Electromagnetic Modeling Activities at the Technical University of Cartagena: a Review

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In this work the electromagnetic modeling activities of the Electromagnetics and Matter Research Group (GEM) at the Technical University of Cartagena are reviewed. In particular, waveguide inverse permittivity measurement techniques, neural network devices modeling and efficiency and electric field uniformity achievement for multimode ovens by using dielectric moulds are reviewed. Additionally, mode stirrers and sample movement studies and electromagnetic shielding techniques are also shown.

1. Introduction

Due to the increasing capability of computers for handling more and more complicated problems and the constant improvement of electromagnetic (EM) simulation codes, the use of modeling and optimization techniques has become a very important field for microwave engineers since they allow the reduction of time for device production and experimental validation.

In this work, we review the activities developed in the last years by the Electromagnetics and Matter Research Group (GEM) at the Technical University of Cartagena. In this way, we show several results and techniques for mode stirrers and sample movement in multimode ovens, inverse permittivity techniques, the use of dielectric moulds for efficiency and electric field distribution optimization, neural networks for device modeling and EM shielding.

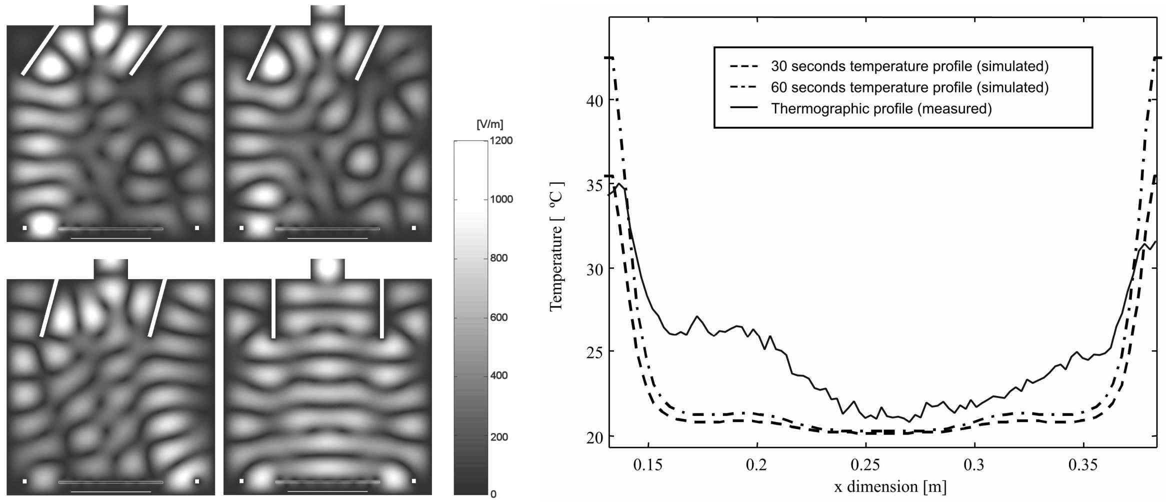
2. Mode Stirrers and Sample Movement in Multimode Cavities

Mode stirrers have been studied for 2D scenarios in [1], [2] by using MATLAB PDE Toolbox™ [3]. For this modeling it was assumed that mode stirrers' movement was fast enough for neglecting thermal migration effects during its movement. In this way an average electric field pattern, as shown in equation (1), was used within the heat equation in order to compute the thermal evolution within a wet clay sample. Figure 1 shows both the simulated scenario and the experimental validation simulations.

$$E_{mean}(x,y) = \sqrt{\frac{\left(\sum_{i}^{N} E_i^2(x,y)\right)}{N}} \qquad (1)$$

where $E_i(x,y)$ is the electric field distribution in the sample for the ith stirrer position.

Three-dimensional scenarios have also been studied in [4] for different sample paths, such as linear or circular ones, within multimode ovens. CST Microwave Studio was used in this case as EM simulator. The best type of movement strongly depended on the sample geometry and permittivity. Optimized movements showed much better results than constant movement within the applicator as shown in [4], [5].



(a) (b)

Fig. 1. Electromagnetic field for different stirrers' positions (a) and experimental validation for a wet clay sample temperature distribution [1] (b)

3. Permittivity Inverse Techniques for Waveguide Holders

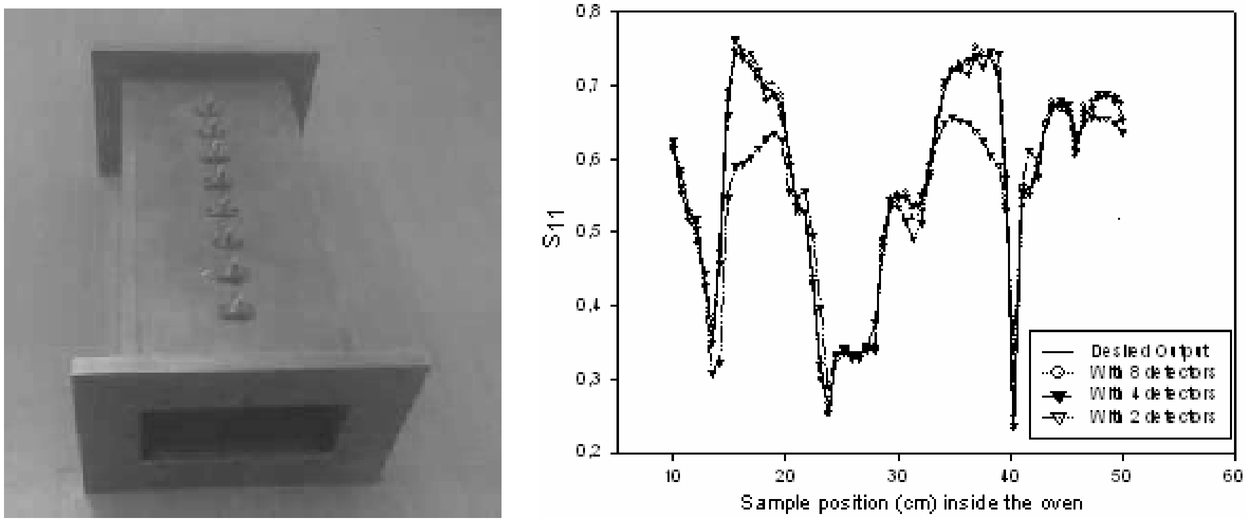
Three techniques (1D, 2D and 3D ones) have been developed for permittivity inverse measurements [6]. All of them use Genetic Algorithms (GA) as optimization strategy although a combination of GA with Gradient based techniques achieve better results both in computational times and accuracy [7].

1D technique is based in monomode waveguide assumption and is only valid for samples fully covering the cross-section. This technique is based in cascade connection of waveguide pieces with different TE_{10} mode impedances [6]. 2D techniques have been implemented by using MATLAB PDE Toolbox™ capabilities whereas 3D scenarios have been computed by using CST Microwave Studio. Samples with non-canonical shapes such as stars or a capital E have been measured. Obtained results for these samples agree very well with literature values. Multilayer dielectric structures have also been measured but in this case precision for estimated permittivity values are much worst than for monolithic materials [7].

4. Usage of Dielectric Moulds for Power Efficiency Optimization and Electric Field Levelling

Dielectric moulds have been used with two different purposes: power efficiency and electric field distribution improvement within multimode ovens. Three works [8]-[10] show that it is possible to achieve very high efficiency values within multimode cavities by properly surrounding the sample with dielectric materials. In fact, both 2D and 3D approaches show that the correct design of multilayer dielectric mouldings around a sample can lead to power efficiencies at the waveguide port around 99%.

The usage of dielectric moulds has also proven to be useful for providing uniform electric field distributions using neither sample movement nor mode stirrers. In fact, in [11] it is shown, both from simulations and experimental tests, that the electric field distribution within the multimode cavity and the sample is very dependent on the dielectric configuration within the



(a) (b)

Fig. 2. Ten port implementation (a) and experimental validation by using 8, 4 and 2 power meters versus Vector Network Analyzer measurement (desired output) (b)

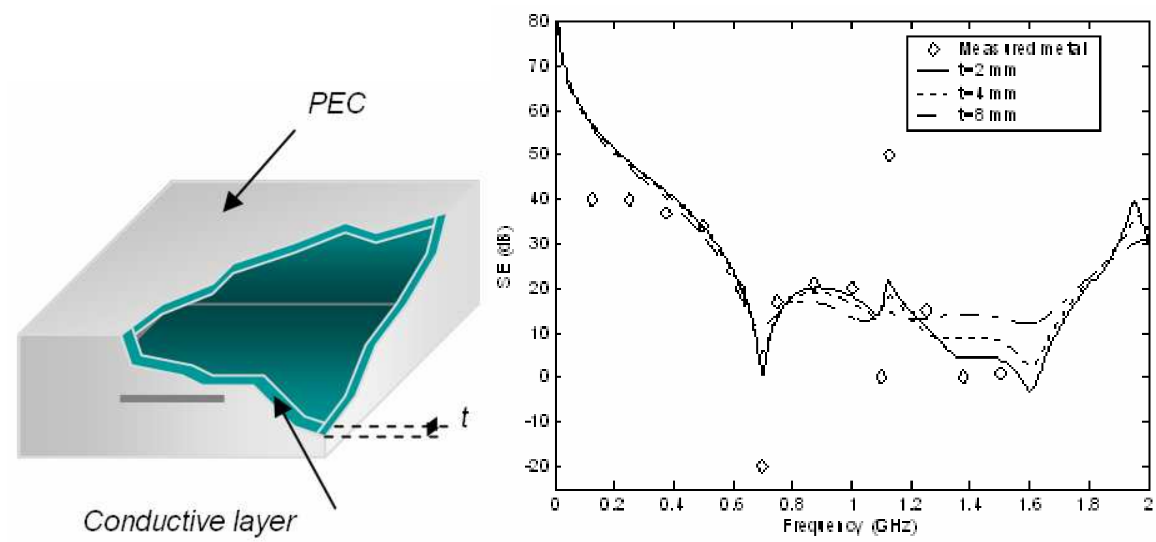
oven. Very good electric field distributions can be achieved even for high-loss materials such as wet clay when using GA optimization techniques.

5. Ten-Port Reflectometer: Neural Network Modeling and Experimental Prototype

In [12], a low-power ten-port waveguide microwave sensor is designed, implemented, calibrated and tested in order to obtain the magnitude of the reflection coefficient. This microwave reflectometer is based on the well known six-port structure but the number of probes and detectors has been increased to eight in order to improve the sampling procedure of the standing wave present at the waveguide.

A neural networks' learning method has been implemented for autonomous calibration. An automated procedure consisting of a moving sample within a multimode cavity has permitted to obtain different reflection coefficient values for this purpose. The device presented in [12] has been calibrated with a Radial Basis Function (RBF) neural architecture, and the error in the operating phase has been analysed for different number of neurons and activation functions. Fig. 2(a) shows the implementation of the reflectometer and Fig. 2(b) shows a comparison of an 8720 Agilent Vector Network Analyzer measurement versus the reflectometer behaviour as a function of employed power meters.

The operating frequency was set to 2.45 GHz and the employed dimensions were that of the WR-340 standard. All the detectors employed at the coaxial ports in this experimental set-up were LTC5530 non-linear power detectors from Linear Technology, whose dynamic range varies from -32 dBm to 10 dBm and its operating bandwidth covers from 300 MHz to 7 GHz. The previous simulations described in [13] were also of the utmost importance in order to validate RBF calibration procedure.



(a) (b)

Fig. 3. Simulation scenario (a) and resonance measurement with metal and simulations for different conductive plastics configurations (b).

TABLE I. OPTIMUM VALUES FOR THE FIRST RESONANCE

Thickness *t* (mm)	**Freq. *f* (MHz)**	$\varepsilon_r^{'}$	$\sigma(S/m)$	t/δ
2	700	2.1	99.1	1.04
4	700	3.5	31.3	1.17
8	692	5.3	6.6	1.07

6. Electromagnetic Shielding Modeling

Conductive plastics have become an alternative to traditional metallic cabinets to shield boxes from electromagnetic interferences. These materials allow a wide range of conductivities that can satisfy any particular design. A design with an outer metallic layer and an inner layer of conductive dielectric can obtain advantages from both materials. In [14] the damping of resonances in enclosures with an aperture through conductive dielectrics is optimized by means of Genetic Algorithms with the aid of CST Microwave Studio. Thickness, permittivity and conductivity of the inner dielectrics have been analysed in order to improve the shielding effectiveness (SE).

As expected, increasing the thickness of the inner conductive layer makes the effect of resonance suppression greater since there is more quantity of material to absorb the energy. This is shown in Fig. 3(b). However, this parameter is limited in the designs due to aesthetic, weight and space limitations. Table I shows the dielectric constant, conductivity and thickness used for the different simulations in Fig. 3(b). These are optimum values to eliminate the first resonance. Results for t/δ, where δ is the skin depth, show good agreement with the approximated value (1.15) obtained in [15].

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