International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 8, August 2017)

Design and Analysis of 24GHz Pyramidal Horn Antenna with Improved Gain

Resham Madan[1], Vinitkumar Jayaprakash Dongre[2]

[1]ME Student, [2]HOD & Associate Professor, Department of Electronics & Telecommunication, Thakur College of Engineering & Technology, Mumbai, India

***Abstract*— In this paper, the design of Pyramidal Horn Antenna for FMCW Radar applications, operating at 24GHz (K-band) frequency, is discussed. The horn antenna is widely used inside the transmission and reception of RF microwave alerts. It's also an assembly of flaring metallic, waveguide and antenna. Horn antennas are extensively used in regions of Wi-Fi communications, electromagnetic sensing, nondestructive trying out and evaluation, radio frequency heating and biomedicine. They're also extensively used as excessive benefit elements in phased arrays and as feed elements for reflectors and lens antennas in satellite, microwave and millimeter wave structures. Furthermore, they serve as an everyday popular for calibration and benefit measurements of different antennas. CST Microwave Studio Software is used for the layout and the simulation of the desired antenna. Antenna system contains the transmitting antenna and the receiving antenna or a single antenna can be utilized for both the purpose.**

We have likewise talked about various antenna parameters for the design, like Gain, radiation pattern, return loss, VSWR. For obtaining better results, many more changes in dimensions may be required. But this will lead to more complex calculations and implementation methods. This paper contains foundation to horn antenna, introduction of the pyramidal horn, its design, analysis & results and conclusion.

***Keywords*—Pyramidal Horn Antenna, FMCW radar, Radiation Pattern, K-band, Flaring**

I. INTRODUCTION

Most widely used and simple microwave antenna is horn antenna. They came into existence in late 1800s. During World War II, with engrossment in microwaves and waveguide transmission lines, it began in 1930.

The horn is extensively used over a large are as satellite tracking, communication dishes throughout the world. Horn antenna maintains as an all-inclusive standard for adjustment and main element for phased array. It is common for reflector antennas and lens antennas and is also used for estimation of other high-gain antennas. It is significantly utilized as a result of its adaptability, ease of excitation, simplicity in construction and overall performance.

Horn antennas have drawbacks that they are huge in size and another is their narrow band. As we go towards the UHF and VHF ranges the dimensions of horn become noticeable and large. With the use of ridges, the bandwidth of horn antennas can be improved. With the introduction of ridges, the bandwidth was improved within the same manner as they improve it in waveguide technology. For wide bandwidth, the specified diverging mode is supported by ridges [1]. While with the beginning of the new era and growth in wireless technology there was further need for measuring these wireless devices. Nowadays, it is widely used in medical equipment, radio astronomy and telecom industry.

Continuous wave (CW) and frequency modulated continuous wave (FMCW) radars areas unit usually used for prime accuracy measurements. CW radar devices have high accuracy and enables relative separations to be resolved however the unambiguous range is restricted by the wavelength. The accuracy of the FMCW radars is lacking in connection to the undeniably higher modern prerequisites. Hence the combination of both systems by combining frequency and phase evaluation methods has proven to be a successful approach, as demonstrated in [2], [3].

Even though different FMCW radars for top accuracy measurements are complete, there's a scarcity of theory showing the utmost capabilities of FMCW radar with section evaluation [10].

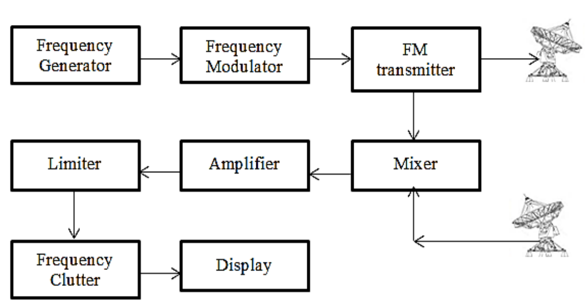

Figure 1: Block diagram of FMCW Radar

Figure 1 shows the basic block diagram of FMCW radar system.

II. Pyramidal (E-H Plane) Horn Antenna

Horn antennas are in vogue in microwave band above 1 GHz. Horn antennas are also known as aperture antenna. This type of antenna provides high gain, wide bandwidth, low VSWR and are very easy to construct. There are various types of horn antennas like E-plane, H-plane, E-H plane or pyramidal horn antenna (figure 2). Aperture antenna is more familiar due to usage of higher frequencies and their increasing demand. This antenna is extremely helpful for craft and satellite applications as these will be simply ascended on their surface [12]. To protect from environmental conditions, we can also use the covering of dielectric material. For higher matching in broad band, the horns are flared exponentially, but it is difficult to fabricate and is expensive. Pyramidal horn antennas have high directivity and gain than sectoral horn antennas. In pyramidal horn antennas, the side lobes in the radiation pattern increases proportional for high frequencies.

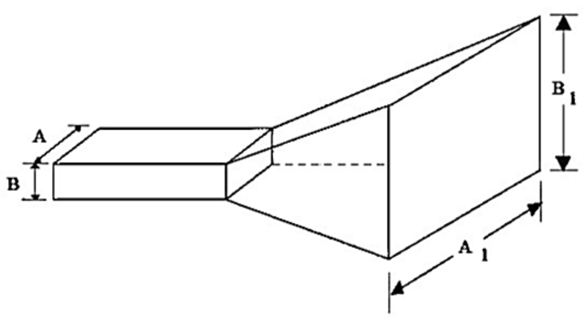

Figure 2: Pyramidal Horn Antenna

III. Design Of Pyramidal Horn Antenna

To design a pyramidal horn with E-plane dimensions B, B_1, L_E, L_1, P_E and H-plane dimensions A, A_1, L_H, L_2, P_H . For feeding the Pyramidal horn, rectangular waveguide is used; having the inner dimensions labeled as A and B, G (Gain) that is easily calculated from waveguide formulae. There are lots of design methods for designing the pyramidal horn antennas [12]. For the designing of pyramidal horn antennas, the most common design equation is:

$$(2\,\xi - 1)\left(\sqrt{2\xi} - \frac{B}{\lambda}\right) - \left(\sqrt{\frac{3}{2\pi}}\,\frac{G}{2\pi\sqrt{\xi}} - \frac{A}{\lambda}\right)^2\left(\frac{G^2}{6\,\pi^2\,\xi} - 1\right) \qquad 1$$

This design equation has to be solved step by step for the value of ξ using trial and error method, which is very complicated and time consuming. Although, the first value of ξ can be taken as:

$$\xi = \frac{G}{2\pi\sqrt{2\pi}} \qquad 2$$

The estimation of ξ that fulfills the equation is near to value computed by equation 2. The horn is mostly designed using design equation 1. Once ξ is calculated, the slant height of pyramidal horn can be calculated as

$$L_E = \lambda\,\xi \qquad 3$$

$$L_H = \frac{\lambda\,G^2}{8\,\xi\,\pi^3} \qquad 4$$

Where, L_E = slant height of horn in E-plane.

L_H = slant height of horn in H-plane.

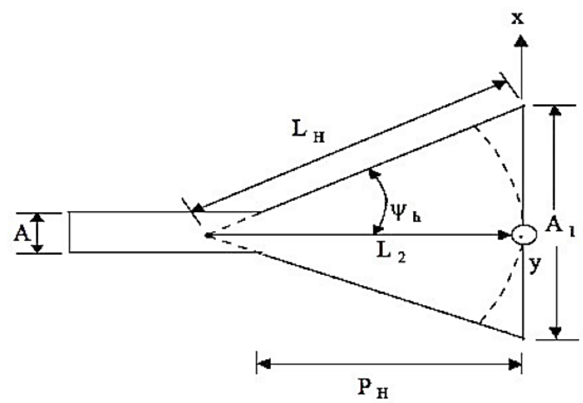

Figure 3: H-plane view

The width A_1 & B_1 in both the E and H plane direction of pyramidal horn are dependent upon the wavelength λ and are given by [6], [12].

$$A_1 = \sqrt{3\,\lambda\,L_H} \qquad 5$$

$$B_1 = \sqrt{2\,\lambda\,L_E} \qquad 6$$

Where, A_1 = horn width in H-plane

B_1 = horn width in E-plane

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 8, August 2017)

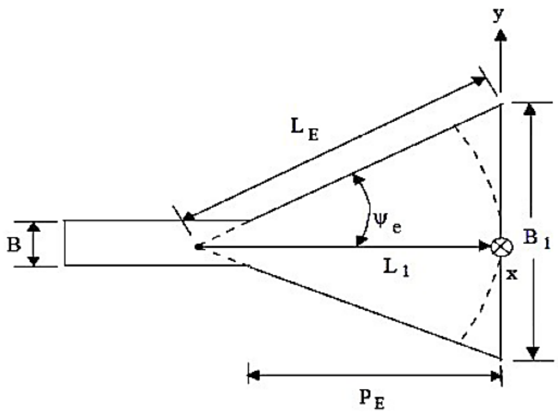

Figure 4: E-plane View

Figure 3 & 4 shows the H-plane and E-plane view of pyramidal horn antenna respectively. The slant height of the pyramidal horn in given by:

$$P_E = (B_1 - B)\sqrt{\left(\frac{L_E}{A_1}\right)^2 - \frac{1}{4}} \qquad 7$$

$$P_H = (A_1 - A)\sqrt{\left(\frac{L_H}{B_1}\right)^2 - \frac{1}{4}} \qquad 8$$

$$L_1 = \sqrt{P_E^2 - \left(\frac{B_1}{2}\right)^2} \qquad 9$$

$$L_2 = \sqrt{P_H^2 - \left(\frac{A_1}{2}\right)^2} \qquad 10$$

The pyramidal horn design is not possible if, P_E is not equal to P_H [7]. Hence, it is a necessary condition for the designing of pyramidal horn antenna.

Also, L_1 = median length of horn in E-plane.

L_2= median length of horn in H-plane.

IV. Flare Angle Of Pyramidal Horn Antenna

The waveguide should be provided with an open out aperture to make the discontinuation of the wave into a gradual transformation. Due to this, all the energy gets radiated in forward direction. This is known as Flaring. If we have tendency to use a straightforward open-ended rectangular conductor as an antenna (without the horn), there would be ohmic resistance (impedance) modification at an aperture because of unforeseen finish of the walls.

A part of wave energy is mirrored back within the conductor, once radio waves motion through the conductor hit the gap, so all of the power isn't radiated. The stationary waves are caused due to reflection which in turn increases the standing wave ratio (SWR), wasting lots of energy and sometimes overheating the transmitter. There is a diffraction of the wave due to small aperture of the waveguide which results in wide radiation pattern with less directivity [9].

For improving these characteristics, flaring of the sides of waveguide is done, which in turn forms a horn type structure [8]. Due to tapering of horn, the impedance progressively changes along the horn's length. With minimum reflection, this tapering of horn allows most wave energy to radiate and it works like an impedance matching transformer. In case of Sectoral horn antenna, it has only one flare angle. There square measures two flare angles within the pyramidal horn antenna, one within the E-plane and another one within the H-plane. The flare angle for the E-plane and H- plane are given by the following relation:

$$\psi_e = \tan^{-1}\left(\frac{B_1}{2\,L_E}\right) \qquad 11$$

$$\psi_h = \tan^{-1}\left(\frac{A_1}{2\,L_H}\right) \qquad 12$$

Where, ψ_e = Flare angle of horn in E-plane.

ψ_h = Flare angle of horn in H-plane.

If the values of ψ_e and ψ_h are equal, then the horn took the state of flawless pyramidal horn antenna.

V. Design Using CST

We have successfully designed and simulated the pyramidal horn antenna in CST MWS software. Below figure shows the structure of simulated pyramidal horn antenna. The table 1 shows the different dimensions as calculated from the above equations.

TABLE 1:
Dimensions of Pyramidal Horn Antenna

Parameter	Value
A	10.67mm
B	4.32mm
A_1	57.40mm
B_1	44.96mm
f	24GHz
λ	12.5mm

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 8, August 2017)

component1:solid1	
Material	Steel-1010
Type	Lossy metal
Mue	1
El. cond.	6.993e+006 [S/m]
Rho	7870 [kg/m^3]
Therm.cond.	65.2 [W/K/m]
Heat cap.	0.45 [kJ/K/kg]
Diffusivity	1.84103e-005 [m^2/s]
Young's Mod.	205 [kN/mm^2]
Poiss.Ratio	0.29
Thermal Exp.	13.5 [1e-6/K]

Figure 5: Properties of Steel 1010

The material used is mild steel (Steel-1010) figure 5 shows the properties of the material used. Mild steel is steel having less percentage of carbon (approx. 0.25%).

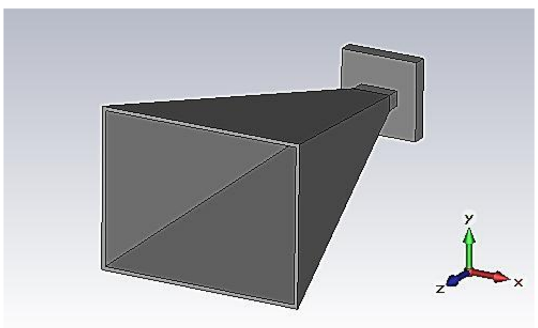

Figure 6: Pyramidal Horn Antenna Designed in CST MW

Figure 6 shows the designed Pyramidal horn antenna with rectangular waveguide as feed.

VI. ANALYSIS AND RESULTS

S-parameters are complex scattering parameters and are called because each the magnitude and part of the signal are modified by the network. The analysis of the design with S_{11} parameter is done on XY-plot. The reflected energy caused due to impedance is match in the system is called the return loss. In other words it gives the estimation of dissimilarity between impedances in transmission lines and loads.

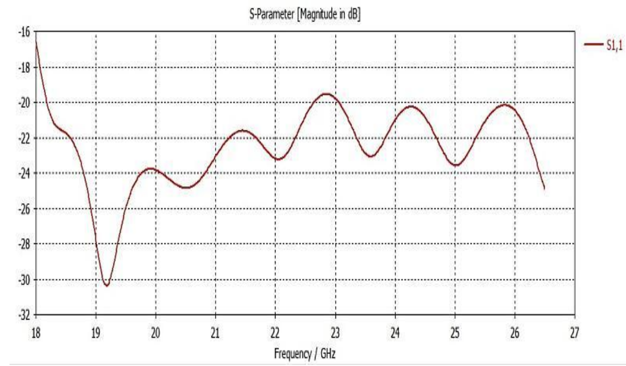

Figure 7: Return loss vs. Frequency.

The return loss is a numerical value that indicates how much of signal that is reflected back into the cable from the terminating equipment. Figure 7 shows the graph plotted between return loss and frequency. Return loss is essential in applications that use simultaneous bidirectional transmission. Return loss is generally calculated in dB. Larger values are better as they indicated less reflection. The value of -35 to- 40 dB and higher are considered acceptable. Results shown are significant figures obtained after the simulation.

Voltage standing wave ratio gives us the value that how our antenna is matched with the load resistance or with transmission line impedance. The value of voltage standing wave ratio calculated through simulation is less than 2 hence can be considered fair for signal transmission when there is low attenuation present.

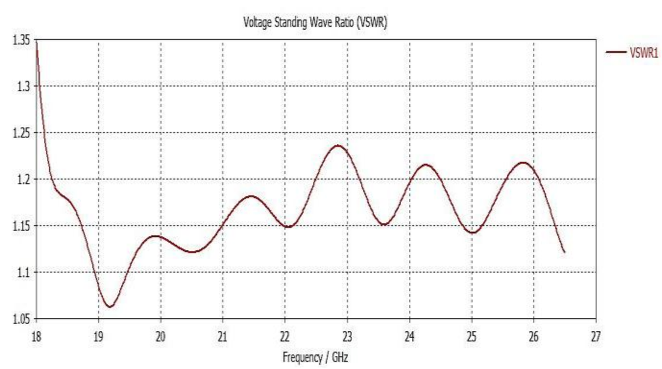

Figure 8: VSWR vs. Frequency

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 8, August 2017)

The graph for VSWR is shown in figure 8. It also concludes that our antenna is matched to the operating frequency. Both Return loss and VSWR assumes a critical part in the study of signal reception and transmission from antenna.

As we know the radiation pattern of the antenna is one of the significant plot that provides us knowledge about the beamwidth angle, and helps in understanding the radiation caused by it. It is a far field radiation plot. By reading the radiation pattern on can easily notice the lobes present in the radiation. In antenna reception and transmission the major lobe is important which provides the information of the directivity and major content of power radiated. It is found from study that the major lobe contains 95% for total radiated power.

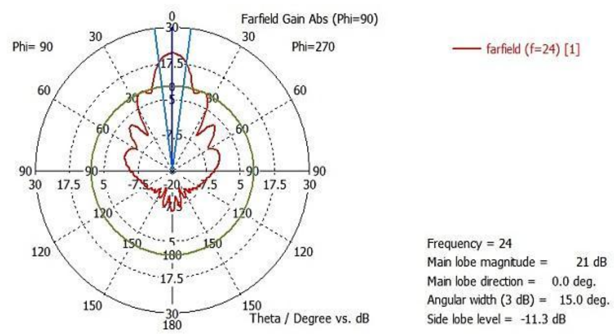

Figure 9: 2D Plot of Radiation Pattern (dB)

The Gain for this Pyramidal horn antenna, as per the design, is 21dB; with the angular width of 15.0 deg. Figure 9 shows the radiation pattern for the simulated pyramidal horn antenna.

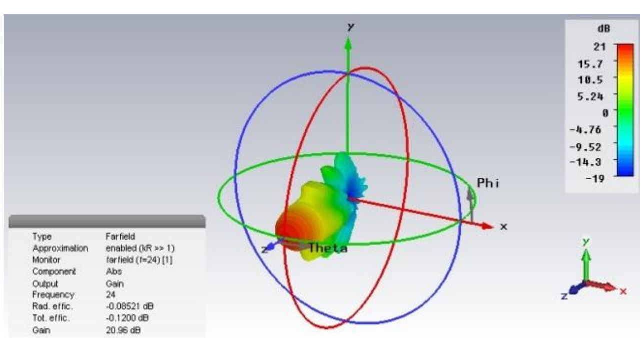

Figure 10: 3D Plot of Radiation Pattern (dB)

Side lobe ratio can be estimated by reading the Radiation pattern of an antenna. The side lobe level is -11.3 dB. The 3D gain plot shown in figure 10 shows the value of the gain for the designed Pyramidal horn antenna.

VII. CONCLUSION

Design presented is a pyramidal horn antenna, operating in the complete K band i.e. 18 to 26 GHz. Pyramidal Horn antenna shave several advantages over other antennas such as their light weight volume, higher directivity, and rigid structure. The main limitation is their size. The size of the horn antenna varies with the change in frequency. Also the horn antennas are designed as per the selected waveguide. Hence, selecting an ideal waveguide is important. There is increasing demand for compact antennas structure. However, pyramidal horn antennas are playing an important role for communication purposes.

This antenna can be used for applications in wireless communications, but the main motive for designing this pyramidal horn antenna is for FMCW Radar application, for the measurement of liquid level inside the large tanks. These antennas are under development and further more changes may require for their better performances. These antennas can be designed by using the coaxial feed. We can use coaxial to waveguide adaptor for feeding the horn antenna, but if we design the coaxial fed horn antenna the overall size will be reduced and cost also. We are also working for the narrow beamwidth antenna design; here in this design we got 15 degree angular beamwidth, this should be less for the FMCW Radar application.

REFERENCES

[1] C. Ozdemir et al. "Ultra-wide band horn antenna design forground penetrating radar: A feeder practice," in 15th International Radar Symposium (IRS), Gdansk, June 2014, pp. 1–4.

[2] G. Woods, D. Maskell, and M. Mahoney, "A High Accuracy Microwave Ranging System for Industrial Applications," IEEE Transactions on Instrumentation and Measurement, vol. 42, no. 4, pp. 812–816, Aug. 1993.

[3] S. Ayhan, M. Pauli, T. Kayser, S. Scherr, and T. Zwick, "FMCW radar system with additional phase evaluation for high accuracy range detection," in European Radar Conference (EuRAD) 2011, Manchester, pp. 117–120, Dec. 2011.

[4] E. Plantie, L.Ramos Emakraim, A.Nugraha and N.K.Subaer, "Optimizatized Wideband Horn antennas of High Gain and Directivity", IEEE, Telecommunication and Information Engineering, Indonesia.,2010.

[5] A.G. Stove, "Linear FMCW radar techniques," IEE Proceedings-F, vol. 139, no. 5, pp. 343–350, Oct. 1992.

[6] Leandro de paula Santos Pereira, "New method for Optimum Design of Pyramidal Horn Antennas", Journal of the Microwaves, Optoelectronics and Electromagnetic Applications, Vol. 10 No-1, June-2011.

[7] M. J. Maybell and P. S. Simon. (1993). "Pyramidal Horn gain calculation with improved accuracy," IEEE Trans. Antenna Propagation 41 (7), pp. 884-889.

[8] Anushruti Jaiswal, Bhavan Vyas, Prof. K. Shambavi," Design and simulation of Pyramidal Horn for Navigation and Surveillance Applications", International Journal of Core Research in Communication Engineering, 2014.

[9] Fazal Muhammad, Hidayatullah Khan and Nasir Saeed, "Design and Simulation of High Gain, Low loss X-band pyramidal Horn Antenna for Broadband Applications," City University Research Journal, vol. 2, no. 2, pp. 138–146, July 2016.

[10] Steffen Scherr, Serdal Ayhan, Mario Pauli, Thomas Zwick, "Accuracy limits of a K-band FMCW radar with phase evaluation," in Proceedings of the 9th European Radar Conference, Amsterdam, The Netherlands, pp. 246-249, Oct. 2012.

[11] Y. Najjar, M. Moneer and N. Dib. (2007). "Design of optimum gain pyramidal horn with improved formulas using particle swarm optimization," Int. J. RF Microwave Comput. Aided Eng. 17 (5), pp. 505–511.

[12] Constatine A. Balanis, "Antenna Theory and Design", John Wiley and Sons, New York , pp 769- 780, 3rd edition, 2005.

[13] Samuel Y. Liao," Microwave Devices and Circuits",3rd Edition, Pearson Publications,2011.