FULLWAVE ANALYSIS OF COUPLED-FINLINE DISCONTINUITIES

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ABSTRACT

The coupling between transmission line sections or resonators is used in a number of components, such as filters, couplers, etc. The general discontinuity problem of coupled-finline sections is considered. Depending on the arrangement, coupling may occur both at the ends or at the sides of the finlines. A particular case is the inductive strip discontinuity. The analysis is carried out expanding the fields in terms of hybrid modes in the transverse direction, according to the generalized transverse resonance method. Computed results are in good agreement with available data.

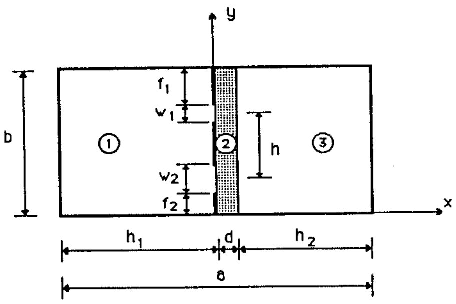

Fig. 1a. Cross sectional geometry of the unilateral finline structure

1. INTRODUCTION

Finline discontinuities are still the objective of several investigations since not many data are available to the circuit designer. Accurate characterizations are of fundamental importance to establish a reliable basis for the design of finline circuits.

An important class of discontinuity problems is that of coupled-finline sections. Coupled finline structures are used in a number of components, such as bandpass and bandstop filters, couplers, etc. Both end-coupling and parallel-coupling may be realized. Such configurations are special cases of the general coupled-finline discontinuity problem depicted in Fig.1. Two finline sections shorted at one end are coupled along the length 's'. For analysis purposes, as discussed later on, the structure is enclosed by two conducting planes. Depending on the choice of the geometrical parameters, Fig. 1 can represent a number of different configurations. The uniform coupled line structure, for instance, is recovered by letting $l_1 = l_2 = s$.

The coupled length 's' can be positive or negative. Negative values correspond to the two finline ends being shifted apart, so that coupling occurs essentially by the finline terminal edges. In such a case the absolute value of s is the finline separation. The inductive strip is a special case of Fig. 1 when s is negative and the line offset is zero (h=0). This configuration has been studied by Koster and Jansen [1] and by Knorr and Deal [2] using the spectral domain method (SDM).

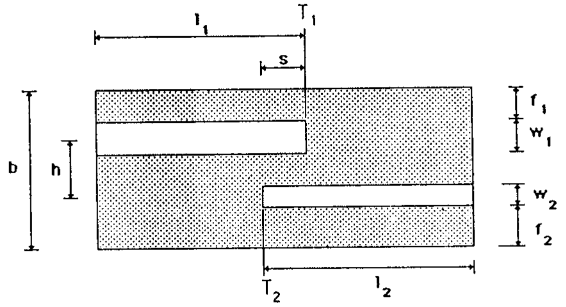

Fig. 1b. Longitudinal section of the coupled-finline discontinuity

The coupled-finline discontinuity of Fig. 1 is analyzed in this paper using the generalized transverse resonance technique introduced in [3]. This method is briefly recalled in the next section. Results have been computed for both end-coupled and parallel-coupled finlines and are presented in section 3. The case of uniform coupled lines is also considered as a special case. Good agreement has been found with the data available in [1] and [2] relative to the inductive strip.

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2. METHOD OF ANALYSIS

The method is based on the computation of the resonant conditions of a finline cavity containing the discontinuity. The resonator is formed by placing electric (or magnetic) walls some distance apart from the discontinuity. It is assumed that only the dominant mode can propagate in each finline section and that higher order modes excited at the discontinuity have negligible amplitudes at the shorting planes. This condition can be met by shifting the terminal planes half a wavelength apart, or by using magnetic walls a quarter of wavelength apart. Losses are assumed to be negligible.

The discontinuity can then be modeled as a (reactive) two-port network. The equivalent circuit representation of the resonant cavity is that of Fig. 2. In terms of the impedance matrix of the discontinuity, the resonance condition is

$$(Z_{11}+Z_1)(Z_{22}+Z_2)-Z_{12}^2 = 0 \qquad (1)$$

where Z_{ik} (i, k = 1,2) are the normalized impedance parameters of the discontinuity, and

$$Z_i = j\tan(\beta_i l_i) \qquad i=1,2 \qquad (2)$$

is the normalized impedance seen from the i-th port. β_i is the propagation constant of the i-th finline. Normalization is made with respect to the characteristic impedances of the two finlines.

At any given frequency, the three unknown parameters of the discontinuity can be computed through (1) and (2) provided three different pairs of resonant lengths l_1, l_2 are known. These are obtained by a transverse resonance analysis of the finline cavity, as described later on.

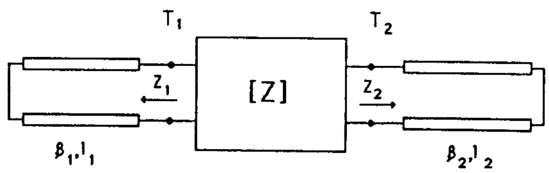

Fig. 2. Equivalent circuit of the finline cavity of Fig. 1b.

This method is equivalent to the tangent method [4] to measure the equivalent circuit parameters of a discontinuity. It is observed that no characteristic impedance definition is needed since only normalized impedances enter the resonant condition (1). With this method the computed impedances of the equivalent two-port are automatically normalized with respect to the characteristic impedances of the two finlines.

Simplification of the problem is obtained when the structure is symmetrical (e.g., $w_1 = w_2$, $f_1 = f_2$, Fig. 1). Let the terminal planes be placed symmetrically ($l_1 = l_2$) so that also $Z_1 = Z_2$. Two types of resonance occur depending on whether the voltages at the ports are equal or opposite. The even (e) and odd (o) resonance conditions are

$$Z_e + Z_{11} - Z_{12} = 0$$

$$Z_o + Z_{11} + Z_{12} = 0 \qquad (3)$$

where

$$Z_{e,o} = j\tan(\beta l_{e,o}) \qquad (4)$$

and l_e and l_o are the resonant lenghts of the two finlines in the case of even and odd resonance, respectively. From (3) one obtains the impedance parameters of the discontinuity

$$Z_{11} = -(Z_e + Z_o)/2\ ; \qquad Z_{12} = -(Z_e - Z_o)/2 \qquad (5)$$

In terms of the series and shunt reactances $X_s = \mathrm{Im}[Z_{11}-Z_{12}]$ and $X_c = \mathrm{Im}[Z_{12}]$ of the equivalent T-network (Fig.3):

$$X_s = -\tan(\beta l_o)$$
$$X_c = -[\tan(\beta l_e) - \tan(\beta l_o)] \qquad (6)$$

Note that both in Fig. 2 and 3, the equivalent network of the discontinuity is referred to the reference planes $T_1 T_2$ located at the finline ends (see Fig. 1). Such a choice leads to impedance parameters having a gentle variation with the coupling length s. Another possible choice would be that of interchanging the reference planes T_1 with T_2. This, however, leads to impedance parameters with polar singularities. This is because the latter choice incorporate the distributed character of the coupled-line region into the equivalent T-network. With the present choice of the reference planes the two finlines of lengths l_1 and l_2, coupled along the distance s, are represented by two lines of the same legnths l_1 and l_2, connected through a two-port network.

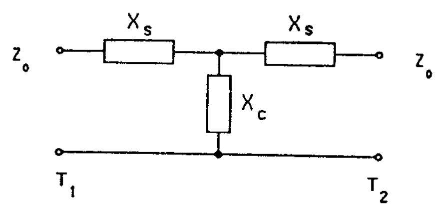

Fig. 3. Equivalent T-network of the symmetrical coupled-line discontinuity

To determine the resonant lengths of the cavity, the EM field is expanded in terms of TE-to-x and TM-to-x modes in the dielectric and air regions (regions 1, 2 and 3 of Fig. 1b). In fact, looking in the transverse x-direction the structure is seen as a discontinuity problem in a rectangular waveguide of inner dimensions $l = l_1 + l_2 - s$ and b. On the plane of the fins, the electric field is zero everywhere except on the two slots, where it is expanded in terms of sets of orthogonal vector functions

$$E_i = \sum_n V_n^{(i)} e_n^{(i)} \qquad i=1,2 \qquad (7)$$

The **e**'s are chosen as the TE and TM eigenvectors of a waveguide with same cross section as the slot pattern.

The boundary conditions on such a plane lead to a homogeneous system of equations in the field expansion coefficients in the various regions. By proper manipulation, the unknowns are reduced to only the expansion coefficients $V_n^{(i)}$ of the E-field (7) in the slot regions. This greatly increase the numerical efficiency of the method with respect to both computing time and memory storage. In fact, only a few expansion terms are normally sufficient to represent the field on the slots, while a much higher number, typically b/w times higher, is required in the waveguide region to properly account for the edge condition [8].

The condition for nontrivial solutions of the resulting homogeneous system constitutes the characteristic equation of the structure. This is a function of the frequency and line lengths l_1, l_2. For any given frequency the characteristic equation is solved for three pairs of resonant lengths to compute through (1) the three unknown parameters of the discontinuity. For symmetrical structures, two pairs of (equal) lengths are computed which correspond to the even (l_e) and odd (l_o) resonances. (Note that *even* and *odd* have different meanings when referred to the resonant lengths l_1,l_2 or to the modes of the coupled finlines.)

As a particular case when $l_1 = l_2 =$ s, the method is used to compute the propagation characteristics of uniform coupled finlines. When no discontinuity is present the resonant condition is simply that the cavity length is a multiple of half a wavelength. The propagation constants at a given frequency are therefore evaluated from the resonant lenghts of the cavity. Assuming the lowest order (m=1) resonance, the propagation constant is simply $\beta = \pi/s$.

Once the characteristic equation has been solved, the electromagnetic field distribution and all other related quantitied, such as the characteristic impedance, can be computed.

3. RESULTS

The method has been tested by comparison with the results in [1] and [2]. The impedance parameters of the equivalent T-network of a symmetrical inductive strip in unilateral finline are shown in Fig. 4 versus the longitudinal separation |s|. Both finlines are centered in the waveguide (f_1= b-f_2, h=0). This figure has been taken from [1]. The computations of Saad and Schuenemann [5] are also reported. It is seen that as the finline separation exceeds ≈ 4 mm, the shunt reactance becomes negligible and the two finlines become practically uncoupleo. The limit value of the series reactance X_s corresponds to the equivalent reactance of the end effect. Our computations are in good agreement with those of Koster and Jansen, though some shift towards Saad and Schuenemann's results is observed. Similar agreement with the results of [2] has been verified.

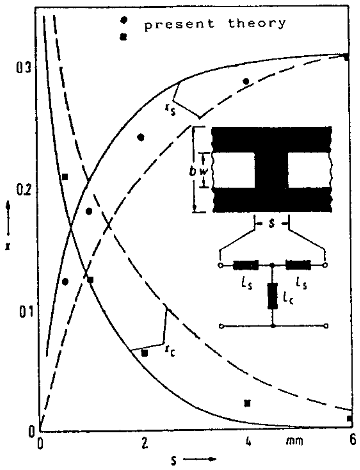

Fig. 4. Normalized reactances of the equivalent T-network of a symmetrical inductive strip. WR28 waveguide; slot widths $w_1=w_2$=0.5 mm. Slot separation s=0.5 mm. Substrate thickness d=0.254 mm, ε_r=2.22, f= 34 GHz.

—— Koster and Jansen [1]; – – – Saad and Schuenemann [2]

A symmetrical parallel-coupled finline discontinuity is considered next. We place the cavity walls symmetrically with respect to the discontinuity ($l_1=l_2$, Fig. 1) so that even and odd resonances can be considered. Fig. 5 shows the computed even and odd resonant lengths l_e and l_o respectively as functions of the separation/coupling length s. The waveguide housing is a WR28, the transverse separation of the finlines is h= 1 mm. Computations have been made at three different frequencies, namely f= 30, 34, 38 GHz. For large negative values of s the two finlines become decoupled. The even and odd resonant lengths tend to the same limit value. As the finline sections are approached, l_e and l_o shift apart with an alternating behavior. For particular coupling lengths, which depend on the frequency, l_e and l_o become coincident again.

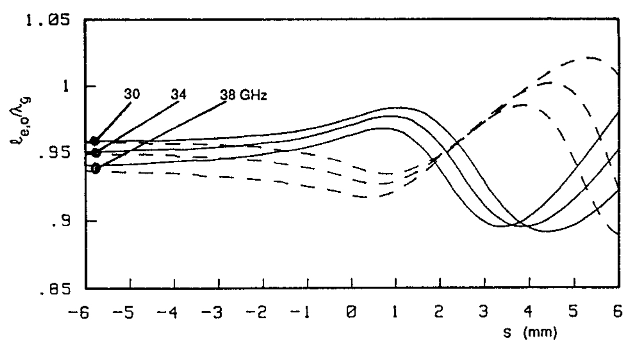

Fig. 5. Normalized resonant lenghts of a symmetrical coupled finline discontinuity as a function of the separation/coupling length s. WR28 waveguide; slot widths $w_1=w_2$= 0.5 mm, slot distance h= 1 mm, substrate thickness d=0.254 mm, ε_r=2.22, f=30, 34, 38 GHz. (—— even, – – – odd resonances).

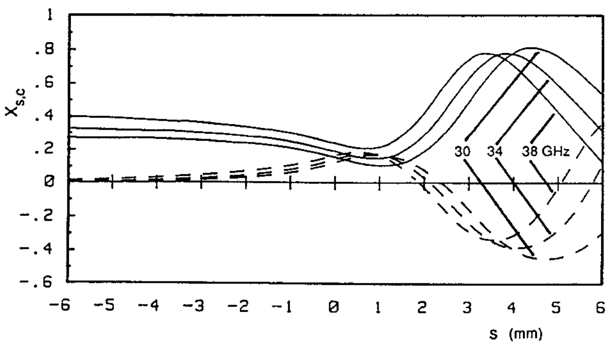

Fig. 6 Reactances of the equivalent T-network, corresponding to the resonant lengths of Fig. 5.
(—— X_s , - - - X_c).

The data of Fig. 5 can be used to evaluate the impedance parameters of the discontinuity. The behavior of the impedance parameters with the coupling length s is strictly dependent on the choice of the reference planes. If the reference plane for each line section is chosen to be coincident with the line end, the reactances of the equivalent T-network are those of Fig. 6 This choice of the reference planes appears to be particularly convenient since the equivalent reactances show a regular behavior with s. For large negative values of s the shunt reactance X_C is zero, whilst X_S tends to the limit value of the end effect for the isolated finline. The end effect is more pronounced the higher the frequency, owing to the stronger excitation of higher order modes. The intersections of the l_e and l_o curves of Fig.4 correspond to the zeros of X_C. In such conditions the two ports of the equivalent network are uncoupled.

Finally, Fig. 7a,b shows the frequency behavior of the even and odd resonant lengths along with the corresponding T-network reactance parameters. These data are relative to a parallel-coupled finline with s = 3 mm.

4. CONCLUSIONS

A general approach to the characterization of both uniform and discontinuous coupled-finline structures has been presented. The analysis method is the generalized transverse resonance technique of [3]. Computed results are in good agreement with data available in the literature.

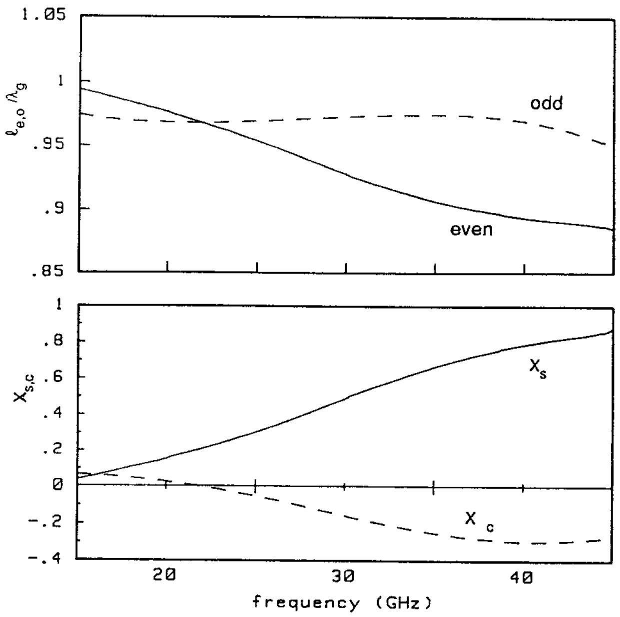

Fig. 7 Normalized resonant lengths and equivalent reactances as functions of frequency. Same structure of Fig. 6 except with s= 3 mm.

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