 doi:10.20944/preprints201607.0009.v1

Article

Analysis of Pyramidal Horn Antenna for J-Band Application

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Abstract: In this research paper, design and development of pyramidal horn antenna for J-band application is reported. It is particularly designed for 17 dB gain and half beam width about 25 degrees at 6.93 GHz. Horn aperture, horn axial length and distance from the throat of the antenna to aperture are the main design constraints which are calculated and used for the antenna design and simulation. Beam width in E-plane and H-plane horn is calculated and it is 19.18 dB and 22.86 dB respectively. The reported antenna design shows good performance for J-band in radiometry, satellite, and radar applications.

Keywords: Antennas; Communication systems; Electromagnetic analysis; Measurements; Radio propagation; Waveguides

1. Introduction

The pyramidal horn is probably the most popular antenna in the microwave frequency ranges (1 GHz to 18 GHz). The gain of a horn is usually very close to its directivity because the radiation efficiency is very good. The horns are often used as standards gain measurement in antenna development. Horn antennas are used as a feeder for larger antenna structure such as parabolic antennas, as standard calibration antennas to measure the gain of other antennas, and as a directive antenna for such devices as microwave radiometric, radar antenna, satellite antenna, dish antenna [1-2]. The advantages of horn antenna are moderate directivity, low standing wave ratio, broad bandwidth, easy to construct and adjustment. One of the first horn antennas was constructed in 1897 by Indian radio researcher Jagadish Chandra Bose in his pioneering experiments with microwaves [3]. The development of radar in World War 2 stimulated horn research to design feed horns for radar antennas. The corrugated horn invented by Kay in 1962 has become widely used as a feed horn for microwave antennas such as satellite dishes and radio telescopes [4-5]. Interest in horn antennas diminishes at the when Guglielmo Marconi successfully achieved the first transatlantic wireless transmission. At that time, it became apparent that lower frequencies were better suited for long distance transmission, and the horn was inadequate for this purpose.

Horn antenna is available in many sizes and shapes such as pyramidal horn, pectoral horn (E pane and H plane), a conical horn, an exponential horn, corrugated horn, ridged horn, septum horn and aperture-limited horn [6-7]. The typical horn antenna is shown in figure 1. The horn can be treated as an aperture antenna. To find its radiation characteristics, to develop an exact equivalent of it, it is necessary that the tangential electric and magnetic field components over a closed surface are known.

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The closed surface that is usually selected is an infinite plane that coincides with the aperture of the horn. When the horn is not mounted on an infinite ground plane, the fields outside the aperture are not known and an exact equivalent cannot be formed. However, the usual approximation is to assume that the fields outside the aperture are zero. Return loss, voltage at standing wave ratio (VSWR), gain, radiation pattern, half power beam width are the parameter through which we can characterize horn antenna for the particular application. For the radiometry, satellite, radar application the antenna is required to resonate in between 4 to 8 GHz, gain between 12 to 40dB, VSWR should be in between 1 to 2 and should maintain the half power beam width near about 20 degrees.

2. Pyramidal horn antenna design

In order to obtain sharper beam and highest directivity than that of the simple open waveguide radiator, the waveguide may be flared into a horn with much higher aperture opening. If width 'a' of the rectangular waveguide is increased to 'a_1' by flaring the waveguide in H-plane, the H-plane horn antenna formed and similarly if we do it for length 'b' of waveguide E-plane sectoral horn will be formed. For given length of the horn, the highest gain is obtained by flaring the waveguide in both H and E-plane to obtain the pyramidal horn.

2.1 Design Calculation

The effective aperture of these pyramidal feed-horns is around 50% of its physical size, so

$$G = \frac{1}{2}\frac{4\pi}{\lambda^2} \tag{1}$$

The optimum aperture length of the horn antenna given as,

$$A_e = \frac{D\lambda^2}{4\Pi} \tag{2}$$

The directivity of a pyramidal horn can be expressed as a combination of the directivities of the sectoral feed horns. The directivity of the antenna is calculated by,

$$D = \frac{\pi}{32}\left(\frac{\lambda}{a}\theta_e\right)\left(\frac{\lambda}{b}\theta_h\right) \tag{3}$$

or

$$D = \frac{G}{\eta} \tag{4}$$

Pyramidal standard gain horns are usually designed under the optimum condition

$$\theta_E = \frac{56\lambda}{b_2}$$

$$b_2 = \frac{56 \times 43.29}{25} \tag{5}$$

$$b_2 = 96.9696mm$$

$$\theta_H = \frac{67\lambda}{a_2}$$

$$a_2 = \frac{67 \times 43.29}{25} \tag{6}$$

$$a_2 = 116.0172mm$$

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$$a_2 = \sqrt{3\lambda\rho_e} \quad \text{Horizontal}$$
$$(116.0172)^2 = 3 \times 43.29 \times \rho$$
$$\rho_e = 103.36mm \tag{7}$$

$$b_2 = \sqrt{2\lambda\rho_h} \quad \text{Vertical}$$
$$(96.9696)^2 = 2 \times 43.29 \times \rho_h$$
$$\rho_h = 108.60mm \tag{8}$$

The equation (5 to 8) represents the design consideration for the pyramidal horn antenna.

The present Horn antenna is simulated using HFSS software. The direction of propagation of E and H field are in the Z direction, Axial length of the antenna is taken on the X-axis and width on Y axis as shown in figure 1. The material used for the simulated purpose is Brass in order to make antenna more efficient and high gain. The inner and outer wall of the antenna is kept at 1mm apart from each other which indicate the thickness of the antenna is 1 mm. The rectangular waveguide dimensions are initially chosen as a_1 and b_1 are 34.84mm and 15.80mm respectively. The size of the opening flare of the horn antenna is calculated by using equation (5) and (6) which results as b_2 = 96.96 mm and a_2 = 116.01 mm. Usually, the optimum (from the point of view of maximum gain) design of a horn is desired because, it results in the shortest axial length. The whole design can be actually reduced to the solution of a single fourth-order equation. For the reliable horn, ϱe must equal to ϱh. Therefore, distance from the throat of the antenna to aperture is calculated using equation (7) and (8) and taken as ϱe = ϱh = 108.60 mm.

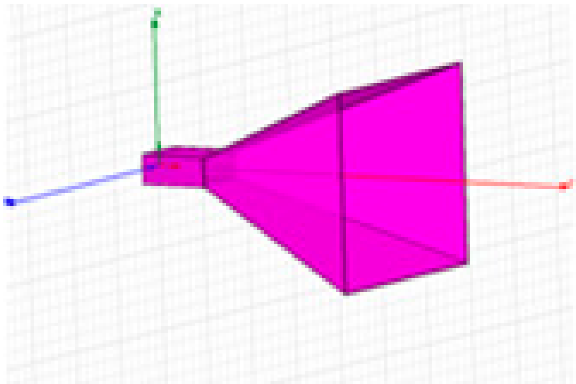

Figure 1. Horn antenna

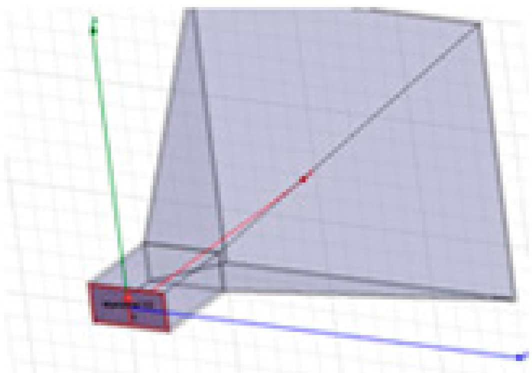

Figure 2. Port assignment

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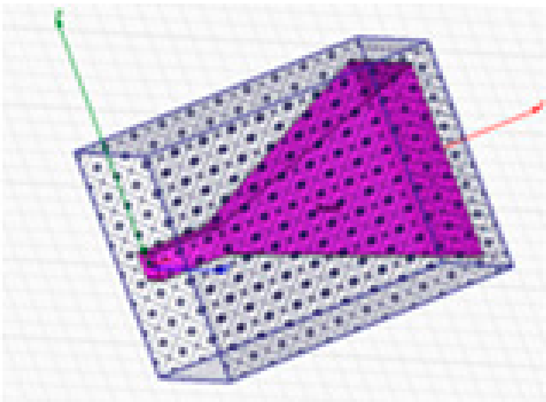

Figure 3. Antenna radiation box

The rectangular waveguide of 34.84x15.84 mm is selected for the length equals to λ of the given frequency which is 43.29 mm at 6.93 GHz. The rectangular waveguide is opened at distance ϱ with opening mouth dimensions of 116.01 mm and 96.96 mm. For the excitation, wave port is assigned at waveguide terminal and it is feed with fundamental TE_{10} mode as shown in figure 2. Radiation box is selected at $\lambda/4$ distance from aperture dimensions surrounding the antenna and front side, in the direction of propagation which is shown in figure 3.

3. Antenna results and analysis

3.1 Return Loss and VSWR

The return loss characteristics of the antenna are shown in figure 4.

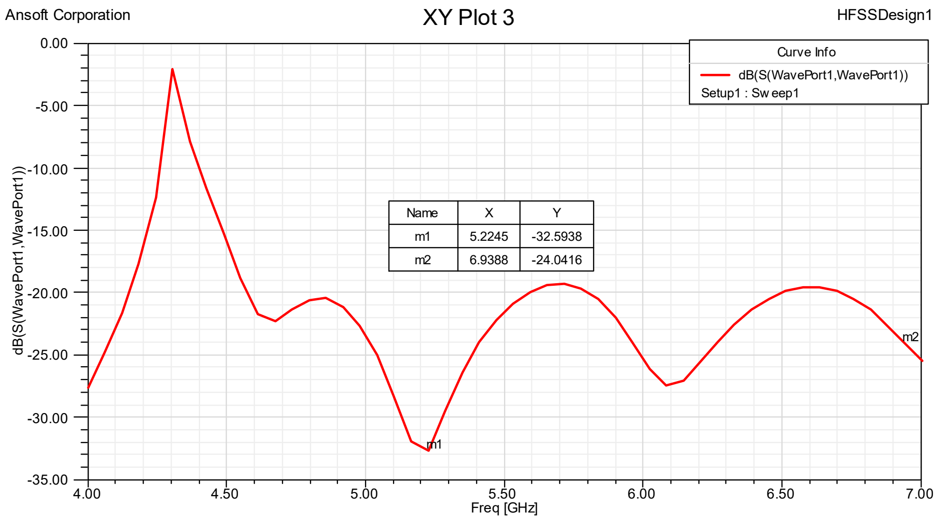

Figure 4. Return loss

It indicate that antenna resonate at 5.22GHz and 6.93GHz for S_{11} = -32.59dB and -24.04dB respectively. The VSWR found in between 1 to 2 for both the frequency mentioned above. This implies that antenna impedance at port and source terminal is well matched. VSWR pattern is shown in figure 5.

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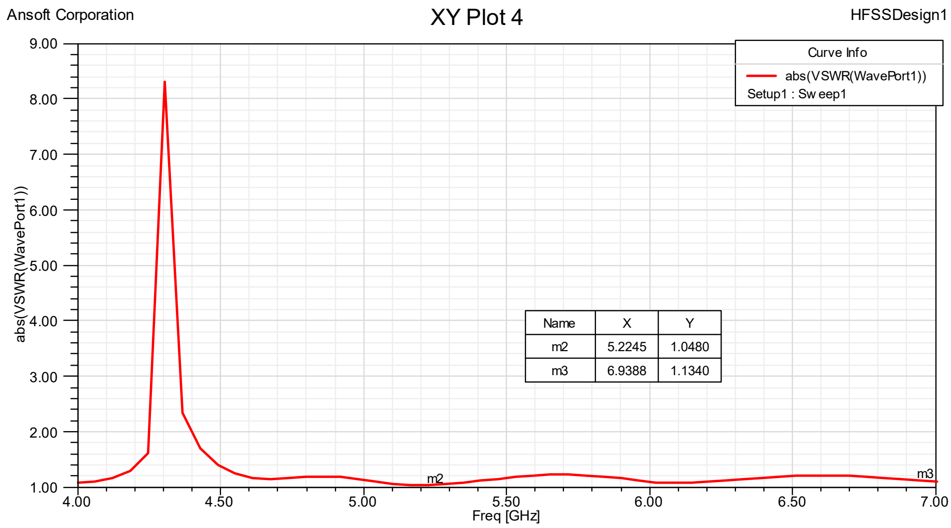

Figure 5. VSWR

3.2 *Radiation pattern*

Radiation of the antenna is at 6.93 GHz having more power in main lobe and less on side lobe for ϕ-0⁰ and θ-90⁰ is shown in figure 6. The results show that pattern is symmetrical in both E and H plane. For the measurement of the radiation of the horn antenna, the gun power supply is placed at 9.9V.

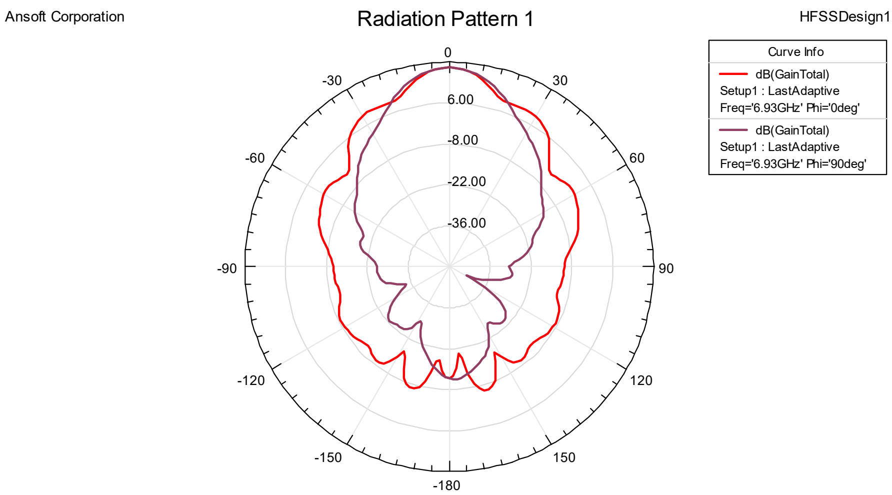

Figure 6. Simulated radiation pattern

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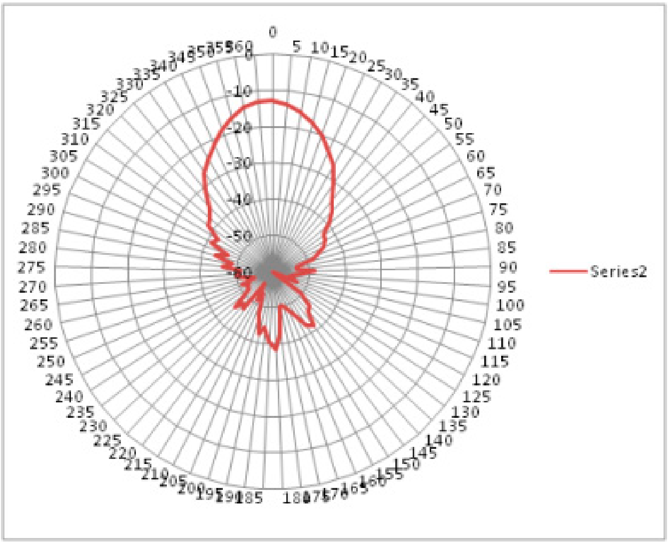

Figure 7. Measured radiation pattern

The antenna under test and the proposed horn antenna are kept at 140 cm apart from each other on rotating test bench over 360°. The measured radiation pattern is shown in figure 7. The simulated and developed antennae show good agreement with each other.

Beam width obtained by the simulation is 19.20 dB and 22.87 dB for ϕ-0° and θ-90°. This beam width is much closer to given beam width of 25 dB in both E and H plane. The results show that antennas possess maximum peak power radiated in the Z direction, with elevation angle ϕ and azimuthal angle θ.

3.2 *Antenna gain*

Figure 8 shows the simulated antenna gain at 6.93GHz. The peak gain of the antenna is in the order of 18.13 dB, which is very close to a theoretical gain of 17 dB. The power measured from the practical setup of the antenna bench is listed in table 1 with respective to the rotating angle of the antenna in 10 dB sequence.

The theoretical gain is calculated by using equation (9),

$$P_R = P_T G_T G_R (\lambda/\pi r)^2 \tag{9}$$

where,

Receiving antenna power (P_R) = -12.86 dB

Transmitting antenna power (P_T) = 5 dB,

Gain of transmitting antenna (G_T)=17 dB

Distance between P_R and P_T antenna (r) = 141cm

hence, gain of receiving antenna (G_R)=14.25 dB which is closer to simulated gain, i.e 17 dB.

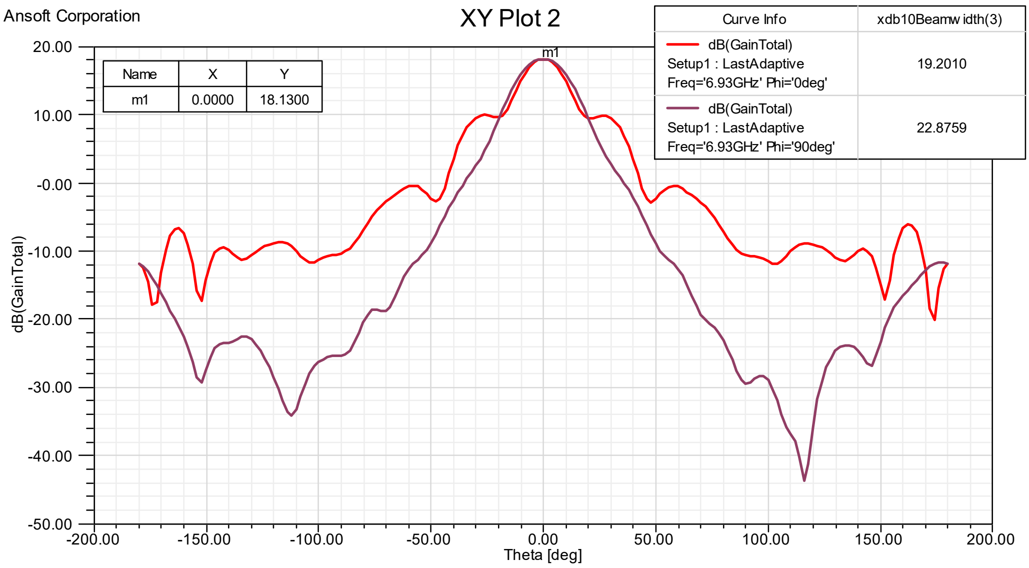

Figure 8. Simulated gain

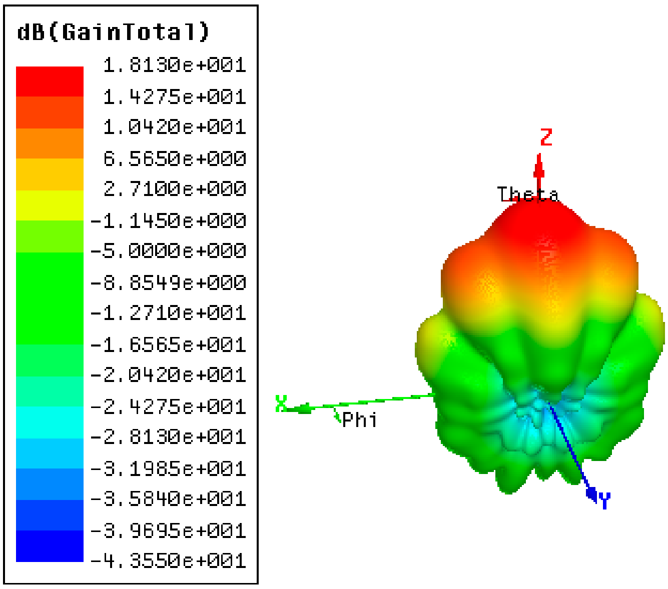

Figure 9. 3D polar gain

Figure 9 shows the 3D gain pattern for pyramidal horn antenna.

3.4 *Antenna directivity*

The total directivity of the antenna is 61.2891 dB at 6.93 GHz. Figure 10 and 11 shows the antenna directivity in Cartesian and Polar plot respectively. In satellite and radar applications, the highly directive antennas are preferable so the given antenna shows the maximum directivity required for high-end applications.

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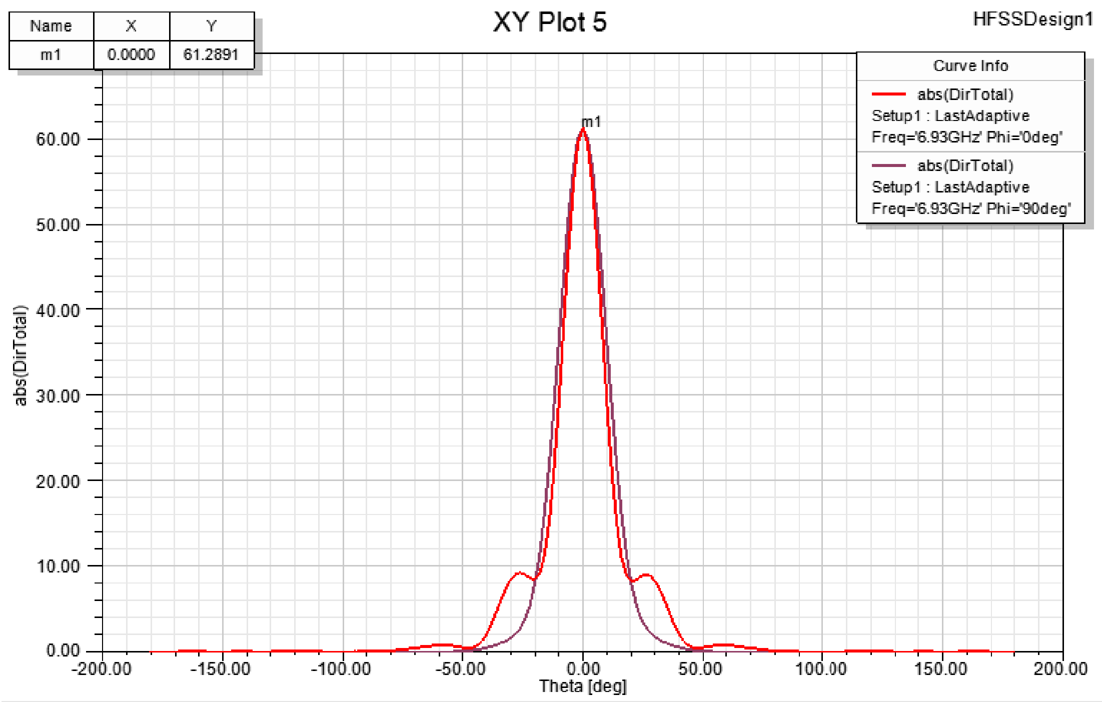

Figure 10. Cartesian antenna directional pattern

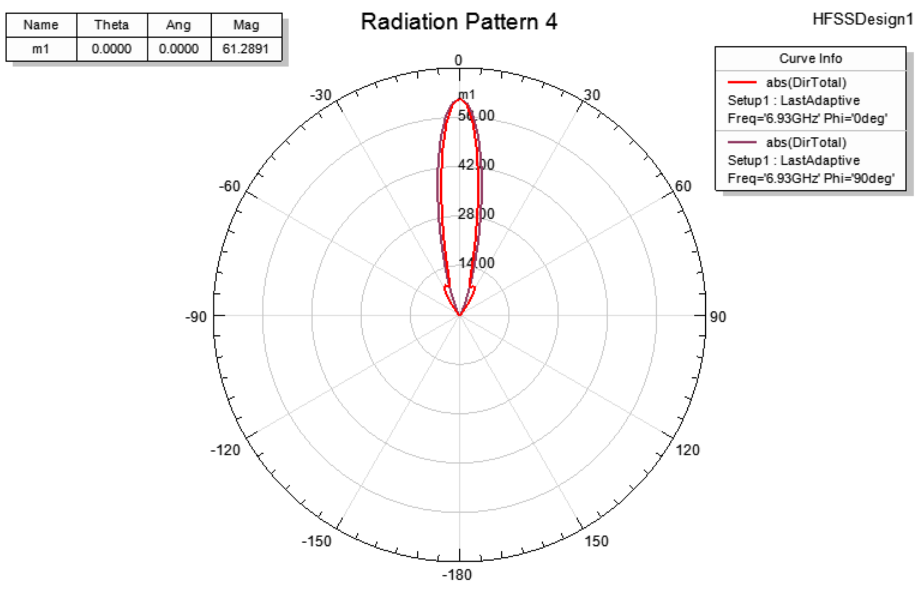

Figure 11. Polar antenna directional pattern

3.5 *Current distribution analysis*

Electric field distribution inside the horn contributes major role in the propagation of microwaves. At the rectangular waveguide, both electric and magnetic fields travelling with corresponding to each other, once the mouth of the rectangular waveguide open at particular distance E field and H field are detached from the rectangular waveguide and travel in free space.

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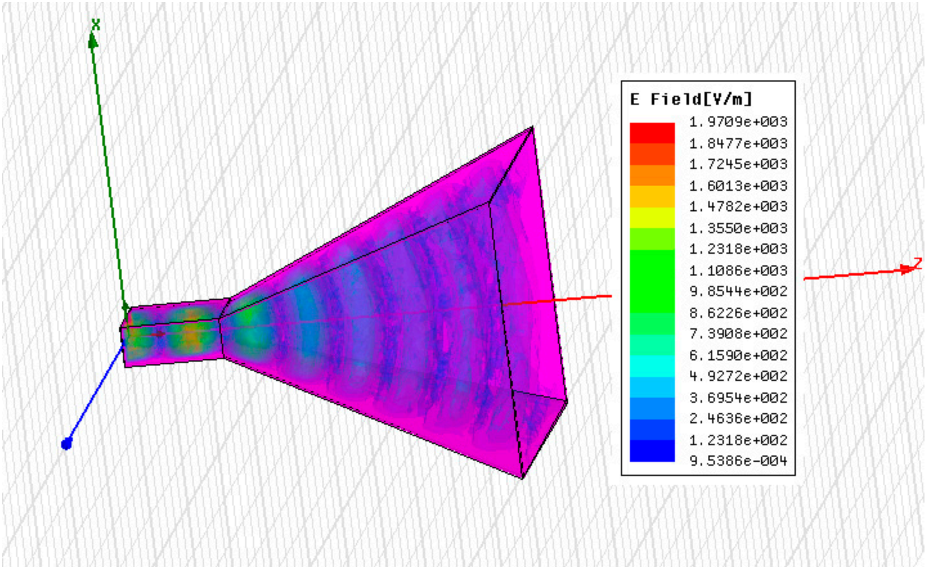

Figure 12. E-field distribution

Because of the pattern characteristics of both E and H-plane sectoral horn, pyramidal horn focuses its beam pattern in E and H plane. The corresponding E-field distribution is shown in figure 12. The surface current density travel along the boundary having a value of 3.93 A/m is shown in figure 13.

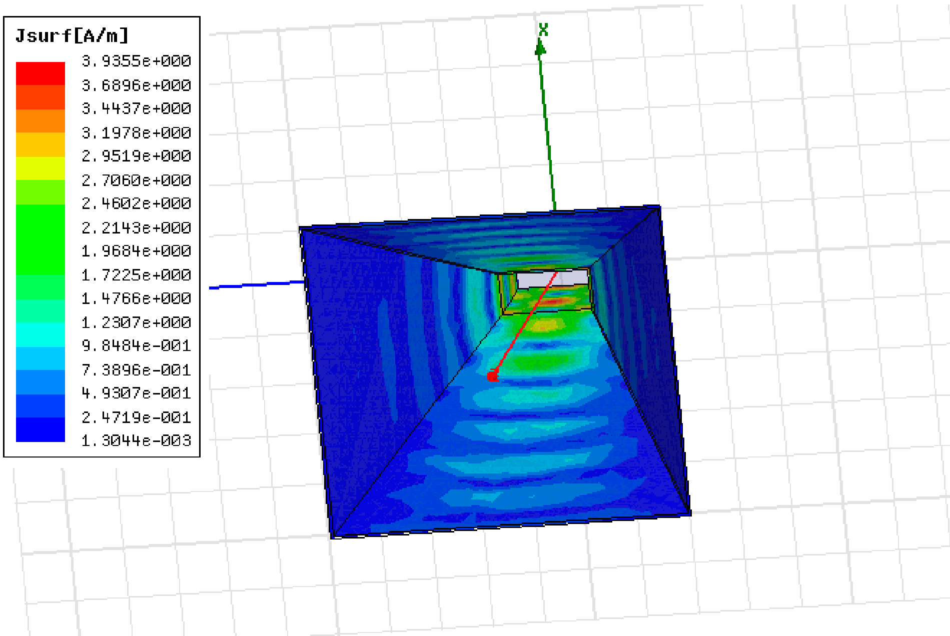

Figure 13. Magnitude of the surface current

Antenna power measurements with 10° step- clock- wise rotation at antenna test bench is shown in table 1 and prototype antenna image is shown in figure 14.

Table 1. Antenna power measurements.

Obs. No.	Angle in degree	Power in dBm
1	0	-12.86
2	10	-15.27
3	20	-20.12
4	30	-26.33
5	40	-34.55
6	50	-39.56
7	60	-43.21
8	70	-46.95
9	80	-53.31
10	90	-48.08
11	100	-53.99
12	110	-53.58
13	120	-59.67
14	130	-50.12
15	140	-45.05
16	150	-42.53
17	160	-48.55
18	170	-50.23
19	180	-38.5
20	190	-44.54
21	200	-47.91
22	210	-51.04
23	220	-47.13
24	230	-45.88
25	240	-51.78
26	250	-51.15
27	260	-52.33
28	270	-50.88
29	280	-46.45
30	290	-43.65
21	300	-41.55
32	310	-38.35
33	320	-35.59
34	330	-27.12
35	340	-21.91
36	350	-16.33
37	360	-12.65

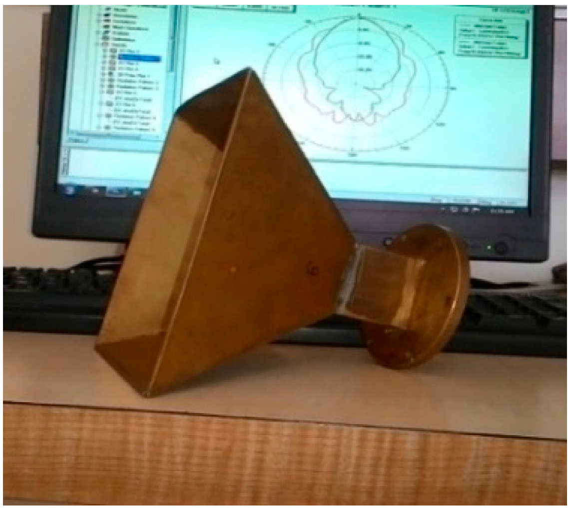

Figure 14. Prototype antenna image

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4. Conclusion

In this investigation, simulated and developed horn antenna results are good agreed with each other. The reported antenna gives the better return loss -24 dB, VSWR 1.13 and gains 18.13 dB. The reported antenna is highly directive with the directivity of 61.28 dB at its peak value. The radiation pattern of measured and simulated antennas is close resemblance with each other. The developed antenna is made up of brass material and it is useful for satellite, radar, radiometry applications.

Acknowledgement

Authors are thankful to the administrative staff of International Centre for Radio Science, Jodhpur, India to perform design and experimental work.

Author Contributions: Authors are equally contributed to this research article for design, material, and analysis.

Conflicts of Interest: “The authors declare no conflict of interest."

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