Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Broad Band 2×4 Horn Antenna Array for High Power Microwave (HPM) Systems Application

Ahmed F. Miligy[1,*], Fatma Taher[2], Taha A. Elwi[3], M.Abdel-aleim M.[4,5], Mohamed Fathy Abo Sree[6], Sara Yehia Abdel Fatah[7,8]

[1] Air Defence College Alexandria University, Alexandria, Egypt
[2] College of Technological Innovation, Zayed University, P.0. Box 19282, Dubai, United Arab Emirates
[3] International Applied and Theoretical Research Center (IATRC), Baghdad Quarter, Iraq
[4] Department of Electronics and Communications Engineering, Faculty of Engineering, Ahram Canadian University, Cairo, Egypt
[5] Department of Communication and Electronics, Arab Academy for Science, Technology and Maritime Transport, Cairo, Egypt
[6] Department of Electronics and Communications Engineering, Arab Academy for Science, Technology and Maritime Transport, Cairo 11799, Egypt
[7] Department of Mechatronics Engineering and Automation, Faculty of Engineering, Egyptian Chinese University, Cairo, Egypt
[8] Higher Institute of Engineering and Technology,EL-Tagmoe EL-Khames, New Cairo, Egypt

Keywords:
High Power Microwave (HPM); horn antenna array, broad band antenna

ABSTRACT

In this paper, a 2 × 4 planar horn antenna arrays for high power microwave (HPM) system applications is introduced. The pyramidal, E-plane-plane, H-plane and the two plates of horn antenna element are analyzed using HFSS. The pyramidal horn is arrayed in a 2 × 4 configuration structure to obtain a high gain for HPM applications. The proposed horn antenna has aperture of 457.2 ×457.2 mm^2 and feeding aperture of 19.05 ×19.05 mm^2 with 1524 mm axial distance between feeder and antenna aperture. The two 1.58 thickness copper plates of the antenna flared and supported using 11 rods of artelon dielectric material of εr= 3. The antenna introduces RL=-35 dB, VSWR=1, Zin=50 Ω, BW=4 GHz and gain of 24 dB at 10 GHz operating frequency.

1. Introduction

High Power Microwave (HPM) systems have gained significant attention in recent research due to their potential applications in military, medical, and industrial sectors. A crucial requirement for an HPM system is the combination of a high-gain antenna and a high-power source to achieve effective radiated power. Various antenna designs have been explored for HPM applications, including helical antennas, horn antennas, and reflectors. These antennas are preferred due to their robust structures, which allow them to handle extremely high power without significant performance degradation. Among them, the horn antenna is widely utilized due to its high-gain characteristics, although its relatively large size remains a challenge in certain applications [1-4].

* *Corresponding author.*
E-mail address: Ahmed_miligy73@yahoo.com

https://doi.org/10.37934/araset.64.4.117

The conventional approach in HPM systems involves using a single very high-power source with a high-gain antenna. However, developing such a high-power source is expensive and complex. An alternative approach is to use an array of medium-power sources combined with an array of antennas, which allows for power distribution while maintaining high radiation efficiency. This approach is particularly beneficial for cost reduction and ease of implementation in HPM system design. Additionally, the demand for wideband applications has increased, making broadband antenna designs more crucial than ever. Recent studies have explored various antenna configurations, emphasizing their role in modern communication, radar, and sensing applications.

Horn antennas are extensively employed in wireless communications for RF microwave signal transmission and reception. Beyond communications, they have applications in biomedicine, nondestructive testing, electromagnetic sensing, and heating. The design of horn antennas typically includes conical, pyramidal, E-plane, H-plane, and two-plate configurations, each suited for specific applications. Among these, the pyramidal horn antenna is highly favored due to its simple structure, high directivity, wide bandwidth, low return loss, and low Voltage Standing Wave Ratio (VSWR) [5-7]. These characteristics make pyramidal horn antennas a preferred choice for HPM applications, where high directivity and power-handling capability are critical [8-12].

Antenna arrays play a crucial role in enhancing radiation characteristics such as gain, beamwidth, and directivity. Recently, the development of horn array antennas for commercial and military HPM applications at microwave and millimeter-wave frequencies has gained momentum [13-18]. Antenna arrays allow for greater flexibility in designing radiation patterns, gain, and phase distributions, making them highly adaptable for diverse applications such as radar, satellite communication, and radio astronomy. Additionally, horn antennas serve as feeding elements for larger antenna structures, including reflectors and lens antennas, further expanding their applications [19-24].

In HPM systems, waveguides are commonly used for feeding antennas due to their high power-handling capacity and minimal RF losses. Waveguides ensure efficient transmission of microwave energy, making them suitable for high-frequency applications. Rectangular waveguides, in particular, are widely employed as feeders for Ultra-High Frequency (UHF) antennas, as well as in waveguide bends, twists, and connecting segments [23-26].

1.1 Knowledge Contribution

Despite extensive research on horn antennas, limited studies have explored the integration of pyramidal horn arrays specifically for HPM applications. In this paper, a 2 × 4 planar horn antenna array operating at 10 GHz for HPM applications is introduced. The design utilizes pyramidal horn antennas, which are simulated and analyzed using HFSS to evaluate their performance in terms of gain, directivity, and radiation efficiency. The proposed array configuration offers an optimized radiation pattern, enhanced directivity, and improved power-handling capability, making it a suitable candidate for future HPM system implementations. This study contributes to the field by proposing an effective array-based horn antenna design tailored for HPM applications, addressing the challenges of power distribution and high-frequency efficiency [28-41].

HPM systems require specialized antennas capable of handling extreme power levels while maintaining high efficiency. Traditional antenna choices for HPM include helical antennas, reflectors, and horn antennas. Among these, horn antennas are widely used due to their ability to sustain high power levels, their simple structure, and their broad bandwidth. Various studies have explored the use of conical and pyramidal horn antennas in HPM applications, demonstrating their effectiveness in providing high directivity and stable radiation patterns. However, research gaps remain in optimizing their design for enhanced radiation efficiency and power-handling capacity.

Horn antennas have been extensively studied in the context of wireless communication, radar, and electromagnetic sensing. Their ability to operate over a wide frequency range without exhibiting strong resonances makes them ideal for broadband applications. Recent studies have focused on improving the gain and efficiency of horn antennas through advanced feeding techniques and optimized waveguide structures. The use of pyramidal horn antennas has gained particular interest due to their ease of fabrication, high gain, and low VSWR.

To achieve high power radiation without relying on a single high-power source, antenna array configurations have been proposed. These configurations utilize multiple radiating elements to enhance directivity and gain while distributing power efficiently. In particular, horn antenna arrays offer a compelling solution for HPM applications by combining multiple medium-power sources. Recent research has demonstrated the effectiveness of planar horn arrays in achieving beam-shaping and directional control, making them suitable for applications in radar, satellite communication, and HPM-based defense systems.

Efficient feeding mechanisms are crucial for ensuring minimal power loss in HPM systems. Waveguides are commonly used due to their low attenuation and ability to handle high power levels. Rectangular waveguides, in particular, are widely employed as feeding structures for UHF and microwave antennas. Advanced waveguide designs incorporating bends and twists have been explored to optimize energy transfer between the transmitter and antenna array.

Although horn antennas and antenna arrays have been extensively studied, limited research has focused on their application in HPM systems operating at high frequencies (10 GHz and beyond). The integration of pyramidal horn antennas in a planar array configuration offers significant advantages, including improved gain, directivity, and power-handling capacity. This study aims to bridge this research gap by introducing a 2 × 4 pyramidal horn arrays for HPM applications, providing a novel solution for power-efficient and high-performance microwave systems.

2. Methodology and Results

2.1 The Horn Antenna Element

A waveguide is a hollow conducting tube that transmits electromagnetic energy from one place in space to another in an effective manner. Various guiding structures exist, including common coaxial cable, two-wire and microstrip transmission lines, hollow conducting waveguides (rectangular & cylindrical), and optical fiber. The preferred operating frequency band, the quantity of power to be transmitted, and the level of transmission losses that may be allowed all influence the choice of structure. Rectangular waveguides are one of the waveguide forms that are used to transmit enormous quantities of microwave power at extremely high frequencies. Waveguides are still necessary in many applications, including high-power systems, millimetre wave systems, feeding antennas, horn antennas and several precision test applications [25-27]. Since there is only one conductor, the hollow rectangular waveguide can only propagate TM and TE waves, TEM waves cannot. We will see that, like the TM and TE modes of the parallel plate guide, the TM and TE modes of a rectangular waveguide have cutoff frequencies below which propagation is not conceivable. The horn antenna is one of the most extensively antenna used and most basic type of microwave antenna belongs to the aperture antenna family. An antenna that is used to send electromagnetic waves from a waveguide into space or receive electromagnetic waves through a waveguide is known as a horn antenna [22-27]. Between the waveguide feeder and free space, it could alternatively be thought of as the impedance matching device. A waveguide and a conical or pyramidal, E-plane, H-plane and the supported two plates horn are the components of this type of antenna. These types of antennas consist of a flare and a rectangular waveguide. The horn antenna should have a big aperture to

produce high gain. On the other hand, directivity and aperture size are dependent on gain and operating frequency, respectively. One of the metrics that is frequently used as a measure of merit to define an antenna's performance is directivity. By forming the highest radiation, directivity is discovered [21-27]. The Waveguide, aperture, and flared angle designs are all part of the design of various horn antennas. The antenna was simulated using the HFSS simulator to acquire results once all parameters had been established and all components had been designed.

2.1.1 Waveguide Feeding and Radiating Element

Pyramidal TE and TM wave functions can be used to describe the fields inside the horn. In a rectangular waveguide, radio waves can propagate in a variety of distinct modes. The predominant method of transverse electromagnetic propagation is chosen for our purposes. The TE_{10} mode in a rectangular waveguide has the lowest attenuation of any mode, and its electric field is vertically polarized. To determine the waveguide's dimensions, we must determine the cut-off frequency for the dominant mode using (1) of propagation [25]. For maximum power transfer, the width of the rectangular waveguide must be twice that of its height (a=2b), and the total length of the waveguide L=0.75 λg as shown in Figure 1 where the cutoff wavelength and the guided wavelength calculated using (2) and (3). For waves to propagate inside the waveguide, the cutoff frequency must be lower than the mode of propagation [25-26]. This is why the operating frequency must be one and a half of the cutoff frequency. The radiating element's design shown in Figure 1 is a crucial component of the overall scheme. Eq. (2) and Eq. (3) were used in the design of this component to cut-off and guide wave lengths.

$$f_{CTEm,n} = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} \quad (1)$$

$$\lambda_c = \frac{c}{f_c} \quad (2)$$

$$\lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}} \quad (3)$$

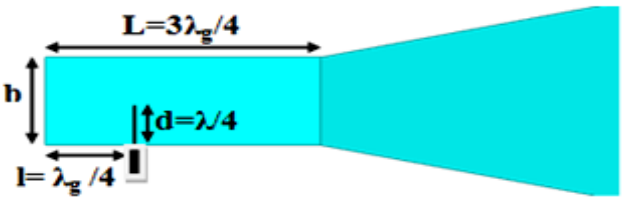

Fig. 1. Figure with short caption (caption centred)

2.1.2 Aperture Design Methodology

The pyramidal horn is also referred to as a standard gain horn because it is frequently used as a benchmark to assess the gain of other antennas. The intended gain G0 and the dimensions a, b of the rectangular feed waveguide are often known when designing a pyramidal horn. The design's goal is to identify the final dimensions shown in Figure 2 (a1, b1, e, h, Pe, and Ph) that will result in the greatest gain [11].

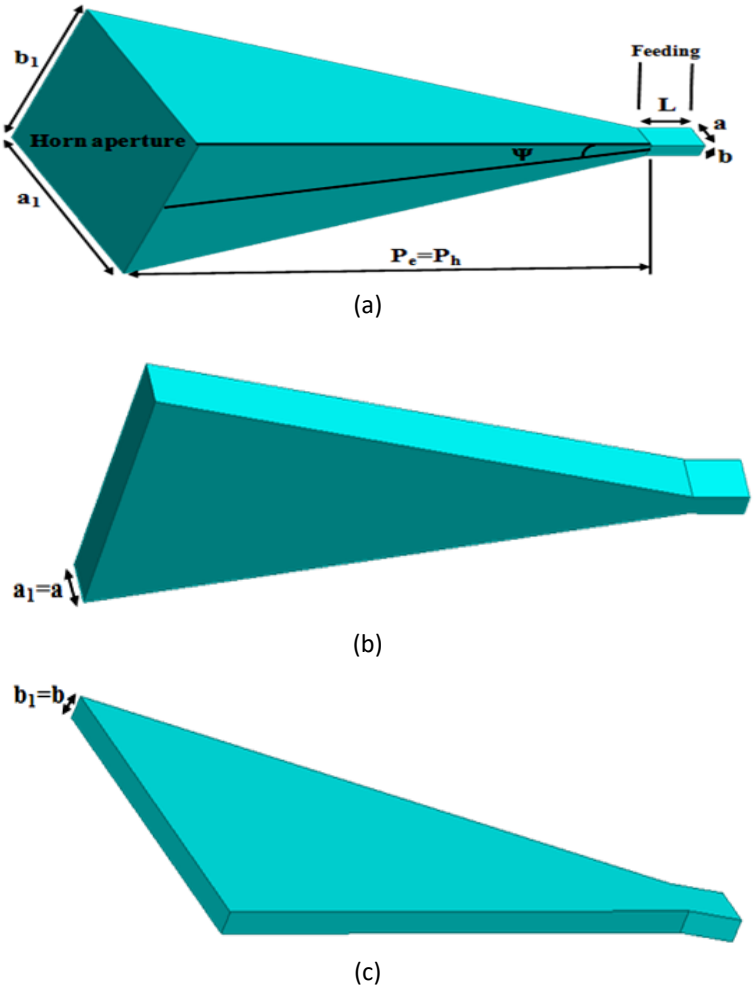

Fig. 2. The 3D view and horn antenna element dimensions (a) pyramidial (b) E-Plane sectored and (c)H-Plane sectored

The horn antenna design structures [11] using mathematical calculation for the proposed antenna are summarized assuming that G0=26 as a desired horn antenna gain as:

i. First step is to calculate the χ value which satisfies the desired gain G0=26 (dimensionless) using Eq. (4).

$$\chi\ (trial) = \chi_1 = \frac{G_0}{2\pi\sqrt{2\pi}} \tag{4}$$

ii. For a pyramidal horn to be physically realizable, Pe and Ph shown in Figure 2 must be equals. Using this equality, it can be shown that use iteration process to calculate χ value using Eq. (5).

$$\left(\sqrt{2\chi} - \frac{b}{\lambda}\right)^2 (2\chi - 1) = \left(\frac{G_0}{2\pi}\sqrt{\frac{3}{2\pi}}\frac{1}{\sqrt{\chi}} - \frac{a}{\lambda\lambda}\right)^2 \left(\frac{G_0^2}{6\pi^3}\frac{1}{\chi} - 1\right) \tag{5}$$

iii. Once the correct χ has been found, determine ρe and ρh using Eq. (6) and Eq. (7).

$$\frac{\rho_e}{\lambda} = \chi \tag{6}$$

$$\frac{\rho_h}{\lambda} = \frac{G_0^2}{8\pi^3}\left(\frac{1}{\chi}\right) \tag{7}$$

iv. Find the corresponding values of a1 and b1 using Eq. (8) and Eq. (9).

$$a_1 = \sqrt{3\lambda\rho_2} \cong \sqrt{3\lambda\rho_h} = \frac{G_0}{2\pi}\sqrt{\frac{3}{2\pi\chi}\lambda} \tag{8}$$

$$b_1 = \sqrt{2\lambda\rho_1} \cong \sqrt{2\lambda\rho_e} = \sqrt{2\chi\lambda} \tag{9}$$

v. The values of pe and ph are equals according to Eq. (10) and Eq. (11) for structure design.

$$\rho_e = (b_1 - b)\left[\left(\frac{\rho_e}{b_1}\right)^2 - \frac{1}{4}\right]^{1/2} \tag{10}$$

$$\rho_h = (a_1 - a)\left[\left(\frac{\rho_h}{a_1}\right)^2 - \frac{1}{4}\right]^{1/2} \tag{11}$$

vi. In order to improve antenna directivity and match the impedance between the waveguide aperture and free space, the flare is used [11]. The total flare angle of the horn should be equal to 2ψ using Eq. (12).

$$2\Psi_e = 2tan^{-1}\left(\frac{b_{1/2}}{\rho_1}\right) \tag{12}$$

vii. Since the overall efficiency of a horn antenna is about 50%, the gain of the antenna can be related to its physical area as a check, the gain of the designed horn was computed using Eq. (13) [11].

$$G_0 = \frac{1}{2}\frac{4\pi}{\lambda^2}(a_1 b_1) = \frac{2\pi}{\lambda^2}\sqrt{3\lambda\rho_2}\sqrt{2\lambda\rho_1} \cong \frac{2\pi}{\lambda^2}\sqrt{3\lambda\rho_h}\sqrt{2\lambda\rho_e} \tag{13}$$

The main dimensions and parameters for the proposed horn antenna element with rectangular waveguide feeding and radiating element is tabulated in Table 1.

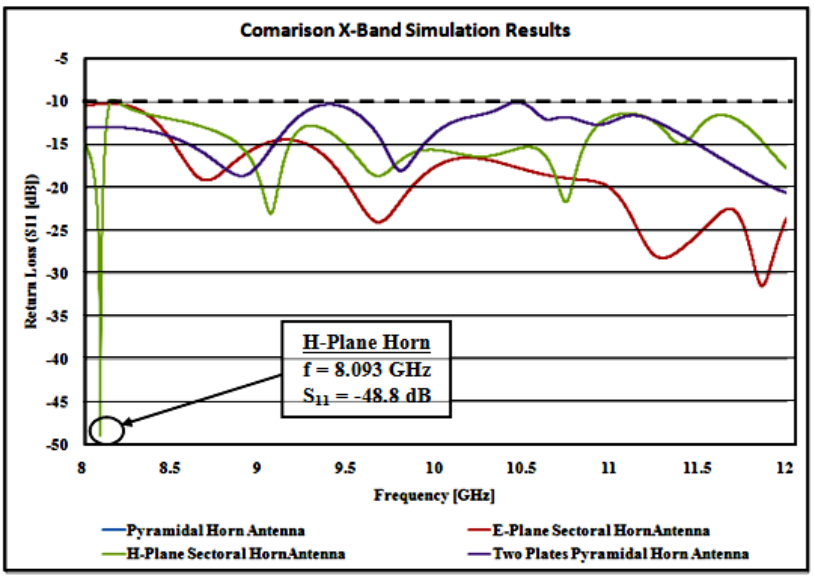

Fig. 2. The horn antenna element varities Return Loss [dB]

Table 1
The dimensions and parameters [mm]

a	b=a/2	a1	b1	L=3λg/4	Pe= Ph	l=λg/4
20.45	10.27	163	129	27.44	275	9.14
d=λ/4	λ	λc	λg	G[dB]	2Ψ [deg.]	
6.818	27.27	40.9	36.5	22.6	E-24.3	H-29

The simulation results such as the return loss, the surface current distribution on the antenna surface, the antenna input real and imaginary impedance are introduced to determine the performance of antennas are shown in Figure 3 to Figure 4 for the proposed pyramidal, E-plane, H-plane and the supported two plates horn.

The proposed pyramidal, E-plane, H-plane and the supported two plates horn as structure varieties are compared and the comparison resulting in that the optimum RL=-20.6, -31.4, -48.8 and -20.6 at 12,11.8,8 and 12 GHz for varieties respectively shown in Figure 3.

The proposed pyramidal, E-plane, H-plane and the supported two plates horn as structure varieties are compared from the view of impedance matching of optimum RL [dB] as shown in table II with the corresponding recommended operating frequency for each variety.

Table 2
The dimensions and parameters [mm]

Antenna Varity	Recommended Frequency [GHz]	Return Loss [dB]
Pyramidal	12	-20.6
E-Plane Sectored	11.8	-31.4
H-Plane Sectored	8	-48.8
Two Plates	12	-20.6

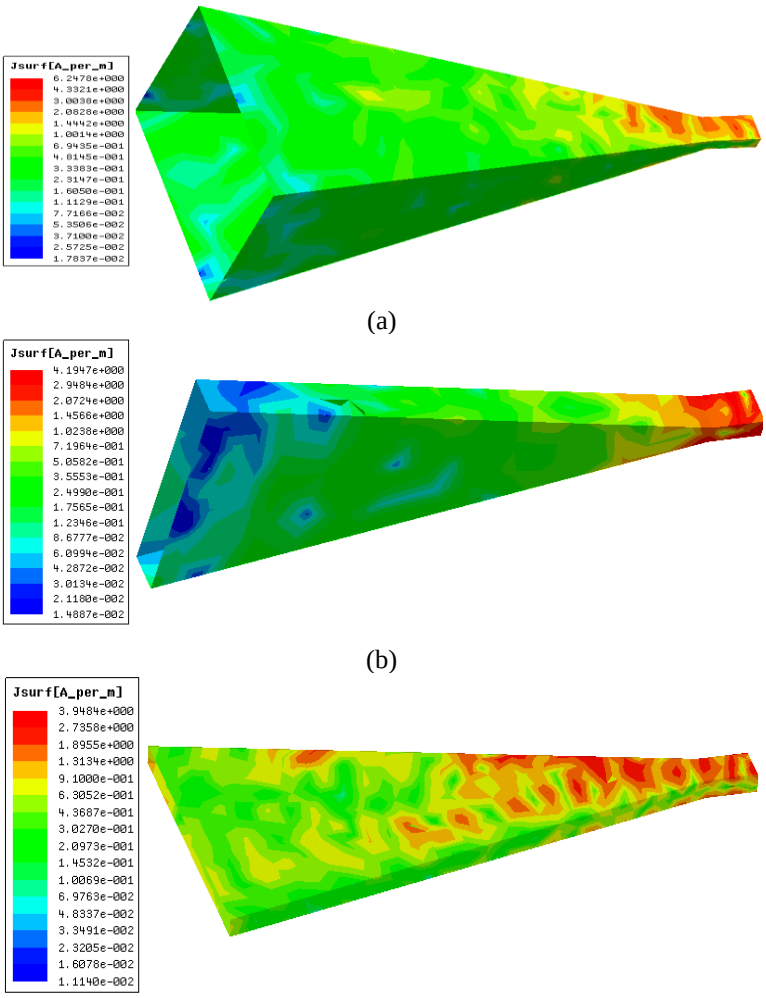

Fig. 3. The Jsurface [A/m] (a) pyramidial (b) E-Plane sectored (c) H-Plane sectored

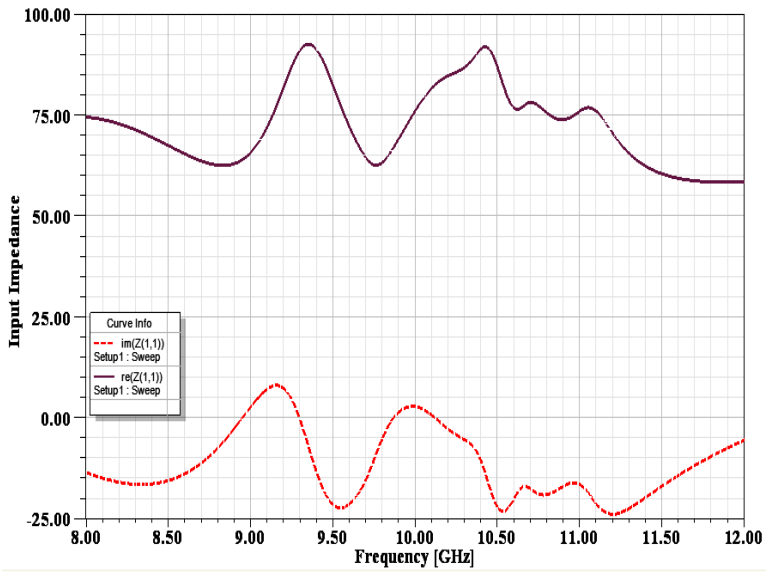

Fig. 4. The real and im. element input impedance [Ohm]

2.2 The Horn Antenna Arrays

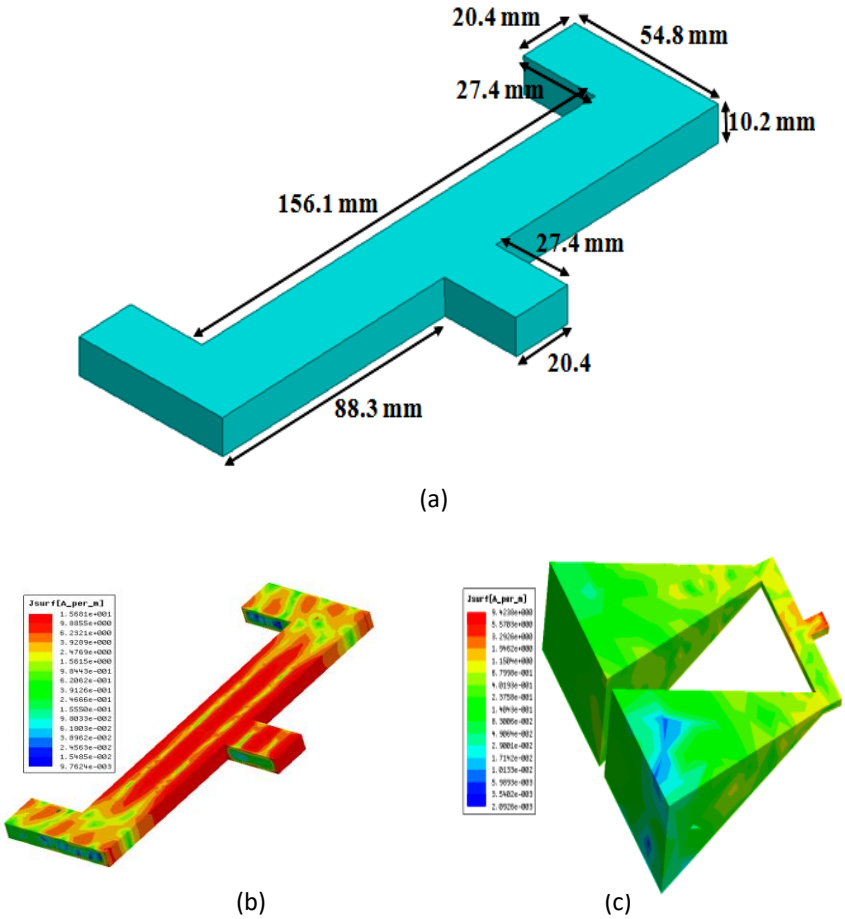

Fig. 5. The two elements Array (a) the Feeding Dimensions (b) the Feeder Jsur. [A/m] (c) the two elements with Feeder Jsur. [A/m]

An antenna array is essentially a collection of antennas that have been arranged to obtain the requisite magnitude and phase overall. They are used to obtain the radiation pattern and gain that the design calls for. By multiplying the array factor by the pattern of the unit elements, the array antenna pattern may be computed. Since consistently distributed current produces the maximum directivity in aperture antenna designs, the amplitude and phase distribution should be uniform to provide the highest directivity in planar antenna arrays. Rectangular waveguides are still employed in many applications today despite being one of the earliest designs of transmission lines for microwave transmissions. Commercially available parts include couplers, detectors, isolators, attenuators, slotted lines and feeding structures covering a range of standard waveguide bands from 1 GHz to more than 220 GHz. The two output ports feeding line is designed with dimensions shown in Figure 6 (a) with the current distribution for the proposed feeder shown in Figure 5 (b) to feed the two elements antenna array with the current distribution shown in Figure 5 (c).

The 1 × 4 linear horn array antennas are constructed using four output ports feeding line of dimensions shown in Figure 6 (a) with its current distribution on the surface of feeder shown in Figure 6 (b). The feeder has a uniform feeding for each element constructing the 1x4 linear horn antenna array shown in Figure 6 (c).

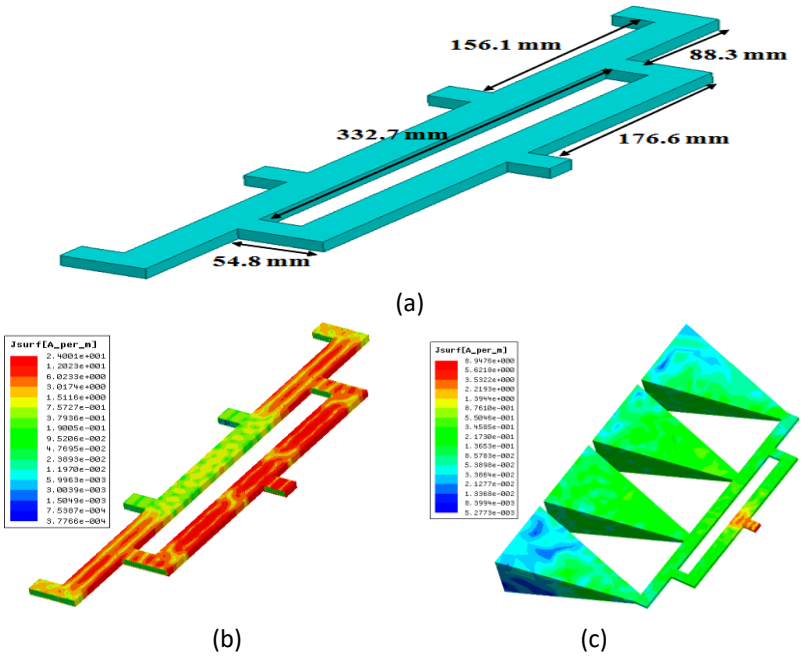

Fig. 6. The Linear Array (a) the Feeding Dimensions (b) the Feeder Jsur. [A/m] (c) the Linear Array with Feeder Jsur. [A/m]

The 2 × 4 planar horn array antenna is constructed using two linear pyramidal horn antenna arrays spacing of 152.8 mm. Each array has four elements has been connected using eight output ports wave guide feeder of surface current distribution using HFSS over the surface of the proposed structure shown in Figure 7 (a) and Figure 7 (b). The uniform feeding is used for both amplitude and phase, Grid structure may be used to suppress grating lobes and improve the efficiency of the aperture. Figure 7 (c) showed the 4x4 planar horn arrays with the surface current distribution on surface for the proposed planar array.

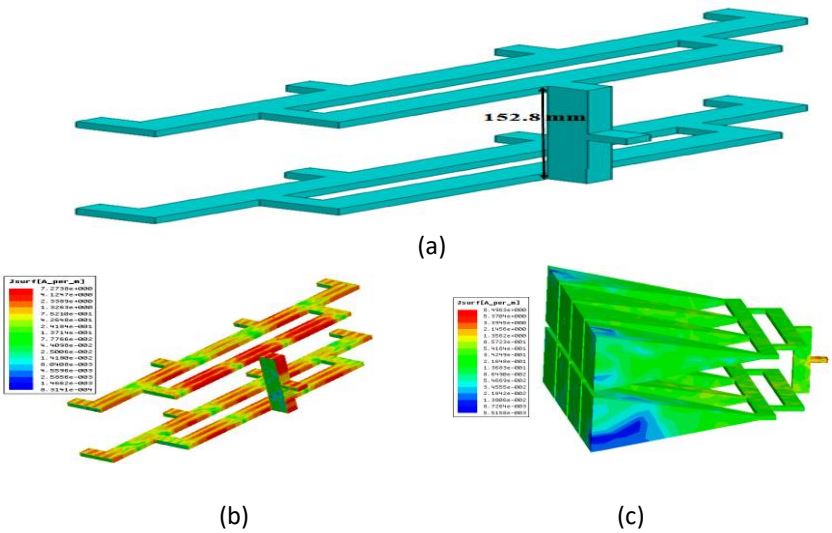

Fig. 7. The Planarr Array (a) the Feeding Dimensions (b) the Feeder Jsur. [A/m] (c) the Planar Array with Feeder Jsur. [A/m]

The different varieties array has been designed, analyzes and simulated using HFSS and resulting in an impedance matching for the input impedance of the array antenna as shown in Figure 8 for both real and imaginary parts in ohm.

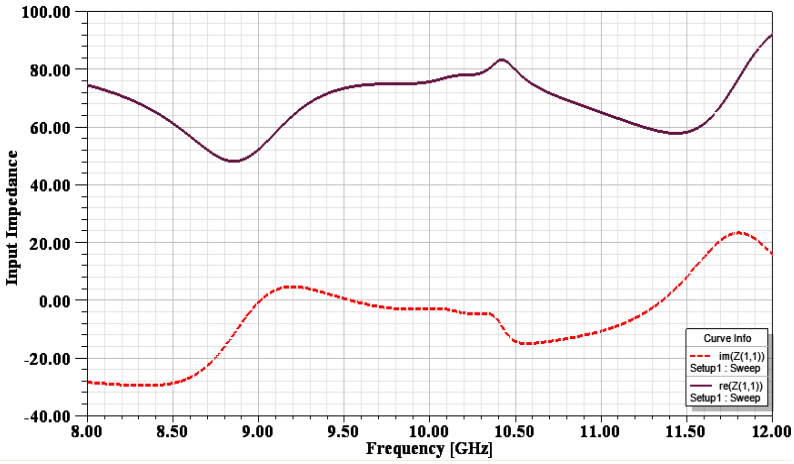

Fig. 8. The Real and Im. Array Input Impedance [Ohm]

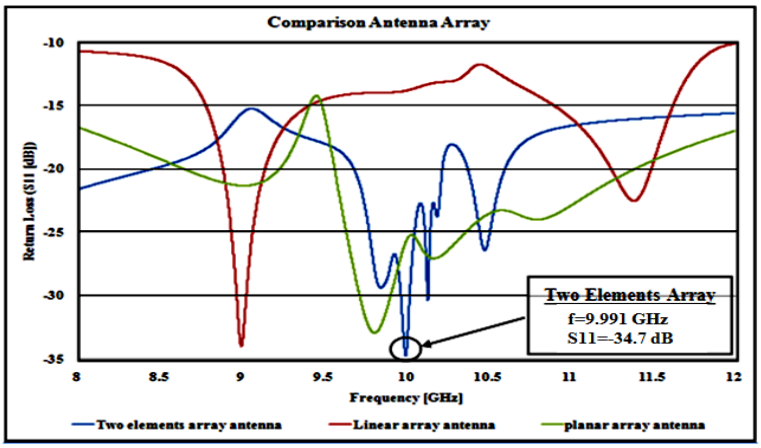

Fig. 9. The Horn Antenna Array Varities Return Loss [dB]

The two elements, linear and planar array as array varieties is compared using HFSS and the comparison resulting in that the optimum RL [dB]=-34.7, -33.9 and -32.9 at 9.99,8.99 and 9.8 GHz for varieties respectively as shown in Figure 9. The proposed two elements, linear and planar pyramidal arrays are compared for the optimum RL [dB] as shown in Table 3 with the recommended operating frequency for each array.

Table 3
The comparision of the Array Varities

Antenna Array Varity	Recommended Frequency [GHz]	Return Loss [dB]
Two Elements Array	9.991	-34.7
Linear Array	8.99	-33.9
Planar Array	9.801	-32.9

2.3 HPM Horn Antenna for Planar Array

A high-gain antenna is required for the HPM for high effective radiated power. The proposed horn antenna, which has high-gain qualities and a huge size and its dimensions shown in Figure 10, is the element of the proposed planar array to meet the requirement of HPM applications.

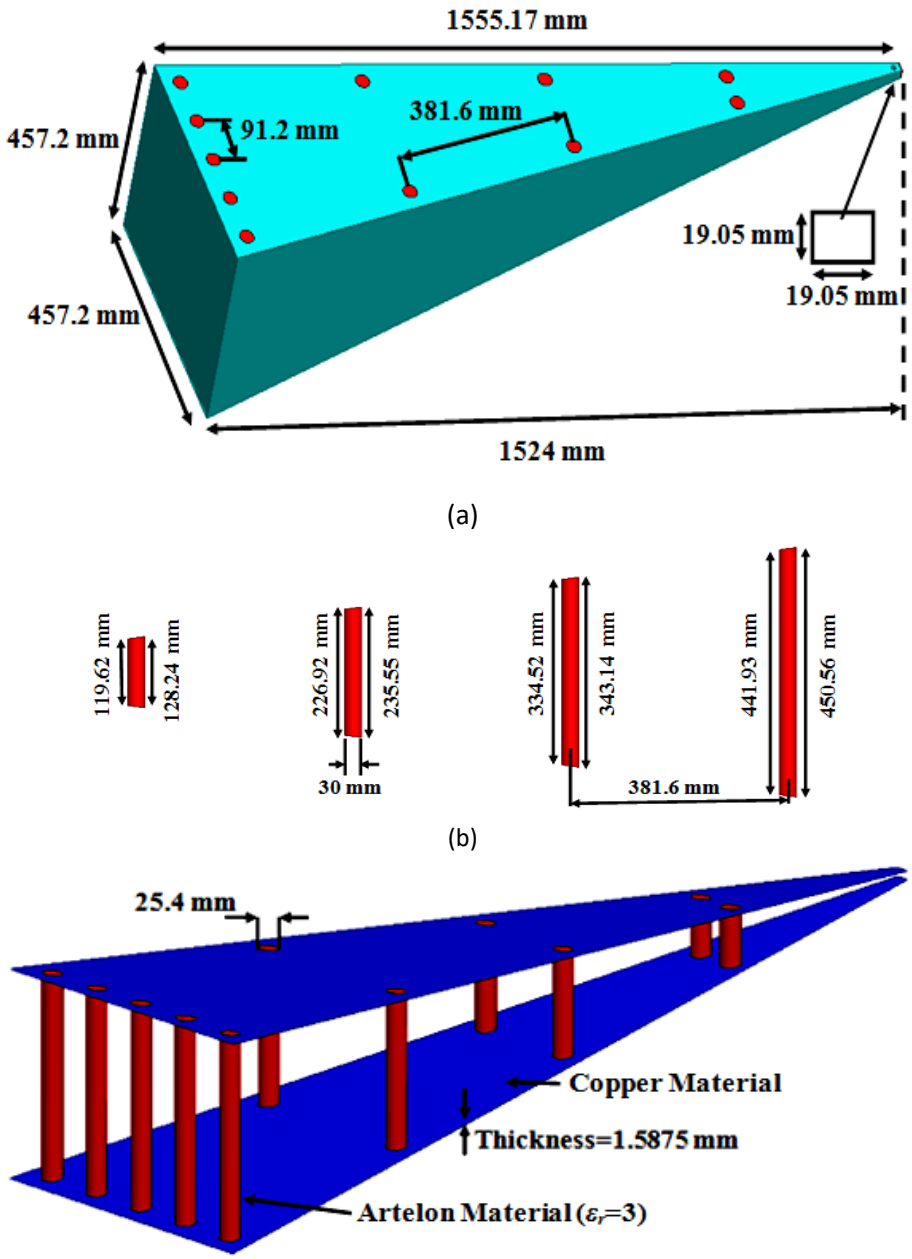

Fig. 10. The HPM Horn Antenna dimensions (a) dimensions (b) Supported and Flaring Dielectric Rods (c) the 3D view

The proposed horn antenna element for the planar array has an aperture of 457.2x457.2 mm2 with 1524 axial distance. The feeding port has rectangular aperture of 19.05x19.05 mm2. The antenna is two plates of copper with thickness 1.5875 mm flared with 11 rods gradually in length of and 25.4 mm diameter artelon dielectric material of dielectric constant permittivity of 3 and

thickness. The main dimensions of antenna, rod dielectric and 3D view of the proposed antenna are illustrated in Figure 10 (a), (b) and (c) respectively.

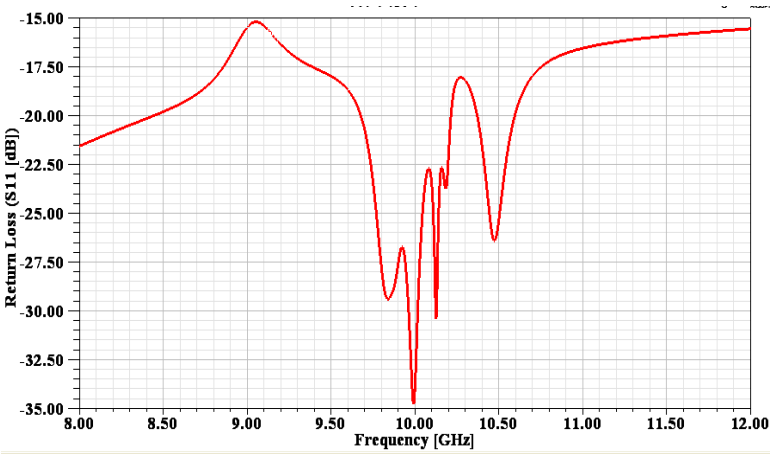

Fig. 11. The HPM Horn Antenna Return Loss [dB]

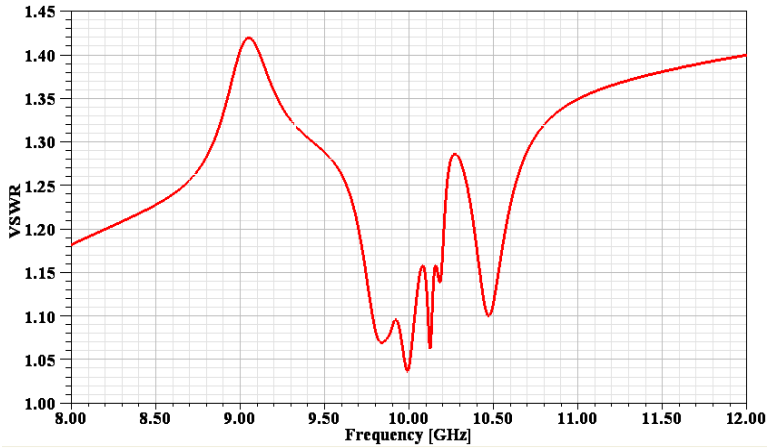

Fig. 12. The HPM Horn Antenna VSWR

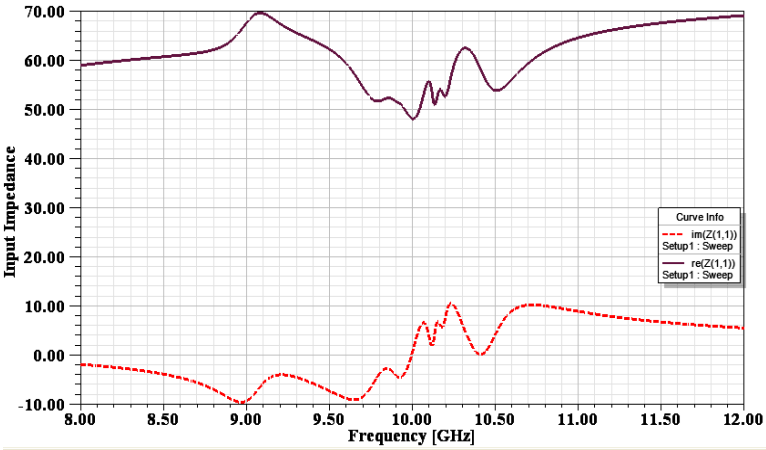

Fig. 13. The Real and Im. HPM Input Impedance [Ohm]

From simulation results using HFSS for the proposed HPM element for planar array the RL =-35 dB at 10 GHz operating frequency with broad BW=4 GHz as shown in Figure 11. The SWR=1 and the input impedance equal 50 ohm which illustrated in Figure 12 and Figure 13.

The 3D radiation pattern and polar plot of the proposed horn antenna is shown in Figure 14. The current distribution over the surface introduced in Figure 15 to demonstrate performance of the proposed horn antenna element for the HPM planar antenna array at 10 GHz operating frequency. THE HPM horn antenna element for the proposed planar array is tabulated in Table 4.

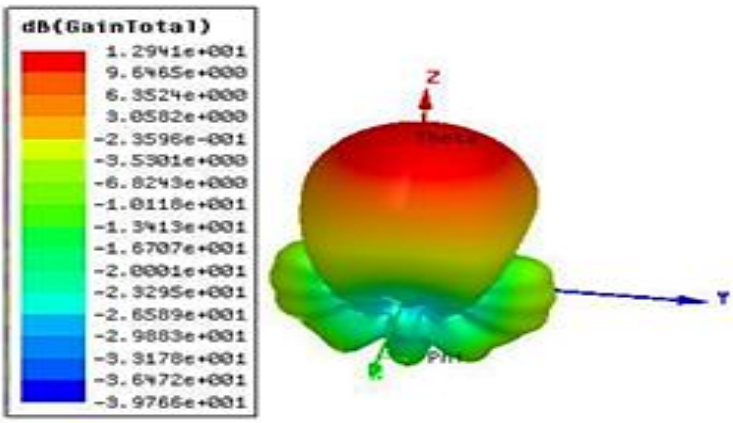

Fig. 14. The HPM Horn Antenna and the 3D radiation pattern

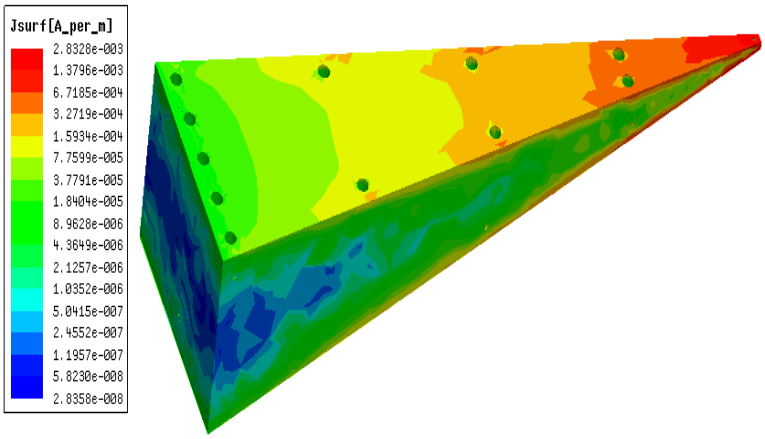

Fig. 15. The HPM Jsurface [A/m]

Table 4
The Hpm Horn Antenna Parameters and Dimensions [mm]

f [GHz]	RL [dB]	Zin [Ω]	B.W [GHz1	G [dB]	Pe= Ph	a1=b1
10	-35	50	4	13	1524	457.2
a=b	# of rods	Rod εr	Plate thickness		a=b	
19.05	11	3	1.58		19.05	

3. Conclusions

The proposed horn antenna element, designed for integration into a 2 × 4 array configuration, has demonstrated exceptional performance tailored to meet the stringent requirements of High-Power Microwave (HPM) applications. This antenna design achieves a high gain of 24 dB at 10 GHz, a critical parameter for ensuring focused energy transmission and enhanced system efficiency in HPM systems. The broadband capability, spanning 4 GHz across the X-band, provides operational flexibility, supporting a wide range of high-frequency applications.

Key performance indicators such as the return loss of -35 dB and a Voltage Standing Wave Ratio (VSWR) of 1 reflect excellent impedance matching, minimizing power loss and maximizing transmission efficiency. The antenna's input impedance of 50 Ω aligns seamlessly with standard RF systems, ensuring compatibility without additional matching networks.

Furthermore, the comparative analysis presented in Table 5 highlights the superiority of the proposed design over existing solutions, particularly in terms of gain, bandwidth, and return loss. The significant improvement in these parameters underscores the antenna's potential for advanced HPM systems, where high power handling, directivity, and efficiency are paramount.

Overall, the proposed 2 × 4 horn antenna array stands out as a robust and efficient solution, offering enhanced performance metrics that address both current and future demands in HPM applications. Future research may explore further optimization of array configurations, material innovations, and thermal management strategies to push the performance boundaries even further.

Table 5
The comparison of relative works

Comparison Ref.	S11 [dB]	Gain [dB]	BW [GHz]
Ref [1]	-35	19.7	3.5
Ref [9]	-20	13	3
Ref [19]	-23	15	4.5
Ref [22]	-22	25	1.5
Ref [27]	-33	20	3
This Paper	-35	24	4

Acknowledgement
This research was not funded by any grant.

References
[1] Choi, Yoon-Seon, Ji-Hun Hong, and Jong-Myung Woo. "Array synthesis horn antenna with an extended horn and a stepped corrugated structure for high-power microwave applications." *Journal of Electromagnetic Engineering and Science* 20, no. 2 (2020): 110-114. https://doi.org/10.26866/jees.2020.20.2.110

[2] Zhou, Xiao, and Tie-Jun Cui. "Efficient evaluation of near-field time-domain physical-optics integral using locally expanded green function approximation." *Progress In Electromagnetics Research* 150 (2015): 41-48. https://doi.org/10.2528/PIER14102507

[3] Umbarkar, Sachin Bhagwat, Harivittal A. Mangalvedekar, Sreedevi Bindu, Archana Sharma, Purnamasi Chotelal Saroj, and Kailash Chandra Mittal. "Analysis of HTEM horn-type antenna for high-power impulse radiation applications." *IEEE Transactions on Plasma Science* 42, no. 10 (2014): 3288-3294. https://doi.org/10.1109/TPS.2014.2320496

[4] Shao, Jinjin, Guochang Liu, Yicai Ji, Guangyou Fang, and Hejun Yin. "UWB TEM horn antenna for the asphalt pavement investigation." *Journal of Electronics (China)* 31, no. 1 (2014): 24-28. https://doi.org/10.1007/s11767-013-3128-9

[5] Xiong, Xiong, Weijun Hong, Shengli Xie, and Xiaoyang Liu. "Impedance model of dipole antenna combined with the structure parameters of GTEM cell." In *Proceedings of the 2014 Sixth International Conference on Computational Intelligence, Communication Systems and Networks*, pp. 44-47. 2014.

[6] Li, Hang, and Shoulin Yin. "An improved TEM antenna designing used in electromagnetic pulse directed radiation." *Progress In Electromagnetics Research Letters* 57 (2015): 17-22. https://doi.org/10.2528/PIERL15040205

[7] Li, Yufu, Xiaoxing Yin, Hongxin Zhao, Lei Wang, and Mei Yang. "Radiation enhanced broadband planar TEM horn antenna." In *2014 Asia-Pacific Microwave Conference*, pp. 720-722. IEEE, 2014.

[8] Kumar, P. Gowtham, P. Chandrasekhar, and SB Sai Rama Raju. "Study on Slotted Waveguide Pyramidal Horn Antenna with Enhanced Directivity." *IPASJ International Journal of Computer Science (IIJCS)* 3, no. 3 (2015).

[9] Gope, U. C., S. Rana, and N. K. Das. "Design fabrication and simulation of pyramidal horn antenna at 950MHz frequency." *International Journal of Engineering and Applied Sciences (IJEAS) ISSN* (2019): 2394-3661.

[10] Chand, R. Kiran, Dr MV Raghavendra, and K. Sathyavathi. "Radiation analysis and design of pyramidal horn antenna." *International Journal of Engineering Research & Technology (IJERT)* 2, no. 10 (2013).
[11] Elliot, Robert S. *Antenna theory and design*. John Wiley & Sons, 2006.
[12] Abhignya, G., B. Yogita, C. Abhinay, B. Balaji, and M. B. R. Murthy. "Design, fabrication and testing of pyramidal horn antenna." *International Journal of Engineering and Applied Sciences* 2, no. 4 (2015): 257953.
[13] Kapade, Shital Pramod, and A. S. Deshpande. "Review of Horn Antenna." *IJARIIE* 3, no. 4 (2017).
[14] Singh, Kirpal, Ajay Siwach, and Lovleen Kaur. "Advancement in designing of wideband horn antenna." *International Journal of Engineering Trends and Technology (IJETT)* 4, no. 4 (2013): 719-722.
[15] Bassam, Sara Banou, and Jalil A. Rashed-Mohassel. "A chebyshev tapered TEM horn antenna." *Piers Online* 2, no. 6 (2006): 706-709. https://doi.org/10.2529/PIERS060902041831
[16] Daniyan, O. L., F. E. Opara, B. I. Okere, Nura Aliyu, Nwachukwu Ezechi, J. Wali, J. Adejoh et al. "Horn antenna design: the concepts and considerations." *International Journal of Emerging Technology and Advanced Engineering* 4, no. 5 (2014): 706-708.
[17] Shankar, S. Gowri, K. Viswavardhan Reddy, and K. Vishnuvardhana Reddy. "Design and simulation of horn antenna in x-Ku band for satellite communications." *Int. J. Res. Sci. Technol.(IJRST)* 1, no. 10 (2014): 6.
[18] Chen, Zhuozhu, and Zhongxiang Shen. "Broadband and low-profile H-plane ridged horn antenna." In *2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, pp. 2319-2320. IEEE, 2015. https://doi.org/10.1109/APS.2015.7305548
[19] Mukhlif, Fadhil. "Analysis and Design Pyramidal Horn Antenna in X-Band." In *International Conference on Communication, Electrical and Computer Networks (ICCECN 2020) Kuala Lumpur, Malaysia*, pp. 1-2. 2020.
[20] Yogesh G S, Chandrappa D N, Anita R, Rajendra Soloni "DESIGN AND SIMULATION OF HORN ANTENNA AT 2GHZ WITH HFSS "International Journal of Advanced Research in Computer and Communication Engineering Impact Factor 7.39,Vol. 11, Issue 1, January 2022.
[21] Barik, Biswa Ranjan, and A. Kalirasu. "Design of a UHF pyramidal horn antenna using CST." *J. Pure Appl* 114 (2017): 447-457.
[22] Girish, K.: Electrical Engineering Department, IIT Bombay. https://nptel.ac.in/courses/ 108101092/ Week-10-Horn-Antennas-Part-1.pdf. Last accessed 12 Jul 2018. https://doi.org/10.26634/jee.12.2.14169
[23] Ördek, Sezgin, and Ahmet Kizilay. "Horn array antenna design for Ku-band applications." In *2015 9th International Conference on Electrical and Electronics Engineering (ELECO)*, pp. 351-354. IEEE, 2015. https://doi.org/10.1109/ELECO.2015.7394505
[24] Douvalis, Vassilis, Yang Hao, and Clive G. Parini. "A monolithic active conical horn antenna array for millimeter and submillimeter wave applications." *IEEE transactions on antennas and propagation* 54, no. 5 (2006): 1393-1398. https://doi.org/10.1109/TAP.2006.874338
[25] Martyniuk, S. Ye, F. F. Dubrovka, O. S. Zakharchenko, and P. Ya Stepanenko. "Effective high-precision analysis of thin asymmetric inductive diaphragm in rectangular waveguide using integral equation method." *Radioelectronics and Communications Systems* 64 (2021): 80-91. https://doi.org/10.3103/S0735272721020035
[26] Moradian, Mahdi, Mohammad Khalaj-Amirhosseini, and Majid Tayarani. "Application of wiggly ridge waveguide for design of linear array antennas of centered longitudinal shunt slot." *International Journal of RF and Microwave Computer-Aided Engineering: Co-sponsored by the Center for Advanced Manufacturing and Packaging of Microwave, Optical, and Digital Electronics (CAMPmode) at the University of Colorado at Boulder* 19, no. 6 (2009): 717-726. https://doi.org/10.1002/mmce.20396
[27] Liu, Rong, HongChao Wu, NaiZhi Wang, and Tong Li. "Design of High Power Microwave Active Phased Array Antenna Unit." In *2022 IEEE 9th International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications (MAPE)*, pp. 175-179. IEEE, 2022. https://doi.org/10.1109/MAPE53743.2022.9935235
[28] High Frequency Structure Simulator software package, HFSS v13, Ansoft Corporation.
[29] Taher, Fatma, Moath Alathbah, Thamer Alghamdi, Mohamed Fathy Abo Sree, and Sara Yehia Abdel Fatah. "Wireless insights into cognitive wellness: A paradigm shift in Alzheimer's detection through ultrathin wearable antennas." *IEEE Access* (2024). https://doi.org/10.1109/ACCESS.2024.3389814
[30] Hassan, Mohamed, and Mohamed Fathy Abo Sree. "Detecting different stages of Alzheimer's disease using an ultra-thin wearable antenna." In *2024 6th International Youth Conference on Radio Electronics, Electrical and Power Engineering (REEPE)*, pp. 1-8. IEEE, 2024. https://doi.org/10.1109/REEPE60449.2024.10479764
[31] Hassan, Mohamed, and Fathy Abo Sree Mohamed. "Detecting Selected Neurodegenerative Diseases through Microwave Technology: Modeling and Identifying Different Stages of Alzheimer's Disease." In *2024 6th International Youth Conference on Radio Electronics, Electrical and Power Engineering (REEPE)*, pp. 1-6. IEEE, 2024. https://doi.org/10.1109/REEPE60449.2024.10479753
[32] Fatah, Sara Yehia Abdel, Fatma Taher, Mohamed Khaled Gad Attya, Karim Ahmed Hosni, Moath Alathbah, Thamer Alghamdi, and Mohamed Fathy Abo Sree. "Advancements in underground object detection: Exploring emerging

techniques and technologies." In *2024 International Telecommunications Conference (ITC-Egypt)*, pp. 852-857. IEEE, 2024. https://doi.org/10.1109/ITC-Egypt61547.2024.10620483

[33] Miligy, Ahmed F., Assem H. Elfeky, Ahmed SI Amar, Alla M. Eid, and Mohamed Fathy Abo Sree. "Enhanced Patch Antenna Characteristics Analysis and Implementation with DGS and SMS." In *2024 International Telecommunications Conference (ITC-Egypt)*, pp. 615-622. IEEE, 2024. https://doi.org/10.1109/ITC-Egypt61547.2024.10620458

[34] Miligy, Ahmed F., Fatma Taher, Mohamed Fathy Abo Sree, Assem H. Elfeky, and Sara Yehia Abdel Fatah. "Advancements in Microwave Technology for Brain Diagnosis: A Comprehensive Survey on Neurodegenerative Diseases, Tumors, and Stroke Detection." In *2024 International Telecommunications Conference (ITC-Egypt)*, pp. 623-630. IEEE, 2024. https://doi.org/10.1109/ITC-Egypt61547.2024.10620454

[35] Alathbah, Moath, Fatma Taher, Mohamed Fathy Abo Sree, Thamer Alghamdi, and Sara Yehia Elshatlawy. "Advancements in microwave technology for congestive heart failure diagnosis." In *2024 International Telecommunications Conference (ITC-Egypt)*, pp. 774-780. IEEE, 2024. https://doi.org/10.1109/ITC-Egypt61547.2024.10620588

[36] Taher, Fatma, A. M. M. A. Allam, Ahmed F. Miligy, Mohamed A. Mohamed, Mohamed Fathy Abo Sree, and Sara Yehia Abdel Fatah. "Metamaterial Structure Effect on Printed Antenna for LTE/WIFI/Cancer Diagnosis." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 46, no. 1 (2025): 237. https://doi.org/10.37934/araset.46.1.237249

[37] Zanah, Farah Wardatul. "ANALISIS PERBANDINGAN PERFORMASI DIRECTION OF ARRIVAL PADA SMART ANTENNA UNIFORM LINEAR ARRAY DENGAN ALGORITMA MUSIC-USV DAN ESPRIT." PhD diss., Universitas Pendidikan Indonesia, 2023.

[38] Sofri, Tasneem, Hasliza A. Rahim, Allan Melvin Andrew, Ping Jack Soh, Latifah Munirah Kamarudin, and Nishizaki Hiromitsu. "Data normalization methods of hybridized multi-stage feature selection classification for 5G base station antenna health effect detection." (2023).

[39] Alobaidi, Omar Raed, Mustafa Ghanim, Mustafa Thamir Wafeeq, Abdulmalek Ahmed Rija, Puvaneswaran Chelvanathan, Badariah Bais, Ameer Alhasan, Mohammad Hasan Basheet, and Nowshad Amin. "Multifunctional Double Band Mesh Antenna with Solar Cell Integration for Communications Purposes." *Journal of Advanced Research in Applied Sciences and Engineering Technology*.

[40] Rahayu, Yusnita, M. Khairon, Khairul Najmy Abdul Rani, and Teguh Praludi. "Detection of Breast Tumour Depth using Felt Substrate Textile Antenna." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 39: 59-75. https://doi.org/10.37934/araset.39.1.5975

[41] Sreelakshmy, R., et al. "Investigation of Split Ring Resonator Based Rectangular Micro-Strip Patch Antenna for Radar Communication." Journal of Advanced Research in Applied Sciences and Engineering Technology 37.1 (2024): 171-178. https://doi.org/10.37934/araset.37.1.171178