Iraqi Journal of Information and Communications Technology(**IJICT**)
Vol.6, Issue 3, December 2023

www.ijict.edu.iq

ISSN:2222-758X
e-ISSN: 2789-7362

CIRCULARLY SHAPED METAMATERIAL FRACTAL RECONFIGURABLE ANTENNA FOR 5G NETWORKS

Marwah H. Jwair [1], Taha A. Elwi [2], Salam K Khamas[3], Aydin Farajidavar [4], Alyani Binti Ismail[5]

[1]Department of Information and Communication Engineering, Al-Nahrain University, Iraq
[2]Ministry of Higher Education and Scientific Research, Baghdad, Iraq, and International Applied and Theoretical Research Center (IATRC), Baghdad Quarter, Iraq
[3]Communications Research Group, Department of Electronic and Electrical Engineering, The University of Sheffield, Mappin Street, Sheffield S1 3JD, UK
[4]Department of Electrical and Computer Engineering, New York Institute of Technology, Old Westbury, NY, USA
[5]Faculty of Engineering, University Putra Malaysia
Email: marwa.halee.it@gmail.com,taelwi82@gmail.com, s.khamas@sheffield.ac.uk, afarajid@nyit.edu, alyani@upm.edu.my
Corresponding Author: Alyani Binti Ismail
Received: 05/06/2023; Revised:15/08/2023; Accepted: 25/09/2023
DOI: **10.31987/ijict.6.3.251**

***Abstract*- This research is an attempt to highlight that the presented antenna design is proposed for modern wireless communication systems, including 5G networks. The proposed antenna design is structured to realize a reconfigurable antenna terminal to suit smart wireless systems. Therefore, the proposed antenna is structured from twelve-unit cells of metamaterial (MTM) inclusions. For this, effectively, the proposed antenna profile is reduced to $0.21\lambda_0$, where λ_o is the free space wavelength at 2.45GHz, which occupies $40 \times 30\ \text{mm}^2$ equivalently. This is accomplished by using T-resonator inductors to conduct 3^{rd} iteration Hilbert-shaped MTM inclusions. The proposed antenna is printed on a substrate to cover the frequency bands from 2.6GHz to 4.4GHz. To optimize the antenna performances, a numerical-parametric analysis based on CST MWS commercial software package formulations is invoked for this study. The suggested antenna performance is numerically evaluated for validation using the HFSS software suite. The antenna has great performance while being sufficiently small to be used with integrated electronics.**

keywords: **MTM, 5G, Sub-6GHz, fractal, T-resonator**

I. INTRODUCTION

There are a lot of criteria to meet the state-of-the-art antenna design because of the recent expansion of contemporary communication networks [1]. Microwave research has undergone a revolution as a result of the long-term development of the concept of artificial materials [1]. One of the most important parts of wireless communications systems, an antenna is a section of a cellular transmission line. Nine different types of antennas, including dipoles monopoles, slot horns, loops, micro-strips, reflectors, helical, dielectric lenses, log periodic, and frequency-independent antennas, have been created over the past 50 years for use in communication and navigation systems. Each type has a particular use for which it is better than the others. Microstrip antennas are utilized in reconfigurable antenna designs the most commonly because they are inexpensive, lightweight, and simple to manufacture [2]. Reconfigurable antennas were initially mentioned in a 1983 D. Schubert patent [2]. The Reconfigurable Aperture Program-(RECAP) was funded by the US Defense Advanced Research Projects Agency(DARPA) in 1999 to research the use of reconfigurable antennas [3]. Broadband networking, cognitive radio,

ISSN:2222-758X
e-ISSN: 2789-7362

and MIMO systems all include reconfigurable antennas. An antenna's frequency, polarization, or emission characteristics might all change as a result. The bulk of antenna reconfigurability techniques alter the electromagnetic fields of the effective aperture [4]. Due to their simplicity of manufacture and inclusion into compact electronic devices like mobile phones and laptops, reconfigurable patch-antennas are the reconfigurable antennas that have been developed the most frequently in recent years. A fundamental reconfigurable patch antenna is composed of several distinct metalized components coupled by switches or tuning elements and delivered aboard an aircraft [4].

By dynamically changing the switch states, different metalized components can come into touch with one another, changing the antenna's overall radiation effectiveness [5]. Multiple input multiple output (MIMO) antennas are used to increase the wireless channels' capacity, however [5]. A large data rate is successfully divided into several streams at lower data rates by the commonly used MIMO technology to support spatial diversity features. MIMO antennas have been designed in a variety of methods by many researchers to function across a broad range of frequency ranges, and they are utilized by multiple wire-free communication technologies, including WLAN, 3G, LTE, and WiMAX (4G) [6]. A MIMO antenna with small dimensions, high gain and performance, CP radiation, as well as broad impedance bandwidth, is also required for many wireless communication systems. Additionally, MIMO systems have been recommended as a means of reducing the impacts of multipath fading [7]. However, especially in portable contemporary MIMO devices and systems, the tight coupling of neighboring antennas may be the worst limitation [8].

Mutual coupling, which is a term for electromagnetic losses brought on by surface wave interactions between antenna elements [10], needs to be decreased in MIMO systems to enhance antenna impedance matching and radiation characteristics [9]. The mutual coupling in this scenario is equivalent to surface wave leakage, albeit varying significantly depending on the array design, separation lengths, and antenna form [11]. Another design based on novel metasurface was proposed in [12] for gain enhancement and direct antenna modulation was published recently for direct antenna modulation. In [13], a design based on Origami technology was developed for MIMO systems in the 5G networks. The proposed work in [14] for a 10GHz wireless power transfer application was proposed using a met surface micro-strip antenna system. Finally, a design of a high gain antenna based on reconfigurable metasurface for 6G systems was proposed in [15].

II. Antenna Geometrical Details

From the feed site to $28\ \mathrm{mm}$, a transmission line is used to build the planned antenna. As shown in Fig. 1, a key-shaped monopole antenna is created by horizontally connecting the transmission line to a strip line. The suggested monopole is positioned below a second patch-based MTM surface array [5] to achieve circular polarization. The suggested MTM surface array is composed of a circular Koch fractal patch of the 3rd iteration and an array of oriented Hilbert curve unit cells. With four circular Koch apertures and cross-section slots, the circular Koch patch is flawed.

The third order of structure is used to create a frequency resonance in the suggested 3^{rd} iteration Hilbert curve unit cell. As a result, each antenna element is built using a 3^{rd} iteration Koch patch geometry arranged in a circle on an FR4 substrate. A CPW microstrip line positioned on the same substrate side as the antenna patch feeds the antenna patch. To suppress surface waves for the patch antenna built on the MTM construction, the array is directed around the patch edges [9]. As a result, the antenna gain-bandwidth product is much improved. To provide bandwidth increase with the greatest

ISSN:2222-758X
e-ISSN: 2789-7362

input impedance coupling, the proposed transformer is coupled with the suggested antenna components. As was already indicated, the suggested transformer has a four-stage binomial structure [4].

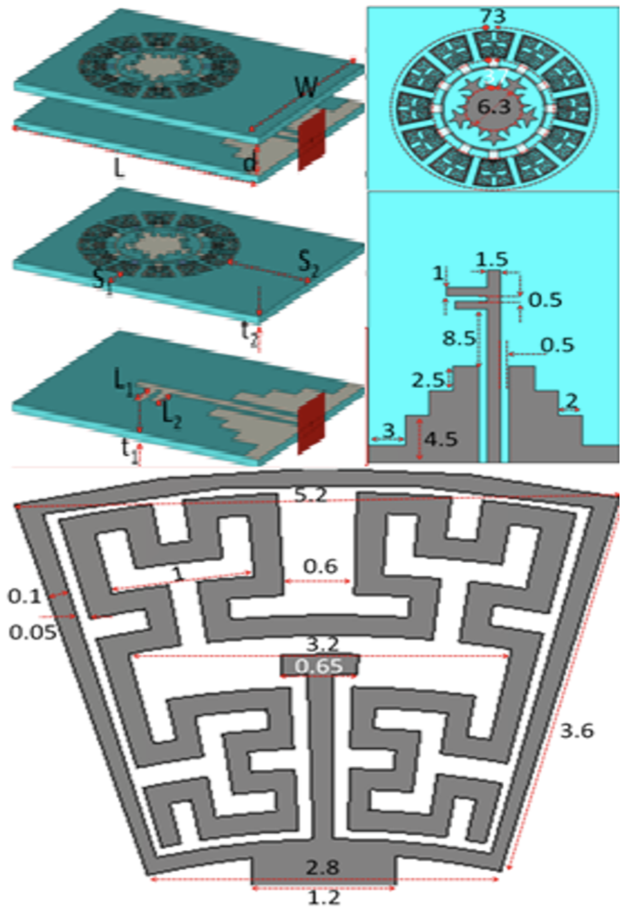

Figure 1: Antenna element structure with all geometrical details in mm scale.

III. MTM Array Characterizations

Numerically, realizing the proposed MTM array characterizations, commercial software packages are invoked. As seen in Fig. 2(a), the proposed MTM array is inserted inside a virtual waveguide to evaluate the band gap through the dispersion spectrum and S-parameters in terms of S_{11} and S_{12} spectra. The authors validated the obtained results from CST MWS using the HFSS software packages. In Fig. 2(b), the dispersion diagram is displayed. The suggested unit cell is found to achieve an outstanding band gap between 2.5GHz and 3GHz. As shown in Fig. 2(c), the calculations are presented for the S-parameters assessment. The acquired results are found to agree with one another in terms of S-parameter spectra. To ensure a transverse electromagnetic mode, the characterization is carried out in the simulation utilizing a virtual waveguide approach. When the switches marked with the color yellow are turned ON, the outcomes shown in Fig. 2(c) are produced. Perfect electrical conductors (PEC) and perfect magnetic conductors (PMC) surround the suggested MTM, which is housed

ISSN:2222-758X
e-ISSN: 2789-7362

inside the analyzed waveguide. As shown in Fig. 2(a), the other two sides are employed for excitation using two waveguide ports. The proposed structure shows high selectivity at certain frequency bands to act as surface selective surfaces. In such a design, it is observed that the proposed structure shows several resonances at $1.5\text{GHz}, 3\text{GHz}, 4.4\text{GHz}$, and 5.6GHz as seen in Fig. 2(c). Such frequency resonances are achieved due to the effects of the fractal geometry introduction that provide excellent size reduction.

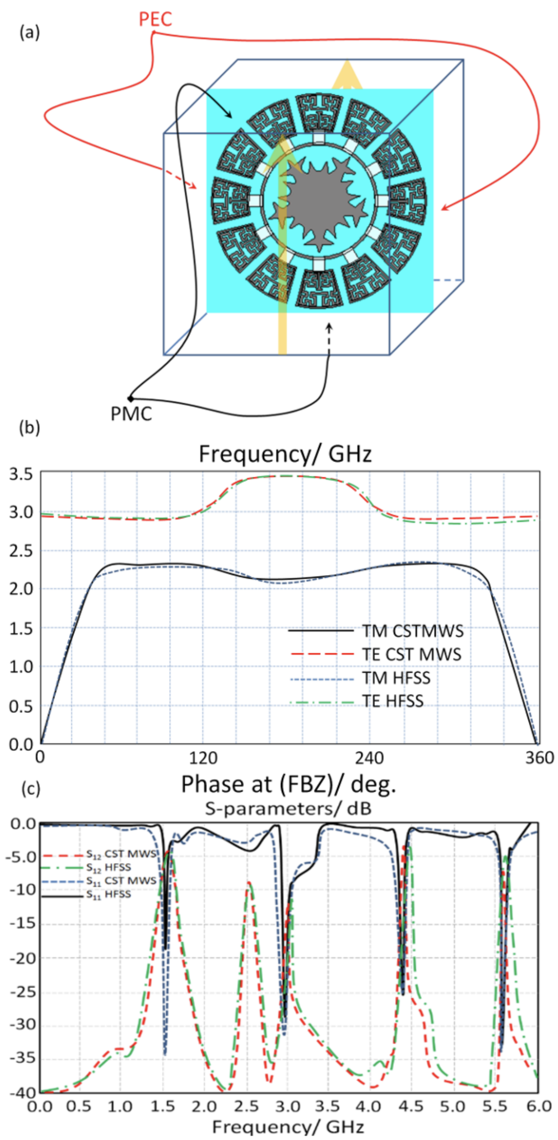

Figure 2: The proposed MTM array characterizations: (a) Simulation setup, (b) S-parameters spectra, and (c) Dispersion diagram.

IV. DESIGN METHODOLOGY

A. *Monopole Dimensions*

With the help of a conventional CPW structure, the suggested monopole is stimulated. Three geometries are used to study the proposed monopole's performance: without a trace printed monopole. The suggested geometry with a single trace is then presented. The third one follows and is based on two traces. The suggested antenna offers two frequency bands rather than just one, as can be seen by the introduction of a single line. Nevertheless, the antenna may function over three frequency bands by raising the trace number. This is explained by the fact that raising the trace member increases harmonic reflections [7], which are caused by reducing the

impedance imaginary component [3], which enhances the achieved impedance matching. The suggested antenna S_{11} spectrum change by altering the trace number is depicted in Fig. 3(a). Fig. 3(b) displays the antenna gain spectrum fluctuations concerning the trace number growth. Since the current surface area is quite small, it is discovered that raising the trace number significantly affects the antenna gain. This is because the current surface area does not significantly change as the number of strip lines increases. This finding is consistent with earlier research, which was reported in [8], according to which the suggested strip line acts as an open setup matching load to regulate the harmonic production.

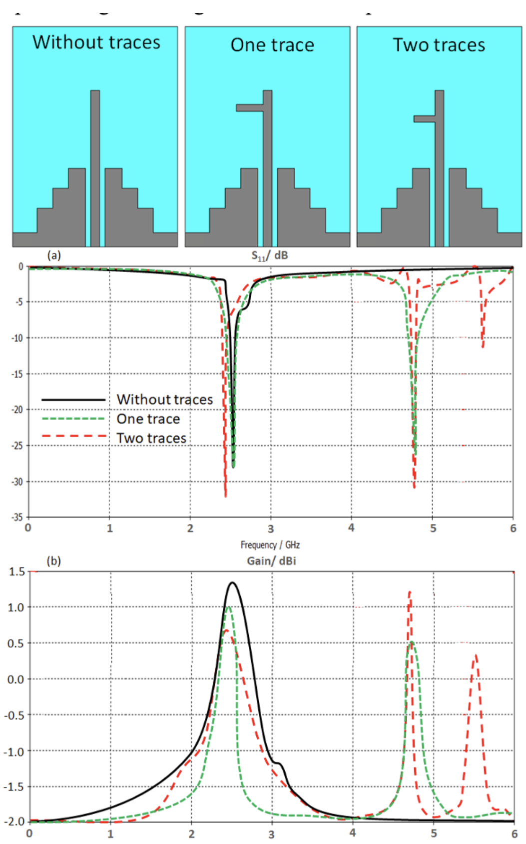

Figure 3: Antenna performance in terms of (a) S11 and (b) gain spectra

ISSN:2222-758X
e-ISSN: 2789-7362

B. Circular-3rdIteration Koch Patch Introduction

The authors then used a numerical parametric study based on varying the vertical separation distance (d) between the proposed monopole and the circular-Koch patch on the proposed antenna S_{11} gain and spectra to understand the effects of adding the proposed circular-Koch patch on the antenna performance. In this study, the

vertical distance is varied in steps of 1 mm, changing the antenna performance from 1 mm to 4 mm. The suggested antenna is found to increase the frequency bandwidth by altering the vertical position, as shown in Fig. 4(a). However, the antenna gain is degraded with increasing the vertical position, as seen in Fig. 4(b). This is caused by increasing the capacitive losses that trap the antenna radiation in energy between the proposed antenna and the second patch layer [10].

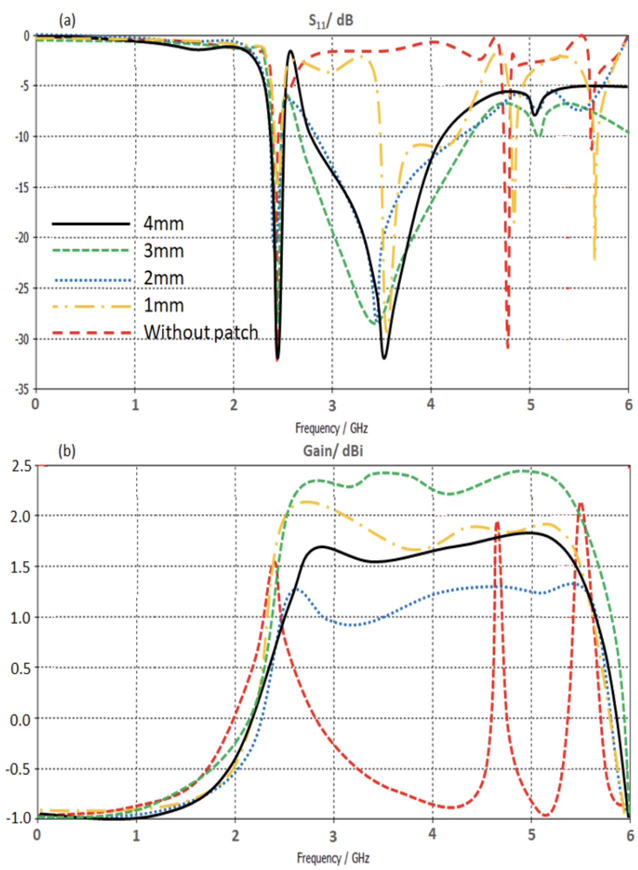

Figure 4: Antenna performance: (a) S_{11} and (b) gain spectra.

C. MTM Array Introduction Effects

The proposed MTM inclusions are introduced to the suggested antenna design with three attempts as 4unit cells, 8-unit cells, and 12-unit cells. Each case is proposed to understand the effect of unit cell introduction on the antenna performance in terms of S_{11} and gain spectra. It is concluded that increasing the proposed MTM unit cells increases the antenna

ISSN:2222-758X
e-ISSN: 2789-7362

bandwidth insignificantly from 10MHz to 100MHz at the first frequency resonance and from 200MHz to 300MHz at the second frequency resonance, as shown in Fig. 5(a). The antenna gain is found to be increased significantly with increasing the proposed MTM unit cell number, as presented in Fig. 5(b). Such enhancements are achieved due to the ability of the proposed MTM array to suppress the surface wave effects at the second patch edges, which is a very effective solution to overcome the antenna limitations [9].

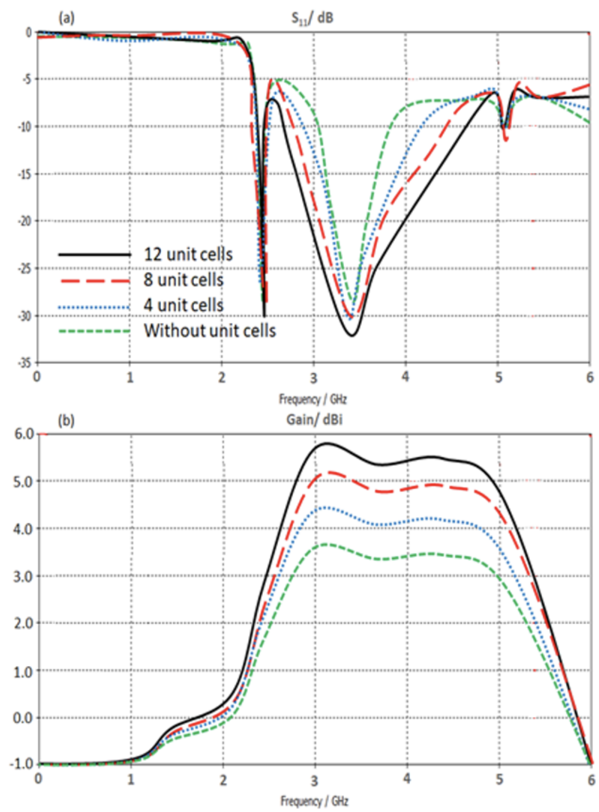

Figure 5:

Antenna performance with unit cell number variation: (a) S_{11} and (b) gain.

D. Switching Effects

The proposed antenna performance, after introducing the second layer, is discussed in terms of different switching situations. In this work, the antenna performances in terms of S_{11} and gain spectra are evaluated, as shown in Fig. 6. It is found by changing the red switches ON, the antenna shows a single frequency band disappear and only two bands stay with good matching as seen in Fig. 6(a). However, when the yellow switches are ON, the antenna offers three frequency bands with excellent matching. It is important to point out that the affected mode with the switching effects is only the third mode at $F_3 = 5.1\text{GHz}$ as shown in Fig. 6(a). The antenna gain spectra are found to be significantly affected by different switching scenarios as depicted in Fig. 6(b) at 5.1GHz. It is found the proposed antenna realizes a gain of 4.5dBi for ON status at 5.1GHz and it is degraded to 1.1GHz at 5.1GHz. This is accomplished by directing the surface current distribution on the second layer, as shown in Fig. 6(c). Therefore, it is obvious that switching OFF the red switches or the yellow switches could realize a significant change in the surface current distributions. Thus, the antenna matching is changed from -13 dB to -4 dB at 5.1GHz specifically through changing the switching scenarios.

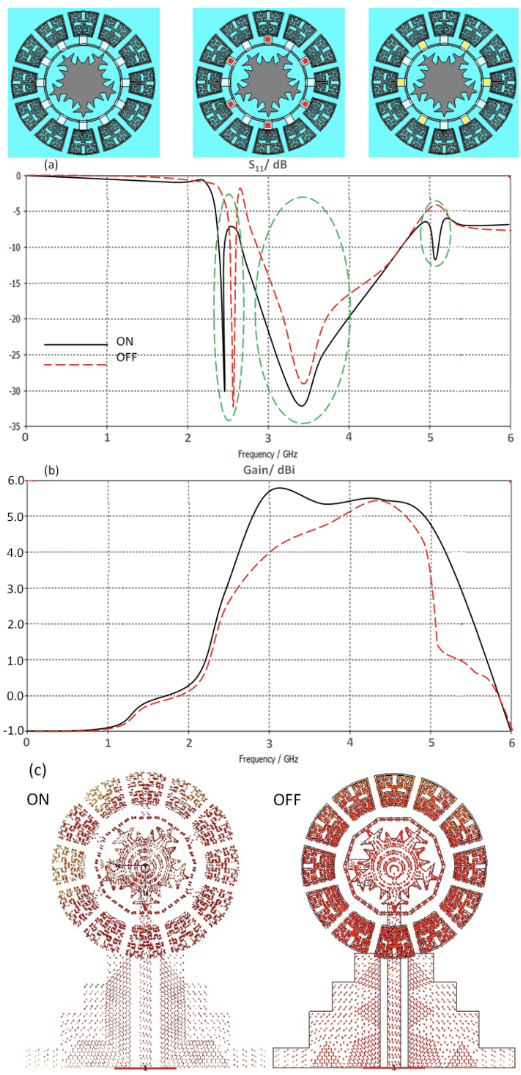

Figure 6:

Different switching conditions for the proposed antenna: (a) S_{11}, (b) gain, and (c) current distributions.

ISSN:2222-758X
e-ISSN: 2789-7362

V. Results validation and Discussions

Using commercial software from the HFSS commercial software package, the results from the preceding section's use of CST MWS are verified. As seen in Fig. 7, there is a high agreement when the data are compared. Numerical tests are performed on the antenna performance in terms of S_{11} and gain spectra and radiation patterns. It is discovered that Fig. 7(a) displays the suggested antenna S_{11} spectrum between 0.1GHz and 6GHz. Fig. 7(b) shows the antenna radiation-patterns at 3.5GHz. It is discovered that the antenna radiation patterns are nearly

typically direct to the second layer. This is a result of the proposed antenna structure's lack of a rear panel ground plane in its design [3].

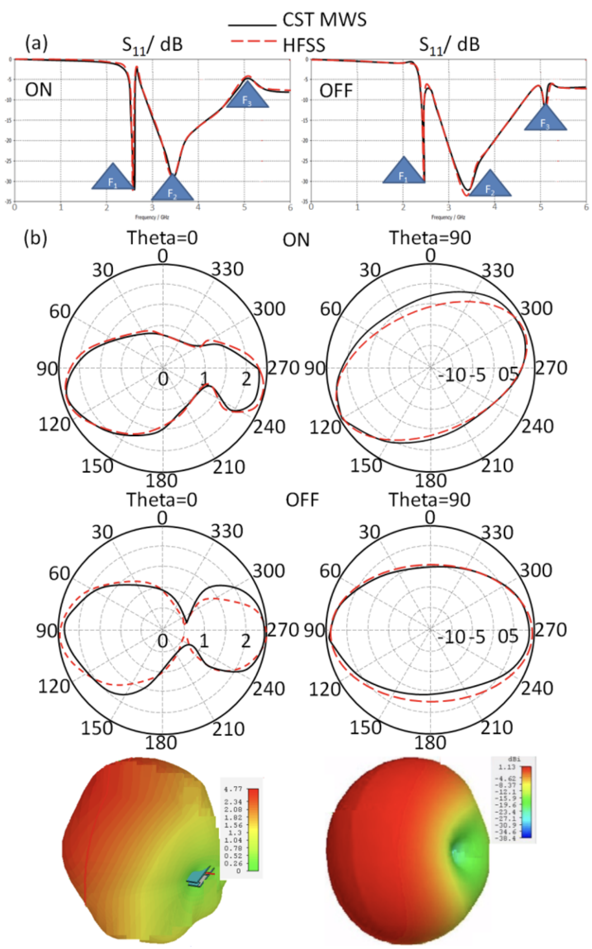

Figure 7: Antenna-performance: (a) S_{11}-spectra and (b)Radiation patterns.

The proposed antenna performance is compared to their identical that were published in the literature. It is found that the proposed antenna provides excellent performance with enough miniaturized size in comparison to the published results as listed in Table 1.

www.ijict.edu.iq
ISSN:2222-758X
e-ISSN: 2789-7362

TABLE I
COMPARISON BETWEEN THIS WORK AND PREVIOUS RESEARCH.

Previous Work	Frequency/GHz	Antenna Dimensions/mm^2	Gain/ dBi
[2]	3.6/3.9/4.9	25 x 25	3.6
[5]	3.5/4.2/5.4/6	32 x 28	3.9
[10]	2.5/3.7/4.9	30 x 40	4.1
[13]	5.5	21 x 17.5	3.5
[2]	3.6/3.9/4.9	25 x 25	3.6
[5]	3.5/4.2/5.4/6	32 x 28	3.9
[10]	2.5/3.7/4.9	30 x 40	4.1
[14]	5.01-6.12	25 x 20	3
This work	2.5, 3.5, 5.1	40 x 30	4, 5.5, 4.5

VI. Conclusion

The suggested antenna is proposed for 5G wireless communication networks. Therefore, the antenna is designed numerically using CST MWS to operate at sub-6GHz frequency bands with miniaturized size. The proposed antenna is found to operate at three frequency bands $2.5\text{GHz}, 3.5\text{GHz}$, and 5.1GHz with a maximum gain of 5.5dBi. The performed antenna is configured from a novel 12 MTM unit cell circular array. It is established that the proposed antenna realizes a major improvement in the bandwidth by increasing the MTM array as well as the radiation properties. The proposed antenna performance is characterized by the radiation patterns at the 3.5GHz frequency band for both ON and OFF scenarios. The proposed antenna radiation patterns are found to be significantly affected by changing the switching scenarios. A numerical simulation based on the HFSS software package is invoked for validations. Lastly, it is established that the suggested antenna is an excellent applicant for wireless communication in modern networks.

Funding

None

ACKNOLEDGEMENT

The author would like to thank the reviewers for their valuable contribution in the publication of this paper.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

www.ijict.edu.iq
ISSN:2222-758X
e-ISSN: 2789-7362

REFERENCES

[1] Al-tameemi A. R., "A Novel Conformal MIMO Antenna Array based a Cylindrical Configuration for 5G Applications," *9th Int. Con. on Elec. Eng., Comp. Sci. & Inf. (EECSI)*, pp. 446-451, Dec. 2022.

[2] Al-khaylani H. H, et.al. "Optically remote-controlled miniaturized 3D reconfigurable CRLH-printed MIMO antenna array for 5G applications", *Microw Opt Technol Lett.*, 65: 603- 610, Jan 2022.

[3] Al-Khaylani H. H., et.al, "A Novel Miniaturized Reconfigurable Microstrip Antenna Based Printed Metamaterial Circuitries for 5G Applications" *Progress In Electromagnetics Research C*, 120: 1-10, May. 2021.

[4] Ahmed H. S. et.al, "Compact MIMO Antenna Array for 5G Applications based Novel Hayder-Koch Fractal Geometry," *International Telecommunications Conference (ITC-Egypt)*, Alexandria, Egypt, pp. 1-5, May. 2022.

[5] Alaukally M. N. N., et.al, "Miniaturized flexible metamaterial antenna of circularly polarized high gain-bandwidth product for radio frequency energy harvesting", *Int J Commun Syst.*, 35(3):234-239, Aug. 2021.

[6] Al-Hadeethi S. T. (2023), "A Printed Reconfigurable Monopole Antenna Based on a Novel Metamaterial Structures for 5G Applications", *Micromachines*, 14(1):131-139.

[7] Kamel, A.S., Jalal, A.S.A. "Novel reconfigurable monopole-based matching circuitry design for 5G and modern wireless communication systems." *Int J Commun Syst.* 2022; 35(14):e5252.

[8] Nafea, S. N. (2018). "Performance Improvement for Patch Antenna Over ISM band (5.725-5.875) GHz Using Multiple Superstrates." *Iraqi Journal of Information and Communication Technology*, 1(1), 11â17.

[9] Ghadeer S. H., "Compact MIMO Antenna Array for 5G Applications," *9th Int. Con. on Elec. Eng., Comp. Sci. & Inf. (EECSI)*, pp. 399-402, Dec. 2022.

[10] Ghadeer S. H., et.al, "An innovative fractal monopole MIMO antenna for modern 5G applications", *AEU International Journal of Electronics and Communications*, 159(154480):1-15, Sep. 2022.

[11] Marwah H. J. et.al, "Circularly Polarized Metamaterial Patch Antenna Circuitry for Modern Applications", *Inte. Jou. of Emerg. Tech. & Adv. Eng.*, 12(12):1-8, Dec. 2022.

[12] Marwah H. J., et.al, "Intelligent Metasurface Layer for Direct Antenna Amplitude Modulation Scheme", *IEEE access*, vol. 10, no. 10, pp.1-13, July 2023.

[13] Y. A. Jassim, M. Ãevik and T. A. Elwi, "10GHz Printed Circuit Antenna for Wireless Power Transfer Applications," *5th Inter. Cong. on Human-Comp. Intera., Opt. & Rob. Appl. (HORA)*, 2023, pp. 1-4.

[14] Humam H., et. al. "ORIGAMI ANTENNA ARRAY SHAPED MOSQUE OF MUHAMMED AL-FATIH FOR VISUAL SIGHT ENHANCEMENT IN MODERN 5G MIMO NETWORKS", *Journal of Engineering and Sustainable Development*, 27(4), 417â428, March 2023.

[15] Zainab S. M. et.al, "Photonic controlled metasurface for intelligent antenna beam steering applications including 6G mobile communication systems", *AEU - International Journal of Electronics and Communications*, Vol. 166, May 2023.

