ANALYSIS METHOD FOR GENERALIZED SUSPENDED STRIP LINES

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SUMMARY

This paper describes an effective analysis method suited to planar transmission lines having multiple conductor sheets, multiple substrates, and multiple grooves or pedestals. A coupled strip line structure is analyzed based on this method. Some experimental results are shown.

INTRODUCTION

Suspended strip lines (SSL's) have recently been used in many areas such as planar filter structures (1) and millimeter wave devices (2) by taking advantage of their easiness in fabrication and low-lossness. SSL's also have a possibility to be used to compose part of monolithic microwave integrated circuits.

This paper firstly introduces the concept of generalized suspended strip lines and an original analysis method suited to characterize these lines. Then, a coupled strip line having a conductor aperture between two strips is analyzed based on this method. The results of analysis are compared with experimental data in the form of capacitance matrix elements.

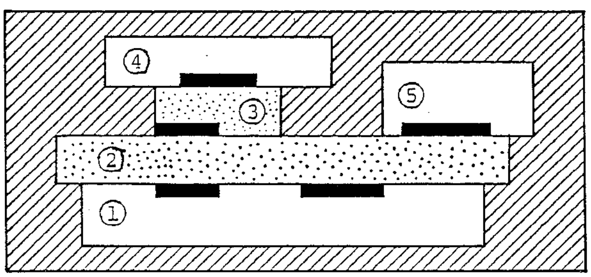

Fig. 1 The cross-sectional view of generalized suspended strip lines.

GENERALIZED SUSPENDED STRIP LINES

Fig. 1 shows the cross-sectional view of generalized suspended strip lines (GSSL's). The cross-section is composed of several homogeneous square regions which are located in parallel and connected. Each of these regions can be filled with either substrate material or air. The boundary surface between adjacent two regions can be occupied partly with strip conductor or extended ground conductor. These structures, therefore, can include substrates which are suspended by grooves or pedestals. A variety of new components can be conceived by applying GSSL's.

ANALYSIS METHOD

We seek the capacitance matrix of GSSL's by assuming weak dispersion in the transmission of the fundamental mode and by extending the analysis method in a previous paper (3).

The outline of analysis steps are as follows:

1)Specify potentials to each conductor.

2)Expand the potential $\phi_i(x_i,y_i)$ in the region i in the Fourier series form as

$$\phi_i(x_i,y_i) = \sum_{n=1}^{\infty} \left[a_{in}\sinh\left(\frac{n\pi y_i}{a_i}\right) + b_{in}\cosh\left(\frac{n\pi y_i}{a_i}\right)\right] \sin\left(\frac{n\pi x_i}{a_i}\right) \quad (1)$$

where a_i is the width of the region i. This potential form satisfies the Laplace's equation within each region.

3)Express the potential at each interface with the first-order spline function. The shape of the spline function determines the coefficients of

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the above Fourier series.

4) Express the total static field energy of this system by

$$W = \frac{1}{2} \sum_{i=1}^{N} \iint \varepsilon_i \left[\left(\frac{\partial \phi_i}{\partial x_i}\right)^2 + \left(\frac{\partial \phi_i}{\partial y_i}\right)^2 \right] dx_i dy_i \qquad (2)$$

5) Minimize W by changing the form of the spline functions as trial functions. A set of linear simultaneous equations is then obtained whose solutions determine the minimum energy W_{min}.

6) The capacitance between two conductors is then related to the minimum energy W_{min}. All element values of the capacitance matrix can be obtained by the same procedure.

The merits of this method are considered as follows:

1) The element values of the capacitance matrix can be easily defined by initially specifying each conductor potential which is also part of trial functions.

2) One of the two boundary conditions, the continuity of potentials, is automatically satisfied since the surface potentials are common to two adjacent regions.

3) The other boundary condition, the continuity of the normal electric flux, is also automatically satisfied by taking the minimum of the total energy. Avoiding the imposition of explicit boundary conditions makes the present method easier than the Green's function method.

4) Since capacitance values are calculated based on the variational principle, the trial functions can be expressed in a relatively simple form to obtain accurate capacitance values.

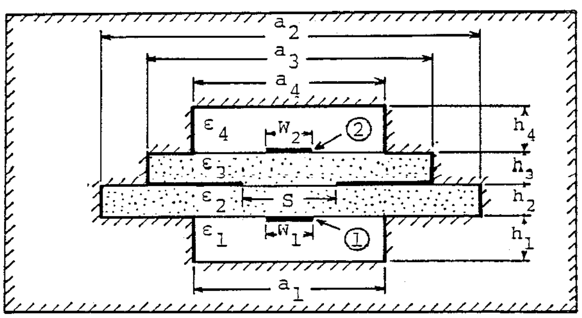

Fig. 2 Aperture coupling structure of two strip lines.

5) The spline function is adaptable to express various types of surface potentials. The minimization procedure of the energy by changing a finite number of spline knot potentials is simpler than that by changing a large number of Fourier coefficients.

6) The simplicity of the method for complicated structures. All problems of GSSL's are finally attributed to a set of linear simultaneous equations.

7) The thickness of conductor can be taken into account only by adding other two new regions.

APERTURE COUPLING OF TWO STRIP LINES

Fig. 2 shows an aperture coupling structure of two strip lines which belongs to the category of GSSL's. The capacitance matrix in this case is defined by

$$\begin{bmatrix} Q_1 \\ Q_2 \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} \\ C_{12} & C_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \qquad (3)$$

where Q_1 and Q_2 are the electric charge on the strip conductor 1 and 2 per unit length due to given potentials V_1 and V_2 against the ground, respectively.

First, we specify $V_1=1$ and $V_2=0$. Then, the spline functions as trial functions are defined as shown in Fig. 3 where p_m, q_m, and r_m are variables to give knot potentials.

Following the above analysis steps, we obtain a set of linear equations for these variables as

$$\sum_m A_{lm} p_m + \sum_m B_{lm} q_m + \sum_m C_{lm} r_m = D_l \qquad (4)$$

where l and m are taken from properly defined sets of numbers depending on the numbers of boundary surfaces and spline knots.

After solving these equations and substituting the solutions to (3), we obtain the minimized energy W_{min} which is also related to C_{11} by

$$W_{min} = \frac{1}{2} C_{11} V_1^2 \qquad (5)$$

C_{12} and C_{22} can be estimated in a similar fashion.

NUMERICAL AND EXPERIMENTAL RESULTS

We take the following parameters for the purpose of comparison between theory and experiment.

$a_1 = 10 \quad a_2 = 18 \quad a_3 = 14 \quad a_4 = 10$

$h_1 = 0.335 \quad h_2 = 0.140 \quad h_3 = 0.130 \quad h_4 = 0.355$

$w_1 = w_2 = 5 \quad S = 2 \sim 14 \quad$ (unit : mm)

$\varepsilon_1^* = \varepsilon_4^* = 1 \quad \varepsilon_2^* = \varepsilon_3^* = 2.22$ (RT Duroid 5880)

Satisfactory convergence on capacitance values has been observed for the Fourier terms more than 200 and the numbers of spline knots more than 20 for each boundary surface. The computation time for estimating one value of C_{11} was about 60s on HITAC M-260D computer.

The line capacitance values were measured with a HP LCR meter by changing the length of the coupled line. Fig.4 shows a reasonable agreement between calculated and measured capacitance values against the dimension of the aperture S. Fig. 5 shows how the coupling coefficient k is controlled by the aperture dimension S where

$$k = \frac{Z_{even} - Z_{odd}}{Z_{even} + Z_{odd}} \tag{6}$$

Z_{odd} : odd mode impedance,
Z_{even} : even mode impedance.

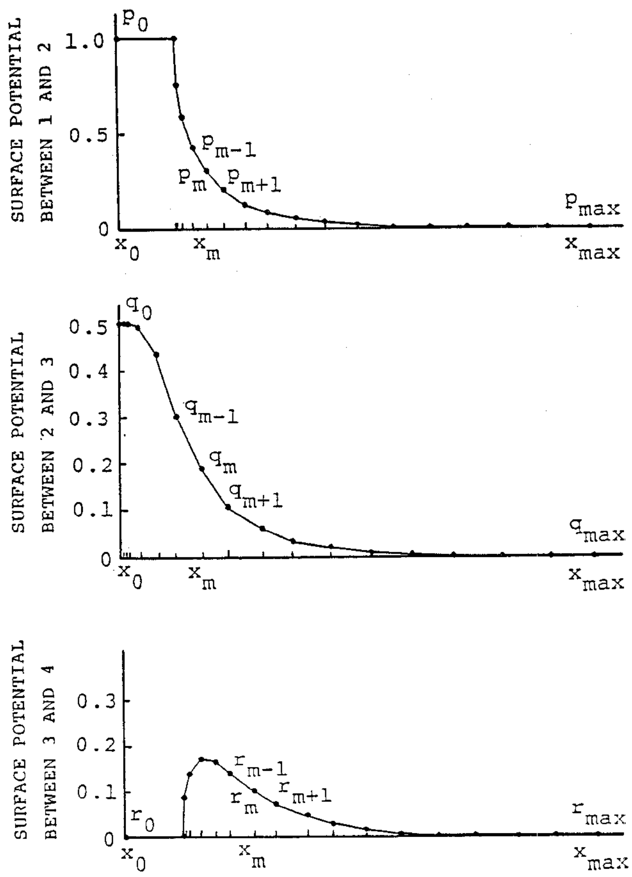

Fig. 3 Spline functions to express the three surface potentials.

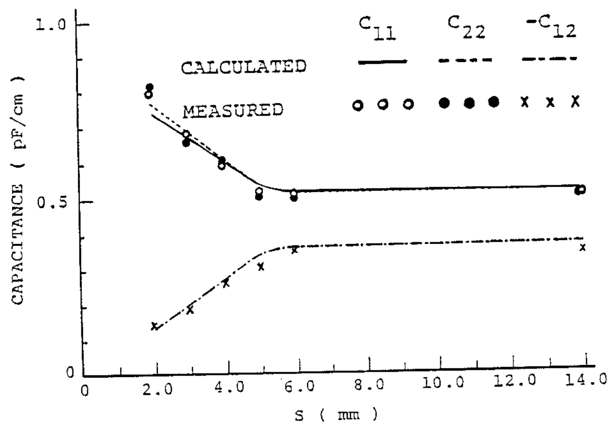

Fig. 4 Calculated and measured values of the capacitance matrix elements.

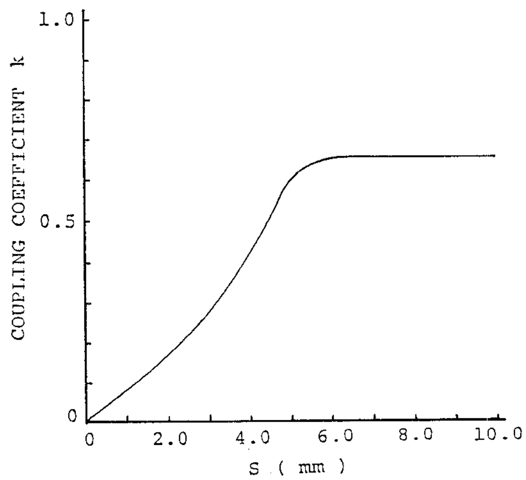

Fig. 5 Coupling coefficient values controlled by the dimension of aperture.

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