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Original Research

ORIGAMI ANTENNA ARRAY SHAPED MOSQUE OF MUHAMMED AL-FATIH FOR VISUAL SIGHT ENHANCEMENT IN MODREN 5G MIMO NETWORKS

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Abstract: Origami antenna technology is initiated recently to resolve different relative issue with visual pollution and antenna embedding inside buildings sights. This technology inspired us to invoke historical sites to shape a novel antenna design-based MIMO (Multi-Input and Multi-Output) technology for 5G systems at sub-6GHz frequency bands. In such a matter, the antenna array is designed to be shaped as Muhammad Al-Fatih Mosque. The proposed antenna array is constructed from 2-elements of a 2D array configuration with a separation distance of λ/10 at 2.45GHz. After conducting several parametric studies using CST Microwave studio, the authors reached to the optimal performance of the proposed design. The proposed antenna array is found to show three frequency bands, of matching S11≤-6dB, 1.7GHz-2.7GHz, 3.1GHz-3.8GHz, and 4.5GHz-5.1GHz with a gain of 5.2dBi, 6.8dBi, and 8.1dBi, respectively. Nevertheless, it is found that the proposed antenna array mutual coupling, S12, is about -20dB over the entire frequency band of interest. Later, the proposed antenna performance is validated using commercial HFSS software package. Finally, the results from the conducted design methodology are found to agree very well with each other.

Keywords: 5G; sub-6GHz; Origami; MIMO; historical design

1. Introduction

Antenna origami is a technique for designing and fabricating antennas using the principles of origami, the Japanese art of paper folding [1]. The goal of antenna origami is to create compact and lightweight antennas with specific performance characteristics that can be easily manufactured using simple and cost-effective techniques. Antenna origami involves folding a conductive material, such as copper, into a specific geometric pattern that forms an antenna structure [2]. The folded antenna structure can be designed to operate at a specific frequency or range of frequencies, and it can be integrated into a variety of devices, such as smartphones, and

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wearable, and unmanned aerial vehicles [3]. The goal of origami antennas is to create lightweight, compact, and low-cost antennas with specific performance characteristics that can be integrated into a wide range of devices and applications [4]. Origami antennas have many potential benefits, including Compactness based complex 1D, 2D, and 3D shapes, lightweight, low-cost, and customizability [5]. Origami antennas have been successfully demonstrated in a range of applications, including wireless communications, radar, and satellite communication [6].

One of the most attractive technologies is a construction based on attractive seen such as historical sights [7] to avoid visual pollution. Visual pollution is a term used to describe the negative impact of man-made structures and objects that are visually intrusive or unsightly, such as billboards, advertisements, power lines, industrial buildings, and urban sprawl [8]. Visual pollution can have a range of negative effects, including Aesthetic degradation, environmental degradation, psychological effects, and economic impacts [9]. There are various efforts underway to address visual pollution, specifically in the field of communication networks [10]. For example, an artificial tree used to hide a mobile transmitting station is called a "monopalm" or "monopine" [11]. These structures are designed to blend into natural surroundings, such as parks or residential areas, to minimize the visual impact of the transmitting station on the surrounding environment.

The authors conducted the use of historical sites to design novel antenna array. The proposed design is realized using a geometrical shape of Muhammad Al-Fatih Mosque. The Fatih Mosque, also known as the Mosque of Muhammad Al-Fatih, is a historical mosque located in Istanbul, Turkey that was built in 1453 [12]. It has undergone several renovations and restorations over the years, including a major restoration in the early 20th century [13]. The Fatih Mosque is an important religious and cultural landmark in Istanbul, and it continues to be an active place of worship for Muslims today [14]. In this work, the design is realized as a Muli-Input-Multi-Output (MIMO) array to suit the applications of the Fifth Generation (5G) networks. MIMO technology involves using multiple antennas at both the transmitter and receiver ends of a wireless communication link to improve the quality and reliability of data transmission [15]. In the context of 5G, MIMO technology is used to increase the amount of data that can be transmitted over a given wireless channel [16].

In this work, the authors developed an antenna shaped of Muhammad Al-Fatih Mosque for MIMO applications. The proposed work is classified as in section 2, the literature survey is discovered. The antenna geometrical details are presented in section 3. The design methodology is explored is section 4. The obtained results are presented in section 5. The paper is concluded in section 6.

2. Literature Survey

A fractal form-based MIMO antenna for sub-6-GHz applications is introduced by Sree, et.al. in [4]. The main objectives while building the MIMO system antenna are to improve scattering signals and maximize performance. Elwi, et.al. [17] proposed a compact dual-function antenna that can operate in the 3.5GHz and mm-wave bands for 5G mobile applications. The frequency reconfigurability method is applied by this antenna. The proposed antenna was drastically scaled down to 15.3 mm 7.2 mm 0.508 mm using a meandering line structure and a shorter ground plane. The use of a dual-port transparent MIMO antenna that resonates in the sub-6 GHz 5G band was advised in [18]. Two identical circular radiating components supplied by a microstrip feedline are built using the high-frequency structure simulator (HFSS) program, which is based on the finite element method (FEM). We explore the implications of the isolation mechanism in two examples. Unlike the second instance, where the components are vertically positioned and oriented in the opposite direction with the same ground, the first situation has two horizontally positioned elements that are aimed in the same direction and are on separate ground planes. In the study [19], numerous slots, partial ground, and defective ground construction techniques are combined to accomplish the benefits of compactness, broad impedance bandwidth, and steady radiation pattern. A compact MIMO patch antenna with an Electromagnetic Band Gap (EBG) structure is provided in [20] for usage in sub-6 GHz UWB 5G applications. More research on antenna performance is being done in the areas of radiation patterns and impedance bandwidth. A compact, self-isolating dual-element MIMO antenna encompassing the GSM-900 (0.88-1.08 GHz) and sub-6 GHz band for the 5G (3.11–4.63 GHz) spectrum has been presented in [8]. The new antenna, together with its array and MIMO configuration, for 5G sub-6GHz applications, is given in [21]. The proposed antenna element works at a core frequency of 5.57GHz for Sub-6GHz 5G communication applications. The target gain of 12 dB is achieved using a four-element array configuration, which raised the bore side gain from 6.66 dB to 12.4 dB. A smaller four-port MIMO antenna with good impedance matching for 5G new radio (NR) sub-6 GHz n77/n78/n79 and 5GHz WLAN is suggested in [22] by Abdulmjeed et.al. to operate between 3.2 and 5.75 GHz. Their initiative [23] intends to develop a compact, 3.5 GHz MIMO antenna that is compatible with 5G. Signal-to-noise ratios in mobile communication systems can be improved with MIMO antennas. To increase channel capacity, the signal-to-noise ratio can be increased. In [24], a flexible transparent wideband four-element MIMO antenna with a linked ground plane was proposed using numerical calculation and experimental measurement study. The recommended antenna has a 2.2GHz-6GHz (92.32%) impedance bandwidth of 10dB and an overall isolation level of more than 15dB. The paper [25] offers a thorough examination of the characteristics of the 5G spectrum allocations, their development, and their characteristics, as well as their MIMO antenna design and its connection to safer user applications and mutual coupling reduction techniques. Nearly every element of 5G is correctly covered, especially the various antenna designs and the performance metrics related to MIMO architecture. The paper also provides a brief description of massive MIMO technology for base station applications. All of these topics are well treated in [26], including the envelope correlation coefficient, efficiency, isolation, size, number of ports, and isolation techniques in compact MIMO antennas to different bands. As mutual coupling has a considerable negative effect on efficiency, envelope correlation coefficients, diversity gain, radiation patterns, gain, and isolation, different approaches are required when constructing MIMO antennas for a limited region. A planar MIMO dipole antenna is recommended in [27] for a future sub-6 GHz 5G application. The MIMO antenna substrate's low surface waves enable efficient separation of the MIMO components. The radiation from the MIMO antenna construction may be changed to create different kinds of desired beams. Modern wireless communication devices are a sign of rapid technological development. With these systems, an antenna is attached to every communication cable. Following the present generational expansions, antennas are becoming smaller, lighter, more portable, wearable, cost-effective, and conformal while maintaining essential performance characteristics like impedance bandwidth, efficiency, gain, directivity, etc. A wide range of antenna designs that are appropriate for a number of wireless communication system applications are provided to readers by the authors [28]. They also discuss the most recent state-of-the-art in conventional and novel antenna technologies. It is crucial to emphasize that new 5G antenna designs will enable fresh breakthroughs in breaking through all outdated development barriers. Wearable models, conformal structures, MIMO configurations, microstrip, and planar monopole antennas are examples of antenna technology. Mobiles, laptops, smart watches, tablets, and other gadgets are examples of planned wireless communication systems.

3. Antenna Geometrical Details

The design specifications of a sub-6GHz 5G antenna will depend on the specific application and use case, but some general design considerations are important to keep in mind. Some of the key design specifications of a sub-6GHz 5G antenna include:

3.1 Frequency Range: Sub-6GHz 5G operates in the frequency range of 600 MHz to 6 GHz, so the antenna must be designed to operate within this range.

3.2 Bandwidth: 5G networks require antennas with a wide bandwidth to support high data rates. The antenna should have a bandwidth of at least several hundred megahertz to support the wide range of frequencies used in 5G networks.

3.3 Gain: The antenna gain determines the strength of the signal that can be transmitted and received. Higher gain antennas can transmit and receive signals over longer distances. The gain of the antenna will depend on the specific application and use case but typically sub-6GHz 5G antennas will have a gain of around 5-7 dBi.

3.4 Polarization: The polarization of the antenna determines the orientation of the electric field of the transmitted and received signal. The most common polarization used for sub-6GHz 5G antennas is linear polarization, which can be either vertical or horizontal.

3.5 Beam width: The beam width of the antenna determines the angle at which the antenna can transmit and receive signals. For sub-6GHz 5G antennas, the beam width should typically be wider than for higher frequency antennas, to accommodate the larger wavelengths of sub-6GHz signals.

3.6 Radiation pattern: The radiation pattern of the antenna determines the direction and strength of the signal transmitted and received. The antenna should be designed to have a uniform radiation pattern over the desired coverage area.

3.7 Size and shape: The size and shape of the antenna will depend on the specific application and use case, but generally sub-6GHz 5G antennas should be designed to be compact and lightweight to enable easy integration into devices and infrastructure.

These are some of the key design specifications to consider when designing a sub-6GHz 5G antenna, but there may be other factors that are specific to the application or use case that need to be taken into account.

In this work the antenna design is fixed to 60×136×1 mm3, the MIMO design (two antennas with MTM in between) is shown in the top left of Fig. 1, also Fig. 1(a) shows domes with radiation element printed on an FR-4 substrate with permittivity of 4.6 and losses about 0.00178. The antenna ground plane is introduced as a coplanar waveguide (CPW) conductive plate as shown in Fig. 1(b). The antenna array is organized on a 2D configuration that is separated with a metamaterial (MTM) spacer of a hexagonal shape. The proposed MTM spacer is organized as a 1D array configuration of 5 unit cells as seen in Fig. 1(c).

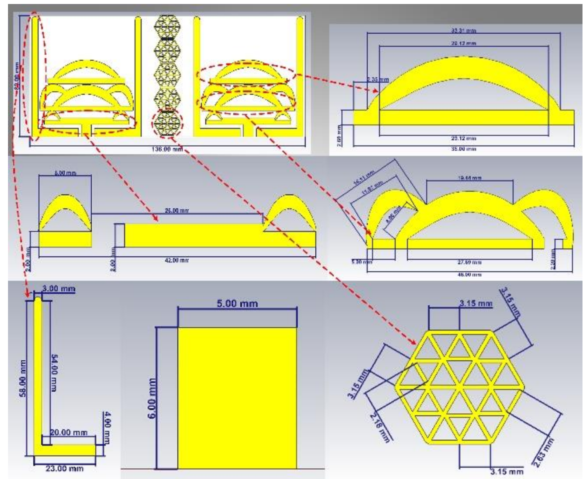

Figure 1. Antenna array design: (a) front view, (b) CPW view, and (c) MTM unit cell.

4. Design Methodology

In the beginning, it is considered several parameters during this section without affecting the original shape of the mosque. Therefore, they are satisfied with the following parameters:

4.1 Effects of changing L-Shaped stub length:

The effects of changing the L-shaped stub length on the proposed antenna array performance in terms of S11 and S12 spectra are shown in Fig. 2. It is found from the obtained results; the antenna matching impedance bandwidth is enhanced significantly by changing the proposed L-Shaped stub length. This realizes the fact that such a structure shows an effect of a matching circuit that is very useful for the proposed antenna performance. However, the antenna coupling effects are found to be significantly decade with increasing the proposed L-Shaped stub length.

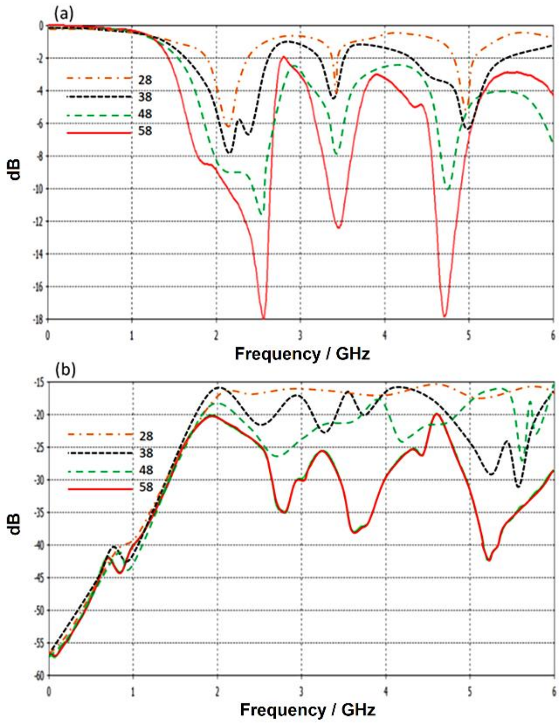

Figure 2. Antenna S-parameters the proposed L-shaped length: (a) S11 and (b) S12 spectra.

4.2 Effects of changing CPW gap:

Next, to explore the effects of varying, the proposed CPW on the proposed antenna performance, the gap space is changed between the proposed CPW from 1mm to 2.5mm with a step of 0.5mm. It is found after reaching the distance of 2.5mm, the antenna realizes an excellent bandwidth with low coupling effects as seen in Fig. 3.

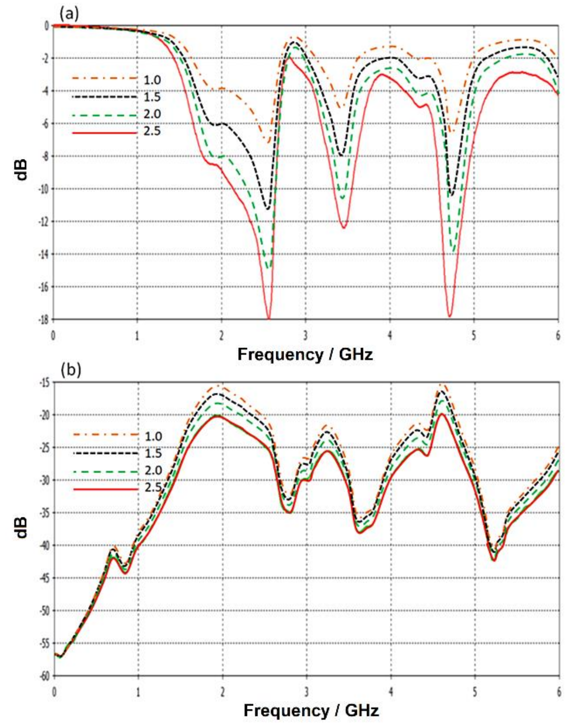

Figure 3. Antenna S-parameters with a varying gap distance of the proposed CPW structure: (a) S11 and (b) S12 spectra.

4.3 Effects of introducing MTM unit cells:

Now, to realize the effects of the proposed MTM unit cell number on the proposed antenna performance, the authors conducted a simulation study by varying the unit cell number from 0 to 5 unit cells with a step of 1 unit cell. It is observed a significant enhancement could be achieved by increasing the unit cell number with an obvious reduction in the mutual coupling can be achieved with increasing the unit cell number. As seen in Fig. 4, the proposed antenna performance shows an excellent enhancement by increasing the proposed unit cell number to 5. It is good to mention that the proposed antenna may not cover the entire frequency bands within sub-6GHz, but shows some resonance within sub-6GHz to be very suitable enough for such applications [6].

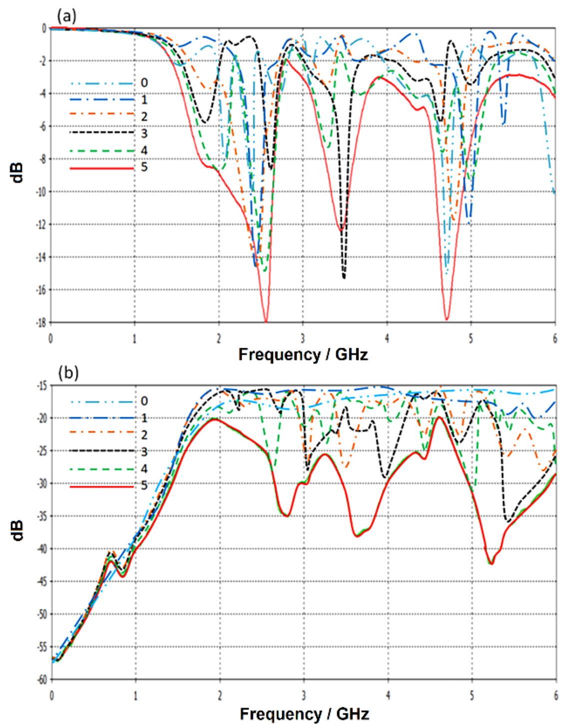

Figure 4. Antenna S-parameters with varying the proposed unit cell number: (a) S11 and (b) S12 spectra.

It is found that the proposed antenna array mutual coupling is reduced significantly with increasing the number of unit cells because of the increase of the surface impedance as series connection facts [8].

5. Results and Discussion

5.1 MTM Characterizations:

To realize the proposed MTM unit cell performance is evaluated in terms of S-parameters spectra and dispersion diagram. Based on the effective medium theory that was explained in [15], Najim, et. al. evaluated the effective constitutive parameters. These parameters describe the inherent characteristics of the proposed fractal structure at the resonance frequency band. Therefore, the permittivity, permeability, and intrinsic impedance are calculated. These calculations are applied to the proposed unit cell. In this analysis, the proposed unit cell is located inside a virtual wave guide structure to evaluate the unit cell basic characteristics. Therefore, the upper and lower walls are assumed to be perfect electric conductors (PEC). While the other side walls are considered to be perfect magnetic conductors (PMC). Therefore, the generated waves inside such wave guides are excited from two wave guide ports to mimic TEM-like free space environment [15]. Thus, the unit cell S-parameters would be used to retrieve the basic constitutive electromagnetic properties as shown in Fig. 5. It is found from the proposed results, the proposed unit cell provides band rejection at 3.5GHz frequency band. The obtained results from CST MWS are validated using HFSS software commercial package.

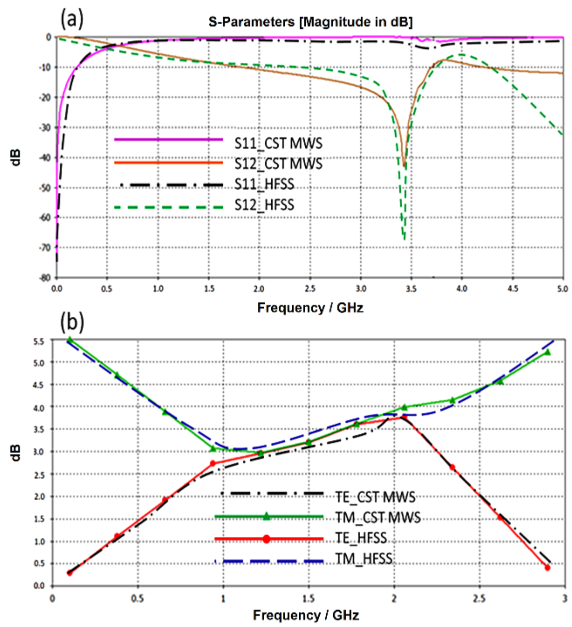

Figure 5. Unit cell performance: (a) S-parameters spectra and (b) Dispersion diagram.

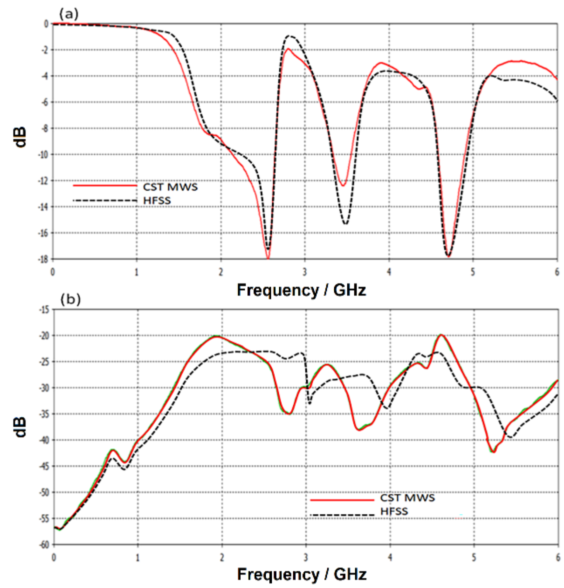

Figure 6. Validated S-parameters: (a) S11 and (b) S12 spectra.

5.2 Antenna Characterizations:

Next, the proposed antenna array performance in terms of S-parameters and radiation patterns is re-evaluated using both CST MS and HFSS software packages. An excellent agreement is found between the obtained results in terms of S-parameters, as seen in Fig. 6.

However, the insignificant discrepancy between the results in terms of radiation patterns due to the effect of boundary conditions differences between the two used software packages as shown in Fig. 7. The evaluated radiation patterns are done at three frequency band of interest at 2.5GHZ, 3.5GHz, and 4.5GHz for 5G applications.

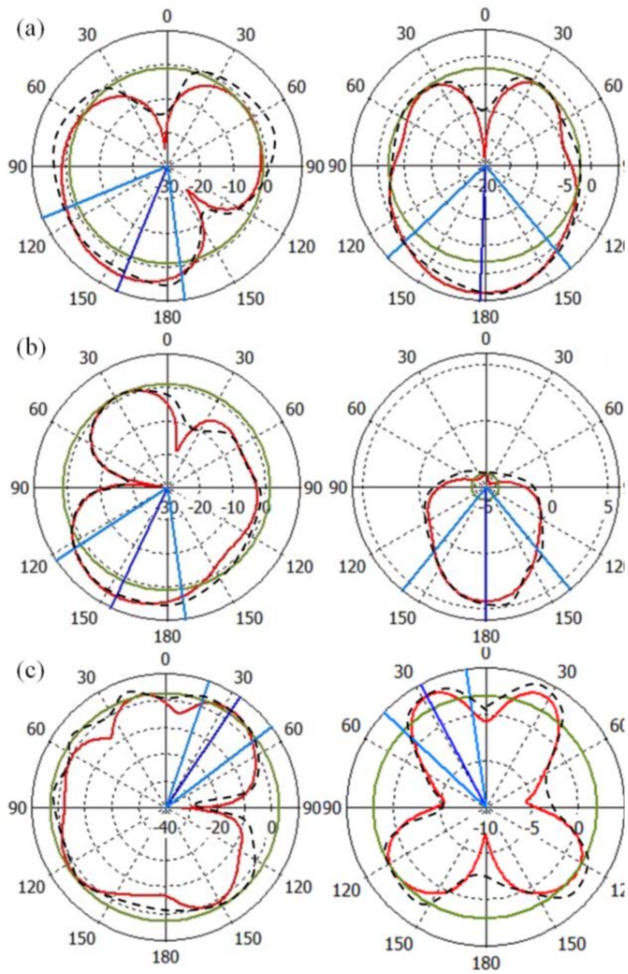

Figure 7. Validated radiation patterns at: (a) 2.5GHz, (b) 3.5GHz, and (c) 4.5GHz.

6. Conclusion

The proposed antenna array is designed using origami technology that is shaped as Muhammad Al-Fatih Mosque. The antenna is printed on an FR-4 substrate to occupy a volume of 60×136×1 mm3. The antenna is designed to provide three main frequency bands around 2.5GHz, 3.5GHz, and 4.5GHz. The antenna elements are separated with five MTM unit cells to reach high size reduction and low mutual coupling. It is found that such bands show S11 magnitude below -10dB with maximum coupling S12 below -20dB. The antenna shows radiation patterns of omnidirectional around most of the frequency band of interest. The antenna design methodology is discussed in this work using CST MWs. Later, the obtained results are validated using HFSS software package. It is found that the proposed antenna elements are separated with a distance of $\lambda/17$. Such separation reduction makes the proposed antenna array shows the minimum distance in comparison to other published designs in the literature. The proposed work is considered the first step in developing a new technology for shaping new antennas to suit the applications of modem indoor communication systems.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Humam Hussein: investigated the analytical methods. Ferhat Atasoy: verified the analytical methods. Taha Elwi: optimized the analysis and discussed the results.

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