RECONFIGURABLE MONOPOLE ANTENNA DESIGN BASED ON FRACTAL STRUCTURE FOR 5G APPLICATIONS

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Abstract- **In this paper, a reconfigurable antenna design for 5G applications is presented. It is based on monopole antenna and fractal structure. The antenna is designed and simulated by using CST Microwave studio. The design structure consists of (monopole) feedline, ground plane, L-shape reflector, fractal structure and PIN diodes. The antenna is printed on (25 × 29 × 1.6 mm3) FR-4 substrate of $\varepsilon_r = 4.3$ and $tan\delta = 0.001$. The antenna shows a resonant frequency at 4.1 GHz with S11=-11.4 dB and an Omni-direction pattern of 1.21 dB gain. The L-shaped reflector is used to maintain the radiation pattern in a specific direction. Moreover, the proposed fractal structure is found to operate as a matching circuit to give another resonant frequency and enhance the antenna performance. Where it is used to give more manipulation in the antenna performance including frequency resonance and radiation patterns. The PIN-diodes are used to give many cases for more current manipulation. Moreover, the authors used RF (50 Ω SMA port) between the monopole antenna and the right side of the ground plane to optimize directing radiation pattern and to eliminate the problems of interference between AC and DC that were produced from using PIN diode. This manipulation leads to change the resonant frequency and radiation pattern to the desired direction. So, all three parts are printed on a single side of the FR4 substrate with no metallization coating on the opposite side. Finally, the HFSS environment is invoked too for more results validation.**

keywords: **Monopole antenna, Reconfigurable antenna, Fifth generation mobile communication network (5G), Fractal.**

I. INTRODUCTION

In wireless communication systems, many applications operate at frequencies below 6 GHz to ensure high speed guided transmission [1]. For this reason, choosing the low frequencies antenna has declined in recent times [1]. The antenna is one of the most essential components of wireless communications systems because it is used in both transmitter and receiver sides [2]. Dipoles/monopoles, slot/horn antennas, loop antennas, microstrip antennas, reflector antennas, helical antennas, dielectric/lens antennas, log-periodic antennas, and frequency-independent antennas are different types of antennas that have emerged in the last fifty years for both radar and communication systems, each of which is better suited to a specific application than the others [3]. Because of their low cost, lightweight, and ease of fabrication [4], printed antennas are the most suitable ones commonly used in reconfigurable designs [5]. Meanwhile, some techniques are used for gain enhancement and miniaturization [6], [7]. Reconfigurable tools based upon electronic devices for realizing direct handling in one actual structure turns into one of the most critical requirements within the present-day techniques [8]. However, polarization reconfigurable antennas with the benefits of improving system capacity, minimizing fading decrease, and also reducing the channel obstruction has brought a lot of focus amongst the antennas scientists [9]. The various advantages of reconfigurable antennas, however, come with a couple of drawbacks, such as the need for additional antenna modification, which necessitates a more complex regulation. Full usage can necessitate sophisticated signal processing and feedback circuits, and more components and more complex manufacturing processes would almost certainly be required than in traditional antenna system embodiments [10]. For example, the authors in [11] used a biasing network to control their

antenna performance-based 7 PIN diodes that limit their use in many portable and handheld devices. However, the proposed design in [12], realized a more attractive design by connecting photo resists that do not need for the biasing system; but such devices show a very slow response due to their rising time slop. In [13], the authors used two PIN diodes to obtain a direct antenna modulation by changing the phase array motion; however, the effects of biasing circuit realize a frequency operation sweep due to the wiring system. The antenna proposed in [14] was applied to control the radiation pattern direction from the broadside to an end fire for OFDM systems. Another design was proposed based on beamforming to reduce the interference in the broadcast surrounding [15]. Moreover, fractal based antenna was proposed to improve the efficiency of a partial ground plane antenna when two diodes were connected to the fractal structure [16]. therefore, the authors in [17] proposed design of Double H-Slot Microstrip patch that operate on three frequencies to enhancement gain and to change radiation pattern in many directional. In this paper, the authors give a systematic study of a reconfigurable printed antenna design based on fractal structure for 5G applications. The CST Microwave studio is used to design and analyze the antenna. So the monopole antenna is designed as a printed strip line over a dielectric substrate with a partial ground plane on the right side only as shown in section II. Next, the L-shaped reflector is added to the monopole antenna to change the radiation direction. Therefore, in section III, the fractal structure is used with the proposed antenna design as a matching circuit to enhance the antenna performance by changing the radiation pattern direction. Later on, the antenna design is connected with four PIN diodes that are located between the reflector and the fractal structures to get reconfigurable frequency and radiation pattern. The RF switches are used to optimize radiation pattern symmetry toward a certain direction which is discussed in section IV. Finally, the HFSS software package is invoked too for more result accuracy.

II. ANTENNA DESIGN BASED L-SHAPED REFLECTOR

In this section, the authors proposed a monopole antenna design that is consisted of a feedline which is printed on FR-4 substrate of $\varepsilon r = 4.3$ and $tan\delta = 0.001$. The substrate width is (W) of 29 mm, length (L) = 25 mm, and thickness (h) = 1.6 mm as shown in Fig. 1. A single ground plane with dimensions of $(4 \times 4.5mm^2)$ is printed on the right side of the feedline. The other geometrical details are presented in Table I.
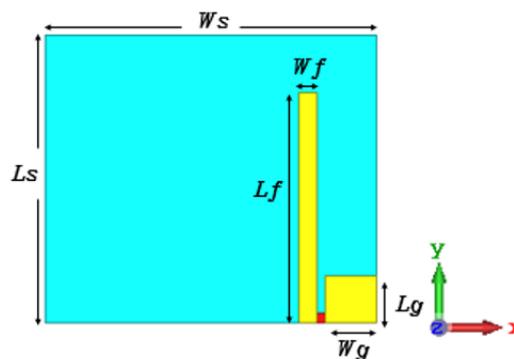
Figure 1: Monopole antenna geometrical design

TABLE I
Monopole Antenna Geometrical Details

Ws	Ls	Lf	Wf	Lg	Wg
29 mm	25 mm	20 mm	1.5 mm	4 mm	4.5 mm

The proposed antenna performance is analyzed and S_{11} is shown in Fig. 2. The simulated results show one resonant frequency at 4.1 GHz with an S_{11} value equal to -11.4 dB in the CST environment, while it showed -14.6 dB at 4.3 GHz in the HFSS environment. The reason for the difference between them, is that HFSS is based on the Finite Element Method (FEM), while CST is based on the Finite Integration in Technique (FIT). Moreover, the 3D radiation pattern of the monopole antenna at the frequency of 3.76 GHz is presented in Fig. 3. The obtained result shows an Omni-directional radiation pattern with a maximum gain of 1.6 dB.
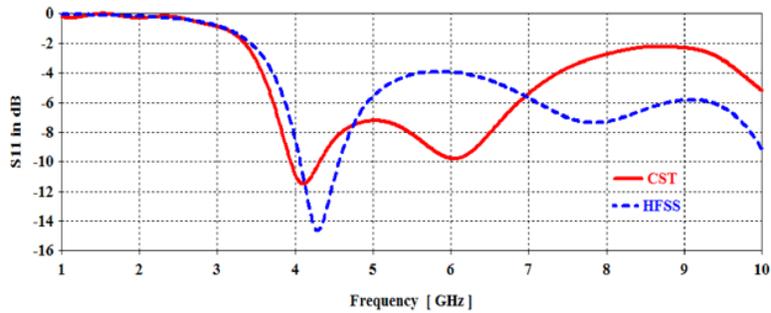
Figure 2: S_{11} in (dB) of the monopole antenna
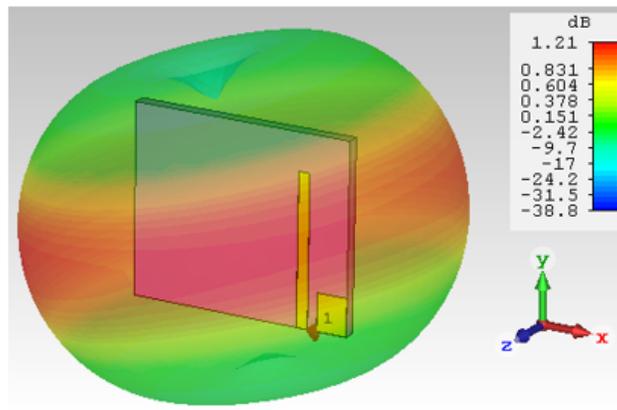
Figure 3: 3D radiation pattern antenna

To maintain the radiation pattern in a specific direction, an L-shaped reflector is added to the left side of the feedline as shown in Fig. 4. The antenna geometrical details are presented in Table II.

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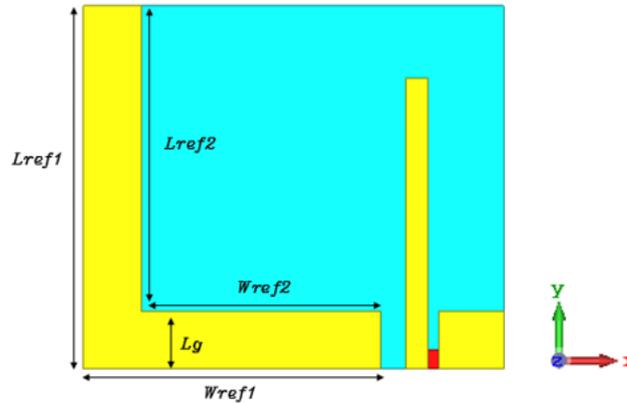
Figure 4: Monopole antenna design with L-shaped reflector

TABLE II
Geometrical Details of Monopole Antenna Design with L-Shape Reflector

Wref1	Lref1	Lref2	Wref2	Lg
20.5mm	25mm	21mm	16.5mm	4mm

The antenna performance is analyzed by using CST MWS in terms of S_{11} and radiation patterns. In Fig. 5(a), the S_{11} result is presented to show good enhancement in comparison to the previous design, where the results showed that the antenna gives S_{11} at 4.2 GHz with a value equal to -27.1 dB. Moreover, the HFSS software package is invoked for more result validation. It is found good agreement is achieved between the two software packages. The 3D radiation pattern antenna is presented in Fig. 5(b). The antenna gain is found equal to 2.6 dB with a change in the direction of the propagation and as shown in Fig. 5(b).

III. RECONFIGURABLE ANTENNA DESIGN BASED ON FRACTAL

Reconfigurable antenna design based on Minkowski fractal shaped with slot dimensions calculated as in [18] is presented in Fig. 6. The fractal structure is added to the antenna, located between the feedline and L-Shape Reflector. The fractal structure is characterized by dimensions of $(15 \times 15mm^2)$ with four rectangular slots, each slot is characterized by dimensions of $(4.5 \times 5mm^2)$ located on a different side compared with the other slots. Other geometrical details are presented in Table III. The fractal operates as a matching circuit inside the antenna which provides another resonant and enhances the antenna performance. Moreover, it is used to give more manipulation in the antenna performance, frequency and radiation.

TABLE III
Geometrical Details of Reconfigurable Antenna Based on MTM Structure

Lm	Wm	W1	W2	W3
15 mm	15 mm	5 mm	5 mm	5 mm

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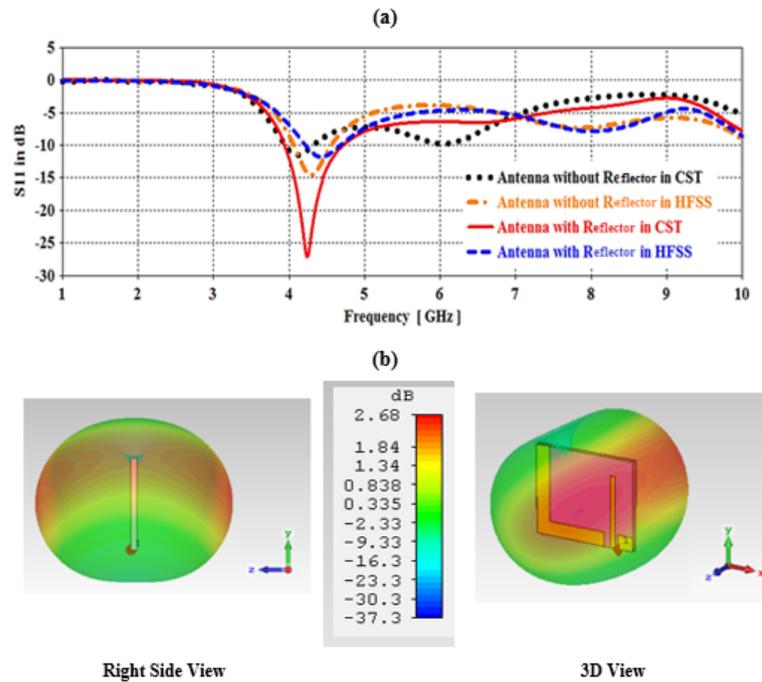
Figure 5: Antenna performance with and without L-shape reflector: (a)S_{11} spectra and (b) 3D radiation patterns
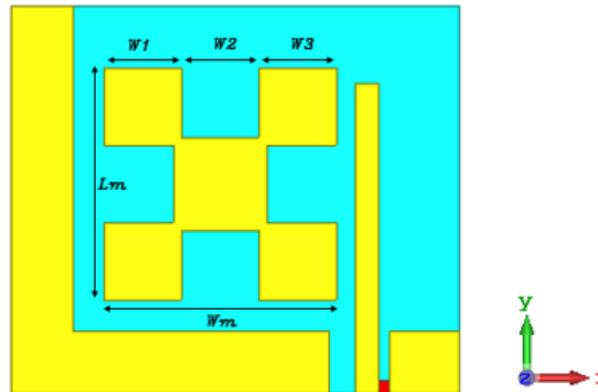
Figure 6: Antenna design based on MTM structure

The antenna is simulated by using a CST environment. The obtained result in terms of S_{11} is presented in Fig. 7(a). It is found that the antenna has two frequency bands. The first one has a resonant at 3.76 GHz with an S11 value equal to -30.45 dB, the second resonance is found to be from 4.76 GHz to 6.94 GHz with S_{11} equal to -19.3 dB as the best value at a frequency of 5 GHz. These results are validated using CST microwave studio in terms of S_{11} spectra. While The obtained result in HFSS is two frequency bands that operate in 3.7 GHz and 9.87GHz with S_{11} that equal -13.34 dB

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and -58.6 dB respectively. And the difference is due to the same reasons mentioned previously that each simulator uses a different approach. So The 3D radiation patterns of the proposed antenna are presented in Fig. 7(b). The antenna gain is found to be 1.28 dB at 3.76 GHz, while the antenna gain becomes 2.67 dB at 5 GHz. The antenna shows a broadside radiation pattern at first resonant while the radiation pattern becomes near to endfire 5 GHz.
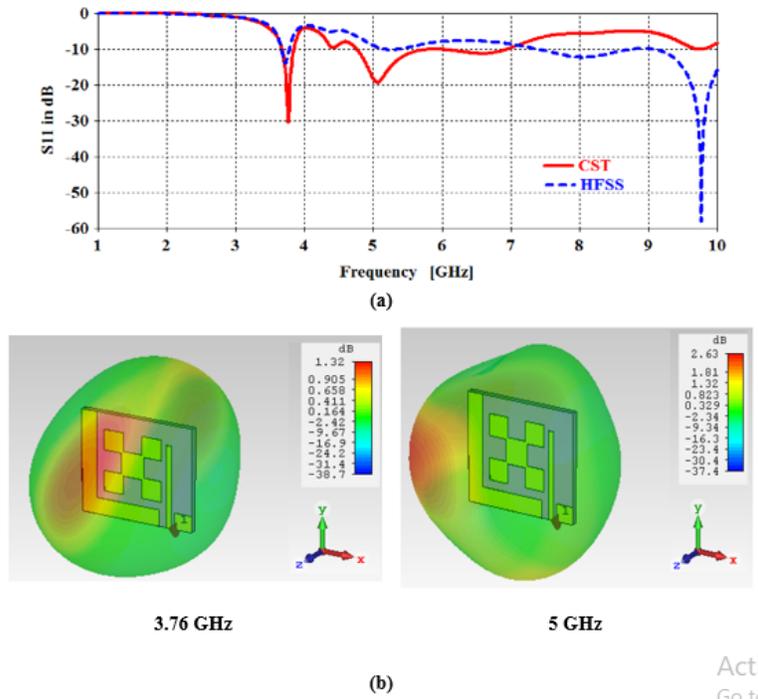
Figure 7: Antenna performance based on: (a) S_{11} spectra and (b) 3D radiation patterns at different frequency bands

Next, four PIN-diode are added to the proposed antenna structure. Diodes are connected between L-shaped reflector and fractal structure as shown in Fig. 8. These diodes work to give more current manipulation in the antenna structure to change both the operating frequency and radiation patterns. The proposed antenna based on a fractal structure with four diodes is simulated. Four cases are presented here; all diodes are OFF, all diodes are ON, Upper diodes are ON while the lower is OFF, and Upper diodes are OFF while the lower is ON. The antenna results in terms of S_{11} are presented in Fig. 9. In the first case, it is found that the antenna has two frequency bands. The first one has a resonant at 3.76 GHz with an S_{11} value equal to -30.45 dB, the second one is found from 4.76 GHz to 6.94 GHz with S_{11} equal to -19.3 dB as the best value at a frequency of 5 GHz. In the second case, the proposed antenna shows two bands. The first band is found at 3.62 GHz with an S_{11} value equal to -30 dB, while the second band is found starting from 4.59 GHz to 7.6 GHz with a minimum S_{11} value at 5 GHz and 7 GHz. In the third case, the antenna shows three resonant frequencies, first one is found at 3.9 GHz with an S11 value equal to -11 dB, the second frequency is found at 4.9 GHz with an S11 value equal to -15.46 dB, and the third one is resonant at 6.5 GHz with S11 value equal to -15.68 dB. In the last case, the obtained result shows two bands. The first one is at 3.65 GHz with S_{11} equal to -19.2 dB. The second one is found starting from 4.74 GHz to

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7.6 GHz with minimum S_{11} value at 5 GHz and 7.1 GHz that equals -20 dB and -22 dB, respectively. Finally, the HFSS is invoked too for more result accuracy validation. So, the difference between CST and HFSS is due to the same reason mentioned previously.
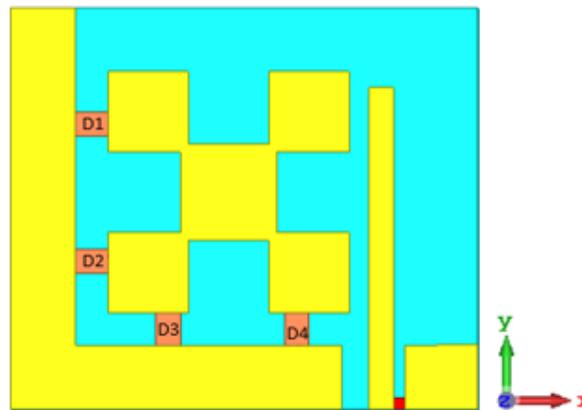
Figure 8: Reconfigurable antenna design based on fractal structure

The radiation patterns of the reconfigurable antenna based on fractal structure are obtained for only four cases: All diodes are OFF, all diodes are ON, Upper diodes are ON while the lower is OFF, and Upper diodes are OFF while the lower is ON. The antenna results are presented in Fig. 10. The antenna radiation is found to change according to the diode switching cases. In the first case, the radiation is found to be a broadside radiator, above and below the antenna, at the first resonant frequency, while it is found to be close to endfire at 5 GHz. In the second case, the radiation is found to be very close to the endfire direction in the first and second resonant frequency; however, it is converted to a broadside at 7 GHz. In the third case, the antenna is radiating to the left side in the first and second resonant frequencies, while it is radiating to the right side in the last resonant frequency. Finally, in the last case, the radiation patterns are found completely at the endfire direction. In the First resonant, the radiation is endfire to the right antenna side. in the second resonant, the radiation is endfire to the left antenna side. In the last resonant, the radiation is close to Omni-direction, vertical circular shape. Table IV shows the comparison of antenna performance with other published work.

TABLE IV
Antenna Performance with Other Published Results

Ref.	Size/ mm^2	(Substrate)	RF. switch	(B.W)/ GHz	Diodes, number	Design .Complexity
[16]	30×60	INP	Varactor	2	2	High
[19]	50×50	FR4	PIN	(2.5-10)	2	High
Proposed work	29×25	FR4	PIN	(3.8-5.1) and (5.9-7.76)	4	Low

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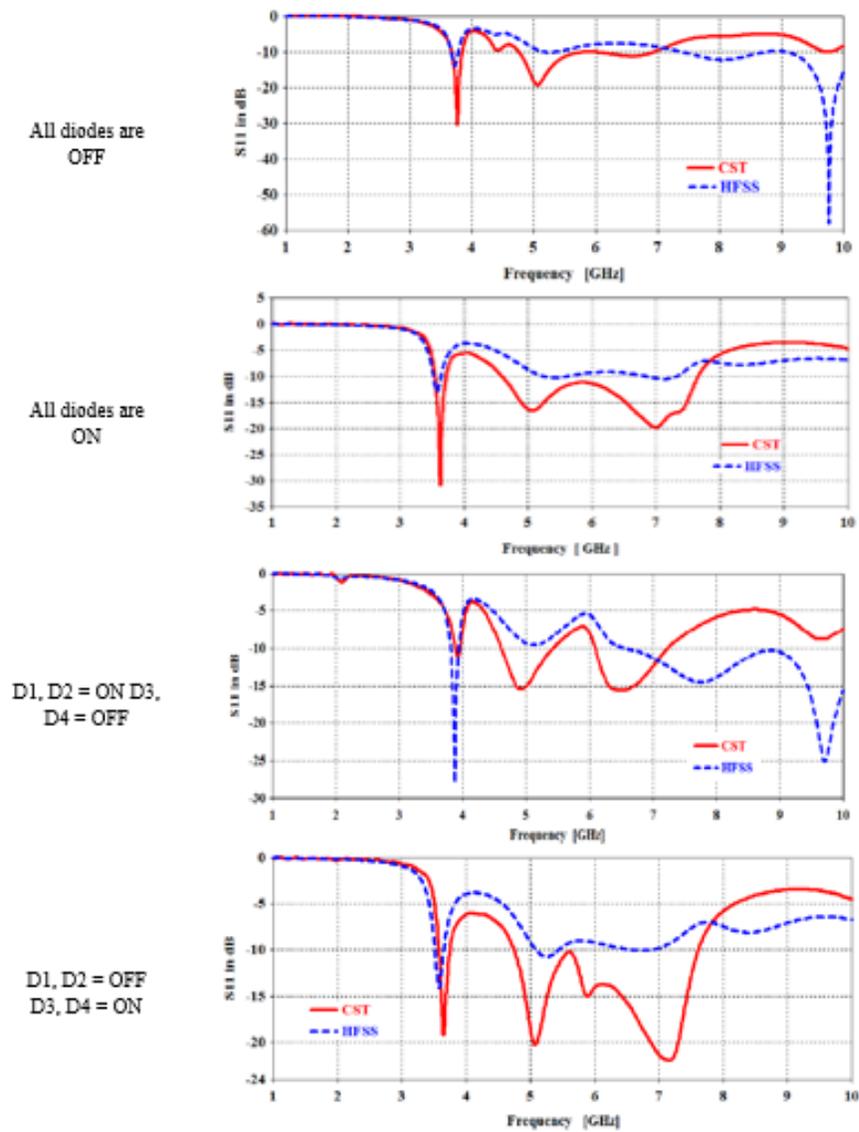
Figure 9: S_{11} results of the reconfigurable antenna based on fractal structure

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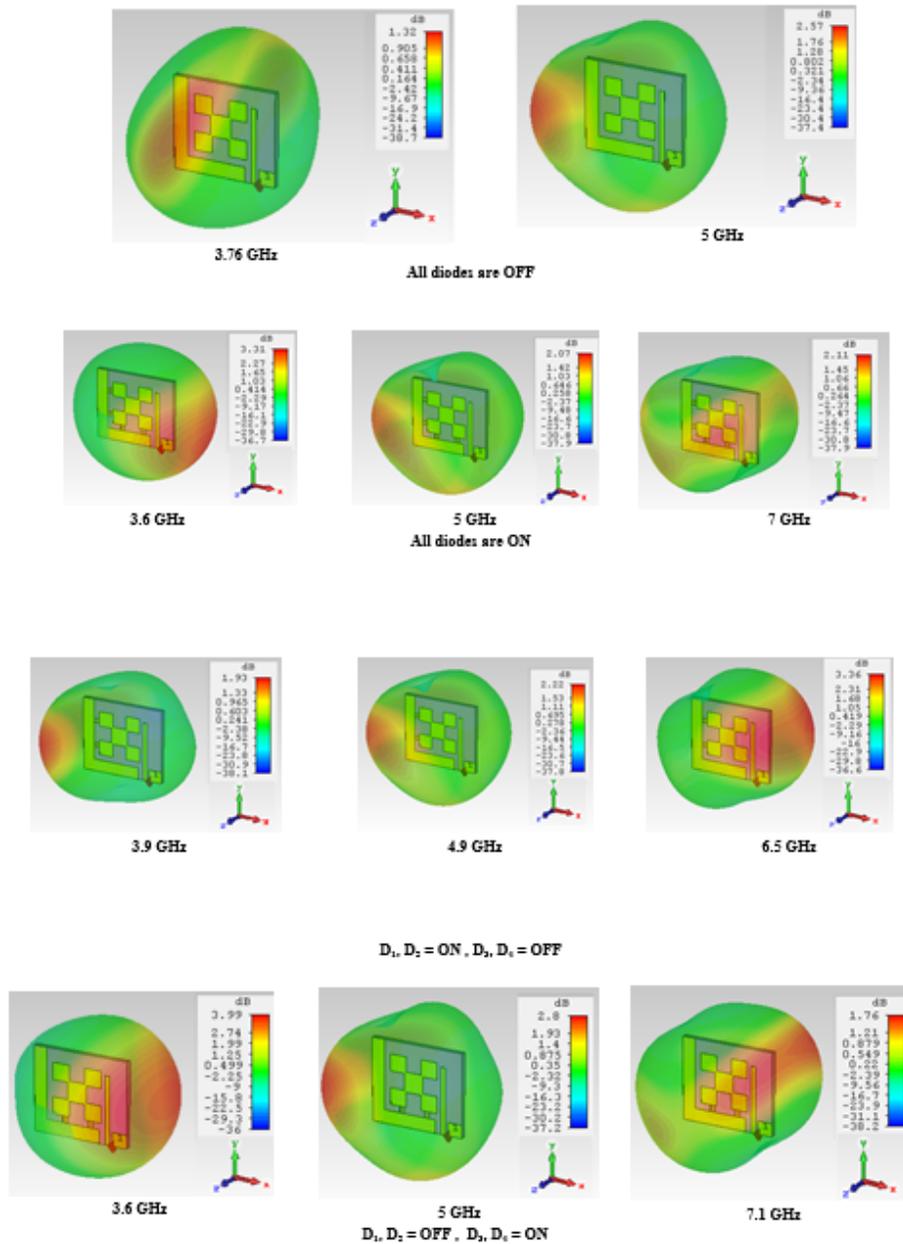
Figure 10: 3D radiation patterns of the reconfigurable antenna based on MTM structure

IV. CONCLUSION

The monopole antenna based on a fractal structure with four diodes is designed and simulated in this paper. Four cases of PIN diodes switching are presented in this work. Each case showed different operating frequency and radiation patterns. In the first case, two frequency bands are achieved, 3.76 GHz with an S_{11} value equal to -30.45 dB, and 4.76 GHz to 6.94 GHz with -19.3 dB at 5 GHz. In the second case, two bands are found at 3.62 GHz with -30 dB and 4.59 GHz to

7.6 GHz with minimum S_{11} at 5 GHz and 7 GHz. In the third case, the antenna is resonant at 3.9 GHz, 4.9 GHz, and 6.5 GHz with S11 values equal to -11 dB, -15.46 dB, and -15.68 dB, respectively. In the last case, two bands are found at 3.65 GHz with S_{11} equal to -19.2 dB and from 4.74 GHz to 7.6 GHz in terms of the radiation pattern, the results showed different radiation types; broadside, endfire or omnidirectional, according to the selected case. Finally, the HFSS software package is invoked to validate the obtained results.

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