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RESEARCH PAPER

Optimization of Pyramidal and Conical Horn Antennas Parameters to Operate with High Radiation Performances for 5G Communication Using CST and HFSS Techniques

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A B S T R A C T:

In this study, the development of typically pyramidal and conical horn antennas which associated with waveguides operation at 28 GHz for 5G communications are designed and their radiation performance are computed and compared using both CST and HFSS simulation techniques. Generally, the computed results indicates that the conical horn displays a better antenna radiation performance with a bandwidth and realized gain values of (48.2) GHz and (18.4) dBi. In addition, the return loss, VSWR and radiation efficiency values obtained for both conical and pyramidal horn antennas are (-42, -45.56) dB, (-23.39, -25.66) dB, (1.02, 1.01) dB, (1.15, 1.11) dB, (99.46%, 99.99%) and (99.67%, 99.99%) by CST and HFSS techniques, respectively. Moreover, both pyramidal and conical horn shapes display a low side lobe level power and angular beam width values of the order of (-8.5 dB), (19.7°) and (-21.4 dB), (18.8°), respectively. Besides, a good agreement of the computed antenna parameters obtained for both proposed antennas with the ones previously obtained by other researchers are observed and the accuracy of the results obtained by HFSS simulation techniques is also clarified. Finally, one concludes that the proposed horn antennas are adequately operate with a radiation performance suitable for many 5G application systems.

KEY WORDS: Aperture antennas; pyramidal horn antenna; conical horn antenna; 5G; CST; HFSS.
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1. INTRODUCTION

Wireless systems for communication have had a huge impact on people's daily lives during the past few decades. As a result, a growing number of consumers are connecting their devices to the current networks today, which is driving up data traffic and increasing the demand for high-speed networks in the years to come. The fifth-generation wireless network, which is now in the planning stages of deployment, is thought to provide a solution to the growing wireless data traffic (Mungur and Duraikannan, 2018). Wireless systems were widely used for many years to establish communication links between various points. Many standards, including 2G, 3G, 4G, and most recently 5G, were created and implemented (Rimi et al., 2022) (Vora, 2015).

The enormous unlicensed bandwidth, notably in the millimeter-wave range, will be utilized by the upcoming 5G communication systems to significantly increase communication bandwidth. It is also anticipated that it would be able to support and supply very high data rates, which will present new challenges for network requirements and antenna design in order to meet the anticipated data rate and capacity (Gemeda et al., 2021) (Bhattacharyya and Puri, 2022) (Yu and Kamarudin, 2016).

The utilization of the millimetre wave frequency band is one of the most effective techniques to enhance the bandwidth among various 5G-enabling technologies (Deng et al., 2015) (Roh et al., 2014). This is due to the existing frequency band's ability to offer such high data rates due to the availability of bandwidth, which is lower than 6 GHz. The mm-wave frequency band has the benefit of being license-

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free and having an enormous amount of bandwidth available. Researchers worldwide are focusing on a number of mm-wave frequency ranges, including 15 GHz, 26 GHz, 28 GHz, 32 GHz, 36 GHz, 38 GHz, and even 60 GHz and 73 GHz (Qamar et al., 2018)(Rappaport et al., 2013). The spectrum of 5G applications is ranges from 20 to 90 GHz (Vijayakumar et al., 2022) (Hindia et al., 2018). (Al-Falahy and Alani, 2017). Researchers will focus on 5G applications, and they should offer better characteristics like ultra-broad bandwidth and high-gain responsiveness by taking into consideration atmospheric absorption and free-space path loss in the anticipated millimetre-wave frequency range of 5G communications (Nshimiyimana et al., 2016) (Nel, 2017).

On the other hand, aperture antennas are antennas with a physical aperture or opening through which electromagnetic waves can pass. They are typically utilized at higher frequencies due to their relatively large size (Pozar, 2012). Aperture antennas are also recognized as horn antennas, because it usually consists of a waveguide with flared end walls that create a megaphone-like construction. The horn aperture can be circular, rectangular, or even elliptical. The pyramidal horn, conical horn, sectoral horn and rectangular waveguide are also types of aperture antennas (Balanis, 2016). Horn antennas are simple to design and manufacture while delivering the user with dependable and consistent performance. In addition, horn antenna provide wider bandwidth, reduced VSWR, higher gain, lower weight, and construction flexibility (Elsayed, 2021). These antennas are incredibly useful for a variety of applications, including aircraft and spacecraft applications, because they are extremely easily mounted on the surface of either spacecraft or aircraft.

The radiation characteristics of pyramidal and conical horn antennas will depend on (the horn's length, which also influences the flare angles of the horn) and (the dimension of the horn at the opening) as well as a and b (the waveguide's dimensions) (Siddique and J, 2022). Additionally, the beam width of horn antennas is generally so narrow, and it is sensitive to obstructions. However, the proliferation of wireless communication devices demands a wider bandwidth, a stable radiation pattern, and enhanced gain (Dixit and Kumar, 2020) (Gazit, 1988). Thus, the mm-wave spectrum has been highlighted as a strong candidate for 5G communications due to its wide bandwidth (Li et al., 2014) and (Hindia et al., 2018). Besides, mm-wave frequencies have shorter wavelengths and greater attenuation than the present cellular communication bands as they pass through air due to oxygen absorption and precipitation. Thus, when the antenna transmits mm-wave frequencies, the frequency of the present cellular bands is less attenuated in free space than the first meter, particularly in outdoor urban environments (Hindia et al., 2018) and (Shahid, 2016). Recently, a **horn antenna for 5G millimetre wave communications that operates at the 28 GHz band (27.5–28.35 GHz), as specified by the Federal Communications Commission** (Imran et al., 2018).The 28 GHz band in this region of the spectrum has received a lot of attention from researchers due to its low atmospheric attenuation, which is an important problem in mm-wave communication that cannot be ignored (Ahmad and Khan, 2017).

Therefore, this work is established for designing and comparing the radiation performance of pyramidal and conical horn antennas operating at 28 GHz using both CST and HFSS simulation methods. Because pyramidal and conical horn are differed in their physical form and the type of waveguide used, they provide different radiation characteristics. The main objective of our investigation is to enhance the performance of these antennas for microwave applications by optimizing their geometrical dimensions. Besides, the 2-D and 3-D view radiation patterns, gain, directivity, VSWR, return loss S11, efficiency, and bandwidth for both mentioned horn shapes are computed and compared. Finally, the reliable horn shape that maintain reasonable radiation performance suitable for 5G application are identified through the comparison of the outcome results with those previously obtained by other research works in the same frequency bands.

2. THEORETICAL MODELLING AND PROPOSED ANTENNA DESIG

Horn antennas are one of the most basic antennas used in microwave frequency ranges. Traditionally, these antennas are often fed from a section of waveguide and are made of metallic materials. Because its structure creates a smooth transition between waveguide and free space, the radio waves are directed into a beam (Balanis, 2016). Horn antennas can take on a variety of shapes, and the most popular varieties of horn antennas are conical and pyramidal as their geometrical constructions are shown in **Figure 1.**

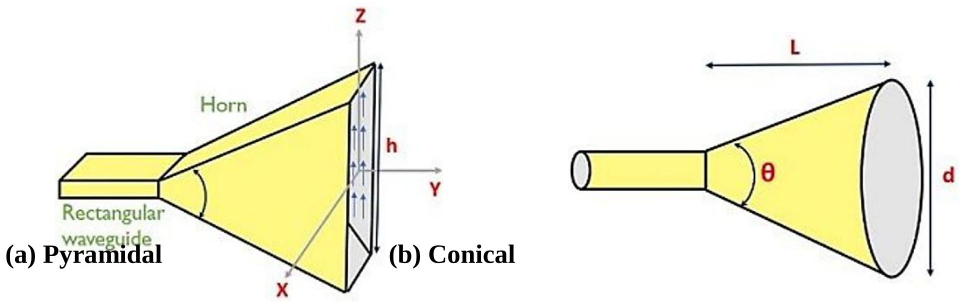

Figure 1: Geometrical construction of pyramidal and conical horn antennas.

Pyramidal horn antennas are connected with rectangular waveguides where the TE10 is the basic mode, and in such cases, one face is enlarged with a pyramidal shape, while conical antennas connected to circular waveguides feed conical horns, and the fundamental mode is the TE11 (Abhignya et al., 2015). A growing number of wireless communication devices require a wider bandwidth, a more consistent radiation pattern, and improved gain (Dixit and Kumar, 2020). Horn antennas are characterized by waveguide flaring that has a significant gain and directional pattern which make it to be utilized for long-distance communication. Due to its small size, easy structure, high gain, and preferred radiation, a perfect electric conductor (PEC) is widely used to create horn antennas. According to **Figure 2 (a)**, the pyramidal horn is the one that is flared in both the electric E- and magnetic H-planes. Its radiation properties can be viewed as a combination of the E- and H-plane sectorial horns (Maybell and Simon, 1993). Also, conical horns are opened in the E and H planes, similar to the pyramidal horn, as illustrated in **Figure 1 (b)** (Shamshad and Amin, 2012) (Ijsr, 2014).

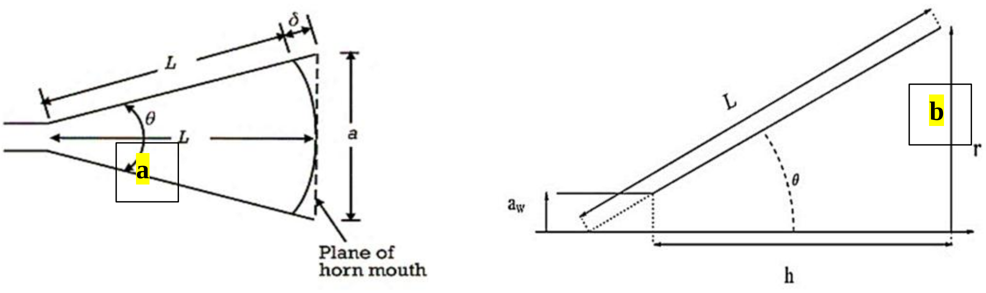

Figure 2. Cross-section of a pyramidal and conical horn antenna with basic dimensions listed (Marhefka and Kraus, 2002).

Where; (θ) is the flare angle, (δ) is a phase shift, (a) is the horn aperture and (L) is the length of the horn, , (h) is the length of the flare section, and (a_w) is the waveguide radius. The performance of horn antennas is notably affected by the value of the phase shift (δ). It turns out that the optimum directivity occurs where the largest flare angle does not exceed a certain value (δ_0). The value of δ_0 must normally be between (0.1-0.4) free-space wavelengths (Murthy et al., 2015). The length of a conventional horn is typically between 2 to 15 wavelengths at the operating frequency.

However, the longer horns are more difficult to mount and use, but they offer higher gain and better directivity [39]. As a result, in this design, δ is set to be equal to 0.375λ (often 0.4λ) and the horn length (L) is assumed to be equal to 2.5λ to maintain the range (Rathod and Kosta, 2008). According to **Figure** 2, the flare angle is related to the dimension of both mentioned horn antenna and are expressed as:

$$\cos\left(\frac{\theta}{2}\right) = \frac{L}{L+\delta} \quad (1)$$

$$\sin\left(\frac{\theta}{2}\right) = \frac{a}{2(L+\delta)} \quad (2)$$

$$\tan\left(\frac{\theta}{2}\right) = \frac{a}{2L} \quad (3)$$

$$\theta = 2\cos^{-1}\left(\frac{L}{L+\delta}\right) \quad (4)$$

$$a_e = a_h = 2L\tan\left(\frac{\theta}{2}\right) \quad (5)$$

The aperture area is the area of the rectangle created by the opening of the horn and is essentially the product of the horn's height and width. Where aperture dimensions are a_e, a_h in the E- and H-planes in free-space wavelength, respectively. The value of (a_e and a_h) are evaluated by using equation (5) and are of the order of (30.49 mm), then the pyramidal horn antenna physically exists and its aperture area is calculated by an expression given by (Marhefka and Kraus, 2002) as:

$$A_P = a_e * a_h = 929.640 \text{ mm}^2 \quad (6)$$

when ($A_P =$ aperture area of the pyramidal horn antenna). By equalizing the rectangular aperture and circular aperture

$$A_C = 929.640\text{mm}^2 (A_C = \pi r^2) \quad (7)$$

when ($A_C =$ the aperture area of the conical horn antenna). Then the radius of the conical horn antenna and its dimensions are evaluated using the following equations (Balanis, 2016):

$$r = \sqrt{\frac{A_c}{\pi}} = 17.2065 \text{ mm} \quad (8)$$

$$D = 2r = 34.413 \quad (9)$$

$$D^2 = 3\lambda L \quad (10)$$

$$L = \frac{D^2}{3\lambda} = 36.8582\text{mm} \quad (11)$$

By implementing the CST and HFSS simulator, pyramidal and conical length are optimized and are, respectively, equal to (27.5 mm) and (36.15 mm). Then the feeding structure has been built to connect easily to a WR28 waveguide transition, at which the numerical simulations also took into consideration. Rectangular waveguide type WR-28 is selected for both pyramidal and conical horn antennas. The waveguide's dimensions for pyramidal (7.11 × 3.56 mm) as well as (a, b) are the waveguide's width and height, respectively. Aaccording to circular waveguide datasheet, one has chosen circular waveguide diameter (D = 8.56 mm) (King, 1950). The geometrical dimension parameters for the pyramidal and conical horn are obtained using equations (6,7,8, and 9) and the results are presented in **Table 1**.

Table 1. Considering the design parameters and dimensions for a pyramidal and conical horn antenna.

Pyramidal horn parameter	**Dimensions**	**Conical horn parameter**	**Dimensions**
a_e**(mm)**	30.49	D (**mm**)	34.413
a_h**(mm)**	30.49	L (**mm**)	36.8582
L **(mm)**	26.785	A_C (**mm^2**)	929.640
A_p**(mm^2)**	929.640		

3. RESULTS AND DISCUSSION

In this section, the simulation results and discussions on the proposed pyramidal and conical horn antennas are presented using both CST and HFSS techniques. Both horn antenna shapes operating in the Ka-band have been successfully modelled with a centre frequency of 28 GHz and a scan frequency ranges from (26-40) GHz. To access an antenna's capabilities, various performance computation is performed, which include the directivity, gain, bandwidth, far-field radiation pattern in 2D and 3D-view, VSWR and return loss for both horn antennas.

The attained results demonstrate that the proposed antenna has a resonance frequency at 28.00 GHz with a return loss value −23.8 dB, -42 dB by CST and -25.66 dB and -45.56 dB by HFSS, for pyramidal and conical horn antennas, respectively, as shown in **Figure 3**. Besides, the S11 parameter which has the quality of covering the 5G band ranging between 26.5 and 40 GHz are maintain values less than -19 dB and -25 dB for pyramidal and conical horns, respectively. Additionally, the fractional bandwidths are calculated from these two figures and the obtained results for both horn shapes are equal to 48.2GHz, which can be considered as a reliable value for 5G application systems and is much better than those achieved previously by other published works.

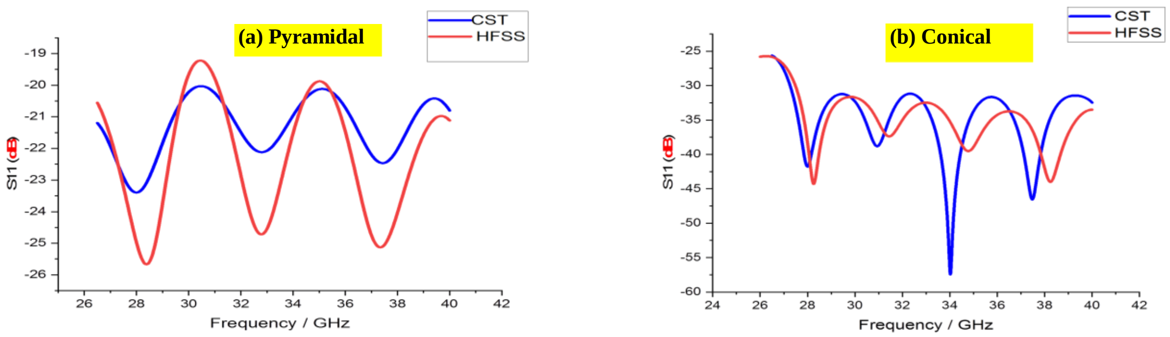

Figure 3. The S11 comparison of pyramidal and conical horn antennas is conducted between HFSS and CST simulation techniques.

The voltage standing wave ratio (VWSR) as a function of frequency of both shapes are also computed and the results are illustrated in **Figure 4**. The achieved VSWR is (1.15, 1.11) for the pyramid antenna while (1.02, 1.01) for the conical horn antenna operating at 28 GHz by CST and HFSS, respectively. The magnitude of VSWR is less than two and is in the range of (1 to 2) which is a desired value and is whispered to be already matched with these values achievements. Thus, the VSWR of the proposed horn antennas is within the standard limits in the range of the operating frequency, making these horn antennas very efficient with small amount of reflected power.

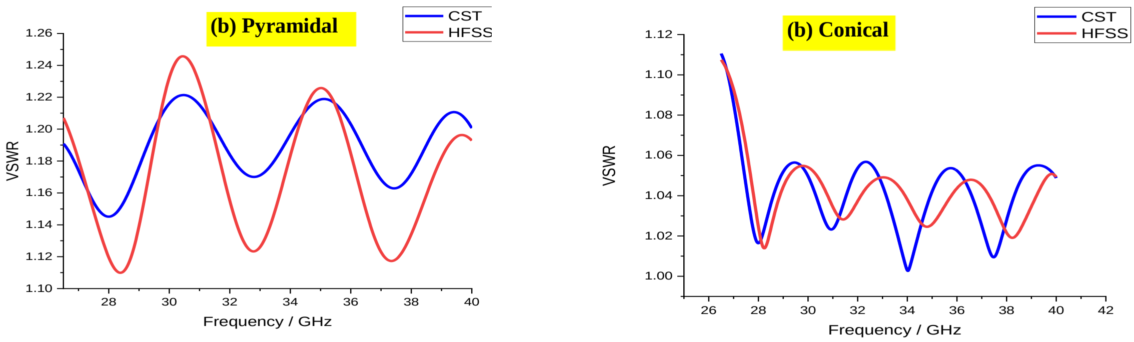

Figure 4. VSWR versus frequency plot of the designed horn antennas

Moreover, the charge and hence electric field distribution of these two horn shapes are evaluated and the results are displayed in **Figures 5**. Similarly, the side lobe level and the angular width of them are simulated and are -8.5 dB, 19.7degrees and -21.4 dB, 18.8 degrees for pyramidal and conical horn antennas, respectively as shown in **Figure 6**. Form this figure one can clearly observe a very low side lobe levels for both horn shapes.

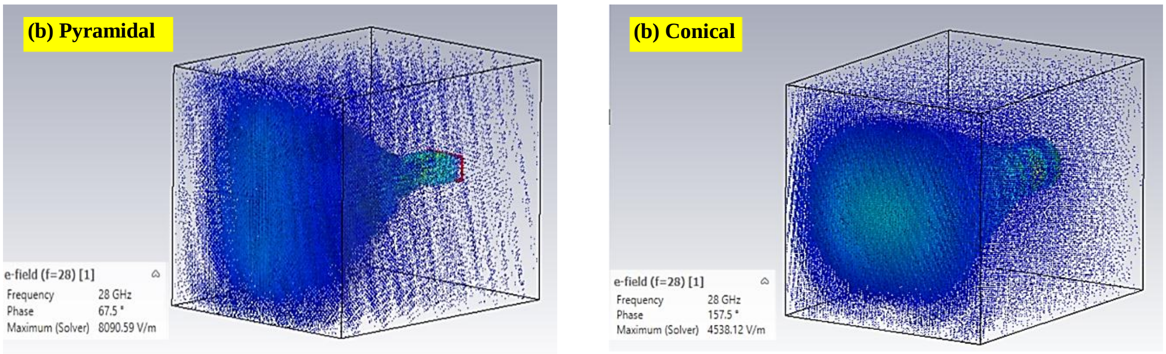

Figure 5. The formation of electric field distribution of both horn shapes.

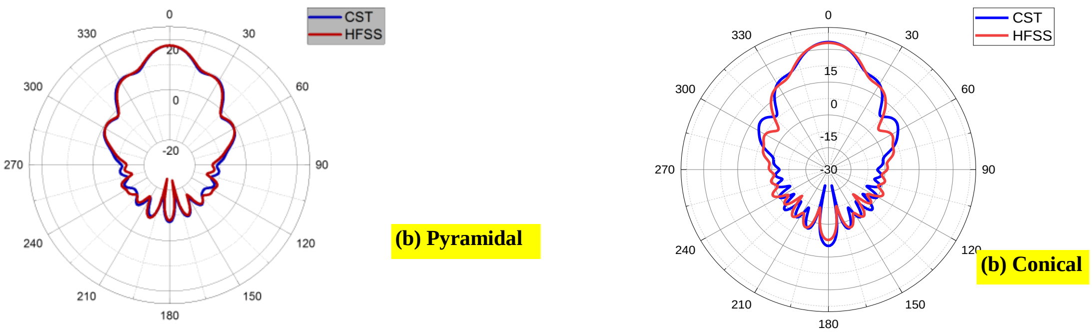

Figure 6. The 2-D radiation pattern at 28 GHz band for pyramidal and conical horn antenna by both CST and HFSS.

The radiation pattern is another parameter that is frequently used to describe the horn antenna at which the plot of the far-field pattern indicates the angular strength of the antenna's power. This parameter is used to illustrate the antenna's gain and directivity at a specific place in space (Balanis, 2005). In **Figures 7** and **8**, the 3-D realized gain of the pyramidal and conical horn antennas at the considered operating frequency are shown. The computed results implies that the antenna has a directional pattern with a realized gain peak of (17.5) dB and (17.25) dB for pyramidal horn antenna by CST and HFSS, respectively, while the realized gain for conical horn antenna equal to 18.4dB with the use of both software. From these 3D radiation pattern plot, one can say that the horn antennas' realized gain effectively met the 5G gain requirements. Additionally, the radiation efficiency which is related the output power to input power is also computed for both pyramidal and conical horn antennas and the results at 28 GHz are 99.99% and 99.67% by CST and HFSS methods, respectively. These higher antenna efficiency values clearly demonstrate that the radiation from our considered horn antenna is at the optimum level.

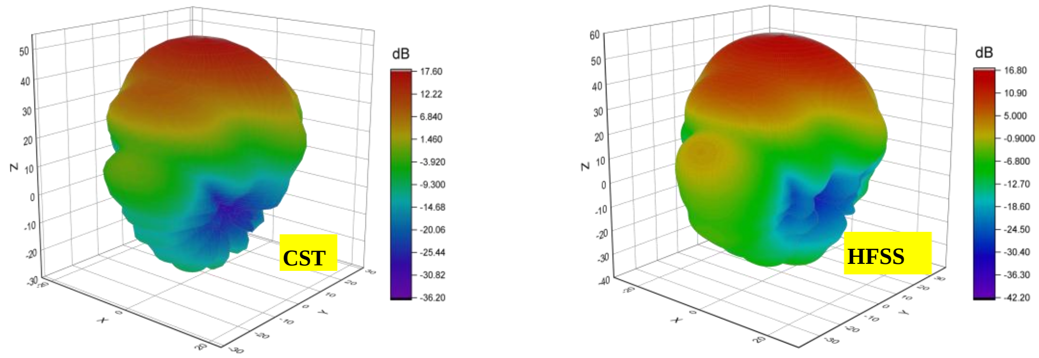

Figure 7. Representing the 3-D Radiation pattern for pyramidal horn antenna by CST and HFSS.

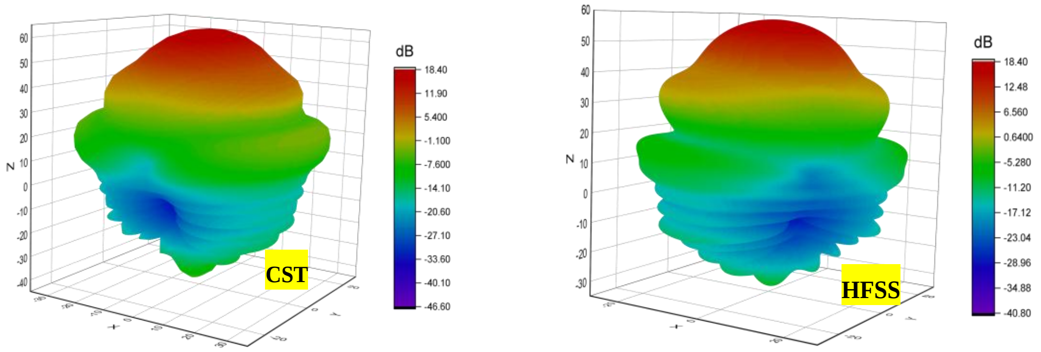

Figure 8. Shows the 3-D polar plot of radiation pattern for conical horn antenna at frequency of 28GHz.

The overall computed results for the realized gain, VSWR, S11, and efficiency parameters for each considered horn shape by both simulation methods are summarized and presented in **Table 2**. It is obviously seen from this table that the conical horn generally provides higher radiation performance, especially in terms of gain and S11. According to the above evaluation, it can be said that the proposed antennas have a very low return loss value which makes the horn antenna efficient and properly matched for the 28 GHz frequency band, over the desired radiation bandwidth. Additionally, those antennas' bandwidth exceeded the 5G channel bandwidth requirement. The results of the simulations clearly agree well with each other and the accuracy of the results obtained with HFSS is observed as compared to the previously published work in the same field and operational frequencies. This behaviour can be attributed to the fact that the HFSS method rely on the frequency domain solver while CST uses a time domain transient solver. On the other hand, the CST time domain solver is suitable for broadband problems.

Finally, comparing the parameters of the computed rectangular and circular horns to those previously calculated or measured for each of the considered pyramidal and conical horn shapes operating at 28 GHz are summarized in **Table 3**. In general, this table illustrates that the majority of the obtained results compare to other research investigations of various horn shapes operating at the same frequency range are in strong agreement. Therefore, it can be said that the proposed antennas are more reliable with suitable radiation performances for more 5G application systems. The proposed antennas have the advantage of operating with good radiation performance and being smaller in size than the majority of those previously designed to operate with the same frequency. Finally, the pyramid and conical horn antennas are examined for circular instead of linear polarization and operating at the same frequency bands.

Table 2. The electrical characteristics of the conventional pyramidal and conical horn antenna parameters.

Antenna parameter	Pyramidal horn		Conical horn	
	CST	HFSS	CST	HFSS
Realized Gain (dBi)	17.4	17.25	18.4	18.4
S11(dB)	-23.8	-25.66	-42	-45.56
VSWR	1.15	1.11	1.02	1.01
Radiation Efficiency %	99.67	99.99	99.46	99.99
SLL	-8.5	NA	-21.4	NA

Table 3. Comparison between computed pyramidal and conical horn antenna parameters with those previously obtained by other researchers.

References	Aperture size	Realized Gain (dBi)	S11 (dB)	Frequency Band	Simulation Techniques
(Di Paola et al., 2019)	______	7.5	-27	Ka	CST
(Helena et al., 2021)	17.9 ×16 **(mm^2)**	12	-39	Ka	CST
(Qi et al., 2019)	2.15×0.34 **(mm^2)**	11.2	-35	Ka	HFSS
P.W. (Pyramidal Horn)	**0.71×30.71 (mm^2)**	**17.5**	**-23.39**	**Ka**	**CST**
	0.71×30.71 (mm^2)	**17.7**	**-25.66**	**Ka**	**HFSS**
(Journal, I., 2013)	146 (**mm)**	12	>10	Ka	COMSOL
P.W. (Conical Horn)	**34.413 (mm)**	**18.4**	**-42**	**Ka**	**CST**
	34.413 (mm)	**18.4**	**-45.56**	**Ka**	**HFSS**

5. CONCLUSIONS

In this article, the pyramidal and conical horn antenna shapes operating at 28 GHz are designed and their radiation performance were compared using both CST and HFSS techniques. The simulation results of both techniques revealed that they were well agree with each other and the accuracy of the results obtained with HFSS was simply observed as compared to previous research works performed theoretically and experimentally in the same field and operational frequencies. In addition, the computed antenna parameters indicated that the conical horn antenna shape maintain better radiation performance compared to pyramidal one having the same geometrical area. In addition, both proposed horn antennas were operated with a realized gain, bandwidth, and radiation efficiency values of (18.4, 18.4) dB, (48.2, 48.2), and (99, 46%, 99.99%) with CST and HFSS techniques. Besides, the far-field radiation pattern simulation of pyramidal and conical horn antennas displayed a small side lobe level power with an angular beam width of the order of (-8.5 dB), (19.7°) and (-21.4 dB), (18.8°), respectively. Finally, the overall outcome results of both considered horn antenna shapes indicated that they were effectively reliable for most 5G application systems.

REFERENCES

Abhignya, G., Yogita, B., Abhinay, C., Balaji, B., Murthy, M., 2015. Design, fabrication and testing of pyramidal horn antenna 2, 3.

Ahmad, W., Khan, W.T., 2017. Small form factor dual band (28/38 GHz) PIFA antenna for 5G applications, Presented at the 2017 IEEE MTT-S International Conference on Microwaves for Intelligent Mobility (ICMIM), pp. 21–24. https://doi.org/10.1109/ICMIM.2017.7918846.

Al-Falahy, N., Alani, O.Y.K., 2017. Design considerations of ultra dense 5G network in millimetre wave band, Presented at the 2017 Ninth International Conference on Ubiquitous and Future Networks

(ICUFN), pp. 141–146. https://doi.org/10.1109/ICUFN.2017.7993764.
Shamshad, F., Amin, M., 2012. Simulation Comparison between HFSS and CST for Design of Conical Horn Antenna 1.
Marhefka, R. J. and Kraus, D. 2002. Antennas for all applications.
Balanis, C.A., 2016. Antenna Theory: Analysis and Design, 4th edition. ed. John Wiley, Hoboken, New Jersey.
Bhattacharyya, A., Puri, D., 2022. A 28 GHz Rectangular Micro strip Patch Antenna for 5G Applications 13, 3.
Elsayed, M. AboSree, M, and AbdElazem M., "Compact wide band antenna for millimetric communications", IOP Conference Series Materials Science and Engineering, doi:10.1088/1757-899X/1051/1/012032.
Deng, S., Samimi, M.K., Rappaport, T.S., 2015. 28 GHz and 73 GHz millimeter-wave indoor propagation measurements and path loss models, IEEE International Conference on Communication Workshop (ICCW). pp. 1244–1250. https://doi.org/10.1109/ICCW.2015.7247348.
Dixit, A.S., Kumar, S., 2020. A Miniaturized Antipodal Vivaldi Antenna for 5G Communication Applications, 7th International Conference on Signal Processing and Integrated Networks (SPIN), pp. 800–803. https://doi.org/10.1109/SPIN48934.2020. 9071075.
Gazit, E., 1988. Improved design of the Vivaldi antenna. IEE Proceedings H (Microwaves, Antennas and Propagation) 135, 89–92. https://doi.org/10.1049/ip-h-2.1988.0020.
Gemeda, M.T., Fante, K.A., Goshu, H.L., Goshu, A.L., 20210201. Design and Analysis of a 28 GHz Microstrip Patch Antenna for 5G Communication Systems. International Research Journal of Engineering and Technology (IRJET) 08, 881–886.
Hindia, M.N., Al-Samman, A.M., Rahman, T.A., Yazdani, T.M., 2018. Outdoor large-scale path loss characterization in an urban environment at 26, 28, 36, and 38 GHz. Physical Communication 27, 150–160. https://doi.org/10.1016/j.phycom. 2018.02.011.
ijsr, G.S., Deepinder Singh, International Journal of Science and Research (IJSR), n.d. Design and Analysis of Conical Horn Antenna for Ku-Band Applications - Count Search. International Journal of Science and Research (IJSR).
Imran, D., Farooqi, M.M., Khattak, M.I., Ullah, Z., Khan, M.I., Khattak, M.A., Dar, H., 2018. Millimeter wave microstrip patch antenna for 5G mobile communication, International Conference on Engineering and Emerging Technologies (ICEET), pp. 1–6. https://doi.org/10.1109/ICEET1.2018.8338623
King, A.P., 1950. The Radiation Characteristics of Conical Horn Antennas. Proceedings of the IRE 38, 249–251. https://doi.org/10.1109/JRPROC.1950.230734
Li, Q.C., Niu, H., Papathanassiou, A.T., Wu, G., 2014. 5G Network Capacity: Key Elements and Technologies. IEEE Vehicular Technology Magazine 9, 71–78. https://doi.org/10.1109/MVT.2013.2295070
Maybell, M.J., Simon, P.S., 1993. Pyramidal horn gain calculation with improved accuracy. IEEE Transactions on Antennas and Propagation 41, 884–889. https://doi.org/10.1109/8.237618
Shamshad, F., Amin, M., 2012. Simulation Comparison between HFSS and CST for Design of Conical Horn Antenna 1.
Shahid, M, Jonathan, R, Linglong, D., 2016 mmWave Massive MIMO - 1st Edition
Mungur, D., Duraikannan, S., 2018. Microstrip Patch Antenna at 28 GHz for 5G Applications 1, 3.
Murthy, M.B.R., Sudhakar, M., Bhogadi, L., 2015. Design and Testing of Pyramidal Horn. IOSR Journal of Electronics and Communication Engineering (IOSR-JECE) 10, 79–85. https://doi.org/10.9790/2834-10327985
Nel, J., 2017. Basic Antenna Design Handbook.
Nshimiyimana, A., Agrawal, D., Arif, W., n.d. LARGE SCALE MILLIMETER WAVE CHANNEL MODELING FOR 5.
Pozar, D., 2011. Microwave Engineering(2012). John Wiley & Sons.
Qamar, F., Siddiqui, M.H.S., Hindia, M.N., Dimyati, K., Rahman, T.A., Talip, M.S.A., 2018. Propagation Channel Measurement at 38 GHz for 5G mm-wave communication Network, IEEE Student Conference on Research and Development (SCOReD), pp. 1–6. https://doi.org/10.1109/SCORED.2018.8711186
Rappaport, T.S., Sun, S., Mayzus, R., Zhao, H., Azar, Y., Wang, K., Wong, G.N., Schulz, J.K., Samimi, M., Gutierrez, F., 2013. Millimeter Wave Mobile Communications for 5G Cellular: It Will Work! IEEE Access 1, 335–349. https://doi.org/10.1109/ACCESS.2013.2260813
Rathod, Jagdish.M., Kosta, Y.P., 2009a. Development of Conical Horn Feed For Reflector Antenna. IJET 1, 71–74. https://doi.org/10.7763/IJET.2009.V1.13
Rathod, Jagdish.M., Kosta, Y.P., 2008. Low cost design & development of conical horn feed for parabolic reflector antenna, International Conference on Recent Advances in Microwave Theory and Applications, pp. 775–777. https://doi.org/10.1109/AMTA.2008.4763081
Rimi, A.A.A., Hati, K., Zugari, A., Aghoutane, M., 2022. High gain of 28 GHz transparent antenna for 5G NR Networks. E3S Web Conf. 351, 01080. https://doi.org/10.1051/e3sconf/202235101080
Roh, W., Seol, J.-Y., Park, J., Lee, B., Lee, J., Kim, Y., Cho, J., Cheun, K., Aryanfar, F., 2014. Millimeter-wave beamforming as an enabling technology for 5G cellular communications: theoretical feasibility and prototype results. IEEE Communications Magazine 52, 106–113. https://doi.org/10.1109/MCOM.2014.6736750
Siddique, A., J, D.R.V., 2022. Fabrication and Testing of an Optimal H-Plane Sectorial Horn Antenna to Operate at 10.52 GHz. International Journal of Engineering Research & Technology 11. https://doi.org/10.17577/IJERTV11IS010173
Vijayakumar, D.S., Adhimoolam, T., Senthilkumar, V., Nataraja, Y., 2022. A Survey on Microstrip Antenna Array Design for 5G Communication 10, 6.

Vora, L.J., n.d. EVOLUTION OF MOBILE GENERATION TECHNOLOGY: 1G TO 5G AND REVIEW OF UPCOMING WIRELESS TECHNOLOGY 5G 02, 11.

Yu, L.C., Kamarudin, M.R., 2016. Investigation of Patch Phase Array Antenna Orientation at 28GHz for 5G Applications. Procedia Computer Science, 2016 International Electrical Engineering Congress, iEECON2016, 2-4 March 2016, Chiang Mai, Thailand 86, 47–50. https://doi.org/10.1016/j.procs.2016.05.012