Sensor and Simulation Notes

Note 503

August 2005

Sidewall Waveguide Slot Antenna for High Power

Carl E. Baum
University of New Mexico
Department of Electrical and Computer Engineering
Albuquerque New Mexico 87131

Abstract

This paper discusses a concept for high-power microwave antennas based on an array of slots in the sidewall where the electric fields are lower. This gives a polarization which is perpendicular to a plane containing the waveguide axis. By combining two such waveguides one can also suppress grating lobes.

This work was sponsored in part by the Air Force Office of Scientific Research.

1. Introduction

For radiating high-power hypoband (narrow band) microwaves, one is faced with significant electrical breakdown problems. One approach involves dividing a rectangular waveguide with metal septa perpendicular to the electric field of the basic $H_{1,0}$ mode [1, 3]. This ideally avoids large electric-field enhancements. Each subguide so formed is then expanded to a large aperture with lower electric field. The set of subguides then leads to a large compound aperture with appropriate control of the phase across the compound aperture to control the direction of the antenna radiation (or radiation pattern). This can be called a split-waveguide antenna.

The polarization of the radiated field is in the plane containing the waveguide axis. One might then ask if there is some kind of design for similar high powers, but with polarization perpendicular to this plane containing the waveguide axis.

The general class of waveguide arrays includes slot arrays, which have found many applications [4]. A general problem for gigawatt applications concerns electrical breakdown at the slots, even with high-dielectric-strength media (vacuum, SF_6) in and around the waveguide, due to electric-field enhancement near the slots. We need to consider designs which minimize this problem. However, it may be difficult to approach the high-power performance of the split-waveguide antenna.

2. Sidewall Slots for Polarization Perpendicular to Plane Containing Waveguide Axis

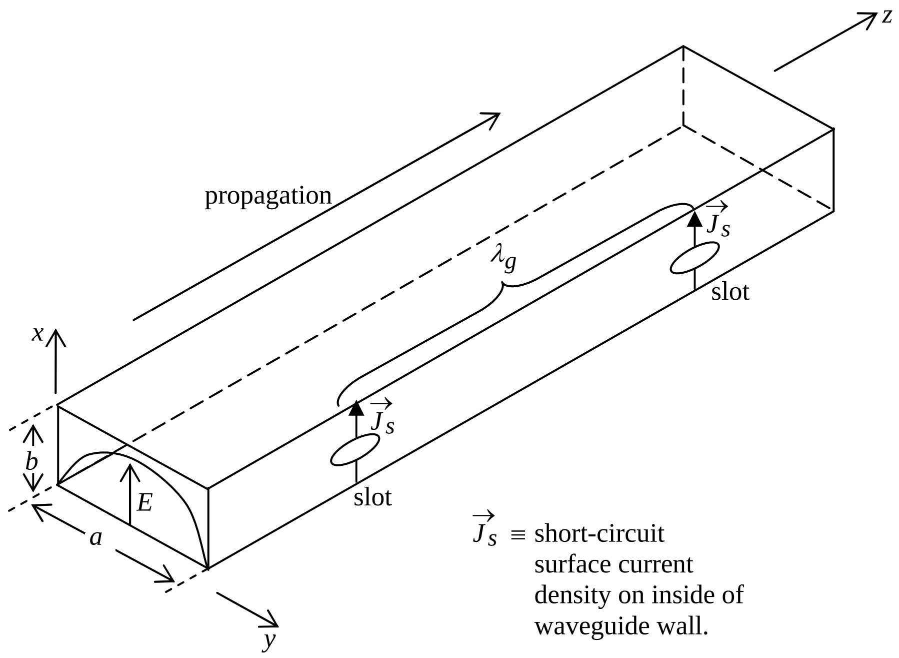
One approach to rotating the polarization would be to take the split-waveguide design and bend each subguide as an H-plane bend (90°) before making E-plane bends and expanding the subguide heights to fill the desired aperture. While this retains the split-waveguide advantages it occupies more volume due to the additional H-plane bends. So let us consider an alternate approach which uses less space.

First, let us observe that the electric field of the fundamental $H_{1,0}$ mode, as indicated in Fig. 2.1A, is maximum in the center of the broad walls and zero (ideally) on the narrower side walls. This suggests that perturbations such as slots might better be placed in the side walls. This will induce electric fields in the vicinity of the slots due to the perturbation of the surface current density and associated magnetic field. These should be smaller, however, than those associated with broad-wall slots due to the perturbation of the large electric fields of the $H_{1,0}$ mode. The same principle applies to a sidewall directional coupler [2].

The orientation of the slots is such that the equivalent magnetic-dipole moment is oriented in the *x* direction, making the antenna beam polarized in the *x* direction. As illustrated in Fig. 2.1, the slots are spaced a guide wavelength λ_g apart to make the main beam (pattern peak) propagate in the *y* direction. As indicated in Fig. 2.1B, the sidewall magnetic field reverses each $\lambda_g / 2$. So only every other magnetic-field peak is used for slot excitation. Other directions are also possible. Note that this spacing also gives grating lobes, a point to which we shall return.

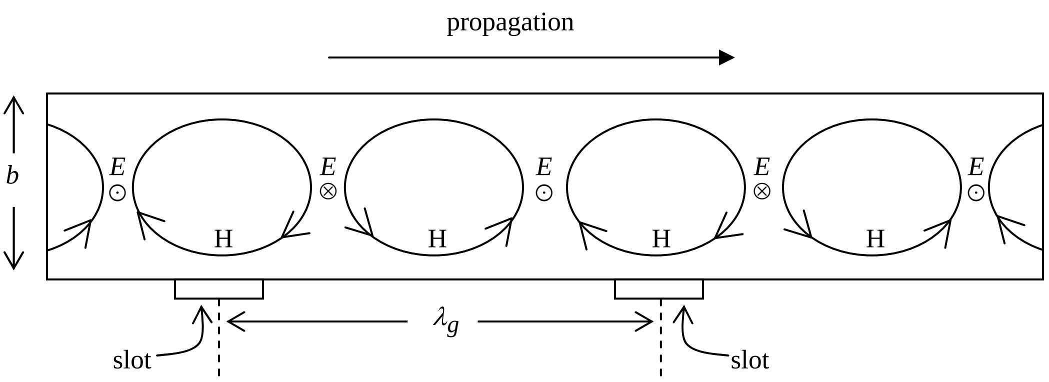
This still leaves the question of the shape of the slots. Assume symmetrical slots (reflection of *x* and *z* coordinates) for polarization control. If the slots are thin in the *x* direction, the induced electric field across each slot is maximum in the center. This indicates that the center should be wider than the ends (*z* extrema). Of course, increasing the length (*z* extent) increases the penetration of the magnetic field (*z* oriented) and the resulting power flow through the slots. An elliptical shape for the slot might be a good starting point.

Once the fields propagate through the slots, one can still construct various structures to expand the field into larger regions before exiting to air through a radome. This aspect is not considered here.



$\vec{J}_s \equiv$ short-circuit surface current density on inside of waveguide wall.

A. Angular view



B. View perpendicular to broad wall

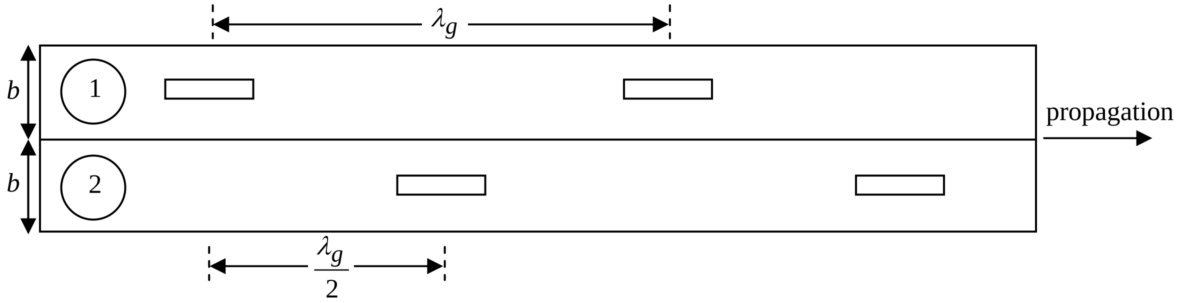
Fig. 2.1 Sidewall Slot Array

3. Combining Two Waveguides to Suppress Grating Lobes

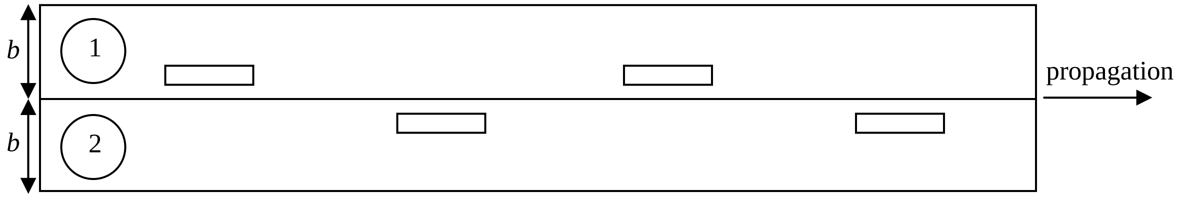
In order to reduce grating lobes, we can shorten the distance between slots by combining two waveguides as illustrated in Fig. 3.1A. In this approach the slots in one guide are alternated with those in the other guide. The phase in the second guide is shifted from that in the first guide by 180° so that both sets of slots operate in the same phase. Now the slots are only $\lambda_g / 2$ apart (in the waveguide propagation direction), suppressing grating lobes (unless λ_g is too much greater than λ, the free-space wavelength).

There is some flexibility in where the slots are placed on the sidewalls. If desired, they can be moved toward the common waveguide broadwall as in Fig. 3.1B. In this case the slots are almost in one common line. Various other patterns are also possible.

Waveguide ② wave is advanced for retarded in phase by 180° relative to wave in ①.



A. Two adjacent waveguides with common broadwall



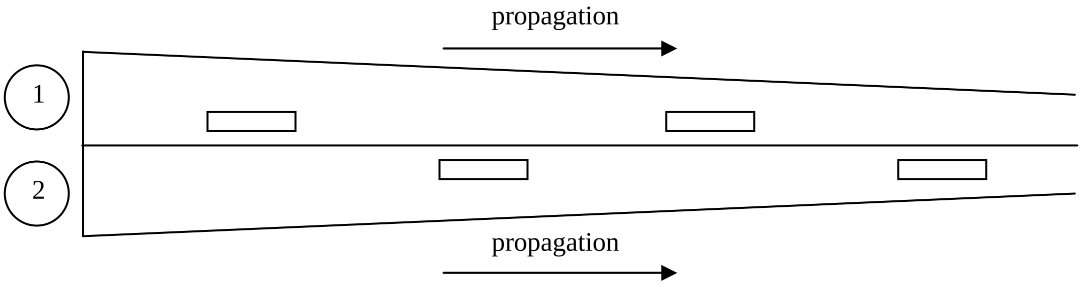
B. Slots moved toward common broad wall

Fig. 3.1 Combining Two Sidewall-Slotted Waveguides

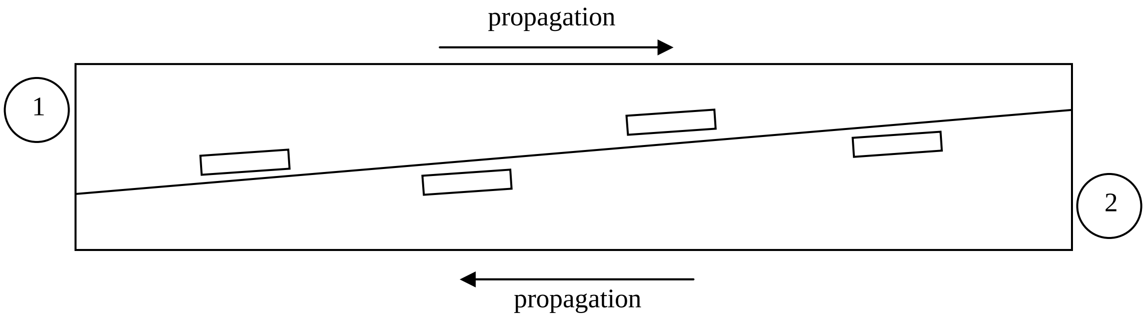
4. Tapering Guide Height

As the wave propagates in the *z* direction in the waveguide, power is lost through the slots. Ideally, an equal power passes through each slot with no remaining power after the last slot. Following a similar procedure in [3], the guide height (b) can be tapered from half the width (*a*/2) at the first slot to zero height after the last slot.

As shown in Fig. 4.1A this tapering feature can be combined with the double-waveguide design discussed in the previous section. In this case both waveguides propagate in the same direction. An alternate approach has opposite propagation directions in the two waveguides as illustrated in Fig. 4.1B. In this case the combined height of the two waveguides is approximately a constant value *a* along the structure. In this latter case, power needs to be fed in from both ends with appropriate control of the relative phases.



A. Parallel-propagating waves in guides



B. Counter-propagating waves in guides

Fig. 4.1 Tapered Waveguides

5. Concluding Remarks

This general design concept leaves various pieces for detailed consideration. The slot shapes (with sharp edges removed, etc.) need to be optimized. The slots, in turn, need to be appropriately transitioned to the external environment.

As the slots become larger, eventually they become large perturbations of the waveguide, making analysis more difficult, and possibly introducing electrical breakdown due to the large electric fields. In this case, the techniques with septa as in [3] become more attractive. In this case the subguides make H-plane instead of E-plane bends. Then bend radius and overall size need to be considered.

References

1. C. E. Baum, “Some Features of Waveguide/Horn Design”, Sensor and Simulation Note 314, November 1988.

2. D. V. Giri, “Canonical Examples of High-Power Microwave (HPM) Radiation Systems for the Case of One Feeding Waveguide”, Sensor and Simulation Note 326, April 1991.

3. C. E. Baum, “High-Power Scanning Waveguide Array”, Sensor and Simulation Note 459, July 2001.

4. M. J. Erlich, “Slot-Antenna Arrays”, ch. 9, pp. 9-1 through 9-18, in H. Jasik (ed.), *Antenna Engineering Handbook*”, McGraw Hill, 1961.