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Modelling of Microwave Applicators with an Excitation through the Waveguide Using TLM Method

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Abstract: In this paper, a real microwave applicator with a waveguide used to launch the energy from the source into the cavity is analyzed using 3D TLM method. In order to investigate the influence of the positions and number of feed waveguides to the number of the resonant modes inside the cavity, obtained results are compared with analytical results and results obtained by using TLM software with an impulse excitation as well. TLM method is applied to the both empty and loaded rectangular metallic cavity, and a very good agreement between simulated and experimental results is achieved.

Keywords: Microwave applicator, Waveguide, TLM method

1 Introduction

Rectangular metallic cavity represents a configuration very suitable for good modelling of some practical heating and drying applicators. The knowledge of the mode tuning behavior has important significance and is helpful in designing these applicators. Moreover, designers should be aware of influence of the dielectric load, and mode of excitation to the resonant modes distribution. For that reason, a number of authors presented some researches of the metallic cavities, based on different approaches [1, 2].

The cavity is the space enclosed by the inner metal walls in which loaded material interacts with microwaves. It is large enough to contain multiple modes. In practical realization of the microwave applicators one of the most important issues is the resonant modes distribution inside the metallic cavity, in order to achieve equally material drying. For that reason the modelling of the real feed is very important, because depending on the feed position, dimensions and orientation, the number of modes will be different. There are many ways to

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couple energy into the cavity. A loop-coupling magnetic field and a probe-coupling electric field can be used. An array of resonant slots is not uncommon. However, a waveguide is generally used to launch the energy from the source into the cavity because it has the advantage of minimizing the reflected power.

TLM (Transmission Line Modelling) method is a general, electromagnetically based numerical method that has been applied very successfully in the area of metallic cavities modelling [3-5]. In earlier researches, TLM simulator with an impulse excitation in specific TLM node has been used to establish particular field distribution inside the metallic cavity. Later, regarding to the fact that this model was different from the real experimental case, a probe loaded into the cavity is used as an excitation. In both cases, the modelled space has been very simple.

The goal of this paper is to investigate the possibilities of 3D TLM method for an analysis of real microwave applicator with an excitation through the waveguide. In this case, a complete modelled space consists of the cavity and one or more waveguides. As an excitation form straight wire conductor (probe) loaded into the waveguide and connected to the generator is used.

TLM method is applied to the both empty and loaded rectangular metallic cavities and all analysis are done in the frequency range of industrial microwave applicators 2.425÷2.475 GHz. In modelling process, the thickness and conductivity of the cavity walls are taken into account, that is, the real characteristics of the walls are modelled. Furthermore, a load (perspex block) is placed in one corner of the cavity implying that the characteristics of the modelled space are variable along all three dimensions.

2 TLM Modelling

In TLM method, an electromagnetic (EM) field distribution in three dimensions, for a specified mode of oscillation in a microwave cavity, is modelled by filling the field space with a network of transmission lines and exciting a particular field component in the mesh either directly or by voltage source placed on the excitation probe.

EM properties of a medium in the cavity are modelled by using a network of interconnected nodes. A typical structure named as symmetrical condensed node (SCN) is shown in Fig. 1. To operate at a higher time-step, a hybrid symmetrical condensed node (HSCN) [6] 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 [7] is implemented to speed up the simulation process.

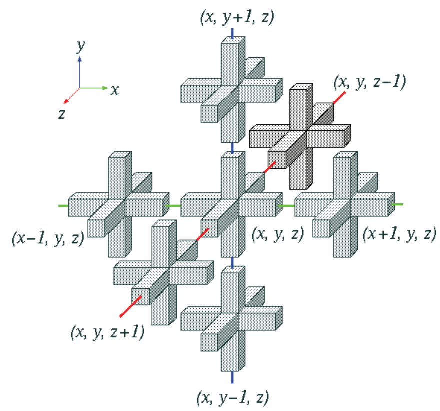


Fig. 1 – *Network of interconnected TLM nodes.*

In this paper, a non-uniform medium of the loaded microwave cavity is modelled by using a non-uniform TLM mesh. Due to non-homogeneity of the medium inside the cavity, TLM node in dielectric is $\sqrt{\varepsilon_r}$ times less than nodes in the rest of the cavity filled with air. The mesh layout in *xy* plane for the structure modelled in this paper is shown in Fig. 2.

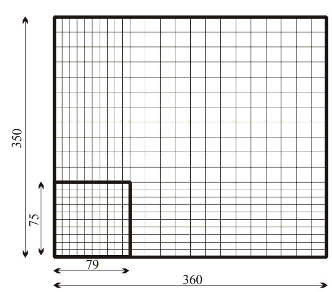


Fig. 2 – *Non-uniform mesh of the loaded cavity in xy plane.*

3 Numerical Analysis

A metallic, rectangular cavity of dimensions a = 360 mm, b = 350 mm and h = 260 mm, is analyzed using 3D TLMscn software [3]. The cavity is made of aluminium ($\sigma = 3.54\,e^{7}$ S/m) with wall thickness of 4.5 mm.

First, a given empty cavity without any feed attached is analyzed using TLM simulator with an impulse excitation of all EM field components. In

Table 1 are shown thus obtained resonant frequencies as well as frequencies analytically calculated using the following equation:

$$\omega_{mnp}^2 \mu_0 \varepsilon_0 \varepsilon = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{p\pi}{h}\right)^2, \tag{1}$$

where m, n and p are the mode indices. As it can be seen, a very good agreement between simulated and analytical results is achieved.

Table 1

Resonant Modes in the Empty Multimode Cavity

Mode		Resonant Frequency (GHz)			
Mode Indices, *m n p*	Mode Type	Calculated Frequency (GHz)	TLM Simulated Frequency		
			Impulse Excitation	WG 1 (Fig. 3a)	WG 1-4 (Fig. 3b)
0 5 2	TE	2.432	2.430	-	-
0 4 3	TE	2.434	2.435	-	2.435
4 1 3	TE, TM	2.439	2.441	-	-
5 3 0	TM	2.446	2.444	-	2.445
2 0 4	TE	2.452	2.452	2.453	2.450
4 4 1	TE, TM	2.458	2.454	-	2.456
0 2 4	TE	2.460	2.459	-	2.459
1 5 2	TE, TM	2.467	2.465	-	2.464
1 4 3	TE, TM	2.468	2.467	2.467	2.468
3 5 0	TM	2.475	2.476	-	2.471

In practice, depending on the position and number of the feeds the number of modes will be different from those shown in specific column of **Table 1**. Moreover, a number of excited modes in the cavity will be smaller compared to theoretical case.

In order to investigate the influence of the feed waveguide to the number of resonant modes, TLM method is applied to the modelling of the multimode cavity with an excitation achieved through a TE10 mode WR340 waveguide of dimensions 86x43x200 mm. The location of the waveguide, WG, is shown in Fig. 3a [3]. A wire probe connected to the generator is used as the excitation of the waveguide.

The simulated S_{11} plot of the given cavity is shown in Fig. 4. The plot gives an indication of the modes that are resonant in the cavity. In this case 3 modes (TE_{204}, TM_{143}, TE_{143}) are seen which is in severe contrast to the 14 analytically calculated modes without the feed position and orientation taken into account (**Table 1**).

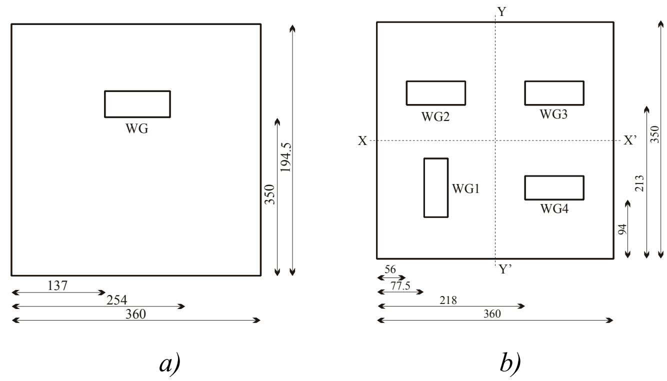


Fig. 3 – *Front view of the a) single-feed cavity, b) four-feed cavity.*

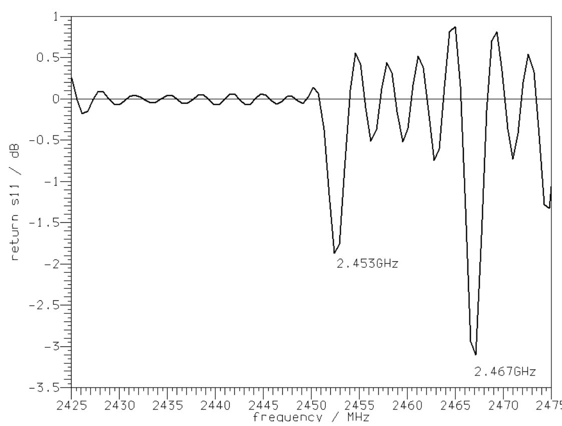


Fig. 4 – *S_{11} of the single-feed empty cavity.*

Furthermore, TLM method is also applied to the four-feed multimode cavity with feed positions shown in Fig. 3b [3]. Obtained results are shown in Fig. 5. The corresponding values of the resonant frequencies are shown in **Table 1**. As one can observe, 11 modes are excited in this case in the frequency range of interest. Also, from Fig. 5 it can be seen that a cross-coupling occurs as the consequence of the presence of more than one feed waveguide.

3D TLM method can be successfully used for modelling of the loaded multimode cavities. In this paper, perspex block of dimensions 79x75x51 mm and dielectric constant $\varepsilon_r = 2.6 - j0.015$ is used as the load inserted in the rectangular cavity of dimensions 360x350x260 mm. The position of the load is shown in Fig. 6 [3].

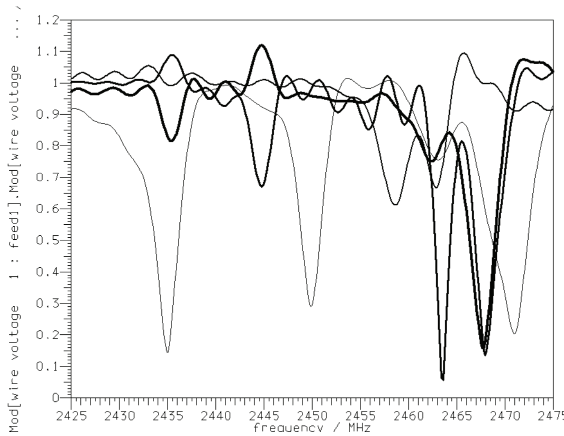


Fig. 5 – *Results obtained using TLM simulator for the four-feed empty cavity,*

WG1 , WG2 , WG3 , WG4

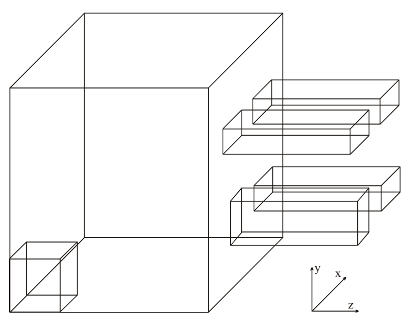


Fig. 6 – M*ultimode cavity loaded with perspex block.*

Resonant frequencies that exist in the loaded cavity without any feed attached as well as the resonant frequencies excited in the four-feed loaded cavity were obtained using TLM simulator. These values are compared with the measured results from the reference [3] and shown in **Table 2**. A very good agreement between measured and simulated results is achieved.

The inclusion of a load leads to a completely new set of modes, different from the ones that exist inside an empty cavity. It can be seen what happens when a load is inserted in the cavity: the modes shift downward in frequency. Also, in the case of the four-feed loaded cavity, some types of modes that exist in the cavity without any feed attached can not be excited as it can be seen from

Table 2. In Fig. 7 are shown results obtained using TLM simulator for the four-feed loaded cavity. As for the empty cavity, the effect of the cross-coupling can be observed. In practical realisation of the microwave applicators with more feed waveguides, this cross-coupling should be minimized by changing the feed position and orientation.

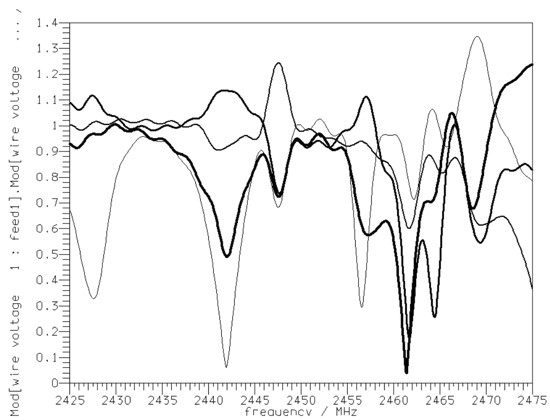


Fig. 7 – *Result obtained using TLM simulator for the four-fee multimode loaded cavity:*

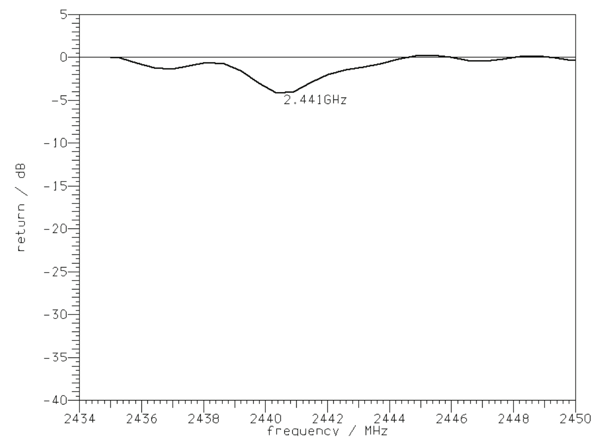
WG1 , *WG2* , *WG3* , *WG4*

Table 2

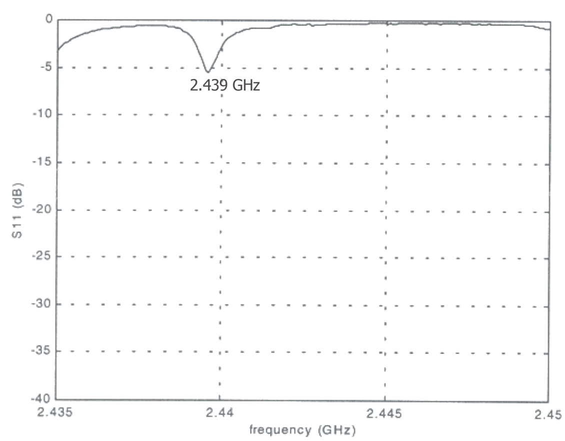
Resonant Modes in the Multimode Cavity with the Perspex Block

Resonant Frequencies (GHz) [3]	TLM Simulated Frequency (GHz)	
	Impulse Excitation	WG 1-4 (Fig. 3b)
2.429	2.429	2.427
2.434	2.434	-
2.439	2.438	-
2.441	2.441	2.441
2.442	2.442	2.442
2.451	2.452	2.448
2.456	2.455	2.456
2.460	2.461	2.461
2.462	2.465	2.465

In addition, in order to illustrate the possibility of 3D TLMscn software for an analysis of real case in which a waveguide is used to launch the energy from the source into the cavity, two examples of single-feed loaded cavities with two different feed positions, that is for feed positions: WG2 and WG4 shown in Fig.3b, are investigated and presented. The simulated S_{11} plots of the analyzed cavities are shown in Fig. 8a and Fig. 9a. In Figs. 8b and 9b are shown corresponding experimental results from the reference [3]. As it can be seen from Figs. 8 and 9, a good agreement between simulated and experimental results is achieved.

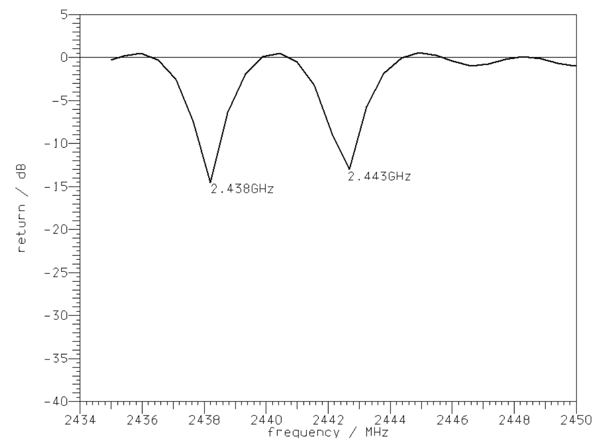


a)

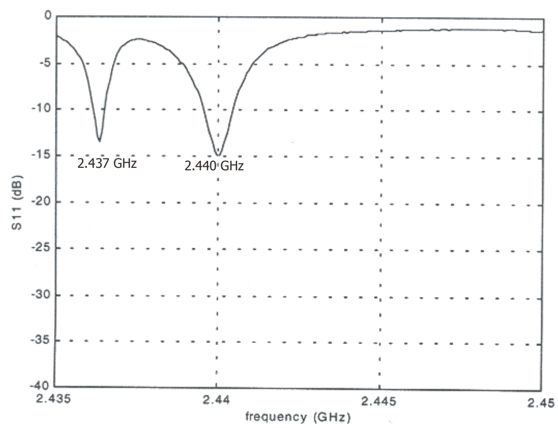


b)

Fig. 8 – *S_{11} of the cavity containing perspex block with feed location WG2 shown in Fig. 3a, a) TLM simulated results, b) experimental results [3].*



a)



b)

Fig. 9 – *S_{11} of the cavity containing perspex block with feed location WG4 shown in Fig. 3b, a) TLM simulated results, b) experimental results [3].*

4 Conclusion

In this paper, both empty and loaded rectangular metallic cavities with an excitation through the waveguide are analyzed in order to investigate the possibilities of TLM method for an analysis of real microwave applicator. As an excitation form straight wire conductor (probe) loaded into the waveguide is used. In the modelling process, the thickness and conductivity of the cavity walls are taken into account, that is, real characteristics of the walls are modelled.

Resonant frequencies that exist in the empty cavity without any feed attached were obtained using TLM simulator with impulse excitation and compared with analytically calculated modes. A good agreement between these results is achieved. On the other hand, it is shown that when the excitation is achieved through the one or more waveguides a smaller number of resonant modes was present in the cavity compared to the theoretical case and that number of excited modes depends on the number and positions of the feed waveguides. It is also observed that when more waveguide feeds are used the cross-coupling between feeds occurs. In practical realization of the microwave applicators, the cross-coupling could be minimized if the feed positions and orientations are properly chosen.

Further, 3D TLM method is applied to determine resonant modes distribution when a Perspex block is loaded into the cavity. For TLM modelling of this structure a non-uniform mesh is used. The inclusion of a load leads to a completely new set of modes, different from the ones that exist inside an empty cavity.

Finally, in order to illustrate that 3D TLMscn software is applicable for an analysis of real case in which a waveguide is used to launch the energy from the source into the cavity, two examples of single-feed loaded cavities with two different feed positions are investigated. A good agreement between simulated and experimental results is achieved.

Presented results completely confirm applicability of TLM method for an analysis of resonant mode distribution inside the real microwave applicator, taking into account the influence of the feed position and the load to the resonant frequencies.

5 References

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

[2] M. Mladenović, A. Marinčić, B. Milovanović: Mode Tuning of Microwave Resonator Loaded with Losses Multilayer Dielectric, Journal of Microwave Power and Electromagnetic Energy Vol. 24, No. 3, 1989, 166-177.

[3] T.V.C.T. Chan, H. C. Reader: Understanding Microwave Heating Cavities, Artech House, Boston, London, 2000.

[4] N. Dončov: Microwave Structures Analysis Using 3-D TLM Method, M.Sc thesis, Faculty of Electronic Engineering, University of Niš, 1999.

[5] B. Milovanović, N. Dončov, A. Atanasković: 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 (World Scientific and Engineering Society) Press, 2000, pp. 327-332.

[6] C. Christopoulos: The Transmission-Line Modelling Method, IEE/OUP Press, 1995.

[7] V. Trenkić: The Development and Characterization of Advanced Nodes for TLM Method, Ph.D. Thesis, University of Nottingham, 1995.