ANALYSIS OF E-PLANE WAVEGUIDE JUNCTION WITH PARTIAL HEIGHT DIELECTRIC AND FERRITE INSERTS

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Abstract

A method is presented to treat a three port E-plane waveguide junction with partial height dielectric and ferrite inserts without finding the propagation constants of the guided modes in the dielectric and ferrite inserts. It is shown that in order to completely describe the fields in the junction some nonphysical terms have to be included in the irrotational set. The numerical results are compared with the experimental results for the E-plane waveguide junction with partial height dielectric and ferrite inserts.

Introduction

The performance of the waveguide junction with partial height ferrite have been successfully analyzed with the field matching method [1] and [2]. By the field matching method the propagation constants of the guided modes in the ferrite and in the dielectric inserts have to be first determined via solving a transcendental equation in order to obtain the S-parameters of the waveguide junction. In [3] a method was proposed to calculate the S-parameters of the waveguide junction with full height anisotropic medium without finding the propagation constants of the guided modes of the anisotropic medium. This method is extended to treat the E-plane waveguide junction with partial height dielectric and ferrite inserts. It is shown that in order to completely describe the fields in the junction some nonphysical terms have to be included in the irrotational set. The numerical results are compared with the experimental results.

Theory

Fig. 1 shows an E-plane waveguide junction containing a partial height dielectric or ferrite cylinder. Applying the equivalence principle, the imaginary boundaries chosen between the center region of the junction and the waveguides are short circuited and magnetic surface currents are introduced at both sides of the inserted short circuits in order to restore the nonvanishing tangential electric fields. The imaginary boundaries are chosen such that the center region of the junction can be treated as a cylindrical resonator excited by magnetic surface currents located at the imaginary boundaries and volume polarization currents within the partial height medium. Due to the partial height medium all the possible modes of the cylindrical resonator are excited. Since the electric displacement $\underline{D}$ is divergentless in the resonator it can be expressed completely as an expansion in terms of a solenoidal set

$$\underline{D} = \varepsilon_o \sum_n e_n \underline{E}_n \tag{1}$$

where $\underline{E}_n$ is the electric field of the nth resonance mode in the empty cylindrical cavity, e_n is the corresponding expansion coefficient. Due to the magnetic surface currents at the imaginary boundaries the magnetic induction $\underline{B}$ can be expressed in the resonator as an expansion in terms of a solenoidal set and an irrotational set

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$$\underline{B} = \mu_o \sum_n h_n \underline{H}_n + \mu_o \sum_n g_n \underline{G}_n + \mu_o \sum_q g_{oq} \underline{G}_{oq} \tag{2}$$

where $\underline{H}_n$ is the magnetic field of the nth resonance mode in the empty cylindrical cavity, $\underline{G}_n$ and $\underline{G}_{oq}$ belong to the irrotational set and h_n, g_n and g_{oq} are the corresponding expansion coefficients. The irrotational modes are defined by

$$\begin{aligned} \underline{G}_n &= \underline{\nabla}\psi_n \\ \Delta^2\psi_n + p_n^2\psi_n &= 0 \\ \frac{\partial\psi_n}{\partial n} &= 0 \quad \text{on the surface of the cylindrical resonator} \\ \underline{\nabla} \times \underline{G}_n &= 0 \end{aligned} \tag{3}$$

$\hat{\underline{n}}$ is the unit normal vector at the surface of the cylindrical resonator and p_n is the eigenvalue for the problem. Since $\partial\psi_n/\partial n = 0$ at the surface of the cylindrical resonator, ψ_n generally does not have a constant term. However a constant term $\underline{G}_{oq}$ are needed for the completeness of the irrotational set. The term along can not physically exist in the resonator. For the E-plane waveguide junction and with TE_{10} dominant mode exciting at one port, $\underline{G}_{oq}$ is φ independence and has constant values on the xy plane

$$\underline{G}_{oq} = \underline{u}_z \sin \frac{q\pi}{L} z \ , \quad q = 1,2,3,\dots \tag{4}$$

L is the height of the junction. From the mathematical point of view, the $\underline{G}_{oq}$ term has the same meaning as the constant term in the Fourier series. Substituting (1) and (2) into Maxwell's equations and making use of the orthogonality properties of $\{\underline{E}_n\}$, $\{\underline{H}_n\}$ and $\{\underline{G}_n\}$ and matching the tangential magnetic fields at the imaginary boundaries one arrives at a matrix equation of infinite dimension, the unknown of which are the amplitudes of the scattered waveguide modes.

Numerical Results

Fig. 2 shows the calculated eigenvalues and the S-parameters of an E-plane empty waveguide junction. The solid lines show the calculated results with the nonphysical terms $\underline{G}_{oq}$ and the broken lines show the calculated results without the nonphysical terms $\underline{G}_{oq}$. The experimental results of [4] are represented by the triangles. It can be seen that for the correctness of the numerical results the irrotational set has to include the nonphysical terms $\underline{G}_{oq}$. Fig. 3 shows the phases of the eigenvalues and the S-parameters of an E-plane waveguide junction with partial height dielectric insert. The numerical results and the experimental results of [4] are represented by the solid lines and the broken lines, respectively. As can be seen the two results agree to a very good extent. The abrupt changes of the phases of the eigenvalues at about 9.2 GHz and 11.2 GHz are due to the resonances of the $EH_{11\frac{1}{2}}$ and $HE_{01\frac{1}{2}}$ modes of the dielectric insert at these frequencies, respectively. Fig. 4 shows the calculated S-parameters (solid lines) and the experimental results (broken lines) of [4] for an E-plane waveguide junction with a partial height ferrite. The agreement between the two results is not so good as the results with dielectric insert. The discrepancy may be due to the inhomogeneity of the constant magnetic field around the ferrite which had about the same diameter as the diameter of the permanent magnet in the experiment. This inhomogeneity of the constant magnetic field around the ferrite leads to different values of permeability tensor elements as the values used in the numerical calculations. Figs. 5 and 6 show the electric-field distributions in the E-plane waveguide junction with ferrite as functions of r. The discontinuities of the electric field at r = a are due to the fact that the magnetic surface currents are introduced there and the discontinuities of the electric field components E_φ and E_z at the ferrite-air interface are accompanied with the Gibbs phenomenon.

Conclusion

A method for the analysis of the E-plane waveguide junction with partial height dielectric and ferrite inserts has been proposed. It has been shown that in order to completely describe the fields in the junction some nonphysical terms have to be included in the irrotational set. The numerical results were compared with the experimental results.

References

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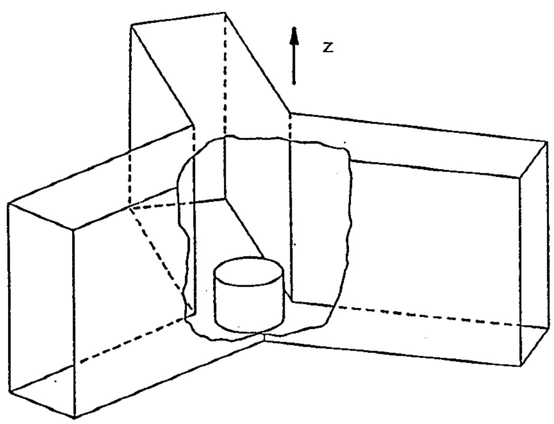
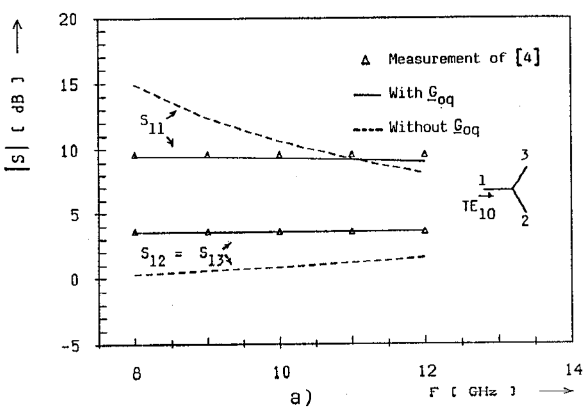
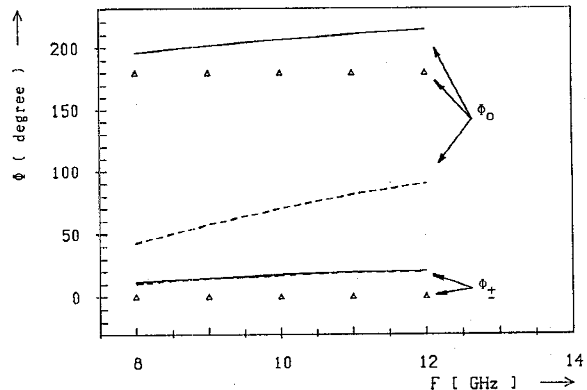


Fig.1 An E-plane waveguide junction with a partial height dielectric or ferrite insert.



a)



b)

Fig. 2 The phases of the eigenvalues and the S-parameters of an empty E-plane waveguide junction.

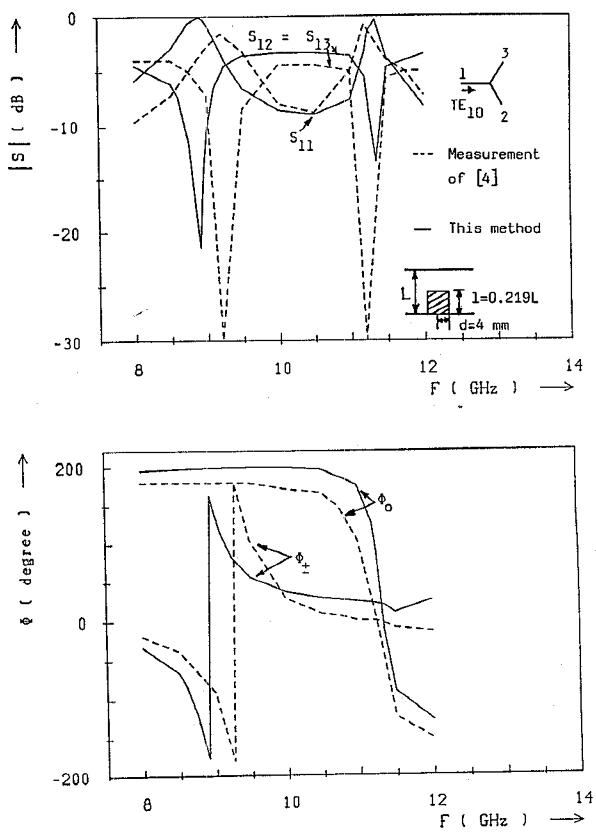


Fig. 3 The phases of the eigenvalues and the S-parameters of an E-plane waveguide junction with a partial height dielectric insert. $\varepsilon_r = 13.5$.

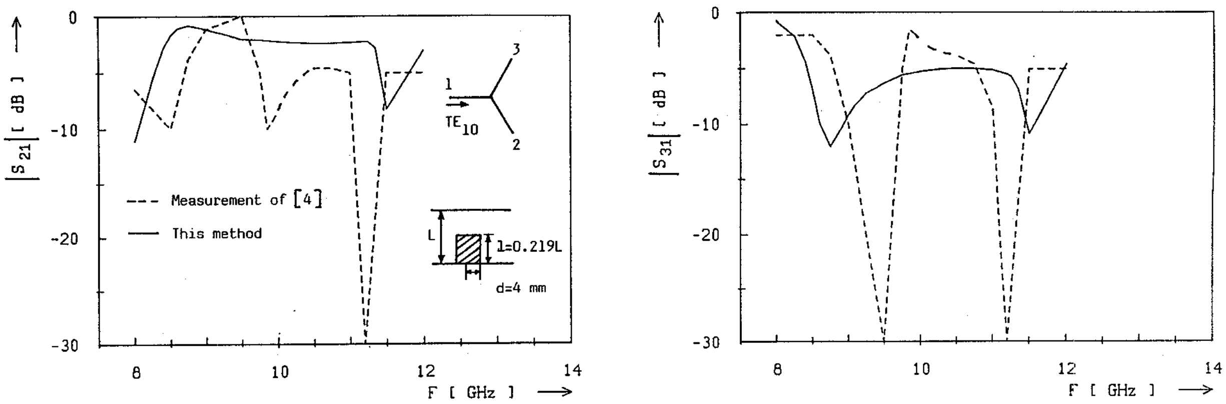


Fig. 4 Performance of an E-plane waveguide junction with a RF2 partial height ferrite. The parameters of the RF2 ferrite: ε_r=13.5, M_s=185 KA/m and g=2.03.

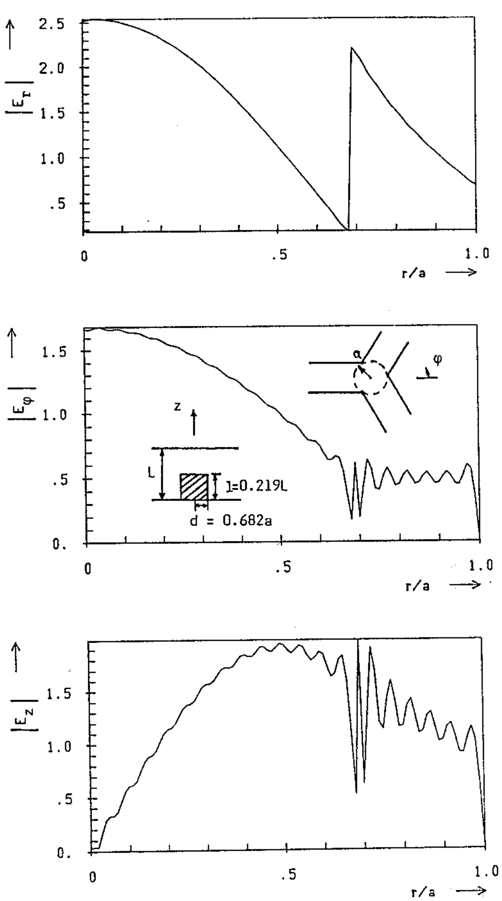


Fig. 5 Electric-field distributions in an E-plane waveguide junction with a partial height RF2 ferrite insert. $z = L/8$ and $\varphi = 60°$.

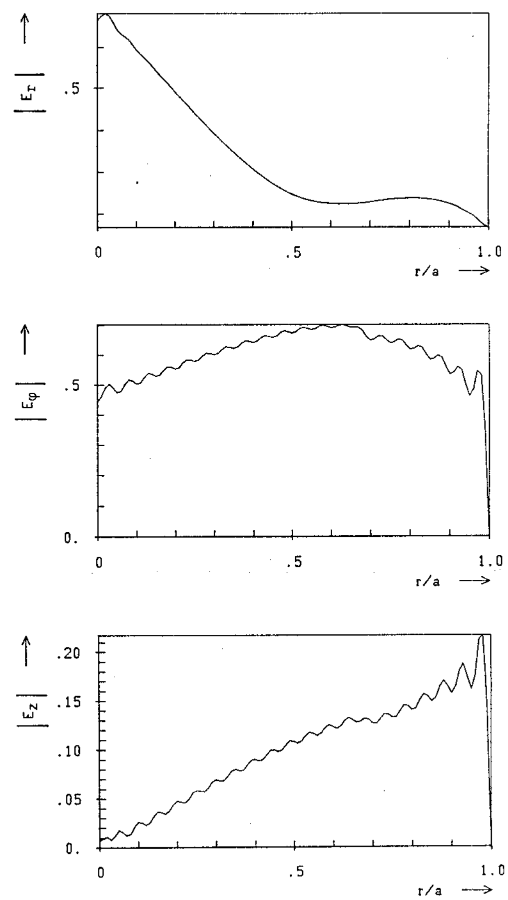


Fig. 6 Electric-field distributions in an E-plane waveguide junction with a partial height RF2 ferrite insert. $z = 3L/4$ and $\varphi = 60°$.