High Power Analysis in Coaxial Combline Resonator Filters

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Abstract

In this paper, the Boundary Integral Resonant Mode Expansion (BI-RME) Method is employed to obtain the generalized admittance matrix of cavity resonators by using the well-known Rao-Wilton-Glisson (RWG) basis functions to model both electric and magnetic current densities in the problem. The method has been implemented inside the FEST3D software, in order obtain the response of coaxial combline filters. Then, the electromagnetic fields can be computed at any point using a novel technique that takes advantage of the Integral Equation formulation solved by the BI-RME method. Once obtained, the electromagnetic fields inside these structures are used to accurately predict high power phenomena such as Multipactor and Corona discharges.

1 INTRODUCTION

Nowadays, coaxial combline resonator filters are widely used in satellite and wireless communication systems, mainly due to their small-size, low cost, wide tuning range and excellent spurious-free performance. These filters may be also employed at high power levels, thus increasing the risk of Multipactor and Corona discharge. Nevertheless, currently there are no suitable software tools for the accurate prediction of high power phenomena, forcing engineers to use simplified models in the design process.

In this paper, an efficient method for performing electromagnetic analysis together with high power study for coaxial combline filters is presented. The electromagnetic characterization of the resonant cavities is performed by means of the Boundary Integral - Resonant Mode Expansion (BI-RME) method [1], which is used to obtain the Generalized Admittance Matrix (GAM) of such cavities in terms of a pole expansion in the Laplace variable domain. The integration into the FEST3D software [2] allows to evaluate the response of combline filters in a wide frequency bandwith efficiently. Besides, it is possible take further profit of the Integral Equation of the BI-RME method and also employ it to compute the electromagnetic fields inside the structures.

Once the fields inside the combline filters are obtained, rigorous breakdown power analysis for corona and multipactor discharges can be performed by making use of the FEST3D high power modules. Interesting results will be presented for some filter examples, showing the region of interests for the study of high power phenomena.

2 THEORY

The BI-RME method [1] has been formulated and applied for 3D problems involving metallic [3, 4] as well as dielectric [5] resonator structures. The fields generated by surface electric and magnetic current densities inside the resonant cavity can be expressed as:

$$\begin{aligned}\vec{E}(\vec{r}) = {} & \frac{\eta}{s}\nabla \int_S g^e(\vec{r},\vec{r}')\,\nabla'_s \cdot \vec{J}(\vec{r}')\,dS' - s\eta \int_S \bar{\mathbf{G}}_0^A(\vec{r},\vec{r}')\cdot \vec{J}(\vec{r}')\,dS' \\ & - \int_S \nabla \times \bar{G}_0^F(\vec{r},\vec{r}')\cdot \vec{M}(\vec{r}')\,dS' + \frac{1}{2}\hat{n}\times \vec{M}(\vec{r})\end{aligned} \tag{1}$$

$$\begin{aligned}\vec{H}(\vec{r}) = {} & \frac{1}{s\eta}\nabla \int_S g^e(\vec{r},\vec{r}')\,\nabla'_s \cdot \vec{M}(\vec{r}')\,dS' - \frac{s}{\eta} \int_S \bar{\mathbf{G}}_0^A(\vec{r},\vec{r}')\cdot \vec{M}(\vec{r}')\,dS' \\ & + \int_S \nabla \times \bar{G}_0^F(\vec{r},\vec{r}')\cdot \vec{J}(\vec{r}')\,dS' + \frac{1}{2}\vec{J}(\vec{r})\times \hat{n}\end{aligned} \tag{2}$$

In (1) and (2), s is the Laplace domain variable ($s = jk$), and g^e and g^m are the Green's functions of the electric and magnetic scalar potentials, whereas $\bar{G}_0^A$ and $\bar{G}_0^F$ are the correspondent dyadics for the electric and magnetic vector potentials of the same cavity, respectively. As a paricularity imposed by the BI-RME method for this kind of problems that involve rectangular cavity resonators, all these Green's functions are those of a rectangular cavity, expressed in terms of the Coulomb gauge [1, 3].

The electric current density $\vec{J}$ is defined on the surface of the metallic perturbations that appear inside the cavity, and are modelled in terms of a mixed expansion of solenoidal and non-solenoidal basis functions $\vec{W}$ and $\vec{V}$, respectively:

$$\vec{J} = \frac{-s}{\eta}\sum_{p=1}^{P} b_p \vec{V}_p + \frac{1}{\eta}\sum_{q=1}^{Q} c_q \vec{W}_q \tag{3}$$

In order to easily deal with cylindrical onsets inside the cavity filters(such as resonant posts, tuning screws, coaxial probes...), as well as for simplifying the treatment of the singular terms of the Green's functions, an alternative expansion of the current density has been considered, employing the well-known Rao-Wilton-Glisson (RWG) basis functions [6]:

$$\vec{J} = \sum_{n=1}^{N} d_n \vec{f}_n \tag{4}$$

where the coefficients d_n can be obtained by means of transformation matrices derived from a singular value decomposition of some of the matrices employed in the BI-RME common approach [3, 7].

On the other hand, the magnetic current density $\vec{M}$ is defined on the surface of the different ports accessing the cavity. This current density is expanded in the general form:

$$\vec{M} = -\sum_{l=1}^{L} v_l \vec{g}_l \tag{5}$$

where $\vec{g}$ is a generic basis function and v its associated coefficient. This expansion (5) can be performed employing different kinds of basis functions, which can be conveniently chosen in order to optimize the efficiency and also simplify the complexity of the method. For example, for the common case of rectangular waveguides used as exit ports, magnetic fields modal vector funcions can be employed for the magnetic current expansion, since the treatment with the double surface integrals with the rectangular cavity Green's functions can be performed analytically [3].

The advantage of the BI-RME formulation is that it allows to obtain a pole expansion in the Laplace domain of the GAM matrix of the whole cavity togegher with the internal perturbations [1]. This way, it is possible to efficiently solve the problem by computing frequency independent matrices that can be easily operated to quickly obtain the filter response in a large bandwith. Therefore, the circuital paremeters of combline structures can be obtained accurately and very fast as compared with other general purpose methods, allowing engineers to design and analyze this kind of structures in a reasonable time without approximation considerations.

Once the structure has been solved, the electromagnetic fields can be computed using expressions (1) and (2). In order to perform this task, it is very important to be able to deal with the singular terms arising in those equations when the observation point is located very close the electric or magnetic sources (which are the metallic perturbations or the acess ports). These singular expressions are found to be:

$$\vec{F}_1(\vec{r}) = \nabla \int_{S'} \frac{1}{4\pi R}\, dS' \tag{6}$$

$$\vec{F}_2(\vec{r}) = \int_{S'} \frac{1}{8\pi R}(\bar{I} + \frac{\bar{R}\bar{R}}{R^2}) \cdot \vec{f}_b(\vec{r}')\, dS' \tag{7}$$

$$\vec{F}_3(\vec{r}) = \nabla \times \vec{F}_2(\vec{r}) \tag{8}$$

where R is the spatial distance between observation and source points, and $\vec{f}_b$ is a RWG basis function. The singularity of the terms above is specially strong in the cases of (6) and (8), which are of the form $(1/R^2)$ and $(1/R^3)$, respectively, and lead to high numerical errors if standard cuadrature rules are used to evaluate the integrals. Fortunately, analytical expressions for this problem can be derived from the results of the previous works [8, 9].

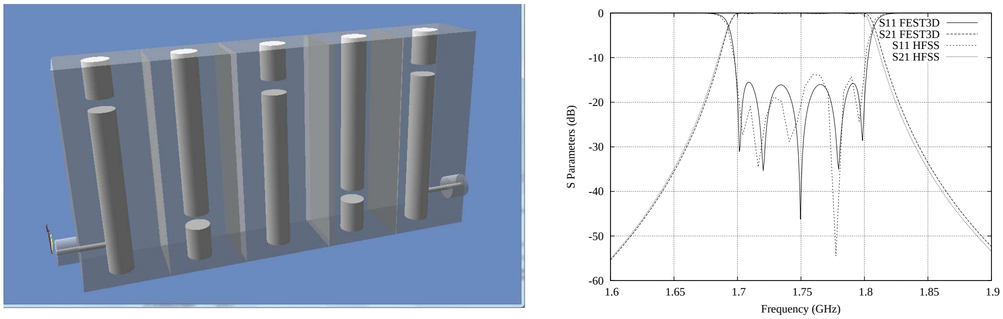
The calculation of the electromagnetic fields inside the combline filters can be employed afterwards to perform different kinds of high power analysis. First, Multipactor (breakdown under vacuum environment) can be accurately modelled by the use of an electron tracking algorithm together with a proper secondary electron yield model [10]. On the other hand, Corona discharge (breakdown under high and intermediate pressure conditions) shall be analyzed through the solution of the free electron density continuity equation by means of the Finite Element method [11]. In the next section some results of the application of these algorithms will be shown.

3 RESULTS

The presented results have been obtained by using the FEST3D software, in which the BI-RME method together with the high power analysis modules have been implemented.

3.1 Example 1: Interdital filter excited with coaxial magnetic coupling

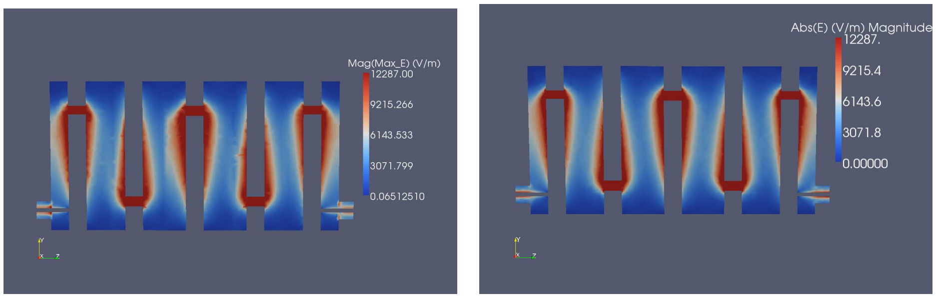
The first filter example is shown in Fig. 1(a). It consists in a 5-cavity interdigital filter excited by coaxial probes, which are contacting resonant cylindrical posts (magnetic coupling). Besides, additional tuning screws have been considered in order to optimize the filter response with more than 15 dB of return losses, as shown in Fig. 1(b). The results of FEST3D are also compared to the Finite Element software HFSS [12] as validation reference. It can be noticed that the two techniques agree very well in the analsys of the structure. The electromagnetic fields inside this interdigital filter can be efficiently obtained with FEST3D by means of the Integral Equation of the BI-RME method commented in the theory section. As a sample, the magnitude of the Electric field at the central frequency (1.75 GHz) is depicted in a 2D cut in Fig. 2(a). The fields are found to be very intense inside the resonant cavities, specially at the air region delimited between the resonant posts and the tunins screws. The results of the BI-RME method agree very well with the fields obtained by the Finite Element technique of the HFSS software, as can be observed in Fig. 2.



(a) General view of the filter.

(b) Scattering parameters of the filter. Results of FEST3D are compared with HFSS.

Figure 1: Geometry and scattering parameters of a combline filter with coaxial magnetic coupling excitation.



(a) FEST3D results

(b) HFSS results

Figure 2: Magnitude of the electric field computed with FEST3D for the combline folded filter. Results are validated with HFSS

Due to the high field values, both corona and multipactor discharges are likely to take place. The corona breakdown algorithm has been applied to study the first cavity of the filter, which is excited by the coaxial magnetic coupling. The breakdown power versus pressure (for air conditions) is shown in Fig. 3. At the pressure of 2.5 mBar, the breakdown power level is found to be minimum (about 3.5 Watt). On the other hand, the resonace condition for multipactor discharge occurs in the air gap between the posts and the tuning screws. For the cavity excited by the coaxial probe, the breakdown power level has been detected at approximately 39.5 Watt.

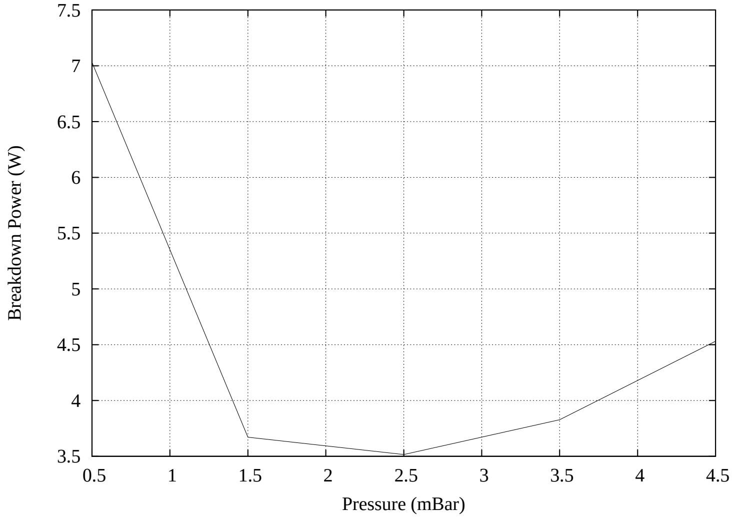


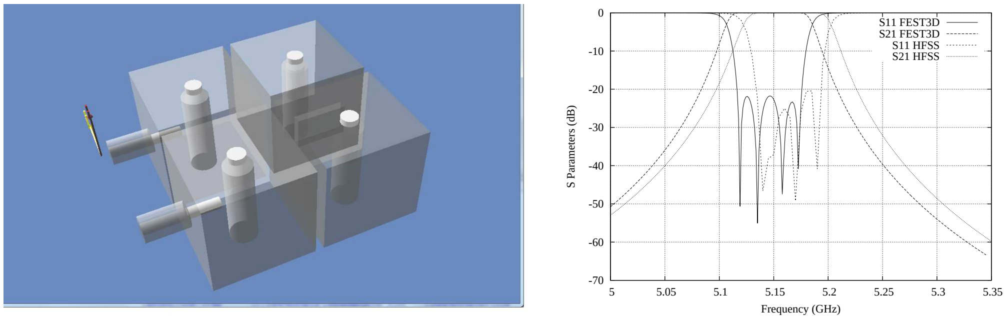
Figure 3: Corona breakdown power versus pressure for the central cavity of the filter, obtained with FEST3D.

3.2 Example 2: Folded filter with reentrant posts

A new filter geometry is shown in Fig. 4(a). This time the geometry is that of a combline folded filter, excited by coaxial probes (no magnetic coupling). The main resonant posts of each one of the four cavities is of reentrant type, which are partially hollow. Besides, tuning screws are included again to optimize the filter response with return losses above 20 dB (see Fig. 1(b)). Again, the results of the FEST3D software are also compared with HFSS for validation, showing very similar responses despite a slight frequency shift. As in the previous example, the BI-RME approach can be employed to compute the electromagnetic fields inside this filter. Two example views are shown in Fig. 5, computed at the central frequency of 5.15 GHz. The field values inside this folded filter are even more intense than in the previous example. The maximum fields values are found in the cavities which are not excited by the coaxial probes, as can be noticed from the views Fig. 5(a) and Fig. 5(b).

For each cavity, the most intense fields are located between the reentrant and the tuning posts. Therefore, this is the air region where corona discharge is produced. As an example, one of the cavities without coaxial excitation has been selected for a corona analysis. In Fig. 6, the curve of pressure versus breakdown power (air conditions) is presented, revealing the the minimum power is reached at a pressure of 6 mBar, with a value of approximately 0.5 Watt. This result proves the high magnitude achieved by the electric field in the surroundings of the metallic posts.

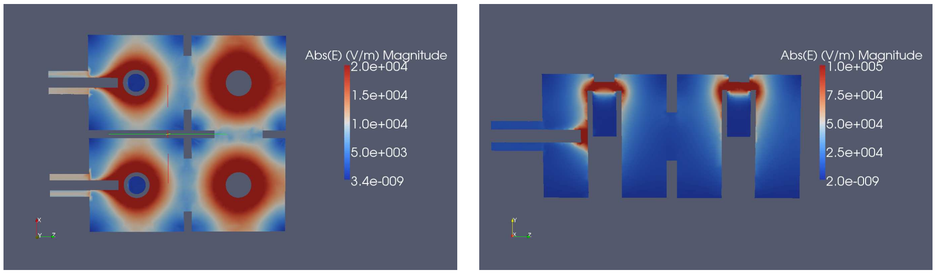
If a multipactor analysis is desired for this filter, the region of interest is not located at the zone where the highest fields are present. In Fig. 7, the electron impact density is plotted for one of the cavities fed by the coaxial



(a) General view of the filter.

(b) Scattering parameters of the filter. Results of FEST3D are compared with HFSS.

Figure 4: Geometry and scattering parameters of a combline filter with coaxial magnetic coupling excitation.



(a) Top view.

(b) Lateral view

Figure 5: Magnitude of the electric field computed with FEST3D for the folded filter.

probe, applying an excitation power of 42.5 Watt. The pictures clearly show how the resonant condition for multipactor discharge is in the gap between the excitation probe and the resonant post, where the impact density is found to be maximum. This phenomenum occurs as a consequence of the small distance between the two metallic cylinders, which is of the order of the probe radius (between 0.6 and 0.7 mm).

4 CONCLUSIONS

An efficient method for performing full electromagnetic and high power analysis inside coaxial combline filters has been presented. The circuital parameters, as well as the fields inside the filters, can be efficiently obtained by means of the BI-RME method. Afterwards, the field values can be employed to predict breakdown powers of either Corona or Multipactor discharges. The whole method has been integrated inside the FEST3D software, which has been employed to present some example cases, showing that the field values inside the filters are intense enough to produce high power phenomena at low power levels, proving therefore the utility of the software in the design procedures.

5 ACKNOWLEDGMENTS

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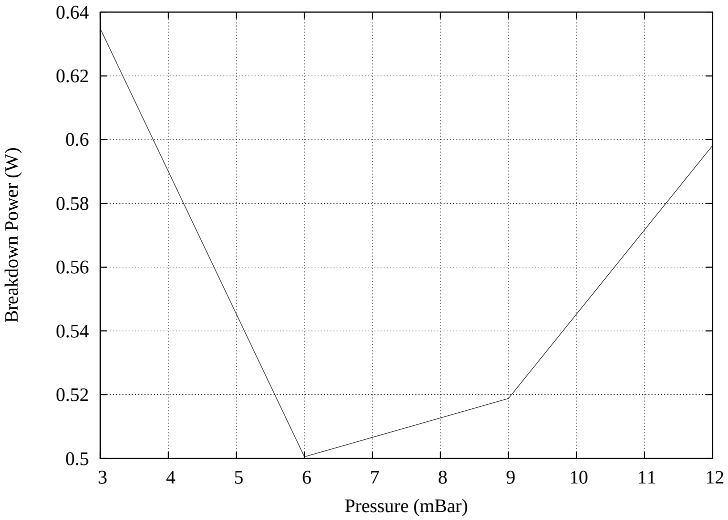
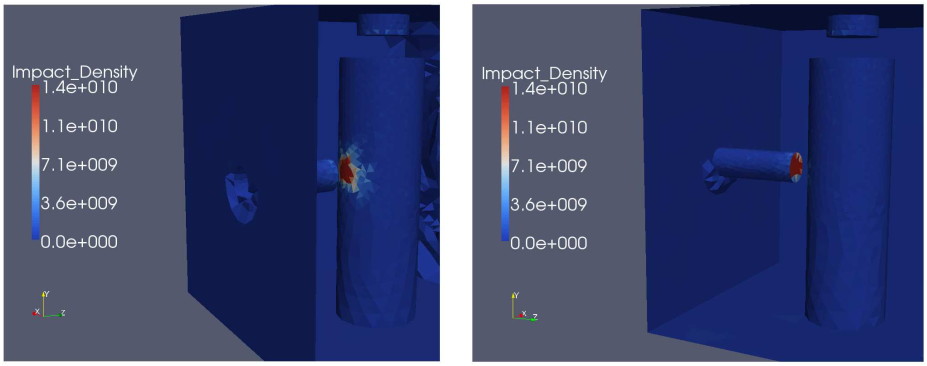


Figure 6: Corona breakdown power versus pressure for the central cavity of the filter, showing that discharge occurs at very low power levels.



(a) View 1 (b) View 2

Figure 7: Electron impact density for one of the cavities excited by the coaxial probes. The maximum impacts occur between the probe and the resonant post, where the multipactor discharge occurs at a power level of 42.5 Watt.

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