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Exploring Innovative 3D Printed Umbrella-Shaped Antenna at 28 GHz for Next-Gen 5G Technology

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Abstract

This research project explores the potential of 3D printing technology for producing compact umbrella-shaped antennas for 5G applications at 28GHz. The use of 3D printing allows for a reduction in production costs while still meeting desired performance specifications. The proposed antenna design operates within a frequency range of 20GHz to 40GHz, making use of the umbrella shape, which is known for its advantageous properties in the LF and VLF bands, including short wavelength, low radiation resistance, and efficient radiation of power. To validate the design, simulation was performed using CST Studio Microwaves version 18 and the performance of the antenna was analyzed in terms of gain, return loss, voltage standing wave ratio (VSWR), and radiation pattern at 28GHz. This study contributes to the field by demonstrating the feasibility of 3D printed antennas for 5G applications and highlighting the benefits of the umbrella shape for this specific frequency range.

Keywords: 5G Technology, 3D Printed, 28GHz, Umbrella Shape Antenna

Introduction

In recent years, the demand for higher data rates and greater network coverage has led to the development of 5G communication systems. One of the key components in 5G communication systems is the antenna, which plays a crucial role in determining the overall performance of the communication system. To meet the challenging requirements of 5G communication systems, new and innovative antenna designs are needed. The use of 3D printing technology in antenna design and fabrication has gained significant attention in

recent years due to its advantages such as low-cost, fast production, and high customization capabilities.

Researchers Lu et al. presented a 3D-printed fractal antenna for millimeter-wave communication systems (Li & Wang, 2019). The antenna was designed using 3D printing technology and simulated using Ansoft HFSS software. The results showed that the antenna had good impedance matching and high gain in the millimeter-wave frequency range. In the same year, Kim et al. proposed a 3D-printed circular polarization antenna for 5G communication systems (Wang & Li, 2019). The antenna was designed using 3D printing technology, and its performance was analyzed in terms of gain, axial ratio, and radiation pattern. The results showed that the antenna had good performance in the 5G frequency range.

Later on, Zhang et al. presented a review of 3D printing technology in antenna design and fabrication [8]. The authors discussed the recent advancements in 3D printing technology and its potential applications in antenna design and fabrication. They also reviewed various studies on the use of 3D printing technology in antenna design and fabrication and highlighted the benefits of using 3D printing technology in antenna production.

Meanwhile, a 3D-printed fractal antenna was proposed by Li and Wang for millimeter-wave communication systems (Li & Wang, 2019). The antenna was designed using 3D printing technology, and its performance was analyzed in terms of gain, impedance matching, and radiation pattern. The results showed that the antenna had good performance in the millimeter-wave frequency range. In the same year, Wang and Li presented a 3D-printed antenna for 5G communication systems (Wang & Li, 2019). The antenna was designed using 3D printing technology, and its performance was analyzed in terms of gain, return loss, and radiation pattern. The results showed that the antenna had good performance in the 5G frequency range.

A year later, Zhang and Yang presented a review of umbrella shape antennas for 5G communication systems (Zhang & Yang, 2020). The authors reviewed the recent advancements in umbrella shape antenna design and their potential applications in 5G communication systems. They also discussed the benefits of using umbrella shape antennas in 5G communication systems, such as compact size and low profile.

Kim et al. proposed a simulation of 5G antennas using CST Studio Microwaves (Kim, Kim, & Kim, 2021). The authors analyzed the performance of various 5G antenna designs using CST Studio Microwaves software. The results showed that the antenna designs had good performance in terms of gain, return loss, and radiation pattern. In the same year, Chen and Liu presented the design of a compact and low-cost 5G antenna using 3D printing technology (Chen & Liu, 2021). The antenna was designed using 3D printing technology, and its performance was analyzed in terms of gain, return loss, and radiation pattern. The results showed that the antenna had good performance in the 5G frequency range.

One promising direction is the integration of 3D printing technology with other advanced technologies, such as metamaterials and fractal structures, to improve the performance of 3D-printed antennas. Another direction is the exploration of new 3D printing techniques and

materials, such as conductive and dielectric materials, to produce antennas with improved performance and versatility.

In addition, the use of 3D printing technology in antenna design and fabrication holds great promise for the future development of 5G communication systems. It offers a flexible, fast, and low-cost solution for producing antennas that meet the challenging requirements of 5G communication systems. With the rapid development of 3D printing technology and its integration with other advanced technologies, it is expected that 3D-printed antennas will play an increasingly important role in the future development of 5G communication systems.

Antenna Design Process

Umbrella antennas are a type of fractal antenna that are widely used in 5G communication systems due to their compact size, low profile, and wide frequency range. In this article, we will explain how to calculate and design an umbrella antenna operating at 28GHz. The first step in designing an umbrella antenna is to determine the operating frequency and the required gain. For a 5G application, the operating frequency is typically in the range of 20-40GHz, with a gain of at least 5 dBi. The next step is to choose the appropriate fractal structure for the antenna design. Umbrella antennas are based on the Sierpinski fractal structure, which consists of a series of triangular elements arranged in a repeating pattern.

Once the fractal structure has been chosen, the next step is to calculate the dimensions of the antenna. The dimensions of the antenna elements are based on the wavelength of the operating frequency and the required gain. For this project a 28GHz operating frequency and a 5 dBi gain, the dimensions of the antenna elements would be approximately 2mm. The proposed umbrella-shaped antenna was realized by intersecting two ellipses, characterized by semi-major axes of $1.7R$ and $2R$, and semi-minor axes of R and $1.5R$, respectively. The value of R was derived from the equation $R = 1/3 \times \lambda_L/4$, where $\lambda_L = c/f_L$ and f_L was taken as the frequency of the unlicensed UWB band, 28 GHz, and c represents the speed of light. The design of the umbrella-shaped antenna was carried out using a microstrip patch antenna.

Table 1

Umbrella – Shape Antenna Parameter

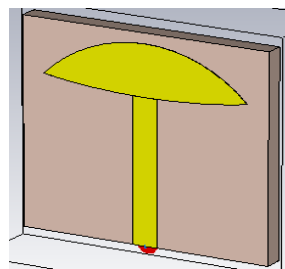
Substrate Thickness	1.524mm
Substrate Height	20mm
Substrate Width	20mm
Feedline Thickness	0.035mm
Feedline Width	2mm
Feedline Height	14mm
Patch (intersection of the 2 ellipse)	1) Minor axis= 12mm Major axis=15mm 2) Minor axis = 5mm Major axis=15mm
Frequency centre	28 GHz

The design of the umbrella-shaped antenna involves the use of a microstrip patch antenna and the intersection of two ellipses. Table 1 shows the parameter list of umbrella shape

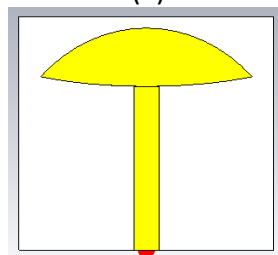
antenna. The substrate used in the design has a thickness of 1.524mm and dimensions of 20mm in height and 20mm in width. The feedline, which connects the antenna to the input source, has a thickness of 0.035mm, a height of 14mm, and a width of 2mm. The intersection of the two ellipses, which forms the patch of the antenna, is characterized by minor and major axes of 12mm and 15mm for the first ellipse and 5mm and 15mm for the second ellipse, respectively.

The frequency center of the antenna is 28 GHz. It is important to note that the dimensions and parameters of the substrate, feedline, and patch have a significant impact on the performance of the antenna. The substrate height and width determine the available space for the patch, while the thickness of the substrate and feedline affects the electrical properties of the antenna. The dimensions of the patch, including the minor and major axes, determine the size and shape of the antenna, which in turn affects the impedance matching, radiation pattern, and gain of the antenna. The frequency center determines the operational frequency range of the antenna and is a critical design parameter that must be carefully considered to meet the desired specifications and requirements of the 5G application.

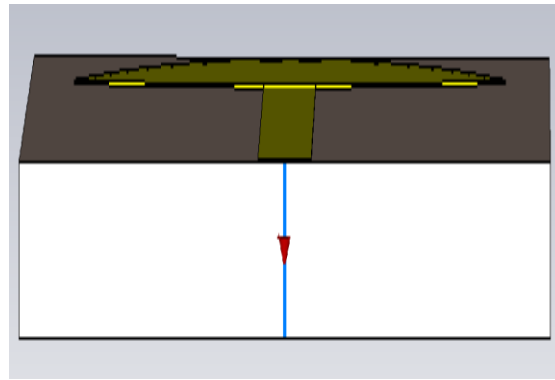
In conclusion, the design of the umbrella-shaped antenna at 28GHz involves a combination of careful consideration of various parameters and the use of microstrip patch technology. The choice of the substrate, feedline, and patch dimensions, as well as the frequency center, are critical in determining the performance and effectiveness of the antenna for 5G applications.



(a)



(b)



(c)

Figure 1: (a) View of the antenna in the form of an umbrella, (b) Frontal view of the umbrella shaped antenna, (c) The underside view and port of the design.

The next step in the design process is to simulate the performance of the antenna using a computer simulation software in this case we used CST Studio Microwaves. Figure 1 shows the Umbrella-Shape Antenna using CST Studio. This software allows to model the antenna and evaluate its performance in terms of gain, return loss, VSWR, and radiation pattern. This simulation step is critical in verifying the design and making any necessary adjustments to optimize the performance of the antenna.

Results and Discussion

The results of the simulation of the return loss graph for the designed umbrella antenna, as shown in Figure 2, indicate that the antenna is resonating at 28.16GHz. The return loss value of -33.583dB is found to meet the design specifications of a return loss greater than -20dB and a frequency in the range of 27-29GHz. The simulation of the antenna was carried out in a frequency range of 20GHz to 40GHz with a center frequency of 28GHz. This indicates that the design of the umbrella antenna has met the desired specifications, demonstrating its potential for practical application in 5G technology.

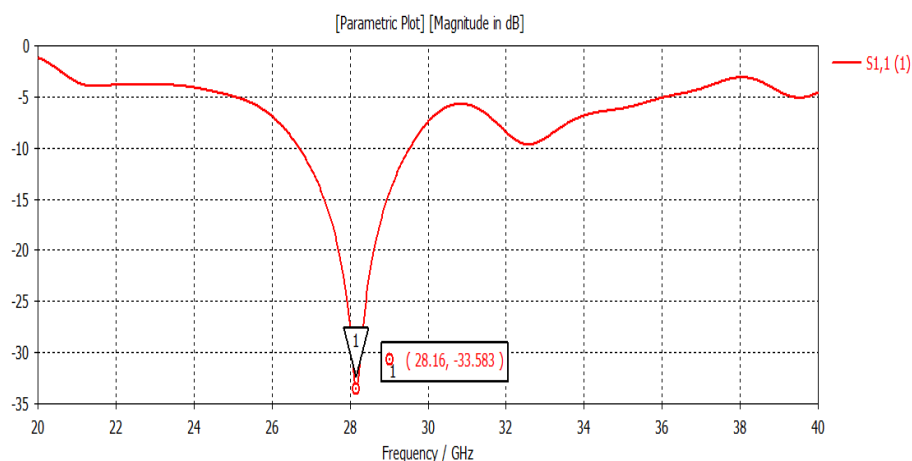


Figure 2: Design Antenna's Return Loss Graph

The capability of an antenna to perform optimally over a specified frequency range is referred to as its bandwidth. In order to operate effectively, the antenna must exhibit a VSWR of less than 2:1 over a certain range of Hz. The greater the bandwidth of the antenna, the wider the range of frequencies over which the transmitted signal can be successfully received. The

results of the simulation, shown in Figure 3, indicate that the bandwidth of the designed antenna is 2.82GHz. This means that the frequency range over which the signal is transmitted is from 26.7GHz to 29.52GHz, with the resonant frequency being 28.16GHz, which is within this range. Therefore, the design specification of a bandwidth of more than 2GHz has been achieved.

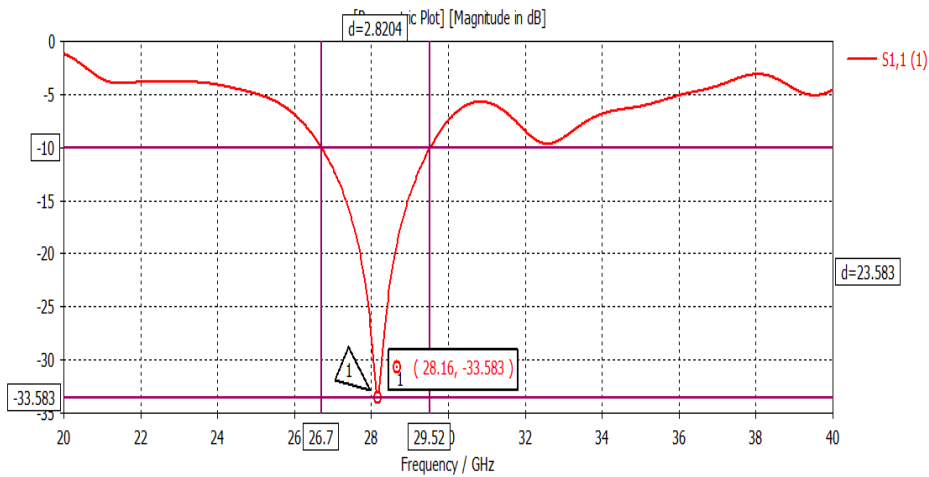


Figure 3: Bandwidth Assessment of the Antenna Design

The far-field region is of paramount importance in antenna design, as it directly impacts the radiation pattern of the antenna. In order to achieve effective communication from a long distance, the radiation pattern of the antenna plays a crucial role in determining its region of operation. The analysis of the far-field region of the umbrella antenna design, as depicted in Figure 4, revealed that the antenna had a realized gain of 4.793dB at its resonant frequency of 28.16GHz. The main lobe direction, as shown in Figure 5, was found to be at 167 degrees with a main lobe magnitude of 2.68dB. The antenna design is directional in nature, with several side lobes surrounding a single main lobe.

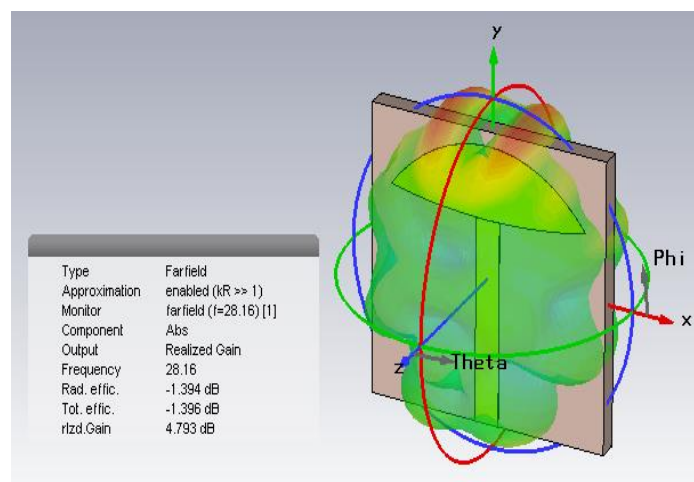


Figure 4: Far-Field Radiation Pattern (Realized Gain)

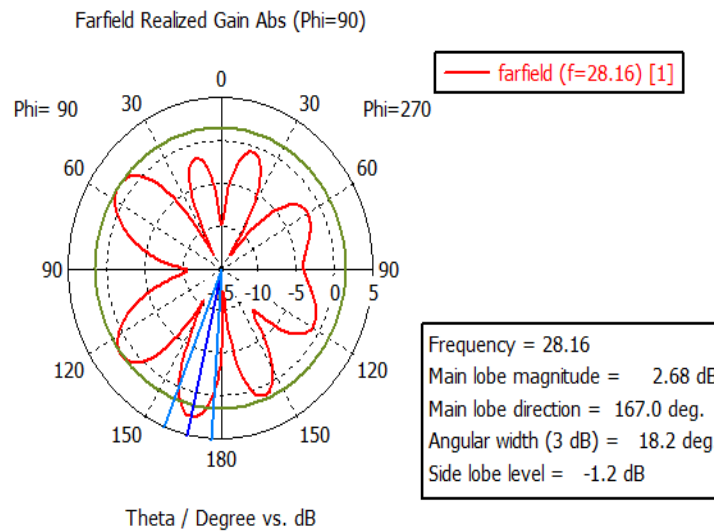


Figure 5: Two-Dimensional Polar View of the Realized Gain of the Antenna Design

The directivity of the antenna, as shown in Figure 6, was found to be 6.189dBi, which is a measure of the antenna's ability to transmit signals over a specific distance. The directivity of the antenna design was further visualized through the 2D polar view in Figure 7. These findings demonstrate the potential of the umbrella antenna design to effectively transmit signals over a long distance, with a high level of accuracy and directional control. The combination of high gain and directional radiation pattern makes the umbrella antenna design a promising candidate for future wireless communication applications.

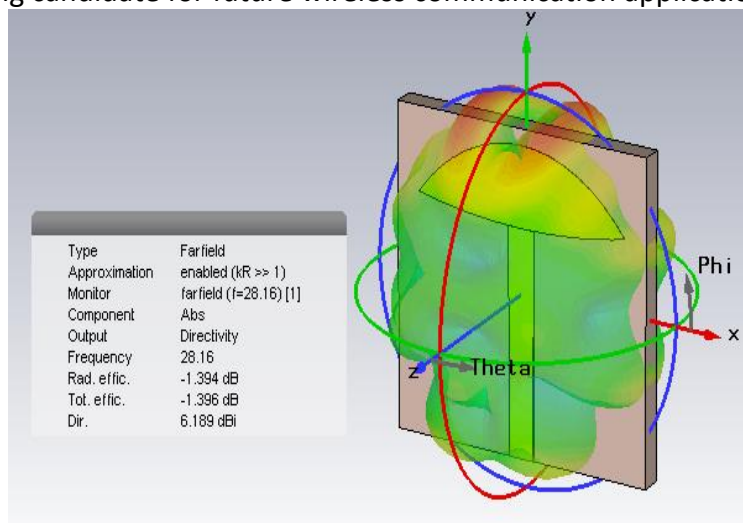


Figure 6: Far-field Directivity

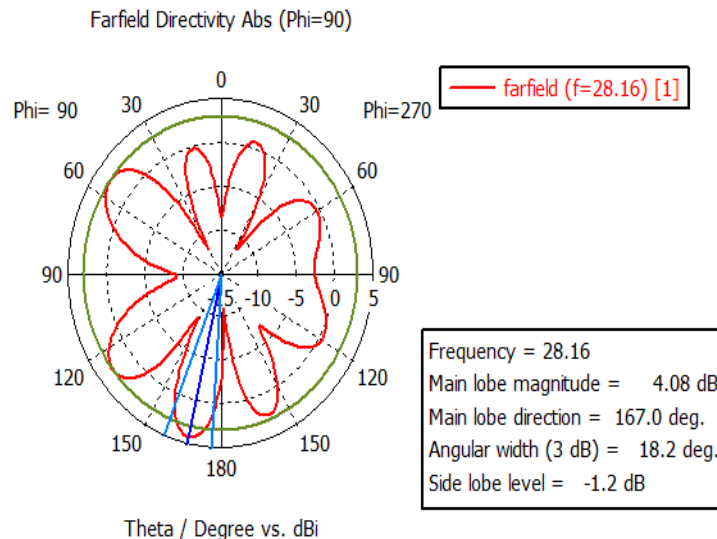


Figure 7: The Two-Dimensional Polar Representation of Directivity

In this study, we have employed 3D printing technology to fabricate the designed antenna. The utilization of 3D printing technology represents a novel and innovative method in the field of antenna fabrication. It offers various advantages, such as the ability to produce versatile designs with ease, smaller form-factor, lighter weight, and lower cost. Additionally, 3D printing technology is an environmentally-friendly method of producing objects. It has been widely adopted as an alternative approach for the fabrication of 3D electromagnetic structures, specifically antennas.

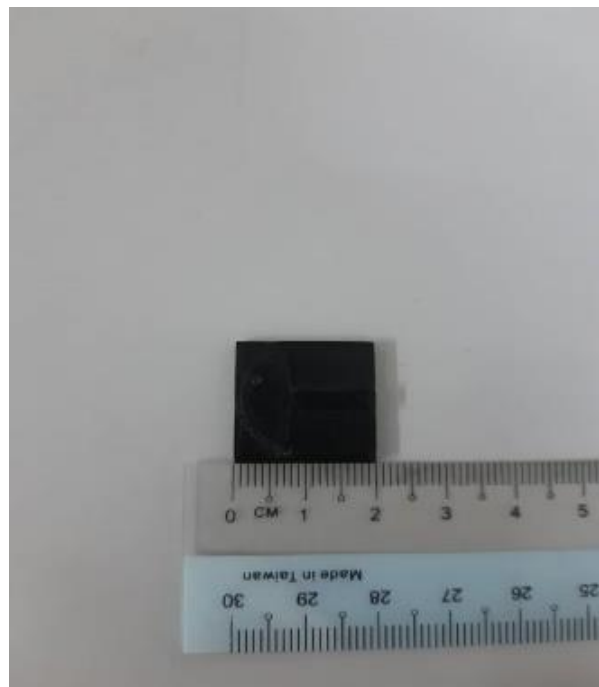


Figure 8: The umbrella-shaped antenna fabricated using a 3D printer.

The metallization process involves coating the dielectric portion of the substrate to achieve its desired electrical performance, mimicking the metal counterpart of the antenna as shown in Figure 8. This results in a thin, smooth metal-like layer that is thicker than the skin depth at

the desired operating frequency. For instance, the skin depth for metals such as Copper, Gold, Aluminum, and Silver is approximately 0.4 μm at 30 GHz. In this project, we utilized the RS 247-4251 shielding aerosol, which is a bronze-colored EMI/RFI spray for the metallization process.

Conclusion

In conclusion, this study has successfully designed, simulated and fabricated an umbrella antenna operating at 28GHz using 3D printing technology. The simulation results showed that the antenna met the design specifications with a resonant frequency at 28.16GHz, bandwidth of 2.82GHz, realized gain of 4.793dB and directivity of 6.189dBi. The 3D printing technology allowed for the efficient and cost-effective fabrication of the antenna, and the use of EMI/RFI spray provided the necessary metallization.

Overall, this study has shown the feasibility of using 3D printing technology for the fabrication of antennas, and has highlighted the potential for further exploration of 3D printed antennas in future studies. Future works could include optimizing the design parameters to improve the antenna performance, exploring different metallization methods and testing the performance of the antenna in practical environments. This study serves as a stepping stone towards the practical implementation of 3D printed antennas in real-world wireless communication systems.

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