EFFECT OF COMPLEX MODES ON FINLINE DISCONTINUITIES

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ABSTRACT

The effect of ignoring complex modes on the solution of finline discontinuity problems is investigated. It is shown that the modal energy distribution at both sides of the discontinuity may be greatly affected by overlooking complex modes, even if they are not strongly excited. Comparison to measured data is also given to justify the validity of the numerical results.

1. INTRODUCTION

The analysis of discontinuities between planar guiding structures, in particular in microstrip and finlines, has accepted increasing interest (e.g. /1/ - /6/). Proper modelling of such discontinuities is fundamental for any successful printed circuit design. In the following, only finline discontinuity problems will be discussed. Extending the discussion to other printed planar structures is, however, straightforward.

Two rigorous approaches have been reported for the analysis of finline discontinuity problems. The first depends on the transverse resonance concept (e.g. /1/ - /3/). Determination of finline high-order modes is not needed for this approach. The problem is completely formulated in terms of homogeneously filled rectangular (or parallel plate) waveguide modes in conjunction with a proper modelling of the tangential field in the metallization plane. The main disadvantages of this approach are:

1.) The effect of the discontinuity on the dominant mode only is available. No information concerning high-order modes can be obtained.

2.) A complex discontinuity which is composed of a number of cascaded simple discontinuities (e.g. steps) has to be analyzed "as a whole". The properties of the individual simple discontinuities cannot, in general, be used to construct an accurate solution for the complex discontinuity due to the lack of information about high-order modes.

3.) Complex discontinuities need a large number of basis functions to properly model the tangential field in the fins' plane. This may lead to dealing with oversized matrices which needs excessive computation time.

The second approach depends on the modal expansion concept (e.g. /4/ - /6/). The generalized scattering or transmission matrix, which contains all information about the dominant as well as the higher order modes is obtained for simple discontinuities (e.g. steps). Complex discontinuities can be analyzed by processing the generalized scattering or transmission matrices characterizing the individual simple steps. The main problem in this approach is the accurate determination of an approximately complete set of finline modes.

As has already been shown /7/, the Singular Integral Equation (SIE) technique is very efficient for determining such a set. It has also been shown that complex modes can be supported by finlines /8/, so that ignoring these modes in constructing an approximately complete set of finline modes may lead to erroneous solutions.

This paper is addressed to study the effect of overlooking complex modes on the solution of finline discontinuity problems.

2. EFFECT OF IGNORING A MODE AT ONE SIDE OF THE DISCONTINUITY

The problem will be discussed for the discontinuity shown in Fig. (1). Waveguides "1" and "2" are assumed to be quite general, except for the restriction that both have discrete modal spectrum, which simplifies the discussion to some extent. Matching N modes of guide "1" to M modes of guide "2" at the discontinuity plane z = 0 can be viewed as "a similarity balance process". The mode coupling coefficient defined in /5/ for the boundary reduction case

$$A_{nm} = \int_{S_2} (\mathbf{e}_m^{(2)} \times \mathbf{h}_n^{(1)*}) \cdot \mathbf{ds} \tag{1}$$

represents a measure of the degree of similarity between the n'th mode in guide "1" and the m'th mode in guide "2" (which has the smaller cross section in the boundary reduction case). Two different modes in either guide "1" or guide "2" are then completely "dissimilar" due to the orthogonality relations /5/

$$\int_{S_1} (\mathbf{e}_n^{(1)} \times \mathbf{h}_m^{(1)*}) \cdot \mathbf{ds} = P_n \delta_{nm},$$
$$\int_{S_2} (\mathbf{e}_n^{(2)} \times \mathbf{h}_m^{(2)*}) \cdot \mathbf{ds} = Q_m \delta_{mn}. \tag{2}$$

δ_{nm} means the Kronecker symbol.

The n'th mode excited in guide "1" (which will be called mode (a)) is balanced by exciting a "similar" field in guide "2". This similar field is, in general, composed of a superposition of all the M modes in guide "2", the magnitude of each depends on its degree of similarity to mode (a). In particular, the magnitude of a mode with a high degree of similarity will dominate the magnitudes of the other, less similar, modes. This similarity balance process is applied to each of the N modes in guide "1".

Let us assume now that the m'th mode in guide "2" (which will be called mode (b)) has the largest degree of similarity to mode (a). Omitting mode (b) from the M modes of guide "2" can only be compensated by increasing the magnitudes of modes being less similar to mode (a), in order to get back the similarity balance. This will disturb the modal distributions (and hence the stored energy) at both sides of the discontinuity. It is important to note that this disturbance does not necessarily depend on how strongly mode (a) is excited. Balancing a weakly excited mode in guide "1" may require strongly excited modes in guide "2" which have a very weak degree of similarity to that mode.

Omitting, however, both mode (a) and mode (b) will have a much smaller effect on the modal distributions, in particular, if both are just weakly excited.

3. EFFECT OF IGNORING COMPLEX MODES ON FINLINE DISCONTINUITIES

As has already been shown /7/, finline modes change their nature as any of the finline parameters changes. A pair of an inductive and a capacitive evanescent modes may become a complex pair, and vice versa, as the slot width (e.g.) changes. If we would analyze a discontinuity using only usual (non-complex) modes it can happen that a pair (or more) of modes on one side of the discontinuity is non-complex, while the corresponding pair on the other side, which has the largest degree of similarity, is a complex one. Both, the modal distributions and the stored energy on both sides of the discontinuity would then be greatly affected, even if the former pair is not strongly excited. The situation is much better if both pairs were complex, so that both would be ignored in the matching process.

4. NUMERICAL RESULTS

In order to check the accuracy of the numerical results, which takes complex modes into account, comparison to measured data in Kaband is demonstrated in Fig. 2, which shows the frequency response of the resistive (Fig. 2a) and reactive (Fig. 2b) parts of the normalized input impedance of the waveguide-finline junction shown in Fig. 3.

Table I shows the stored energy distributions at both sides of the finline discontinuity shown in Fig. 4, computed with and without taking complex modes into consideration. Due to the large slot width ratio (s_1/s_2 = 35), convergence had to be achieved by using 20 modes at both sides of the discontinuity. The incident field is the dominant mode at side "1" carrying unit power. The dominant mode at side "2" shows a standing wave pattern within the distance l between the discontinuity and the open circuit. It stores capacitive energy because l is slightly larger than half a guide wavelength for this mode (l = 5.0 mm, λ_{g2} = 8.945 mm). If complex modes are omitted the stored energy is calculated with an error of 19.34 %. The total energy, on the other hand, which is stored in both the dominant mode and all higher order modes turns out to amount to -0.4059 taking complex modes into account while it is +0.1272 if these modes are omitted. The corresponding normalized input impedance at the discontinuity plane is -j0.1039 with and +j0.0001 without complex modes. The error is larger than 100 %, because the effect of overlooking complex modes has changed the capacitive nature of the structure between the discontinuity and the open circuit into an inductive one.

It should be pointed out that this severe error is due to overlooking only one pair of complex modes (namely the 8'th and 9'th modes at side "2"), which are only weakly excited. The error would be much more disastrous if many complex mode pairs would exist on one or both sides of the discontinuity.

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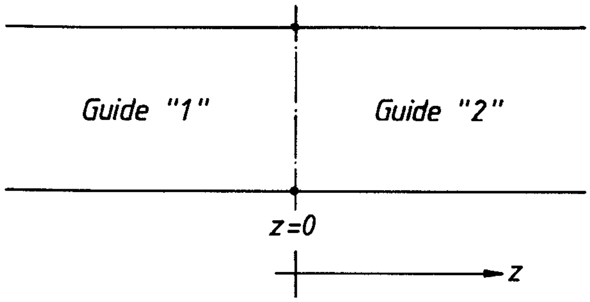

Fig. 1: *A discontinuity between two general waveguides*

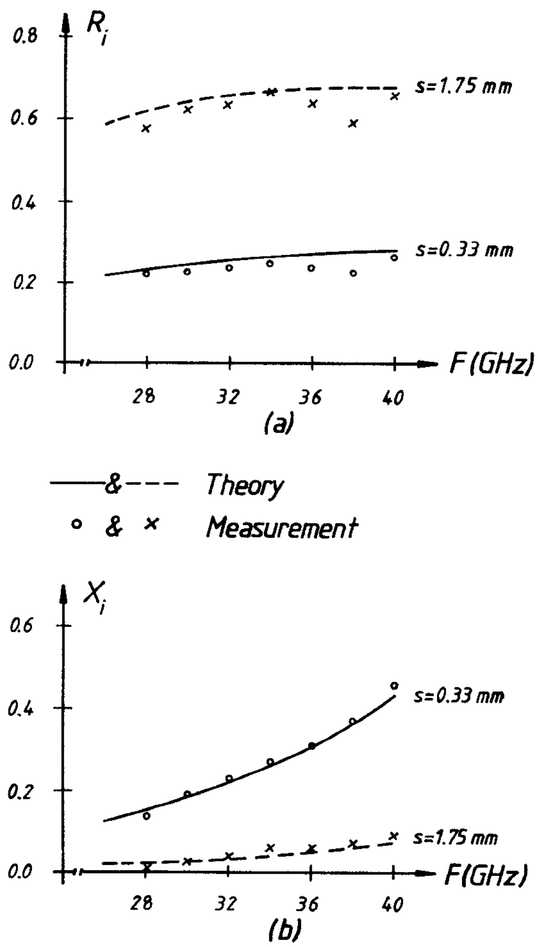

Fig. 2: *Frequency response of the normalized input impedance of the waveguide-finline junction shown in Fig. 3*
a) normalized input resistance
b) normalized input reactance

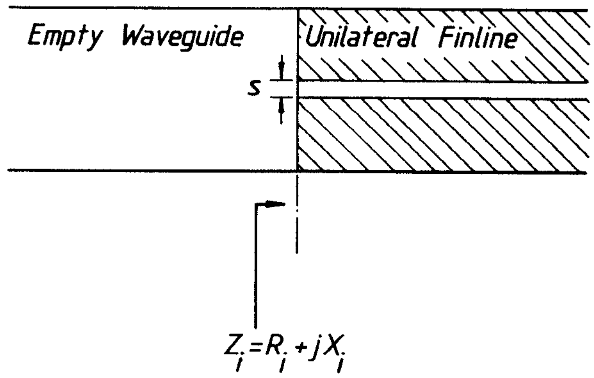

Fig. 3: *A waveguide-finline discontinuity*
Parameters: WR-28 housing, substrate thickness = 0.254 mm, substrate dielectric constant = 2.22.

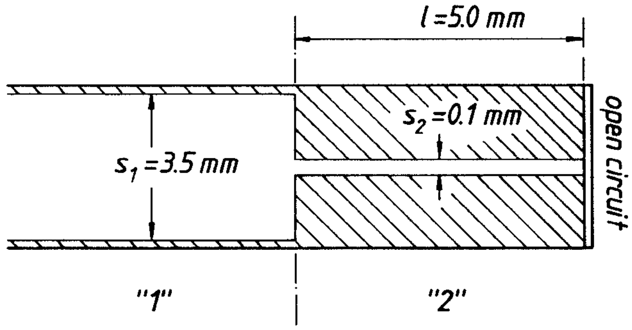

Fig. 4: *A unilateral finline discontinuity*
Parameters: as in Fig. 3

mode order	1	2	3	4	5	6	7	8	9	10
ß 1/(mm)	0.4853	-j0.6209	-j1.1519	-j1.6490	-j1.6513	-j1.7001	-j1.7043	-j1.8729	-j1.8770	-j2.0855
energy with C.M.	+0.2554	+0.0046	+0.1409	+0.0001	+0.0043	-0.1749	+0.0976	+0.0009	-0.0009	-0.0632
energy without	-0.0003	+0.0044	+0.1204	+0.0001	+0.0033	-0.2510	+0.1377	+0.0009	-0.0008	-0.0911

mode order	11	12	13	14	15	16	17	18	19	20
ß 1/(mm)	-j2.1089	-j2.1094	-j2.4184	-j2.4409	-j2.5746	-j2.6949	-j2.7514	-j3.0220	-j3.1225	-j3.1641
energy with C.M.	+0.0610	+0.0192	+0.0005	-0.0007	+0.0065	-0.0279	+0.0081	+0.0724	+0.0030	-0.0012
energy without	+0.0000	+0.0000	+0.0006	-0.0011	+0.0037	-0.0458	+0.0061	+0.0264	+0.0005	-0.0392

Table I-a

mode order	1	2	3	4	5	6	7	8	9	10
ß 1/(mm)	0.7024	-j0.6037	-j0.7271	-j1.5945	-j1.6488	-j1.6772	-j1.7427	0.0073 -j1.8699	-0.0073 -j1.8699	-j1.8886
energy with C.M.	-0.8219	+0.0630	+0.2718	+0.0381	+0.0000	+0.0054	+0.0375	-0.0008	-0.0008	-0.0016
energy without	-0.6629	+0.0879	+0.3971	+0.1023	+0.0000	+0.0198	+0.1278	-------	-------	-0.0000

mode order	11	12	13	14	15	16	17	18	19	20
ß 1/(mm)	-j1.9680	-j2.3999	-j2.4095	-j2.4667	-j2.4745	-j2.5318	-j2.6976	-j3.0679	-j3.1139	-j3.2065
energy with C.M.	+0.0006	+0.0164	-0.0174	-0.0035	+0.0181	+0.0002	+0.0175	+0.0035	-0.0167	-0.0153
energy without	+0.0221	+0.0058	-0.0132	-0.0053	+0.0022	+0.0002	+0.0089	+0.0032	-0.0058	-0.0027

Table I-b

Table I: *Modal energy distribution of the discontinuity shown in fig. 4 with and without taking complex modes into account. Operating frequency = 30 GHz*
a) at side "1"
b) at side "2"