AN ACCURATE AND FAST ONE-STEP ANALYSIS OF WAVEGUIDE FILTERS WHICH INCLUDES THE EDGE CONDITIONS

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Abstract

The Coupled-Integral Equations Technique (CIET) is applied to accurately determine the frequency response of waveguide filters in a *single step.* A 4-resonator H-plane filter is analyzed by the Mode-Matching Technique (MMT) and the CIET for comparision and results in a reduction of CPU time of the order of 400. A set of coupled integral equations for the tangential electric fields at the apertures of the discontinuities are derived and solved the moment method. Basis functions, which include the edge conditions at each of the discontinuities, are used to achieve numerical efficiency. It is shown that four basis function, which include the edge conditions, are sufficient to over a broad range of frequencies.

Mit Hilfe der gekoppelten Integralgleichungsmethode wird die genaue Berechnung eines Hohlleiterfilters demonstriert. Der grosse Vorteil der hier vorgestellen Method gegenüber anderen bekannten Verfahren liegt darin, dass die Brechnung der Streumatrix nicht iterativ erfolgt, d.h. die Diskontinuitäten werden nicht einzeln berechnet und dann rechnerisch hintereinandergeschaltet, sondern im selben Rechnungschritt. Das führt auf eine Reduzierung der Rechenzeit von über 400, wie an dem Beispiel eines 4-Resonatpr H-Ebenen Filters im Vergleich mit der bekannten Mode Matching Method gezeigt wird. Die Integralgleichungen für das tangentiale elektrische Feld werden in der Blendenöffnung entwickelt und mit Hilfe der Momentenmethode gelöst. Es werden Basisfunktionen benutzt, die die Kantenbedingungen in der Diskontinuitätsebene befriedigen. Es wird gezeigt, dass vier Basisfunktionen ausreichend sind, um Konvergenz zu erzielen.

1 INTRODUCTION

Microwave filters are widely used components in modern microwave communications systems [1]. Waveguide technology is often employed in implementing these frequency selective devices whose frequency response must be accurately predicted before the actual implementation is carried out in order to save cost and time.

In the Mode-Matching Technique (MMT), the generalized scattering matrix of the structure is determined by cascading the scattering matrices of the different discontinuities [1]. The method is, however, known to converge slowly when sharp metallic edges are present in the structure and suffers from the phenomenon of relative convergence [2].

In this work, we propose to modify the Mode-Matching Technique (MMT) in three major ways. Include the edge conditions, eliminate the phenomenon of relative convergence and formulate the problem in a single step thereby making the description of the interactions between the discontinuities systematic. A set of coupled integral equations for the electric field at the discontinuities result, hence the name the Coupled-Integral-Equations Technique (CIET) [3].

Numerical results obtained from the CIET are compared to those from the MMT to demonstrate the accuracy and speed of the new technique.

2 THEORY

The theory is presented for the example of a four-resonator H-plane filter structure which consists of a lossless rectangular waveguide of cross section $a \times b$ and 5 symmetric H-plane irises of thickness L as depicted in figure 1. The apertures of the irises are $a_i = a - 2b_i$ where b_i is the width of one side of the i^{th} iris.

We assume that only the fundamental mode TE_{10} is incident, with amplitude equal to unity, from the left side.

We introduce additional degrees of freedom in the problem in a such a way that the boundary conditions of the electric field are *always* satisfied. Let the true electric field distributions ($E_y(x)$) at the discontinuities be given by the unknown functions $X_i(x)$. Using the boundary conditions of the transverse electric field at the different discontinuities we can express the modal coefficients in each region in terms of integrals of the functions $X_i(x)$. A set of coupled integral equations for the unknown functions X_i are derived from the continuity conditions of the magnetic field H_x at the different discontinuities. To solve this set of coupled integral equations, we expand the functions $X_i(x)$

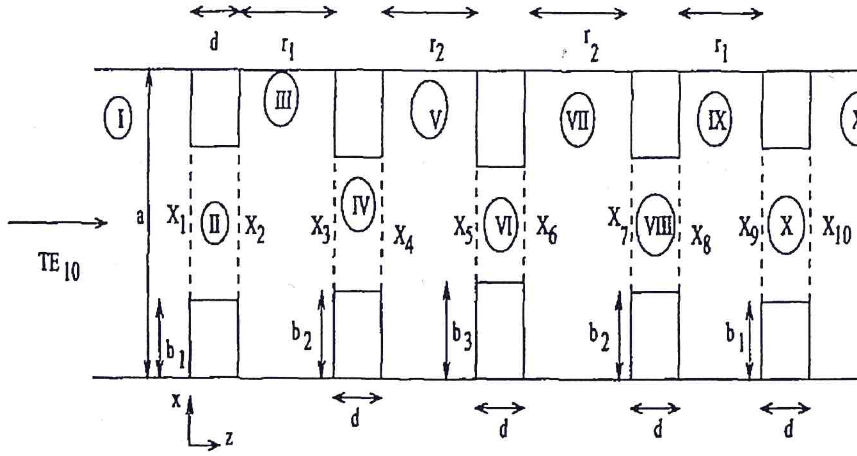

Figure 1: Cross section of a 4-Resonator H-plane filter.

in series of basis functions as follows

$$X_i(x) = \sum_{j=1}^{M} c_{ij} B_{ij}(x), \quad i = 1,..,10. \tag{1}$$

By applying Galerkin's method to the set of coupled integral equations, a set of coupled linear equations in the expansion coefficients results. Here, the following set of basis functions are used

$$B_{ik}(x) = \frac{sin[k\pi \frac{(x-b_i)}{a_i}]}{[(x-b_i)(a_i+b_i-x)]^{1/3}}, \quad k = 1,3,5,\ldots \tag{2}$$

3 NUMERICAL RESULTS

A 40 MHz 28 dB return-loss level filter was designed using standard filter synthesis in combination with the Mode-Matching Technique. This example was chosen specifically to highlight the characteristics of the two methods. Figure 2 shows the return loss of such a filter as obtained from the MMT when 45/15 modes are used in the design (synthesis) and analysis process. A convergence study was then conducted for this filter for both methods. Figure 3 shows the return loss of this filter as obtained from the CIET (solid line) with 4 edge-conditioned basis functions and from the MMT. As the number of modes in the MMT increases, especially those to model the iris discontinuities, the numerical results of the MMT approach those obtained from the CIET. However, even with 100 modes at the irises, the MMT has not reached convergence yet. This is demonstrated in figure 3 where the two rightmost poles of figure 3 are shown to merge. The CPU-time comparison

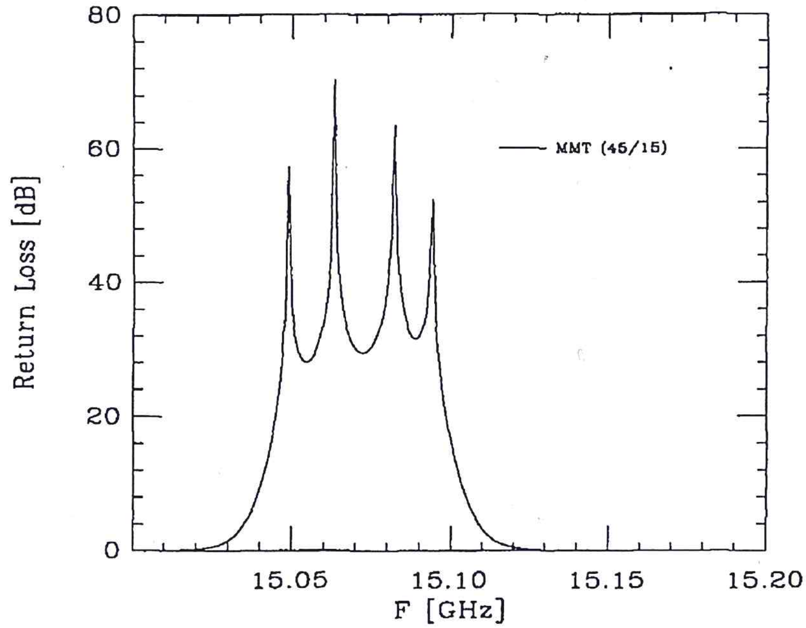

Figure 2: Return loss (dB) as a function of frequency as obtained from the MMT with 45/15 modes.

between the MMT with 100/15 modes and the CIET with 4 edge-conditioned basis functions amounts to a factor of 400.
The convergence of the CIET is shown in figure 4 for $M = 1, 2, 4, 5$ and 10 basis functions. Convergence is reached with only 4 basis functions.

4 CONCLUSIONS

The coupled-Integral-Equations Technique was successfully applied to accurately analyze H-plane waveguide filters in one step. A large reduction in the CPU time over the Mode-Matching Technique (MMT) is achieved by using basis functions which include the edge conditions.

5 REFERENCES

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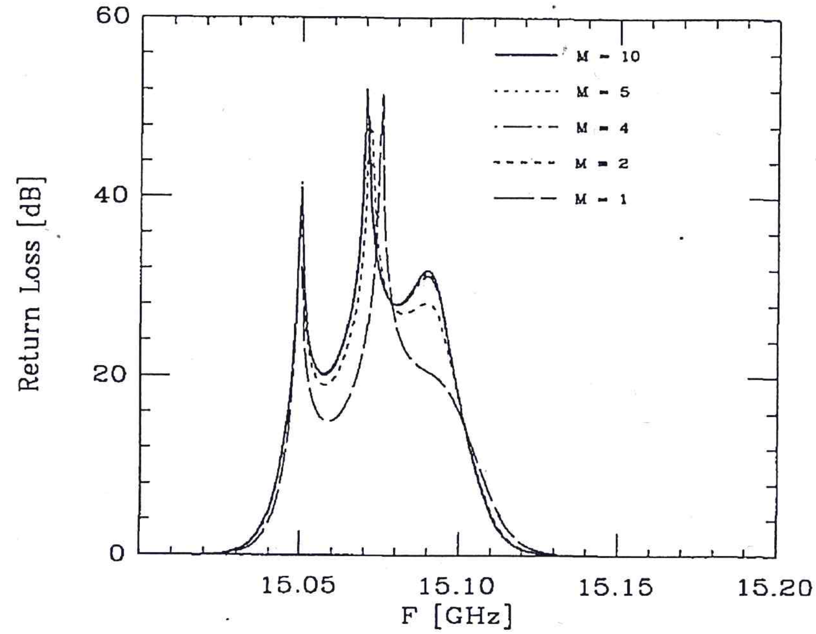

Figure 3: Return loss (dB) as a function of frequency as obtained from the CIET (solid line) with 4 basis functions and the MMT with 85/15 and 100/15 modes. The CIET reduces CPU time by a factor of 400.

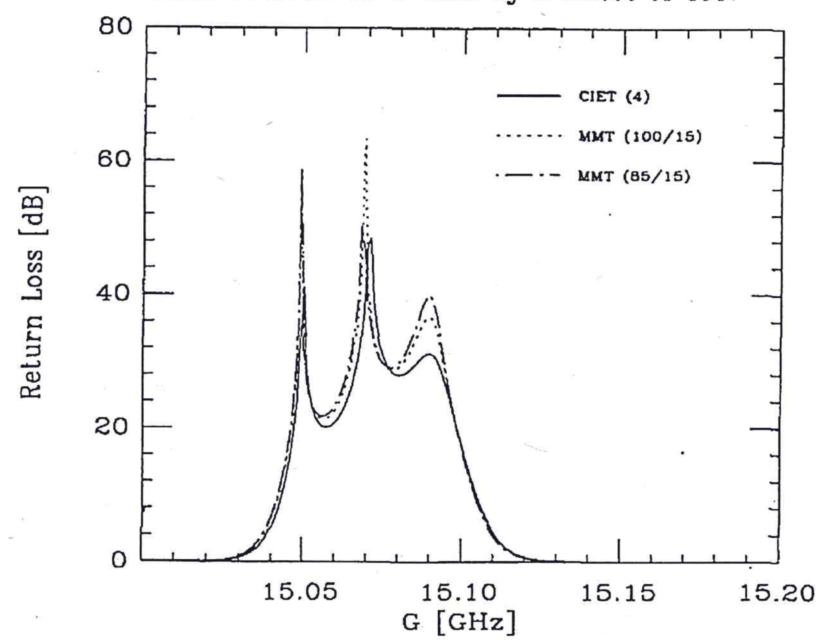

Figure 4: Return loss (dB) as a function of frequency for M=1,2,4,5 and 10 basis functions within the CIET.