Broad Band Analysis of Arbitrarily Shaped Microwave Filters Using a Novel Singular Value Decomposition Technique

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Abstract—**A new full-wave electromagnetic analysis method based on the Boundary Integral Resonant Mode Expansion (BI-RME) is presented in this paper. The technique allows the computation of the broad band circuital response of arbitrarily shaped cavity filters. The coaxial excitation of this kind of filters is rigorously modeled by taking into account the high order modes on the coaxial aperture. A singular decomposition algebraic procedure has been implemented in order to obtain the solenoidal and non-solenoidal counterparts contributions of the electric current density inside the cavity needed by the BI-RME formulation. This method is simple and avoids some issues associated to star and loop based functions which are typically used for the same purpose.**

I. Introduction

In this paper we propose an efficient technique for the broadband analysis of a wide variety of microwave filters. The method is based on the well known Boundary Integral Resonant Mode Expansion (BI-RME). This numerical technique was first proposed at the University of Pavia (Italy) for the evaluation of the cut-off frequencies of arbitrarily shaped waveguides [1]. Later, it was extended to the calculation of the resonant modes of three dimensional cavities [2], and for the broadband characterization of E-Plane [3] and H-Plane [4] filters. In recent years, the BI-RME method was applied to the efficient evaluation of the circuital parameters of three dimensional microwave devices [5]. Moreover, the coaxial

excitation included in some of these structures has also been modelled rigurously [6]. In all cases, the results are very accurate and agree well with those provided by commercial software packages, like HFSS.

However, the rigorous coaxial excitation model is limited to cylindrical probes not touching the metallic areas of the structures of the resonators, since the original technique assumes specialized basis functions for implementing the BI-RME method [7]. These basis functions are tailored for cylindrical geometries, and they are divided in two sets (solenoidal and non solenoidal), due to the specific characteristics of the BI-RME formulation.

In our case, we extend for the first time the technique for the analysis of complex microwave filters where the coaxial probe is connected to the inner metallic post of the input and output interdigital cavities (see Fig 1). For this situation, the particular basis functions employed in [7] are no longer valid, and a more general set of expansion functions such as RWG [8] is needed. Unfortunately, these RWG basis functions can not be used in their original form when applyng the BI-RME method, and some kind of numerical procedure is required in order to obtain their solenoidal and non-solenoidal contributions. A new procedure based on an algebraic singular value decomposition (SVD) numerical technique has been employed in this contribution, for the first time, for dividing the original

RWG in solenoidal and non-solenoidal counterparts.

II. Theory

The BI-RME method allows a broadband analysis of microwave devices, avoiding time consuming frequency loops required by other numerical techniques like Finite Elements or other standard Integral Equation Formulations. The admittance parameters of a structure are written by using the BI-RME technique in terms of frequency independent terms, and a fast convergent summation:

$$\mathbf{Y} = \frac{1}{jk\eta}\mathbf{Y}^A + \frac{jk}{\eta}\mathbf{Y}^B + \frac{jk^3}{\eta}\sum_{i=1}^{M'}\frac{\mathbf{y}^{(i)}\mathbf{y}_T^{(i)}}{k_i^2 - k^2} \quad (k \leq k_{max}) \quad (1)$$

where $\mathbf{Y}^A$ and $\mathbf{Y}^B$ are frequency independent matrices, and represent the pseudo-static behaviour of the circuits. On the other hand, the last term is a fast convergent summation (depends on $1/k_i^4$, with only M' terms) of the eigenvalues k_i and eigenvectors $\mathbf{x}^{(i)}$ ($\mathbf{y}^{(i)} = k_i^{-1}\mathbf{C}_T\mathbf{x}^{(i)}$; $\mathbf{C}_T$ is a matrix of the BI-RME formulation) of the BI-RME cavity resonator containing the device under analysis. The previous expression represents accurately the frequency response of the analyzed microwave device up to k_{max}. The M' terms of the summation depends on the k_{max} parameter.

For solving the generalized eigenvalue problem arising in the BI-RME formulation [5], we have modelled the inner conductor with triangular cells, where RWG basis functions $\mathbf{f}_n$ have been defined. These basis functions are divided into solenoidal $\mathbf{W}_{sol}$ and non solenoidal $\mathbf{V}_{nsol}$ parts after a SVD decomposition algorithm. Applying this algorithm two transfomation matrices are found ($\mathbf{t}^W$ and $\mathbf{t}^V$), and the next relations are established:

$$\mathbf{W}_{sol} = \mathbf{t}^W\mathbf{f}_n \quad ; \quad \mathbf{V}_{nsol} = \mathbf{t}^V\mathbf{f}_n \quad (2)$$

Once these transformations have been performed the new solenoidal and non-solenoidal basis functions can be introduced into the general BI-RME formulation presented in [5] for solving the eigenvalue problem. Finally, the excitation ports of the microwave devices are taken into account and the admittance parameters expression presented in Eq. (1) is used for evaluating the electric response.

III. Results

As an example of the numerical technique developed in this paper, we have analyzed a fith order interdigital bandpass filter shown in Fig. 1. In this case 2716 original RWG basis functions have been employed for modelling the input and output cavities where the coaxial probes are touching the center conductor of the cavities. After the SVD is applied, the RWG functions are transformed into 918 solenoidal and 1768 non-solenoidal basis functions.

We have validated the proposed method by comparing the response (Magnitude of the S_{11} parameter) of the filter to those given by the commercial software packages HFSS[©] and MICIAN[©]. As can be seen in Fig. 2, the agreement shown between our technique and the other software tools is very
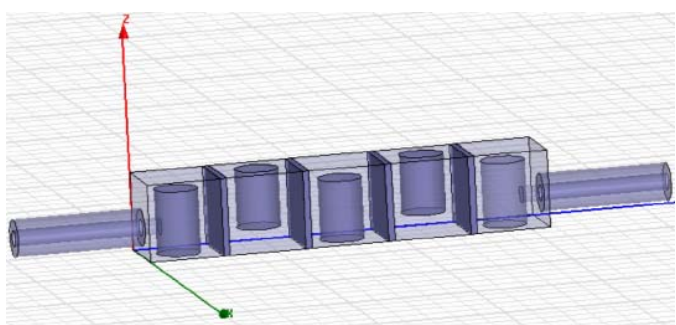

Fig. 1. Fifth order interdigital band pass filter. The coaxial input and output probes are touching the inner posts of their corresponding interdigital cavities.

good. Moreover, whereas the simulation time for BI-RME is around three minutes, for HFSS and MICIAN can take two or three hours on the same computer.
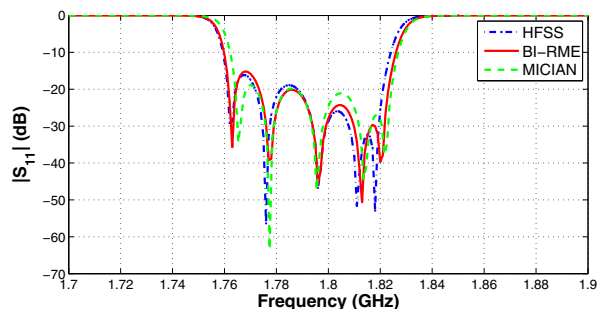

Fig. 2. $|S_{11}|$ scattering parameter for the interdigital filter of Fig. 1. BI-RME results are compared to those given by the commercial software tools HFSS[©] and MICIAN[©].

Finally, to show the important of the SVD algorithm in order to find the solenoidal and non-solenoidal contributions of the original RWG basis functions, in Fig. 3 we present the S_{11} parameter of the interdigital filter for different BI-RME numerical implementations. First, the results after the SVD technique are depicted in red solid line. Also, the same BI-RME analysis has been carried out by using the original non transformed RWG basis functions, and the results are represented in green dahed line. The last result corresponds to a tranformation of the RWG into star (non-solenoidal) and loop (solenoidal) basis functions similar to the one proposed in [5]. As can be seen in Fig. 3 the second and third numerical procedure yield to wrong filter responses. The reason for the numerical error when using the original RWG functions is that Eq. (1) is not longer valid, and the filter response is not expressed in term of fast convergent summation. In the case of the star-loop basis functions the numerical algorithm also fails, since the null-space (solenoidal basis functions) is not properly represented when the mesh of the structure is touching the cavity walls (the mesh is open on the contact surface). This problem was not found in [5] due to the analysis of microwave devices modelled with only closed meshes.
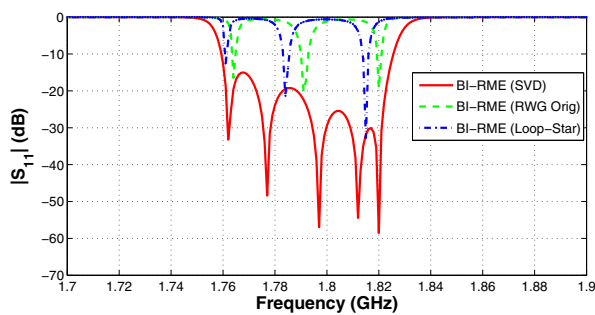
Fig. 3. $|S_{11}|$ scattering parameter for the interdigital filter of Fig 1. Three numerical implementation are compared: The application of the SVD algorithm, the original RWG basis functions and the star-loop basis functions.

CONCLUSION:

A numerical technique based on the BI-RME method has been proposed for the analysis of complex microwave devices with coaxial excitation. For the first time, the coaxial probe touching the inner conductor has been modelled rigurously within a broadband analysis framework. A new algorithm based on a Singular Value Decomposition (SVD) has been introduced for obtaining the solenoidal and non-solenoidal contributions of RWG basis functions with the BI-RME formulation. Results show a very good agreement with commercial software with a reduced simulation time.

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REFERENCES

[1] G. Conciauro, M. Bressan, and C. Zuffada, "Waveguide modes via an integral equation leading to a liner matrix eigenvalue problem," *IEEE Transactions on Microwave Theory and Techniques*, vol. 32, no. 11, pp. 1495–1504, Nov. 1984.

[2] P. Arcioni, M. Bressan, , and L. Perregrini, "A new boundary integral approach to the determination of the resonant modes of arbitrarily shaped cavities," *IEEE Transactions on Microwave Theory and Techniques*, vol. 43, no. 8, pp. 1848–1855, Aug. 1995.

[3] P. Arcioni, M. Bressan, G. Conciauro, , and L. Perregrini, "Wideband modelling of arbitrarily shaped e-plane componentes by the boundary integral-resonant mode expansion method," *IEEE Transactions on Microwave Theory and Techniques*, vol. 44, no. 11, pp. 2083–2092, Nov. 1996.

[4] G. Conciauro, P. Arcioni, M. Bressan, and L. Perregrini, "Wideband modelling of arbitrarily shaped h-plane componentes by the boundary integral-resonant mode expansion method," *IEEE Transactions on Microwave Theory and Techniques*, vol. 44, no. 7, pp. 1057–1066, Jul. 1996.

[5] P. Arcioni, M. Bozzi, M. Bressan, and L. Perregrini, "A novel cad tool for the wideband modeling of 3d waveguide components," *International Journal of RF and Microwave Computer Aided Engineering*, vol. 10, no. 3, pp. 183–189, May 2000.

[6] M. Bressan, L. Perregrini, and E. Regini, "Efficient cad of generalized coaxial probes in rectangular waveguide using the 3d bi-rme method," in *36th Euopean Microwave Conference*.   Manchester, UK: IEEE, 2006, pp. 1163–1166.

[7] F. Mira, M. Bressan, G. Conciauro, B. Gimeno, and V. E. Boria, "Fast s-domain modeling of rectangular waveguides with radially symmetric metal insets," *IEEE Transactions on Microwave Theory and Techniques*, vol. 53, no. 4, pp. 1294–1303, April 2005.

[8] S. M. Rao, D. R. Wilton, and A. W. Glisson, "Electromagnetic scattering by surfaces of arbitrarily shape," *IEEE Transactions on Antennas and Propagation*, vol. 30, no. 5, pp. 409–418, May 1982.