Optimized Reflector Position for Vlasov Antennas

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Abstract— This paper presents a Vlasov antenna with optimized reflector position and angle suitable for high power microwave applications. With the proposed configuration, the reflector is directly attached to the waveguide, which is an advantage and makes it simpler to radiate in the direction of the axis of the waveguide. Bevel-cut and Step-cut Vlasov antennas, designed for operation at 3 GHz, are used to validate the effect of the reflector. In addition to proper radiation of the direction of maximum radiation, the optimized reflector results in increased antenna gain and reduced half-power beamwidth.

1. INTRODUCTION

High Power Microwave (HPM) sources, such as the Backward-Wave Oscillator (BWO), the gyrotron, and the vircator (virtual cathode oscillator), generate power in cylindrically symmetric transverse electric TE_{0n} or transverse magnetic TM_{0n} modes. The side lobe generation, gain reduction, and inefficient power loading on the antenna aperture, make these modes unsuitable for driving conventional antennas. This gave the idea of using mode converters at the output of these sources to convert these modes into a plane-parallel linearly polarized beam. Vlasov antenna is one of the most known mode converters used. The well-known Vlasov types are the Step Cut and the Bevel Cut antennas [1]. The step cut, originally suggested by Vlasov, has sharp edges and therefore may suffer from electrical breakdown when radiating HPM. The bevel cut, which was later suggested by Nakajima, avoids the sharp points of step cut, and as a result has a more suitable shape for HPM applications. However, a Vlasov antenna with either the bevel or step cut has its maximum radiation shifted by some angle with respect to the axis of the waveguide.

In [2], a comparison of the performance of bevel-cut and step-cut Vlasov antennas in HPM is conducted, concluding that the bevel cut has better performance in such applications. Other studies focused on increasing the gain of bevel-cut and step-cut Vlasov antennas. In [3], a reflector is added to a bevel-cut Vlasov antenna to increase its gain and to obtain more directive radiation. In [4], two methods are proposed for increasing the gain of a bevel-cut antenna, one using a parabolic cylinder reflector, and the second using a horn. In [5], the step cut is studied in the presence of a parabolic reflector. However, none of these studies considered bringing back the maximum radiation along the axis of the waveguide.

In this paper, an optimized reflector position for Vlasov antennas is presented, which will help, with the proper rotation angle, to orient the generated waves along the $+Z$ direction, which is the axis of the waveguide in our case. In addition, with our proposed configuration, the reflector is directly attached to the waveguide structure, decreasing the size of the usual Vlasov antennas with reflectors, and eliminating the need of extra components to hold the waveguide and reflector together. The proposed reflector is applied to a bevel-cut and a step-cut Vlasov antennas to evaluate its performance. It could also be applied to the cut proposed in [6], where the same results will hold.

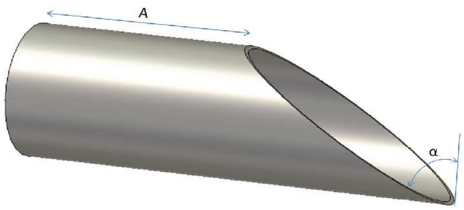
2. BEVEL-CUT VLASOV ANTENNA

Both step- and bevel-cut Vlasov antennas are the result of shaping the end part of a circular waveguide. For operation at 3 GHz, the used circular waveguide has a radius of 45 mm and a length of 300 mm.

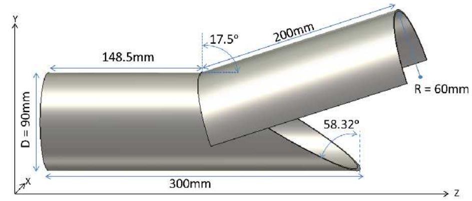
2.1. Bevel-cut Vlasov Antenna without Reflector

A Vlasov antenna with a beveled cut is shown in Figure 1(a). The cut angle α is the single parameter available for optimization, and it has the main effect on the gain and radiation patterns of the antenna. The angle that maximizes the gain of the antenna is given by [1]:

$$\alpha = \sin^{-1}((\rho_{0n}\lambda)/(2\pi a)) \tag{1}$$



(a) Bevel-cut Vlasov antenna



(b) Bevel-cut Vlasov antenna with reflector

Figure 1: Bevel-cut Vlasov antenna: (a) without reflector and (b) with reflector.

where ρ_{0n} is the n-th root of the equation $J_0(\rho_{0n}) = 0$, λ is the wavelength, a is the inner radius of the waveguide, and J_0 is the Bessel function of the first kind and zeroth order.

For the TM_{01} circular waveguide designed for 3 GHz, $a = 4.5\,\text{cm}$ and $\lambda = 10\,\text{cm}$. Also, $\rho_{01} = 2.405$, so the bevel cut will be calculated as follows:

$$\alpha = \sin^{-1}((2.405 \times 10)/(2\pi \times 4.5)) = 58.32\,^{\circ} \tag{2}$$

The highest gain according to the equation is obtained at a cut angle of 58.32°. This result has been verified by simulations using ANSYS HFSS [7]. For this angle, the resulting peak gain is 10.9 dB. The gain patterns, computed in CST MWS [8], are shown in Figure 3. Maximum radiation is obtained in the shifted direction corresponding to $\theta = \theta_m = 28°$ and $\phi = 90°$, computed using HFSS.

2.2. Bevel-cut Vlasov Antenna with Reflector

A reflector having the shape of a half hollow cylinder is attached to the bevel-cut Vlasov antenna as shown in Figure 1(b). The added reflector has the optimized values of 60 mm for the cylinder radius and a length of 200 mm (height of the cut cylinder). Upon rotating the reflector by a specific angle, it is seen that as the angle increases the shift angle approaches to origin. The initial bevel-cut Vlasov antenna gives a maximum computed gain of 10.3 dB, with the maximum radiation along the $\theta = 28°$ and $\phi = 90°$ direction. The optimized reflector angle for perfect direction along the $+Z$ axis is seen at angle of 17.5°. For this angle, the maximum radiation is back along the axis of the waveguide, i.e., $\theta = 0°$ and $\phi = 90°$.

This bevel-cut antenna operates at 3 GHz as shown in the reflection coefficient plot (S_{11}) shown in Figure 2. It has a gain of 10.9 dB and a reduced HPBW, as indicated in Figures 3(a) and 3(b). It is shown that, for the case with the reflector, the maximum radiation is redirected along the axis of the waveguide.

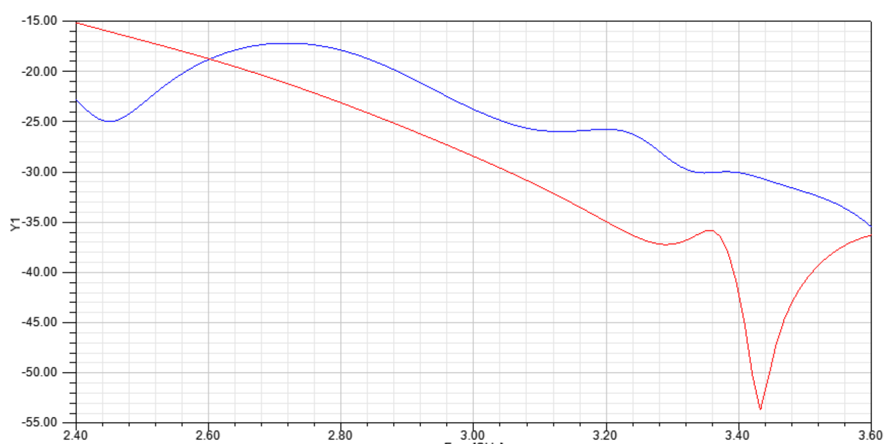
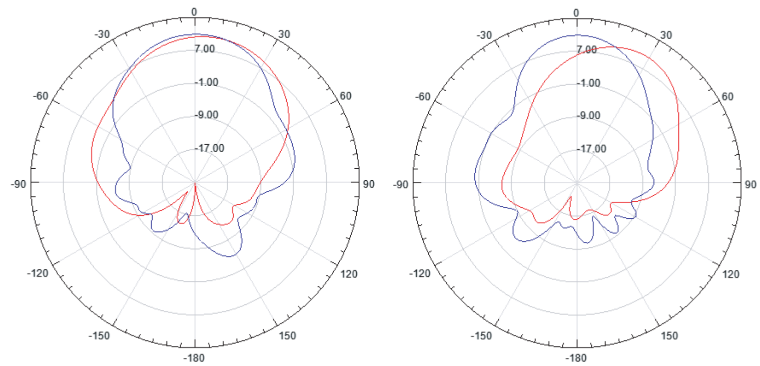


Figure 2: Reflection coefficient computed using HFSS, with no-reflector case shown in red, and with reflector in blue.

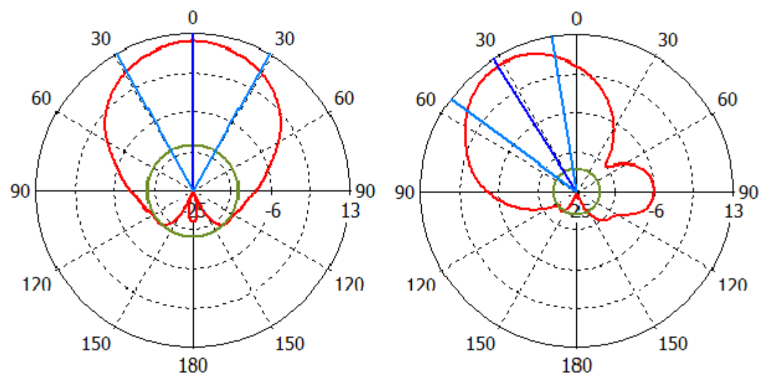
2.3. Verification of the Results Using CST

The results in Section 2.2 have been verified using CST. The gain patterns in the two cases (without and with reflector) are shown in Figures 4 and 5. As can be seen, the maximum gain of the antenna



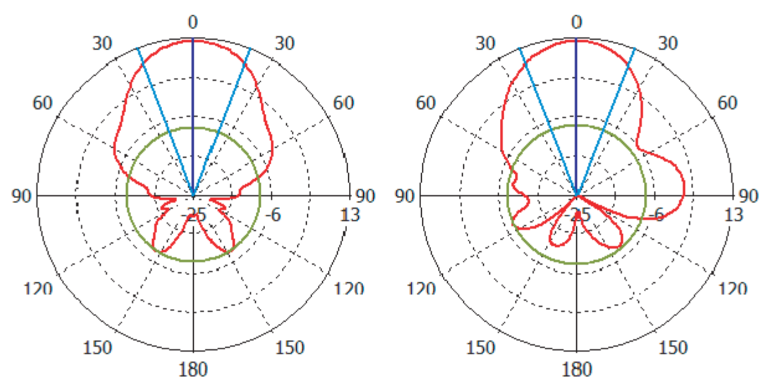
(a) (b)

Figure 3: Simulated gain patterns computed using HFSS, with initial bevel-cut results shown in red and proposed design results in blue. (a) Red in the plane formed by the X-axis and the point of maximum radiation ($\theta = \theta_m,\ \phi = 90°$), blue in $\phi = 0°$ plane. (b) $\phi = 90°$ plane.



(a) (b)

Figure 4: Bevel cut simulated gain patterns using CST without adding the reflector. (a) In the plane formed by the X-axis and the point of maximum radiation ($\theta = \theta_m,\ \phi = 90°$). (b) $\phi = 90°$ plane.



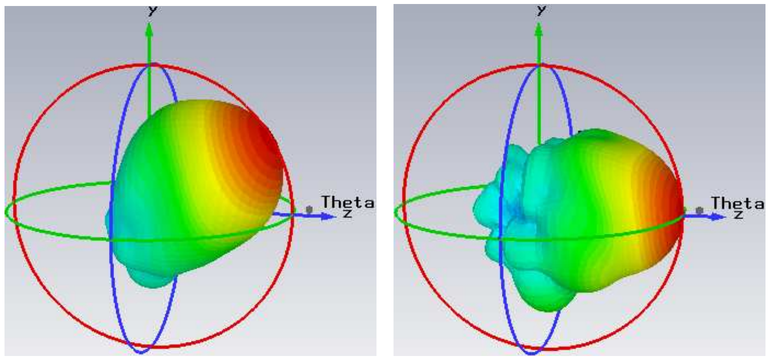
(a) (b)

Figure 5: Bevel cut simulated gain patterns using CST after adding the reflector. (a) $\phi = 0°$ plane. (b) $\phi = 90°$ plane.

is redirected along the axis of the waveguide. The 3D gain patterns comparing the two cases, are shown in Figure 6. Furthermore, the peak gain has increased and HPBW has decreased, as listed in Table 1.

3. STEP-CUT VLASOV ANTENNA

The step cut is determined by two parameters, A and B, as indicated in Figure 7(a). The value of A is fixed at 148.5 mm, which is the same value obtained with the bevel cut after finding the

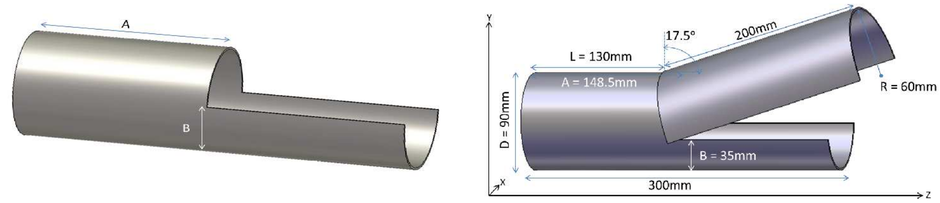


(a) Without reflector (b) With reflector

Figure 6: Bevel cut 3D gain patterns using CST: (a) without reflector and (b) with reflector.

Table 1: Comparison of the radiation characteristics of the bevel-cut antenna having and without having an added reflector computed using CST.

With/Without Reflector	**HPBW° at $\phi = 0°$ plane**	**HPBW° at $\phi = 90°$ plane**	**3D Gain (dB)**
Without Reflector	58.4	44.5	10.88
With Reflector	41.7	42.9	12

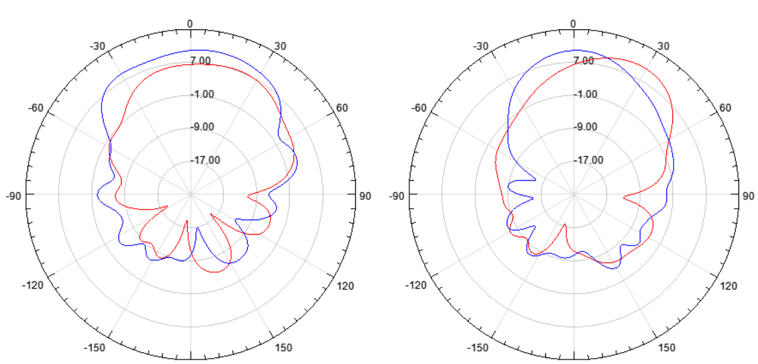


(a) Step-cut Vlasov antenna (b) Step-cut Vlasov antenna with reflector

Figure 7: Step-cut Vlasov antenna: (a) without reflector and (b) with reflector.

angle α. For comparison purposes, the step-cut Vlasov is designed so that it has the same angle of maximum radiation obtained with the bevel cut, which is 28°. For this purpose, B is found to be 35 mm. The gain patterns of the step-cut Vlasov antenna, computed using HFSS in the $\theta = \theta_m = 28°$ and $\phi = 90°$ planes, are shown in Figures 8(a) and 8(b) respectively.

The same reflector used in Section 2.2 is then attached to the step-cut antenna as shown in Figure 7(b). Here, L is the distance between the waveguide port and the start of the reflector. By inspecting Figure 8(b), the concept of rotating the reflector is validated and maximum radiation



(a) (b)

Figure 8: Step cut simulated gain patterns, with initial step-cut results shown in red and proposed design results in blue. (a) Red in the plane formed by the X-axis and the point of maximum radiation ($\theta = \theta_m$, $\phi = 90°$), blue in $\phi = 0°$ plane. (b) $\phi = 90°$ plane.

is obtained along the waveguide axis for a rotation angle of 17.5° similar to the one used for the bevel-cut case.

4. CONCLUSION

In Vlasov antennas with step cuts or bevel cuts, the maximum radiation is shifted by some angle with respect to the axis of the waveguide. In previous work, reflectors have been used to focus the beam in some direction. In this paper, a reflector attached to the waveguide structure was proposed, and its rotation angle was optimized to obtain maximum radiation along the axis of the waveguide. The advantages of this reflector structure are the smaller overall size of the antenna, its simpler design in terms of attaching the reflector to the waveguide, an increased gain and a decreased HPBW. The proposed reflector was tested with both bevel-cut and step-cut Vlasov antennas.

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