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EDGE CORRECTIONS FOR MICROSTRIP PLANAR ANALYSIS MODELS

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ABSTRACT

Microstrip planar waveguide models of circuits that use the equivalent width and equivalent dielectric constant for each region fail to accurately predict performance. A better model is described that does not use equivalent parameters directly, but instead uses a dual fringe correction which more accurately models the real fringe fields.

INTRODUCTION

Planar waveguide analysis of stripline and microstrip circuits which includes junction and discontinuity effects can be carried out by using Green's functions (1) for simple shapes and combining those shapes using segmentation and desegmentation to build a model of a complex shape. The basic procedure is a subject of numerous publications (1-12), including a reference book by Gupta, et al (13). In the literature, fringe fields are accounted for by an equivalent width, and for microstrip the velocity of propagation is accounted for by an effective dielectric constant. These parameters are easy to obtain. For stripline, this procedure gives accurate results, but for microstrip it does not and is theoretically invalid.

The problem is that a microstrip line propagates energy in two dielectric media and at a different rate in each. When considering a transmission line, only one direction of propagation is important, and so the equivalent width and dielectric constant will yield the correct impedance and velocity. However, for a general shape, energy propagates in many directions, and the above approach would require a different equivalent width and dielectric constant for each direction of propagation on a given shape. For example, in a cross junction of lines with different impedances, the junction area would have to have two effective dielectric constants at once, whereas the computation process allows only one.

A new model that accurately accounts for the fringe fields and avoids this difficulty is the essence of this paper. Fringe corrections are made both in the dielectric and in air, each in the proper proportions for the dimensions of the shape being studied. The portion of the fringe that is in air is attached to the model by segmentation. The fringe widths are derived so that impedance and propagation velocity are correct in all parts of the model at once.

DEVELOPMENT

The fringe model is developed from the equivalent parameters of a transmission line as shown in Fig. 1. All of the field under the line in Fig. 1(A) is in the substrate, as is some of the fringe field on each side. However, some of the fringe field passes through the air above the substrate as well as the substrate itself. These fields may be represented by the parallel capacitance model of Fig. 1(B). The fringe is therefore modeled as two fringes, one in the substrate dielectric and one in the air (or other medium) outside the substrate as in Fig. 1(C). These fringe widths depend strongly on the width of the strip, and also on frequency. This is called the dual fringe model to distinguish it from the equivalent width model of Fig. 1(D).

The widths of the fringe fields on the dual fringe model are related directly to the equivalent width model. The dual fringe model has the same total width and capacitance as the equivalent width model. Equating these capacitances and widths yields

$$W_d = W + 2f_d = W_e \frac{(\epsilon_e - 1)}{(\epsilon_r - 1)} \quad , \qquad (1)$$

$$W_a = 2f_a = W_e - W_d \quad , \qquad (2)$$

where

W = physical width of the microstrip line
W_e = equivalent width of the line
W_d = width of the line plus dielectric fringe
W_a = width of the air fringe (sum of both sides)
f_d = width of each dielectric fringe region
f_a = width of each air fringe region
ϵ_r = material relative dielectric constant
ϵ_e = effective dielectric constant.

The fringe widths, f_d and f_a, from these equations will yield the correct impedance and velocity of propagation for a planar model of the transmission line without using the equivalent width or dielectric constant directly in the model. The equivalent width and dielectric constant may be obtained from any good microstrip computer program, such as that published by March (14), from which the dual fringe model widths are easily calculated.

For shapes other than transmission lines, the widths of the fringes on each edge are influenced by the distance to the opposite edge. The correct fringe to use is that for a transmission line with this same width. If

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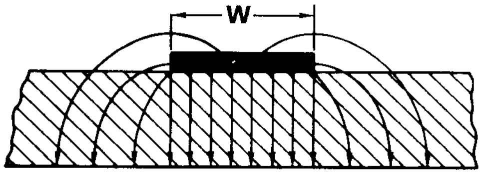
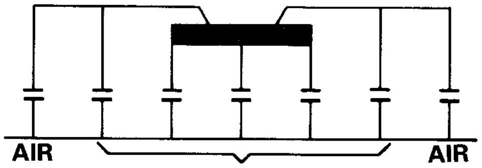
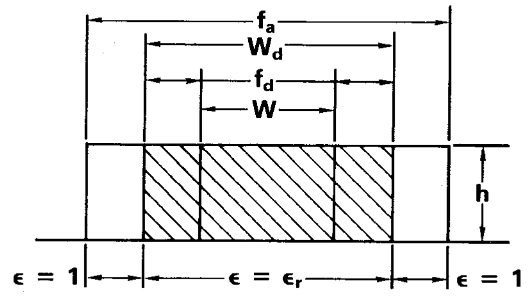


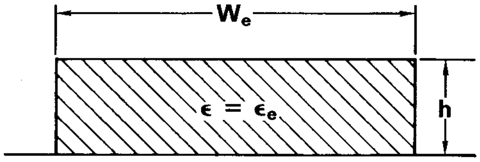
(A) MICROSTRIP FRINGE FIELDS



(B) MICROSTRIP CAPACITANCE MODEL



(C) MICROSTRIP PLANAR MODEL USING AIR FRINGE AND FULL MATERIAL DIELECTRIC CONSTANT



(D) EQUIVALENT WIDTH MODEL

Fig. 1 Development of microstrip fringe model

the opposite edge is not parallel, an average distance must be used, since nonconstant fringes are very difficult to realize.

These fringes are attached to the original shape by addition and segmentation. The dielectric fringe is added to the original shape dimensions the same as for stripline to yield an equivalent shape size, as shown in Fig. 2. The air fringe is then attached by segmentation to form the complete model. Shapes thus derived can then be combined with other shapes using the standard segmentation and desegmentation processes.

CALCULATIONS AND VERIFICATION

Both the dual fringe and equivalent width models of the fringe field have been applied to the study of a branch-line hybrid coupler, realized on alumina at 9.6 GHz, shown in Fig. 3(A). Junction effects completely dominate the characteristics of this hybrid. A planar model of one junction of this hybrid using equivalent widths and dielectric constants is shown in

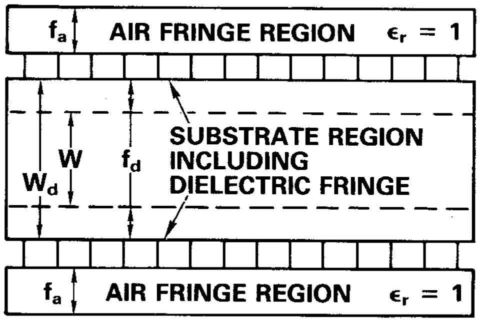
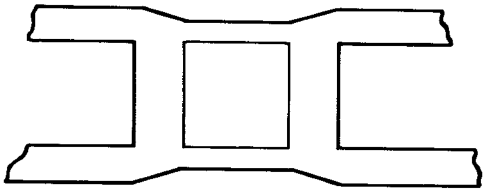
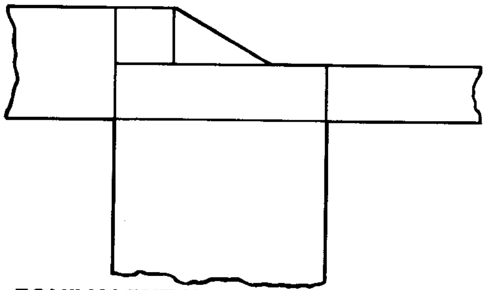


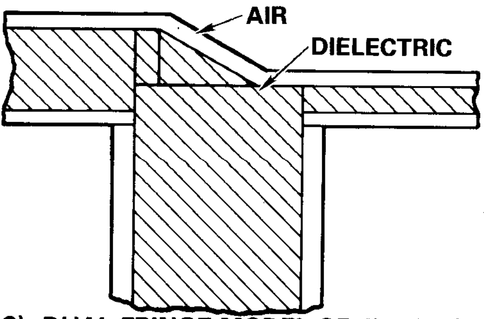
Fig. 2 Attachment of fringe areas by addition and segmentation



(A) EXPERIMENTAL HYBRID



(B) EQUIVALENT WIDTH MODEL OF JUNCTION



(C) DUAL FRINGE MODEL OF JUNCTION

Fig. 3 Models of a microstrip hybrid

Fig. 3(B), and another model using the dual fringe approach is shown in Fig. 3(C). In both cases, the junction area is broken into simple shapes for which Green's function expansions are available. The difference between the two models is that the dual fringe model uses one dielectric constant for the dielectric portion throughout, while the equivalent width model uses a different one for each of the three lines, and an average value for the three shapes that comprise the junction itself. In both cases, a complete hybrid is modeled by connecting four junctions together, taking advantage of symmetry.

Both planar hybrid models have been evaluated using the method of Gupta (13), where the shapes are evaluated by the appropriate Green's function expansions and combined by the segmentation process to yield the S-parameters of the complete hybrid. The results are compared graphically with the measured data in Fig. 4. Even though both models predict a resonant frequency higher than measured, the dual fringe model predicts the resonant frequency more closely than the equivalent width model. The return loss and coupling coefficients are also more accurately modeled by the dual fringe approach, especially near the design frequency of 9.6 GHz. The difference between the measured data and the dual fringe calculations can be attributed to losses (which neither planar model takes into account) and possible production uncertainties such as material properties and etch-back factor.

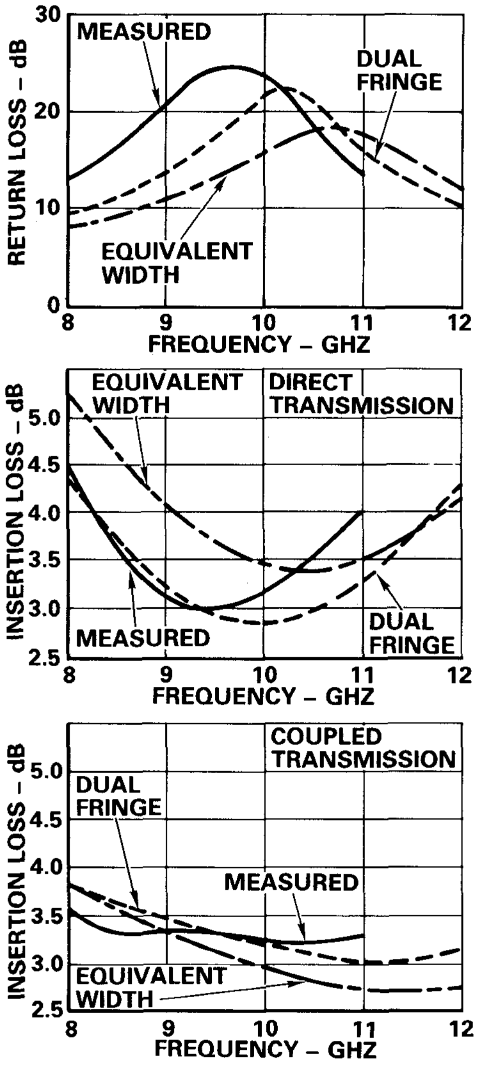


Fig. 4 Comparison of dual fringe model, equivalent width model, and measured data

It is important to note that both fringe models are exact only at one frequency (9.6 GHz). However, both models are sufficiently accurate over a band to study the overall performance of the hybrid. The dual fringe model seems to predict a slightly higher resonant frequency, but the equivalent width model predicts an even higher resonant frequency. The source of this error has not been identified.

CONCLUSIONS

The dual fringe model for planar microstrip circuits accurately models the impedance and propagation velocity everywhere in the model without resort to equivalent widths and equivalent dielectric constants. The end result is a model that more accurately represents the actual fringe fields, and thus results in more accurate calculations.

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