High-Gain Reconfigurable Antenna System Using PIN-Diode-Switched Frequency Selective Surfaces for 3.5 GHz 5G Application

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***Abstract*—This paper presents a high-gain reconfigurable antenna that uses PIN-diode-switched frequency selective surfaces (FSSs). The proposed antenna is prototyped for 5G applications, operating at 3.5 GHz. Numerical characterization of the structure is performed using CST Microwave Studio. Four cases of diode configurations are analyzed, confirming the design approach of the circuit for steering the beam and enhancing the gain.**

Keywords—Fifth generation, frequency selective surfaces, gain enhancement, sectoral antenna

I. Introduction

Recently, there has been increasing growth of communication systems due to the emerging demands on quality and capacity, which stimulate interest in reconfigurable antenna technologies [1]. By adapting their operation characteristics, such as radiation pattern, resonance frequency, bandwidth and polarization, reconfigurable antennas can enhance communication quality, improve energy efficiency and reduce effects of interfering signals [2]–[4].

Several methods for the design of reconfigurable antennas have been reported which include steering the beam by introducing parasitic elements in stacked [5] or planar [6] configurations, exciting different working modes of a single antenna [7], reconfiguring the electrical structure of the antenna [8], etc. Frequency selective surfaces (FSSs) have become a viable option to reconfigure antennas' properties [9, 10]. The FSS can be electronically reconfigured by varying its characteristics with active devices such as varactor [11] or PIN diodes [12], resulting in the control of its transmission and reflection properties and the change of frequency responses by modifying the equivalent geometry, hence altering the radiation pattern of the antenna.

This paper focuses on the development of an antenna using four PIN-diode-switched FSS arrays to reconfigure its radiation pattern for 5G applications. It is analyzed for four different cases of antenna reconfigurability.

II. FSS Design

FSSs are formed of basic elements etched on a dielectric substrate, arranged in a planar periodic structure, which provides filtering properties that can pass or block electromagnetic waves. The FSS frequency response depends on the substrate thickness h, and permittivity ε_r, the geometry of the planar circuit and the spacing between the elements within the structure, the periodicity and polarization of the incident wave [13] (Fig. 1).

The reconfigurable FSS (RFSS) proposed in this paper is based on the four-arms star geometry, which has been previously demonstrated to be applicable to reconfigurable antennas [14] and FSSs [15]. Initially, the unit cell dimension is defined as $W_x = W_y = 30$ mm, approximately a third of a wavelength, and then a rectangular patch is designed as $L_x = L_y = 22$ mm, where the arms are shaped. From the edges, lines cross the rectangular patch with $d_x = d_y = 3$ mm, and the four-arms star geometry is achieved. The switch point is positioned in the center by a small rectangular patch of $s_x = s_y = 3$ mm, with a gap of $g = 1$ mm. Bias lines are added with width $b = 1$ mm to all arms in the horizontal direction. The final geometry and its parameters are illustrated in Fig. 2.

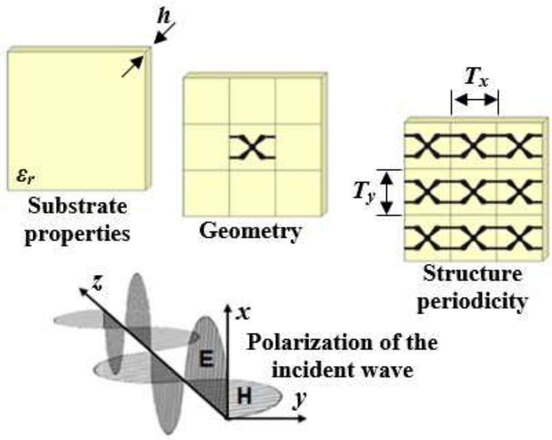

Fig. 1. Parameters that affect the FSS frequency response.

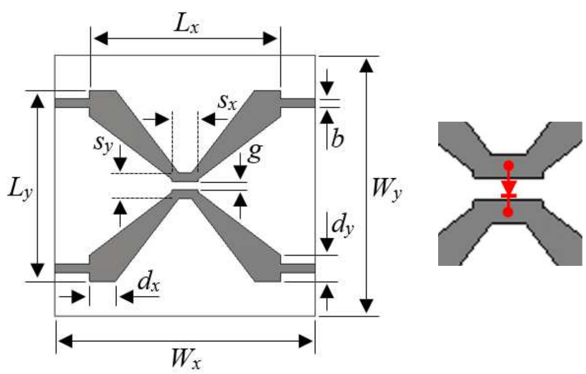

Fig. 2. Four-arms star geometry parameters and PIN-diode inserted.

The RFSS was designed on a Rogers Duroid/RT 6002 dielectric substrate with $\varepsilon_r = 2.94$, $h = 0.508$ mm, and loss tangent of 0.0012, and simulated in CST Microwave Studio. The PIN diodes used are Infineon BAR 64-03, inserted at the switch point as shown in Fig. 2. Using a biasing voltage, the PIN diodes are switched to off- and on-states, hence the geometry's effective length and its respective resonance frequency changes.

The four-arms star geometry with PIN diode is polarization dependent and its transmission coefficient results are presented in this section. The proposed FSS was designed for 3.5 GHz, and Fig. 3 illustrates the results of transverse electric (TE) polarization (vertical in Fig. 2) for the off- and on-states with resonant frequencies at 5.9 GHz and 3.47 GHz, respectively. The resonant frequency in the off-state is approximately twice when compared to on-state due to fact that the geometry in that state is composed of two separate parts. Fig. 4 presents the results of transverse magnetic (TM) polarization (horizontal in Fig. 2) for the off- and on-state; in this case the resonant frequencies for both states remain practically the same at 6.72 GHz and 6.71 GHz, respectively. This is due to the fact that the electric field in this polarization is perpendicular to the PIN-diode leads, thus the switching operation is of hardly any effect.

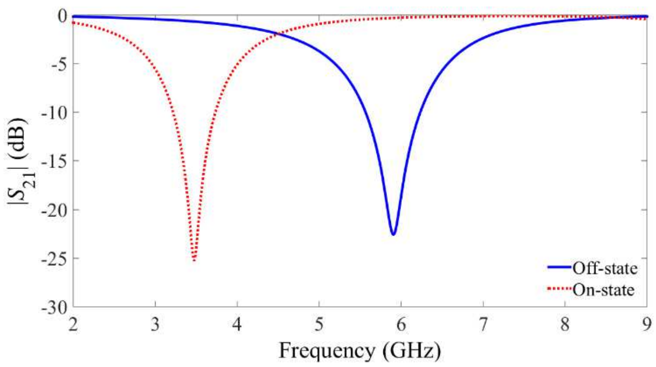

Fig. 3. Frequency response of the RFSS in TE polarization.

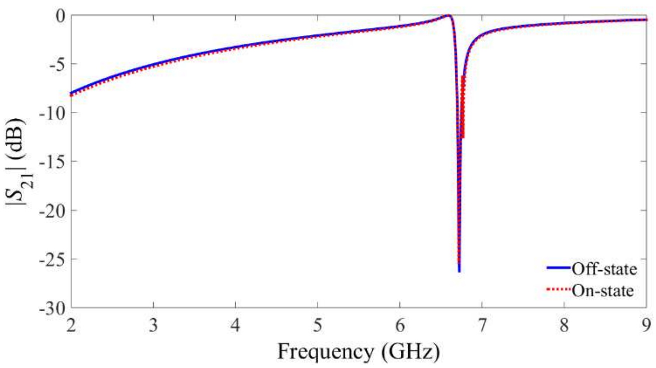

Fig. 4. Frequency response of the RFSS in TM polarization.

III. Reconfigurable Antenna

The primary antenna chosen in this work is a dipole due to its well-known omnidirectional radiation pattern. The antenna was designed for the same resonance frequency of the RFSS, when the PIN-diodes are in their on-state (3.5 GHz), with a total length of 35 mm. The distance from the dipole to the centers of the FSSs is 60 mm.

The reconfigurable antenna consists of four FSS arrays of 4 × 4 elements placed with an angle of 45° in relation to the centered point, where the dipole is located (Fig. 5a). The proposed antenna has four cases of operation, where the PIN-diodes in certain section of the FSSs are in off- or on-states, as shown in Fig. 5b. When the diodes are in the off-state, the FSS has a high transmission coefficient at the desired frequency, allowing the incident electromagnetic (EM) waves to pass. In the on-state, the FSS has a high reflection coefficient, reflecting the incoming EM wave. Thence, this mechanism converts the omnidirectional radiation pattern of the dipole into a directive one. By switching the states, the beam can be reoriented, and its gain is enhanced.

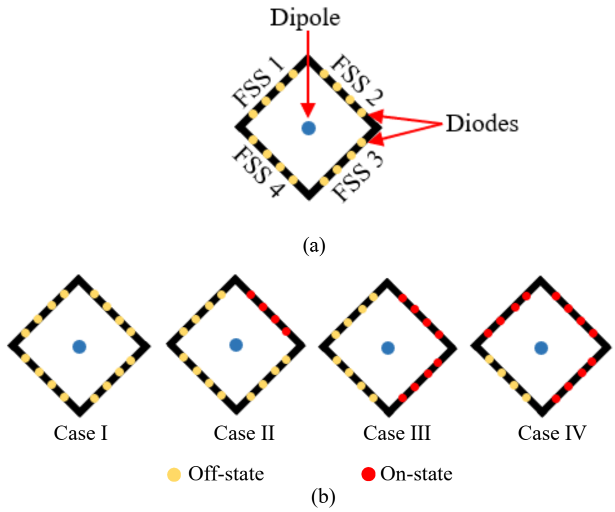

Fig. 5. Reconfigurable antenna: (a) schematic and (b) diodes configuration.

Fig. 6 shows the radiation pattern for the first case (Case I), when all diodes are in the off-state. In this case, the FSSs let the incident EM wave pass due to the fact that their resonant frequency is different from that of the dipole. Therefore, it can be observed that the radiation pattern follows an omnidirectional behavior, with a gain of 1.8 dBi.

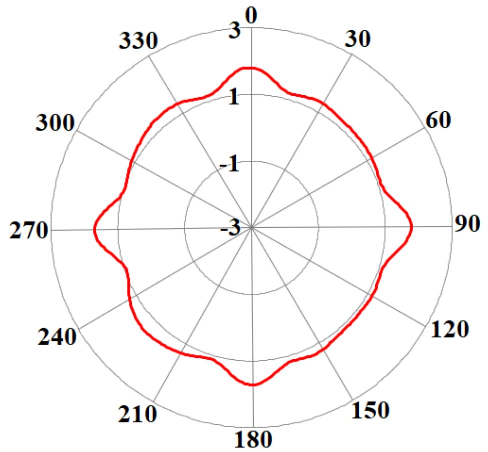

Fig. 6. Radiation pattern of the proposed antenna for Case I at 3.5 GHz.

In the second case (Case II), shown in Fig. 7, one FSS sector is switched so that its diodes are in the on-state, thus reflecting the EM wave and steering the beam in the opposite direction. This makes the radiation pattern more directive when compared with the dipole, with maximum gain of 7.46 dBi at θ = 225° and a Half Power Beamwidth (HPBW) of 66.6°.

Two FSSs have their diodes in the on-state in the third case (Case III), where the beam is steered away from them. The maximum gain of around 7.7 dBi is obtained at θ = 210° and 330°, the gain at θ = 270° is 4.47 dBi. It can be seen that in this case, the radiation pattern of the antenna system is also directive. When compared to the previous case, it has a gain improvement towards the side directions.

In the last configuration (Case IV), FSS 1, FSS 2 and FSS 3 (Fig. 5a) have their diodes in on-states, blocking the EM wave in their direction, which directs the beam toward FSS 4. The gain is enhanced to 10.2 dBi at $\theta = 225°$ with a HPBW of 38.2°.

Obviously, the beams of Cases II, III and IV investigated here can be rotated by 90°, 180° or 270° if the respective other FSS's are switched to their on-states. This makes the proposes antenna configuration a viable option for 5G beam switching applications.

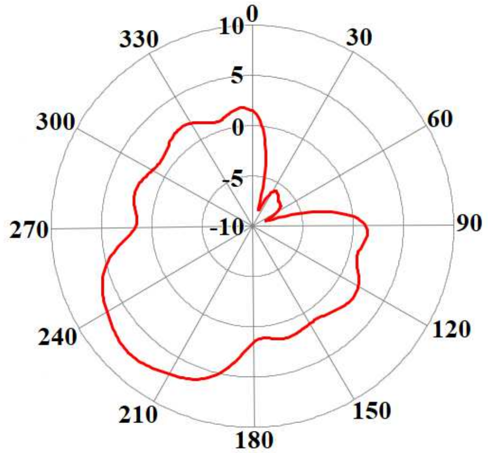

Fig. 7. Radiation pattern of the proposed antenna for Case II at 3.5 GHz..

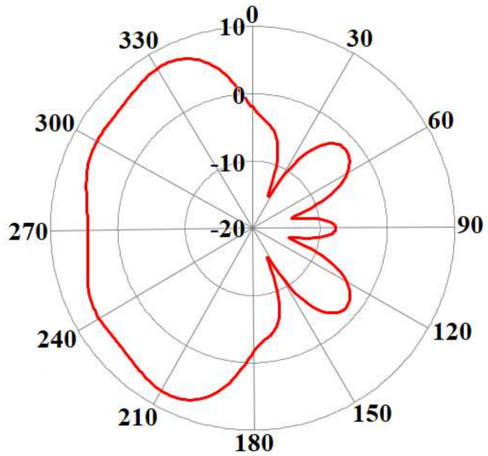

Fig. 8. Radiation pattern of the proposed antenna for Case III 3.5 GHz..

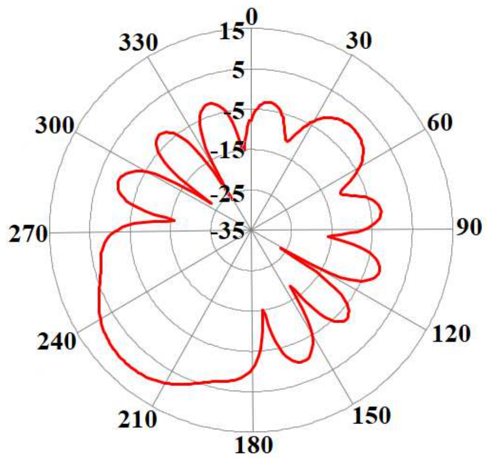

Fig. 9. Radiation pattern of the proposed antenna for Case IV at 3.5 GHz..

IV. Conclusion

In this paper, the development of a reconfigurable antenna using PIN-diode-switched FSSs operating at 3.5 GHz is detailed. Four cases of diode configurations are considered, showing that when the diodes are in on-states, the FSSs reflect the EM wave and consequently steer the beam. Numerical results show an increase in gain for cases II, III and IV. The proposed antenna shows to be a good and easy option to be used for applications (e.g. 3.5 GHz 5G) where the control of beam directions is needed.

References

[1] C. A. Balanis and P. Ioannides, *Introduction to Smart Antennas*. Morgan and Claypool Publishers, 2007.

[2] M. Shirazi, J. Huang, T. Li, and X. Gong, "A switchable-frequency slot-ring antenna element for designing a reconfigurable array," IEEE Antennas Wirel Propag. Lett., vol. 17, no. 2, pp. 229-233, Feb. 2018, doi: 10.1109/LAWP.2017.2781463.

[3] A. Haskou, A. Pesin, and A. Louzir, "Compact pattern-switching patch antenna," in Proc. 50th Eur. Microw. Conf., 2021, pp. 432-435, doi: 10.23919/EuMC48046.2021.9337953.

[4] B. Mohamadzade, R. M. Hashmi, R. B. V. B. Simorangkir, A. Lalbakhsh, and H. Ali, "A planar dynamic pattern-reconfigurable antenna," in Proc. 15th Eur. Conf. Antennas Propag. (EuCAP), 2021, pp. 1-3, doi: 10.23919/EuCAP51087.2021.9411272.

[5] M. A. Hossain, I. Bahceci, and B. A. Cetiner, "Parasitic layer-based radiation pattern reconfigurable antenna for 5G communications," IEEE Trans.Antennas Propagat., vol. 65, no. 12, pp. 6444-6452, Dec. 2017, doi: 10.1109/TAP.2017.2757962.

[6] W. Deng, X. Yang, C. Shen, J. Zhao and B. Wang, "A dual-polarized pattern reconfigurable Yagi patch antenna for microbase stations," IEEE Trans.Antennas Propagat., vol. 65, no. 10, pp. 5095-5102, Oct. 2017, doi: 10.1109/TAP.2017.2741022.

[7] B. K. Ahn, H. Jo, J. Yoo, J. Yu, and H. L. Lee, "Pattern reconfigurable high gain spherical dielectric resonator antenna operating on higher order mode," IEEE Antennas Wirel Propag. Lett., vol. 18, no. 1, pp. 128-132, Jan. 2019, doi: 10.1109/LAWP.2018.2882871.

[8] J. Ouyang, Y. M. Pan, and S. Y. Zheng, "Center-fed unilateral and pattern reconfigurable planar antennas with slotted ground plane," IEEE Trans. Antennas Propagat., vol. 66, no. 10, pp. 5139-5149, Oct. 2018, doi: 10.1109/TAP.2018.2860046.

[9] W. Li, Y. Wang, S. Sun, and X. Shi, "An FSS-backed reflection/transmission reconfigurable array antenna," IEEE Access, vol. 8, pp. 23904-23911, 2020, doi: 10.1109/ACCESS.2020.2970611.

[10] Yueh-Lin Tsai, Ruey-Bing Hwang, and Yu-De Lin, "A reconfigurable beam-switching antenna base on active FSS," in Proc. 15th Int. Symp. Antenna Technol. Applied Electromagn., 2012, pp. 1-4, doi: 10.1109/ANTEM.2012.6262333.

[11] A. Gomes Neto, J. C. e Silva, A. G. Barboza, D. Formiga Mamedes, I. B. G. Coutinho, and M. de Oliveira Alencar, "Varactor-tunable four arms star bandstop FSS with a very simple bias circuit," in Proc. 13th Eur. Conf. Antennas Propag. (EuCAP), 2019, pp. 1-5.

[12] M. Abdollahvand et al., "Reconfigurable FSS based on PIN diodes for shared-aperture X/Ka-band antennas," in Proc. 15th Eur. Conf. Antennas Propag. (EuCAP), 2021, pp. 1-4, doi: 10.23919/EuCAP51087.2021.9411211.

[13] B. A. Munk, *Frequency Selective Surfaces: Theory and Design*. New York: Wiley, 2000.

[14] D. Formiga Mamedes, A. Gomes Neto, and J. Bornemann, "Reconfigurable corner reflector using PIN-diode-switched frequency selective surfaces," in IEEE AP-S Int. Symo. Dig., 2020, pp. 127-128, doi: 10.1109/IEEECONF35879.2020.9329791.

[15] D. Formiga Mamedes, A. Gomes Neto, J. C. e Silva, and J. Bornemann, "Design of reconfigurable frequency-selective surfaces including the PIN diode threshold region," *IET Microw., Antennas Propag.*, vol. 12, no. 9, pp. 1483-1486, 2018, doi.org/10.1049/iet-map.2017.0761.