Design and Analysis of X band Pyramidal Horn Antenna Using HFSS.

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Abstract—**In the paper, the design of pyramidal horn antenna is described. The software used for designing purpose is Ansoft HFSS 12. Discussion about the antenna parameters obtained for the design is done. However, to obtain better results many more adjustment in the designs may be required. These adjustments may comprise more complex calculations and implementation techniques. Pyramidal horn can be designed in a variety of shapes in order to obtain enhanced gain and bandwidth. The designed Pyramidal Horn Antenna is functional for each X-Band application.**

Index Terms—**Finite Element Method (FEM), Gain, Graphical User Interface (GUI), Return loss.**

I. INTRODUCTION

We suppose that the electromagnetic technology is a new or a modern development but, the history of horn antenna is actually more than a hundred year ago. Sir Oliver Lodge (1851-1940) demonstrated microwave waveguide transmission lines in 1894. After that we just need to go one step further to get a horn antenna. After three years later in 1897 Sir Jagadish Chandra Bose (1858-1937) constructed first horn antenna. Bose's horn operated in the millimeter wave range and was able to ring bells and ignite powder at a distance during his experiments in Calcutta. His design based on circular waveguide with circular horn. He performed some of his experiments in the 60 GHz range which is becoming popular nowadays.

Most of the concepts invented in the 1890s were gone. Horn antennas were no exception. During 1930s, horn antenna saw a return. The horn design between the decimeter and centimeter ranges were keen topics under study. The beginning of World War II brought an explosion in microwave antenna development. However, the horn antenna is an ideal antenna for these frequencies encountered during World War II. The rectangular waveguide became the common transmission line for the centimeter wavelength. Advancement in the design took place when the waveguide was flared creating the popular and common pyramidal horn shape. For further improvement in radiation pattern the dielectric lenses were used.

One of the biggest drawbacks of horn antennas is that they are large in size. As we move towards the UHF and VHF ranges the dimensions of horn become significantly large. Their other drawback is their narrow band. The improvement in the bandwidth of horn antennas was first made by the use of ridges. The ridges introduced improved the bandwidth in the same manner as they improve it in waveguide technology. The ridges support the required radiating mode for a wider bandwidth. The Double-Ridged Guide Horn antennas and their cousins the dual polarized quad-ridged horn antennas remained as originally introduced for about two decades. While with the beginning of the new millennium and growth in wireless technology there was further need for measuring these wireless devices. Horn antenna nowadays finds its places in telecom industry, radio astronomy and medical equipments.

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II. PYRAMIDAL HORN ANTENNA

Horn antennas also known as aperture antenna are popular in the microwave band generally above 1 GHz. These antenna provide high gain, relatively wide bandwidth, low VSWR, and they are ease to construct. There are three basic types of rectangular horn: Sector-E horn, Sector-H horn and pyramidal horn. Aperture antenna may be more familiar today than in the past because of the increasing demand for more sophisticated forms of antennas and the utilization of higher frequencies. This construction is very useful for aircraft and spacecraft applications. They can be very easily flush mounted on the skin of the aircraft or spacecraft,[1]. They can also be covered with a dielectric material to protect them from hazardous conditions of the environment. The horns can be also flared exponentially which provides better matching in a broad frequency band but is technologically more difficult and expensive [1]. Pyramidal horns are ideally suited for rectangular waveguide feeders. The head of horn antenna called as horn acts as a gradual transition from a waveguide mode to a free-space mode of the EM wave. The point that concerns us is why it is necessary to consider the horns separately instead of applying the theory of waveguide aperture directly. This is because of the so-called phase error occurred due to the difference between the lengths from the center of the feeder to the center of the horn aperture and the horn edges. This makes the uniform-phase aperture results invalid for the horn apertures. The usable bandwidth of horn antennas is typically of the order of 10:1 and can be up to 20:1. The pyramidal horn provides higher gain and directivity than the Sectoral horn antennas. The side lobes in the radiation pattern of the pyramidal horn antenna increases proportional for the high frequencies.

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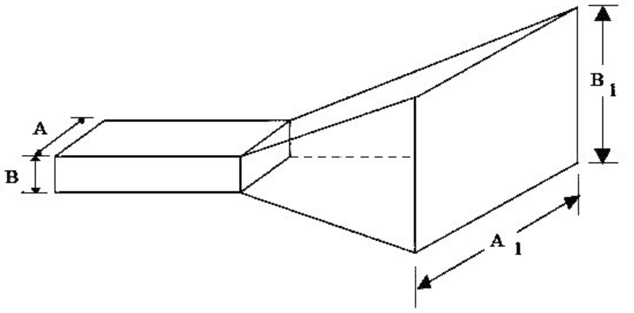

Figure1 Horn antenna

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 . The Pyramidal horn is connected with feeding rectangular waveguide having inner dimensions A and B , gain G which are generally known through waveguide datasheet; the other parameters are then calculated and pyramidal horn is designed. The parameters are calculated using MATLAB 2010b.

There are different design methods used for designing pyramidal horn antennas. [1], the design equations most commonly used for designing is

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

This design equation has to be solved iteratively for the value of ξ using trial and error method, which is difficult and time consuming. However, the first value of ξ can be taken

$$\text{As } \xi=\frac{G}{2\pi\sqrt{2\pi}} \quad (2)$$

Now we can suppose that the value of ξ that satisfies the equation is near to value calculated by (2).The equation is solved using MATLAB as for the faster solution for iterative process. In the paper the pyramidal horn is designed optimally using design equation (1). Once ξ is calculated the other dimensions of pyramidal horn can be calculated as

$$L_E=\lambda\xi \quad (3)$$

$$L_H=\frac{\lambda G^2}{8\xi\pi^3} \quad (4)$$

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

L_H = slant height of horn in H-plane.

The width in both the E and H plane direction of pyramidal horn are dependent upon the measure of intended wavelength λ and are given by [1] ,[6]

$$A_1=\sqrt{3\lambda L_H} \quad (5)$$

$$B_1=\sqrt{2\lambda L_E} \quad (6)$$

Where, A_1 = horn width in H-plane.

B_1 = horn width in E-plane.

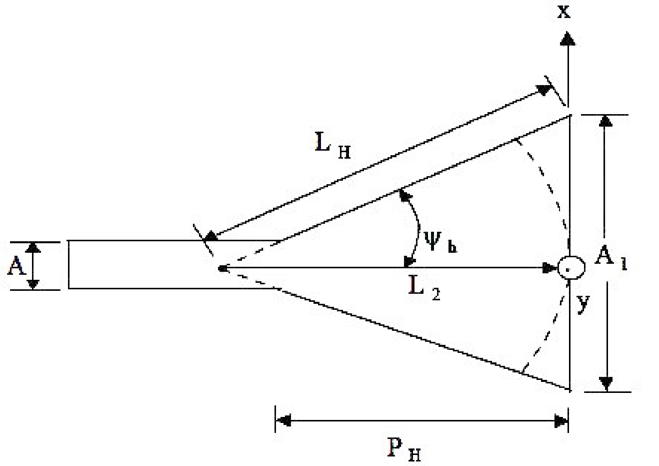

Figure 2 H-plane view

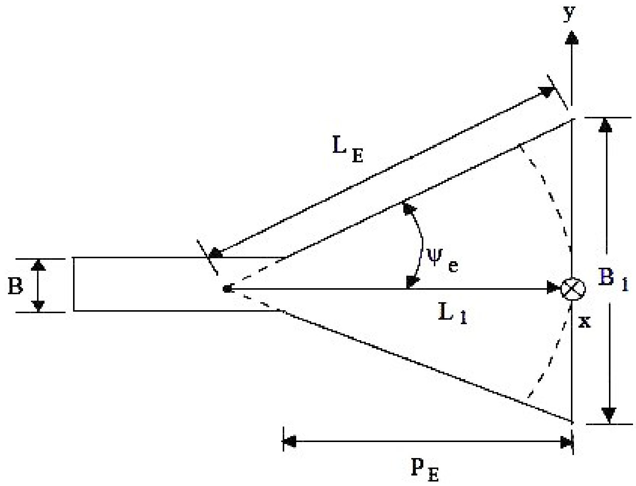

Figure 3 E-plane view

The slant height of the pyramidal horn is given by

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

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

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

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

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

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

L_2 = median length of horn in H-plane.

The representation can be easily understood by the Figure 2 and Figure 3. Once all the values are calculated the pyramidal horn can be easily realized.

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IV. FLARE ANGLE FOR PYRAMIDAL HORN ANTENNA

The Sectoral E and H-Plane horn antennas have only one flare angel. Whereas, in the pyramidal horn antenna there are two flare angles one in the E-plane and other in the H-plane. The flare angle for the E-plane and H- plane are given by

$$\psi_e = \tan^{-1}\left(\frac{B1}{2L_E}\right) \quad (11)$$

$$\psi_h = \tan^{-1}\left(\frac{A1}{2L_H}\right) \quad (12)$$

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

ψ_h = Flare angle of horn in H-plane.

In case ψ_e and ψ_h are found to be equal the horn took the shape of perfect pyramidal horn antenna.

V. WAVEGUIDE IN PYRAMIDAL HORN

The transmission as well as reception of electromagnetic signal through free space in microwave communications is very important. Our antenna present in the system acts as an impedance transformer between the source and free space in this communication system. A waveguide may behave as an antenna if its load end is matched to free space intrinsic impedance. Many organizations supply most products either in brass/copper waveguide or in aluminum. For example, Metrology grade products have their waveguide sections machined to a very high accuracy from solid material. But we cannot apply the science of waveguides emission to the pyramidal antenna emission. The rectangular waveguides are used for the construction of pyramidal horn antenna, [5]. Depending upon the application in which horn has to be used the waveguide is selected accordingly. For rectangular waveguides the accepted limit of operation is between 125% and 189% of lower cutoff frequency. For WR-90 cutoff is 6.57 GHz. At the lower cutoff frequency the waveguide simply stops working.

Table I. Specifications for WR-90, WR-75 and WR-62

WR No	Operating range (GHz)	Gain (dB)	A (mm)	B (mm)
WR-90	8-12	10~25	22.86	10.16
WR-75	10-15	10~25	19.05	9.525
WR-62	12-18	10~25	15.7988	7.8894

The wall thickness is0 .05 cm and the material use is PEC for construction of the waveguide. In the paper, the waveguide used is WR-90.

One limitation to the pyramidal horn is the use of different waveguide at different frequency range due to which the shape of the horn to be fixed to the waveguide also changes.

VI. DESIGN USING HFSS

HFSS it stands for High Frequency Structure Simulator. It is a high performance electromagnetic field simulator for arbitrary 3D volumetric passive device modeling. It takes advantage of the Graphical User Interface (GUI). Solutions to your EM problems are quickly and accurately obtained as HFSS integrates design modeling, visualization, simulation and automation in an easy to learn environment. **It** is a complete software tool for the modeling and simulation of different antenna systems and wide-ranging radiating structures. It can also be used to learn more about antennas to get imminent into the conduct of the particular antennas. HFSS is very user friendly software that can advantage user to foresee antenna performance and achieving better results before building the realistic model. HFSS makes it easy to analyze each and every parameter very accurately. But this software requires a good knowledge of coordinate system. HFSS employs the Finite Element Method (FEM), adaptive meshing, and brilliant graphics to give you unparalleled performance and insight to all of the 3D Electromagnetic problems. Below, the designed structure on HFSS will be discussed. The designed horn antenna is X-band pyramidal horn antenna working for X band frequency range. The dimensions of the design are given as; the waveguide used for the design is WR-90 with A = 22.86 mm and B = 10.16 mm. The value of ξ calculated by using (2) is 11.5539. After, applying the iterative process to find the value that satisfies the equation (1) the value of ξ is found to be 11.1157. As the computed value of ($P_E = P_H$) = 272.9 mm Hence, the design is valid. The design can have realistic model. The thickness of the horn is taken as 0.5mm. Once we have our dimensions the design can be virtually implemented on the HFSS using rectangular coordinate system.

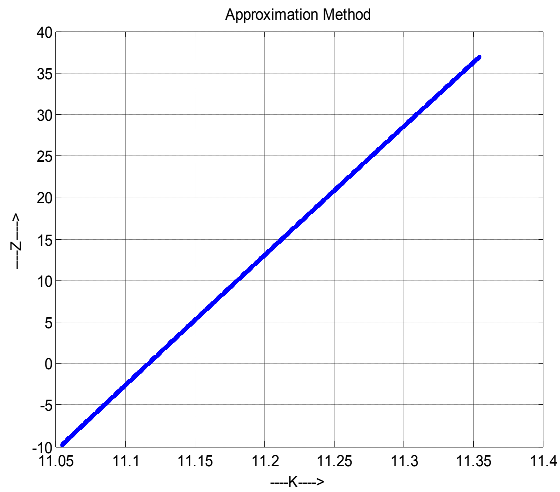

Figure 4 Approximated value of ξ

Now, it is easy for us to construct solid model of the computed pyramidal horn antenna, having in hand all the dimensions required to be representing in a proper Cartesian coordinate system. After we are done with positioning the design, the model created in the HFSS modeler window is as shown in Figure 4. Now to analyze the pyramidal horn antenna generated, the radiation boundaries are created. The boundaries are show in the Figure 6 and Figure 7. Other results obtained after simulation are the return loss,

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directivity, voltage standing wave ratio (VSWR), and radiation pattern.

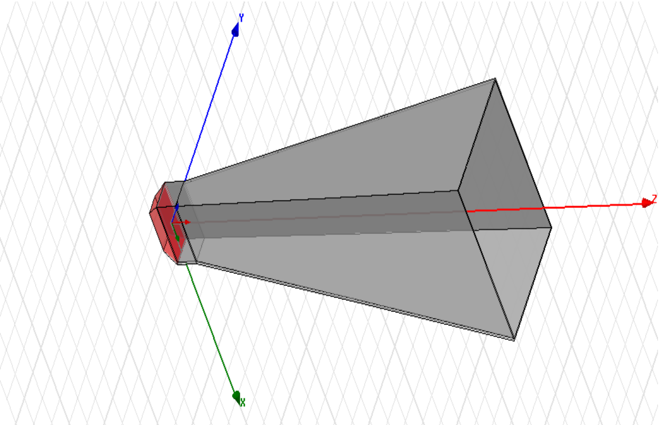

Figure 5 Designed Pyramidal Horn in HFSS

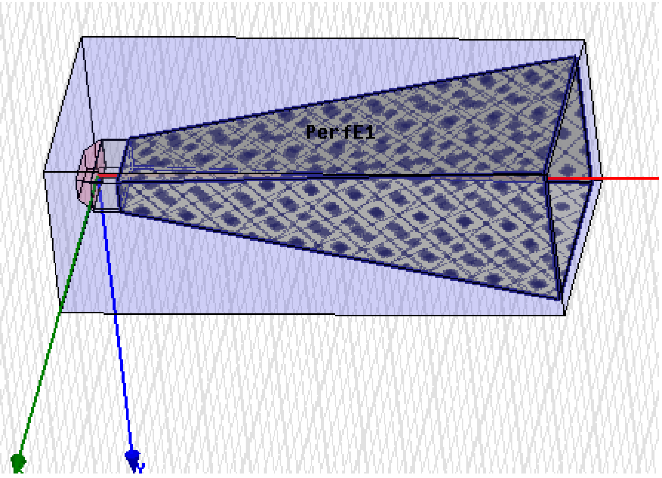

Figure 6 Inner Radiation Boundaries.

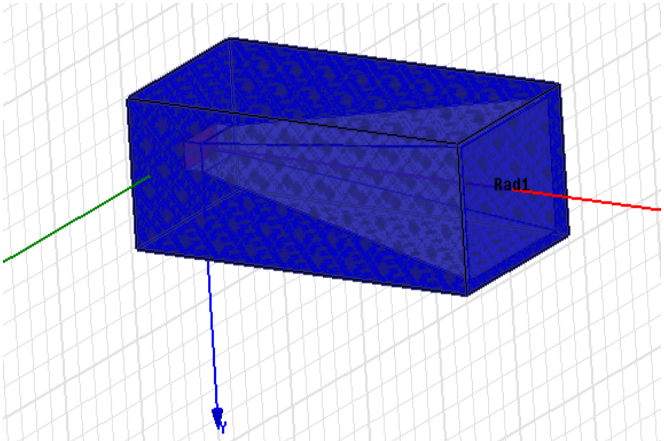

Figure 7 Outer Radiation Boundaries.

The antenna is studied under these boundaries and all the results are according to the boundary extremes the temperature of the antenna is set to 22°C with an impedance matching of 50 ohm. Virtual environment for work space provide us with the ability to maintain ideal conditions required for our analysis. The air box radiation boundary behaves as anechoic chamber for the analysis of antenna.

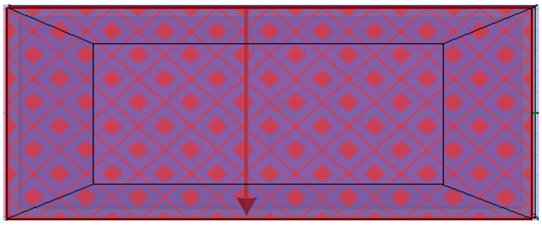

Figure 8 Lumped Port.

Different excitation techniques can be used for example, using wave port in which we can use coaxial cables for the excitation or we can use lumped port excitation. However, use of coaxial cable induces more errors due to improper impedance matching and coaxial losses if present in the cable. Hence to exclude those, designed antenna is excited by defining a lumped port to the waveguide as shown in Fig. 8.

VII. ANALYSIS AND RESULTS

S-parameters are complex scattering parameters and are called because both the magnitude and phase of the input signal are changed by the network. The analysis of the design with S(1,1) parameter is done on XY-plot 1 is shown below.The reflected energy caused due to impedance ismatch in the system is called the return loss.In other words it is a measure of dissimilarity between impedances in metallic transmission lines and loads. The return loss is a numerical value that indicates how much of signal that is reflected back into the cable from the terminating equipment. 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 below are significant figures obtained after the simulation.

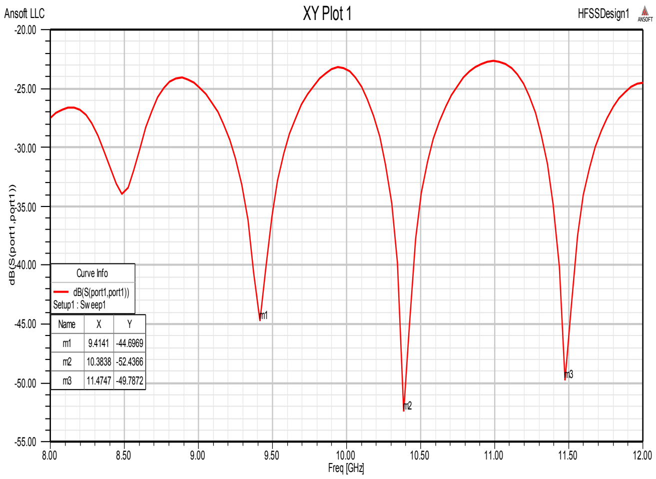

Figure 9 Returnloss vs. Frequency.

Voltage standing wave ratio gives us the value that how our antenna is matched with the load resistance or with transmission line impedance. The graph for VSWR is given below. 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.

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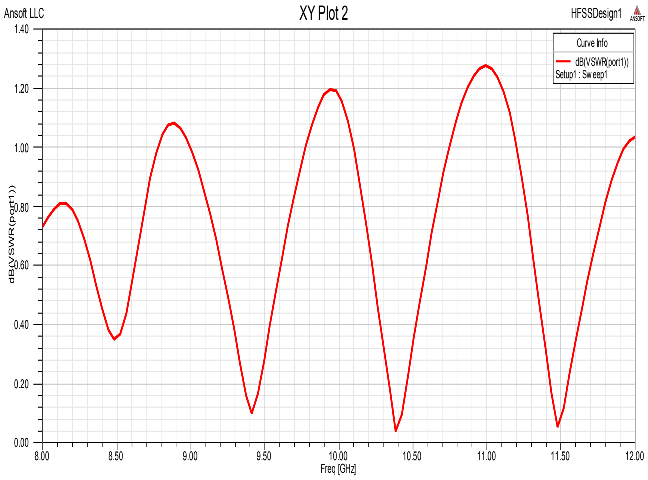

Figure 10 VSWR vs. Frequency.

It also concludes that our antenna is matched to the operating frequency. Both Returnloss and VSWR plays an important role in the study of signal reception and transmission from antenna.

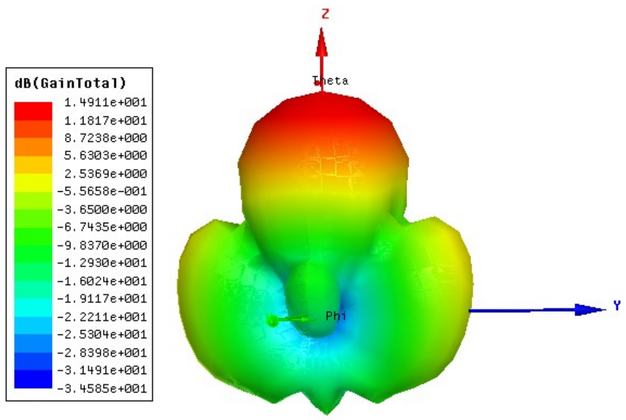

Figure 11 3D Directive Gain Pot in dB.

The 3D gain plot shown in Figure 10 shows the value of the gain for the designed Pyramidal horn antenna.

$$G_o = 2\pi \frac{A_1 B_1}{\lambda^2} \quad (13)$$

Where, G_o =Directive Gain of the Horn antenna.

The maximum gain is found within the ideal conditions and is more because higher conductive material is used for the horn funnel construction. The maximum value is found to be 14.911 dB.

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.

Side lobe ratio can be estimated by reading the Radiation pattern of an antenna. The obtained radiation pattern for the simulated pyramidal horn antenna is shown in Fig. 12

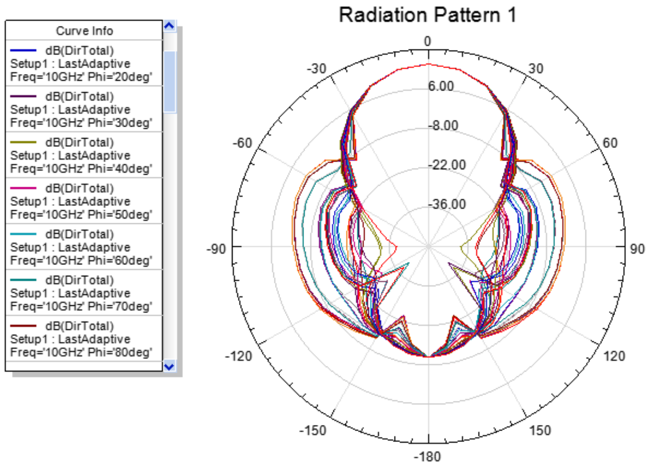

Figure 12 Radiation Pattern (dB).

VIII. Conclusion

Design presented is an Optimum Pyramidal horn antenna, operating in the complete X band i.e. 8-12 GHz. Pyramidal Horn antenna shave several advantages over other conventional antennas such as their light weight volume, higher directivity, and rigid structure. The main limitation in the ever increasing applications of these antennas is their size. The size of the antenna varied with the change in frequency. Also the horn antennas have to be designed as per the selected waveguide. Hence, selecting an ideal waveguide is important. There is increasing demand for compact antennas structure. However, from communication point of view pyramidal horn antenna are playing important role. This antenna can be used for applications in wireless communications, or for astrophysical experiments based on the study of the Cosmic Microwave Background. These antennas are used significantly where directivity of the signal or information is of main concern. These antennas are under development and further more changes may require for their better performances. These antennas can be enhanced using ridges, better conductive materials and dielectric lens.

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