

## Original Research

# ORBITAL ANGULAR MOMENTUM-BASED SLOT ARRAY ANTENNA FOR MODERN APPLICATIONS

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**Abstract:** Millimeter waves are the most promising waves for different modern wireless communication networks. This is due to their ability to carry big data with enhanced channel capacity. However, mm-waves suffer from low propagation due to the effects of high attenuation factors with high frequencies. Therefore, in this work, a three-dimensional structural antenna design with a slot array is proposed to achieve high gain through a two-port feeding operation for orbital angular momentum applications of modern communication systems. Also, the improved bandwidth of the proposed antenna makes it an excellent candidate for fifth-generation (5G) communications systems. The antenna basically depends on two concentric structures with conductive circular cross-sectional area. The first structure is shaped as a three-dimensional cone with a cylindrical waveguide. The second structure is shaped as a circular disc with a circular aperture. The two parts of the proposed antenna are centered to be fed with two discrete ports from the side with a 90° phase difference. It is determined that the proposed antenna offers an exceptional gain to vary from 10dBi to 20dBi within the frequency band from 3GHz to 30GHz. It is realized that such enhancement after introducing a conductive circular reflector underneath the conductive cone. The antenna shows a matching impedance below -10dB over the entire frequency band of interest. The antenna radiation properties at 25GHz and 26GHz at the

E-plane and H-plane are characterized. Finally, the antenna performance is validated using two software packages based on CST studio and HFSS algorithms.

**Keywords:** Fifth generation; Orbital angular momentum; Slot array; Three-dimension antennas; Two ports.

## 1. Introduction

Several applications have recently been developed to take advantage of millimeter wave's capacity to travel through various mediums for Contemporary technologies like wireless communication, detection, and remote sensing [1]. As a result of atmospheric turbulence, however, the impact of millimeter wave (mmw) medium attenuations increases rapidly with propagation distance. [2]. As a result, many study groups used various ways to investigate the benefits of mmw with minimal propagation limitations effects by employing Orbital Angular Momentum (OAM) waves [3]. Novel antenna designs have been discussed in the literature for such approaches, such as the

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horn antenna which has been presented using a mode combination technique to generate twisted waves with various OAM orders [4]. Another contribution was to create OAM waves using a circular array of rectangular planar monopole antennas to span frequencies between 20GHz and 160GHz. The proposed work in [5] was created for 60GHz wireless communication link applications using mmw with dual OAM modes antenna. A ring resonator with two feeding ports and a 90° hybrid coupler was used to create the antenna. The radiation beams were focused toward the bore sight direction using a parabolic reflector. An OAM mode reconfigurable antenna with numerous ports and PIN diodes on the feeding network was proposed in [6] the antenna can be used at 2.4 GHz. The use of a circular antenna array to operate at 28 GHz was proposed in [7] for a unit-/multi-cast OAM mode data transmission antenna. The authors in [8] presented a single-arm spiral antenna element based on a mechanical reconfigurable circular array to create OAM waves for 5G applications within the frequency ranges from 3.4 GHz to 4.7 GHz. At 5.8 GHz, a hemispheric dielectric resonator antenna generates two OAM states from two orthogonal signals. The use of the OAM property was exploited by coupling the OAM wave generators to a Maxwell fish-eye lens to construct a lens antenna for 3D beam steering at microwave frequencies [9]. A fan-beam-shaped quasi-Yagi slotted array antenna was suggested for 5G mobile terminals operating at 28 GHz [10]. In another matter, the use of THz antennas based on a planer metasurface layer was proposed in the antenna design in different research papers including 3D and 3D configuration. For example, the antenna based on a printed metasurface of a fractal shape was presented in [11] from a grapheme layer for modern THz communication systems. Another

antenna array based on a bowtie structure was organized to increase the photocurrent density in the range of 200THz to 400THz for infrared and optical communication systems [12]. The design of an antenna based on a cross lines array with a 3D structure was developed in [13] to tune the antenna bandwidth for OAM applications at the optical ranges. The antenna was developed to be organized and structured as a 3D array that was operating at THz ranges from 100THz to 180THz for detection applications [14]. An antenna array was developed from 230×230 element [15] to be applicable for Orbital Angular Momentum (OAM) systems at 10THz frequency bands. Another work was proposed in [16] for biomedical detections using a phased array at 1THz systems. The antenna that was proposed in [17] is used for modern application systems in the optical ranges for inter-digital communication chips. In [18], an antenna array was developed for water purification at the infrared ranges using single-walled carbon nanotubes. The antenna that was proposed in [19] is for sensing applications at 2THz skin detection. Another design was proposed in [20] for array communication systems in optical energy harvesting. A 3D antenna design for modern applications is proposed in this paper to generate OAM modes. The antenna is designed as a slotted cone circular structure with a circular reflector excited by two feeds. CST studio software packages were used to numerically test the antenna performance. The proposed design is validated numerically using the HFSS algorithm. In section 2, the design specifications are discussed. In section 3, the findings are discussed. Finally, section 4 finalizes this paper in the conclusion.

## 2. Antenna Geometrical Details

The geometrical specifics of the projected antenna will be explained in this section. The dimensions of the antenna are shown in millimeters, as seen in Figure 1. The intended use of the suggested antenna is as an OAM antenna. In this design, the wave is guided between the microwave source and the free space impedance by the use of a circular cross-sectional cut cone. Consequently, the cone shape has elliptical slots to mitigate tangential surface waves and concentrate the primary beam onto the direction of the sight bore. Two horizontal and one vertical microwave port, with a phase shift of 900, activate the antenna as well, creating a circular motion on its transverse axis. A circular ground plane reflector is used to enhance the Freon-to-back ratio and maintain directivity in the main lobe direction of the antenna. The entire antenna size is determined to be  $70 \times 100 \times 100 \text{mm}^3$  and is made of a conductive aluminum 3D structure, as shown in Fig. 1. To provide consistent microwave transmission across a broad range of frequencies, the antenna is connected using PNC-type connections. This section presents the presented methods for designing the antenna. The parametric research was done using numerical simulation, following a three-step process:

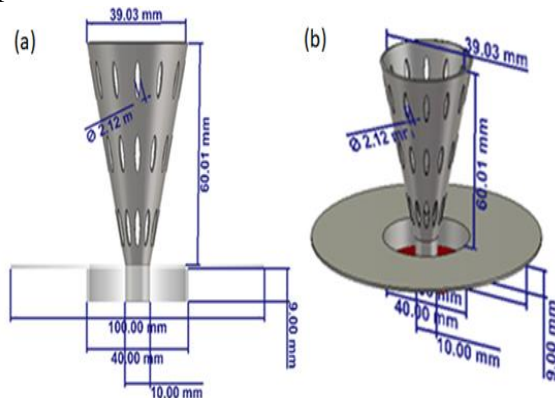


Figure 1. Antenna geometrical details.

### 2.1. Cone Dimension

The proposed antenna structure is constructed with a cone of  $L=100\text{mm}$  height. The height can be adjusted from 90mm to 120mm with a step of 10mm. It has been discovered that the suggested height of the antenna causes a notable change in the antenna's gain-bandwidth product as  $L$  varies. However, this variation becomes significant after  $L=110\text{mm}$ . Therefore, the authors decided to keep the distance  $L=100\text{mm}$  to avoid a size increase. The proposed research involves monitoring the antenna performance by analyzing the  $S_{11}$  and gain spectra, as seen in Fig 2.

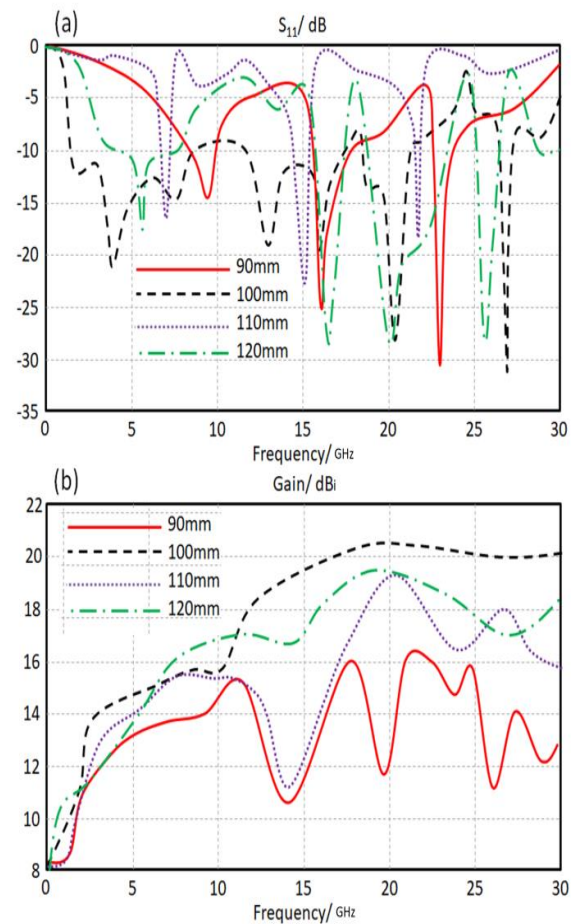
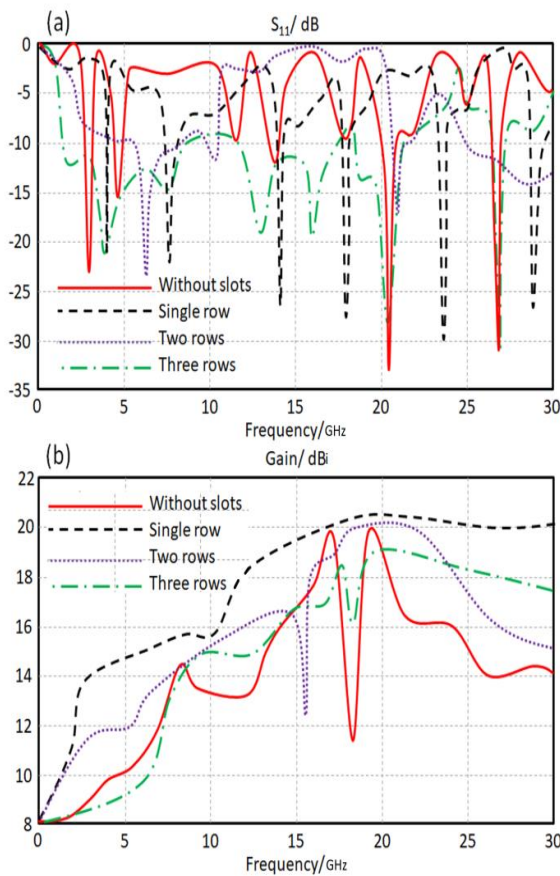


Figure 2. Antenna performance concerning the cone length variation: (a)  $S_{11}$  and (b) gain.

### 2.2. Slot Number Effects

The proposed antenna is structured with a flare cone of elliptical slot arrays. We found by introducing these slots, a significant enhancement is achieved. Fig. 3, presents the proposed antenna performances in terms of S11 and gain spectra. It is found that the proposed antenna provides a bandwidth after introducing the proposed slots from 3 GHz up to 30 GHz with a maximum gain of 20 dBi.

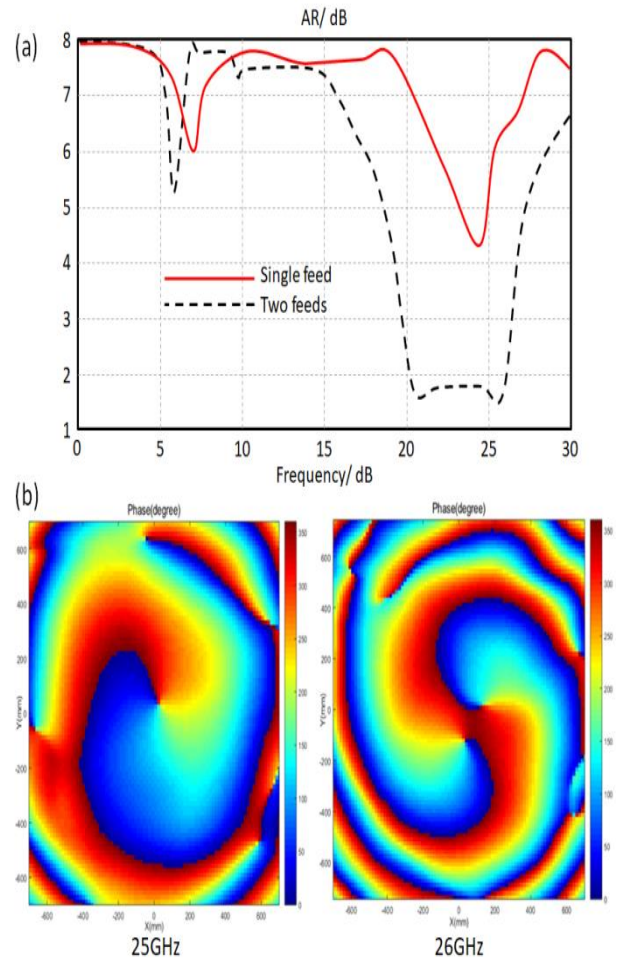


**Figure 3.** Antenna performance concerning the slot number variation: (a) S<sub>11</sub> and (b) gain.

### 2.3. Feed Structure Effects

The antenna is stimulated with two ports that have a phase shift of 90 degrees to activate the modes of OAM configuration. It has been determined that the suggested antenna exhibits an excellent ratio below 3dB over the frequency range of 20GHz to 27GHz, as seen in Fig 4(a).

The proposed antenna has been observed to exhibit OAM modes at frequencies of 25GHz and 26GHz, as seen in Fig 4(b).



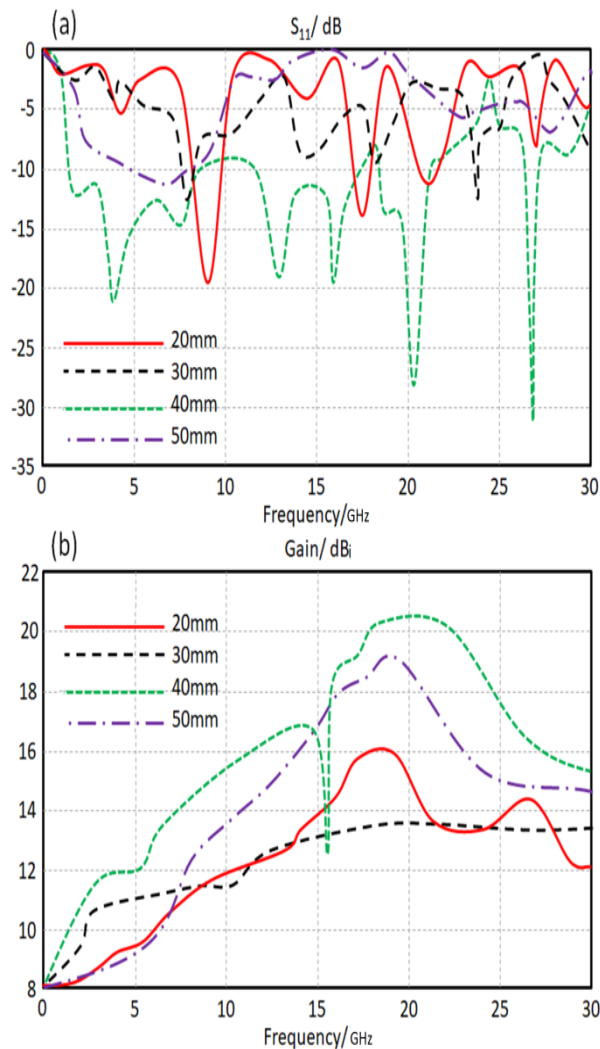
**Figure 4.** Antenna radiation performance: (a) AR and (b) Radiation field distribution at 25GHz and 26GHz.

### 2.4. Matching and Radiation Antenna Properties

This section presents the antenna's impedance matching and radiation features, specifically in terms of gain and S11 spectra, relative to the antenna's gain. The circular aperture at the feeding network of the antenna is modified to investigate its impact on the antenna's performance. The modification involves increasing the antenna's inner aperture from 20mm to 50mm at the feed point, the impedance bandwidth is significantly affected. Thus, it is



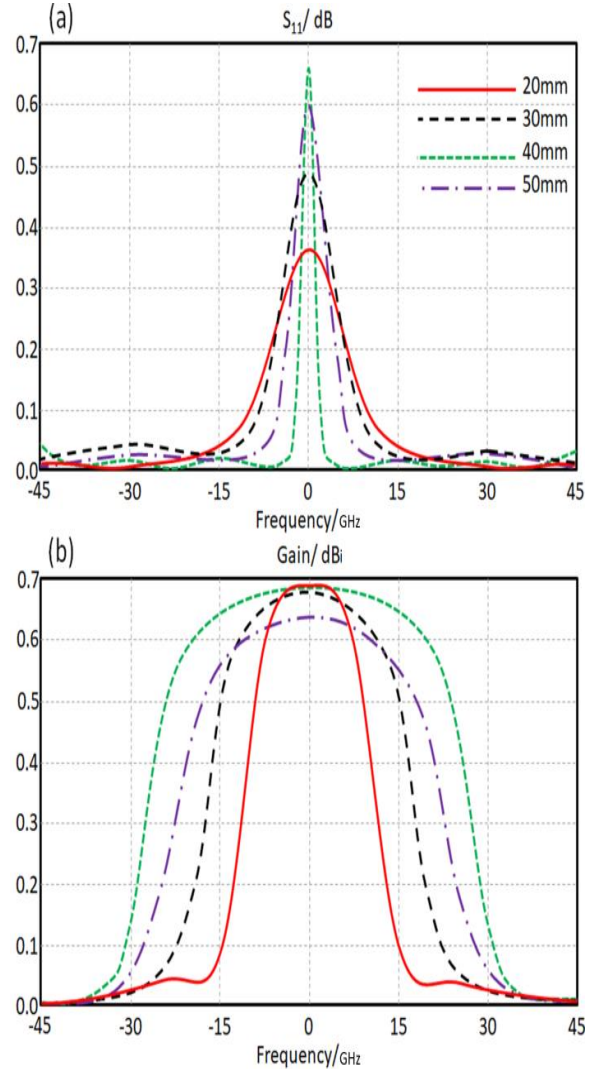
found when the antenna's inner aperture diameter is 40mm, the maximum bandwidth enhancement can be seen in Fig. 5(a). The antenna gain is enhanced significantly by changing the inner aperture diameter as shown in Fig. 5(b). The authors considered the aperture diameter of the optimal antenna design to be 40mm because; the maximum bandwidth and gain enhancements are achieved with this dimension.



**Figure 5.** Antenna performance with changing the antenna aperture coupling diameter: (a)  $S_{11}$  and (b) gain spectra.

Now, the antenna radiation properties are presented in Fig. 6 in terms of surface current

and field distributions on the antenna surface. It found that the antenna provides maximum distribution at the cone aperture when the feeding cross-sectional diameter is 40mm in comparison to other values.

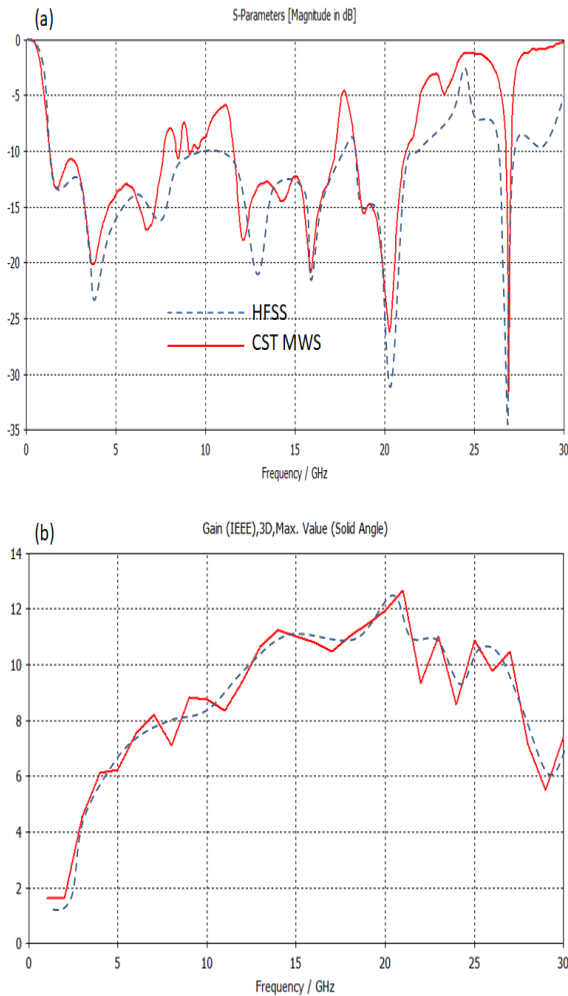


**Figure 6.** Antenna surface field distribution on the antenna reflector with changing the antenna aperture coupling diameter: (a) E-field and (b) H-field.

### 3. Results Validation and Discussion

After arriving at the optimal antenna design, the obtained results are validated numerically using HFSS. The performance of the proposed antenna in terms of  $S_{11}$  and gain spectra are compared to those obtained from HFSS. It is found that the obtained results from the used software packages provide excellent

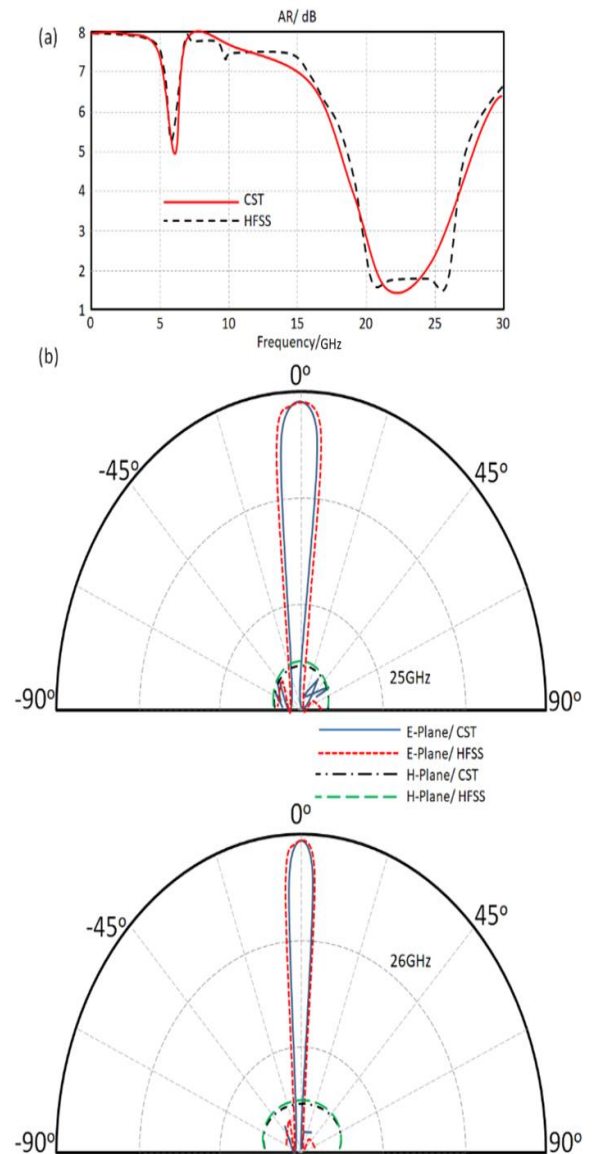
agreements. The findings obtained from the two software programs are shown in Fig 7. The antenna design being offered offers a high gain bandwidth product as a result of the tangential traveling phenomenon, which was elucidated in reference [21].



**Figure 7.** Antenna performance validation: (a) S11 and (b) gain.

The antenna axial ratio (AR) is presented in Fig. 8(a) to show that the proposed antenna AR is about 3dB at 25GHz and 26GHz the frequency bands of interest. The E-plane and H-plane display the antenna radiation patterns at 25GHz and 26GHz, respectively, as shown in Fig 8(b). Antenna reflector effects achieve strong E-plane

normalization, leading to an end-fire radiation pattern, as discussed in [22].



**Figure 8.** Antenna radiation properties: (a) AR and (b) radiation patterns at 25GHz and 26GHz.

Lastly, we compare the suggested antenna performance to the findings found in the literature. This comparison is listed in Table I; which confirms that the proposed design provides great advancements over the other published results.

**Table 1.** A comparison performance between the obtained results and other published design performances in the literature.

Reference	Antenna substrate	Antenna Type	Frequency band/ GHz	Gain/ dBi
[1]	RT Duroid	Pharaonic ankh-key broadband antenna	60.5-72	8.4
[2]	Taconic TLY	New gridded parasitic patch stacked microstrip antenna.	60	8.4
[3]	Liquid Crystal Polymer	Patch antenna array	57 and 64	16.7
[4]	RT Duroid	Single band microstrip patch antenna	59.93	17.1
[5]	Silicon	Double F slot patch antenna	58.10	5.4
This work	PTFE	3D	3-30	20

#### 4. Conclusions

An improved gain bandwidth product 3D antenna construction is proposed in this study. It is found that the proposed antenna provides an excellent bandwidth,  $S_{11} \leq -10\text{dB}$ , over the frequency bands from 3 GHz to 30GHz with a maximum gain of 20dBi. The antenna performance in terms of  $S_{11}$ , gain, AR, and CSTMWS is used to compute radiation patterns, which are then compared to the results acquired by HFSS. The results show that the two software programs are highly compatible with one another. At the 25GHz and 26GHz frequency resonances, the suggested antenna produces OAM radiation patterns. The antenna radiation pattern is found to be mostly focused toward the end-fire to provide an excellent front-to-back ratio of about -30dBi. The antenna provides an excel ratio below 3dB for the frequencies between 20GHz to 27GHz. The antenna gain is found to be about 20dBi at 25GHz and 26GHz. This is achieved because the current distribution is mostly accumulated at the antenna center. The OAM rotational wave is obtained when the two feeds are used to accumulate the current motion at the antenna center for this work. The proposed antenna is suitable for use in 5G communication networks operating at millimeter wave frequencies.

#### Conflict of interest

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

#### Authors' contributions:

Arkan Mousa Majeed developed the Methodology of the research, made the formal analysis and investigation wrote the original draft, and was responsible for funding acquisition.

Zaid A. Abdul Hassain and Taha A. Elwi developed the methodology of the research, made the formal analysis and investigation wrote the original draft, and was responsible for funding acquisition.

Jayendra Kumar and Ahmed E. Saleem made the formal analysis and investigation, participated in writing the article, reviewed previous literature, and participated in editing and project administration.

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