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Analysis of Feed Waveguide Length Influence on EM Field in Microwave Applicator Using TLM Method

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Abstract: A microwave applicator based on metallic cavity with a waveguide used to launch the energy from the source into the cavity is modelled using time-domain 3-D TLM method enhanced with model for modelling of wire and boundaries. An influence of waveguide length on EM field distribution inside the cavity is analyzed, in terms of modes presence and corresponding EM field levels.

Keywords: Microwave applicator, waveguide, TLM method.

1 Introduction

In practice, the microwave applicator is represented by cavity, that is the space enclosed by the inner metal walls in which loaded material interacts with microwaves. Since it is large enough to contain multiple resonant modes, rectangular metallic cavity represents a configuration suitable for adequate modelling of some practical heating and drying applicators. The knowledge of the mode tuning behavior in a cavity under loading condition (i.e. physical and electrical parameters of a load) forms an integral part of the studies in microwave heating and it has significant implication for the design of these applicators. Consequently, the rectangular metallic cavities have been the research subject of a number of authors.

As there is no analytical solution for the most cases of widely used partially loaded cavity, except for the case of a slab dielectric [1], computational electromagnetic techniques emerge as an invaluable tool in the cavity design. Several numerical techniques are available for microwave heating studies; among them the

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finite difference time domain (FD-TD) [2] and transmission line matrix (TLM) [3], known as full-wave methods, are the most popular in the field [4–6]. Also, the finite element method (FEM) is found to be a reliable technique for microwave heating applications [7]. In addition, some measurement work has been carried out, in order to experimentally investigate the mode tuning behavior under loading condition [8–10].

When practical realization of the microwave applicators is concerned, one of the most important issues is the resonant modes distribution inside a metallic cavity, in order to achieve equally material drying. Theoretically, cavity has a number of modes whose resonant frequencies and corresponding EM field level depend on dimensions and EM properties of a medium inside the cavity. Inaccuracy that may occur in practice is usually a result of dependence of EM field distribution on the feed position, dimensions and orientation. As regards feeding technique, several ways may be used to couple energy into the cavity. A loop-coupling magnetic field and a probe-coupling electric field can be used [9, 10]. Furthermore, an array of resonant slots is not uncommon [10]. In this way energy can be directly inserted in the cavity. However, in the case of microwave applicators, feeding technique assume using a waveguide to launch the energy from the source into the cavity, is the most common since it has the advantage of minimizing the reflected power [10].

TLM (Transmission-Line Matrix) time-domain method [3] is a general, electromagnetically based numerical method that has been developed and applied to a variety of cavity modelling problems [6, 11]. The research subject has been accounted for an analysis of an influence of a load with different EM and geometrical characteristics as well as influence of a probe directly inserted in a cavity. Modelling space was simple, consisting of the cavity. An additional improvement of the TLM method, in terms of boundary conditions, has allowed taking into account the presence of a waveguide, acting as an interface between a feed, in form of wire probe loaded into the waveguide and connected to the generator, and a cavity space. In this case, a complete modelled space is more complex as it consists of the cavity and one or more waveguide [12].

The goal of this paper is to investigate how feed waveguide influences EM field strength and distribution of resonant modes in the cavity. In that order, the TLM method was applied to an empty rectangular metallic cavity with an excitation through a waveguide, which length was varied. An analysis was carried out in the frequency range $f = [0-4]$ GHz.

2 TLM Modelling

In the conventional TLM time-domain method, electromagnetic field strength in three dimensions, for a specified mode of oscillation in a 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 [3]. Electromagnetic properties of different mediums in the cavity are modelled by using a network of interconnected nodes, a typical structure known as the symmetrical condensed node - SCN (Fig. 1) [13]. Each node describes a portion of the medium shaped like a cuboid or a slice of cake depending on the applied coordinate system (rectangular/cylindrical). Additional stubs can be incorporated into the TLM model to account for inhomogeneous materials and/or electric and magnetic losses in the modelled mediums. An efficient computational algorithm of scattering properties, based on enforcing continuity of the electric and magnetic fields and conservation of charge and magnetic flux [13] is implemented to speed up the simulation process.

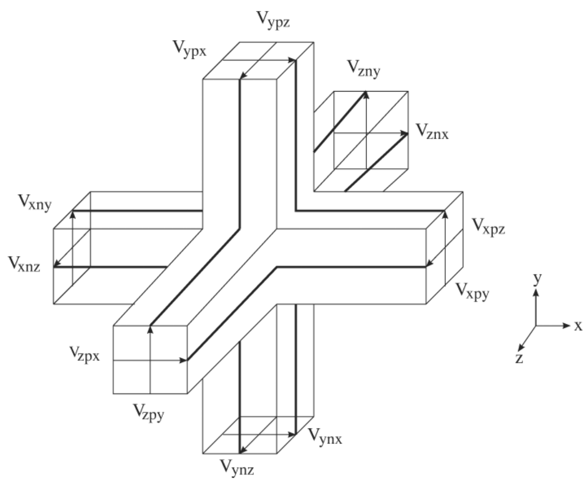

Fig. 1. Symmetrical condensed node - SCN.

TLM wire node is based on SCN with one small modification in the form of additional link and stub lines interposed over the exiting network to account for increase of capacitance and inductance of the medium caused by wire presence [14]. This wire network is usually placed into the centre of the TLM nodes to allow modelling of complex wire structures, e.g. wire junctions and bends (Fig. 2).

The single column of TLM nodes, through which wire conductor passes, can be used to approximately form the fictitious cylinder which represents capacitance and inductance of 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 TLM network and the mean dimensions of the node cross-section in the direction of wire running [15].

As in every numerical simulation, in TLM time-domain method it is also neces-

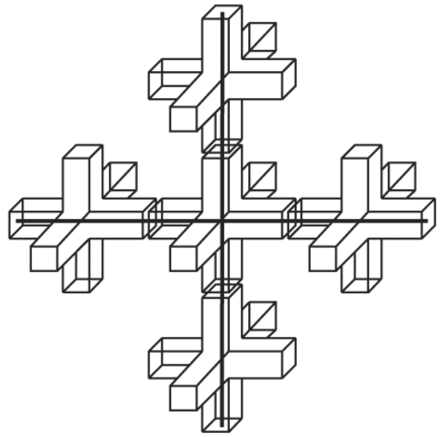

Fig. 2. Wire network embedded within the TLM nodes.

sary 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 [16]. 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

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

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

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.

3 Numerical Results

An empty, metallic, rectangular multimode cavity is analyzed using 3-D TLMscn software. The dimensions of the cavity, $a = 360$ mm, $b = 350$ mm and $h = 260$ mm, were chosen to follow the experimental model [10].

First, an empty cavity without any feed attached was analyzed using TLM simulator with an impulse excitation of all electric field components applied to the node (15, 15, 15). Simulated electric field components (E_z) in TLM node (20, 20, 20) are shown in Fig. 3.

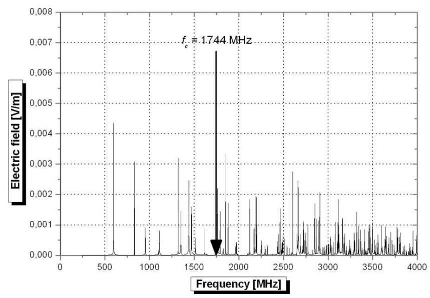

Fig. 3. TLM results of cavity without any feed attached.

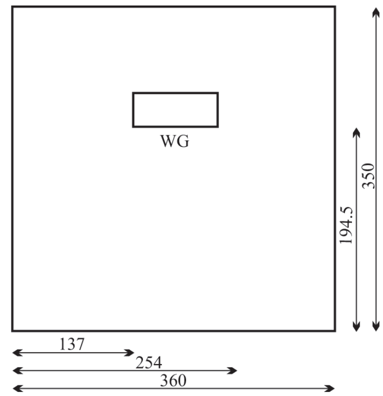

Fig. 4. The position of the feed waveguide.

In order to illustrate the influence of the feed waveguide length on the resonant modes distribution, the TLM method was applied to the multimode cavity with an excitation achieved through a TE_{10} mode of $WR340$ waveguide of dimensions $a =$ 86 mm, $b = 43$ mm, whereas its length was varied within the range $l = (100 - 250)$ mm. The position of the feeding port on the cavity wall, labelled as WG, is shown in Fig. 4 [10].

By inserting the probe (of radius $r = 0.5$ mm) $\lambda/4$ into the waveguide and $\lambda g/4$ from the short end of the waveguide [10], electric field was excited (Fig. 5). The

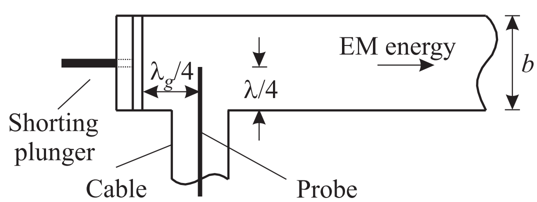

Fig. 5. Coupling into a waveguide through electric field.

shorting plunger can be used in practice for additional adjustment. The feed probe, modelled through the TLM wire node, was connected to the real voltage source: $V_{source} = 1$ V and $R_{source} = 50\ \Omega$. The simulated electric field components (E_z) in corresponding TLM node, when different lengths of the waveguide have been considered, are shown in Fig. 6.

Any waveguide is characterized by a cut-off frequency for each mode depending on the waveguide dimensions [15]. Thus, an air-filled waveguide $WR340$

$(a \times b = (86 \times 43)$ mm), operating at $f = 2.45$ GHz with dominant TE10 mode, has a cut-off frequency $f_c = 1.744$ GHz. This means that any wave below f_c would not propagate, that is the waveguide should be acting as a high-pass filter.

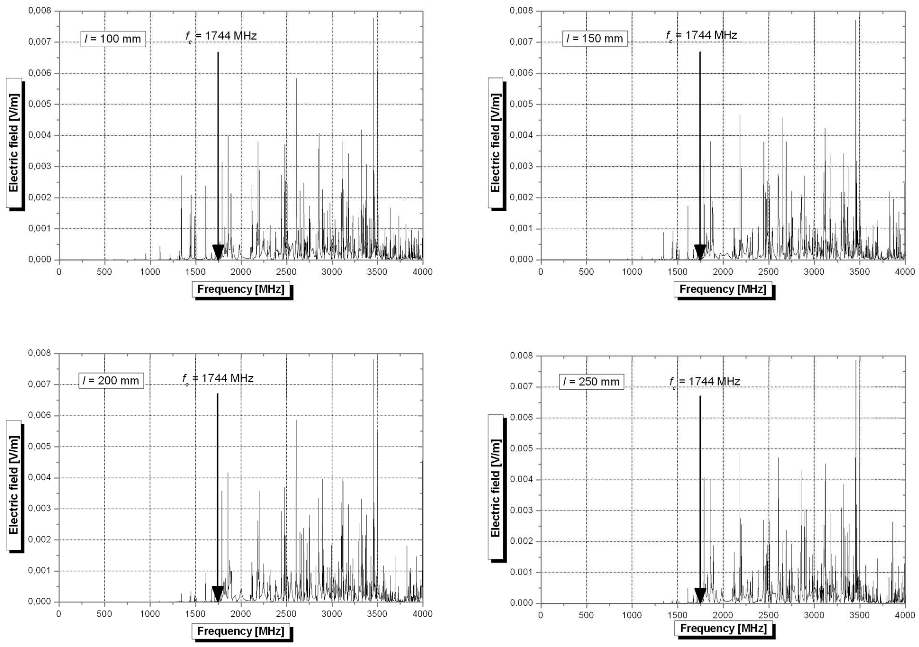

Fig. 6. TLM results of simulated cavity for different length of feed waveuide.

According to the results revealed in Fig. 6, the influence of the waveguide length on the EM field distribution may be observed. Theoretically, if the waveguide has infinite length it would act as an ideal high-pass filter. However, obtained results show that in practice, with finite waveguide lengths, resonant modes occur below cut-off frequency f_c . In these cases, number of modes and corresponding EM field level depend on waveguide length. In applicator design, the $WR340$ length of 200 mm related to wavelengths is enough for practical realization where waves below the cut-off frequency become enough repressed.

In order to illustrate effect of waveguide presents, in terms of filter characteristics, in Table 1 are given frequencies which correspond to minimum waves propagating for each length of the waveguide considered. For better illustration, this dependence of minimum mode frequency on waveguide length is given in Fig. 7. as well. As can be seen, this minimum mode frequency moves towards the cut-off frequency ($f_c = 1.744$ GHz) with increasing the waveguide length.

Furthermore, if we consider just one particular mode, for example $f = 1611.2$

Table 1. Minimum mode fruequency values for different waveguide lengths

Waveguide length [mm]	100	150	200	250
Minimum mode frequency [MHz]	830	951	1106	1344

MHz, a decline of the corresponding EM field level when a waveguide length is increased may be observed. The corresponding results are revealed in Table 2 and Fig. 8.

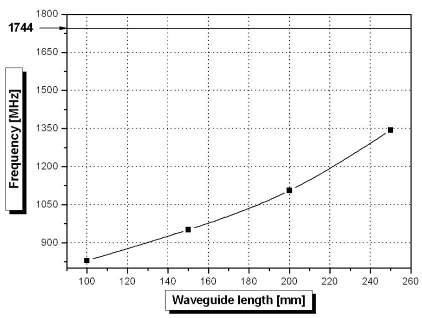

Fig. 7. Dependence of minimum mode frequency on waveguide length.

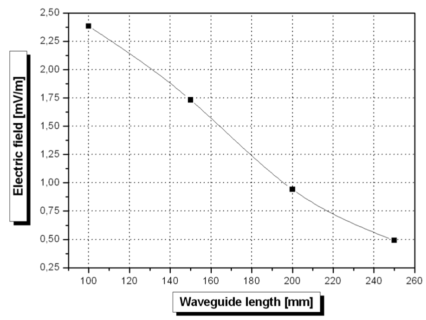

Fig. 8. Dependence of electric field level on waveguide length for mode $f = 1611.2$ MHz.

Table 2. Electric field level values for different waveguide lengths for mode $f = 1611.2$ MHz

Waveguide length [mm]	100	150	200	250
Electric field level [mV/m]	2.383	1.731	0.942	0.492

4 Conclusion

In this paper, an microwave applicator based on rectangular metallic cavity with an excitation through a waveguide was analyzed using TLM method. In order to investigate the influence of feed waveguide length on an EM field distribution, researches have been carried out for different lengths of the feed waveguide.

Presented results confirm that feed waveguide attached to the cavity has a roll of a high-pass filter. Besides, it was observed that the length of the waveguide had an effect on preventing propagation of EM waves below the cut-off frequency. In overall, when practical realization of the microwave applicator is concerned, the waveguide of adequate length related to wavelength in waveguide should be used as an excitation.

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