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DESIGN, FABRICATION AND TEST OF PARABOLIC CYLINDER REFLECTOR AND HORN FOR INCREASING THE GAIN OF VLASOV ANTENNA

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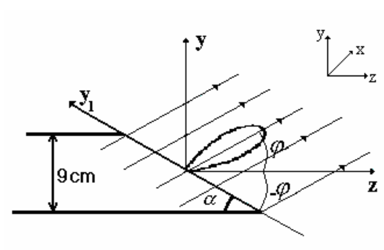
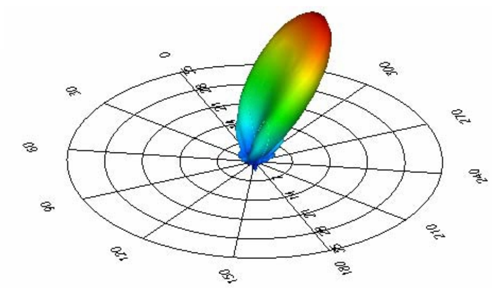
Abstract—This paper proposes two methods for increasing the Gain of Vlasov Antenna. The first method, using a Parabolic Cylinder Reflector, results in a 7 dB increase in the Gain. The second method, constructing a Horn on the aperture, increases the Gain by about 5 dB. The results were checked using a prototype antenna and there was a close agreement.

1. INTRODUCTION

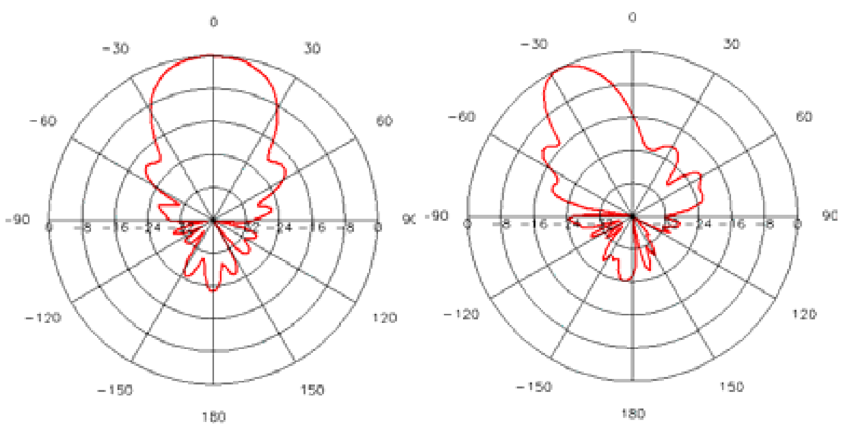
Reference [1] gives a thorough description of Vlasov antenna, a prototype of which working in the X-band (8.6 GHz) was designed and fabricated. A simulation was conducted using HFSS software which computed the Gain at 14.5 dB. The paper focuses on Parabolic Cylinder Reflector and conical Horn as the means to increase the Gain. A Vlasov antenna is made by a pen shaped cut at the tip of a circular waveguide. The cutting angle depends on the operating frequency and the waveguide diameter [2]. For a circular waveguide with a diameter of $2a = 9\,\text{cm}$ at the central frequency of $f = 5.6\,\text{GHz}$, the propagating modes would be: TE11, TE21, TE01, TE21, TE31, TE41 TM01, TM11 and TM21 [4]. In order to prevent Gain loss and distortion in the pattern, a single mode Horn is desired. An excitation from the end of the waveguide would produce only TM mode waves that are symmetrical with respect to φ. So, of all these modes, the only mode that propagates is the TM01 mode. Figure 1(a), illustrates a Vlasov antenna, where α is the cutting angle and φ determines the direction of radiation [1]. Figure 1(b) shows a 3-D pattern and Figure 1(c) shows the E-plane and H-plane patterns.



(a)



(b)



(c)

Figure 1. (a) Vlasov antenna with a diameter of $2a = 9\,\text{cm}$ at the central frequency of $f = 5.6\,\text{GHz}$, cutting angle $\alpha = 25^\circ$ and direction of radiation $\varphi = 27^\circ$. (b) 3-D pattern of Vlasov antenna with $2a = 9\,\text{cm}$ at $f = 5.6\,\text{GHz}$. (c) Right hand figure E-plane pattern, and left hand figure H-plane pattern.

Using HFSS software the antenna parameters were determined to be: The antenna Gain $G = 14.5\,\text{dB}$, $(\text{HPBW})_E = 18^\circ$, $(\text{HPBW})_H = 37^\circ$. Sections 2 and 3 discuss the design, simulation, fabrication and assembly of the Horn and reflector in a comprehensive way.

2. PARABOLIC CYLINDER REFLECTOR

2.1. Design of Parabolic Cylinder Reflector

Figure 2 represents a cross- section view of a parabolic reflector. Figure 3 demonstrates the Vlasov antenna position in front of the reflector. Important parameters in reflector design are diameter (d) and focal length (f) by which other parameters are determined.

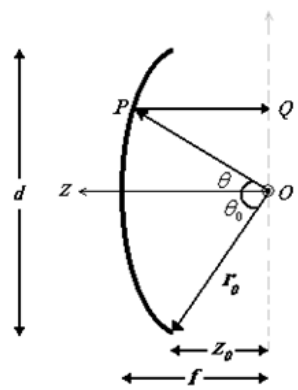


Figure 2. Front view of the parabolic reflector.

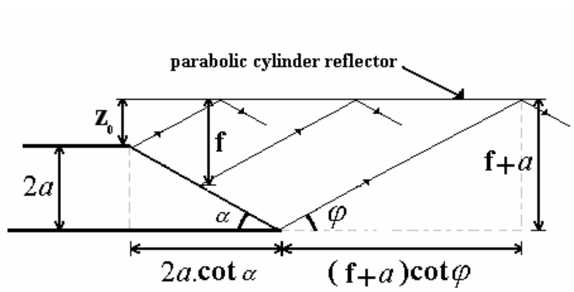


Figure 3. 2D view of Vlasov antenna with parabolic cylinder reflector.

The followings are equations applicable to parabola:

$$y = \left(\frac{1}{4f}\right) x^2 \tag{1}$$

$$OP + PQ = 2f, \quad \mathrm{tg}\theta_0 = d/2Z_0, \quad Z_0 = f - d^2/16f \tag{2}$$

The value of θ_0 is determined using the feed pattern and the intensity of the pattern at the edge of the reflector. If it is desired to have an intensity of less than 8 dB at the edge of the reflector (with respect to the center of the reflector), the reflector has to cover 180 degrees around the antenna [4, 6], therefore:

$$\begin{aligned} &\theta_0 = 90^\circ,\ \mathrm{tg}\theta_0 = d/2Z_0 \Rightarrow Z_0 = 0 \\ &Z_0 = 0, \quad Z_0 = f - d^2/16f \Rightarrow d = 4f \end{aligned} \tag{3}$$

In practice, when $d > 4f$ a better efficiency is achieved. The focal length can be determined using the following formula [5]:

$$f = \frac{G\lambda^2}{64 \cdot \pi \cdot \eta \cdot a \cdot \cos\varphi} \tag{4}$$

in which G represents the Gain of the Vlasov antenna with reflector. η is a number between 0.6 and 0.7. φ is the cutting angle and a is the waveguide radius. In order to reach a Gain of 21 dB, the focal length should be:

$$f = \frac{G\lambda^2}{64 \cdot \pi \cdot \eta \cdot a \cdot \cos\varphi}, \quad G = 21\,\mathrm{dB} \Rightarrow f = 6.7\,\mathrm{cm}$$

So, diameter of reflector (d) is: $d \geq 4f \Rightarrow d \geq 4 \times 6.7$. In practice, $d = 32\,\mathrm{cm}$.

Another important parameter in the design of the reflector is the length L. It should be determined such in a way that the reflector, reflects the outgoing waves emanated from the Vlasov antenna at an angle of φ as shown in Figure 3. Regarding this fact it can be shown [4]:

$$L \geq 1.2[(f + a) \cdot \cot\varphi + 2a \cdot \cot\alpha] \tag{5}$$

where $\alpha = 25^\circ$ is the appropriate cutting angle for a $d = 9\,\mathrm{cm}$ antenna diameter at a frequency of $f = 5.6\,\mathrm{GHz}$ [1].

In order to reduce diffraction, the reflector length is usually taken 1.2 times longer than the theoretical size. The reflector length is therefore calculated (from Equation (5)) as follows:

$$L \geq 1.2 \times [(6.7 + 4.5) \times \cot 27^\circ + 2 \times 4.5 \times \cot 25^\circ] \Rightarrow L \geq 50\,\mathrm{cm}$$

So, $L = 60\,\mathrm{cm}$ is suitable value.

The following table gives the calculated values for simulation and manufacturing.

2.2. Simulation of Vlasov Antenna with Reflector Using HFSS Software

Using reflector characteristics we can simulate Vlasov Reflector-mounted antenna by HFSS software. HFSS does not support drawing

Table 1. Values for designed reflector.

f	d	L
6.7 cm	32 cm	60 cm

parabola, however the square planes, as shown in Figure 4, makes the modeling of Parabolic Cylinder Reflector possible. Figure 4 illustrates a 3D structure of a Vlasov antenna equipped with reflector and the absorbing boundary.

Figure 5, through juxtaposing rectangular planes, provides a 2D view of Figure 4 in 2 directions.

Figure 6 demonstrates a 3D view pattern of valasov antenna containing a Parabolic Cylinder Reflector simulated using HFSS software.

The Gain resulted from antenna with reflector is simulated at 21 dB, a figure in full agreement with our calculation. HFSS enables us to simulate half power beam width for E and H planes. These values are $(\text{HPBW})_E = 17°$ and $(\text{HPBW})_H = 11°$. These patterns are shown in Figures 7 and 8.

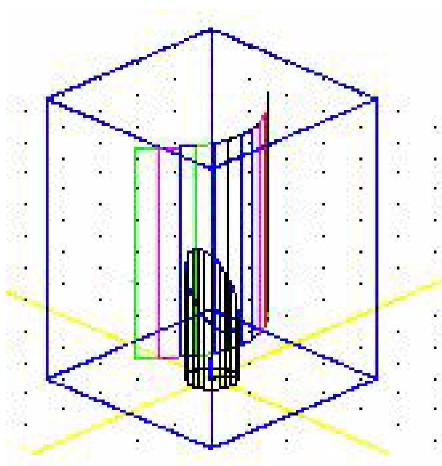


Figure 4. Illustrates a 3D structure of a Vlasov antenna equipped with reflector and the absorbing boundary in HFSS software.

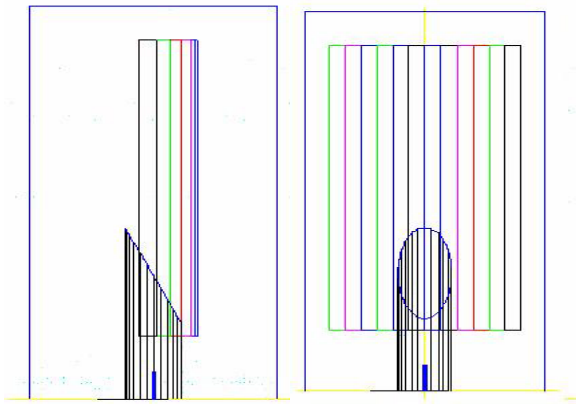


Figure 5. 2D view of Figure 4, in 2 directions.

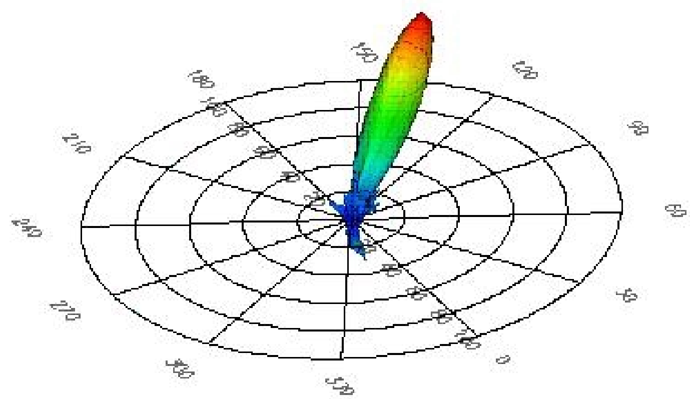


Figure 6. 3D view pattern of valasov antenna containing a Parabolic Cylinder Reflector.

2.3. Fabrication of Vlasov Antenna and Parabolic Cylinder Reflector

To build a Parabolic Cylinder Reflector an aluminium rectangular sheet is bent in 12 places until it takes a parabolic shape (dimensions are given in paragraph 2-1). A tuning screw is also devised which changes distance of reflector from antenna, resulting various focal lengths. The oversized reflector aperture ($60\,\text{cm} \times 32\,\text{cm} = 1920\,\text{cm}^2$) dictates a 18 m space of antenna room in order to perform a test. We were unable to perform the test as we failed to meet the conditions.

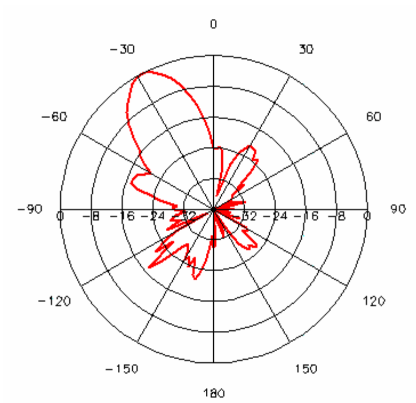


Figure 7. Half Power Beam Width for E-plane $(\text{HPBW})_E = 17°$.

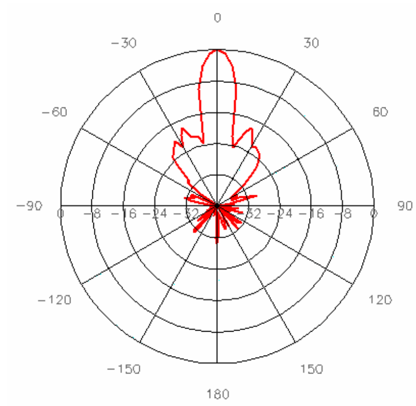


Figure 8. Half Power Beam Width for H-plane $(\text{HPBW})_H = 11°$.

3. GAIN INCREASE USING HORN

3.1. Design of Horn

The outgoing waves emanating from elliptical mouth of Vlasov antenna can be assumed as uniform plane waves which form a 27 degree $(\sin\varphi = \frac{f_c}{f} = 27°$ (deviation with respect to horizon. This has been shown in Figure 9.

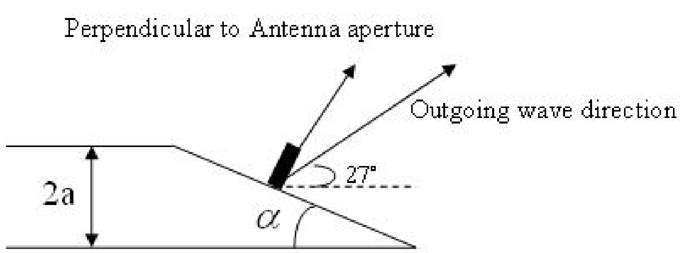


Figure 9. Directions of outgoing waves and antenna aperture vector.

The Horn must be designed so in a such a way that waves direction from antenna is perpendicular to Horn aperture, as shown in Figure 10. This causes outgoing waves resemble TEM waves. Therefore the Gain increases, purity of waves modes increase and finally side lobe level decreases [5].

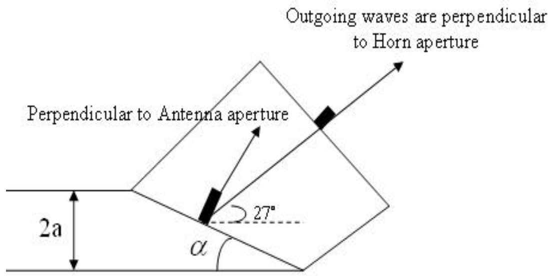


Figure 10. Wave direction from antenna is perpendicular to Horn aperture.

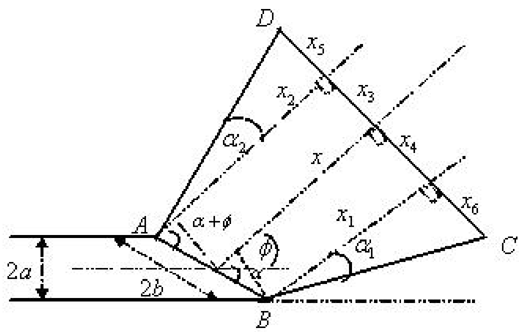


Figure 11. Vlasov antenna equipped with circular Horn structure.

Now we want to calculate angles and dimensions of the Horn. Figure 11 illustrates Vlasov antenna equipped with circular Horn. From Figure 11, we can show that:

$$x_1 = x - b\cos(\alpha+\phi), \quad x_2 = x + b\cos(\alpha+\phi) \tag{6}$$
$$x_3 = x_4 = b\sin(\alpha+\phi) \tag{7}$$

Horn aperture is symmetrical around its center. So,

$$x_5 = x_6, \quad x_5 = x_2 \mathrm{tg}\alpha_2, \quad x_6 = x_1 \mathrm{tg}\alpha_1 \tag{8}$$

Now we can determine diameter of the Horn aperture (DC length) and all of the angles in Figure 11.

$$\begin{aligned} DC &= x_3 + x_4 + x_5 + x_6 \\ \hat{A} &= \alpha + \phi + \alpha_2, \quad \hat{B} = \alpha_1 + 90^\circ + 90^\circ - \alpha - \phi \\ \hat{C} &= 90^\circ - \alpha_1, \qquad \hat{D} = 90^\circ - \alpha_2 \end{aligned} \tag{9}$$

The values α, ϕ, a, b are related to the Vlasov antenna ($\alpha = 25°$, $\phi = 27°$, $a = 4.5\,\text{cm}$, $b = a/\sin\alpha$). In order to calculate Horn's dimensions and angles, values x, α_1, α_2 must be given such values that first, Equation (8) satisfied and second, antenna's function might not suffer from any change in x, α_1, α_2, values. Having the values for x, α_1, α_2, the rest quantities are attainable through Equations (6) to (9). Having taken $x = 5\lambda$, thus:

$$f = 5.6\,\text{GHz} \Rightarrow \lambda = 5.3\,\text{cm}, \quad x = 5\lambda = 26.5\,\text{cm}$$

In practice, we consider $x = 26\,\text{cm}$ and $\alpha_1 = 12°$, $\alpha_2 = 7°$.

3.2. Horn Simulation at the Tip of Antenna

Taking the above points into consideration, antenna and Horn simulation was performed using HFSS software. Figure 14 gives a view of E-plane pattern of antenna and Horn set. Comparisons between this pattern and Vlasov antenna pattern showed that variation in 3 dB beam width related to E-plane were small. Though when the Horn is used, H-plane pattern will be narrowed by 20 degree compared to H-plane of Vlasov antenna. Through HFSS software, we simulated this antenna (Figure 12) and drew its 3D pattern as in Figure 13. Gain for this antenna was calculated at 19 dB. Figures 14 and 15 represent E-plane and H-plane. Values for Half Power Beam Width are $(\text{HPBW})_E = 13°$, $(\text{HPBW})_H = 16°$.

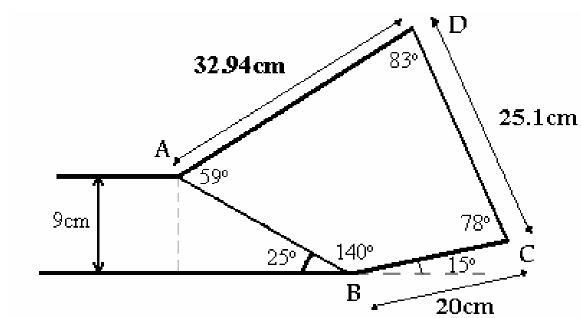


Figure 12. Simulated Vlasov antenna equipped with circular Horn structure.

Comparing Figures 14 and 1(c), it will be observed that Side Lobe Levels in Horn antenna are much lower than those of Side Lobe Levels in Vlasov antenna.

The Gain increase, as shown in Figures 14 and 15, results from narrowing E-plane and H-plane.

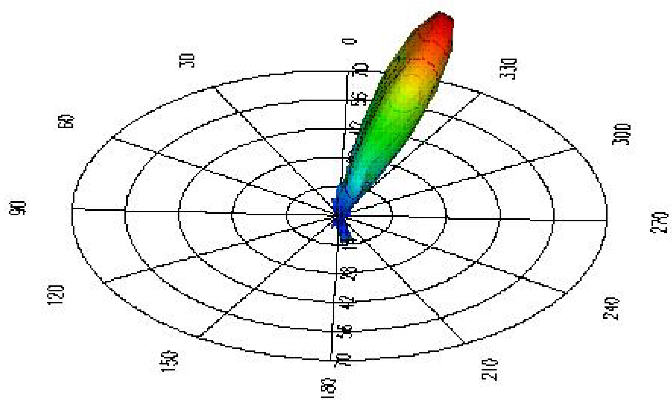


Figure 13. 3D pattern of Vlasov antenna equipped with circular Horn.

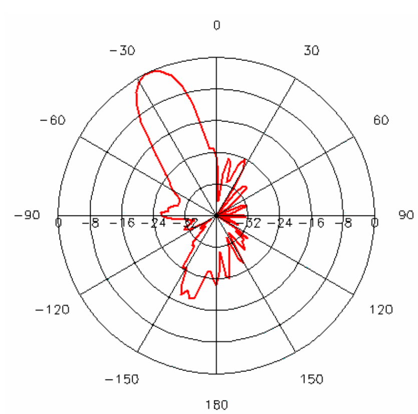


Figure 14. Half Power Beam Width $(\mathrm{HPBW})_E = 13°$.

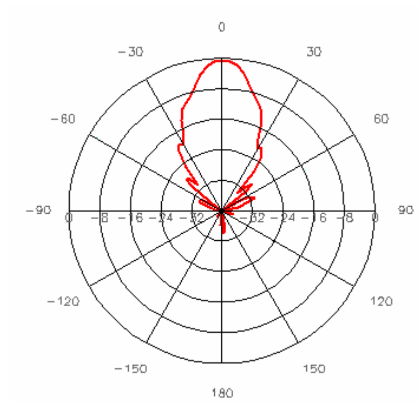


Figure 15. Half Power Beam Width $(\mathrm{HPBW})_H = 16°$.

3.3. Fabrication of Vlasov Antenna and Circular Horn

To build a circular Horn (based on the dimensions given in 3-1 paragraph) first an ARALDIT mould is made. As the second step, the mould is metalized (Figure 16). There exists differences in dimensions with the model designed (Figure 11), that arises from the problems involving the fabrication. The next step involving another simulation with new dimensions was accomplished with no sensible variations in parameters.

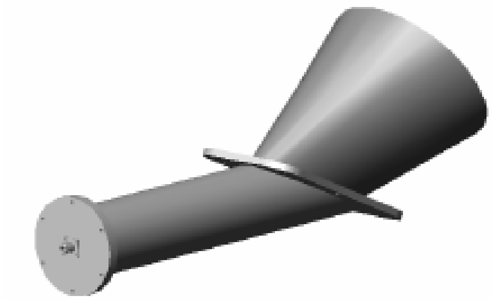


Figure 16. Fabricated Vlasov antenna equipped with circular Horn.

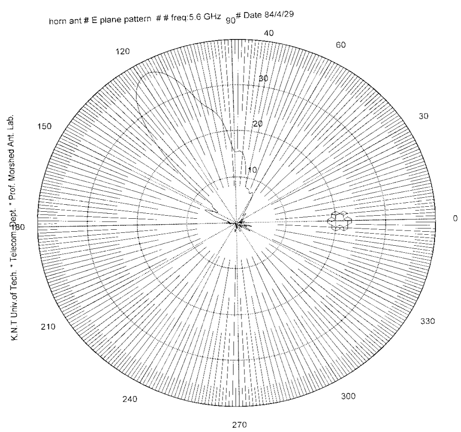


Figure 17. E-plane pattern of Horn antenna, $(\mathrm{HPBW})_E = 13.7°$ at frequency $f = 5.6\,\mathrm{GHz}$.

3.4. Test Results for Vlasov Antenna and Circular Horn

Both Vlasov antenna and circular Horn were tested. The measured patterns are shown respectively in Figures 17 and 18. The Table 2 provides the results for these two figures.

Table 2. Results for fabricated Vlasov antenna equipped with circular Horn.

Test results	3 dB B.W	F/B Ratio	S.L.L
E-Plane	13.7°	36.2 dB	−21.7 dB
H-Plane	16.2°	37.3 dB	−38.6 dB

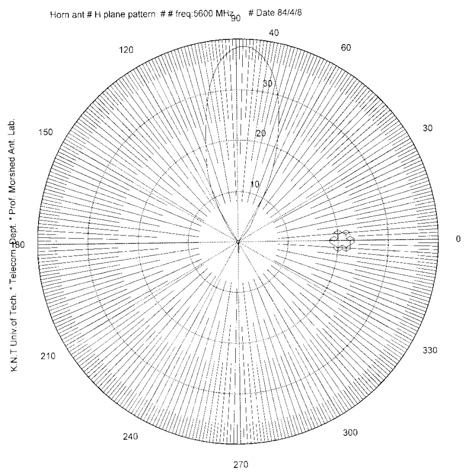


Figure 18. H-plane pattern of Horn antenna, $(\mathrm{HPBW})_H = 16.2^\circ$ at frequency $f = 5.6\,\mathrm{GHz}$.

Table 3. Comparison between half power beam width and Gain for all of structures.

Only Vlasov	$(\mathrm{HPBW})_E$ 18°	$(\mathrm{HPBW})_H$ 37°	Gain 14.5 dB
Designed Vlasov & Horn	$(\mathrm{HPBW})_E$ 13°	$(\mathrm{HPBW})_H$ 16°	Gain 19 dB
Fabricated Vlasov & Horn	$(\mathrm{HPBW})_E$ 13.7°	$(\mathrm{HPBW})_H$ 16.2°	Gain 21 dB
Designed Vlasov & Reflector	$(\mathrm{HPBW})_E$ 17°	$(\mathrm{HPBW})_H$ 11°	Gain 21 dB

4. CONCLUSION

Paragraphs 2 and 3 offered two methods of Gain increase applicable to Vlasov antenna. The first one recommends the use of Parabolic Cylinder Reflector and the second one finds the inclusion of circular Horn at the aperture of antenna suitable. In the both methods H-plane beam width must be decreased when the Gain increase is desired (E-plane beam width shows no considerable change). The results obtained from simulations and tests enable us to make a comparison between half power beam width and Gain, the result of which is included in the following table.

The design and making of Vlasov antenna, circular Horn and reflector were completed. Tests were carried out on antenna together with circular Horn. Table 2 lists the results of these tests that are compatible with simulation results.

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