Analysis Method for Microstrip Line Power Dividers with Arbitrary Branching Circuit Pattern

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ABSTRACT

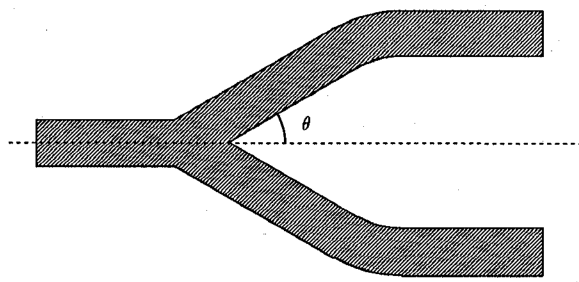
The transmission and reflection properties of 3-dB microstrip line power dividers with a straight-line and curved branching circuit pattern have been analyzed based on the eigenfunction-weighted boundary integral equation method. Branching patterns can be arbitrary in this method. Theoretical values of scattering parameters are in reasonable agreement with initial experimental results at microwave frequencies.

I. Background

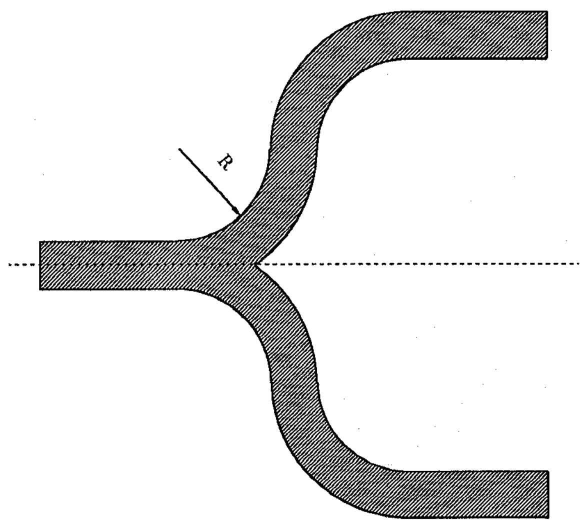
Microstrip line power dividers play an important role in the design of microwave systems and antenna arrays. The analysis method of practical dividers still remains at the stage of calculations of scattering parameters using the characteristic impedances with the qusi-TEM approximation[1], which does not include dispersion effects. A dispersion effect has been considered to some extent in a waveguide model theory [2], however, their approximate consideration of effective magnetic walls may produce some unpredictable errors in the case of small distances between the two strip conductors of Y-junctions or power dividers.

II. Branching Circuit Structures

Fig.1(a) and Fig.1(b) show a straight-line branching circuit and a curved branching circuit to be analyzed in this paper, respectively. The determination of dimensions of the circuit pattern as shown in Fig.2 is based on the method employed in the design of dielectric waveguide curved coupler[3]. The propagation constants and characteristic impedances at every point along the microstrip lines are firstly calculated precisely using our method. Then, the general scattering parameters of the power dividers are estimated based on the transmission line network theory.



(a) Straight-line branching circuit pattern



(b) Curved branching circuit pattern

Fig.1 3-dB microstrip line power dividers

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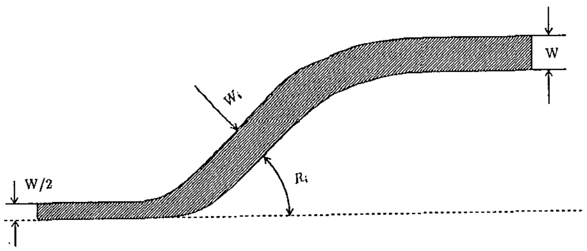

Fig.2 A half of an arbitrary branching circuit pattern based on the symmetry

III. Analysis Method

In the previous paper [4], the eigenfunction-weighted boundary integral equation method (EW-BIEM) has been proposed to analyze the characteristics of planar transmission lines with finite metallization thickness including microstrip lines, coplanar waveguides, and micro-coplanar strip lines, in which eigen-functions satisfying regular boundary conditions have been employed instead of Green's function. The prominent advantages of this method are that all of the boundary integral equations can be set up only on the fields on the surfaces of the conductor strips and the interface between air and dielectric subregions and this method can be applied to the analysis of complicated 3-dimensional planar structures with relatively short CPU time.

IV. Treatment of Branching Circuit Pattern

Fig.1 shows the configurations of the two kinds of microstrip line power dividers. Because of the symmetry with regard to the central plane, these dividers can be transformed to a set of curved non-uniform microstrip lines with a magnetic sidewall. The half symmetrical section of 3-dB microstrip line power dividers with an abitrary branching circuit pattern, as shown in Fig.2, is firstly divided into N uniform microstrip line sections along the curved propagation direction, for the i-th section with the sizes of W_i and R_i (i=1,2,...,N). R_i is defined as the radius of the circular line perpendicular both to the conductor line and central magnetic wall plane. Following the EW-BIEM method, a set of coupled boundary integral equations is set up for the cross-section of the i-th microstrip section as listed in [4]. In the i-th section, for example, the above integral equations can be easily transformed to four homogeneous linear equations by discretization, which enentually result in the following equation:

$$det[H_i(W_i, R_i, f, \beta_i)] = 0 \quad (i = 1, 2, ..., N) \tag{1}$$

where $[H_i]$ and β_i denote the coefficient matrix and the propagation constant in the i-th section, respectively.

Out of the three definitions of the characteristic impedance, the following general expression has been selected as the dispersive characteristic impedance for the i-th section of a microstrip line:

$$Z_i = Z_0/\sqrt{\varepsilon^i_{eff}} \tag{2}$$

where Z_0 and ε^i_{eff} denote the characteristic impedance of a microstrip line filled with air and the effective relative dielectric constant along the propagation direction of the i-th section, respectively.

V. Scattering Parameters

Curved non-uniform microstrip lines with magnetic walls have been transformed to a simple transmission line network with N cascaded sections. Based on the network theory [5], the transmission parameter matrix $[T^i]$ of the i-th section can be expressed as follows:

$$[T^i] = \frac{1}{2\sqrt{Z_i Z_{i+1}}} \begin{bmatrix} (Z_i + Z_{i+1})e^{-j\beta_i l_i} & (Z_{i+1} - Z_i)e^{-j\beta_i l_i} \\ (Z_{i+1} + Z_i)e^{j\beta_i l_i} & (Z_i + Z_{i+1})e^{j\beta_i l_i} \end{bmatrix} \tag{3}$$

where, β_i, Z_i and l_i correspond to the propagation constant, the characteristic impedance and the length of the i-th section, respectively.

The whole transmission parameter matrix $[T]$ for the microstrip discontinuity can be simply expressed with N cascaded section matrices using the connected network theory as follows:

$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} = \begin{bmatrix} T^1_{11} & T^1_{12} \\ T^1_{21} & T^1_{22} \end{bmatrix} \cdots \begin{bmatrix} T^i_{11} & T^i_{12} \\ T^i_{21} & T^i_{22} \end{bmatrix} \cdots \begin{bmatrix} T^N_{11} & T^N_{12} \\ T^N_{21} & T^N_{22} \end{bmatrix} \tag{4}$$

where, the superscript i denotes the i-th section.

Based on the transformation relations between S-parameters and T-parameters, the general scattering parameters for 3-dB microstrip line power dividers can be derived theoretically.

VI. Numerical Results

According to the above analysis, various 3-dB microstrip line power dividers with arbitrary branching circuit pattern can be designed. In the numerical calculations, taking N=20 discretizations sections ensures the accuracy of about 1.0% and typical computation time for one frequency point is about 4 minutes on a Sun 4 workstation. Fig.3 provides a series of theoretical curves of scattering parameters for 3-dB microstrip line power dividers with straight-line branching pattern at different angles θ and with curved branching pattern at different radii R. With the decrease of angle θ or the increase of radius R, the slowly changing branch produces the small reflection loss and transmission parameters of the two output ports get access to 3-dB. On the other hand, the reflection loss is also decreased with the increase of the operating frequency.

VII. Initial Experimental Results

On the experimental calibration, the above 3-dB microstrip power dividers designed based on the consideration of low reflection power level at the input port have been measured by means of a HP 8510B network analyzer. Fig.4 compares theoretical values with initial experimental results for the two 3-dB microstrip line power dividers. It is seen that the theoretical curves are in reasonable agreement with the experimental results. Some ripples seen in these experimental curves have been caused with the resonance phenomena produced by the unmatched connections between the coaxial line and microstrip line.

VIII. Potential Applications of This Analysis Method

This analysis method can be extended to analyze a number of microstrip line components such as dividers and couplers with arbitrary circuit patterns.

Acknowledgement

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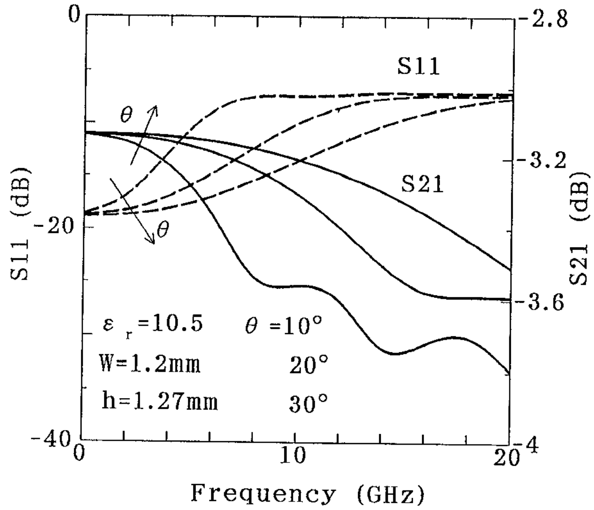
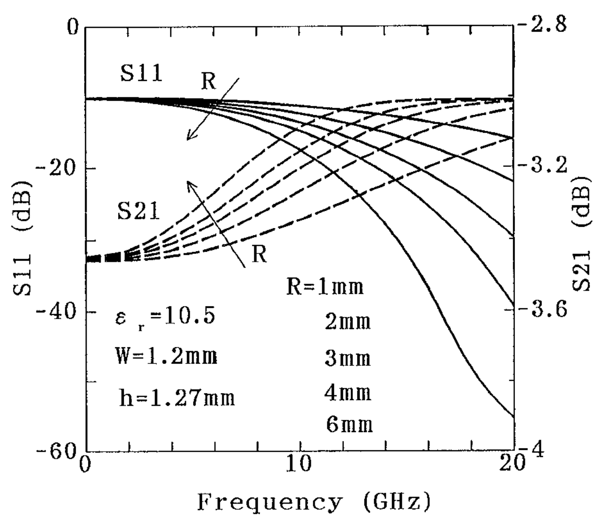
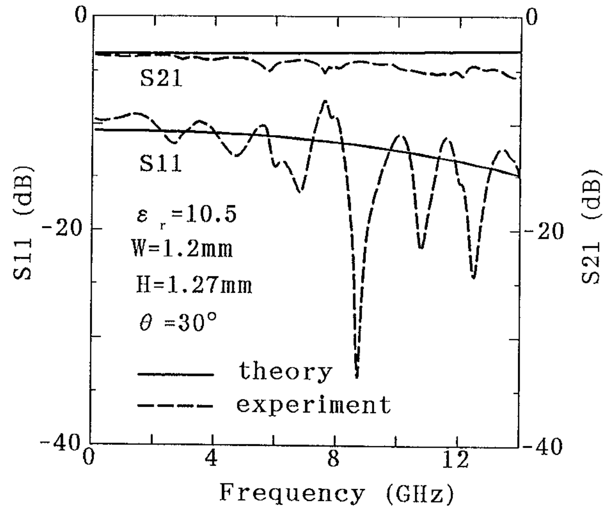


(a) Straight-line branching circuit pattern

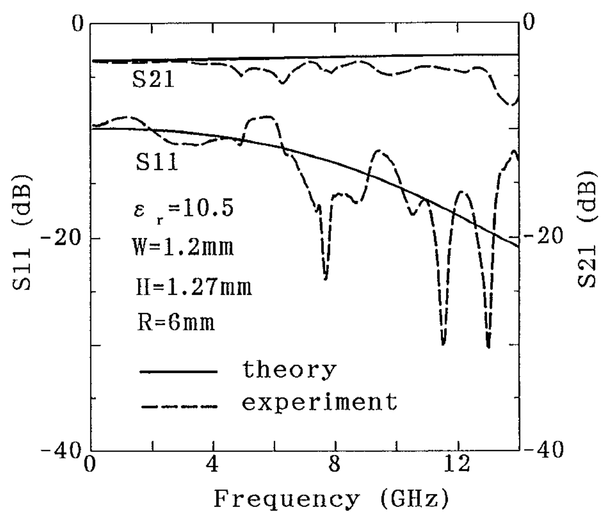


(b) Curved branching circuit pattern

Fig.3 Scattering parameters of microstrip line power dividers vs frequencies



(a) Straight-line branching circuit pattern



(b)Curved branching circuit pattern

Fig.4 Theoretical and experimental results for scattering parameters of 3-dB microstrip line power dividers