Analysis of Real Feed Probe Influence to the Resonant Frequencies and Field Distribution in the Cylindrical Metallic Cavity Using 3D TLM Method

Bratislav Milovanović[1], Aleksandar Marinčić[2], Nebojša Dončov[3], Vera Marković[1], Jugoslav Joković[1], Aleksandar Atanasković[1]

Abstract – **For the example of the cylindrical metallic cavity with circular cross-section, the real excitation modeling, using TLM wire node, is presented. The small wire conductor, as an excitation form, is used according to the wanted type of mode in the cavity. The modeling process is described and the obtained TLM numerical results are compared with the experimental ones, to the aim of verification of the method. Besides, the influence of length and radius of real feed probe to the resonant frequencies of TM and TE modes in frequency range *f* = [1.5-3.5] GHz is analysed. TLM results, in the case of empty cavity with real excitation probe, are compared with results calculated by using the theoretical approach, that is TLM simulator with impulse excitation. Finally, field strength versus length of real feed probe are investigated and the appropriate conclusions are given.**

Keywords – **TLM method, Microwave applicator, Cavity, Real excitation, Wire node, 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 behaviour 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 [1,2,3]. Also, some experimental work has been done in order to investigate the mode tuning behaviour experimentally [1,2].

TLM (Transmission-Line Matrix) method is a general, electromagnetic based numerical method that has been applied very successfully in the area of cylindrical metallic cavities modeling [3,4,5]. In all this applications, an impulse excitation was used to establish desired field distribution in the modeled cavity.

[1]Bratislav Milovanovic, Vera Markovic, Jugoslav Jokovic and Aleksandar Atanaskovic are with the Faculty of Electronic Engineering, Beogradska 14, 18000 Nis, Serbia and Montenegro, E-mail: [bata, vera, jugoslav, beli]@elfak.ni.ac.yu

[2]Aleksandar Marincic, SANU member, is with the Faculty of Electrical Engineering, Bul. Kralja Aleksandra 73, 11000 Beograd, Serbia and Montenegro, E-mail: marmarij@eunet.yu

[3]Nebojsa Doncov is with the Flomerics Ltd, Electromagnetic Division, Notthingam, United Kingdom, E-mail: nebojsa@flomerics.co.uk

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 of resonant frequencies and field strength in the case of impulse excitation being different from the experimental ones. With some improvements in TLM method, it is possible to model a 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 (probe, loop, waveguide 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 real excitation in the form of wire conductor loaded in the cylindrical metallic cavity with circular cross section. TLM method is applied to the cavity with dimensions a = 7 cm and h = 14.24 cm. On this way, it is possible to investigate the influence of the real excitation, that is length and radius of wire conductor, to the resonant frequencies of the cavity. In this paper 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. The analysis is incomplete, as empty cavity only is considered, but some important conclusions can be drawn that are still valid for the loaded cavity. In order to verify TLM method the obtained numerical results of resonant frequencies for modes in frequency range f = [1.5-3.5] GHz are compared with the experimental ones. Experimental set up for resonant frequencies measurement is shown on the Fig. 1.

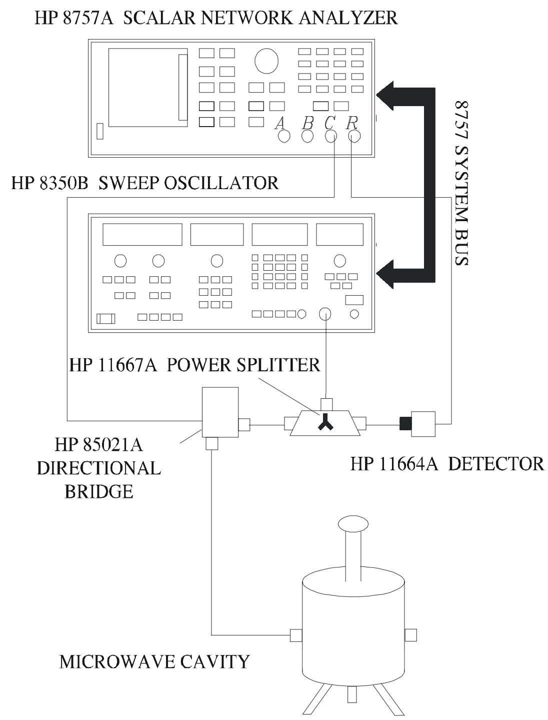

Fig. 1. Experimental set up for resonant frequency of the cylindrical metallic cavity measurement

II. TLM MODELLING

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.

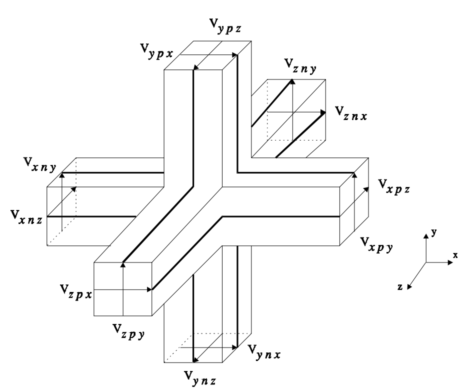

Fig. 2. Symmetrical condensed node

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.

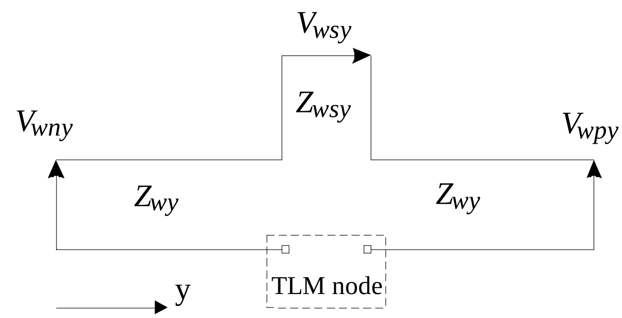

Fig. 3. Wire network

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 (Fig. 4). 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.

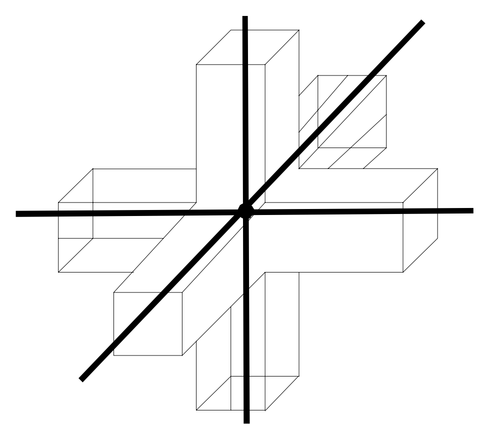

Fig. 4. Wire network segments embedded within the TLM node

IV. NUMERICAL ANALYSIS

The numerical results, which illustrate the effect of the real excitation probe presence to the resonant frequency and field distribution, are presented for a empty cavity with circular cross-section. Dimensions of the investigated cavity are a = 7 cm and h = 14.24 cm. For modeling of this cavity non uniform TLM mesh with 43x43x32 was used. At the same time, a real excitation in form of small straight wire conductor is modeled by using TLM wire node. An excitation probe is placed in the height l = 7.24 cm from bottom on the cavity, slightly different from $h/2$, in the r direction. In this way, it is possible to excite modes having r-component of the electrical field in the cavity. Excitation probe is fed by voltage source V_{source} = 1 V and R_{source} = 50 Ω. The resonant frequencies are determined from the reflection characteristic (S_{11} plot).

A. Probe Length Influence to the Resonant Frequencies

The radius of the excitation probe is chosen to be r = 0.5 mm and length d is variable in order to investigate the influence of the length of wire conductor, to the resonant frequencies of the cavity.

The obtained TLM numerical results and experimental results of resonant frequencies for modes in the frequency range f = [1.5-3.5] GHz, versus length of the real excitation probe d, are shown in the Fig. 5. The circle symbols indicate the results obtained by using TLM method with real excitation and triangle ones 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.

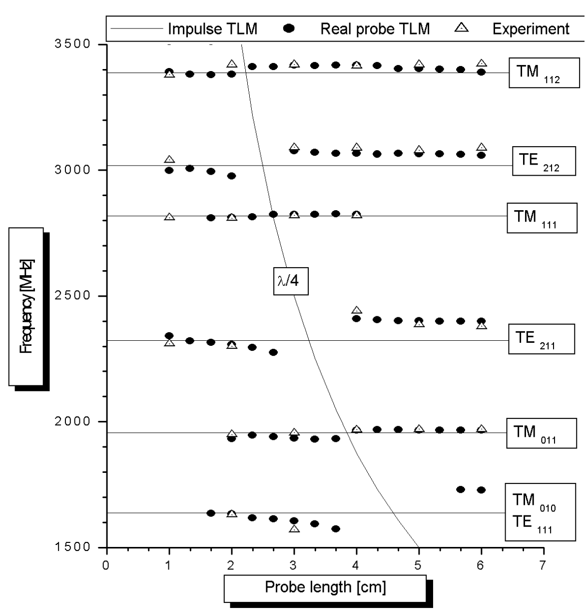

Fig. 5. Resonant frequencies versus probe length

As it can be seen from Fig. 5, in comparison with results calculated by using 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 probe in the cavity.

The Fig.5. also shows that the values of resonant frequencies for TM and TE modes considerable depend on the real excitation 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 case of TE modes,, deviation of resonant frequencies are higher than in the case of TM modes. In the area of capacitive character of probe impedances (d<λ/4), due to increasing of wire conductor length the values of resonant frequencies shift to lower frequencies. In inductive area (d>λ/4) both TLM and experimental results of resonant frequencies have higher values than in the case applying TLM method with impulse excitation. Also, due to increasing 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 Fig. 6. and 7. are shown S_{11} plots for the probe length d = 3 cm, obtained experimentally and by using TLM method, respectively.

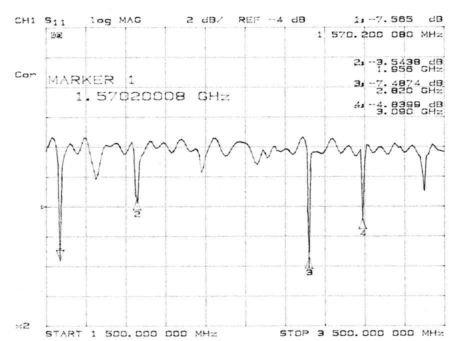

Fig. 6. S_{11} plot obtained experimentally (d = 3 cm)

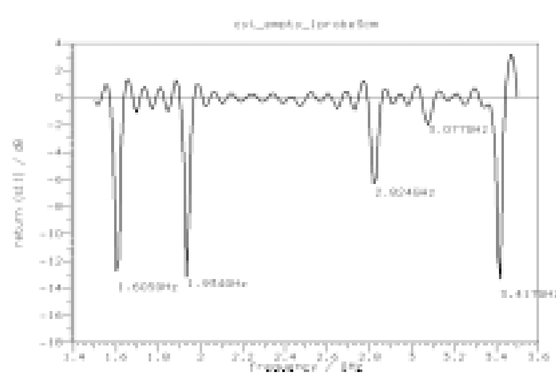

Fig. 7. Numerical TLM results (d = 3 c m)

B. Probe Radius Influence to the Resonant Frequencies

Further, in order to investigate the influence of the radius of wire conductor to the resonant frequencies of the cavity, TLM model is applied for the constant value of length of real feed probe d = 3 cm as a parameter, and different values of the radius of excitation probe r in the range r = (0-0,5) mm. Obtained TLM results in the Fig. 8-12. present resonant frequencies for TE_{111}, TM_{011}, TM_{111}, TE_{212}, and TE_{211} modes versus radius of excitation probe.

It should be noted that frequency corresponding quarter-wavelength for probe (d = 3 cm) used in this case is f = 2.5 GHz (Fig. 5). Therefore, in observing frequency range f = [1.5-3.5] GHz, the probe impedance has capacitive character for frequency in range f = [1.5-2.5] GHz and inductive character in range f = [2.5-3.5] GHz. In the capacitive area (f < 2.5 GHz) TE_{111} and TM_{011} are excited. The values of resonant frequencies of these modes increase due to reducing of the radius of wire conductor and tend toward theoretical values (Fig. 8. and 9). In the other side, in the area of inductive character of probe impedances (f > 2.5 GHz), due to reducing of the radius of wire conductor the values of resonant frequencies of TM_{111}, TE_{212} and TM_{112} modes (Fig. 10 - 12), decrease and tend toward theoretical values as well.

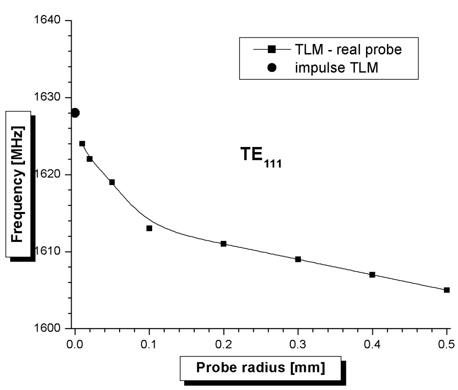

Fig. 8. The resonant frequencies for TE $_{111}$ mode versus probe radius of excitation probe, calculated by using TLM approach

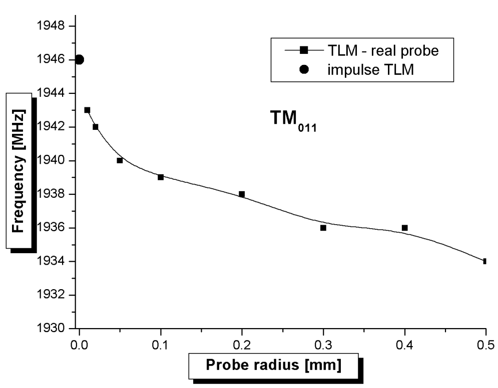

Fig. 9. The resonant frequencies for TM $_{011}$ mode versus radius of excitation probe, calculated by using TLM approach

Comparing the obtained results for all excited modes, it can be seen that TM_{111} mode has the least deviation of frequency versus probe radius: $f\,|_{r=0}$ = 2821 MHz, $f\,|_{r=0.5mm}$ = 2824 MHz. Also, it should be noted that, in this case, TM_{211} is not excited (Fig.5), because probe length d=3cm is approximately equal corresponding quarter-wavelength for this mode frequency: f_{res}= 2331 MHz, $\lambda/4$= $(3\times10^8/2331\times10^6)/4$ = 3.2 cm.

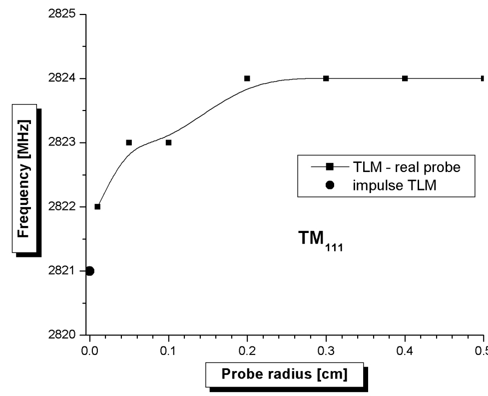

Fig. 10. The resonant frequencies for TM $_{111}$ mode versus radius of excitation probe, calculated by using TLM approach

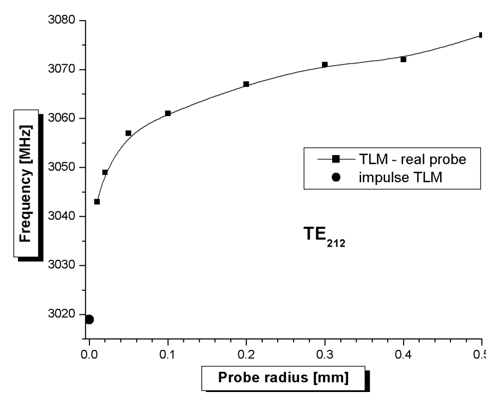

Fig. 11. The resonant frequencies for TE $_{212}$ mode versus radius of excitation probe, calculated by using TLM approach

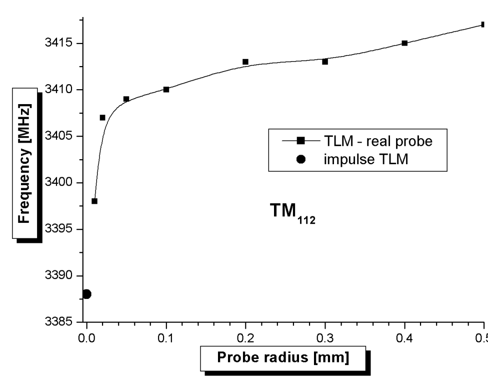

Fig. 12. The resonant frequencies for TM $_{112}$ mode versus radius of excitation probe, calculated by using TLM approach

C. Probe Length Influence to the Field Strength

In the Fig. 13. and 14. are shown the obtained numerical and experimental results of field strength versus length of the real excitation probe *d,* for dominant TE_{111} and TM_{011} modes, respectively. The values of field strength are presented as S_{11} magnitude in dB. Also, in the same figures probe length corresponding quarter-wavelength of modes frequency are presented. Presented numerical and experimental results are obtained for constant value of probe radius r = 0.5 mm.

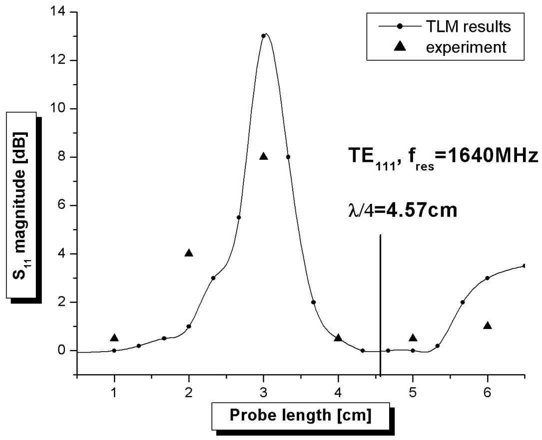

Fig. 13. Field strength versus probe length for dominant TE_{111} mode

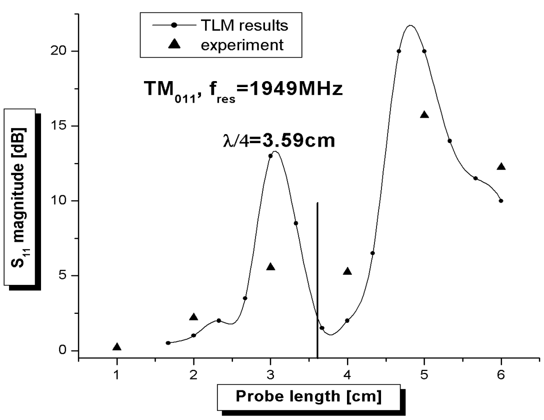

Fig. 14. Field strength versus probe length for TM_{011} mode

As it can be seen from Fig. 13. and 14, there is good agreement between numerical TLM and experimental results, which also indicates good TLM modeling of the real feed probe in the cavity.

The Fig. 13 and 14. also shows that there is no reflection, that is modes are not excited, for the values of probe length corresponding quarter-wavelength in frequency of TM_{011} and TE_{11} modes. In the other hand, Fig. 13. and 14. give information which probe length *d* should chose to the aim of achieving greatest reflection for corresponding modes, that is operating frequency for applicator.

V. CONCLUSION

In this paper, real excitation probe in a empty cylindrical metallic cavity is modeled by using TLM method and influence of feed probe to the resonant frequencies and field distribution is analyzed. TLM numerical technique has been implemented in the appropriate software and applied to the problem of determining resonant frequencies and field strength 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 probe.

The influence of the feed probe length and radius to the resonant frequencies of the cavity is analysed for TM and TE modes which excited in frequency range f = [1.5-3.5] MHz. The obtained results where a small probe inside the cavity is used as an excitation show that values of resonant frequencies depend on both length and radius of wire conductor. This dependence is related with character of probe impedances.

Also, in this paper at the first time influence of feed probe to the field distribution in cavity is investigated, using 3D TLM method. Comparing obtained numerical and experimental results good agreement is observed.

According to previously showed results a general conclusion can be derived that TLM approach gives valid results. Therefore it is expected that these resonant structures can be successfully modeled by TLM method, independently of probe location and dimensions, and presence of dielectric sample. TLM technique gives possibilities for modeling of microwave applicator with different mode and position of excitation. Significance of this approach is that TLM technique gives information which dimensions and position of real feed probe should be chosen to the aim of achieving greatest reflection in operating frequency range in the real case of microwave applicator.

ACKNOWLEDGEMENT

This work was supported by Ministry of Science, Technologies and Development of Republic of Serbia, under the project NP EE (National program of Energetic Efficiency) 306 -85B.

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, Nis, Yugoslavia, 306-309, 1997, pp.214-217, Nis, Yugoslavia, 1999.

[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.