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A SPECTRAL DOMAIN HYBRID FIELD ANALYSIS OF PERIODICALLY INHOMOGENEOUS MICROSTRIP LINES

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SUMMARY

Single and coupled periodically inhomogeneous microstrip lines have been analyzed using a hybrid mode spectral domain field analysis. The field computation method will be explained principally, the convergence of the method and the numerical effort will be critically discussed. Applications of the theoretical results have been applied to the design of microstrip- and waveguide filters, to antennas and to the design of a Podell-coupler with equalized even and odd mode phase velocities and a high directivity. Measurements are compared to the theoretical results.

INTRODUCTION

Examples of periodically inhomogeneous microstrip lines are shown in Fig.1. These lines are interesting for applications in microwave circuits because:

1) the phase velocity of electromagnetic waves on single periodically inhomogeneous microstrip lines is much smaller than the velocity of light in the medium around the line,

2) the transmission of electromagnetic waves along a priodically inhomogeneous line is characterized by pass bands and stop bands and

3) because the phase velocities of the even mode and the odd mode on coupled periodically inhomogeneous microstrip lines can be equalized by careful design of the geometry of the lines.

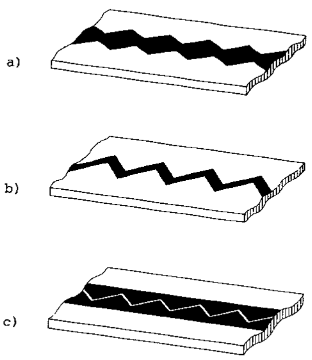

Fig.1: Three examples of periodically inhomogeneous microstrip lines.

Periodically inhomogeneous microstrip lines therefore are used in slow wave structures, as phase shifters, as filter elements and, in the case of the coupled lines e.g. with a zigzag slot structure, as directional couplers (Podell coupler /9/) with high directivity.

THE NUMERICAL METHOD

Several authors have described single inhomogeneous microstrip lines using cascaded pieces of homogeneous microstrip lines of small lengths (e.g. /1,2-6/). Periodically inhomogeneous coupled microstrip lines have only been investigated experimentally (e.g. /7-8/). In this work a numerically exact spectral domain field method is used to analyze single as well as coupled periodically inhomogeneous microstrip lines.

The numerical method used here bases on the work of Jansen /10-12/ for computing the transmission properties of homogeneous microstrip lines; this method, which is numerically very efficient, is changed so that inhomogeneous microstrip lines can be analyzed. Because of the shortness of the availble place in this communication only some fundamental aspects can be given here to describe what has been done; a long description is under preparation /13/.

A covered microstrip line as it is shown in Fig. 2a with e.g. a zigzag metallization structure as it is shown in Fig.2b is considered. For the description of the hybrid modes on this structure two electromagnetic potentials in y-direction are introduced:

$$\phi^i(x,y,z) = \sum_{k=-\infty}^{+\infty} \phi_k^i(x,y)\, e^{j(\frac{2\pi k}{p} z - \beta z)} ,$$

$$\psi^i(x,y,z) = \sum_{k=-\infty}^{+\infty} \psi_k^i(x,y)\, e^{j(\frac{2\pi}{p} z - \beta z)} , \qquad (1)$$

with $i=I,II$, $k_i^2 = \omega^2 \mu_0 \varepsilon_0 \varepsilon_r^i$.

In contrast to the case of the homogeneous microstrip line in the case of the periodically inhomogeneous microstrip lines the potential functions must also be periodical functions in dependence on the coordinate z with the same periodicity p as the line structure has (Floquet´s Theorem, /14/).

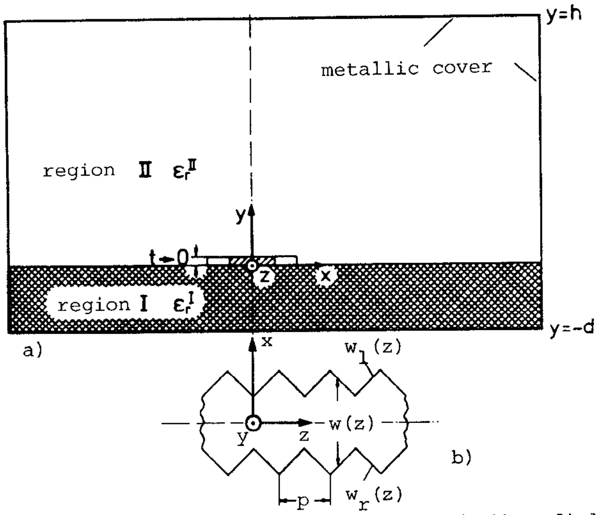

Fig.2: The covered microstrip line and the field regions used in the analysis (a) and a zigzag metallizations structure (b) as an example for a periodically inhomogeneous microstrip line.

The potential functions Φ_k^i and Ψ_k^i can be written in a form so that they fullfill the boundary conditions at the cover of the microstrip line (Fig.2a). Using the potential functions, the electromagnetic fields of both field regions (Fig.2a) can be calculated so that only the amplitude coefficients of the series expansions given in (1) must still be determined.

This is done by fullfilling the boundary conditions of the electromagnetic fields in the boundary between region I and region II (plane y=0, Fig. 2a). An electric current density $\vec{J}$ and a fictive magnetic current density $\vec{M}$ are assumed in the boundary. Then the boundary conditions are:

$$\left(\vec{H}^{I} - \vec{H}^{II} \right)\Big|_{y=0} \times \vec{e}_y = \vec{J} \; ;$$

$$\left(\vec{E}^{II} - \vec{E}^{I} \right)\Big|_{y=0} \times \vec{e}_y = \vec{M} \; . \qquad (2)$$

The electric current density and the magnetic current density are described by spectral domain series expansions and the boundary conditions for the tangential electric field strength in the plane y=0 is introduced. The resulting eigenvalue equation is solved using the moment method (Galerkin's method).

In the case of the periodically inhomogeneous coupled microstrip lines a similar method as shortly described above is used; only the symmetry of the structure which e.g. is assumed in Fig.2b for the metallization structure in x-direction is no longer given in the case of the coupled lines (Fig.3). Therefore the description e.g. of te current density on the metallic strip is much more complicated and must be described by a two dimensional series expansion in this case.

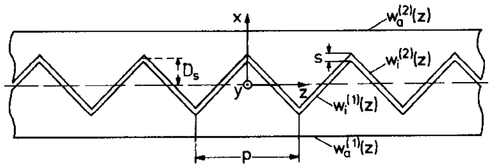

Fig.3: Example of a periodically inhomogeneous coupled microstrip line.

NUMERICAL AND EXPERIMENTAL RESULTS

Intensive investigations have been carried out to prove the convergence behaviour of the applied numerical method e.g. in dependence on the expansion functions for the current density in the metallization. Sinus- and cosinusfunctions with and without an additional edge term for describing the fields at the edges of the metallization as well as spline functions have been used as expansion functions. Fig.4 shows the convergence of the numerical method in dependence on the number of the elements I_v of the series expansions for the current density and for three different expansion functions.

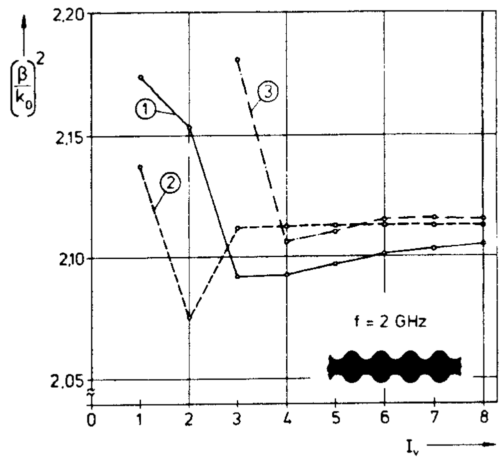

Fig.4: The convergence of the numerical method for three different expansion functions and in dependence on the number of the elements of the series expansions. 1) sin/cos, 2) sin/cos + edge term, 3) spline functions.

For the final computations the sinus- and cosinusfunctions combined with an edge term were used because the calculations showed the best convergence properties with these functions.

The current- and voltage distribution of the fundamental mode, the effective dielectric constant and the characteristic impedance of single microstrip lines with a sinusoidally shaped and zigzag metallization structure have been calculated in dependence on the geometrical parameters of the structure and on the frequency. For periodically inhomogeneous coupled microstrip lines with a sinusoidally shaped coupling slot and a zigzag coupling slot the effective dielectric constant has been computed. Fig.5 as an example shows the comparison between the calculated and the measured effective dielectric constant of two periodically inhomogeneous single microstrip lines with a zigzag shaped metallization structure of the periodicity p=15 mm. The stop bands and the pass bands can clearly be recognized. The agreement beween theory and measurement is very good despite the complicated field theoretical background and the big numerical effort.

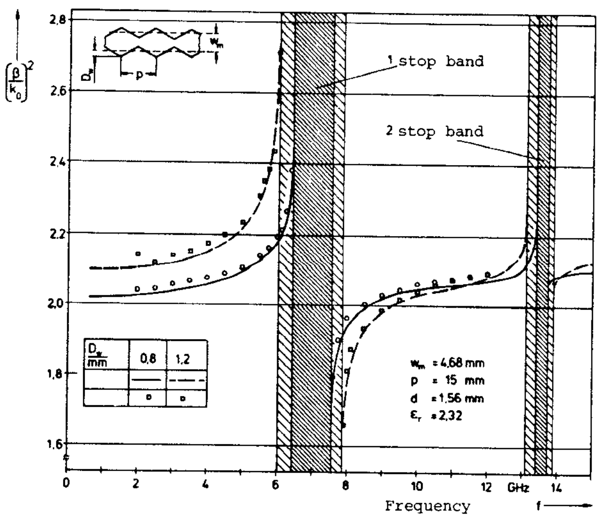

Fig.5: The effective dielectric constant of a microstrip line with a zigzag structure in dependence on the frequency.

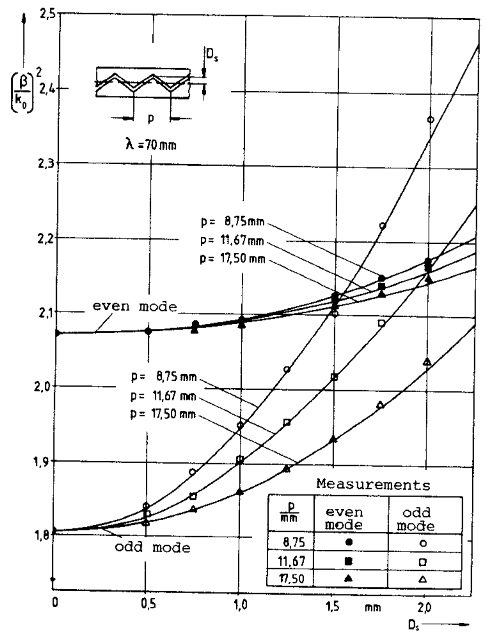

Fig.6: The effective dielectric constants of coupled microstrip lines with a zigzag slot.

In Fig.6 the calculated and measured effective dielectric constants of the fundamental even mode and odd mode on coupled microstrip lines with a zigzag shaped coupling slot in dependence on the height D_s of the zigzag structures are shown for three lines with different geometrical periodicities. The effective dielectric constant of the even mode is only slightly dependent on the parameter D_s whereas the dependence of the odd mode effective dielectric constant on D_s is stronger. As a result the phase velocities of the even and the odd mode can be equalized for a special value D_s which is dependent on the periodicity and the frequency additionally.

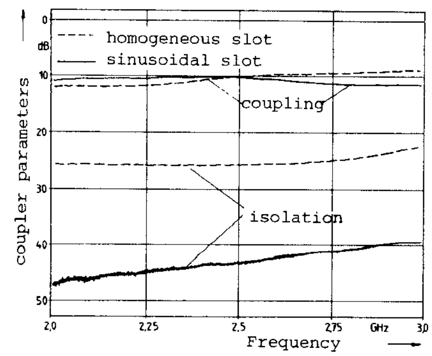

Fig.7: The measured coupling coefficient and the isolation of a Podell coupler designed with the theory described above.

The results of this calculations can be used to design microstrip directional couplers with high directivity as they have been proposed by Podell in 1970. As a design example Fig.7 shows the experimental coupling coefficient and isolation of a Podell coupler with a sinusoidally shaped coupling slot in comparison with the results for a homogeneous coupled microstrip line coupler; the improvement of the directivity is higher than 15 dB over the whole frequency band.

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