DIRECTIVE PLANAR EXCITATION OF AN IMAGE-GUIDE

Y. Shih, J. Rivera, and T. Itoh

Dept. of Electrical Engineering
The University of Texas
Austin, Texas 78712

ABSTRACT

An image-guide is excited by a Slot Yagi-Uda array created in the ground plane so that the majority of the energy travels in a specified direction. The method is useful for implementing planar devices for image-guide structures.

Introduction

Recently, image-guides have been investigated by a number of workers for application in millimeter-wave integrated circuits.[1,2] To date, an image-guide is typically excited by a tapered section inserted into an open-ended waveguide or a waveguide horn designed for the least amount of insertion loss and reflection. These structures with good design are useful for interfacing the image-guide with conventional waveguide circuits. However, if true millimeter-wave integrated circuits are built with image-guide structures, it is necessary that solid state devices are incorporated in or near the image-guide so that they interface the latter directly or possibly by way of planar networks such as microstrips. Direct implementation of solid state devices is not very rewarding as the junction created by the device causes a number of problems such as radiation and impedance mismatch.

To alleviate such problems, Solbach recently proposed a slot structure in the ground plane of the image-guide and placed a detector diode in the slot.[3] With an appropriate design, detector efficiency was found to be relatively good. One of the problems of such a structure, however, is that the slot created in the ground plane is bidirectional, that is, it captures the guided waves coming from both directions. Or if the slot is used for excitation, the power is split into both directions in the image-guide.

This paper proposes a method for substantially increasing the directivity of the excitation from the slot in the ground plane. This scheme consists of multi-slots in the ground plane arranged in a Yagi-Uda array arrangement (Figure 1). Unlike the phased array arrangement, the Yagi-Uda array requires only one element to be active, thus reducing the number of required active devices. Actually, a monopole type Yagi-Uda array inserted into the dielectric guide has been reported.[4] However, the present structure is much more appropriate for millimeter-wave circuits because the slot structures are amenable to planar fabrication technology.

Design Criteria

The slots in the ground plane of an image-guide can behave as the elements of a Yagi-Uda array by adjusting the width, length, and spacing of the slots. The parameters of interest are defined in Figure 2.

The length of the driving element is chosen so that it is at half-wavelength resonance. Note that the slot can be viewed as a short-circuited slot-line with the dielectric slab of the image-guide as the substrate. Hence, to determine the resonant length, the analysis developed by S. Cohn[5,6] was utilized and yielded a second-order approximation for the guided wavelength. Design data was available from various curves in Cohn's analysis and the slot-line parameters were substituted to give the length of the resonant slot. In addition, the end effect in a shorted slot had to be taken into account. Research conducted by Knorr and Saenz[7] indicates that this factor serves to increase the resonant length by as much as 20%.

To obtain the maximum excitation of the image-guide mode in one direction, it is necessary to adjust the Yagi-Uda slot parameters. By lengthening and shortening the parasitic slots, reflector and director elements are created to increase the coupled energy along a specified direction. The research conducted by several authors[8,9] indicates that the reflector length is approximately 5% longer than that of the driver and the director is about 10% shorter.

The optimum reflector spacing was experimentally determined[8] to be $\lambda g/4$. As for the director spacing, a maximum gain can be achieved by adjusting the width and length of the slot as long as such spacing does not exceed $0.3\lambda g$. Note that λg in our application should be the guide wavelength of the E^y_{11} mode in the image line, and is determined by applying the method of effective dielectric constants.[10] To this end, we first obtain ε_{eff} for the vertically polarized modes

$$\varepsilon_{eff} = \varepsilon_r - \left(\frac{k_y}{k_o}\right)^2 \tag{1}$$

where k_y is the solution to the eigenvalue equation

$$\left(\frac{k_y}{\varepsilon_r}\right) \tan k_y b - \sqrt{(\varepsilon_r - 1)\, k_o^2 - k_y^2} = 0 \tag{2}$$

Next, the structure is replaced with a hypothetical vertical slab of width 2a and infinite height and dielectric constant ε_{eff}. By solving the eigenvalue equation of this hypothetical structure for the phase constant, k_x, in the slab region, we obtain the propagation constant of the guide mode from $k_z = \sqrt{\varepsilon_{eff}\, k_o^2 - k_x^2}$, and thus, the guided wavelength, λg.

Finally, the width of the slots is adjusted to vary the input impedance so that the optimum gain is obtained. Rigorous determination of the impedance is too complex to be practical for this study, and thus the slot widths were determined experimentally.

This work was supported in part by U.S. Army Research Office Grant DAAG29-78-G-0145, and in part by Joint Services Electronics Program F49620-77-C-0101.

Although an active device may be directly implemented in the driving slot, our objective here is to study the coupling between the slot array and the image-guide. To this end, we studied several methods of exciting the slot by an external source. Fig. 3a is one of such structures. Although this configuration deviates from the planar type design, a good impedance match can easily be obtained to enhance efficient excitation of the driving slot. It is thus appropriate for laboratory studies. Figure 3b proposes a planar type feed with a slot-line. Design of an efficient feed by this mechanism is more difficult.

Experimental Results

Various configurations were tested and the following parameters were used: a design frequency of 7.5 GHz, a ground plane thickness of 0.1 mm, and a dielectric constant of 10.0. Yagi arrays with only two elements (driver and reflector, driver and director) were tested first. The measured front-to-back ratios of transmitted power are shown in Figure 4. A relatively high ratio is obtained with the reflector behind the driving slot. However, the bandwidth is very narrow. A wider bandwidth (but a lower ratio) appears in the case of the driver and director when the width of the director is larger. By introducing more directors into the array, a higher ratio and wider bandwidth is obtained. The results for 3, 4, and 5 element arrays are shown in Figure 5.

Conclusion

The principles of the Yagi-Uda array are applied to the slot-fed image line in order to reduce the radiation losses and increase the energy transmitted in the specified direction. The experimental results show that even with a two-element design, one can obtain greater transmission in the forward direction. A five-element design proved to have a wider bandwidth while maintaining an overall increase in directivity in the desired direction. The results reported in this paper are believed to be viable and can prove to be effective in the design of planar millimeter-wave circuits using image-guide structures. It is expected that an increased number of director elements improve the front-to-back excitation ratio even further, provided a careful design is carried out.

References

1. B-S. Song, T. Itoh, "Distributed Bragg Reflection Dielectric Waveguide Oscillators," IEEE Trans. MTT, vol. MTT-27, No. 12, pp. 1019-1022, December 1979.

2. J. A. Paul and Y.-W. Chang, "Millimeter-wave Image-guide integrated passive devices," IEEE Trans. MTT, vol. MTT-26, No. 10, pp. 751-754, October 1978.

3. K. Solbach, "Slots in dielectric image line as mode launchers and circuit elements," IEEE Trans. MTT, accepted for publication, paper no. k-214.

4. W. K. McRitchie and J. C. Beal, "Yagi-Uda array as a surface-wave launcher for dielectric image lines," IEEE Trans. MTT, vol. MTT-20, pp. 493-496, August 1972.

5. S. B. Cohn, "Slot line on a dielectric substrate," IEEE Trans. MTT, vol. MTT-17, pp. 768-778, October 1969.

6. E. A. Mariana, et. al., "Slot line characteristics," IEEE Trans. MTT, vol. MTT 17, pp. 1091-1096, December 1969.

7. J. B. Knorr and J. Saenz, "End effect in a shorted slot," IEEE Trans. MTT, vol. 21, pp. 579-580, September 1973

8. H. W. Ehrenspeck and H. Poehler, "A new method for obtaining maximum gain from Yagi antennas," IRE Trans. on Antennas and Propagation, vol. Ap-7, pp. 379-386, October 1959.

9. R. M. Fishenden and E. R. Wiblin, "Design of Yagi aerials," Proc. IEE (London), vol. 96, pt. III, pp. 5-12, March 1959.

10. T. Itoh and B. Adelseck, "Trapped image guide for millimeter-wave circuits," IEEE Trans. MTT, vol. MTT-28, pp. 1433-1436, December 1980/

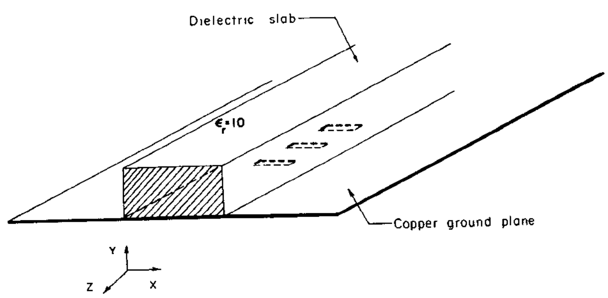

FIGURE 1: SLOT-FED DIELECTRIC IMAGE LINE.

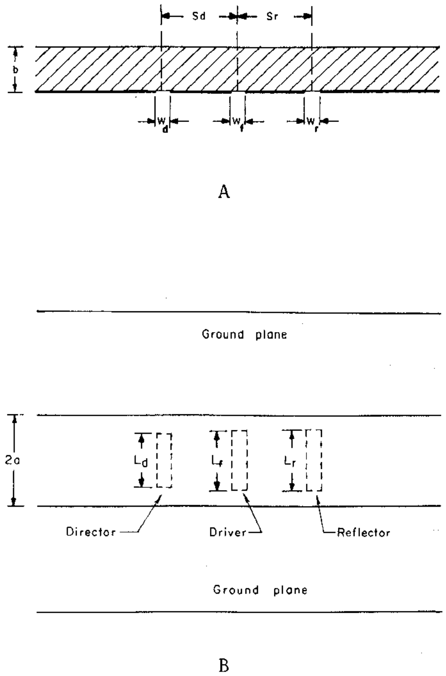

FIGURE 2: DIMENSIONS OF DIELECTRIC IMAGE LINE, (A) SIDE VIEW, (B) TOP VIEW.

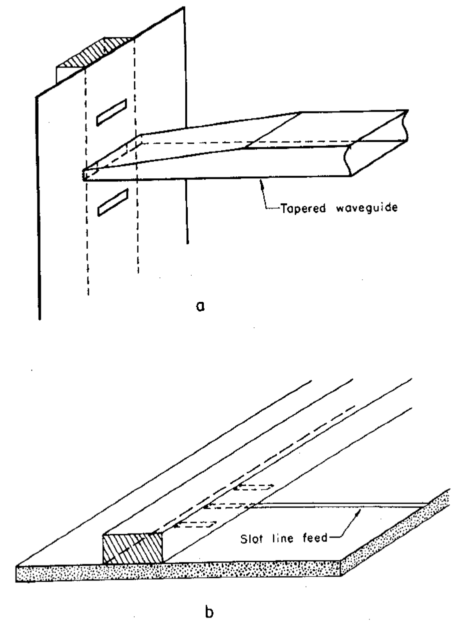

FIGURE 3: FEEDING METHODS, (A) REDUCED HEIGHT WAVEGUIDE FEED, (B) SLOT LINE FEED.

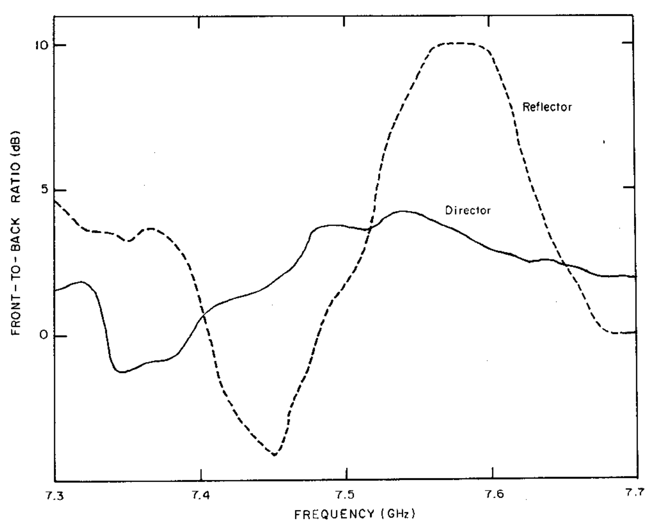

FIGURE 4: FRONT-TO-BACK POWER RATIO VS. FREQUENCY (REFLECTOR CASE: L_f = 7.8 mm, W_f = 0.5 mm, L_r = 8.2 mm, W_r = 0.3 mm, S_r = 3.5 mm; DIRECTOR CASE: L_f = 7.9 mm, W_f = 1.0 mm, L_d = 7.2 mm, W_d = 1.0 mm, S_d = 3.4 mm).

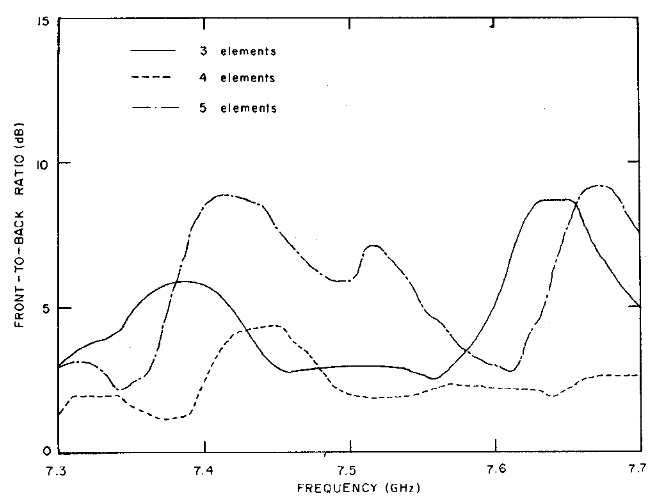

FIGURE 5: FRONT-TO-BACK POWER RATIO VS. FREQUENCY FOR MULTI-ELEMENT ARRAYS (L_f = 7.8 mm, W_f = 0.5 mm, L_r = 8.2 mm, W_r = 0.3 mm, S_r = 3.5 mm, L_d = 7.0 mm, W_d = 0.6 mm, S_d = 5.2 mm).