Design and low-power testing of a microwave Vlasov mode convertor

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ABSTRACT

A circular waveguide with a shaped open end forms the launcher component of a Vlasov mode convertor. This paper compares the gain pattern obtained for an open end with a step cut with that for a beveled cut. Determination of the gain pattern is the first step in the design of a high-power mode convertor intended for X-band (8 to 12 GHz).

Introduction

Many high-power microwave (HPM) sources, such as the backward-wave oscillator (BWO), the gyrotron, and the vircator, generate power in cylindrically symmetric transverse electric (TE) or transverse magnetic (TM) modes. These modes are not suitable for driving conventional antennas because of sidelobe generation, gain reduction, and inefficient power loading on the antenna aperture. One improved antenna for these HPM sources is a Vlasov mode convertor.[1] This device converts circular TM or TE waveguide modes into a good approximation to a plane-parallel linearly polarized beam with a Gaussian profile.

Figure 1 shows the mode convertor. It consists of a circular waveguide with a shaped end, and one or more reflectors (only one is indicated). The waveguide end radiates the microwaves in a given pattern against the reflector, which in turn redirects the energy into a beam with a parallel wave front, or some other directional characteristic, if desired. In the design of such a radiator the configuration of the aperture at the waveguide end must be optimized for the waveguide mode to be radiated.

A waveguide aperture with a step cut, as originally suggested by Vlasov,[1] has sharp edges and therefore may suffer from electrical breakdown when radiating high-power microwaves. The beveled cut due to Nakajima[2] avoids sharp points, and may be more suitable for high-power applications. In this paper we compare the gain pattern from these two apertures, as a first step in designing a mode convertor for a high-power BWO radiating in X-band (8 to 12 GHz).

The angle α of the bevel is the single parameter available for optimization of the radiator. For an efficient radiator the phase front of the waveguide mode at the aperture should match the phase front of the wave in free space. Therefore, the optimum aperture angle α should be approximated by

$$\cos\alpha = c/v_{ph}, \tag{1}$$

where v_{ph} is the phase speed of the waveguide mode. In a cylindrical waveguide the phase speed of the TM_{nm} mode is

$$v_{ph} = c\left[1 - (p_{nm} r_0 \omega / c)^2\right]^{-1/2}, \tag{2}$$

where p_{nm} is the m^{th} root of the equation $J_n(pr_0) = 0$, ω is the circular frequency, and r_0 is the inner radius of the waveguide. For a TM_{01} mode, $p_{01} = 2.405$, and

$$\cos^2\alpha = 1 - (2.405 r_0 \omega / c)^2. \tag{3}$$

For a frequency of 8.6 GHz and inner radius $r_0 = 2.38$ cm, the bevel angle is $\alpha = 34.14°$. This estimate does not take into account complications such as diffraction at the waveguide aperture. Measurements presented previously[3] showed that the optimum bevel angle is close to 30°, in reasonable agreement with the estimate.

Measurements

By reciprocity, the gain from the waveguide antenna can be determined by using the waveguide as a receiver for microwaves of the appropriate frequency. Figure 2 shows the antenna pattern mapping system. A cw source at 8.6 GHz radiates a horizontally polarized wave from a horn antenna toward the open end of the circular waveguide. The waveguide is mounted on a model tower. The head of the tower provides roll plane rotation about the azimuthal angle ϕ. The whole tower is mounted on a pedestal, which can rotate about a vertical axis to vary the polar angle θ. The signal measured at the exit of the TM_{01} waveguide is mixed down to 1 kHz, and converted to a dc voltage that is proportional to received power. This voltage, and the angles ϕ and θ from the model tower, are supplied to a computer for later processing.

Figure 3 shows the gain for a waveguide cut at $\alpha = 90°$, i.e., a cut perpendicular to the axis. Figure 3(a) is a contour plot of the gain, Fig. 3(b) is the gain along a horizontal cut through the center, and Fig. 3(c) is the gain along a vertical cut through the center. The measurements show the gain profile expected for a TM_{01} mode, an azimuthally symmetric pattern with a hole in the center at $\theta = 0°$. The gain peaks at 15 dB at an angle of about $\theta = 25°$ and falls off for larger angles in agreement with theory.

Figure 4 gives the same data but for a bevel angle of 30°. Figures 4(a) and 4(b) display the reflection symmetry in the beveled waveguide, and the vanishing gain in the center. Concentration of the gain in the direction along $\phi = 0$ and $\theta = 30°$ is clear from Fig. 4(c). The peak gain is 15 dB. However, now the side lobes are much smaller than for the case with a straight cut, down 20 dB from the peak. Also notice the low gain due to shielding from the lip of the bevel, at $\phi = 180°$ between $\theta = 0°$ and $\theta = 90°$. The width of the gain profile at 0 dB is 82°, among the narrowest of the three bevel cuts tested earlier.[3]

Figure 5 plots the gain for a step-cut aperture as indicated in the figure. The radius of the waveguide is 2.38 cm, and the length of the cut is 7.06 cm. The peak gain is slightly higher than for the bevel cut, about 17 dB, but the beam is wider, about 90°. Moreover, the side lobes in the backward direction are much larger than for the bevel cut.

Conclusion

We conclude that the optimum waveguide for use in a Vlasov mode convertor for high-power microwaves remains the 30° bevel cut. The step-cut waveguide has a slightly inferior gain pattern, and moreover, the sharp corners on the waveguide edge could cause breakdown problems for high-power applications.

The measured gain pattern, together with a similar map of the phase pattern for the 30° bevel cut waveguide, will be used to design a reflector along the lines of Ref. 4. However, the first reflector planned for testing is a flat plate instead of the parabolic reflector used in similar mode-conversion systems for overmoded waveguides.

References

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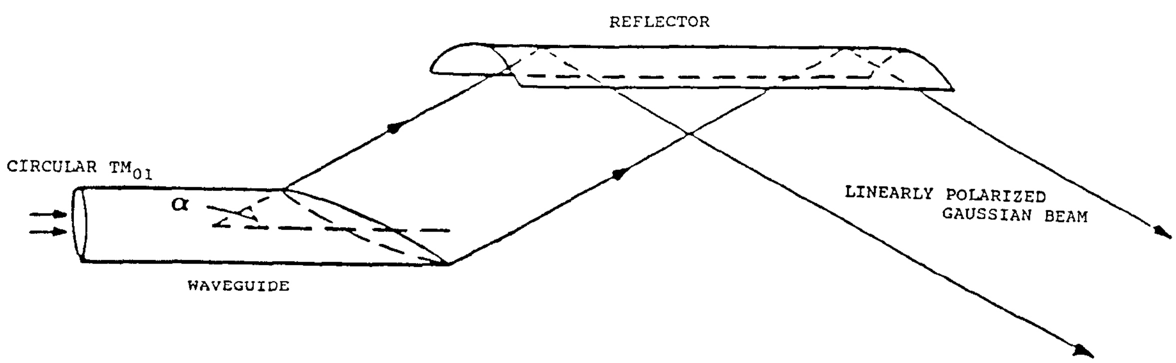

Figure 1. Vlasov mode convertor. The waveguide shown has a bevel cut, located close to the focal point of a parabolic reflector.

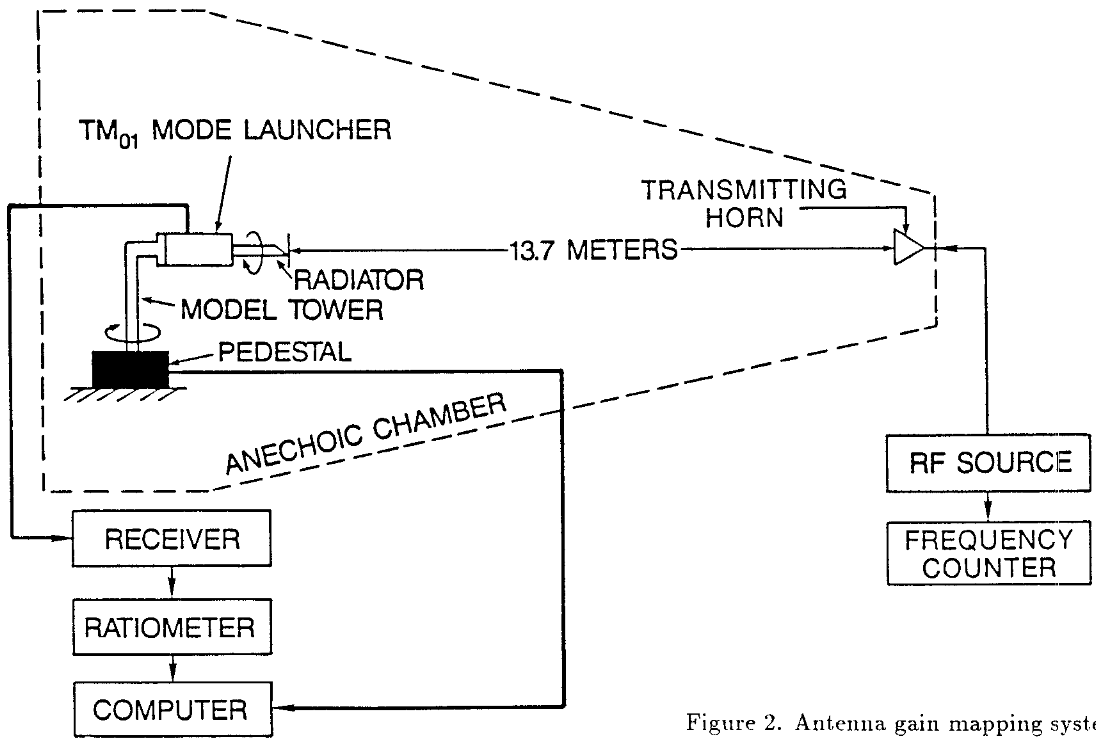

Figure 2. Antenna gain mapping system.

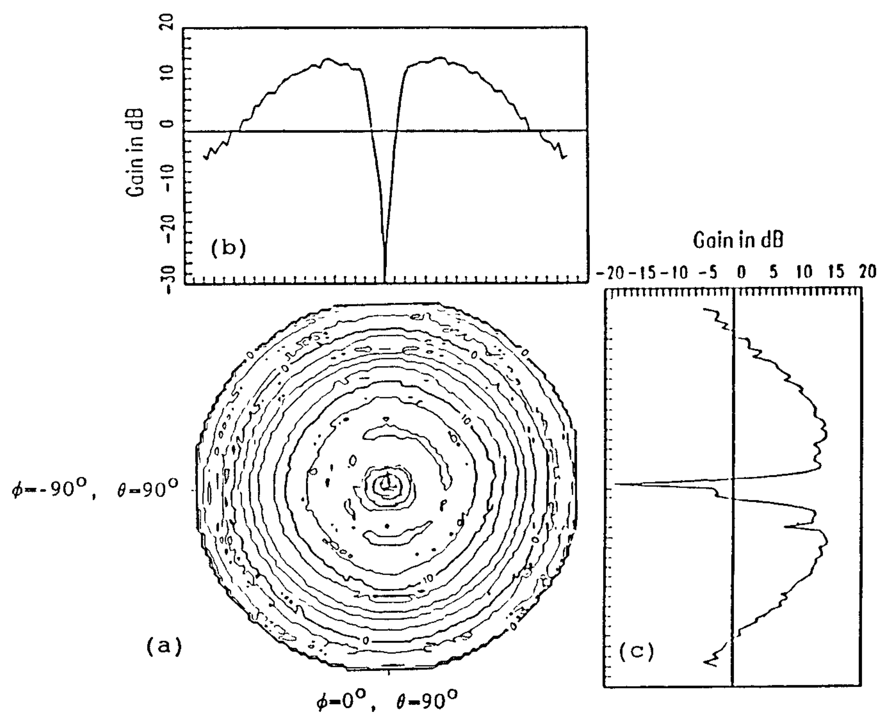

Figure 3. Gain for a circular waveguide with a straight cut ($\alpha = 90°$). (a) Contour plot: the azimuthal angle ϕ varies from $\phi = -180°$ to $\phi = 180°$ in the counterclockwise direction, the radial coordinate θ varies from $\theta = 0°$ in the center to $\theta = 90°$ at the edge. (b) gain along horizontal cut through the center (from $\phi = -90°$, $\theta = 90°$, through $\theta = 0°$ to $\phi = 90°$, $\theta = 90°$). (c) gain along vertical cut through the center (from $\phi = \pm 180°$, $\theta = 90°$, through $\theta = 0°$ to $\phi = 0°$, $\theta = 90°$).

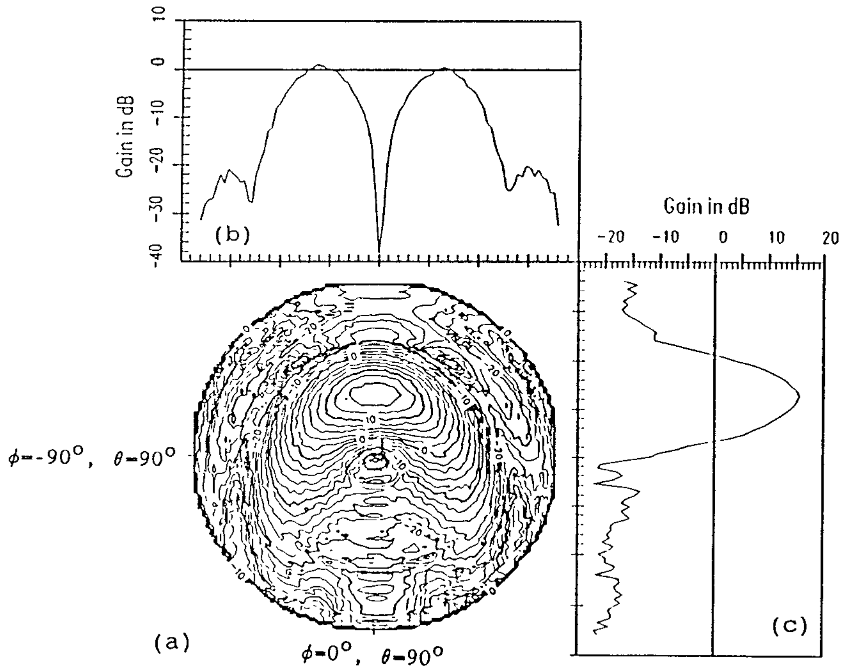

Figure 4. Same as figure 3 except for $\alpha = 30°$.

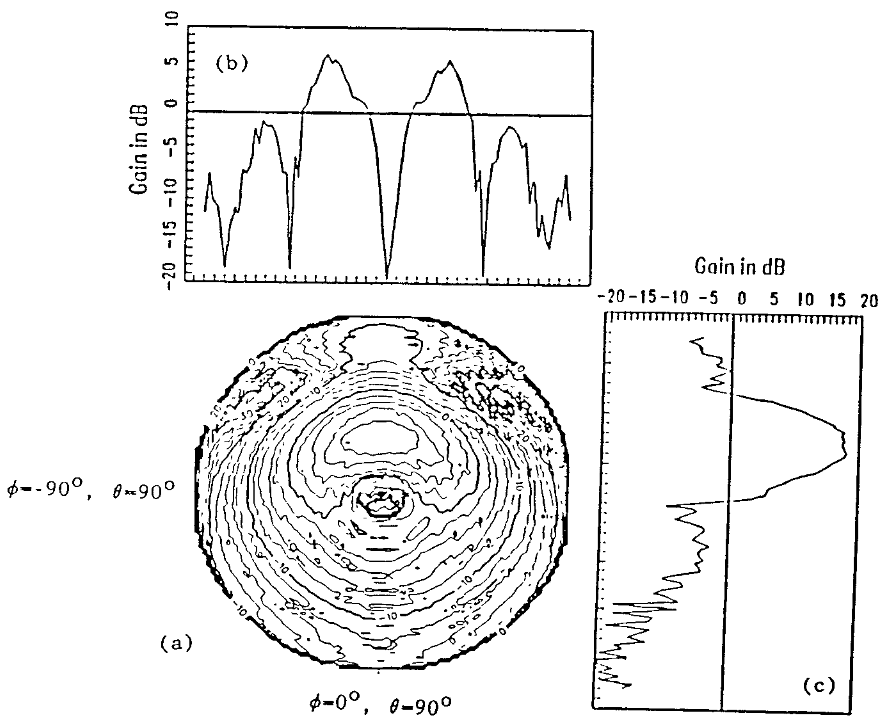

Figure 5. Same as figure 3 except for a step cut.