TLM based Analyses of EM Field Coupling to Wire Probes Inside Metallic Cavity

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Abstract— **This paper presents results achieved through electromagnetic (EM) field analysis in a microwave cavity where wire probes are used for modes excitation and detection. The compact wire model is implemented into the software based on 3-D TLM (Transmission-Line Matrix) numerical method, in order to take into account EM properties of a probe. Presented numerical results, compared with measured data, provide information regarding probe dimension and position influence on resonant modes of EM field inside a metallic cavity.**

Keywords- Cavity resonators, Wire probe, Electromagnetic analysis, Numerical Modeling, TLM method

I. INTRODUCTION

A metallic cavity represents a configuration suitable for adequate modeling of some microwave devices used in communication (filters, power dividers) or in industry (heating and drying applicators). Also, such configuration is typical closed environment for PCBs (Printed Circuit Boards). When practical realization of cavity is concerned, one of the most important issues is the EM field resonant modes distribution inside the metallic cavity, in order to achieve optimum transfer of energy or equally material drying.

There are many ways to couple energy into the cavity [1]. Generally, input and output ports of microwave cavity devices are realized by a coaxial probe that ensures coupling with corresponding EM field component. In practice, the probe has influence on a number of excited modes, leading to completely different results from those reached by theoretical approach. Also, the probe presence tends to shift modes in frequency and sometimes splits degenerate modes. Furthermore, relative amplitudes of resonances are variable for different probe locations and dimensions. Another problem in EM field consideration is accurate mode identification. Although reflection (S_{11}) and transmission (S_{21}) characteristic plots provide information about the number of modes in the cavity, they do not indicate exactly which modes are present. For these reasons, the knowledge of the mode tuning behavior in the cavity under particular conditions of excitation and detection forms an integral part of EM field studies and it has significant implication in microwave devices designing [2, 3].

As there is no analytical solution for the most cases of widely used cavities with wire probes, computational electromagnetic techniques emerge as an invaluable tool in the cavity design. TLM (Transmission-Line Matrix) time-domain method is a general, electromagnetically based numerical method that has been developed and applied to a variety of modeling problems [4]. Since the TLM software has been improved by implementation of the wire node [5], enabling the modeling of wires, the goal of this paper is to investigate the possibility of the 3-D TLM method for an EM field analysis in a microwave cavity where modes are being excited and detected through a probe. Furthermore, an accurate numerical investigation of the influence of excitation and detection elements on modes, including comparison with measured results, is presented.

II. TLM MODELING

In the conventional TLM time-domain method, EM field strength in three dimensions, for a specified mode of oscillation in a metallic cavity, is modeled by filling the field space with a network of link lines and exciting a particular field component through incident voltage pulses on appropriate lines. An efficient computational algorithm of scattering properties, based on enforcing continuity of the electric and magnetic fields and conservation of charge and magnetic flux [6] is implemented to speed up the simulation process. EM properties of different mediums in the cavity are modeled by using a network of interconnected nodes, a typical structure known as the symmetrical condensed node - SCN [6] and additional stubs incorporated into TLM network to account for inhomogeneous materials and/or electric and magnetic losses. Cavity walls are modelled as external boundaries of arbitrary reflection coefficient by terminating the link lines at the edge of the problem space with an appropriate load [6].

Wire probes, used for excitation and monitoring purposes inside the cavity, can be inherently described by additional link and stub lines interposed over the exiting network to account for increase of capacitance and inductance of the medium caused by their presence [5]. This wire network is usually placed in the centre of the TLM nodes (so called TLM wire node) in order to allow easy modelling of possible complex wire configurations, e.g. wire junctions and bends (Fig. 1). The single column of TLM nodes, through which wire conductor passes, can be used to approximately form the fictitious cylinder which represents capacitance and inductance of wire per unit length. Its effective diameter, different for capacitance and inductance, can be expressed as a product of factors empirically obtained by using known characteristics of TLM network and the mean dimensions of the node cross-section in the direction of wire running [7]. Such compact wire model allows for simple incorporation of voltage/current sources and lumped loads and takes into account the physical dimensions of wire probes [7], determined only by TLM mesh resolution.

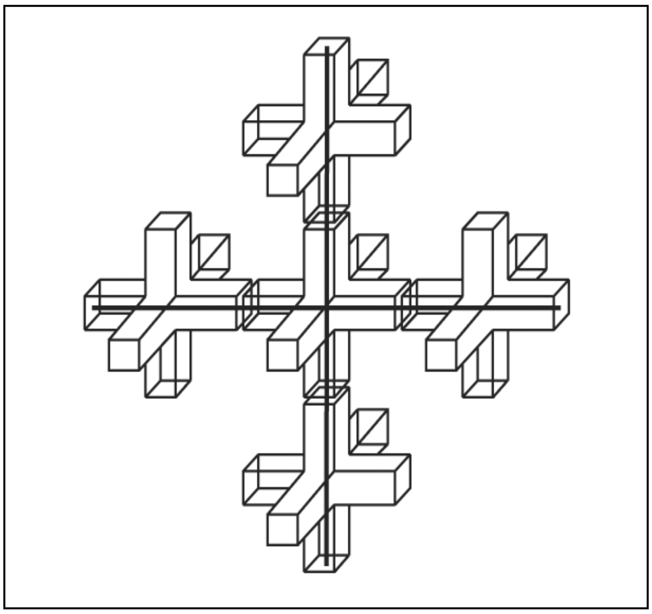

Figure 1. Wire network embedded within the TLM nodes

Following the experimental approach that using inner conductor of coaxial guide as a probe, numerical characterisation of EM field inside the cavity can be done by introducing wire ports at the interface between wire probes and cavity walls and calculating the scattering matrix. Model of wire port *i* incorporating in general voltage source $V_{source,i}$ and wire load $R_{port,i}$ is shown in Fig. 2.

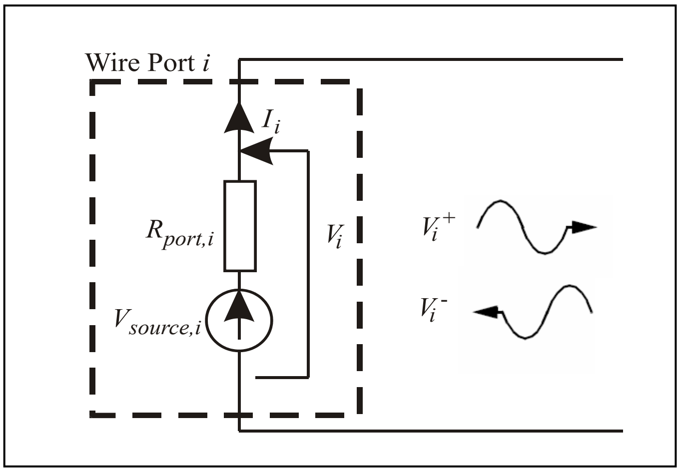

Figure 2. Equivalent circuit for TLM wire port *i*

As TLM wire node defined at wire port *i* gives wire current I_i and voltage V_i as output of TLM simulation, calculation of scattering matrix is straightforward. If wire port 1 is excited, S_{11} parameter, representing the reflection coefficient at wire port 1, can be calculated through wire port current I_1, or alternatively through wire port voltage V_1

$$S_{11} = \frac{V_1^-}{V_1^+} = 1 - \frac{2R_{port,1} I_1}{V_{source,1}} = \frac{2V_1}{V_{source,1}} - 1 \tag{1}$$

In this case, S_{21} parameter, representing the transmission coefficient at wire port 2, for the case of equal port characteristic impedances ($Z_{c1} = Z_{c2}$) and taking into account that $V_{source,2} = 0$, can be calculated through wire port current I_2 or alternatively through wire port voltage V_2

$$S_{21} = \frac{V_2^- / \sqrt{Z_{c2}}}{V_1^+ / \sqrt{Z_{c1}}} = -\frac{2R_{port,2} I_2}{V_{source,1}} = \frac{2V_2}{V_{source,1}} \tag{2}$$

III. RESULTS AND ANALYSES

Numerical TLM results, illustrating the influence of wire probes on resonant modes within a cavity, were obtained by modeling of the rectangular cavity of dimensions: a = 35 cm, b = 37 cm and h = 26.9 cm, which are in accordance with the experimental cavity model [8]. Since the analyzed cavity was filled with air, the medium inside the cavity was modeled by uniform TLM network of dimension $(x \times y \times z) = (36\times35\times27)$ nodes, while the cavity walls were presented by perfect conducted metal. The frequency range of interest was f = [500÷1000] MHz.

An excitation of the EM field inside the cavity was achieved through the wire feed probe of radius r = 0.5 mm, connected to the real voltage source with characteristics as follows: $V_{source,1}$ = 1V and $R_{port,1}$ = 50Ω, according to characteristics of the coaxial cable used as a probe in the experiment. The feed probe position was chosen to be in the middle of the top wall of the cavity ($x = a/2$, $y = b/2$) along the z-axis, ensuring excitation of TM_{mnp} with odd indexes m and n. For resonant frequencies detection according to the reflection characteristic (S_{11}), the feed probe was also used as a receiving one. In practice, receiving probes are usually used for EM field characterisation procedure, which is based on a current inducted in a receiving probe, referred to as transmission procedure. In our case, the receiving probe, terminated with $R_{port,2}$ = 50Ω and placed parallel to the feed probe, was moved toward the edge of the cavity wall and set into the position $x = 3a/4$, $y = b/2$.

Fig. 3 provides an overview of how electric field magnitudes for TM_{110} and TM_{111} modes, obtained according to the reflection characteristics (S_{11}), change as a function of the feed probe length. The revealed results give information about lengths of the probe that should be used in order to provide the best results in terms of energy entering the cavity as well as conditions which disable modes to be generated (probes of small lengths as well as lengths equal to $\lambda/4$ at the corresponding mode frequency).

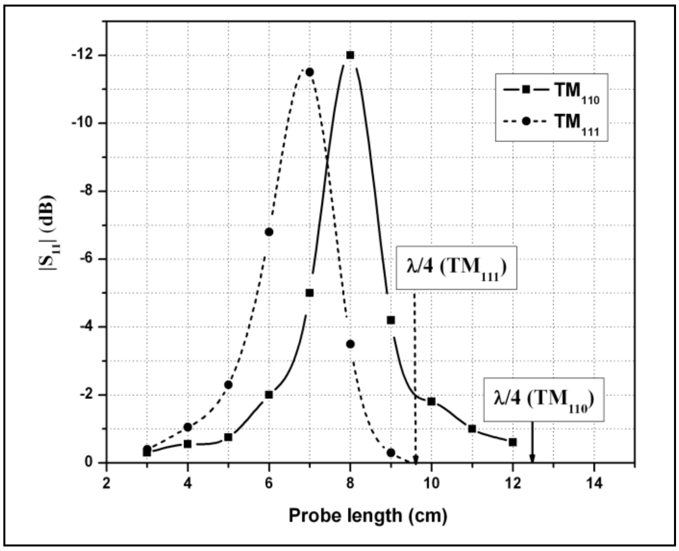

Figure 3. Magnitude of S_{11} versus feed probe length for TM modes

In Fig. 4 are given obtained numerical and measured results representing transmission coefficient (S_{21}) between two probes of length d = 5 cm. Although the chosen position of the feed probe (a/2, b/2) provides generation only of TM_{110} and TM_{111} modes in the considered frequency range, both simulated and experimental results presented in Fig. 4 show the existance of a peak which value corresponds to the resonant frequency of TM_{210} mode. From the theoretical point of view, this mode can not be excited for chosen feed position, meaning that in practice it emerges as consequence of the current inducted in the receiving probe (*3a*/4, *b*/2), acting as secondary excitation. Similarly, it can be shown that for the same position of the feed probe (a/2, b/2) and receiving probe position (a/2, 3b/4) emerges peak corresponding to TM_{120} mode. Generally, conclusion can be derived that position of the receiving probe can influence arising of so-called secondary modes.

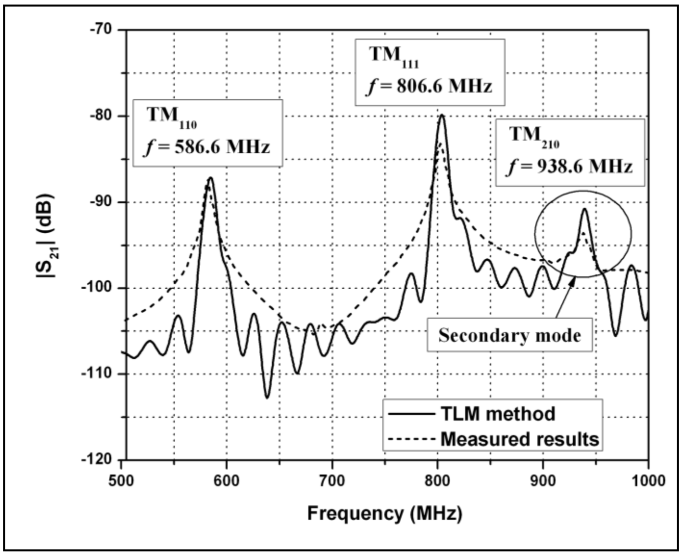

Figure 4. Magnitude of the transmission coefficient (S_{21}) between two probes of length d = 5cm

In Fig. 5 are shown resonant frequencies of the excited modes as a function of the probe length, when the resonant frequencies were obtained according to the both reflection and transmission characteristics. On the other hand, theoretical values of resonant modes were analytically calculated. According to the results revealed in Fig. 5, we have found that resonant frequencies shifting occurred as a result of probe length changing. The resonant frequencies values, within the capacitive area of input probe impedances (where probe length is smaller than $\lambda/4$ at the corresponding frequency) are below the analytical ones and they are gradually plunging with increasing the probe length. It should be noted that TM_{210} mode, existing as a secondary mode, also shows the same behaviour, in terms of resonant frequency dependence versus probe length. In addition, we find that deviations of the resonant frequencies of TM_{110} and TM_{111} are greater when both probes are used. Namely, presence of receiving probe additionally shifts resonant frequencies in comparison with the case when only a feed probe is inserted into the cavity.

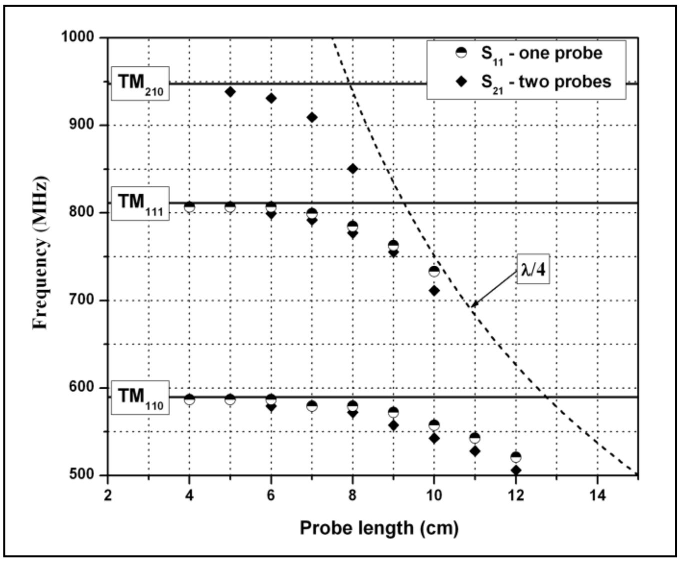

Figure 5. Resonant frequencies of TM modes versus probe length

IV. CONCLUSION

Significance of the approach is that TLM modeling provides full characterization of a metallic cavity in terms of real feed and monitoring conditions, related to the best energy entering the cavity, as well as, optimum coupling between probes, including influence of wire probes to EM field in the cavity.

Analyses based on results of reflection (one probe) and transmission (two probes) provide information regarding probe dimension and position influence on the EM field distribution within the cavity, in terms of conditions which are requested to ensure excitation and detection of modes, resonant frequencies and EM field level, making TLM cavity model a very useful source of information and impartial advice for designers of microwave applications based on cavity resonators.

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