2021 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC) | 978-1-6654-4015-8/21/$31.00 ©2021 IEEE | DOI: 10.1109/IMOC53012.2021.9624742

Gain Enhancement of Bio-inspired Antenna Using FSS for 28 GHz 5G Application

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***Abstract*—This paper presents an antenna bio-inspired in the Wayfaring-tree leaf geometry with its gain enhanced by using a frequency selective surface (FSS). The proposed antenna is prototyped for 5G applications. The numerical characterization of the structure is performed using the commercial software CST. The gain of the bio-inspired antenna is enhanced by the FSS to a total gain of 8.68 dBi of the antenna system, thus demonstrating that employing an FSS is a viable technique for that purpose.**

Keywords—Bio-inspired antenna, frequency selective surfaces, fifth generation, gain enhancement

I. Introduction

In recent years, there has been a growth of communication systems, causing an intense information traffic from various types of applications for wireless communications between people and machines. This demand on higher data rate services in communication systems has required the use of frequency bands in the millimeter-wave (mm-wave) range [1–3]. The fifth-generation (5G) communication system has defined the following bands for mm-wave applications: N257 (26.5–29.5 GHz), N258 GHz (24.25–27.5 GHz), N260 (37.0–40.0 GHz), and N261 (27.5– 28.35 GHz) [4].

Microstrip patch antennas have been attractive for 5G applications due to their characteristics of low-cost, low-profile, compactness, multi-band or broadband operation, and easy fabrication [5, 6]. These types of antennas are composed of a radiating element etched on a dielectric substrate and a ground plane on the opposite side [7]. The performance of the antenna depends on the geometry chosen which can be a conventional patch shape (rectangular, circular, triangular, etc.) or more complex ones (e.g., fractal [8]). During the last decades, various methods for designing high gain antennas were reported. These methods include conventional approaches such as antenna arrays and new ones such as artificial magnetic conductors [9], electromagnetic band-gap structures [10] and frequency selective surfaces (FSSs) [11]. Recently, the interest in using FSSs has grown due to its transmission and reflection properties.

Bio-inspired geometries have attracted interest among microwave engineers to design new microstrip antenna geometries. This study has started due to similarities of a leaf's characteristics and antennas in terms of reception of electromagnetic waves, i.e. in the way that leaves capture sunlight and transform it into chemical energy for the plant's survival [12].

This paper presents a 28 GHz (N257) bow-tie antenna which is the bio-inspired version of the Wayfaring-tree leaf geometry and uses an FSS to enhance the antenna's gain. The leaf geometry is designed based on the superformula proposed by Gielis [13].

II. Design

A. Bio-inspired antenna

The printed antenna proposed in this work is bio-inspired by the Wayfaring-tree leaf geometry. This leaf is predominantly found in the Northeast of North America [14]. The shape of this leaf is large, oval, slightly wrinkly-looking, with round-toothed edges.

The proposed antenna has a length of L_v and width of W_v, as shown in Fig. 1. A Matlab® code was developed for the design of the patch of the antenna, using image processing to adapt contours from the leaf according to the superformula of Gielis (1) [13]. The image obtained from the polar geometric transformations using mathematical functions is converted into a DXF (Drawing Exchange Format) file to be imported and simulated in CST.

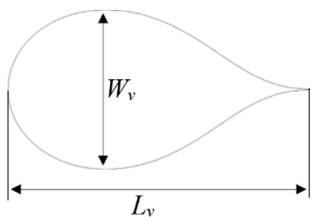

Fig. 1. Parameters of the proposed antenna geometry.

$$r(\theta) = \left(\left| \frac{1}{a} \cdot \cos\left(\frac{m}{4} \theta \right) \right|^{n_2} + \left| \frac{1}{b} \cdot \sin\left(\frac{m}{4} \theta \right) \right|^{n_3} \right)^{-\frac{1}{n_1}} \quad (1)$$

To obtain the shape shown in Fig. 1, the parameters used are $a = 1$, $b = 1$, $m = 1$, $n_1 = 0.5$, $n_2 = 0.5$, $n_3 = 0.5$. The antenna was designed with one leaf each located on the top and bottom sides of the dielectric substrate, with a truncated ground plane of width g. It is fed through the microstrip line with width of m_x. To design it for the required frequency of operation, the initial dimensions of the bio-inspired antenna were set as those of the bow-tie antenna and then optimized to final dimensions as shown in Fig. 2. The parameters are $W_a = 6$ mm, $L_a = 5.3$ mm, $W_v = 2.14$ mm, $L_v = 1.68$ mm, $m_x = 0.58$ mm, $m_y = 2.8$ mm, and $g = 1.05$ mm.

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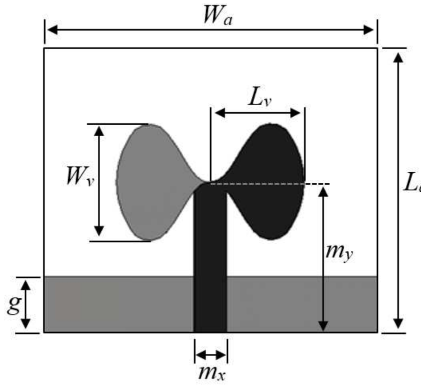

Fig. 2. Designed antenna and its dimensions with dark and light shades indicating front and back metallization, respectively.

B. FSS

The FSS design is based on the four-arms star geometry (Fig. 3), which has been previously demonstrated to be applicable to reconfigurable antennas [11] and FSSs [15]. To achieve this geometry, initially, the basic cell is dimensioned with W_x = W_y = 4.1 mm, and a rectangular patch element is designed with L_x = L_y = 3.25 mm, from whose corners the arms are shaped. From the edges, lines cross the rectangular patch with d_x = d_y = 0.6 mm. A small rectangular patch is etched at the center point to connect all the arms, s_x = s_y = 1.0 mm. Finally, the four-arms outside part is detached from the metallic surface and the four-arms star is completed.

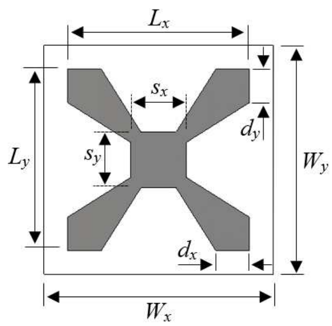

Fig. 3. Geometry and parameters of the four-arms star FSS.

III. Results

The numerical characterizations were obtained using the commercial software CST Microwave Studio. All proposed structures are designed on a Rogers Duroid/RT 6002 dielectric substrate with ε_r = 2.94, h = 0.508 mm, and loss tangent of 0.0012.

The frequency response for the bio-inspired antenna is presented in Fig. 4. The result shows the resonant frequency at 27.96 GHz, with a reflection coefficient of -60.58 dB; the encircled edge provides a better current distribution, which gives a better impedance match, and a bandwidth from 25.69 to 31.32 GHz, based on -10-dB reflection, which includes the desired frequency range of the N257 band (26.5 - 29.5 GHz).

The radiation pattern in the E-plane, according to the coordinate system of Fig. 9, has an end-fire behavior with maximum gain, in the perpendicular direction, of 1.25 dBi at θ = 7° and 1.58 dBi at θ = 185°, Fig. 5a. In Fig. 5b, the radiation pattern for the H-Plane is more directive, due to the antipodal structure being fed by the microstrip line, with a gain of 4.55 dBi at θ = 260°, and the Half Power Beamwidth (HPBW) is 175.3°.

The FSS was designed for 28 GHz, and Fig. 6 illustrates the numerical results for the transmission coefficient of transverse electric, TE, and transverse magnetic, TM, polarization, and normal incidence, with resonant frequencies at 27.88 GHz and 27.94 GHz, respectively.

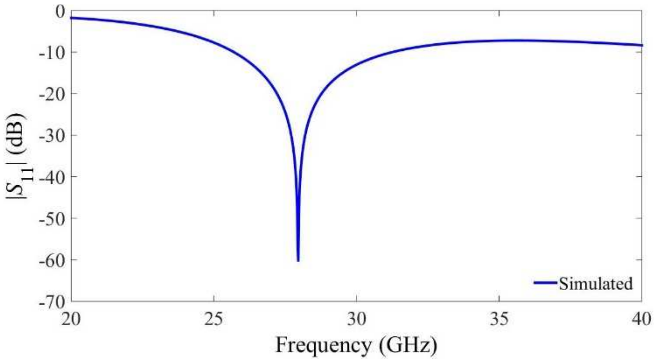

Fig. 4. Simulated result for the bio-inspired antenna.

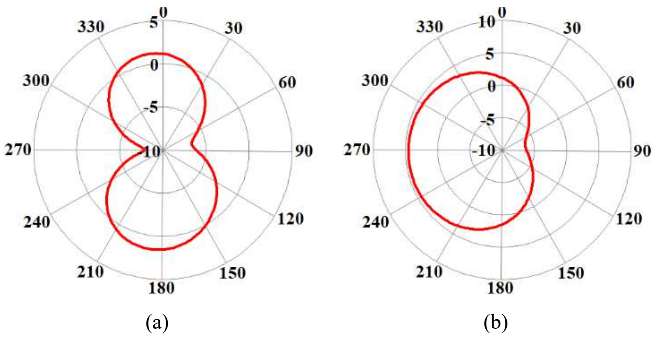

Fig. 5. Simulated radiation pattern of the bio-inspired antenna in the (a) E-plane and (b) H-plane; coordinate system according to Fig. 9.

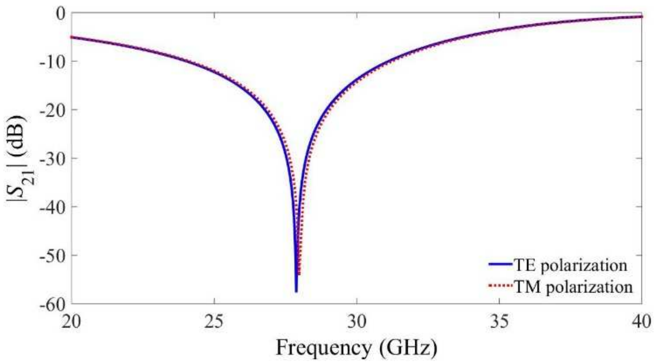

Fig. 6. Simulated result for the FSS.

In order to enhance the gain of the bio-inspired antenna, an FSS operating at the same frequency (28 GHz) is used. The FSS has a band-stop behavior, which allows to steer the beam forward from the antenna. Fig. 7 demonstrates the schematic diagram, where the FSS is spaced at a distance of d = 2.5 mm behind the antenna. The designed FSS consists of 3 × 3 elements and overall dimensions of 12.3 mm × 12.3 mm. The antenna is centralized with respect to the FSS.

The radiation pattern of the antenna system (bio-inspired antenna and FSS) is directive in the E-plane, with maximum gain in the perpendicular direction at θ = 357° and HPBW of 64.1°, as shown in Fig. 8a. In the H-plane, the radiation pattern is also more directive, and in the direction forward from the antenna at θ = 338°, the HPBW is 77.2°. FSS proves to be a viable option to enhance the gain, and if it is a reconfigurable FSS, it can reconfigure the antenna radiation pattern.

Fig. 9 shows the 3D radiation pattern for the bio-inspired antenna with FSS, whose vertical and horizontal radiation pattern are illustrated in Fig. 8a and Fig. 8b. From the 3D radiation pattern, the antenna gain obtained is 8.68 dBi.

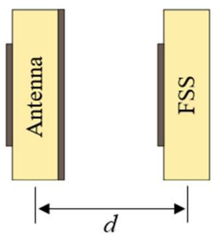

Fig. 7. Schematic diagram of proposed enhanced gain antenna using FSS.

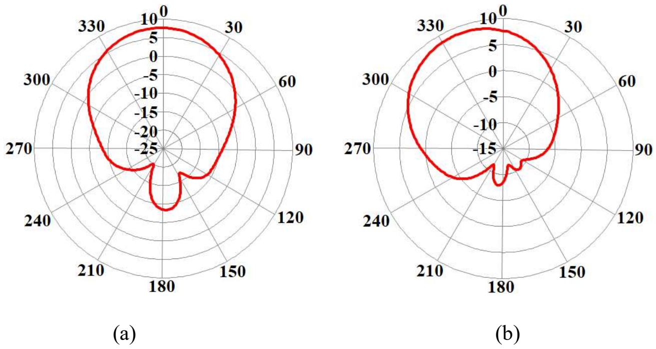

Fig. 8. Simulated radiation pattern of the antenna with enhanced gain in the (a) E-plane and (b) H-plane.

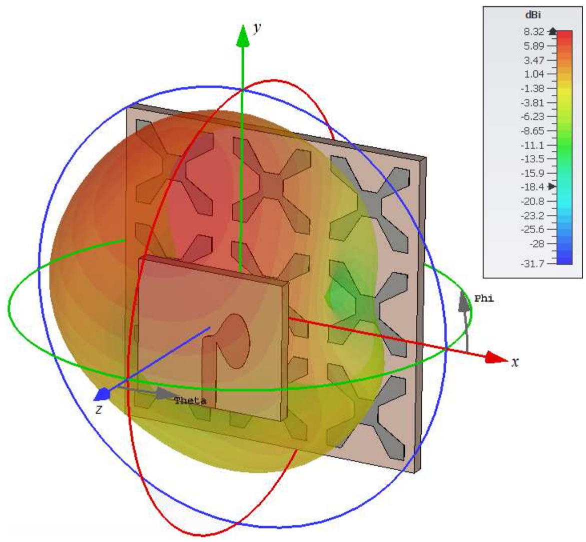

Fig. 9. 3D view of the simulated radiation pattern of the antenna using FSS to enhance the gain.

IV. Conclusion

In this paper, the development of a bio-inspired antenna operating in the 5G N257 band is detailed, and the enhancement of the gain is obtained by using an FSS. Numerical results show an increase in the gain of 6.43 dB in the E-plane and 4.14 dB in the H-plane. It was also observed that the radiation pattern for both planes became more directive. The beam was steered to a forward direction in relation to the antenna plane, with an overall gain of 8.68 dBi which presents a gain enhancement of 4.04 dB.

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