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CAD of E-Plane Circuits with Field-Theory Based Lookup Tables and Discontinuity Models

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Abstract

In this paper, a novel CAD procedure for E-plane circuits is presented. The CAD method uses field-theory based lookup tables, discontinuity models and an innovative interpolation technique based on physically realistic functions. Several finline circuit components were designed and measured. The CAD results are in good agreement with the experimental results.

Introduction

New versions of commercial microwave CAD programs allow the users to define their own models for circuit design. Most often, user-defined models are implemented in the form of analytical expressions. However, "fast" formulas for complicated E-plane structures are difficult to develop because too many variable parameters must be included in the analytical expressions. Hence, such formulas are often inaccurate, long to compute and restricted in range. As Jansen [1] has pointed out for the case of microstrip and monolithic circuit CAD, programs based on field-theory (such as the Transmission Line Matrix (TLM) and the Spectral Domain methods (SDM)) are much more accurate and flexible for modeling planar lines and circuit elements. Naturally, numerical programs are too slow for interactive circuit design. However, through the use of multi-dimensional lookup tables generated with field-theoretical tools, very fast CAD routines can indeed be realized.

Field-Theory Based Lookup Tables Generation and Interpolation

We have developed a number of original user-defined modeling tools for E-plane circuit design, which are presented for the first time in this paper. Using an accelerated Spectral Domain technique [2] which is one order of magnitude faster than a regular SDM program, we generate two-dimensional lookup tables for the effective dielectric constant and the voltage-power impedance of unilateral and bilateral finlines. The input parameters for the table-generating program are the inner dimensions of the waveguide enclosure, substrate permittivity, thickness, and lateral position of the substrate. These parameters are usually fixed in advance and will not be modified during a typical phase of the design procedure. The parameters varied during analysis and optimization are gapwidth and frequency. A graphical representation of a lookup table is shown in figire 1.

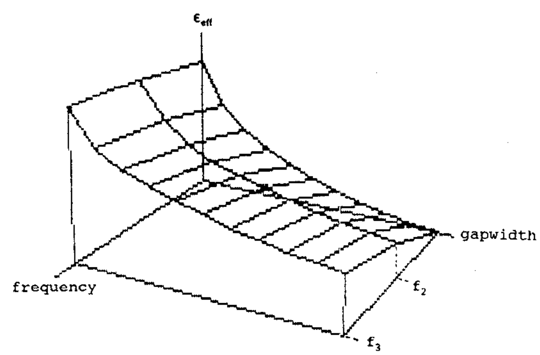

Figure 1: A graphical representation of a lookup table.

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The interpolation technique used to extract information from these lookup tables is a combination of linear and physically realistic functions.

Meier [3] has shown that the effective dielectric constant and the characteristic impedance of a finline can be approximately expressed as follows:

$$\epsilon_{eff} = k_e - (\lambda/\lambda_g)^2 \qquad (1)$$

$$Z_{eff} = \frac{Z_{0\infty}}{\sqrt{k_e - (\lambda/\lambda_g)^2}} \qquad (2)$$

where k_e is the so-called equivalent permittivity determined by a test measurement. A better approximation is obtained by assuming that k_e is frequency dependent:

$$k_e = k_{e0} + k_{e1}*f \qquad (3)$$

so that in the most general form, ϵ_{eff} is very closely emulated by the expression:

$$y = A + B*f + C/f^2 \qquad (4)$$

Where

y: ϵ_{eff} or Z_{eff}

A, B and C: unknown coefficients to be determined by the lookup tables.

Since three coefficients are present in the formula three data points are required to determine the coefficients. The system of equations required to be solved at a given gapwidth is:

$$y_1 = A + B*f_1 + C/f_1^2$$
$$y_2 = A + B*f_2 + C/f_2^2$$
$$y_3 = A + B*f_3 + C/f_3^2$$

Using elimination and back-substitution technique

$$C = [k_2*(y_1-y_2)-k_3*(y_1-y_3)]/k_5 \qquad (5)$$
$$B = [y_1-y_2-C*k_4]/k_3 \qquad (6)$$
$$A = y_1-B*f_1-C*k_1 \qquad (7)$$

Where

$$k_1 = 1/f_1^2$$
$$k_2 = f_1 - f_3$$
$$k_3 = f_1 - f_2$$
$$k_4 = k_1 - 1/f_2^2$$
$$k_5 = k_2*k_4 - k_3*(k_1 - 1/f_3^2)$$

k_1, k_2, k_3, k_4 and k_5 are functions of f_1, f_2 and f_3 only, that is they do not depend on frequency, f, nor on gapwidth, d. Hence they can be stored together with the lookup table and equations (4) to (7) can then be used to determine the corresponding ϵ_{eff} and Z_{eff} at various frequency points.

Simple functions that can be used to perform fast and accurate interpolation with respect to gapwidth have not be found. Therefore eleven data points with linear interpolation are used to determine the ϵ_{eff} and Z_{eff} at various gapwidth.

Since ϵ_{eff} and Z_{eff} are usually quite insensitive to frequency, interpolation is first performed with respect to frequency then with respect to gapwidth. An error less than 0.5 percent in ϵ_{eff} and 4.0 percent in Z_{eff} have been achieved by our interpolation technique over the entire waveguide bands of WR22, WR28 and WR90.

E-Plane Circuit CAD Program

Lookup tables and available closed-form expressions for discontinuities are used in combination to implement dispersive models for unilateral finline such as line section (figure 2), shunt inductance (figure 3) and step inductance [4] (figure 4) in our current version of a E-plane circuit design program. In addition, two interpolation schemes are implemented. The first

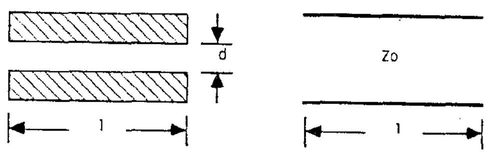

Figure 2: Finline section and its equivalent circuit

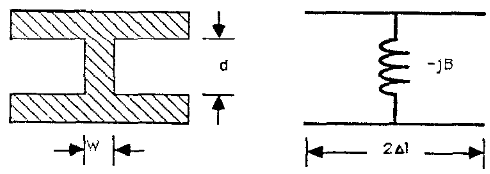

Figure 3: Symmetrical inductive strip and its equivalent circuit.

scheme uses linear interpolation with respect to both frequency and gapwidth which requires lookup tables of dimensions 11x11. The second scheme uses physically realistic functions to interpolate with respect to frequency and linear interpolation with respect to gapwidth which requires lookup tables of only 3x11 values. The program was used to design step transformers, tapers and bandpass filters. Some design results are given in the following section.

CAD Results

The return loss characteristic of a transformer implemented by cascading two ideal transmission line sections is shown in figure 5. Superimposed on that curve is the return loss of a transformer implemented using two finline sections with the same impedance and electrical length as the ideal transmission line sections but take into account the step discontinuity parasitics. The figure shows that the equivalent series inductance of the step increases the reflection quite considerably and cannot be neglected.

A multi-step taper was designed. The return loss curves of the initial design, a linear-step profile, and of the optimized profile are shown in figure 6. The optimization goal was that the return loss should be less than 40 dB.

To demonstrate the good agreement between the modeling procedure and measurements, figure 7 shows the insertion loss of a unilateral finline bandpass filter with three resonators and a matched load on each side. The particular filter was designed empirically and measured by C. Verver at the Communications Research Centre in Ottawa. Superimposed on the measurement plot is the computer generated characteristic obtained by entering the dimensions of the structure into the analysis program. Note that no losses were included in the computer analysis, and higher-mode interaction between the metallic strips in the filter were not considered.

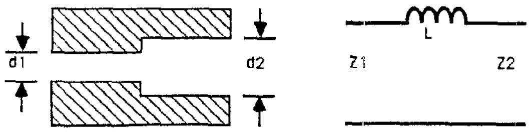

Figure 4: Inductive step and its equivalent circuit

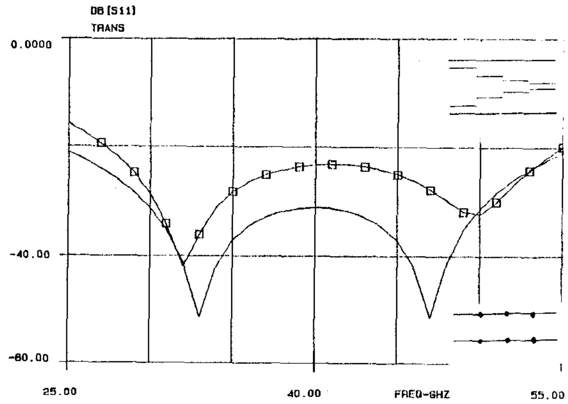

Figure 5: Return loss curves of a step transformer. The curve without marker was obtained with an ideal transmission line model while the curve with marker was obtained with a dispersive finline model.

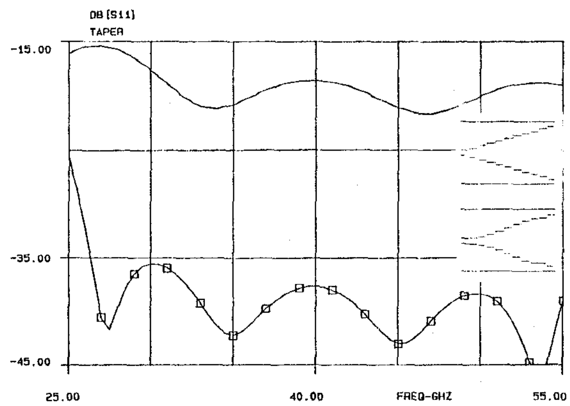

Figure 6: Return loss curves of a multi-step taper. The curve without marker was obtained with a nine-step linear profile while the curve with marker was obtained with an optimized nine-step profile.

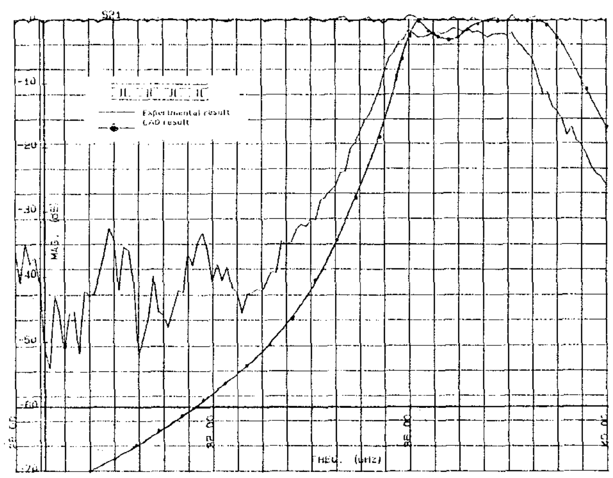

Figure 7: Insertion loss curves of a three-resonator filter. The curve without marker was measured and the other was computer generated.

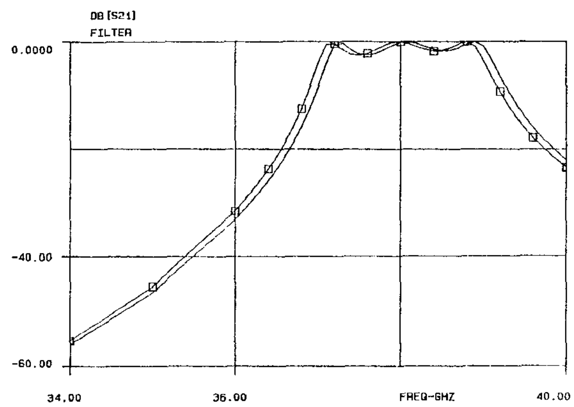

Figure 8: Insertion loss curves of a three-resonator filter. The curve with marker was generated by linear interpolation with respect to both frequency and gapwidth. The curve without marker was generated with the proposed interpolation scheme.

Finally, figure 8 shows the insertion loss curves of the above filter that were generated using two different interpolation schemes. One of them was generated using linear interpolation with respect to both frequency and gapwidth, and the other was generated using the new interpolation scheme given above.

Conclusion

A CAD procedure for E-plane circuits using field-theory based lookup tables for the analysis of straight finline sections has been developed. The lookup tables are generated with an accelerated spectral domain program and interpolated with respect to frequency using physically realistic functions. This procedure considerably reduces the size of the lookup table since only three frequency points are needed for each gapwidth. Interpolation with respect to the gapwidth is linear.

Discontinuities are modeled using a combination of these lookup tables with closed-form expressions. All models have been implemented in TOUCHSTONE SENIOR and thus take advantage of all capabilities inherent in this software. Agreement with measurements is good and ultimately depends on the accuracy of the models used.

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