Analysis of the Transition from Rectangular Waveguide to Shielded Dielectric Image Guide Using the Finite-Difference Time-Domain Method

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***Abstract*— The transition from a rectangular waveguide to a shielded dielectric image guide is analyzed using the finite-difference time-domain (FDTD) method. This method has not been applied to three dimensional dielectric waveguide discontinuities before. The transition problem under consideration demonstrates the ability of the FDTD technique to model rather complex structures where two different transmission media exist. The calculated return loss agrees very well with data obtained using other techniques which validates the application of the FDTD method for this problem.**

I. Introduction

RECENTLY, the dielectric image guides have gained interest in their applications in millimeter-wave integrated circuit designs [1]. The dielectric image guide is easy to fabricate and offers greater tolerance and lower loss as compared to other conventional microwave transmission lines (microstrip line and coplanar waveguide) at submillimeter wave frequencies. The objective of this letter is to demonstrate the applicability of the finite-difference time-domain (FDTD) technique [2] to transitions involving dielectric waveguides and to prove the versatility of the method and its capability to handle rather complex circuit geometries. The two types of transitions shown in Figs. 1 and 2 are analyzed. The first transition from a rectangular waveguide to a shielded dielectric image guide has been studied in the past using a rigorous hybrid-mode analysis based on the mode matching technique [1] and serves as validation. The second transition is geometrically more complex as it uses a dielectric wedge in front of the image guide in order to reduce reflections and improve efficiency. The presence of this wedge has been found to be very efficient in many practical implementations since it reduces the return loss to the point that the transition effects can be de-embedded from measurements [3]. The wedge in this geometry is modeled using the "staircase" approximation and the performance of the transition is computed in the time and frequency domains using the FDTD method. From this analysis, it has been found that the presence of the wedge can improve the performance of the transition by as much as 3 dBs.

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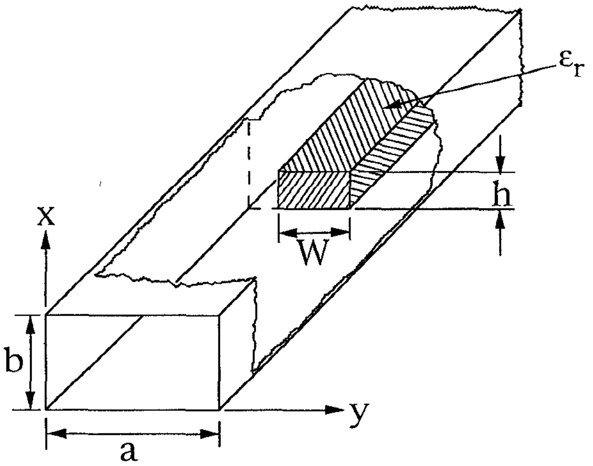

Fig. 1. Transition from a rectangular waveguide to a shielded dielectric image guide.

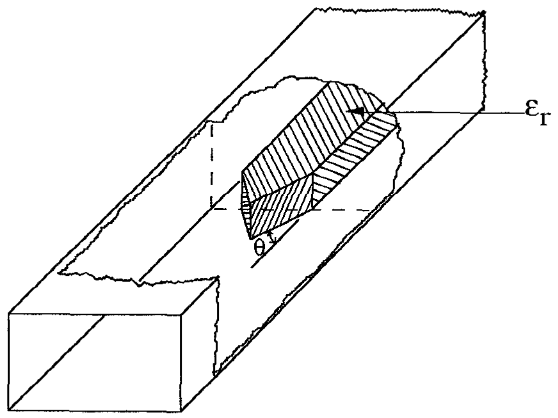

Fig. 2. Transition from a rectangular waveguide to a shielded dielectric image guide through a wedge.

II. Approach

The FDTD method is well known [2] and thus will not be presented here. The excitation mechanism used in this research is similar to that described in [4]–[6]. To approximate the TE_{01} mode, the amplitude of the incident field has a half wavelength sinusoidal distribution across the rectangular guide in the y-direction and is uniform in the x-direction. Moreover, the incident field has a spatial variation in the z-direction given

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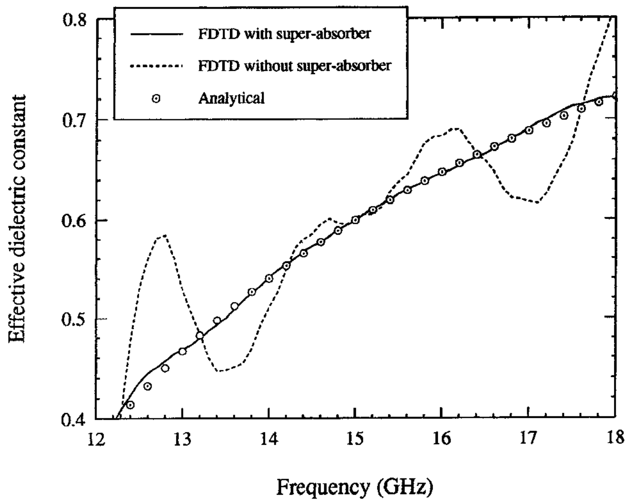

Fig. 3. The effective dielectric constant of an empty WR-62 rectangular waveguide. $a = 15.798$ mm and $b = 7.899$ mm.

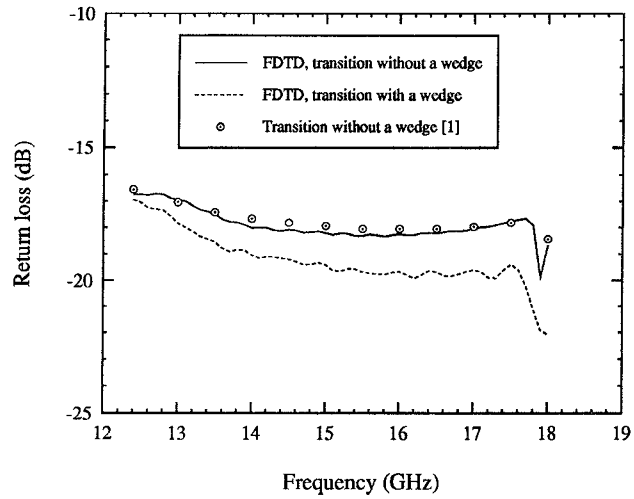

Fig. 4. Return loss of the transitions shown in Figs. 1 and 2. $a = 15.798$ mm, $b = 7.899$ mm, $W = 7.1091$ mm, $h = 3.1596$ mm, $\epsilon_r = 2.53$, $\theta = 45°$.

by a Gaussian envelope imposed on a sinusoidally varying carrier. The super-absorbing first-order Mur condition [7], [8] is used at the front and back walls of the waveguide in order to simulate an infinitely long waveguide. Numerical experiments have shown that such an absorbing boundary condition (ABC) reduces reflections appreciably compared to, for example, first-order Mur without the super-absorber. The above ABC's require a choice for the incident velocity of the waves, or equivalently ϵ_{eff}. At the front wall, an $\epsilon_{r,\text{eff}}$ that corresponds to the velocity of the waves in an empty waveguide, at a frequency which is approximately at the middle of the frequency range of interest, is chosen. On the other hand, at the back wall, an $\epsilon_{r,\text{eff}}$ that corresponds to the velocity of the waves in the shielded dielectric image guide is chosen. An estimate of this latter $\epsilon_{r,\text{eff}}$ may be obtained using the compact 2-D/FDTD technique [9], [10] or the mode matching technique [11]. It should be mentioned that the above choice of $\epsilon_{r,\text{eff}}$ assumes that only the propagating dominant mode exists in the dielectric waveguide. In case that higher order propagating modes exist, other forms of ABC's should be used, e.g., the dispersive ABC [12].

III. Results

Fig. 3 shows the effective dielectric constant of an empty rectangular waveguide obtained using the three dimensional FDTD technique described above with and without the application of the super-absorber. Both sets of data are compared to the analytically obtained effective dielectric constant of the empty waveguide. It can be seen that the results derived using the super-absorber in conjunction with the first-order Mur ABC agree very well with the analytically obtained data. Fig. 4 shows the magnitude of S_{11} of the transitions shown in Figs. 1 and 2 when a TE_{01} mode is incident. The FDTD results of the transition without the wedge are in very good agreement with those obtained using a rigorous hybrid-mode analysis [1]. As expected, the wedge reduces the return loss since in this case a smoother transition exists from the rectangular guide to the image line. It should be mentioned that it would have been very difficult to model the transition with the wedge if it were to be analyzed using the hybrid-mode analysis described in [1]. The FDTD has the advantage of being capable to model any volumetric structure with rectangular cells. It is also worth mentioning that the total mesh dimensions used in the analysis of the transition are 20×40×200 in the $\hat{x}$, $\hat{y}$ and $\hat{z}$ directions, respectively.

IV. Conclusion

The FDTD technique has been successfully used to model the transition from a rectangular waveguide to a shielded dielectric image guide. The FDTD method is very simple to implement compared to other techniques. The derived results agreed very well with those already published in the literature. It has been shown that using a wedge can improve the performance of the transition by as much as 3 dBs. The letter shows the potential of using the FDTD method to analyze more complicated three dimensional dielectric lines transitions and discontinuities such as those in [13], [14].

References

[1] J. Strube and F. Arndt, "Rigorous hybrid-mode analysis of the transition from rectangular waveguide to shielded dielectric image guide," *IEEE Trans. Microwave Theory Tech.*, vol. 33, pp. 391–400, May 1985.

[2] K. Kunz and R. Luebbers, *The Finite Difference Time Domain Method for Electromagnetics*. Boca Raton, FL: CRC press, 1993.

[3] G. Ponchak and L. Katehi, "Development of leaky wave antennas for layered ridge dielectric waveguide," in *IEEE AP-S Symp. Dig.*, Ann Arbor, MI, June 1993, pp. 580–583.

[4] P. Alinikula and K. Kunz, "Analysis of waveguide aperture coupling using the finite-difference time-domain method," *IEEE Microwave Guided Wave Lett.*, vol. 1, pp. 189–191, Aug. 1991.

[5] S. Chu, W. Huang, and S. Chaudhuri, "Simulation and analysis of waveguide based optical integrated circuits," *Comput. Phys. Commun.*, vol. 68, pp. 451–484, 1991.

[6] M. De Pourcq, "Field and power-density calculations in closed microwave systems by three-dimensional finite differences," *IEE Proc.*, vol. 132, pt. H, no. 6, pp. 360–368, Oct. 1985.

[7] K. Mei and J. Fang, "Superabsorption—A method to improve absorbing boundary conditions," *IEEE Trans. Antennas Propagat.*, vol. 40, pp. 1001–1010, Sept. 1992.

[8] V. Betz and R. Mittra, "Comparison and evaluation of boundary conditions for the absorption of guided waves in an FDTD simulation, " *IEEE Microwave Guided Wave Lett.*, vol. 2, pp. 499–501, Dec. 1992.
[9] A. Asi and L. Shafai, "Dispersion analysis of anisotropic inhomogeneous waveguides using compact 2D-FDTD, " *Electron. Lett.*, vol. 28, no. 15, pp. 1451–1452, July 1992.
[10] N. Dib and L. Katehi, "Dispersion analysis of multilayer planar lines containing ferrite regions using an extended 2D-FDTD method, " in *IEEE AP-S Symp.*, Ann Arbor, MI, June 1993, pp. 842–845.
[11] A. Engel and L. Katehi, "Low-loss monolithic transmission lines for submillimeter and terahertz frequency applications, " *IEEE Trans. Microwave Theory Tech.*, vol. 39, pp. 1847–1854, Nov. 1991.
[12] Z. Bi, K. Wu, C. Wu, and J. Litva, "A dispersive boundary condition for microstrip component analysis using the FDTD method, " *IEEE Trans. Microwave Theory Tech.*, vol. 40, pp. 774–777, Apr. 1992.
[13] S. Bhooshan and R. Mittra, " On the design of transitions between a metal and inverted strip dielectric waveguide for millimeter waves, " *IEEE Trans. Microwave Theory Tech.*, vol. MTT-29, pp. 263–265, Mar. 1981.
[14] J. Malherbe, J. Cloete, and I. Losch, "A transition from rectangular to nonradiating dielectric waveguide, " *IEEE Trans. Microwave Theory Tech.*, vol. MTT-33, pp. 539–543, June 1985.