# ANALYSIS OF MICROSTRIP FILTERS WITH A COMBINED MODE-MATCHING AND METHOD-OF-LINES PROCEDURE

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## ABSTRACT

A combined Mode-Matching and Method-of-Lines technique is used to perform a full-wave analysis of a 5-pole interdigital shielded microstrip filter. The method offers significant memory savings over other full-wave methods. Predicted results show good correspondence with measured data.

## 1. INTRODUCTION

The ongoing search for more efficient full-wave analysis methods for solving electrically large structures has resulted in several investigations into the combining of methods. Several authors [1,2] have reported on using two-dimensional techniques to find field distributions at cross-section planes in the structure and then using the mode-matching technique to do a full three-dimensional analysis. None of these methods have yet been extended to more complicated structures such as microstrip filters. Recently, Wu [3], used a combination of the Method-of-Lines and Mode-Matching techniques specifically formulated for the problem of dielectric waveguide components.

This paper uses the MOL together with a modified mode-matching technique, as described in [4] for the analysis of microstrip steps. The technique is extended significantly by applying it to the problem of a five-pole interdigital filter in shielded microstrip instead of single discontinuities. The structure is assumed to be lossless. The MOL is used to calculate a number of modes and corresponding field patterns for each cross-section. At each discontinuity, the fields are matched to produce generalized S-matrices, which are cascaded to complete the analysis. This approach has a number of advantages compared to other full-wave analysis methods.

i) Foremost is the efficient usage of memory. The combination of the two methods ensures that the 3D-structure is discretized in only one dimension, with a resultant reduction in matrix sizes. As an example, the biggest matrix used in the analysis of the interdigital filter in this paper is a 60x60 complex matrix.

ii) A second advantage is that the execution time increases only linearly with an increase in the number of discontinuities in the z-direction. This characteristic is of special importance where structures with lengths of several wavelengths need to be analyzed, especially if the structure only comprises a few discontinuities.

iii) Thirdly, modal information is available at each point in the structure. This is especially useful if higher-order modes start to degrade the performance of circuits, such as the transmission zero in the filter discussed here.

iv) Finally, the S-parameters of the circuit is available directly without any additional computation.

The use of the combined method to analyze a fifth-order interdigital shielded microstrip filter, as shown in fig. 1, is the topic of this paper.

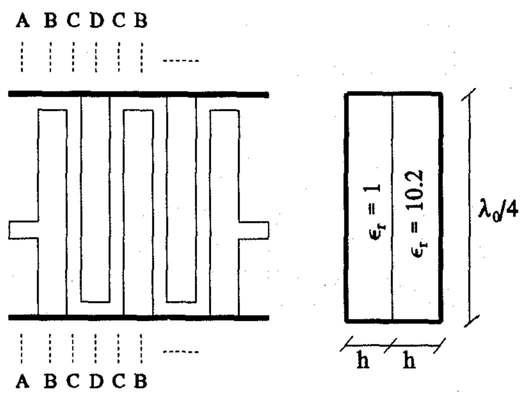


**Figure 1**: Filter Layout

Section 2 discusses the application of MOL and section 3 that of mode-matching. Section 4 presents results of the measured filter compared to that of the proposed method. It is clear that the method accurately predicts the existence of the transmission zero in addition to having good correspondence with the rest of the data.

## 2. TWO-DIMENSIONAL ANALYSIS

The filter is split up into five sections, as shown in figs.1 and 2. At each section, the structure is discretized into a number of lines running from top to bottom.

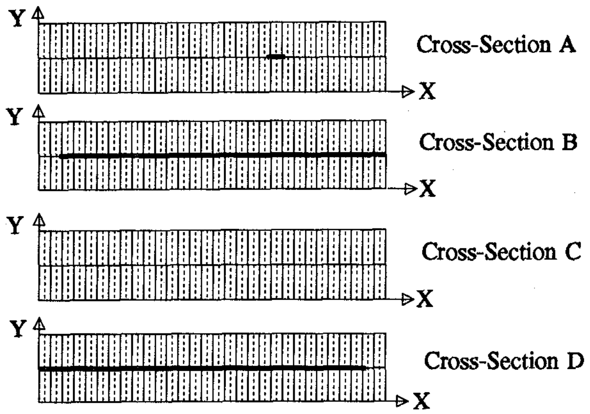


**Figure 2**: Discretization of regions A to D
-- = h-lines — = e-lines

It is important to note that, due to the use of an equidistant discretization pattern, the physical dimensions can only be approximated by the analysis.

Using MOL as described by Pregla [5], the transformed fields at each of these lines are expressed in analytic form. Enforcing the boundary conditions leads to eqn. 1, with $E_{xg}$ and $E_{zg}$ the x- and z-directed electric field components at the air-dielectric interface for lines not ending on the conducting strip and $\gamma$ the propagation constant.

$$[\,Y_{reduced}(\gamma)\,]\begin{bmatrix}[E_{xg}]\\ [E_{zg}]\end{bmatrix} = 0 \qquad (1)$$

An infinite number of values for $\gamma$, each one the propagation constant of a mode, can be calculated by setting $\det[Y_{reduced}]=0$. The function is however, ill-behaved and contains poles interspersed with zeros as well as sharp transitions.

By calculating the positions of these poles directly from simplified expressions for the Y-matrix, the second-order Newton-Raphson root-finding algorithm in eqn. 2 is used to iteratively search for zeros in each interval between two successive poles. Both the first and second derivatives are calculated numerically.

$$x_n = x_{n+1} + \alpha\Delta_x$$

$$\Delta_x = -\left(\frac{f(x_n)}{f'(x_n) - \dfrac{f''(x_n)\,f(x_n)}{2f'(x_n)}}\right) \qquad (2)$$

## 3. MATCHING THE FIELDS

A well-known mode-matching procedure as proposed by Omar and Schünemann [6] is used as a basis for matching the fields at the discontinuity plane. The integrals are, however, modified to use the transformed fields which are discrete in the x-direction but analytical in the y-direction. Implementing this method results in the formulation of eqn. 3. Subscripts A and B designates the areas on either side of a discontinuity and [a] and [b] are column vectors with $a_i$ and $b_i$ the amplitude of the i-th incident and reflected modes respectively .

$$[P]([a_A]+[b_A]) = [A]([a_B]+[b_B])$$
$$[A^*]^t([a_A]-[b_A]) = [Q^*](-[a_B]+[b_B])$$

$$P_{n,n} = \int_{S_A}(\bar{e}_{An}\,x\,\bar{h}^*_{An})\cdot d\bar{S}_A \qquad (3)$$
$$Q_{m,m} = \int_{S_B}(\bar{e}_{Bm}\,x\,\bar{h}^*_{Bm})\cdot d\bar{S}_B$$
$$A_{n,m} = \int_{S_B}(\bar{e}_{Bm}\,x\,\bar{h}^*_{An})\cdot d\bar{S}_B$$

The generalized S-matrix is computed from this as

$$\begin{bmatrix}[b_A]\\ [b_B]\end{bmatrix} = \begin{bmatrix}[S_{11}] & [S_{12}]\\ [S_{21}] & [S_{22}]\end{bmatrix}\begin{bmatrix}[a_A]\\ [a_B]\end{bmatrix} \qquad (4)$$

The integrals are computed by replacing the integration in the x-direction with a summation to include the field values at discrete lines. The integral in the y-direction is expressed in terms of the transformed field quantities to make use of the analytic form of these quantities. The general form of the integrals are shown in eqn. 5.

The *e* and *h* vectors in eqn.5 contain the tangential field values at the air-dielectric interface, while the *I* matrices are diagonal matrices containing the computed integrals in the y-direction. It is clear that only the fields at the air-dielectric interface need to be computed by the MOL. The notation $b^+$ and $b^-$ should be interpreted as infinitely close to the air-dielectric interface as approached from the top and bottom respectively. All the matrices are either column vectors or diagonal matrices. This ensures very fast calculation times and efficient memory usage.

$$A_{n,m} = \begin{bmatrix} [\tilde{e}_{xBm}(b^-)] \\ [\tilde{e}_{xBm}(b^+)] \\ [\tilde{e}_{yBm}(b^-)] \\ [\tilde{e}_{yBm}(b^+)] \end{bmatrix}^t \begin{bmatrix} [I_q^{IIh}] & & & \\ & [I_q^{Ih}] & & \\ & & -[I_q^{IIe}] & \\ & & & -[I_q^{Ie}] \end{bmatrix} \quad (5)$$

$$x \begin{bmatrix} [\tilde{h}_{yAn}(b^-)] \\ [\tilde{h}_{yAn}(b^+)] \\ [\tilde{h}_{xAn}(b^-)] \\ [\tilde{h}_{xAn}(b^+)] \end{bmatrix}^*$$

## 5. RESULTS

From figs. 1 and 2, it is clear that the filter consists of only three different discontinuities. Each one is characterised with a generalised S-matrix, designated $S_a$ etc. as in fig. 3.

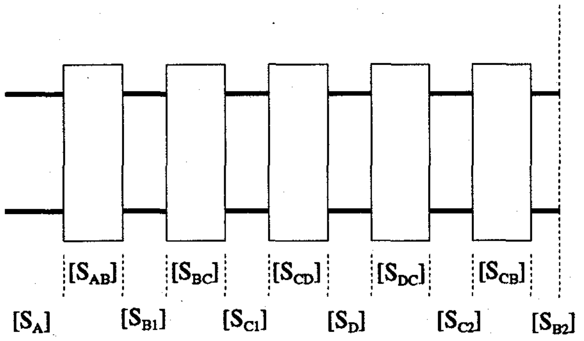


**Figure 3**: Cascaded S-matrix Model of Filter

The S-matrices are then coupled with sections of transmission line and cascaded to obtain the final result.

The analysis was carried out on a 586-based PC running MATLAB 4.0. Thirty e-lines and thirty-one h-lines were used for the two-dimensional MOL and sixty modes were used in each section for the mode-matching.

Two filters, denoted A and B, were manufactured and measured. The predicted frequency response of $S_{21}$ is compared with both sets of measured data in fig. 4.

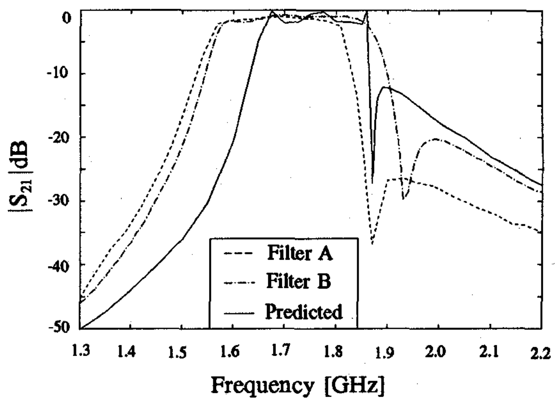


**Figure 4**: Transmission Coefficient of Filter

The most important feature of fig. 4 is the prediction of the transmission zero. This is a modal effect and can only be predicted by full-wave solvers for *closed structures*. It is clear that the position of this zero is very sensitive to manufacturing tolerances, as it shifted by quite a distance from one filter to the next. The predicted position lies between the two measured values.

The predicted low band roll-off differs from the measured one by 0.1GHz. The deviations cannot be attributed to a lack of convergence in the mode-matching procedure, as special care was taken to ensure convergence. Rather, one should look at the effect of discretization distance and the errors introduced in the dimensions of the model due to the use of a uniform discretization pattern.

## 6. CONCLUSIONS

The results in fig.4 shows that the combined mode-matching and method-of-lines technique can be used to analyze complex problems with good results. The method shows promise for the use in electrically large problems due to the efficient usage of memory and the linear way in which the numerical effort increases with increase in the length of the structure.

## 7. REFERENCES


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