Verification of TLM Compact Wire Model in Cylindrical Mesh applied to Determining of Transmission Coefficient in Cavity

Tijana Dimitrijević, Jugoslav Joković, Nebojša Dončov

***Abstract* – This paper presents a verification of a compact wire model implemented in the 3-D TLM cylindrical mesh based on comparison of numerical and measured results of cavity transmission characteristics. The TLM compact wire model in a cylindrical mesh is based on wire structures parameters calculation in conditions of variable cross-section of the TLM nodes through which wire conductor passes due to nature of cylindrical grid along the wire path. Obtained numerical results have been compared with the corresponding results reached by TLM method based on a rectangular grid, and the correctness of the method has been experimentally verified.**

***Keywords* – TLM method, cavity, wire model, cylindrical mesh, transmission characteristic**

I. Introduction

A cylindrical metallic cavity represents a configuration very suitable for good modelling of devices used in some practical microwave applications, such as applicators used in the processes of dielectric material heating and drying or power dividers used for distribution of information in communications systems [1,2]. Even though there are many ways to couple energy into the cavity [1], input and output ports of microwave cavity devices are generally realized by coaxial probe that ensures coupling with corresponding electromagnetic (EM) field component. Therefore, the reflection (S_{11}) and transmission (S_{21}) characteristics are common parameters in cavity exploration.

For purpose of an analysis of metallic cavities the TLM (Transmission-Line Matrix) time-domain method [3], as a general, electromagnetically based numerical method, is very suitable [4,5]. In recent years, TLM enhancement in form of a compact model for wire structures has been developed [6], yielding a significant improvement in the required computer resources compared to the traditional TLM method. Model allows for accurate modelling of wires with a considerably smaller diameter than the TLM node size. It uses a special wire network embedded between nodes to model signal propagation along the wires, while allowing for interaction with the electromagnetic field. Its implementation into the rest of TLM mesh, based on rectangular grid, is straighforward as mean cross-section dimensions of nodes through which wire conductor runs can be easily kept constant along the wire path.

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When modelling of structures of rectangular geometry is concerned, the network of TLM cubic shaped nodes in a Cartesian grid comes up as a good solution. However, for problems with cylindrical or spherical symmetry it is more appropriate to use nodes that model directly non-cubic shaped blocks, enabling problem boundaries to be described more accurately. If a rectangular mesh is used to model a cylindrical structure, a curved boundary would have to be described in a step-wise fashion which might result in deviation of resonant frequencies values as well as in excitation of unwanted modes. Since a numerical error caused by step-wise approximation depends on the mesh resolution, it could be reduced by applying the TLM mesh of greater resolution, which, on the other hand, results in increasing a simulation time. Moreover, increasing of a mesh resolution is limited since an implementation of the compact wire model into the rest of the TLM mesh demands that the ratio between dimensions of a wire conductor and dimensions of nodes through which the wire conductor passes is optimal. Thus, a greater resolution of applied rectangular TLM mesh enables a cylindrical cavity to be precisely modelled only if a probe of relatively small radius is used [7, 8].

The fact that two opposite demands have to be fulfilled is the main disadvantage of using a rectangular grid for modelling of a probe-fed cylindrical cavity. In order to overcome such limitations, even though a procedure of a compact wire model implementation is much easier in a rectangular grid compared to a cylindrical grid, we found more profitable to implement the wire model into the cylindrical grid. This approach enables the precise modelling of cavity boundaries independently of mesh resolution applied, but an error may arise due to variable mean cross-section dimensions of cylindrical TLM nodes, through which a wire conductor (placed in the radial direction) passes, resulting in different wire network properties from one node to another. This has been solved by implementation of an additional connecting procedure for wire segments belonging to TLM nodes with different cross-sections into the TLM algorithm.

Efficiency of the wire model adapted to cylindrical mesh was verified on the case of an empty cylindrical metallic cavity of radius *a* and height *h*. The transmission coefficient, based on two probes inserted into the cavity, has been considered numerically and experimentally (Fig.1). For a numerical modelling purpose, according to experimental procedure, one probe was used as the real feed, while other was used to monitor established distribution of EM field inside the cavity.

The TLM results, corresponding to the transmission coefficient obtained for various probes length in the frequency range f = [1.5 ÷ 3.5] GHz, have been evaluated against the results reached by the TLM method based on the rectangular coordinate system and experimental results obtained by using the set-up shown in the Fig.1a.

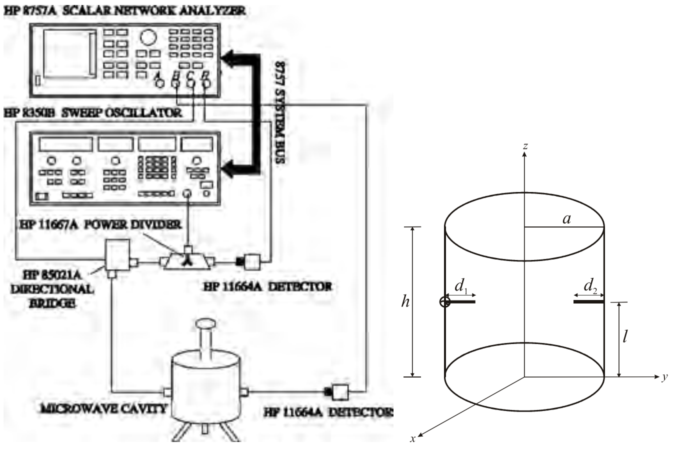


Fig. 1. a) Experimental set up for resonant frequency measurement
b) Cylindrical cavity with feed and receiving probes

II. TLM MODELLING

In the TLM time-domain method, EM field strength in three dimensions, for a specified mode of oscillation in a cylindrical metallic cavity, is modelled by filling the field space with a network of link lines and exciting a particular field component through incident voltage pulses on appropriate lines [4]. EM properties of different cavity loads are modelled through network of interconnected nodes, known as a symmetrical condensed node (SCN)]. Each node describes a portion of the medium shaped like a cubic (Cartesian rectangular mesh) or a slice (Non-Cartesian cylindrical mesh) depending on the coordinate system applied. Additional stubs can be incorporated into TLM model to account for inhomogeneous materials and/or electric and magnetic losses.

When cylindrical structures are concerned, a non-Cartesian cylindrical mesh in the coordinate system (φ, r, z) can be used for the modelling purpose. The coordinate system used and the port designations are shown in Fig. 2. Simulation proceeds exactly as for a SCN with stubs in a Cartesian grid. The only modification involves the calculation of stub parameters where account must be taken of the details of the new geometry.

The TLM wire node is based on a SCN with one small modification in the form of additional link and stub lines interposed over the existing network to account for increase of capacitance and inductance of the medium caused by wire presence [6]. The single column of TLM nodes, through which a wire conductor passes, can be used to approximately form the fictitious cylinder which represents capacitance and inductance of a 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 the TLM network and the mean dimensions of the node cross-section in the direction of wire running [6].

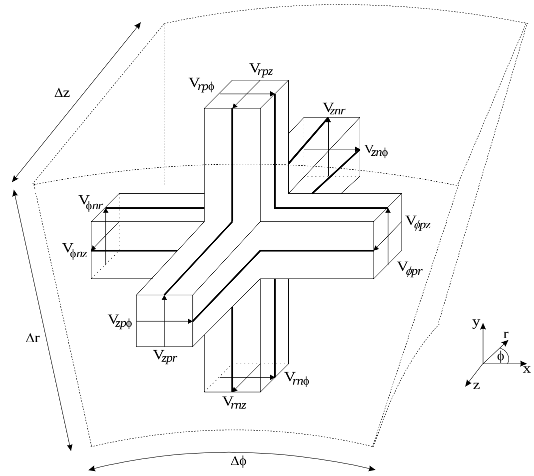


Fig. 2. A cylindrical SCN

An equivalent radius of the fictive cylindre in a cylindrical grid for calculating the capacitance and inductance, r_{Cr} and r_{Lr}, respectively, for wire segment running along r direction are $r_{Cr} = k_{Cr}\Delta r_c$ and $r_{Lr} = k_{Lr}\Delta r_c$, where Δr_c represents mean dimension of the node cross-section in r direction ($\Delta r_c = \left(\frac{(r_i + r_{i+1})}{2}\Delta\varphi + \Delta z\right)/2$, where r_i and r_{i+1} are lower and upper limits of the TLM wire node in radial direction (Fig.3), while k_{Cr} and k_{Lr} are factors empirically obtained by using known characteristics of TLM network.

Distributed capacitance and inductance per unit length, needed for modelling of wire segments, may be expressed as:

$$C_{wr} = \frac{2\pi\varepsilon}{\ln(r_{Cr}/r_w)},\; L_{wr} = \frac{\mu}{2\pi}\ln(r_{Lr}/r_w) \qquad (1)$$

where r_w is a real probe radius.

An equivalent radius of the fictitious cylinder can be easily kept constant along nodes column in a rectangular grid. However, in a cylindrical grid for a wire conductor in the radial direction, as it is shown in Fig. 3, mean cross-section dimensions of TLM nodes, through which a wire passes, vary making difficult to preserve distributed capacitance and inductance of a wire per unit length.

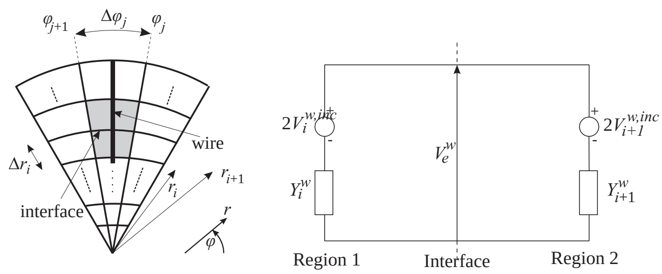


Fig. 3. TLM nodes in $r\varphi$ plane through which wire runs and an interface between two nodes

As result, admittance of the wire network link line, interposed over the existing network to account for wire presence, varies from one TLM node to another (Fig.3). To solve this, an additional connecting procedure for wire segments with different link-lines admitances has been implemented into the existing TLM-based software.

Reflected voltages on both directions of the interface between nodes with different cross-section, which at the same time represent incident voltages respect to the node center for the next time step, can be expressed as follows:

$$V_i^{w,ref} = \frac{Y_i^w - Y_{i+1}^w}{Y_i^w + Y_{i+1}^w}\left(V_i^{w,inc} - V_{i+1}^{w,inc}\right) + V_{i+1}^{w,inc} \qquad (2)$$

$$V_{i+1}^{w,ref} = \frac{Y_i^w - Y_{i+1}^w}{Y_i^w + Y_{i+1}^w}\left(V_i^{w,inc} - V_{i+1}^{w,inc}\right) + V_i^{w,inc} \qquad (3)$$

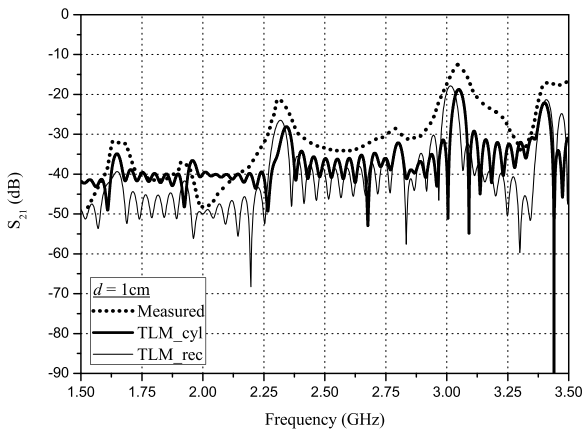
where $V_i^{w,inc}$ and $V_{i+1}^{w,inc}$ are the incident voltages.

III. Numerical Results

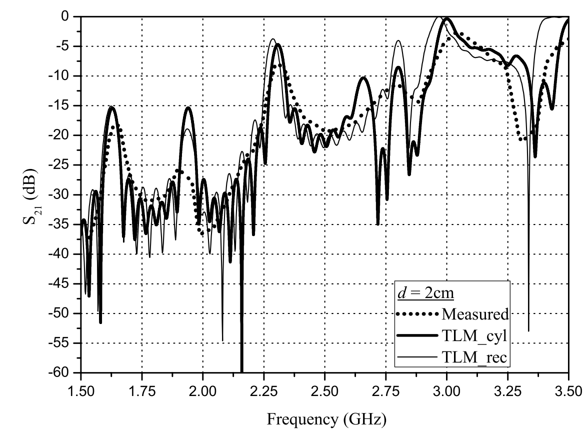
The TLM method based on a cylindrical grid enhanced with the wire node model has been used to analyze resonant modes distribution within the considered cavity containing two wire probes, representing feed and receiving probe. Dimensions of the modelled cavity, a = 7 cm and h = 14.24 cm, was chosen to follow the experimental ones (Fig. 1b). The feed probe was placed at the height l = 7.4 cm from the cavity bottom, slightly different from h/2, in the radial direction, whereas the receiving probe was placed at the same height and direction, opposite to the feed probe. In this way, it is possible to excite and simultaneously detect modes which have the radial component of the electrical field in the cavity. In order to model a real coaxial cable characteristics, the feed probe was connected, through the TLM wire port, to the real voltage source: V_{source} = 1 V with the resistance R_{port1} = 50 Ω, whereas the resistance of the receiving port was R_{port2} = 50 Ω. For cavity space modelling, a cylindrical TLM mesh of resolution ($\varphi \times r \times z$) = (36×28×32) was used.

The radius of probes has been kept constant r = 0.5mm, whereas theirs lengths have been varied in the range $d_1 = d_2 = d$ = [1÷5]cm. In Fig. 4. the transmission coefficient characteristics obtained by TLM method based on a cylindrical grid are compared with corresponding results reached by a rectangular grid based TLM method and with experimental results as well. As can be seen, there is a very good agreement between considered results, in terms of resonant frequencies values and EM field level. Thus, possibilities of the TLM method based on a cylindrical grid as a tool for modelling and analyses of transmission procedure in an empty cavity are confirmed. It should be noted that the difference between numerical and experimental results regarding smoothness of graphs emerges as a result of numerical modelling procedure where has been assumed that the walls have been made out of perfectly conducted metal.

However, in the case of a small probe length, as for the length of d = 1cm, it is apparent that, compared to the TLM method based on a rectangular grid, a cylindrical grid based TLM method gives better agreement with the experimental results in terms of the EM field level. There is a deviation of about 10dB when a rectangular grid based TLM method is used. One of the reasons for this feature is that in the case of a small probe length a numerical error occurs due to applied TLM rectangular network resolution which results in a small number of nodes through which wire conductor passes. This error could be avoid if the TLM rectangular network of greater resolution is being used, but, it demands that a radius of a probe is reduced in order to preserve the optimum ratio between a probe radius and TLM node dimensions requested when the compact TLM wire model is applied.



a)



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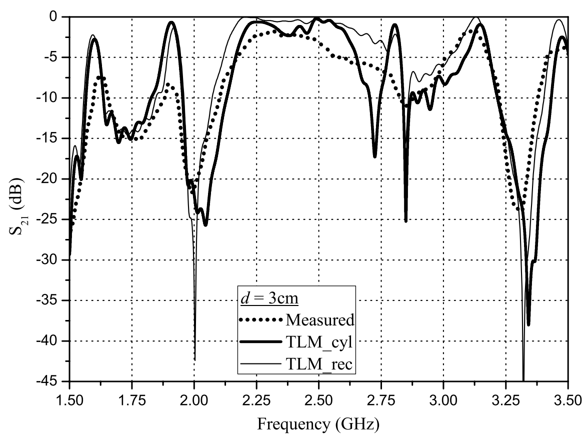

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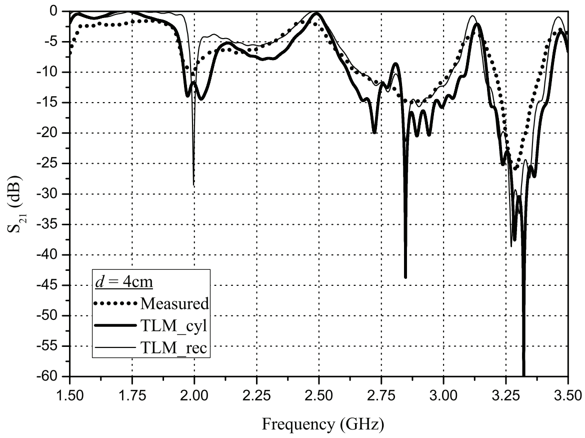

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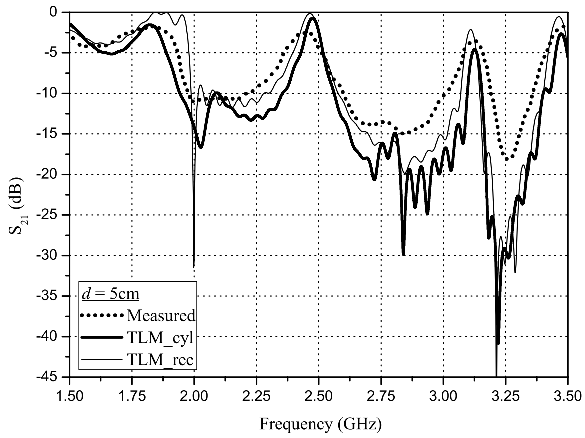

e)

Fig. 4. The transmission coefficient for various feed and receiving probes lengths a) 1cm, b) 2cm, c) 3cm, d) 4cm, e) 5cm

Furthermore, a cylindrical grid enables modelling of probes with much greater radius compared to the TLM method based on a rectangular grid. Fig. 5 shows dependence of a maximum radius that could be modelled on the probe length. In the case of cylindrical cavity modelled in the rectangular grid of resolution ($x \times y \times z$) = (43×43×32), the probe radius can be maximally 0.5 mm [8] so the modelling process could be carried out. On the other hand, when the cylindrical grid ($\varphi \times r \times z$) = (36×28×32) is being used the maximum value of the probe radius that could be modelled is much greater and depends on the probe length.

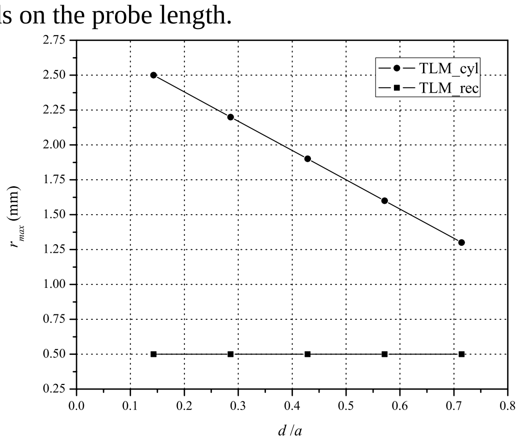

Fig. 5. Comparison of maximum probe radius vs. probe length in rectangular and cylindrical grid

IV. Conclusions

In this paper, the compact wire model implemented to TLM method based on a cylindrical coordinate system, have been experimentally verified. However, since mean cross-section dimensions of TLM nodes, through which wire conductor passes, is not constant along the nodes columns in a cylindrical grid in a radial direction, an implementation procedure is more complex to carry out in a cylindrical than in a rectangular mesh. This means that wire network parameters have to be calculated taking into account inconsistence of the capacitance and inductance of the wire per unit length. For that reason, an additional connecting procedure for wire segments with different EM properties has been implemented into the existing cylindrical grid based TLM software.

The wire model adapted to cylindrical TLM mesh has been applied to the problem of an analysis of transmission characteristics in an empty cylindrical cavity, when an EM field has been excited and detected via wire probes. The results have been verified by comparison with both experimental and results based on a TLM rectangular grid. The main advantage of using a cylindrical instead of rectangular grid for the purpose of modelling a probe-fed cylindrical cavity is that enables accurate modelling of boundaries, since a numerical error caused by the step-wise approximation of boundaries is avoided. Also, a cylindrical grid enables modelling of probes with much greater radius compared to the TLM method based on a rectangular grid.

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