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Computer-Aided Analysis for the Design of Broad Classes of Microwave Couplers, Filters, and Transmission Lines

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The use of a flexible, computer-aided analysis for designing broad classes of microwave couplers, filters, and transmission lines, is described. The convergence characteristics are illustrated for computations of impedance and phase velocity of an isolated microstrip line. Design curves are presented for a coupler configuration employing microstrip over a slotted ground plane. Experimentally determined performance characteristics are presented for a directional coupler designed using these computer generated design curves.

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COMPUTER-AIDED ANALYSIS FOR THE DESIGN OF BROAD CLASSES OF MICROWAVE COUPLERS, FILTERS, AND TRANSMISSION LINES

INTRODUCTION

A large class of microwave couplers and filters uses uniform, coupled transmission line sections. The routine design of such components using slot line, sandwich slot line, coplanar waveguide, and other transmission lines, has been impeded by a shortage of information quantitatively describing coupled and isolated line electrical performance for such transmission lines. For this reason, previous efforts to incorporate these media in couplers and filters have been substantially empirical [1-3]. It is the purpose of this report to illustrate the usage of a computer-aided analysis which can furnish a design basis for such microwave couplers and filters. Similarly, one can compute the propagation characteristics (characteristic impedance and phase velocity) of a variety of isolated transmission lines, including those which are inhomogeneously filled with dielectric material.

ANALYSIS APPROACH

Consider the rather arbitrary cross section of an isolated transmission line depicted in Fig. 1. This transmission line is taken to be uniform in the propagation direction and is filled inhomogeneously over the cross section with dielectric regions characterized by relative permittivities ϵ_{r1}, ϵ_{r2}, and ϵ_{r3}. Regions A and B represent cross sections of perfect conductors. The transmission line representation in Fig. 1 is the "filled" configuration. Fictitiously removing the dielectric regions shown in Fig. 1 while retaining the same conductor geometry, results in a second cross section, which is the "empty" configuration.

By invoking transverse electromagnetic (TEM) propagation models, electrostatic capacitances, C and C_e, are associated with the conductor pairs for the filled and empty configurations, respectively. In terms of these electrostatic capacitances, the propagation characteristics of the inhomogeneous structure in Fig. 1 can be written as

$$Y_0 = c \sqrt{C C_e} \qquad (1)$$

and

$$v = c \sqrt{\frac{C_e}{C}}, \qquad (2)$$

where Y_0 is the characteristic admittance of the transmission line depicted in Fig. 1, v is its phase velocity, and c is the speed of light in free space. Computer-aided methods for numerically evaluating the capacitances C and C_e have been described by several investigators [4-7].

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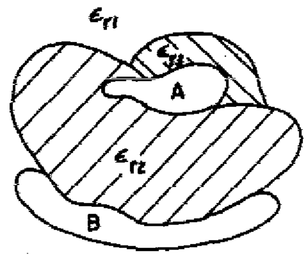


Fig. 1 — Cross section of an inhomogeneously loaded transmission line

An equivalent charge analysis, similar to that of Pontoppidan [7], has been programmed in FORTRAN IV for use on the CDC 3800 digital computer at the Naval Research Laboratory Research Computation Center. This analysis uses a pulse function expansion of equivalent sources and point matching of the boundary conditions. The convergence of the numerical solution used in this analysis is illustrated in Figs. 2 and 3. These figures show the variation in computed line impedance and phase velocity as the number of equivalent charge functions is varied on the strip and ground plane of a nominally 50-ohm microstrip line. Values due to Bryant and Weiss [8] are shown for reference. Convergence here produced agreement to within 3% compared to reference values. In this comparison it is to be noted that C and C_e in Eqs. (1) and (2), were each approximately computed, as were the reference values.

The coupled transmission lines treated in this work are characterized by the admittances and phase velocities of the even and odd modes [8] of propagation. In terms of these quantities it has been shown how to design microwave couplers and filters [9]. When a procedure similar to that described for the isolated transmission line is followed, TEM propagation models can be used for both filled and empty coupled line cross sections. The even and odd mode admittances and phase velocities are expressed as

$$Y_i = c \sqrt{C_i C_{e,i}} \tag{3}$$

and

$$v_i = c \sqrt{\frac{C_{e,i}}{C_i}}, \tag{4}$$

where i is either e for the even mode or o for the odd mode, and c is the speed of light in free space. Here, C_e is the capacitance per unit length of one transmission line in the filled problem with voltages of 1 v relative to ground impressed on each line in the filled, coupled structure. C_o is similarly defined for one transmission in the filled, coupled structure with voltage of +1 v and −1 v to ground impressed on the lines, respectively, $C_{e,e}$ and $C_{e,o}$ are similarly defined for the empty, coupled line structure.

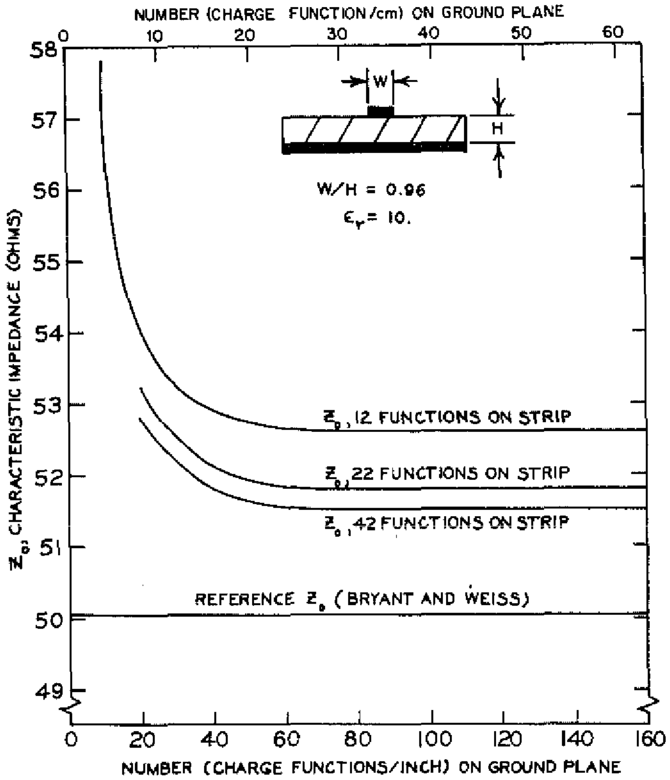


Fig. 2 — Convergence of computed microstrip impedance

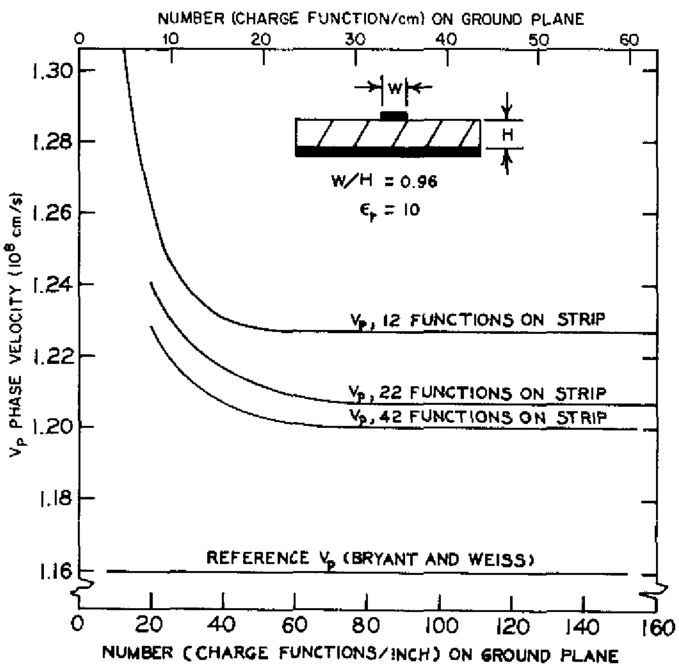


Fig. 3 — Convergence of computed microstrip phase velocity

An equivalent source formulation similar to Pontoppidan's [7] has been programmed in FORTRAN IV to evaluate the capacitances in Eqs. (3) and (4). The details of this computer-aided analysis can be understood by reference to Ref. 10. The next section presents some computations made by applying this analysis to a coupled line configuration of microstrip over a slotted ground plane. The validity of those computations is supported by describing a directional coupler designed and fabricated based upon the computer-generated values.

EXAMPLE

The directional coupler design was based on the computed information shown in Figs. 4 and 5. The coupled line cross section of this coupler is shown in the inserts in these figures. In Fig. 4 plots of midband coupling and input impedance for a quarter-wavelength-long section are given versus strip width W and conductor spacing S on a substrate with a thickness H of 0.025 inch (0.64 mm) and overall width extent L of 1.0 in. (2.54 cm). The relative permittivity of the substrate material was taken to be 10.0. All conductors in the cross section are 0.00025 in. (0.0064 mm) thick. Figure 5 displays the even- and odd-mode phase velocities (v_e and v_o) for similar variations in the configuration geometry. Figure 6 displays the even and odd mode impedances (Z_{oe} and Z_{oo}) in a similar manner.

The coupler was fabricated on a 2 by 1 by 0.025-in. (5.08 by 2.54 by 0.064-cm) portion of alumina substrate using thin film techniques. The circuits on each side of the substrate are shown in Figs. 7a and 7b. The layout used here is a variation of that used by Garcia [3] in a wideband, quadrature, 3-dB coupler developed empirically. The performance of the coupler developed in this work is illustrated in Figs. 8a, 8b, and 8c. The designed midband value is 5.4 dB, while the measured value is 5.3 dB. The coupling is 6.0 ± 0.7 dB over a 60% bandwidth about the midband frequency. Over more than an octave band, the return loss is 19.5 dB or better and the directivity is better than 14 dB. It is to be noted that this device is the result of a single design attempt using computer-generated results.

The directional coupler described here is one of several different types of directional couplers that have been successfully designed and fabricated using the analysis described here. Other couplers are the reduced ground plane microstrip coupler [11] and the edge-coupled microstrip with dielectric overlay coupler [10,12].

DISCUSSION

The method described here is characterized by the following aspects. First, it is suitable for analyzing and designing isolated and coupled microwave transmission lines with a wide variety of cross-sectional configurations. These configurations can have either homogeneous or inhomogeneous dielectric loading. Second, although a TEM propagation model is invoked, both TEM and lightly dispersive media have been treated adequately by this method. A third feature is that the method can be used to take into account effects of both finite metallization thickness and substrate edge effects for MIC components as was the case for the example presented here. This method is also capable of treating packaging effects (side walls, etc.) within the constraints imposed by a TEM model.

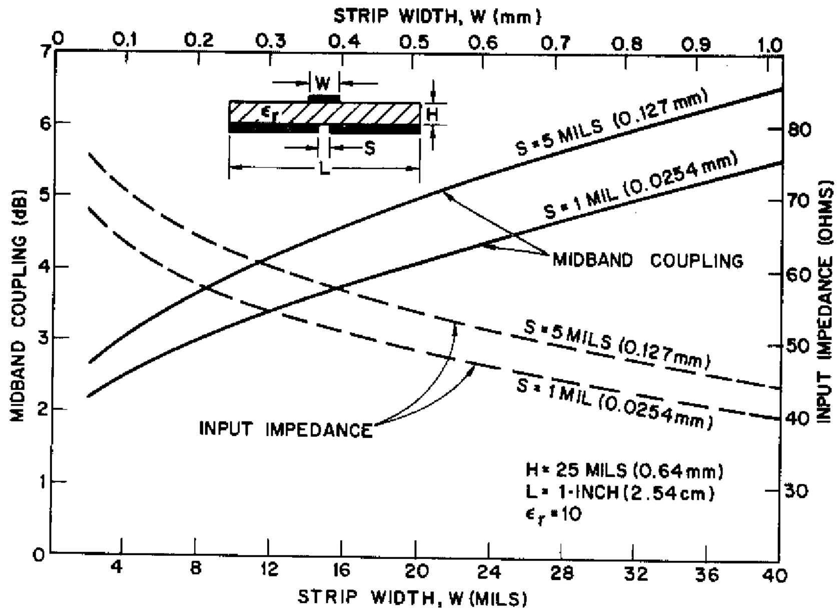


Fig. 4 — Midband coupling and input impedance for microstrip/slotted-ground-plane configuration

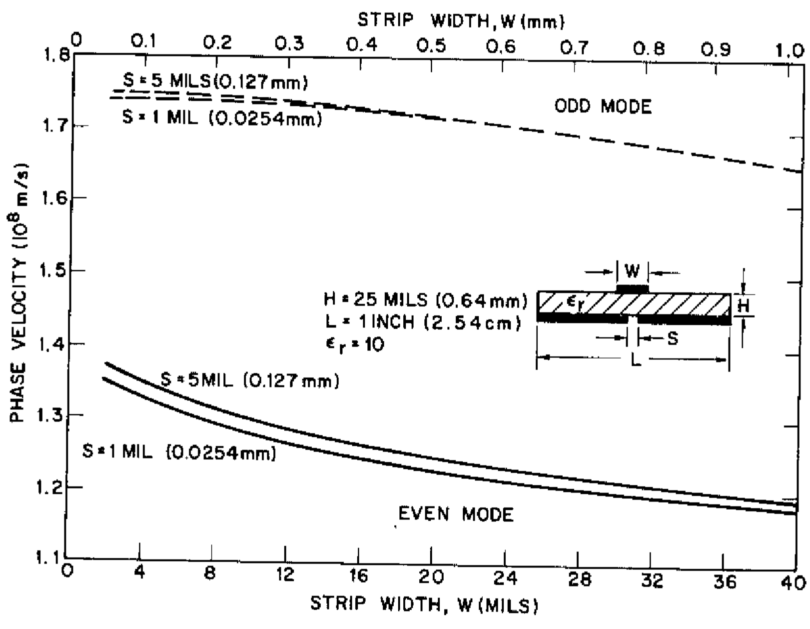


Fig. 5 — Evan- and odd-mode-phase velocities for microstrip/slotted-ground-plane configuration

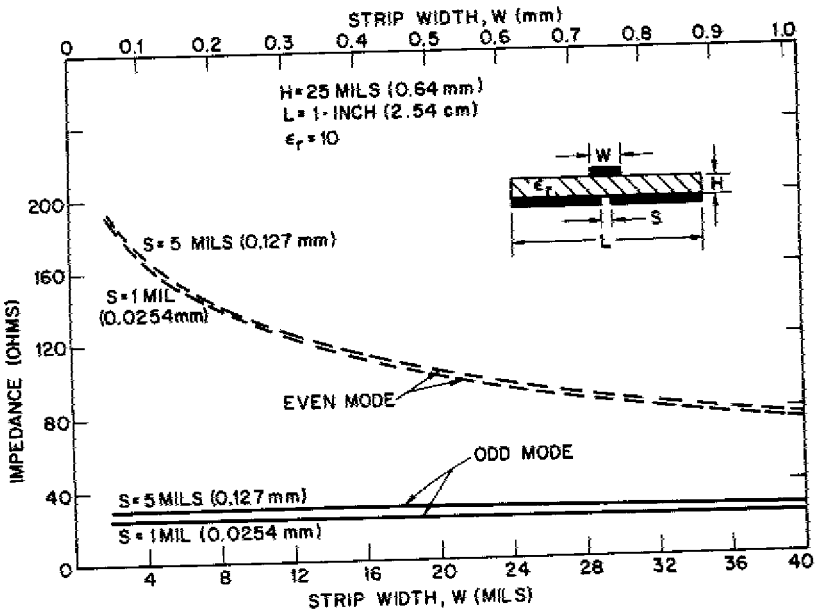
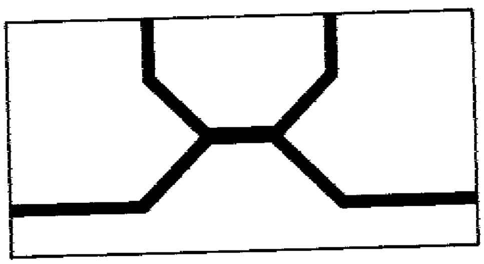
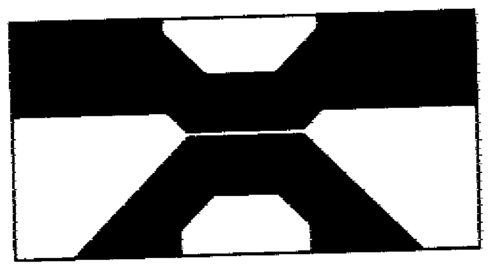


Fig. 6 — Even- and odd-mode impedances for microstrip/slotted-ground-plane configuration

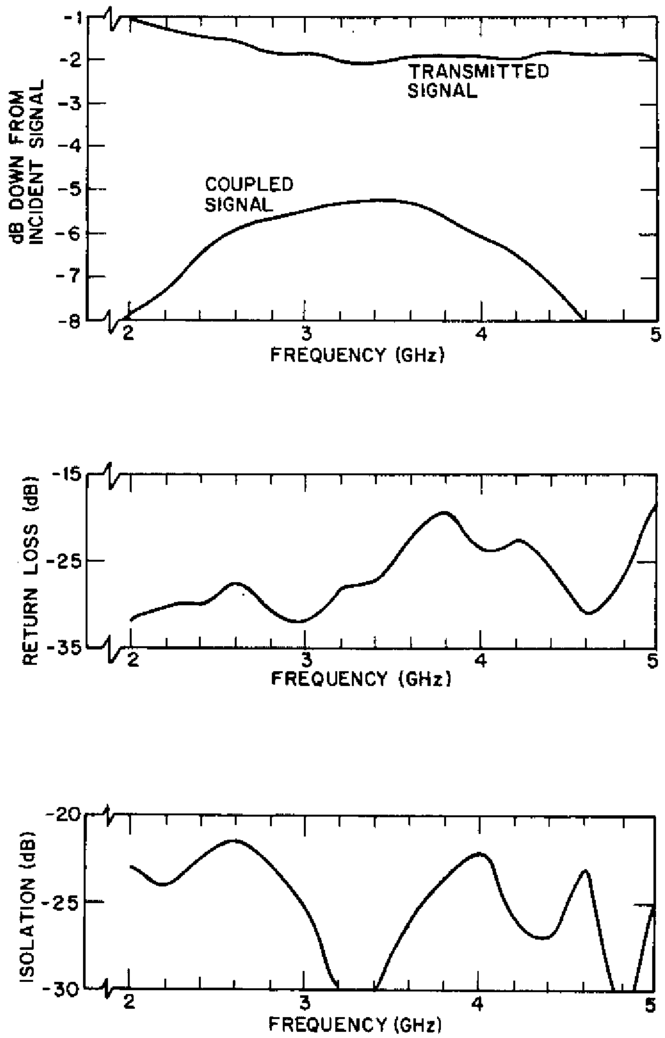


(a) Top-side pattern



(b) Bottom-side pattern

Fig. 7 — Circuit for microstrip/slotted-ground-plane coupler



(a) Coupled and transmitted signals

(b) Return loss

(c) Isolation

Fig. 8 — Microstrip/slotted-ground-plane coupler performance

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