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ABSTRACT

The antenna is structured in three dimensions, employing a conductive cylindrical cone as its base. This cone configuration is achieved through the etching of an elliptical slot array onto the antenna. To enhance its performance, a conductive circular reflector is situated beneath the cone, thereby augmenting its gain. The antenna demonstrates operational bandwidth across various frequencies: Ultra-Wideband (UWB) operates at approximately 5 GHz, extending to about 15 GHz; Wideband (WB) is cantered at roughly 20 GHz, while narrowband operates at approximately 27 GHz. Within the frequency range of interest, the antenna's gain varies between 3dBi and 15dBi. Geometric specifications of the antenna are optimized through numerical parametric analysis conducted using the CST MWS Software Package. Upon determining the optimal design, its efficacy is validated using another software package employing HFSS Simulation Technology. The results obtained from both software packages exhibit a high degree of concurrence, affirming the antenna's effectiveness.

1. Introduction

The use of millimeter wave (mmW) propagation in various media for modern applications such as wireless communication, detection and remote sensing has recently been used in several applications. Millimeter-wave technology operates in the frequency band between 30 GHz and 300 GHz and is widely used in microwave and wireless communication applications. It is used in 5G

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networks to provide high-speed wireless connection and in fixed wireless access services for broadband services. It is also very important in mobile backhaul applications, point to point microwave links and Wi-Fi to transmit high-capacity data. In addition, mmWave is used in vehicle communication, imaging and sensing systems short-range device to device communication, satellite links and astronomical observations as well as in scientific research and military applications. mm wave technology offers high data rate, accuracy, and flexibility, making it an essential part of current microwave and wireless technology. However, the impact of medium attenuation of mmW on the propagation distance increases rapidly due to atmospheric turbulence. OAM waves have been gaining interest in mmw and terehertz communication because OAM based antennas is especially useful in mm wave and terethertz communication which are being developed for high capacity, short range wireless communication. OAM modes can provide higher data rates in these frequency range. Various research groups have used different techniques to explore the benefits of mmw with minimum propagation limitation effects by using OAM waves [3-4].

Novel antenna designs that have been considered for these techniques have been covered in the literature, including: A horn antenna of mode combination technique was proposed by the authors in [5] in order to produce twisted waves with various OAM orders. An additional suggestion was made to produce OAM waves over the frequencies of 20GHz to 160GHz by employing a circular array of rectangular planar antennas based on monopole antennas. The suggested project in [6], was created for wireless communication link applications at 60GHz using mmw and twin OAM modes antenna. A ring resonator with two feeding ports connected to a 90° hybrid coupler served as the basis for the antenna's design. The radiation beams were directed towards the boresight direction using a parabolic reflector. A reconfigurable antenna in the OAM mode with multiple ports that is controlled by PIN diodes on the feeding network and operates at 2.4GHz was proposed in [7]. A circular antenna array was used in [8] to suggest a concept for a unit-/multi-cast OAM mode data transmission antenna that operates at 28 GHz. A mechanically reconfigurable circular array-based single-arm spiral antenna element was presented by the authors in [9] to produce OAM waves between 3.4 and 4.7 GHz for 5G applications. Two orthogonal signals supplied into a hemispherical dielectric resonator antenna at 5.8 GHz produce two OAM states. By connecting the OAM wave generators to a Maxwell fish-eye lens, a lens antenna for 3D beam steering at microwave frequencies was proposed and made possible [10-20]. For 5G mobile terminals operating at 28 GHz, a quasi-Yagi slotted array antenna with fan-beam characteristics was suggested [21-33]. For contemporary applications, a 3D antenna design is suggested in this paper. In order to produce OAM modes, the antenna is designed as a slotted cone circular construction with a circular reflector that is excited by two feeds. Using CST MWS for numerical testing and HFSS for validation, the antenna's performance is assessed. Section II discusses the design specifications. Section III discusses the findings. Section IV contains the paper's conclusion.

2. Methodology

2.1 antenna geometrical details

The antenna geometrical details will be discussed in this section. *For a conical horn, the dimensions that give an optimum horn are [13]:*

$$d = \sqrt{3\,\lambda\,L}$$

where d is the diameter of the cylindrical horn aperture, L is the slant height of the cone from the apex, λ is the wavelength. The proposed design parameters are L=60.01 mm and d= 39.03 mm. As seen in Fig. 1, the antenna dimensions are presented in the mm scale. The proposed is deigned to work as an orbital angular momentum (OAM) antenna. In this design a circular cross sectional cut cone is introduced to guide the wavelength smoothly between the microwave source and the free space impedance [7]. Therefore, the cone design is defected with elliptical slots to minimize the tangential surface waves and focus the main beam toward the sight bore direction [9]. In a different perspective, a 90° phase shift is applied to two horizontal and vertical microwave ports on the antenna to excite it and produce a circular motion on the transverse axical of the antenna [11]. In order to preserve directivity at the main lobe direction and improve the reon to back ratio, a circular ground plane reflector is placed behind the antenna [12]. The total antenna size, as shown in Fig. 1, is determined to be 90×100×100mm^3. It is made of a conductive aluminium 3D structure. PNC type connectors are used to feed the antenna in order to sustain microwave feeding across a broad frequency range.

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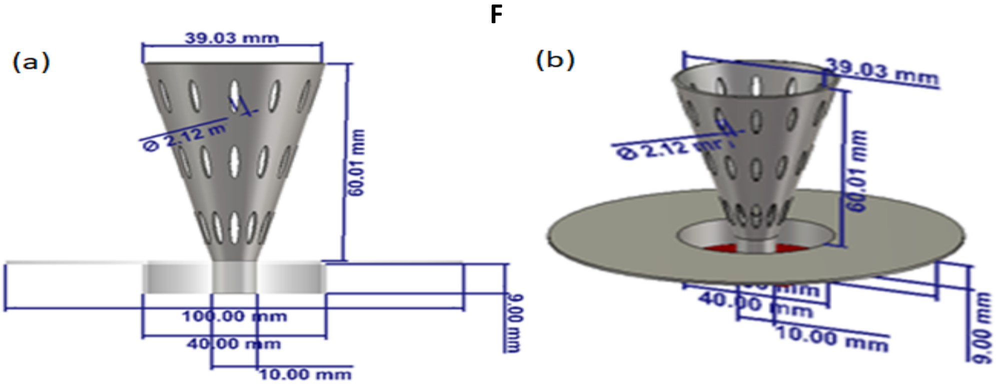

Fig. 1. Antenna geometrical details

2.2 Design Methodology

The proposed antenna design methodology is introduced in this section. We conducted the study based on three steps as presented in the following:

2.2.1 Cone height

The suggested antenna is built around a cone component whose height, H, can be adjusted in steps of 30 millimetres from 30 to 90 millimetres. It is discovered that altering H causes the antenna gain to shift significantly. This shift is ascribed to the fact that the reactive impedance varies in relation to the propagation in free space [7]. Thus, in order to understand the impacts of it parametrically, the authors carried out this study. As shown in Fig. 2, we discovered that the suggested antenna offers an outstanding gain spectrum when H is equal to 60mm.

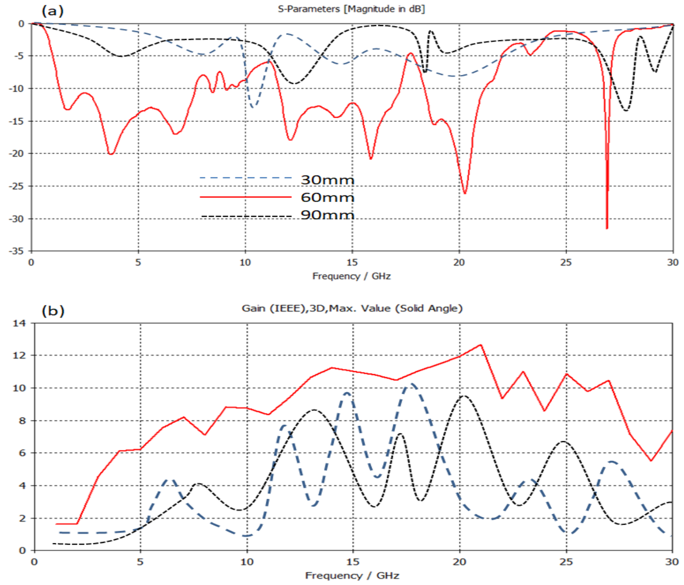

Fig. 2. S11 and gain spectra of the proposed antenna with changing H value; (a) S11 and (b) gain

2.2.2 Upper aperture

The impact of altering the upper aperture diameter on the suggested antenna's performance is investigated statistically by adjusting it in increments of 10mm, from 30mm to 50mm. The purpose of this study is to remove the reflection effects caused by the upper aperture fringing effects of diffraction. The aperture radius (R) has a significant impact on the fringing from the higher aperture diffraction effects [4]. The effects of varying R on the antenna gain spectra are shown in Fig. 3. With its maximum output gain, it is discovered that the suggested antenna offers an outstanding gain at R=40mm.

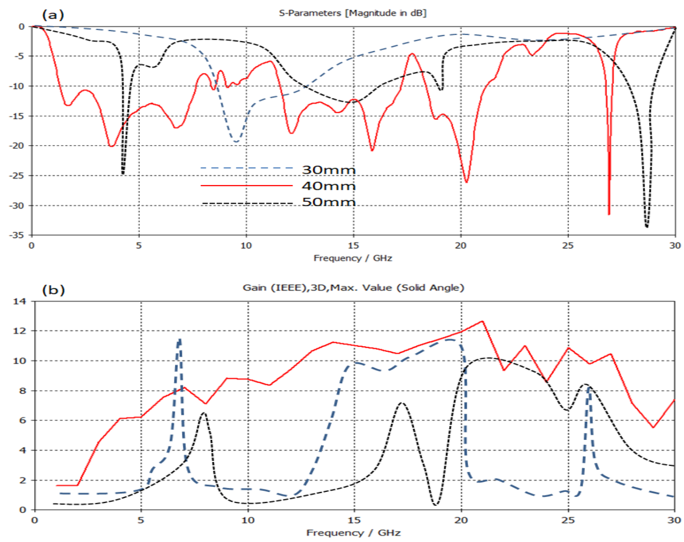

Fig. 3. S11 and gain spectra of the proposed antenna with changing R value; (a) S11 and (b) gain

2.2.3 Reflector

On the back of the suggested antenna is a conductive reflector. It is investigated what happens when the reflector's outer diameter (D) is altered. In this investigation, D was adjusted in steps of 50mm from 50mm to 150mm. As shown in Fig. 4, we discovered that the suggested antenna offers a great gain output value at 100mm.

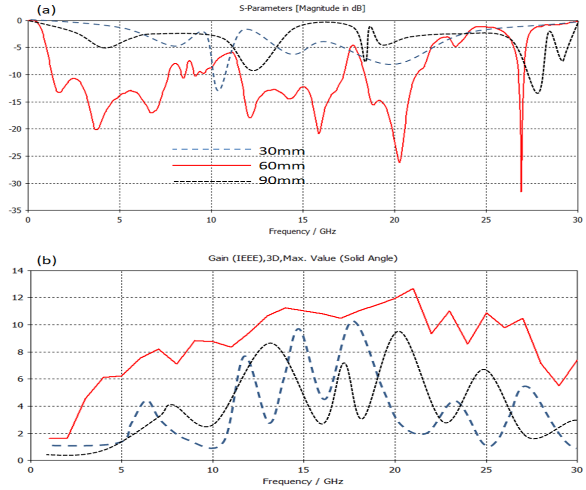

Fig. 4. S11 and gain spectra of the proposed antenna with changing D value; (a) S11 and (b) gain

2.2.4 Slots effects

Once the ideal dimensions have been determined, the consequences of the slot faults are assessed by incorporating them into the suggested design. We discovered that the suggested antenna gain increases quickly when the suggested slots are included, which is in line with the same discovery in [12]. Eliminating the reactive portion between the antenna cone and the reflector layer allows for this improvement [9]. After adding the suggested slots, the suggested antenna offers a notable improvement, as shown in Figure 5.

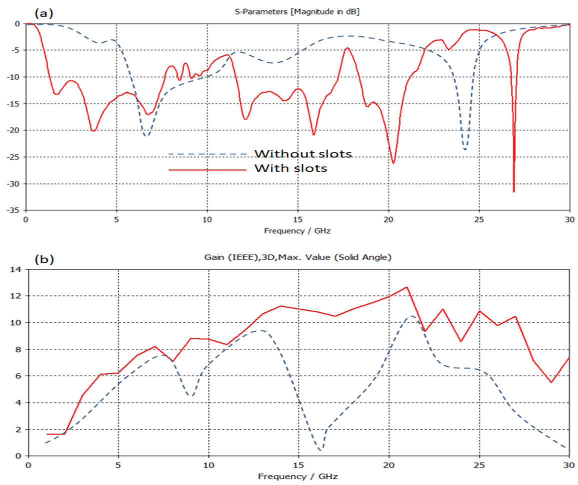

Fig. 5. S11 and gain spectra of the proposed antenna with introducing the slot array; (a) S11 and (b) gain

3. Results

Using the HFSS software tool, the best possible design for the suggested antenna performance is quantitatively verified. It is discovered that there is good agreement between the suggested antenna performance assessed using CST MWS and those obtained from HFSS. We discovered the obtained outcomes in terms of gain and S11 spectra. However, as shown in Fig. 6, the radiation patterns of the suggested antenna in the E- and H-plans are assessed and contrasted with one another.

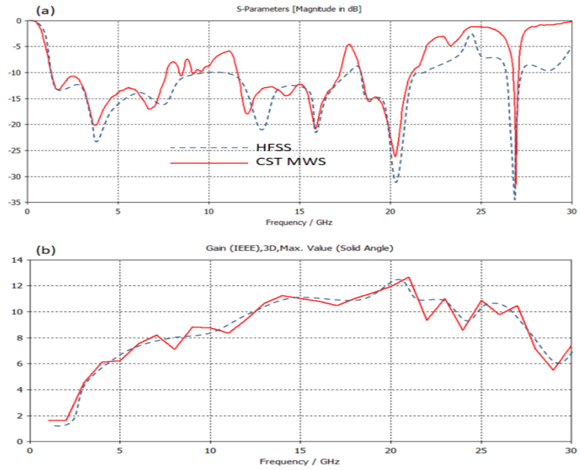

Fig. 6. S11 and gain spectra validation of the proposed antenna

The proposed antenna is compared to other published designs in the literature as listed in Table I. It is found that the proposed antenna provides excellent gain bandwidth product in comparison to the published results in the literature with enough miniaturized size.

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

Reference	Antenna size	Antenna Type	Frequency band	Gain	Applications
[1]	15.2×16.5×1.6mm3	Microstrip	35-40GH	------	Glucose sensing system
[2]	6.25×6.25mm2	Microstrip	30GHz	------	Food sensing system
[3]	400×200mm2	Two ports horn antenna	32Ghz to 38GHz	12dBi	Rader detection
[4]	100×100mm2	Isotropic horn antenna/ OAM	100GHz to 300GHz	------	Remote sensing
[5]	250×250mm2	Horn Antenna	20GHz to 60GHz	12dBi	Land mine detections
[6]	2.8×2.4mm2	Microstrip antenna	20GHz and 160GHz	1.5dBi and 7dBi	5G applications
[7]	3.5×3.5mm2	Microstrip antenna	38GHz	-----	Modern communication systems
This work	90×100×100mm3	3D slot array antenna	UWB operates around 5 GHz, UWB functions	3dBi to 15dBi	Modern wireless systems

			in the vicinity of 15 GHz, WB is cantered around 20 GHz, and narrowband operates at approximately 27 GHz		
[1]	15.2×16.5×1.6mm3	Microstrip	35-40GH	------	Glucose sensing system

From figures 2-5, we can see that the following goals from the proposed antenna :

1. **Antenna Structure:**
    - Slot Array: Adding a slot array is a popular method of increasing an antenna's gain and bandwidth. In essence, slots are holes in the antenna's conductive material that interact with electromagnetic waves to provide the appropriate radiation characteristics.
    - Conductive Cone Structure: This structure most likely acts as the antenna's radiating element. Conical antennas are renowned for their broad frequency range broadband performance and ease of impedance matching.
    - Conductive Reflector: To increase the antenna's directivity and gain, the conductive reflector is positioned behind the radiating element. Reflectors assist in directing the energy that is radiated in a specific direction.
2. **Gain Enhancement:**
    - 15dBi Gain: as an antenna has a gain of 15dBi, it concentrates electromagnetic radiation in one direction, which improves performance as compared to an isotropic radiator. This significant gain level is very helpful for point-to-point communications and long-distance communication.
    - Gain Variation: The antenna's performance might be tailored for particular frequency bands or radiation patterns based on the variation in gain from 3dBi to 15dBi. It is crucial for the practical application of the antenna to comprehend the conditions that lead to either higher or lower gain.

3. **Bandwidth:**
    - Effective Bandwidth: It's remarkable that the stated effective bandwidth ranges as follows UWB operates around 5 GHz, UWB functions in the vicinity of 15 GHz, WB is centered around 20 GHz, and narrowband operates at approximately 27 GHz. It indicates that the antenna has a broad frequency range of operation, which makes it adaptable to several wireless communication standards (such Wi-Fi, cellular, and satellite) that use distinct frequency bands.
4. **Size and Practicality:**
    - Compact Dimensions: The antenna's 90x100x100 mm^3 size makes it comparatively small, making it ideal for integration into small communication terminals or other compact systems or equipment. For practical deployment, this compactness is a benefit.
5. **Performance Evaluation:**
    - Software Tools: The comprehensiveness of the antenna design process is demonstrated by the utilization of two distinct software packages for performance

evaluation and validation. These programmes are probably electromagnetic simulation programmes, like HFSS, CST Studio Suite, or others, which are capable of precisely modeling and analyzing antenna performance.

- Consistency in Results: The high degree of agreement between the outcomes produced by the various software programmes supports the antenna design's dependability and precision. This consistency implies that the simulated findings and the antenna's actual performance should be fairly close.

6. **Practical Applications:**
   - Wireless Communication: The antenna is appropriate for a range of wireless communication applications, including point-to-point communications, satellite communication, and 5G networks, due to its wide bandwidth and high gain.
   - Upcoming Technologies: Because of its performance in the 20GHz millimeter-wave frequency band, it is well-suited for upcoming applications and technologies like Industry 4.0 and driverless cars that demand high data rates and low latency.

4. Conclusions

In this work, we have designed a 3D structure in an attempt to develop a product antenna with a high gain bandwidth to be used in modern wireless communication systems. The gain enhancement is achieved by adding a slot array to the conductive cone structure, with the conductive reflector attached to it. The proposed antenna has a gain at 20GHz of 15dBi, with an effective bandwidth range as UWB operates around 5 GHz, UWB functions in the vicinity of 15 GHz, WB is centered around 20 GHz, and narrowband operates at approximately 27 GHz. However, the suggested antenna gain varies between 3dBi and 15dBi. The antenna size is small enough to be used in any compact system, with a maximum size of 90x100x100mm^3. We validate the antenna performance with two different software packages. We found a good agreement between the results of the conducted software packages.

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