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COUPLING THROUGH A SLOT BETWEEN A DIELECTRIC IMAGE LINE AND A PARALLEL PLATE GUIDE

By

R.D. Nevels
Department of Electrical Engineering
Texas A&M University
College Station, Texas 77843

and

C.M. Butler
Department of Electrical Engineering
University of Mississippi
University, Mississippi 38677

ABSTRACT

In this paper we formulate the exact integral equation for the tangential electric field in a slot in a parallel plate waveguide covered by a dielectric slab. The integral equation is solved numerically and the power transmitted into the far space wave and bi-directional surface wave is investigated.

Introduction

In this paper we analyze a parallel plate waveguide with one plate perforated by a slot and covered by a dielectric slab (see Figure 1a). This device could find applications both as a method of launching surface waves in a dielectric image line and as a coupler between an image line and a standard metal waveguide. A similar structure employed as a millimeter-wave dielectric image line detector-circuit has recently been reported on by Solbach [1]. A major problem in the design of image line couplers is radiation losses incurred at slot or notch discontinuities in the line. In this paper we investigate both the radiated power and the power coupled into surface waves as a function of slot width and image line slab thickness. Integral equations are formulated for the unknown tangential slot electric field which is solved for by use of the method of moments [2].

Theoretical Analysis

The excitation is a V-volt TEM incident wave traveling in the positive z-direction whose TEM field can be (suppressed time variation $e^{j\omega t}$)

$$\underline{E}^{inc} = \frac{V}{h} e^{-jkz} \hat{\underline{x}} \qquad (1a)$$

$$\underline{H}^{inc} = \frac{V}{\eta h} e^{-jkz} \hat{\underline{y}} \qquad (1b)$$

with $k = \omega\sqrt{\mu\varepsilon}$, $\eta = \sqrt{\mu/\varepsilon}$ • Hy and H_y^d are formulated in terms of equal and opposite equivalent magnetic currents on the interior and exterior sides of the shorted slot (Fig. 1b). Enforcement of the continuity of magnetic field in the slot leads to the integral equation below for E_z^A.

$$\int_{-w}^{w} E_z^A(z')[g(h,z;h,z')+2g^d(h,z;z')]dz' = H_y^{sc}(z) \;;\; z\varepsilon(-w,w) \qquad (2)$$

where $g(h,z;h,z')$ and $g^d(h,z;z')$ are respectively the Greens functions for a magnetic line source in a parallel plate waveguide and in a dielectric slab [3].

By partitioning the interval (-w,w) into N equal segments of length $\Delta = 2w/N$ and by selecting the match-point locations z_m at pulse centers according to $z_m = -w + (m-1/2)\Delta$, one may establish the following approximation of the integral equation.

$$\sum_{n=1}^{N} E_n[Y_{mn} + Y_{mn}^d] = H_y^{sc}(z_m), \quad m = 1,2,\ldots,N \qquad (3)$$

in which E_n is the unknown coefficient of the n^{th} pulse located at z_n. The matrix elements in (3) are defined as

$$Y_{mn} = \int_{z_n-\Delta/2}^{z_n+\Delta/2} g(h,z_m;h,z')dz' \qquad (4)$$

$$Y_{mn}^d = 2\int_{z_n+ /2}^{z_n+\Delta/2} g^d(h,z_m;z')dz' \qquad (5)$$

Equation (3) is solved numerically for E_n.

The total time average power per unit (y-direction) width in the parallel plate guide is $P^{inc}=V^2/2\lambda h$. The total time average power transmitted through the slot is given by

$$P^T = \frac{1}{2} \mathrm{Re} \int_A -\underline{M} \cdot \underline{H}^* \, ds \qquad (6)$$

where magnetic current in the dielectric slab is $\underline{M} = -2M_y\hat{y} = 2E_z^A\hat{y}$ and H* is the conjugate of the magnetic field in the dielectric slab. The total time average power transmitted through the slot per unit (y-direction) width can be expressed in term of the numerically determined slot tangential electric field pulse amplitudes by

$$P^T = -\mathrm{Re} \sum_{m=1}^{N}\sum_{n=1}^{N} E_m E_n^* \int_{z=-\Delta/2}^{\Delta/2}\int_{z'=-\Delta/2}^{\Delta/2} g^{d*}(h,z+z_m;z'+z_n)dz'dz \qquad (7)$$

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where g^{d*} is the conjugate of the dielectric slab Green's function. By separating g^{d} into space wave and surface wave components in the far field, the power lost in space wave radiation P^{f} and coupled into the bi-direction surface P^{S} can be found.

RESULTS

The results shown in figure 2 indicate that the space wave far field coupling efficiency (P^{f}/P^{T}) is greatest when the slot width is 2w>>t. However a minimum in the space wave coupling efficiency occurs between $3\lambda_d/8<t<\lambda_d/2$ regardless of slot width. A corresponding maximum in the surface wave launching efficiency (P^{S}/P^{T}) occurs over this same range. It is noted however that a space wave launching device is most efficiently made by using a wide slot. The results in figure 2 also suggest that a surface wave launching device is much more efficiently made by using a slot with a narrow width covered by a slab of thickness $3\lambda_c/8<t<\lambda_d/2$.

References

[1] K. Solback, "Millimeter-Wave Dielectric Image Line Detector-Circuit Employing Etched Slot Structure," IEEE Trans. MTT, Vol. MTT-29, pp. 953-58; Sept. 1981.

[2] R.F. Harrington, Field Computation by the Method of Moments, New York: Macmillan, 1968.

[3] R.E. Collin, Field Theory of Guided Waves, New York: McGraw Hill, 1960.

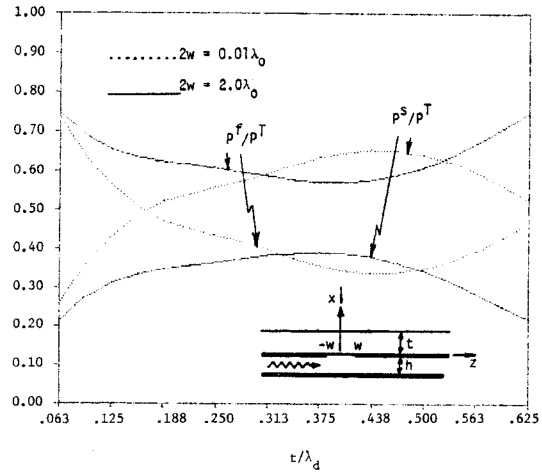

Fig. 2. Power coupled into space wave P^{f} and bidirectional surface wave P^{S} normalized by the total power transmitted through the slot P^{T}.

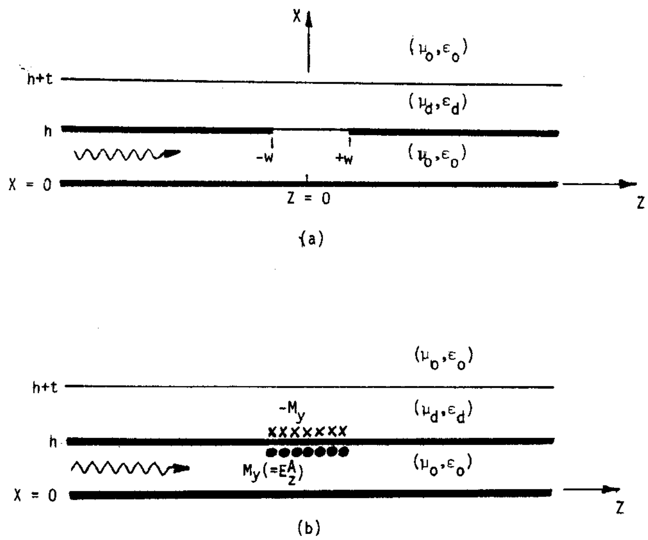

Fig. 1. (a) Slot coupled parallel-plate guide and image line. (b) Equivalent configuration with shorted slot and radiating magnetic currents.