SOLUTION OF FIN-LINE DISCONTINUITIES THROUGH THE IDENTIFICATION OF ITS FIRST FOUR HIGHER ORDER MODES

M. HELARD J. CITERNE
Laboratoire "Structures Rayonnantes"
E.R.A. au C.N.R.S. n° 1015
I.N.S.A. - 35043 RENNES Cédex - FRANCE

O. PICON V. FOUAD HANNA
Centre National d'Etudes des Télécommunications(CNET)
Centre PAB - Division ETR
92131 ISSY-LES-MOULINEAUX - FRANCE

Abstract

The dominant and the first four higher order modes in a unilateral fin-line are accurately described from a thorough Spectral Domain Approach. Then, coupling coefficients between eigenmodes at a discontinuity that have to be introduced into the scattering matrix formulation, are directly computed in the Spectral Domain. Finally, fin-line discontinuities often used for impedance transformation are investigated and comparison with measurements in K_a band are given .

Introduction

Recently, fin-line discontinuities often used for impedance transformation [1,2] have been investigated by a direct modal analysis [3] in a manner which could be believed very straightforward for computer aided design of some active circuits [4,5] .In fact, the efficiency of the direct modal analysis for solving waveguide discontinuity problems especially depends upon existing facilities to evaluate the set of eigenmodes.

Till now, there are mainly two kinds of numerical methods that can succeed in eigenmodes evaluation in fin-line structures. The first kind includes methods which are basically derived from a mode matching operation with rectangular waveguide modes [6,7] while the second kind rather gathers spectral analysis in FOURIER domain.

Despite appearances, a complete review of numerous works about fin-line discontinuity problems reveals the lack of both theorétical and experimental results establishing a solid basis for fin-line circuit design.

The aim of this paper is three-fold : 1) to give an accurate evaluation of five eigenmodes of the unilateral fin-line (figure 1) via a thorough Spectral Domain Approach, 2) to perform calculations of the generalized scattering matrix with 10x10 elements in the case of the single step slot width discontinuity (figure 1) by combining the direct modal analysis and the Spectral Domain Approach, 3) to compare between theory and experiments in the K_a band.

1- Evaluation of eigenmodes of a unilateral fin-line

In the conventional Spectral Domain Approach, the field components of the hybrid guided wave are expressed in terms of $\tilde{E}_z(\alpha_n,y)$ and $\tilde{H}_z(\alpha_n,y)$ the n th coefficient of the FOURIER series with respect to x of the axial electric and magnetic field components $E_z(x,y)$ and $H_z(x,y)$. For a unilateral fin-line, the standard computational scheme uses an admittance representation of continuity and discontinuity conditions at the slot interface y = D. The advantage of such a representation lies in the possibility to describe with a good precision rather the aperture field in the slot more than the current distribution on metallic fins.

Therefore, the key point for an efficient eigenmode evaluation in an unilateral fin-line lies in the suitable choice of the set of basis functions into which, the slot aperture field have to be expanded. As shown in [9] the dominant mode can be accurately described by means

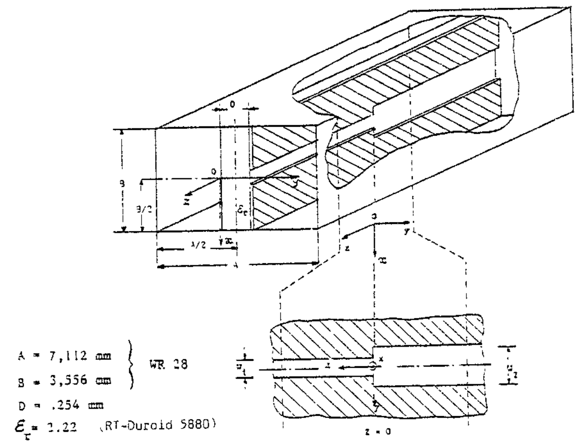


Figure 1: Step slot width discontinuity in a unilateral fin-line with a boxed - in substrate.

of a single $E_x(x,D)$ basis function : the unit rectangular pulse denoted $f_1(x)$ in table I. However, to describe both the dominant and the higher order modes, the aperture field expanded with the basis functions denoted $f_1(x)$, $f_2(x)$, $f_3(x)$ and $f_4(x)$ in table I appears as a more judicious choice. Checks of this aperture field have been made in two limit cases for the unilateral fin-line : the standard rectangular waveguide ($\varepsilon_r \to 1$; $W/B \to 1$) and the rectangular waveguide loaded symmetrically by a dielectric slab ($W/B \to 1$). They allowed to conclude about its completeness at least on five eigenmodes.

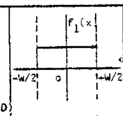
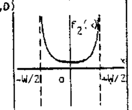
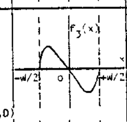
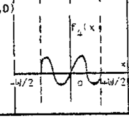
$E_x(x,D)$		$f_1(x)=\begin{cases}1. & ;\lvert x\rvert \le W/2\\ 0 & ;\lvert x\rvert > W/2\end{cases}$	$\tilde{f}_1(m)=\frac{2}{\alpha B}\sin\frac{\alpha_m W}{2}$
		$f_2(x)=\begin{cases}\frac{1.}{(1.-(2x/W)^2)^{1/2}} & ;\lvert x\rvert \le W/2\\ 0 & ;\lvert x\rvert > W/2\end{cases}$	$\tilde{f}_2(m)=\frac{\pi W}{2B}J_0(\frac{\alpha_m W}{2})$
$E_z(x,D)$		$f_3(x)=\begin{cases}2x/W.(1.-(2x/W)^2)^{1/2} & ;\lvert x\rvert \le W/2\\ 0 & ;\lvert x\rvert > W/2\end{cases}$	$\tilde{f}_3(m)=-\frac{j\pi}{\alpha B}J_2(\frac{\alpha_m W}{2})$
		$f_4(x)=\begin{cases}\frac{\sin(4\pi x/W)}{(1-(2x/W)^2)^{1/2}} & ;\lvert x\rvert \le W/2\\ 0 & ;\lvert x\rvert > W/2\end{cases}$	$\tilde{f}_4(m)=-\frac{j\pi W}{4B}\left[J_0(2\pi-\frac{\alpha_m W}{2}) - J_0(2\pi+\frac{\alpha_m W}{2})\right]$

Table I: Basis functions and associated m th FOURIER coefficient. ($\alpha_m = 2m\frac{\pi}{B}$)

Dispersion characteristics of the five first eigenmodes of a unilateral fin-line in K_a band are plotted in figure 2. They show that its frequency band for a single mode operation is quite identical to those of the standard WR 28 rectangular waveguide.

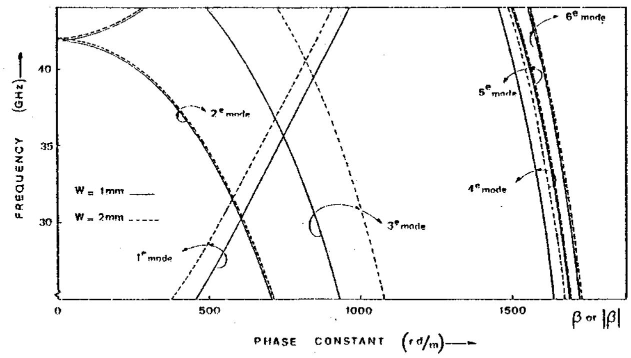


Figure 2: Dispersion characteristics of eigenmodes in a unilateral fin-line

Another check of the aperture field is to compute the eigenmode distribution to be sure of the boundary conditions as shown in figure 3 for the E_x component of the second evanescent mode.

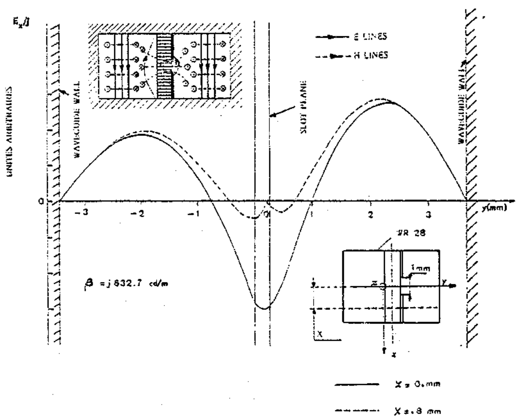


Figure 3: E_x field component of the second evanescent mode. F= 40 GHz.

II -Single step slot width discontinuity in a unilateral fin-line

The scattering matrix formulation of an axial waveguide discontinuity derived from a direct modal analysis is concisely described in [3]. It assembles two reflection and two transmission blocks denoted $\bar{\bar{S}}_{11}$, $\bar{\bar{S}}_{22}$ and $\bar{\bar{S}}_{12}$, $\bar{\bar{S}}_{21}$ respectively. These matrix blocks have MXN elements according to the numbers M and B of eigenmodes that are used in field expansion in waveguides at each side of the discontinuity plane z = 0 (see figure 1). During the derivation of matrix elements both coupling coefficient between eigenmodes at the discontinuity plane and power flow incident on it, have to be computed. By transforming them to the FOURIER domain and using the PARSEVAL's theorem, the computation is made easier with the eigenmode spectral field components.

Figure 4 gives both the insertion and the return losses of a single slot width disontinuity in K_a band. Presently, the number of eigenmodes employed in each waveguide is the same i.e. M = N. Systematics tests of convergence reported in figures 4 and 5 show that instabilities of the results versus the number of eigenmodes concern the phases rather than the moduli.

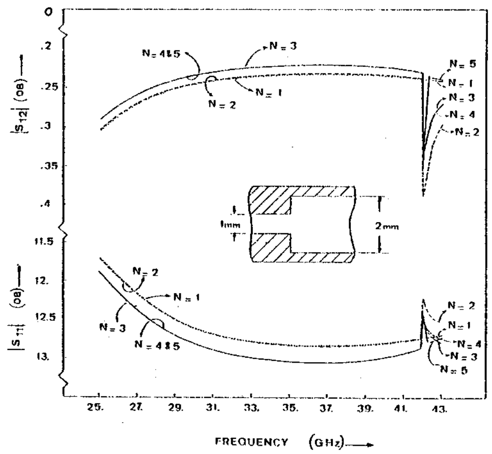


Figure 4: Moduli of reflection and transmission coefficients of a step slot width discontinuity in a unilateral fin-line

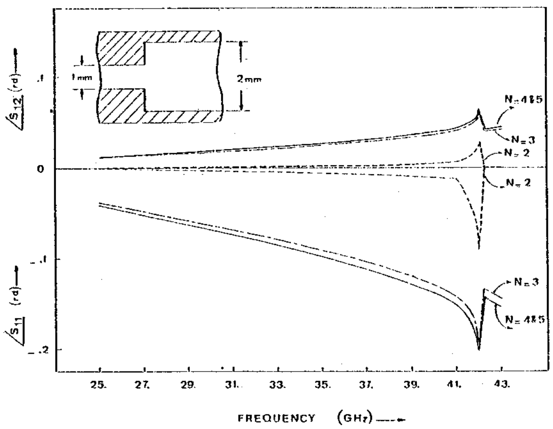


Figure 5: Phases of reflection and transmission coefficients of a step slot width discontinuity in a unilateral fin-line.

Because of the choice of the mode ration M/N has not been found of crucial importance, it can be conjectured that the relative convergence phenomena is not a redhibitory problem. Numerous tests of convergence within the heuristic criterion $M/N = W_1/W_2$ have given quite similar results to those reported in figures 4 and 5.

III-Comparison between theory and experiment in K_a band

In order to evaluate objectively effectiveness of the direct modal analysis for computer aided design of fin-line circuits, the device shown in figure 6 has been fabricated and its characteristics calculated and at last measured. The aim was to determine the insertion and return losses of a pair of interacting "back to back" steps in slot width (a notch with the terminology in [4]) through "back to back" waveguide to unilateral fin-line transitions. The main difficulty was of course to match the transitions i.e. to prevent unwanted reflections from both the waveguide to fin-line junction and the fin-line taper.

These imperfections in the transition has been taken in consideration in the calculations through the computation of their scattering matrix.

Results depicted in figure 7 reveals that the transition waveguide to fin-line indeed reflects amounts of the incident power and emphasizes the imperfections inherent in the reflectometer. Nethertheless, at frequencies for which the transitions are matched (return loss greater than +25 DB in figure 7) the effect of the extraneous sources of error in the reflectometer is minimized and then the theory and experiments are found consistent.

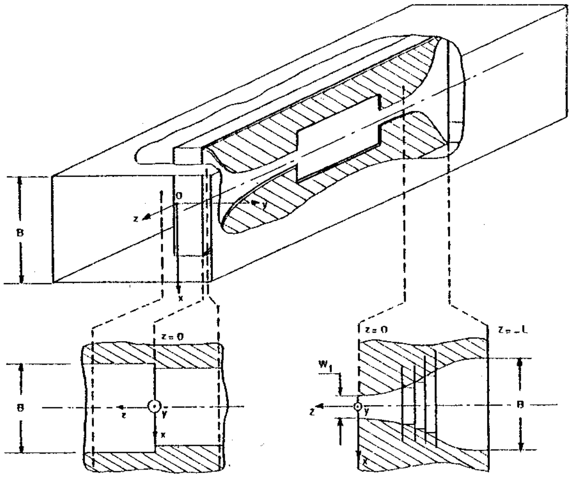


Figure 6: Transition waveguide to unilateral fin-line notch.

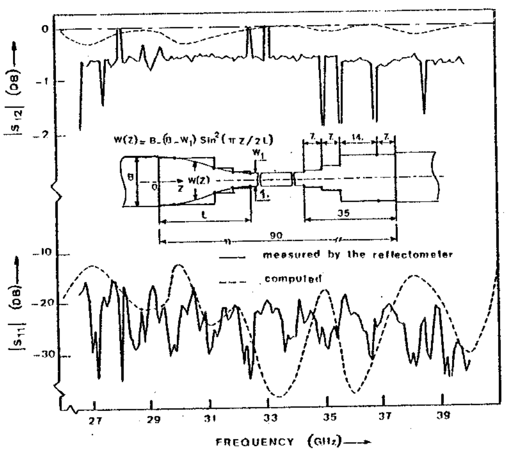


Figure 7: Reflection and transmission of the transition waveguide to unilateral fin-line.

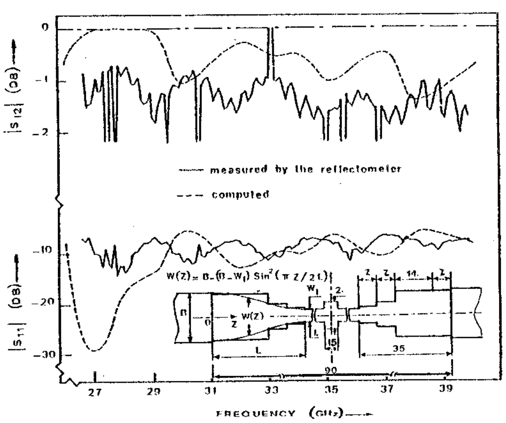


Figure 8: Reflection and transmission of a notch (lenght:1.5 mm)

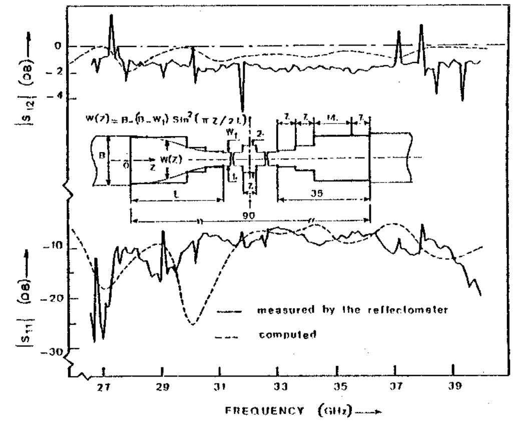


Figure 9: Reflection and transmission of a notch (lenght:7.mm)

Conclusions

The spectral Domain Approach combined with the direct modal analysis appears as a very promissing technique for calculation of scattering matrix elements of fin-line discontinuities.

Convergence is necessary both in the waveguide eigenmode evaluation and in the waveguide discontinuity problem. In the case of a unilateral configuration, results show that a relatively simple slot aperture field allowed an unambiguous identification of five eigenmodes. Moreover, they show that within such an identification the relative convergence phenomena on scattering parameters can be ignored.

Practical waveguide to fin-line transitions must be improve for bringing more decisive conclusionsabout the comparison between the theory and the experiments.

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