High Gain Radial Line Slot Array Antenna (RLSA) Integrated with Frequency Selective Surface (FSS) for mm-wave 5G Applications

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Abstract. The proposed RLSA antenna incorporates a new metamaterial designed at 26 GHz resonance frequency, utilizing a Rogers 5880 substrate layer that has a 1.575 mm thickness. The diameter of the RLSA antenna in Free-space wavelength is $17.34\lambda_0$. This RLSA antenna, equipped with a frequency selective substrate (FSS) metamaterial reflector, operates within the frequency range of 22.5 to 30.5 GHz, obtaining a 24.58 dBi realized gain. This development is capable of enhancing the gain and reducing the side lobe level, making it compatible with 5G millimeter-wave applications.

Keywords RLSA antenna, FSS, millimeter wave (mm-wave) applications; 5G

1. Introduction

With the growth of the world's population and the increasing number of users adopting generation (4G) wireless technology network congestion has become a notable issue. As a result, there is a push towards advancing generation (5G) technology. 5G provides connectivity, minimal delays, high data transfer rates, and reliable communication channels [1]. Generation (5G) wireless communication systems require antennas that can operate across a frequency range deliver high efficiency maintain a compact design and offer strong directivity [2]. Creating an antenna involves making trade-offs, between factors like signal strength, cost, size, and effectiveness. It's important to strike a balance among these elements to improve the antenna's performance and suitability for wireless communication usage [3]. Although reflector dishes are commonly used for high gain antennas in microwave communications and modern wireless technologies their large size poses challenges, for fitting into today's 5G systems [4]. Conventional methods of planar array antenna designs have a disadvantage associated with limited gain [5]. In contrast, researchers are passionate in the technique antenna design of radial line slot array (RLSA) because of their significant efficiency, low profile, and superior directivity[6]. Following this, many studies have attempted to improve the RLSA antenna by arranging slots to achieve various polarizations, such as circular [3], linear [7], and dual linear [8]. Furthermore, investigations have concentrated on modifying the RLSA antenna radiation pattern, resulting in patterns such as isoflux[9], conical [10], and squinting beam [11]. In the conventional linear polarization RLSA design, the slots are placed in a ringed pattern separating equivalent to 1/2 of the guided wavelength [12]. A variety of interesting solutions exist to alleviate the limits of RLSA antennas in terms of gain, reflection coefficient, efficiency, and reduction of side lobe levels [13]. The basic constraint of RLSA antennas is their narrow radiation bandwidth [14]. Moreover, when the number of slots is reduced to attain a compact RLSA antenna, the side lobe levels are increased [15]. In addition, as the gain is enhanced, the directivity bandwidth drops, limiting their utility in applications requiring both high gain and a large propagation bandwidth [16]. In this work, a low-cost RLSA antenna with linear polarization merged with metamaterial frequency selective surface (FSS) is proposed. The FSS acts as a reflector and it reduces the side lobe levels due to its ability to act as a band stop filter as it suppress surface waves that propagate along the RLSA antenna structure. Hence, surface waves can contribute to side lobes, so reducing their propagation helps in lowering side lobe levels .

2. Configuration of Antenna Design

The combination of the frequency selective surface (FSS) metamaterial with the RLSA antenna allows the FSS to conduct a stop-band filter without degradation the performance of the RLSA antenna where it maintain a broad bandwidth, enhance the gain, and reduce the side lobe level. The simulated results for both RLAS and FSS designs were utalized by Computer Simulation Technology (CST) 2023. The presented results shown in this proposal are reflection coefficient (S11), radiation pattern, and gain.

2.1. Design of RLSA Antenna

By utalizing a substrate layer of Rogers RT/Duroid 5880 which has a thickness of h=1.575 mm, a tangent loss of tanδ =0.0009, and a a permittivity of εr=2.2 RLSA antenna is designed as shown in Figure 1. A 50Ω SSMA connector is used to feed the RLSA antenna. The diemnsions of antenna parameters are described in Table 1, following the technique reported in [2].

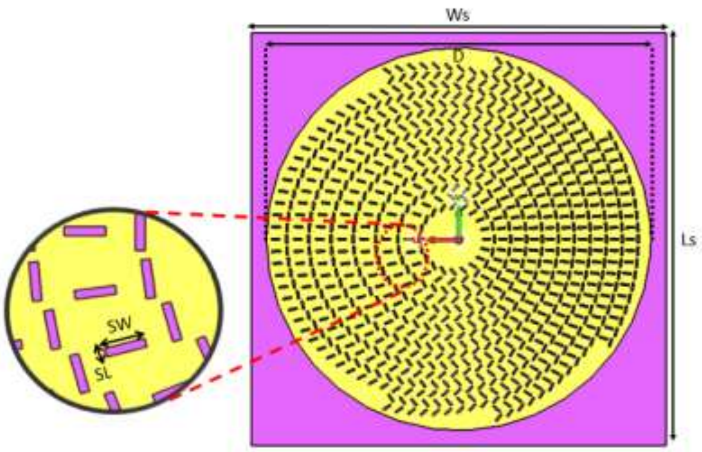

Figure 1. RLSA antenna design configuration

Table 1. Initial parameters of the RLSA antenna.

Symbol	Parameter	Value (mm)
(Ls) and (Ws)	Substrate length and width	220
D	Disk diameter	200
SW	Slot width	1
SL	Slot length	4.5

2.2. *Frequency Selective Surface (FSS) Design Configuration*

The outermost layer consists of frequency selective surfaces (FSS) as shown in Figure 2. with an array of conducting unit cells. The FSS is composed of metallic square ring resonator which is resonating at a particular frequency band while remaining not visible to others [17], essentially acting as a band stop filter and creating a reflective surface. This FSS design functions as a reflector for the antenna, increasing gain across the target frequency range at resonance frequency of 27 GHz. The unit cells array of the FSS are placed on the edge of the substrate to reduce the sidelobe level. The FSS can suppress surface waves that propagate along the RLSA antenna structure. Surface waves can contribute to side lobes, so reducing their propagation helps in lowering side lobe levels. The design parameters for the square unit cell of the FSS are outlined in Table 2. Additionally, the FSS unit cell is derived from [18] and it is written as:

$$Z_{FSS} = \frac{\left[\omega^2 C_1 - \left(1-\omega^2 C_1 L_1\right)\left(1-\omega^2 C_2\right) - \left(1-\omega^2 C_2 L_1\right)\left(1-\omega^2 C_3\right)\right]}{j\omega C_1\left(1-\omega^2 C_2\right)\left(1-\omega^2 C_3\right)} \quad (1)$$

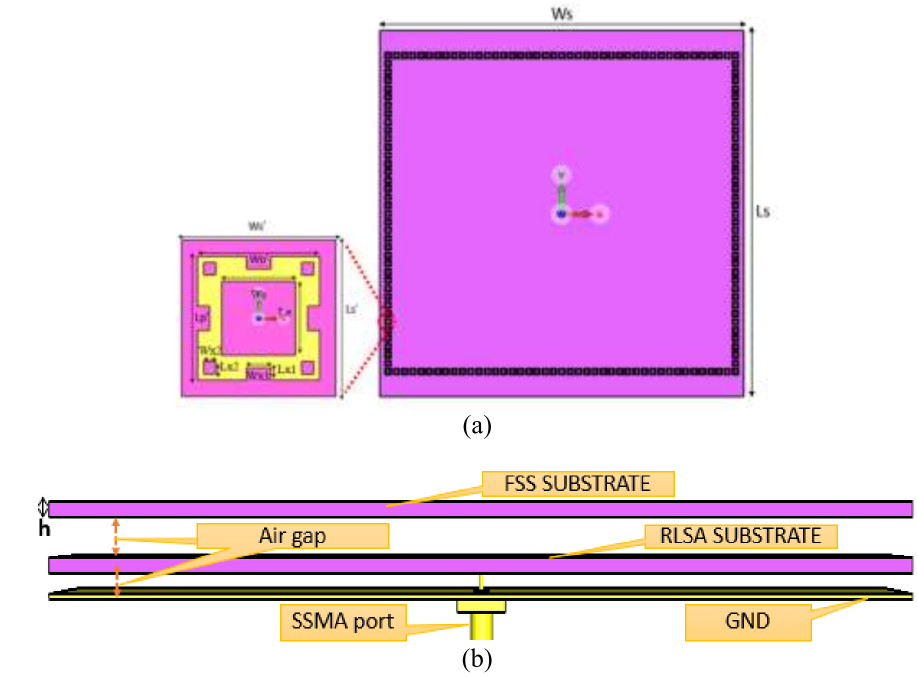

Figure 2. (a) Design configuration of the FSS reflector. (b) Side view of the RLSA antenna integrated with FSS

Table 2. FSS unit cell parameters

Parameters	Values (mm)
(Ws') and (Ls')	4.78
(Wp') and (Lp')	3.78
(We) and (Le)	4.5
Wx1	0.756
Lx1	0.378
(Wx2) and (Lx2)	0.378

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3. Results and Discussion

The conductive slotted square ring provides a wide bandwidth response in FSS as long as all 4th sections are equivalent to the λ/4 wavelength. The outer ring of the square patch operates in the high-frequency band, whereas the inner ring handles the low-frequency band and exhibits stopband performance, as depicted in Figure 3. It can be observed that the FSS is resonating from 22.5 GHz to 30.5 GHz with a -50 dB at 27 GHz.

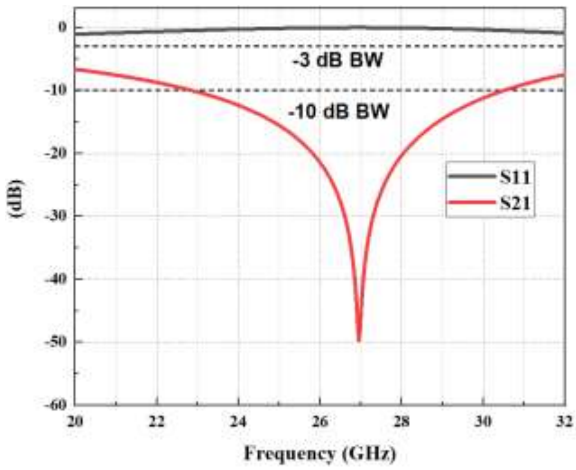


Figure 3. Transmission (S11) and Reflection (S21) simulated results of the proposed FSS unit cells

It can be observed that the reflection coefficient S11 without the integration of FSS is operating at dual bands operating at (22.3-25) GHz and (25.9-31) GHz. However, after the FSS is merged with the RLSA antenna, it is operating at (22.5-30.5) GHz. As a result, the FSS reflects the wave transmission, as illustrated in Figure 4.

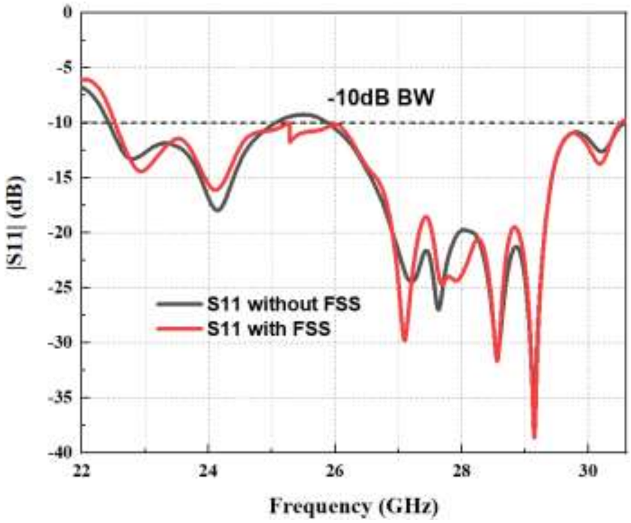
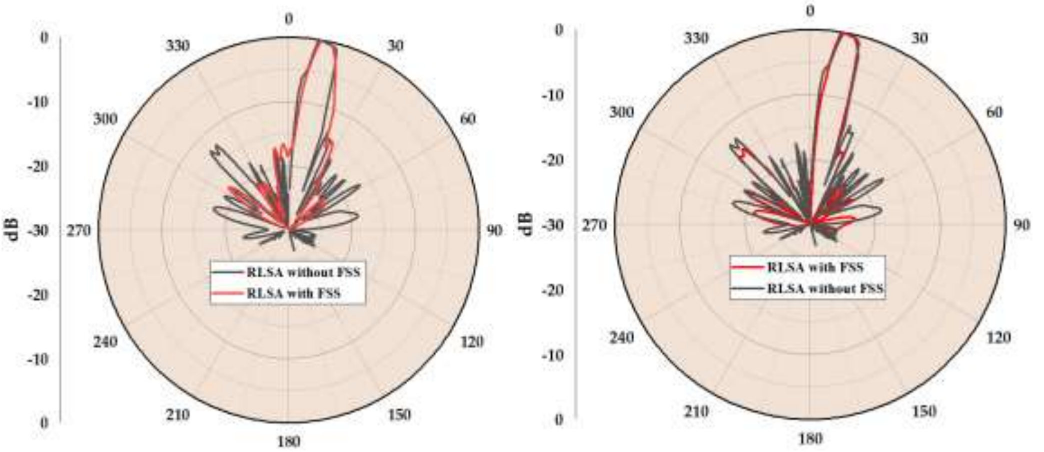


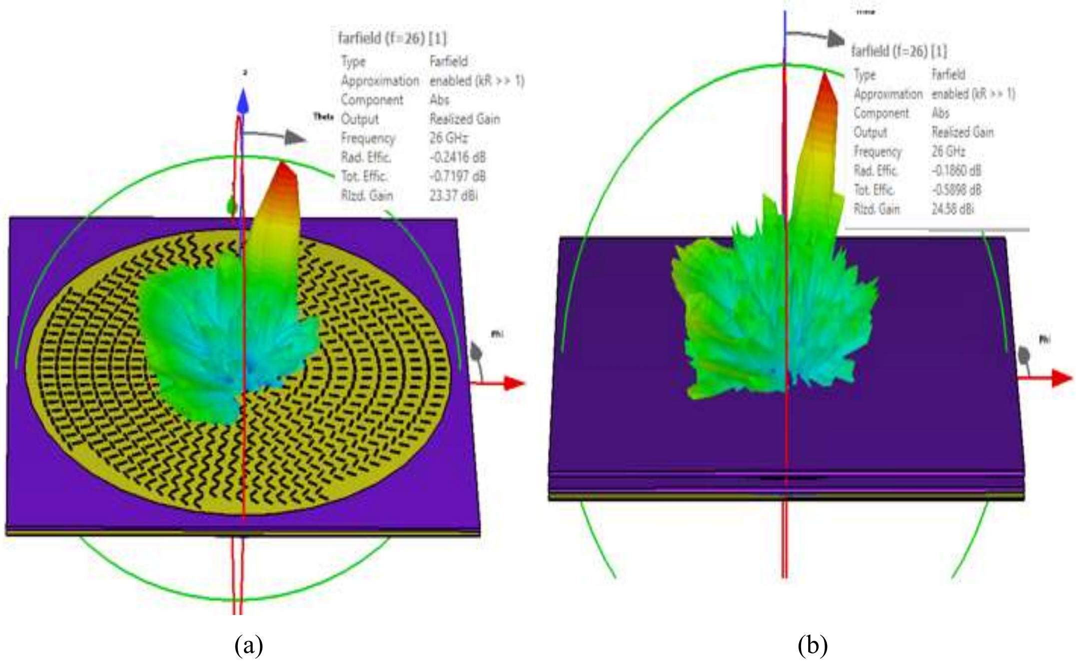
Figure 4. Reflection coefficient (S11) performance of the RLSA antenna with & without FSS combiantion

The main beam's radiation pattern is tilted by 10°. However, with the integration of the RLSA and FSS, side lobe levels are supressed at both 26 GHz and 28 GHz, as shown in Figures 5(a) and 5(b). Additionally, the gain is improved by 1.2 dBi, as depicted in Figure 6.



(a) (b)

Figure 5. Radiation pattern simulated results for the RLSA antenna with and without FSS at: (a) 26 GHz, (b) 28 GHz



(a) (b)

Figure 6. Farfield 3D plot of the RLSA antenna at 26 GHz: (a) without FSS, (b) with FSS

Table 3. Comparison with previous work

Ref.	Frequency Range (GHz)	Design Technique	RLSA Size (mm)	XPOL	Gain (dBi)
[19]	(19-20.1)	Identical slot arrangement	345	CP	NA
[13]	(15.2-18)	RLSA with reflection cancelling slots	210	LP	28.3
[7]	(11.96-12.08)	RLSA with DRA	223.2	LP	26.7
[2]	(22-29.5)	RLSA with CRR	100	LP	19.5
Proposed	**(22.5-30.5)**	**RLSA with FSS**	**200**	**LP**	**24.58**

XPOL: polarization, NA: Not Available, LP: Linear Polarization, CP: circular Polarization

4. Conclusion
In this work we proposed a high-gain RLSA antenna with the combiantion of an FSS reflector that is capable to enhance the gain and supress the side lobe level. The antenna is linearly polarized and achieves an 8 GHz bandwidth with a peak realized gain of 24.58 dBi, indicating its promising potential for fifth-generation millimetre-wave applications.

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