Transmission Line Modelling of an Eccentrically Loaded probe Coupled Cylindrical Cavity

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***Abstract*— In this paper, numerical TLM (Transmission Line-Matrix) method is applied to model an eccentrically loaded cylindrical cavity in order to analyze an impact of the eccentricity on the resonant frequency values. Two different types of meshes are considered, the structured, rectangular mesh and the unstructured, tetrahedral mesh and their possibilities and advantages are emphasized.**

***Keywords*— Transmission Line-Matrix, cavity, eccentrically load, unstructured mesh**

I. INTRODUCTION

Transmission-Line Matrix (TLM) method is a full-wave time-domain computational technique, which represents invaluable tool for solving electromagnetic (EM) problems [1]. Application of this method for modeling of resonant probe-coupled loaded cavities provides better understanding of the mode tuning behavior in the cavity under loading condition and feeding/monitoring coupling mechanism, allowing users to make necessary changes to optimize the microwave design [1-6]. The precise modelling of physical and electrical parameters of a cavity load is of particular interest in microwave heating and biomedical applications [2-7]. A cylindrical cavity loaded with a concentric dielectric cylinder represents a very suitable model used to study various materials in microwave heating and biomedical applications based on hyperthermia treatment [2,7]. Particularly, the eccentrically loaded cylindrical cavity is considered to determine variation in the frequency if the load is not positioned at the cavity centre and also to investigate localized heating spots [2].

Generally, the TLM numerical method use time and space discretization for solving EM problems, starting from structure representation in rectangular coordinates with a cuboid shaped node as the basic building block, regardless of a structure geometry. When the rectangular mesh is used to model the structures of a cylindrical geometry, boundaries are described approximately using so-called stair-case approximation. However, this might cause numerical errors, such as a resonance deviation or excitation of unwanted modes. By applying a finer mesh, the error could be reduced, but on the account of the time and memory. Therefore, cylindrical mesh is proven to be more convenient for describing of cylindrical structures due to a perfect alignment [8]. An in-house code based on the TLM method [9] enables precise modelling of the cylindrical boundaries irrespective of the mesh resolution ensuring reliable results whilesaving computer resources.

The modelling of probe-coupling mechanism in a cavity is important in a microwave cavity design since wire elements (probe or loop) are used for excitation and detection of resonant modes in practice. Generally, the presence of probes in the cavity as well as theirs positions and dimensions have considerable influence on the level of energy entering the cavity, coupling between probes, and excited and detected resonant modes [10,11]. Additionally, resonances induced in the cavity, which can be determined according to the cavity and load dimensions, in practice are shifted due to the influence of the wire elements dimensions [11].

Modelling of wire elements in the TLM is based on the empirically based compact wire TLM model, which uses a special wire network embedded within the regular network of TLM nodes. It allows modelling of signal propagation along the wire and the two-way interaction between the electromagnetic field and the wire, while taking into account physical dimensions of the wire probes which can be much smaller than the node size and hence limited only by the mesh resolution [12]. However, as it is explored in [7], when the cubic mesh which uses this compact wire model is applied to a probe-coupled cylindrical cavity resonator, with probes placed along the radial direction, in order to satisfy the requirement of applying the mesh of higher resolution to achieve more precise modelling of boundaries it is necessary to use the probe radius that is significantly smaller than the physical one since it must be at least 4 times smaller than the cross-section size of TLM nodes through which the wire propagates [12]. As a result, the maximum probe radius that could be used is limited [7,9,11]. A problem of choosing an adequate rectangular TLM mesh and herewith the probe radius limitation, become more pronounced when a coaxial load is placed into the cavity requiring finer mesh to be applied.

The capabilities of the cylindrical TLM mesh, related to analyses of reflection and transmission procedures, have been confirmed on the example of a probe-coupled cylindrical cavity loaded with a concentric dielectric cylinder [7]. Advantages of the presented method in terms of meshing mechanism togather with compact wire model implementation are considered with regards to the corresponding rectangular TLM method. The fine space discretization used to model the coaxially shaped dielectric sample characterized by a high permittivity, such as water, limits the radius of the radially placed wire structures. On the other hand, the cylindrical mesh allows for modelling of wire elements with larger radius of probes coupled in the radial direction. However, due to its nature, the cylindrical mesh cannot be applied for modeling of the cavity with the load placed eccentrically, while the rectangular one gives that possibility, through applying the finer mesh for modelling of the load. Besides the rectangular TLM mesh, an unstructured mesh offers huge possibilities for modelling of arbitrary shaped geometries allowing for curved boundaries to be smoothly described yielding reliable results.

In this paper, the TLM method based on both structured and unstructured meshes has been used to model a probe-coupled cylindrical cavity with an eccentrical load in order to investigate how eccentricity affects the field distribution in the cavity. Different types of the meshing mechanisms are compared in terms of computational requirements and efficiency.

II. TLM METHODOLOGY

The TLM method is a well-known time-domain numerical method extensively used for electromagnetic simulations using the equivalences between Maxwell's equations and transmission line theory [1]. To model a problem, space a network of interconnected transmission lines is used. It is defined via parameters that correctly represent the properties of the sampled media. Two main procedures within the iterative TLM algorithm are the connection and the scattering. Equivalent impedances/admittances of each cell are calculated according to the problem geometry definition including media properties, whereby a dielectric presence is characterized by its relative permittivity and loss tangent. If a medium of a considered structure is not homogeneous it is important to maintain time-synchronism in the TLM mesh due to different velocity of pulses propagation [1]. As an output of the simulation in the considered case of probe coupled cavity, a voltage or a current induced in the wire is obtained which is further manipulated to determine the reflection and transmission coefficient.

Originally, the TLM method was developed in a Cartesian grid with the unit cell as a cubic or rectangular cell. However, to enable precise boundary description in structures that align to the cylindrical coordinate system, it is more efficient to use an orthogonal curvilinear mesh based on a "slice of cake" node described with radial and angular coordinates. More recently, the unstructured TLM based on the Delaney tetrahedral mesh has been developed [13] with a basic tetrahedral node. Its advantages are found in applications of arbitrary geometry, since this kind of mesh is the most conformal to any kind of geometry.

III. RESULTS AND DISCUSSION

This section presents results obtained by both structured and unstructured TLM meshes used to investigate how the movement of the concentrically placed load inside the cylindrical cavity resonator impacts the distribution of resonant modes inside the cavity resonator. The schematic of the cavity resonator with the eccentrical load is shown in Fig.1. Dimensions of the considered cavity resonator are a = 7 cm and h = 14.24 cm while the water is used as the cylindrical dielectric sample of radius a_{diel} = 3 cm and permittivity ε_r = 77 - j6. Two wire probes with length $d_1 = d_2 = d$ = 2.5 cm are used as the excitation and receiving probes, and they are placed at the height l = 7.4 cm from the bottom of the cavity, along the radial direction and opposite to each other. The eccentricity of the load is labeled with "*ecc*" in the figure.

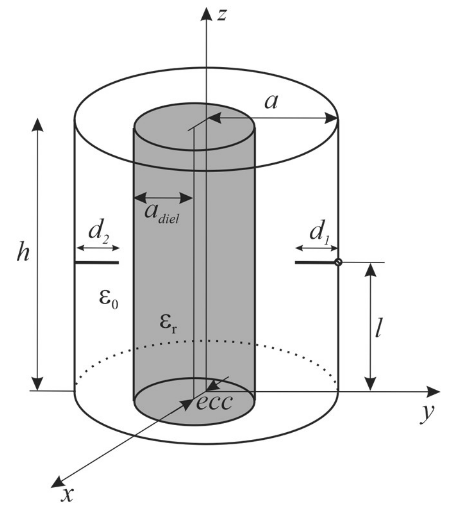


Fig. 1. The schematic of the probe-coupled cylindrical cavity with an eccentrically placed load

A. Modeling in a structured mesh

The modelling of a probe-coupled cavity with a coaxially placed cylindrical dielectric sample has been already carried out by applying the cylindrical TLM mesh and the conventional rectangular mesh, in order to compare theirs possibilities in [7]. The convergence of the results is provided by properly chosen rectangular and cylindrical meshes, while the care is taken of simulation time and computer resources. In order to achieve time synchronism in the scattering procedure, the TLM node size used for describing the load has been set to be smaller compared to the nodes sizes in the rest of the cavity filled with air. Hence, in case of modelling by the rectangular mesh, the coaxially loaded cavity is modelled by the mesh with the mesh of (x×y×z) = (197×197×142) nodes. Similarly, the cavity with an eccentrically placed load is modelled by the same mesh size (x×y×z) = (197×197×142) nodes, with the node sizes as follows: $\Delta x_{air} = \Delta y_{air}$ = 3.1mm, $\Delta x_{diel} = \Delta y_{diel}$ = 0.35 mm. To achieve eccentrical position of the load, the load is moved along x direction by ecc = {1,2,3} cm. Fig. 2. illustrates the rectangular mesh in x-y cross section for the case of the load placed eccentrically in x direction.

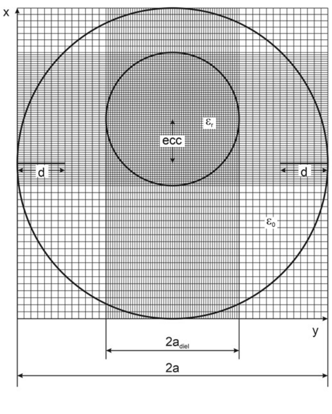


Fig. 2. The TLM rectangular mesh of the eccentrically loaded cylindrical cavity in x-y cross-section

Fig. 3. shows the simulation results of S parameters of the cavity with the load placed eccentrically along the *x* direction obtained by the rectangular TLM mesh for three values of the load movement, *ecc* = {1,2,3} cm. As can be seen, the eccentricity causes shift in resonant frequencies with respect to the case when the load is concentrically placed. The shifting is larger as the load is moved more away from the cavity centre, e.g., for larger eccentricity. Fig.3. also shows that the shifting does not have the same direction for all resonant modes, i.e., in some cases the frequency increases while in other decreases.

B. Modeling in UTLM mesh

The same eccentrically loaded cylindrical cavity is also modelled via unstructured TLM method with the following number of cells: the number of tetrahedral cells is 35.440, the number of regular cubes is 11.847, and the number of cuboids is 8.715. Fig. 4. illustrates the 3D model of an eccentrically loaded cylindrical cavity generated using the unstructured mesh. Here, coaxial wires are physically included in the model and excitation is achieved via the waveguide modes. The corresponding results of simulations are presented in Fig.5. for eccentricity of 3 cm together with the referent case of the concentrically placed load. These results confirm the conclusions regarding the influence of the eccentricity on the resonant frequency values obtained by using the rectangular TLM mesh.

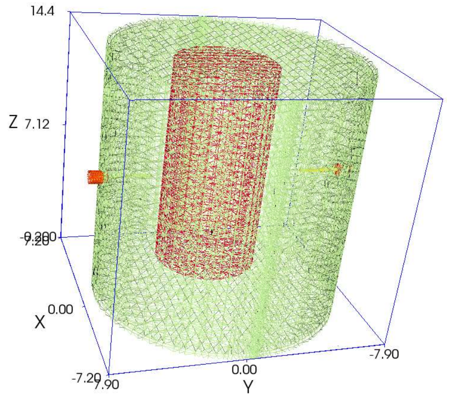
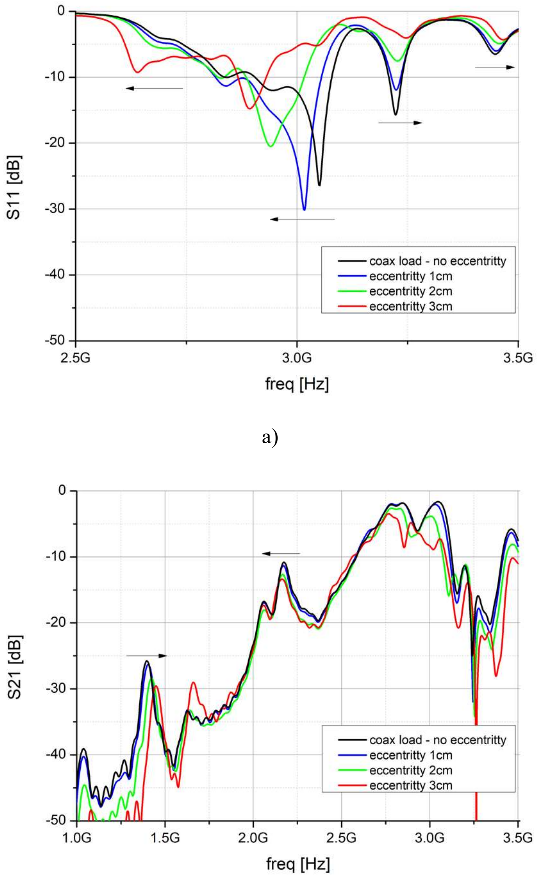


Fig. 3. An model of eccentrically loaded cylindrical cavity in UTLM.

Compared to the rectangular mesh which requires around 5.5M of nodes, unstructured TLM mesh needs only 56k nodes for simulations which proves that unstructured mesh is much more efficient than the rectangular mesh.

IV. CONCLUSION

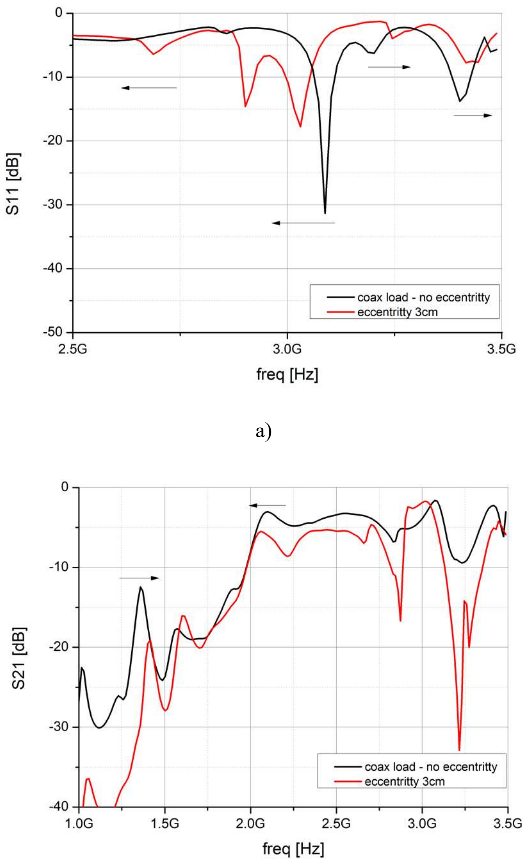
This paper investigaets possibilitilies of the structured and unstructured TLM solvers on an example of a probe coupled cylindrical cavity with an eccentrically placed dielectric load in order to analyze the impact of the eccentricity on the resonant modes.



a)

b)

Fig. 4. Results of: a) reflection characteristic, b) transmission characteristic, based on simulations using the rectangular TLM mesh.



a)

b)

Fig. 5. Results of: a) reflection characteristic, b) transmission characteristic, based on simulations using the unstructured TLM mesh.

A general advantage of the proposed solvers is seen in the possibility of modeling of a probe-coupled loaded cylindrical cavity resonator irrespective of the dielectric sample position, which is not the case if the cylindrical mesh is applied. The adequate modelling of an inhomogeneous medium of a coaxially loaded cylindrical cavity resonator in a rectangular mesh, for any load position, can be achieved by relevant changing of the cell sizes along both axes in transverzal plane. However, an unstructured TLM mesh is shown to be much more efficient than the rectangular mesh requiring much smaller number of cells for describing the problem.

Results obtained from both solvers confirm that resonant modes in the cavity resonator are shifted due to the load eccentricity. The shifting is more pronounced as the eccentricity is larger. However, there is no upward or downward trend within the frequency range of interest, but the resonances shift either to higher or lower value, depending on the mode of oscillation in the cavity resonator. Therefore, it would be useful to analyze the field distribution for the specific modes in the loaded cavity, which will be the part of future investigations.

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