Modelling of Losses in a Microwave Applicator Using TLM Method

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Abstract - **In this paper, a microwave applicator based on loaded rectangular cavity is analyzed by using 3-D TLM software in order to investigate effects of the conducting and dielectric losses on EM field in the cavity.**

Keywords – **Microwave Applicator, Cavity, Losses, Waveguide, TLM**

I. Introduction

The utilization of microwaves in industry has led to the development of a number of microwave applicators in the processes of dielectric material heating and drying. A rectangular metallic cavity represents configuration very suitable for adequate modelling of some practical heating and drying applicators. The knowledge of the mode tuning behaviour under load and feed conditions has important significance and is helpful in designing these applicators. For that reason, a number of authors presented their researches of the metallic cavities, based on different approaches [1, 2].

When practical realization of microwave applicators is concerned, one of the most important issues is the resonant modes distribution inside the metallic cavity, in order to achieve equally material drying. Regarding applicator design process, the cavity walls and dielectric characteristics modelling has practical significance. As there is no analytical solution for the most cases of widely used loaded cavities, computational electromagnetic techniques emerge as an invaluable tool in the applicator design.

TLM (Transmission Line Modelling) method is a general, electromagnetically based numerical method that has been applied successfully to the wide range of problems. In that context, it has been applied to the modelling of metallic cavities loaded with dielectrics with different geometrical and electromagnetical properties [3, 4]. For establishing desired field distribution within the modelled cavity an impulse excitation of corresponding electromagnetic (EM) field component [4] or a real feed probe modelled by using TLM wire node [5] may be used.

This paper focuses on TLM modelling and analysis of how cavity walls and dielectric load losses influence EM field in the cavity.

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II. TLM Modelling Procedure

In the TLM time-domain method, electromagnetic 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 [6].

Electromagnetic properties of mediums in the cavity are modelled by using a network of interconnected nodes (Fig. 1), a typical structure being the symmetrical condensed node (SCN) [7]. Each node describes a portion of the medium shaped like a cuboid or a slice of cake depending on the applied (rectangular/cylindrical) coordinate system (grid).

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 is implemented to speed up the simulation process.

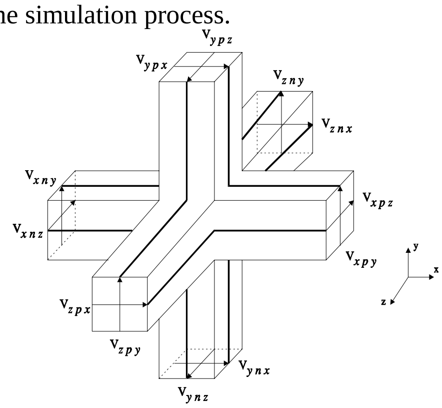

Fig. 1. Symmetrical condensed node

As in every numerical simulation, in TLM time-domain method it is also necessary to describe boundaries. External boundaries of arbitrary reflection coefficient ρ_w are modelled in TLM by terminating the link lines at the edge of the problem space with an appropriate load [7]. If the characteristic impedance of a link line differs from the intrinsic impedance of a medium, the equivalent link line reflection coefficient, ρ_{ij}, will be different from ρ_w. The link line reflection coefficient, ρ_{ij}, can be found by terminating the link line, of characteristic impedance Z_{ij}, with the same resistance:

$$\rho_{ij} = \frac{R - Z_{ij}}{R + Z_{ij}} = \frac{(1+\rho_w) - \hat{Z}_{ij}(1-\rho_w)}{(1+\rho_w) + \hat{Z}_{ij}(1-\rho_w)}, \qquad (1)$$

where a normalized characteristic impedance is introduced as $\hat{Z}_{ij} = Z_{ij} / Z_{ij}^{s}$.

If the external boundary represents an electric or magnetic wall we have $\rho_w = \rho_{ij}$. Otherwise, ρ_{ij} will depend on Z_{ij}. External boundaries modelling in TLM method, described by equation (1), will provide good results only if incident wave is perpendicular to the external boundary.

In many industrial processes, the water is often used as a cavity load. Losses in medium within a cavity can be incorporated in TLM model by introducing loss stubs into the scattering points that is nodes. The loss stubs may be viewed as infinitely long, or equivalently, as terminated (matched) by their own characteristic impedances. 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 [7]:

$$G_e = \sigma_e \, f(\Delta x, \Delta y, \Delta z), \tag{2}$$

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:

$$\varepsilon^* = \varepsilon_0 \varepsilon_r^* = \varepsilon_0 \varepsilon_r' - j\sigma_e / \omega \,. \tag{3}$$

III. Numerical Results

Numerical results, illustrating the influence of the losses on resonant modes of the cavity, were obtained by modelling of the rectangular cavity with dimensions: a = 36 cm, b = 35 cm and h = 26 cm using TLM approach. The medium inside the cavity was modelled by uniform TLM network of dimension $x \times y \times z = 36 \times 35 \times 26$ nodes ($\Delta x = \Delta y = \Delta z = 1$ cm) where hybrid symmetrical condensed node (HSCN) was used.

In order to study effects of cavity walls and dielectric losses, numerical TLM results, representing E_z field component in TLM node (20, 20, 20), which were obtained in the case of impulse excitation of E_z field component applied to the nodes (1÷15, 1÷15, 1÷15), were considered. At the beginning, the analyzed cavity was filled with air, representing homogeneous lossless dielectric of relative permittivity $\varepsilon_r = 1$. The second stage of the analysis was accompanied with TLM modelling of fully air-filled cavity with hypothetically complex permittivity ε_r = 1-j0.01, representing homogeneous medium with losses. In both cases, reflection coefficent of the walls was varied, that is either cavity walls were presented by perfect conducted metal characterized by ρ = - 1 or ρ = - 0.99 was used to model losses in the cavity walls. The time-domain outputs for all considered cases are shown in Fig. 2.

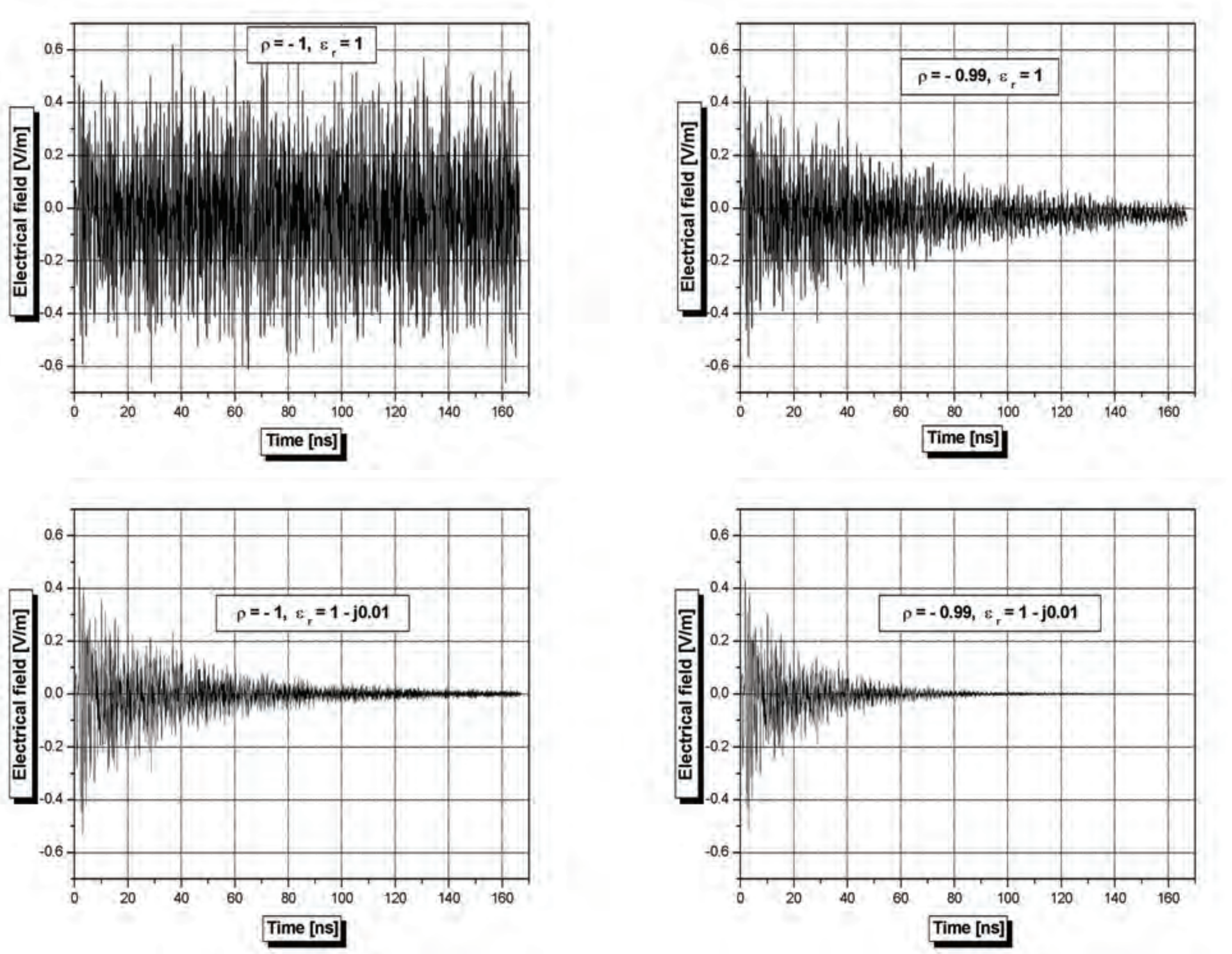

Fig. 2. Time-domain TLM results for air-filled cavity with different characteristics of walls and medium inside the cavity

When the lossless cavity is considered, the graph shows that envelope remains constant through period of time, whereas in the case when conducting losses as well as dielectric losses were taken into account an exponential decline of envelope is seen.

Corresponding frequency-domain results in the frequency range f = [500 ÷ 2000] MHz are shown in Fig. 3. It can be observed that amplitudes of the peaks, referred to as modes, are significantly reduced in the presence of conducting losses, but the same resonances can still be identified. Also, numerical results obtained for the lossless cavity shows greater oscillations of frequency-domain signal (as a result of time domain signal cut-off), compared to the cavity including conducting losses.

As far as homogeneous medium with losses (ε_r = 1 - j0.01) is concerned, presented graphs show that the presence of load losses has the same influence on the resonant modes as cavity walls reflection coefficients. On the other hand, when both cavity walls and load losses are incorporated, resonant modes peaks are additionally reduced, leading to difficulties concerning modes identification, especially when resonant frequencies are close.

Finally, partially loaded cavity with filling factor $t/h=0.2$ is analyzed. As a dielectric layer, placed on the cavity bottom, water at the temperature 20° is used. Relative dielectric constant of water ε_r = 81 - j10 is calculated from Debby's formula [8]. For more accurate modeling of this problem, a finer mesh within the homogeneous dielectric sample with losses and cells with arbitrary aspect ratio suitable for modelling of particular geometrical features, were applied. Corresponding numerical results in time and frequency domain are given in Figs 4. and 5, respectively. In the case of cavity without losses in the walls frequency-domain graph contains greater oscillations as a result of time domain signal cut-off. According to presented graphs conclusion can be derived that influence of the cavity walls losses on the resonant modes, in terms of frequencies and corresponding field level is not significant when the cavity contains good absorbing load, as water.

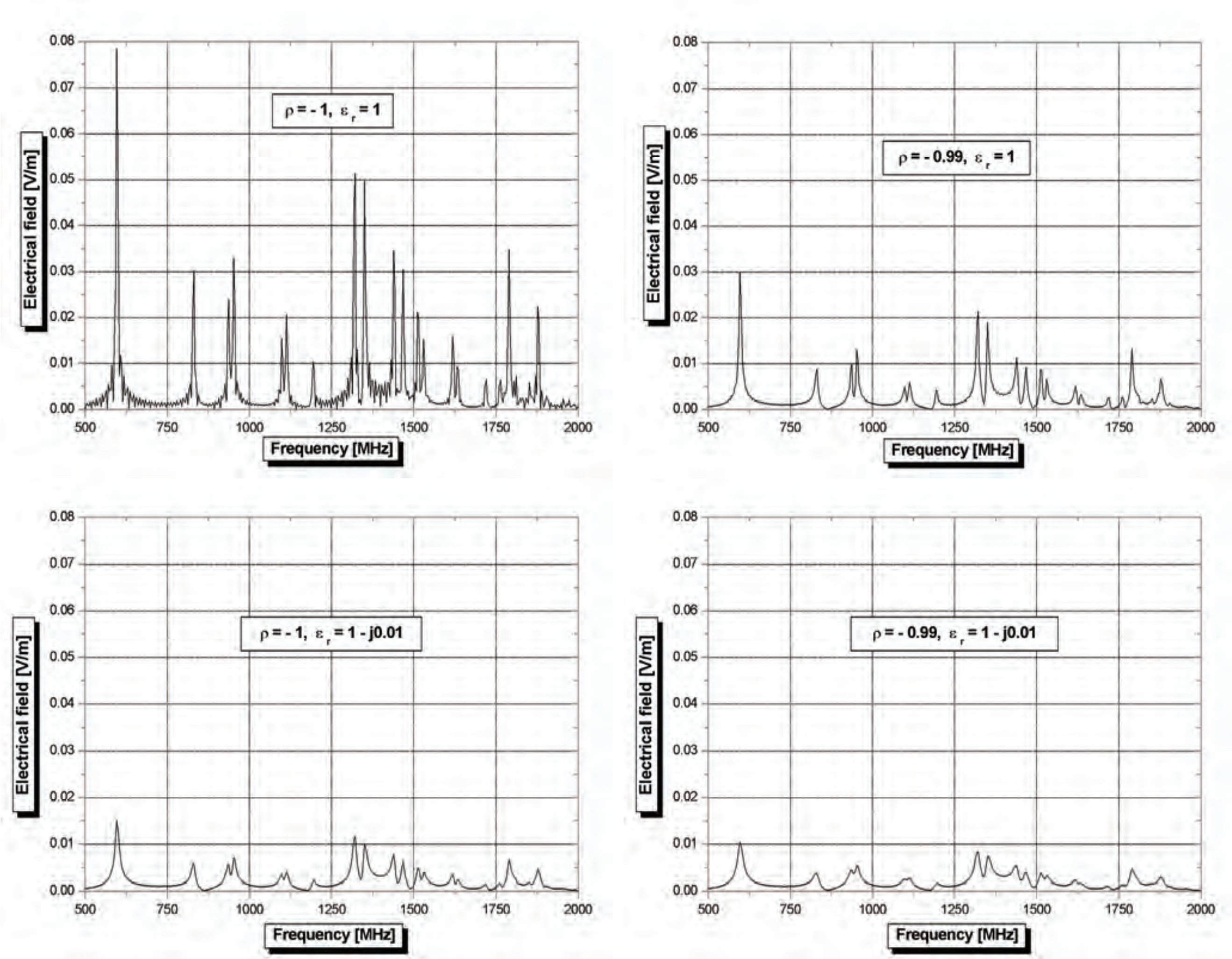

Fig. 3. Frequency- domain TLM results for air-filled cavity with different characteristics of walls and medium inside the cavity

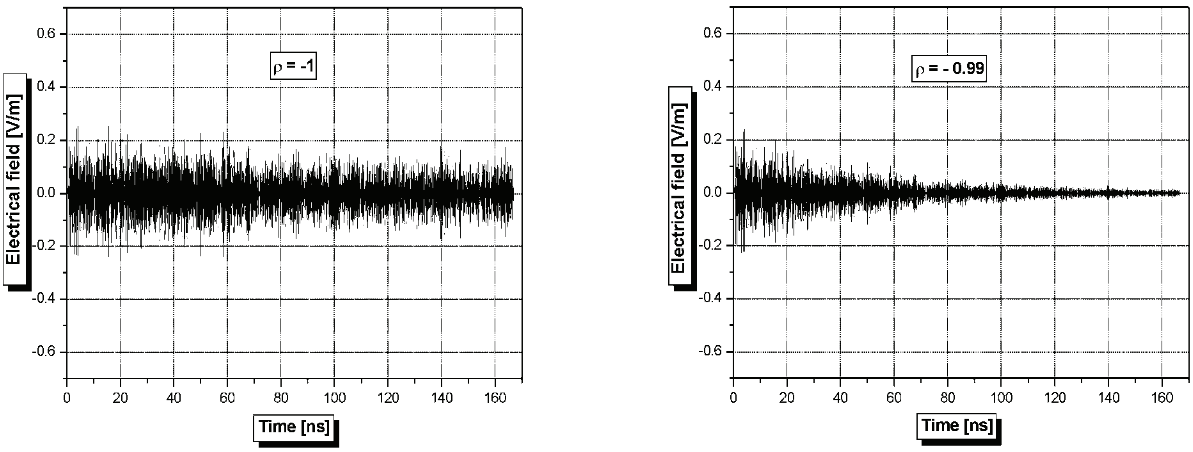

Fig. 4. Time-domain TLM results for partially loaded cavity with different reflection coefficients of walls

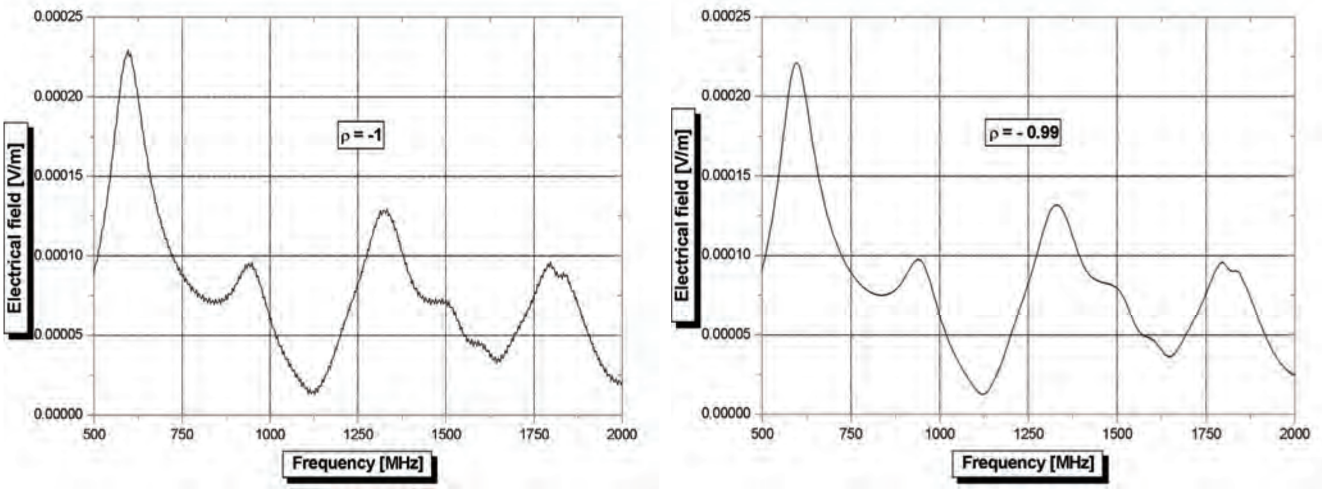

Fig. 5. Frequency-domain TLM results for partially loaded cavity with different reflection coefficients of walls

IV. CONCLUSION

This paper proposes TLM modelling of characteristics of microwave applicator based on conducting rectangular cavity loaded with dielectric layer. The cavity configurations with different reflection coefficients, representing losses in cavity walls, were analyzed in time and frequency domain by using 3-D TLM approach. Also, 3-D TLM software was applied to study effects of losses in dielectric load, represented by complex permitivity, in the cases of fully and partially loaded cavity for determining resonant modes in practical applications.

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