The metal ground plate plays an important role of the scattering of an antenna, as it reflects mostly the incident wave's energy. To reduce the scattering component outside the operating bandwidth, the conventional background plane can be replaced by an FSS [10] since it acts as a perfect reflector in the band and passes completely the signal outside the band. However, microstrip antennas have some disadvantages such as low gain, and narrow bandwidth [1]. Therefore, these types of antennas are often used in microwave applications or RCS reduction applications. The antenna design as a method of reducing RCS based on requirements for defense applications is a separate research direction for researchers. Antennas with little or no visibility to the radar system are a necessary feature in the background of stealth technology, airborne vehicles, and military applications.

Meanwhile, to reduce RCS, the antenna is designed by combining FSS and a microstrip resonator in [9]. This antenna worked in the frequency range from 3 to 10 GHz. As result, the RCS values declined significantly. But the disadvantage of this design was the radiation characteristics of the antenna have slightly been affected and the small change of the resonant frequency. To overcome this problem, the FSS is designed by using a genetic algorithm (GA) applied in reducing the RCS of the microstrip antenna [7]. In this paper, the RCS of the antenna working in the X band is simulated and measured. The maximum RCS reduction value peaked at 24 dB at 8.8 GHz frequency.

In another study, a patch antenna combined with miniaturized FSS cells was presented [17]. The results showed that this antenna had reduced RCS by 3 dB almost over the whole band of 1-20 GHz. When compared with a reference, for wide incident angles the radiation characteristics were maintained. This proposed approach did not change the original structure of the antenna. Following the same approach, an RCS antenna was designed to operate in the C-band [18]. The RCS study was performed with multiple co-polarization angles and cross-polarization ratios. The obtained results showed that the RCS was reduced in advance and the radiation pattern was maintained compared to the original antenna.

In this work, in the same way of the above studies, an antenna with RCS reduction is implemented. Not only a significant RCS reduction is realized, but the radiation characteristics are better than the original antenna. In this study, an RCS reduction scheme is proposed to reduce the scattered signal from an object using microstrip antennas. This approach used the replacement of the metal ground layer with the layer formed by the FSS cells and the metal plane. Compared with the original antenna, the proposed antenna has almost no undisturbed radiation efficiency and good RCS reduction ability in the frequency range of 24-32 GHz with incident angles. These results show the effectiveness of the proposal.

The rest of the paper is structured as follows. Section 2 describes the design of the antenna in detail. The simulation results and discussions are presented in Section 3. Finally, some conclusions of the paper are listed in section 4.

## 2. ANTENNA DESIGN

In this work, a microstrip antenna working in the 28 GHz-band of 5G is studied. The geometry of microstrip antennas consists of a metal patch placed on a ground plane, with a thin dielectric substrate in-between. The patch has various configurations such as square, rectangular, thin strip, circular, elliptical, triangular, etc. In this work, the rectangular patch is used. In general, the dimensions of the microstrip antenna are calculated by using the microstrip antenna's equations as given in [1]. As mentioned above, this paper studies a microstrip antenna with a resonant frequency of 28.3 GHz. The schematic top view and side view of this antenna are illustrated in Fig. 1.

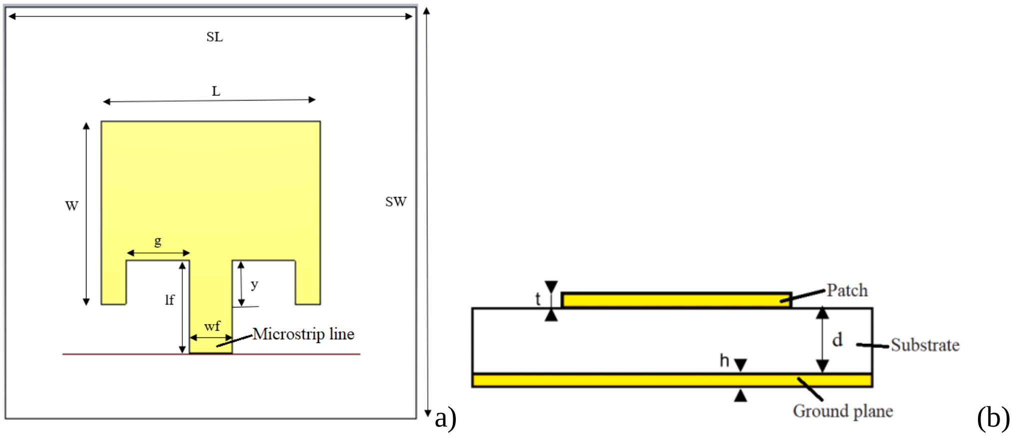


*Figure 1*. The microstrip antenna: (a) Frontview, (b) Side view.

In this work, the optimization of these dimensions is essential to achieve certain goals. Here, we use the optimization tool in the software program MATLAB. The total size of this antenna is about $19.85 \times 19.85\ mm^2$. It was placed on FR4 with a thickness of $t = 0{,}035\ mm$ and loss tangent of 0.0009. The size values of the reference antenna are specifically listed in Table 1. The microstrip antenna is produced with the microstrip feed line. The input impedance of the feed line is 50 Ohms.

*Table 1*. Parameters of the reference antenna

| Parameter | L | W | SL | SW | y | lf | wf | g | t | d |
|---|---|---|---|---|---|---|---|---|---|---|
| Value (mm) | 3.6 | 4.2 | 19.85 | 19.85 | 0.9 | 1.6 | 0.8 | 1.2 | 0.035 | 0.3 |

Figure 2a illustrates the design of a single FSS unit. This single cell was in the shape of intersecting stripes. The geometric dimensions of this single cell are d1 = 6.3 *mm*, d2 =1.3 *mm*, d3 = 1.2 *mm*, d4 = 6.8 *mm*.

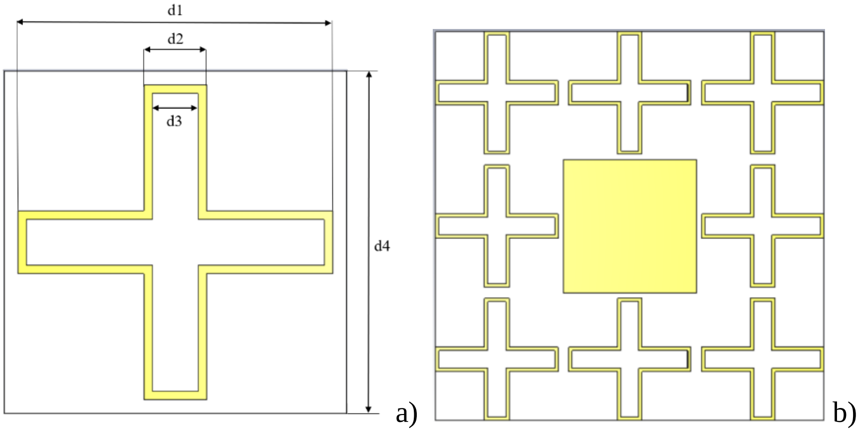


*Figure 2.* (a) Cell FSS and (b) FSS array

In this work, using the rectangular microstrip patch antenna over FSS-based design in [10], the geometry of the FSS is illustrated in Fig. 2b. The FSS is placed on a substrate named Rogers RT5880 with a relative dielectric constant of $\epsilon_r$=2.2 and loss tangent of $\delta$ = 0.0009. The thickness of the FSS is $h$ = *0.035 mm*. The FSS, depicted in Fig. 2b, consisted of 8 FSS unit cells and a square with the edges of 6.25 *mm*. For reducing the RCS of the microstrip antenna (named the reference or original antenna), its solid metal ground plane is replaced by a ground plane made up of the proposed FSS cells. This method has the advantage that it does not change the shape of the original antenna but a design with a significantly lower RCS.

RCS is a parameter that measures the ability of a radar signal to reflect toward a radar receiver. There are two types of the RCS: a monostatic RCS and a bistatic RCS. The monostatic RCS is where the transmitting and receiving antennas are in the same location, while the other is where the receiving and receiving antennas are separated and placed in two different locations. In design goals for low observable or low-profile (stealth) targets, the RCS parameter should be minimized as much as possible. The units of the RCS of three-dimensional targets are meters squared ($m^2$) or for normalized values decibels per squared meter (dBsm) or RCS per squared wavelength in decibels ($RCS/\lambda^2$ in dB) [1].

Using the radar equation [1] the relation between the RCS and the observation distance from the target can be written as [19]:

$$R_{max} = \left[\frac{P_t G^2 \sigma \lambda^2}{(4\pi)^3 P_{min}}\right]^{1/4} \tag{1}$$

where:

$P_{min}$ – minimum detectable received power, *W*

$\lambda$ – wavelength, *m*

$P_t$ – transmitted power of the radar, *W*

$G$ – antenna gain,

$R_{max}$ – maximal detection distance of the target, *m*

$\sigma$ – radar cross section, *m*

As can be seen in Eq. (1), the maximal detection distance can be reduced to 1/2 then the RCS parameter can be reduced by 16 times of the original value.

## 3. RESULTS AND DISCUSSIONS

In this paper, the microstrip antenna with a low RCS value is designed in the frequency range from 24 to 32 GHz applied for 5G. The antennas are designed and simulated using the software program CST Studio Suite 2019. The reflection coefficients (the S11 and S21) of the FSS layer have been simulated and the results are shown in Fig. 3. From the figure, it can be seen that the designed FSS has a resonant frequency of 28.3 GHz. The value of this resonance frequency was approximately 33 GHz.

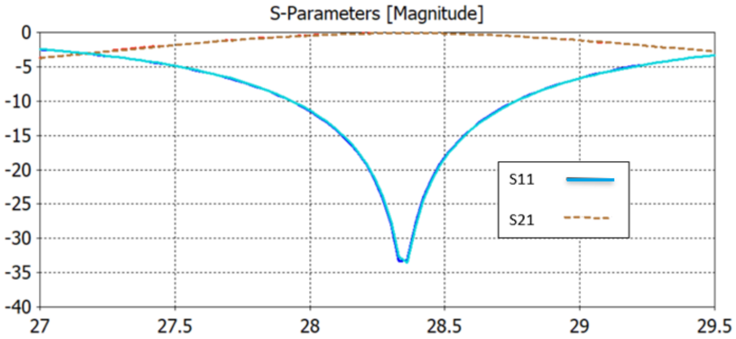


*Figure 3.* Reflection coefficients S11, S21 of array FSS.

Figure 4 illustrates the simulation results of reflection coefficient S11 for both the original antenna and the proposed antenna in the 24-32 GHz frequency range.

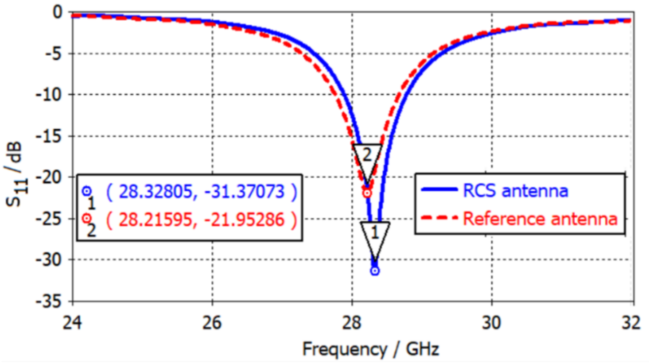


*Figure 4.* Reflection coefficients S11 of the reference (red line) and proposed antennas (blue line)

In theory [1] when the return loss is less than 10 dB, it means that 30% of the signal will be reflected into the transceiver, and the antenna efficiency is 70%. Thus, the goal to be achieved is the return loss value as lower than 10 dB as possible. As shown in Fig. 4, the reflection coefficient values of both antennas are less than -10 dB covering from 27.9 GHz to about 28.8 GHz. However, the reflection coefficient of the original antenna has the lowest value of -22 dB while the proposed antenna has better impedance matching and a reflection coefficient of approximately -31dB at a resonant frequency of about 28.3 GHz. The received bandwidth is about 1GHz.

To better understand the properties of these antennas, the surface current distributions on both antennas at 28.3 GHz are shown in Fig. 5.

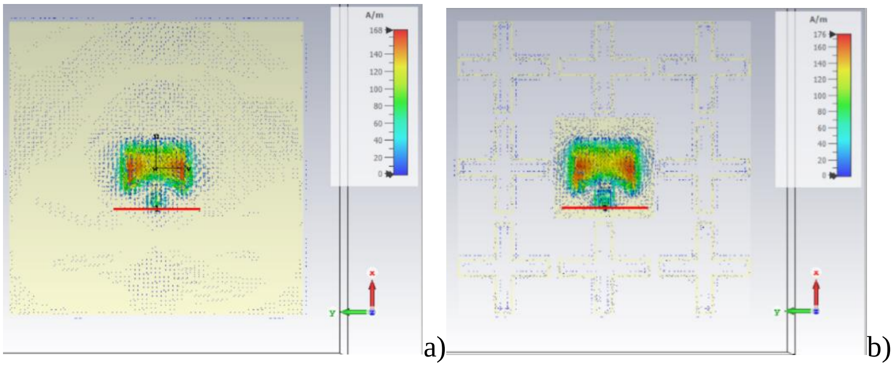


*Figure 5.* Surface current distributions above two antennas at 28.3 GHz (a) the reference antenna and (b) the proposed antenna.

Theoretically, the radiated efficiency of the antenna mainly depends on the surface current distribution [1]. Fig. 5 shows that the maximum surface current of the original antenna (about 168 A/m) is smaller than that of the proposed antenna (about 176 A/m). As a result, the proposed antenna shows a significantly reduced RCS value without affecting the radiation efficiency compared to the original antenna.

Radiation patterns of the two antennas at about 28.3 GHz are illustrated in Fig. 6 and Fig. 7. Figure 6 shows the 3D radiation pattern of two antennas, whereas the 2D radiation patterns - in Fig. 7.

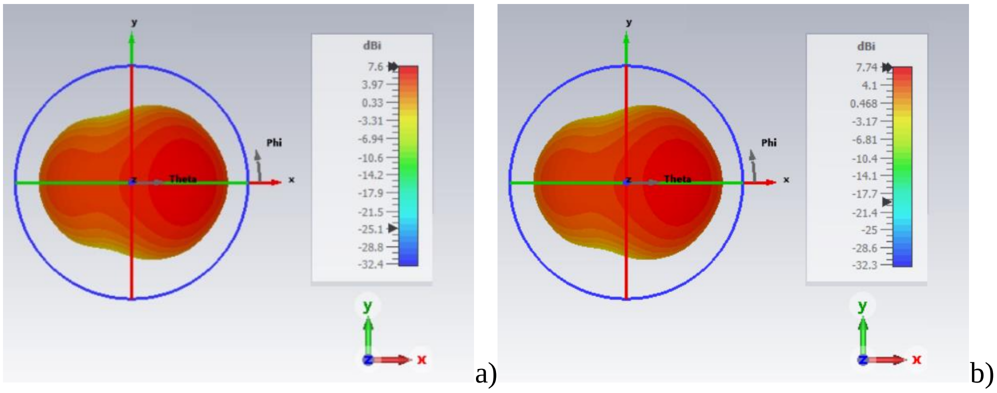


*Figure 6.* 3D radiation pattern of the reference antenna (a) and the RCS antenna (b)

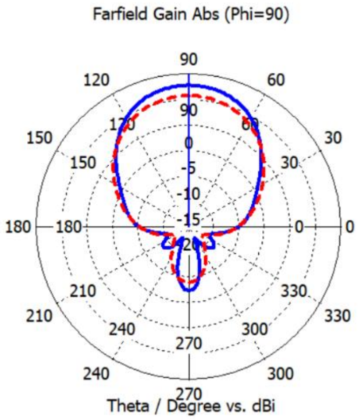
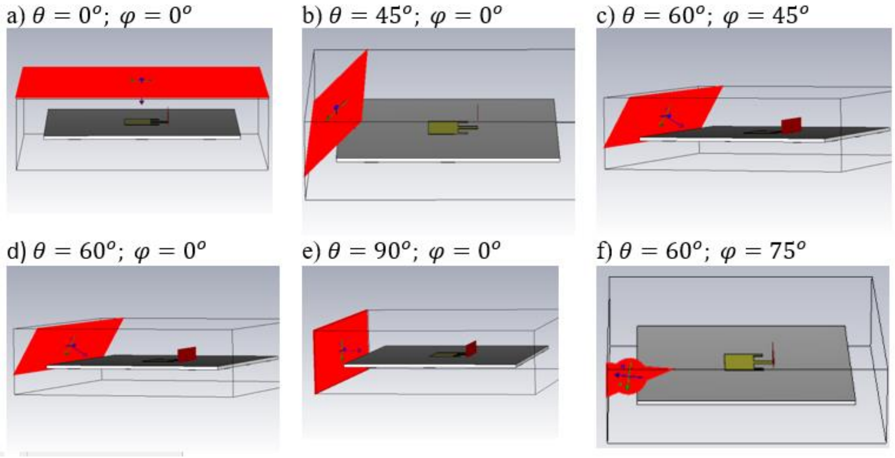


*Figure 7.* 2D radiation pattern of both antennas
(the blue-the RCS antenna; the red - the reference antenna)

The gain of the original antenna and the RCS reduction antenna at 28.3 GHz were 7.6 and 7.74 dBi, respectively. The gain of the proposed antenna is increased by 0.14 dB compared to the reference antenna. Thus, it can be confirmed that the proposed antenna's radiation pattern retained good results despite changing the ground layer.

The target position angles are varied. The monostatic radar cross-section of the target was simulated at 28.3GHz with incident angles from 0-180 degrees as shown in Fig. 8.



a) $\theta = 0^o;\ \varphi = 0^o$ b) $\theta = 45^o;\ \varphi = 0^o$ c) $\theta = 60^o;\ \varphi = 45^o$

d) $\theta = 60^o;\ \varphi = 0^o$ e) $\theta = 90^o;\ \varphi = 0^o$ f) $\theta = 60^o;\ \varphi = 75^o$

*Figure 8*. The target position angles

The RCS values are measured in various cases of different radar signal directions toward the antenna surface are depicted in Fig. 9. The backscattered electromagnetic energy from the antenna surface indicated the backscatter measurements.

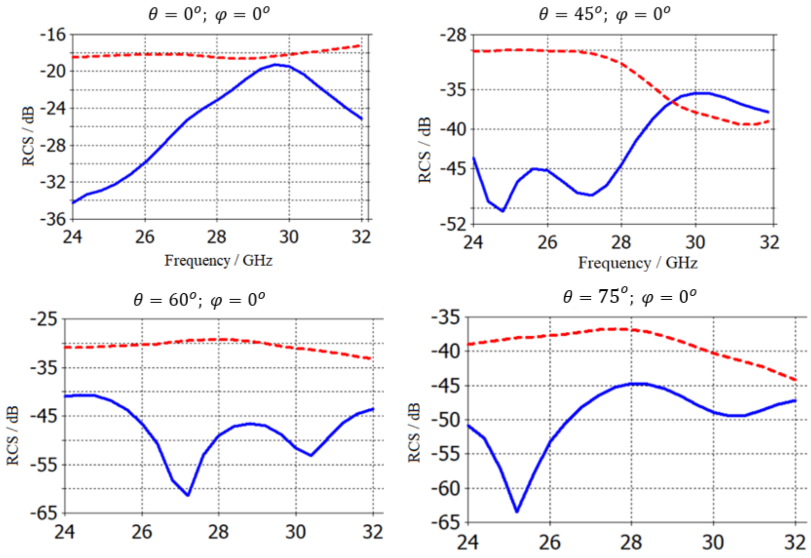


Figure 9. Monostatic RCS of the reference antenna (red line) and RCS antenna (blue line)

As illustrated in Fig. 9, the original antenna has an RCS maximum of about 40 dB while it peaks at 64 dB for the proposed antenna. In general, varying the incident angle to the antenna surface affects the reduction of RCS. For example, in direction with angles (θ = 45° φ = 0°), the maximum RCS of the original antenna is about 40 dB and the proposed antenna is nearly 50 dB. When the angle changes (θ = 75° φ = 0°), the values are approximately 45 dB and 65 dB, respectively.

*Table 2*. RCS with the various target positions

| θ/φ | $0^o$ | $30^o$ | $45^o$ | $60^o$ | $90^o$ |
|---|---|---|---|---|---|
| $0^o$ | -34.28 | -33.5 | -32.93 | -32.2 | -31.85 |
| $15^o$ | -38.81 | -36.65 | -37.6 | -37.73 | -43.52 |
| $30^o$ | -34.37 | -39.1 | -42.97 | -45.68 | -40.38 |
| $45^o$ | -50.4 | -43.46 | -44.82 | -43.15 | -42.83 |
| $60^o$ | -61.4 | -52 | -53.17 | -51.27 | -60.5 |
| $75^o$ | -63.48 | -58.24 | -58.36 | -54.58 | -63.65 |
| $90^o$ | -56.59 | -58.19 | -62.82 | -61.39 | -71.75 |
| $120^o$ | -64 | -53.7 | -54.62 | -55.48 | -56.77 |
| $140^o$ | -48.43 | -41.98 | -43.62 | -41.56 | -45.61 |
| $160^o$ | -34.03 | -38.97 | -46.91 | -38.51 | -33.88 |
| $180^o$ | -32.73 | -32.62 | -32.41 | -32.33 | -32.17 |

From Table 2 it can be seen that when the angles were ($\theta = 90^o$ $\varphi = 90^o$), the maximum RCS value was 71.75 dB.

The results of comparing the characteristics of the proposed antenna with those previously performed in the literature are represented in Table 3. All antenna designs were performed with FSSs.

*Table 3*. Comparison of the proposed antenna and the others from the previous studies

| Microstrip antenna | Dimensions (mm) | Thickness (mm) | Maximum RCS reduction | S11 | Resonant frequency | Frequency range |
|---|---|---|---|---|---|---|
| [7] | 60*60 | 1.52 | -33 | -31 | 4.5 GHz | 6.25–12 GHz |
| [9] | 50*50 | 2.5 | -37 | -25 | 5 GHz | 3–10 GHz |
| [17] | 60*60 | 1 | -37 | -30 | 5.6 GHz | 2–18 GHz. |
| [18] | 64.62*64.62 | 1.57 | -64 | -23 | 6 GHz | 3–13 GHz |
| This work | 19.85*19.85 | 0.35 | -71 | -31 | 28.3 GHz | 24–32 GHz |

The dimension of the antenna in this work decreased obviously. The proposed antenna dimensions are smaller than the other by about 60% [9] or 70% [18]. The result shows that the S11-value of the proposed and the design in [7] are the same, which is better than others. In addition, the RCS of the proposed is significantly improved at the resonant frequency.

## 4. CONCLUSION

In this work, a microstrip antenna with reduced RCS is proposed for application to 5G communication systems. The FSS cells are replaced with the metallic ground, obvious RCS reduction is performed for multiple angles. Excellent RCS reduction in frequency ranges from 24 – 32 GHz is simulated. The antenna resonates at 28.3 GHz with a reflection coefficient of -31 dB and narrow bandwidth of about 1 GHz. The achieved gain of the proposed antenna is

7.74 dB. The RCS antenna has a low-profile structure with dimensions 19.85×19.85mm$^2$. Therefore, it can be easily integrated into devices where space is limited. The radiation pattern of the proposed antenna is almost unchanged compared to the original microstrip antenna. With these superior features, the proposed antenna can be used in applications requiring low RCS platforms.

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## TÓM TẮT

## THIẾT KẾ VÀ MÔ PHỎNG ANTEN VỚI VIỆC GIẢM TIẾT DIỆN RA-ĐA THẤP LÀM VIỆC TRONG DẢI TẦN SỐ 28 GHz CỦA 5G

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Bài báo đã thiết kế và mô phỏng anten vi dải phẳng với đặc tính tiết diện ra-đa (RCS) thấp làm việc trong dải tần số 28 GHz của 5G. Cấu trúc này là sự kết hợp giữa các bề mặt tần số chọn lọc và anten vi dải. Bề mặt tiết diện ra-đa đơn tĩnh thấp nhờ sử dụng các bề mặt tần số chọn lọc thay thế bề mặt kim loại đặc. Tần số cộng hưởng ở dải tần 28 GHz. Hệ số phản xạ của thiết kế đề xuất có giá trị lớn hơn (khoảng 31 dB) so với giá trị của anten vi dải ban đầu trước khi thay đổi (21 dB). Giá trị RCS đạt giá trị thấp ở dải tần từ 24-32 GHz. Ngoài ra, dạng đồ thị bức xạ hầu như không thay đổi. Thiết kế và mô phỏng các anten bằng cách sử dụng phần mềm CST Microwave Studio 2019.

*Từ khóa:* Anten vi dải, bề mặt tần số chọn lọc, tiết diện ra-đa đơn tĩnh (RCS), ứng dụng mạng không dây 5G, 28 GHz, hệ số phản xạ.