Modeling of a Loaded Cylindrical Metallic Cavity with Real Excitation Using 3-D TLM Method

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Abstract – **For the example of the cylindrical metallic cavity with circular cross section loaded with a lossy dielectric slab placed on the bottom of the cavity, the real excitation modeling, using TLM wire node, are presented. As an excitation form, a straight wire conductor is used, according to the wanted type of mode in the cavity. Water at a temperature of 15°C is used as a dielectric layer. The modeling process is described and the obtained TLM numerical results in frequency range $f = [1.5 - 3]$ GHz are compared with the experimental ones. Comparing numerical results and experimental ones, an excellent agreement is observed. Also, in order to investigate the influence of real probe length to the resonant frequencies of modes, TLM results with real probe are compared with results calculated by using the theoretical approach, that is TLM method with impulse excitation, and the appropriate conclusions are given.**

Keywords – **TLM method, microwave applicator, cavity, real excitation, wire node, lossy dielectric sample, resonant frequency**

I. Introduction

Cylindrical metallic cavities represent a configuration very suitable for good modeling of some practical heating and drying applicators. The knowledge of the mode tuning behavior under loading condition has important significance and would help in designing these applicators. For this reason, some researches of the cylindrical cavities, based on using the different approaches, were presented by a number of authors [1-3]. Also, some experimental work has been done in order to investigate the mode tuning behavior experimentally [1,2].

TLM (Transmission-Line Modeling) method is a general, electromagnetic based numerical method that has been applied very successfully in the area of cylindrical metallic cavities modeling [3-5]. In all this applications, an impulse excitation was used to establish desired field distribution in the modeled cavity. However, this way of enhancing the wanted TE or TM mode is different from the experimental case where a small probe inside the cavity is used as an excitation. This difference in the cavity excitation causes that the TLM results in the case of impulse excitation being different from the experimental ones. With some recent improvements in TLM method, it is possible to model a small probe inside the cavity using TLM wire node [6] and to investigate the influence of the real excitation to the resonant frequencies of the cavity.

In practice, depending on the position and the mode of excitation (waveguide, capacitive probe, inductive loop or slots), the number of modes will be different from theoretical case. For instance, placing the coaxial cable in the middle of cavity height will not generate modes with even-mode numbers in z-plane. From the remaining odd-mode numbers some modes will not be excited, depending on whether they have an electric field component in the direction of the source electric field. The resulting electric field distribution will then be given by the sum of the modes excited in the cavity. Another problem is identification of the precise modes. Although the S_{11} plots give the number of modes in the cavity, they do not indicate exactly which modes are present. This situation is made worse when many modes are present. The probe presence also tends to shift the modes and sometimes split degenerate modes.

The goal of this paper is to describe the possibilities of TLM method for modeling of loaded microwave applicator with real excitation probe. The applicator is represented in the form of a cylindrical metallic cavity loaded with a homogeneous lossy dielectric sample placed on the bottom of the cavity. As the microwave applicator is often used for drying of wet material, which as a dominant element within itself have water, as a dielectric layer, water, at a temperature 15°C, is used.

TLM method is applied to the cavity with dimensions $a = 7$ cm and $h = 14.24$ cm, loaded with a homogeneous lossy dielectric sample with thickness $t = 3$ cm, placed on the bottom of the cavity. As an excitation form straight wire conductor loaded in the cavity is used. Excitation probe is placed in the height $l = 7.24$ cm (slightly different from $h/2$) from bottom on the cavity, in the r direction. The probe length is variable in order to investigate the influence of the real excitation presence to the resonant frequencies of the cavity. Obtained TLM results for resonant frequencies in the case of cavity with real excitation are compared with results calculated by using the theoretical approach, that is TLM with impulse excitation. Also, in order to verify TLM method the obtained numerical results of resonant frequencies for TE_{111} and TE_{211} modes in frequency range $f = [1.5 - 3]$ GHz are compared with the experimental ones. Experimental set up for resonant frequencies measurement is shown on the Fig. 1.

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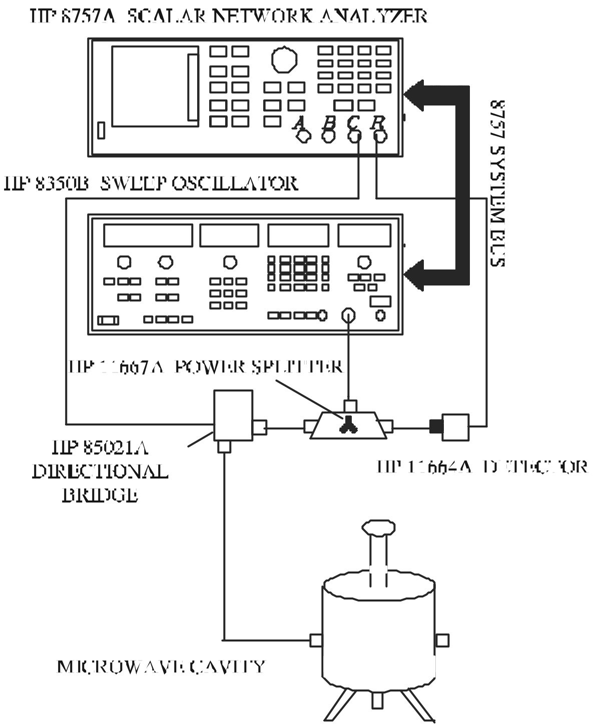

Fig. 1. Experimental set up for resonant frequency of the cylindrical metallic cavity with circular cross-section measurement

II. Problem Modeling

In TLM method, an electromagnetic (EM) field distribution in three dimensions, for a specified mode of oscillation in a microwave cylindrical cavity, is modeled by filling the field space with a network of transmission lines and exciting a particular field component in the mesh by voltage source placed on the excitation probe. EM properties of a medium in the cavity are modeled by using a network of interconnected nodes, a typical structure being the symmetrical condensed node (SCN), which is shown in Fig. 2. To operate at a higher time-step, a hybrid symmetrical condensed node (HSCN) [7] is used. An efficient computational algorithm of scattering properties, based on enforcing continuity of the electric and magnetic fields and conservation of charge and magnetic flux [8] is implemented to speed up the simulation process.

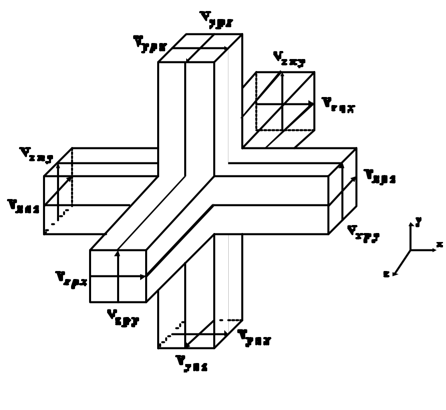

Fig. 2. Symmetrical condensed node

For accurate modeling of this problem, a finer mesh within the dielectric layer and cells with arbitrary aspect ratio suitable for modeling of particular geometrical features, are applied.

Losses can be incorporated in a TLM model by introducing loss stubs into the scattering points (i.e. nodes). The loss stubs may be viewed as infinitely long, or equivalently, as terminated (matched) by their own characteristic impedance. The matched stubs can be used to model both 'electrical' and 'magnetic' losses. In the HSCN, the presence of matched stubs is incorporated directly into the scattering matrix. Given the effective electrical conductivity σ_e, loss 'electrical' element for the 3-D time-domain TLM method is defined as [8]:

$$G_e = \sigma_e f(\Delta x, \Delta y, \Delta z) \tag{1}$$

where: Δx, Δy and Δz are dimensions of TLM node in the x, y and z directions respectively. Complex permittivity is related to effective electrical conductivity as:

$$\varepsilon^* = \varepsilon_0 \varepsilon_r^* = \varepsilon_0 \varepsilon_r' - j\sigma_e/\omega. \tag{2}$$

III. TLM Wire Node

In TLM wire node, wire structures are considered as new elements that increase the capacitance and inductance of the medium in which they are placed. Thus, an appropriate wire network needs to be interposed over the existing TLM network to model the required deficit of electromagnetic parameters of the medium. In order to achieve consistency with the rest of the TLM model, it is most suitable to form wire networks by using TLM link and stub lines (Fig. 3) with characteristic impedances, denoted as Z_{wy} and Z_{wsy}, respectively.

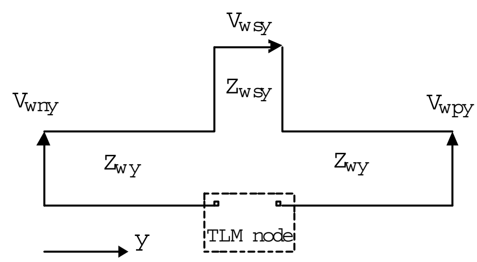

Fig. 3. Wire network

An interface between the wire network and the rest of TLM network must be devised to simulate coupling between the electromagnetic field and the wire. In order to model wire junction and bends, wire network segments pass through the center of the TLM node In that case, coupling between the field and wire coincides with the scattering event in the node which makes the scattering matrix calculation, for the nodes containing a segment of wire network, more complex. Because of that, a simple and elegant approach is developed [6], which solves interfacing between arbitrary complex wire network and arbitrary complex TLM nodes without a modification of the scattering procedure.

IV. Numerical Analysis

The numerical results, which illustrate the effect of the real excitation probe on the resonant frequency, are presented for a cavity with circular cross-section. Dimensions of the investigated cavity are chosen to be $a = 7$ cm and $h = 14.24$ cm, starting from the example from [3]. Cavity is loaded with dielectric sample placed on the bottom of the cavity. The thickness of dielectric layer is $t = 3$ cm. Permittivity of hypothetical lossy homogeneous dielectric sample is equal to that of water at a temperature $15°$C ($\varepsilon_r = 77 - j5$).

For modeling of this cavity non-uniform TLM mesh with $45 \times 45 \times Nz$ nodes was used. The real excitation in form of small straight wire conductor is modeled by using TLM wire node. The excitation probe is placed on the height $l = 7.24$ cm from bottom on the cavity (slightly different from $h/2$), in the r direction (Fig. 4.). In this way, it is possible to excite modes having r-component of the electrical field in the cavity.

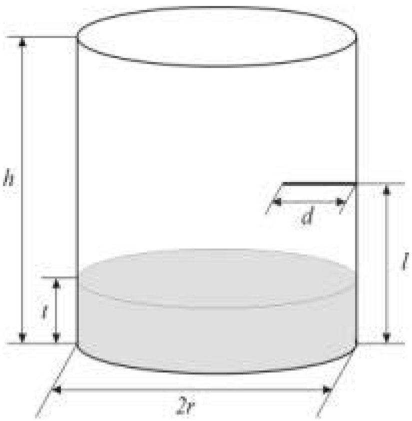

Fig. 4. Real excitation loaded in a metallic cavity with circular cross section ($a = 7$ cm, $h = 14.24$ cm, $t = 3$ cm, $l = 7.24$ cm)

The radius of the excitation probe is $r = 0.5$ mm and length d is variable in order to investigate the influence of the real excitation presence to the resonant frequencies of the cavity. Excitation probe is connected with voltage source $V_{source} = 1$ V, $R_{source} = 50\ \Omega$. The resonant frequencies are determined from the reflection characteristic (S_{11} plot).

The obtained TLM numerical results and experimental results of resonant frequencies for modes in the frequency range $f = [1.5 - 3]$ GHz, versus length of the real excitation probe d, are shown in Table 1. To the aim the of illustrating the agreement between experimental and numerical TLM results and dependence of resonant frequencies of probe length, obtained results are shown in the Fig. 5. The circle symbols indicate the results obtained by using TLM method with real excitation and triangle indicate experimental results. The straight lines present the values of resonant frequencies calculated by using TLM method with impulse excitation. Also, quarter-wavelength curve is presented in order to identify areas of capacitive and inductive character of probe impedance.

As it can be seen from Table 1 and Fig. 5, in comparison

Table 1. The resonant frequencies versus probe length, calculated by using TLM method and experimentally, respectively

d [cm]	Resonant frequencies f_{res} [MHz]							
	TE_{114} Theoretical value =1809MHz		TM_{015} Theoretical value =2151MHz		TE_{215} Theoretical value =2463MHz		TM_{116} Theoretical value =2928MHz	
	TLM	exp.	TLM	exp.	TLM	exp.	TLM	exp.
2	1807	1805	2137	2138	2441	2414	2923	2931
3	1789	1776	2136	2128	2571	2504	2953	2952
4	1949	1891	2155	2143	2542	2504	2959	2958
5	1890	1880	2163	2146	2522	2505	2959	2963
6	1891	1875	2160	2145	2532	2504	2959	2965

with results calculated by using theoretical approach where an impulse excitation was used, the obtained TLM numerical results in the case of applying real excitation show a much better agreement with experimental ones, which indicates good TLM modeling of the real excitation probe.

The Fig.5. shows that the values of resonant frequencies for both TE and TM modes considerable depend on the real probe length d. The results calculated by using TLM method and experimental ones, where a probe inside the cavity is used as an excitation, are strongly deviate from the results calculated by using the theoretical approach where an impulse excitation was used to establish desired field distribution in the modeled cavity. In the area of capacitive character of probe impedances ($d < \lambda/4$), due to increasing of wire conductor length the values of resonant frequencies shift to lower frequencies. In inductive area ($d > \lambda/4$) results of resonant frequencies have higher values than in the case applying TLM method with impulse excitation. Also, due to in-

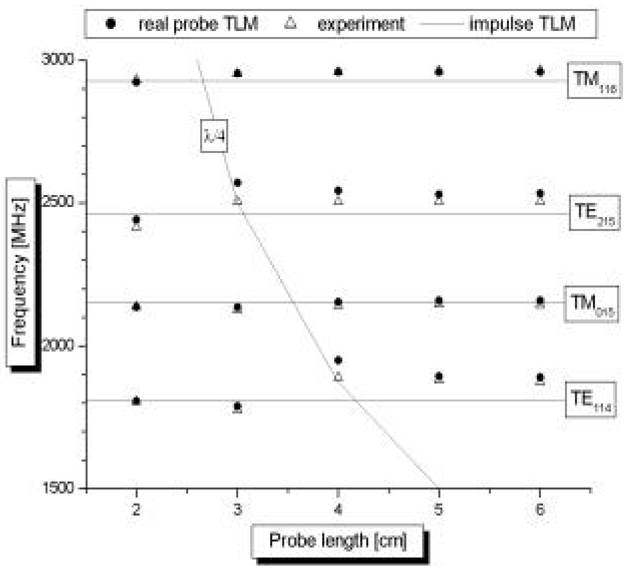

Fig. 5. Resonant frequencies of excited modes in frequency range $f = [1.5 - 3]$ GHz versus probe length

creasing probe length resonant frequencies decrease and tend toward theoretical values.

To the aim of illustrating the good agreement between experimental and numerical TLM result, in the Figs. 6. and 7. are shown S_{11} plots (reflection characteristic) for the probe length $d = 5$ cm, obtained experimentally and by using TLM method, respectively.

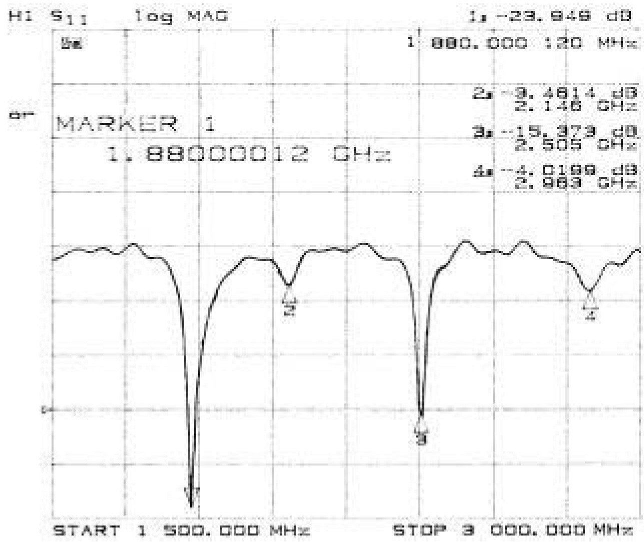

Fig. 6. S_{11} plot in frequency range $f = [1.5 - 3]$ GHz for the probe length $d = 5$ cm, obtained experimentally

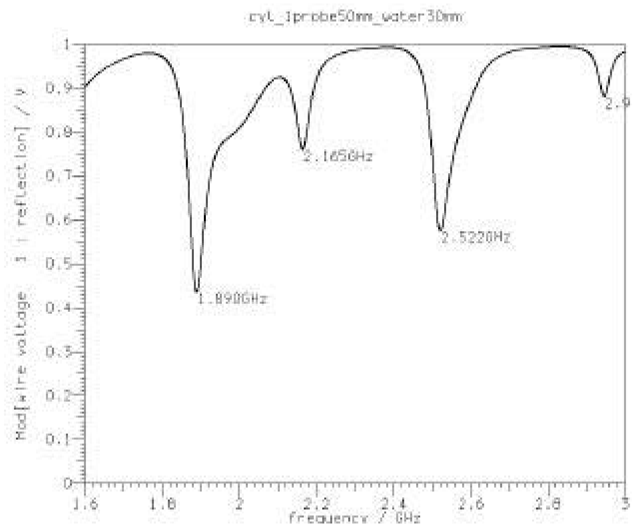

Fig. 7. Voltage reflection in frequency range $f = [1.5 - 3]$ GHz for the probe length $d = 5$ cm, obtained by using TLM method

V. Conclusion

In this paper, real excitation probe in a loaded cylindrical metallic cavity is modeled by using TLM method and influence of real probe presence to the resonant frequencies is analyzed. TLM numerical technique has been implemented in the appropriate software and applied to the problem of determining resonant frequencies as important information in the microwave applicator design.

In comparison with results calculated by using the theoretical approach where an impulse excitation was used, the obtained TLM numerical results in the case of real excitation show a much better agreement with experimental ones, which indicates good TLM modeling of the real excitation.

Also, the influence of the probe length to the resonant frequencies of modes in the frequency range $f = [1.5 - 3]$ GHz are investigated. The obtained results where a probe inside the cavity is used as an excitation show that values of resonant frequencies depend on length of wire conductor. This dependence is related with character of probe impedances.

In this paper, for the first time, real excitation in a loaded cylindrical metallic cavity with lossy dielectric sample is modeled by using TLM method. According to previously showed results a general conclusion can be derived that TLM approach gives valid result. Therefore it is expected that these resonant structures can be successfully modeled by TLM method, independently of probe position and dimensions and location of dielectric sample in the cavity.

References

[1] A. Baysar, J.L. Kuester and S. El-Ghazaly, "Theoretical and Experimental Investigations of Resonance Frequencies in a Microwave Heated Fluidized Bed Reactor", *IEEE MTT-S Digest*, pp.1573-1576, 1992.

[2] S. Ivkovic, B. Milovanovic, A. Marincic and N. Doncov, "Theoretical and Experimental Investigations of Resonance Frequencies in Loaded Cylindrical Microwave Cavity", *Proc. of the Third IEEE TELSIKS'97 Conference*, Niš, Yugoslavia, 306-309, 1997.

[3] B. Milovanovic, N. Doncov, V. Trenkic and V. Nikolic, "3-D TLM Modelling of the Circular Cylindrical Cavity Loaded by Lossy Dielectric Sample of Various Geometric Shapes", *Proc. of the Third International Workshop on TLM Modelling*, Nica, France 187-195, 1997.

[4] N. Doncov, "Microwave structures analysis using 3-D TLM method", M.Sc thesis, Faculty of Electronic Engineering, University of Nis, 1999.

[5] B. Milovanovic, N. Doncov, A. Atanaskovic, "Tunnel Type Microwave Applicator Modelling using TLM Method", *Problems in Modern Applied Mathematics, A Series of Reference Books and Textbooks: Mathematics and Computers in Science and Engineering*, WSES Press, pp.327-332, 2000.

[6] V. Trenkic, A.J. Wlodarczyk, R.A. Scaramuzza, "Modelling of Coupling Between Transient Electromagnetic Field and Complex Wire Structures", *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields*, Vol.12, No.4, pp.257-273, 1999.

[7] C. Christopoulos, "The Transmission-Line Modelling Method", *IEE/OUP Press*, 1995.

[8] V. Trenkic, "The Development and Characterization of Advanced Nodes for TLM Method", Ph.D. Thesis, University of Nottingham, 1995.