A Comparison Between TLM and FD-TD for Calculating SAR in the Human Body

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Abstract

A study to evaluate a commercial package based on the Transmission Line Matrix (TLM) for use in medical applications has been initiated. The modelled power deposition in a sample was compared with results in the literature based on the Finite Difference Time Domain (FD-TD) method. Good agreement was found between the two modelling techniques. The effect of flange size on the near fields was also observed. Dielectric filled rectangular waveguide was used to launch the signal through a distilled water matching layer.

Introduction

Non-invasive microwave measurement of temperature in biological media has been investigated [1,2] for many applications including cancer detection and monitoring of hyperthermia treatment. Microwave measurements, like infra-red measurements, can reveal temperature. Their better penetration into the media because of their lower frequency permits internal temperature measurements. The process of obtaining a thermal image is not simple. We are investigating ways of obtaining the structure of the biological medium from MRI images. This allows an accurate electromagnetic model to be set up. We use the SAR to obtain a weighting function for our radiometers, relating the power deposited in each model cell to the transmitted power and the antenna properties to obtain the contribution of the black body radiation from that cell to the total power received by a radiometer. The radiometer can be used to monitor hyperthermia or to detect diseased cells that have a higher temperature than the surrounding healthy tissue. Concurrently, this study allows us to consider the matching requirements for microwave measurements on the body. In order to validate our future work, this paper compares the TLM method used in our Micro-Stripes software with the results obtained by the Research Institute of Electronics at Shizuoka University, Japan, [3] using the FD-TD method.

Model Description

We have modelled propagation into an homogeneous medium as well as a layered medium simulating part of the human body. We use the same model as Shizuoka University with the same electrical properties for the biological materials: a homogeneous saline solution and a 4-layered medium consisting of distilled-water (9.5 mm), skin (1.9 mm), fat (9.5 mm) and muscle layer extending to infinity, see Figure 1. We use a rectangular waveguide at 1.2 GHz. The aperture measures 20.4 mm x 15.6 mm and is fully filled with a low loss dielectric. The cubic cell size is taken as 1.9 mm. A TE_{10} mode is set up at a distance of 37.24 mm away from the aperture.

Table 1. Shows the electrical properties used for the model.

	Dielectric Constant	Conductivity (S/m)
0.4% Saline Solution (30°C)	75.1	1
Skin	49.7	1.7
Fat	5.6	0.16
Muscle	49.7	1.7
Distilled Water	76.4	0.26
Waveguide Dielectric	86.7	0.001

Table 1. Electrical Properties of Model at 1.2GHz.

Both the homogeneous and the 4-layered medium have been modelled with both an infinite metal flange and a finite metal flange (47.6 mm x 43.8 mm). Only the magnitude of the electric field is compared with the results of the Japanese experiment. The normalised specific absorption rates

$$SAR = \frac{1}{2}\left(\frac{\sigma}{\rho}|E|^2\right) \tag{1}$$

defined by the Japanese team represent the absorbed power by the lossy media. They allow us to obtain the weighting function for a radiometer placed at that same point as the transmitter. The weighting function can be used to determine the emitted power from the each medium cell, and finally to obtain the temperature of each medium cell. Normally several radiometers working at different positions and frequencies are necessary to solve this problem. The objective of this work is to test the TLM method in this specific application.

We used planes of symmetry compatible with the TE_{10} mode to reduce computing time in this study. The plan Oxz is defined as a magnetic wall and the Oyz as an electric wall. All other boundaries are defined as absorbing boundaries. This yielded a fourfold reduction in computing time. We utilized graded meshes to coincide with the internal surface of the waveguide In spite of modifications to the meshing, the internal surfaces of the waveguide did not exactly coincide with the mesh. This could be the cause of some minor calculation inaccuracies. We also employed lumped cells in the air medium around the waveguide. This reduces significantly the computing times and the data files in the non-crucial zones. Lumped cells are used for describing all the free space around the waveguide in the infinite flange model, whereas they are used at a distance from the first medium layer (9.5 mm) in the finite flange model to take account of the air-medium interface. We have checked that these modifications do not affect the accuracy of the simulation. A graded mesh has been used to describe the depth of the skin using 4 cells to increase the accuracy of the simulation.

Results and Discussions

We obtain similar field patterns to the FD-TD method for each model. The curves (Figures 2 - 5) show comparisons between the two methods. We have plotted the E fields and not the SAR. The curves show field propagation into the medium and outwards, parallel to the surface of the air/medium interface just below the interface. The results produced by both methods appear to be similar but the TLM method indicates an appreciably smaller depth of penetration of the power for the case of 4-layer model. The effect of different materials can clearly be seen. The skin thickness is considerably smaller than the wavelength therefore its influence is small. The skin is described by 4 smaller cells instead of only one, so it looks thicker on the patterns than it is in the model. The graded meshes act on the relevant area of the graph like a zoom. The fat layer drops the power with a higher attenuation coefficient. We can confirm that the size of the metal flange has a noticable effect (Figures 3 and 4). We also note the lateral spreading of the electrical field in the 4-layered medium.

The dielectric inside the waveguide fixes the maximum frequency at 1.7 GHz for this waveguide by equation (2).

$$f_{\max} = \frac{c}{10}\min(\sqrt{\epsilon_r\mu_r}\Delta x, \sqrt{\epsilon_r\mu_r}\Delta y, \sqrt{\epsilon_r\mu_r}\Delta z) \qquad (2)$$

This means that a smaller cell size will be required if we need to model higher frequencies or use a higher dielectric constant in the waveguide. This later option would decrease the waveguide dimensions and improve the antenna directivity. Multi-frequency measurements are necessary to obtain a 3 dimensional temperature map.

Conclusions

This work shows that in the coupling problem between a dielectric-filled waveguide and a complex biological medium, the TLM method gives similar results to the FD-TD method. The system we have set up allows us to investigate the matching between the antenna and the tissue. Effects of varying the waveguide size can also be easily monitored. We are now attempting to improve our description of the biological medium. Other parts of the human body are also being analysed, especially the head where the lateral spreading effect by the fat layer does not occur. We shall also improve the design of the antenna to increase the depth of penetration and the resolution of future thermography systems for multi-frequency measurement.

We conclude that we shall be able to use the TLM method to continue our microwave thermography project, linking it to MRI generated images for accurate structural information and to available data on electrical properties of tissue for information affecting the propagation of microwave power. TLM has been widely used for EM scattering problems and this work reassures us that the technique is adequate for our requirements.

References

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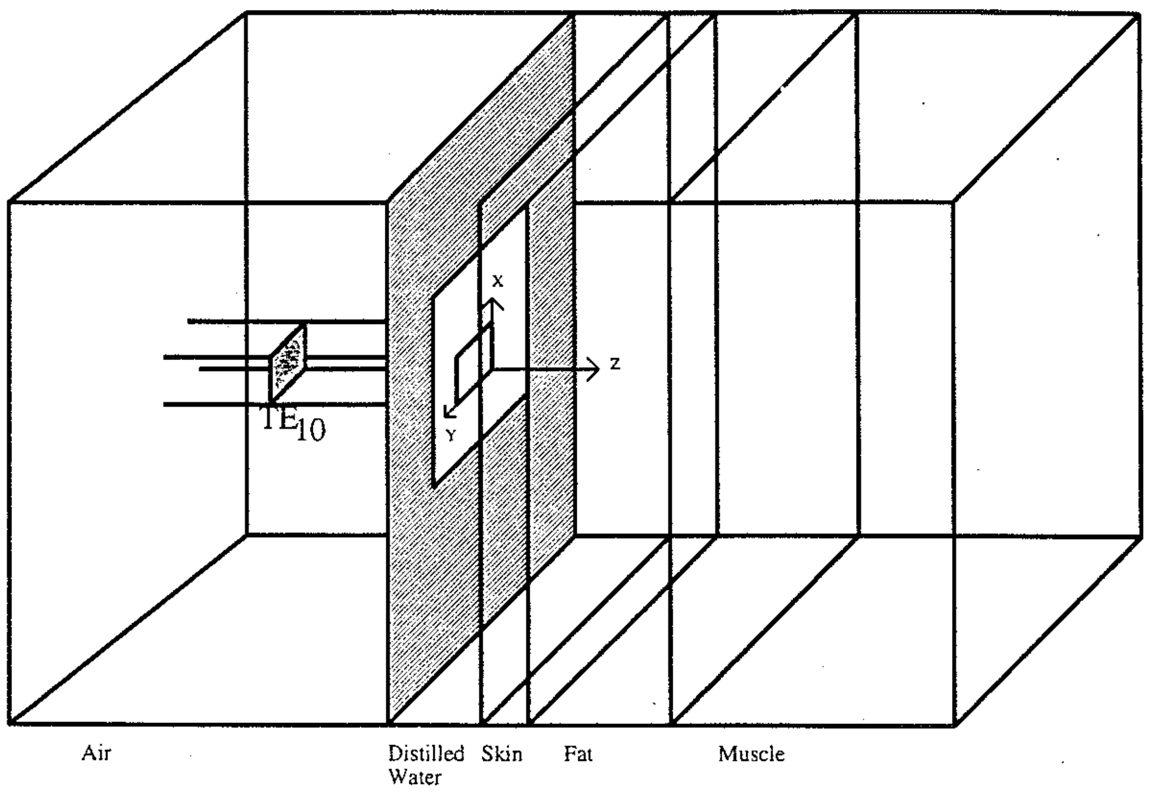

Figure 1. Diagram of the System being Modelled

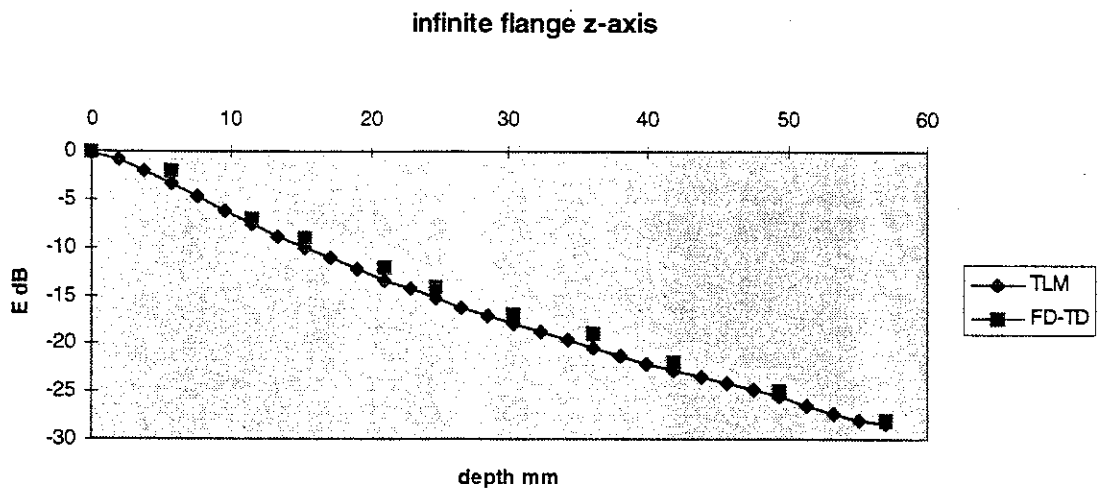

Figure 2. Plot of Electric Field along the Z-axis for an Homogeneous Medium

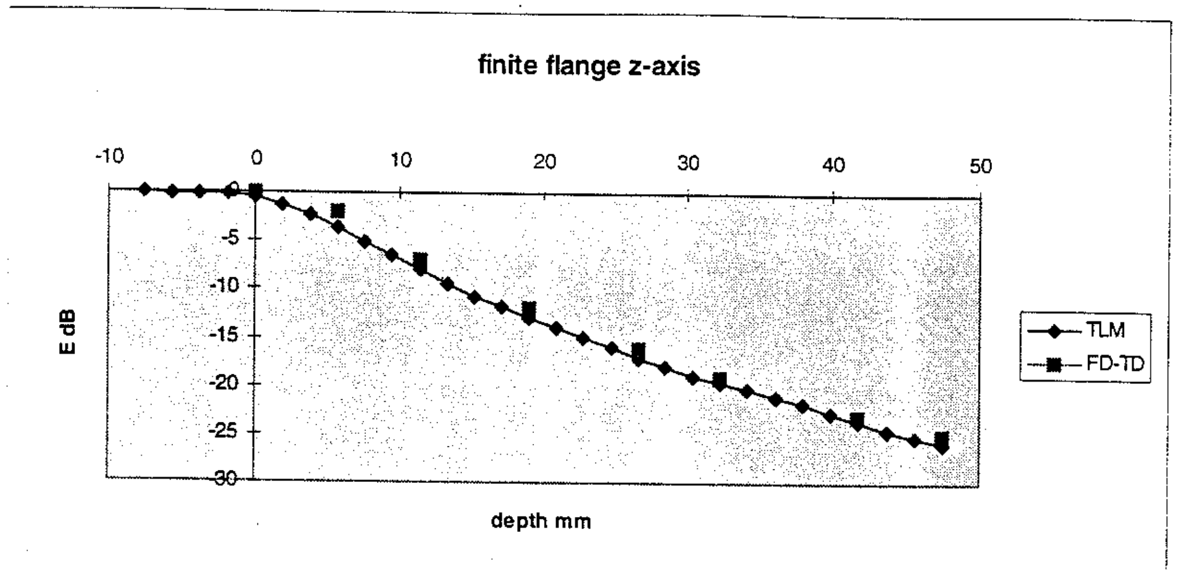

Figure 3. Plot of Electric Field along the Z-axis for an Homogeneous Medium

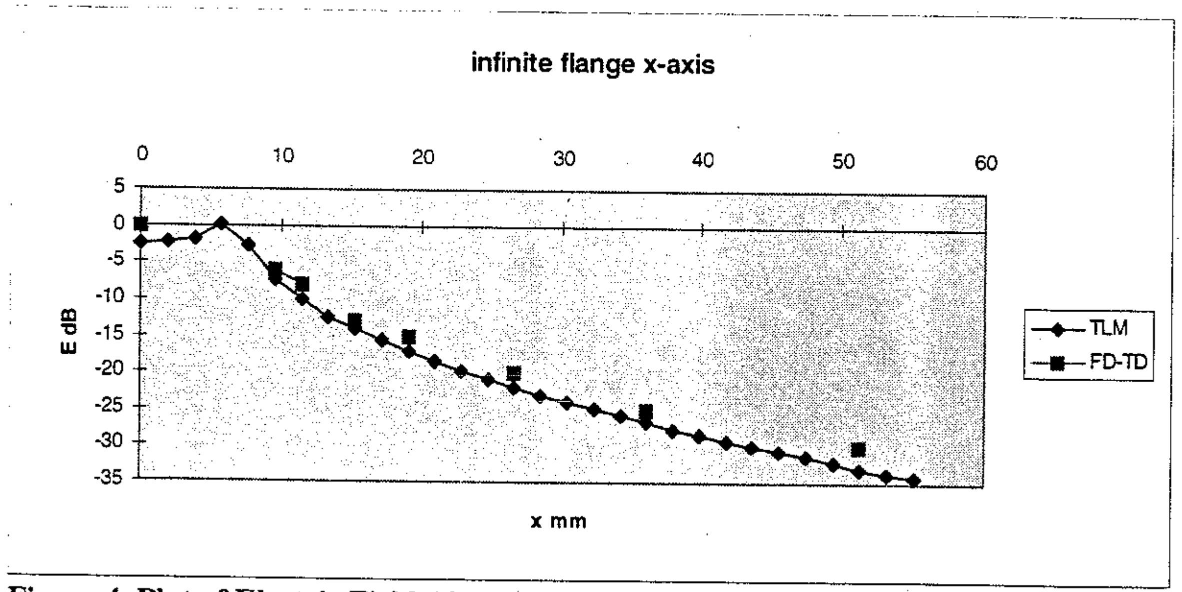

Figure 4. Plot of Electric Field Along the X-axis in an Homogeneous Medium

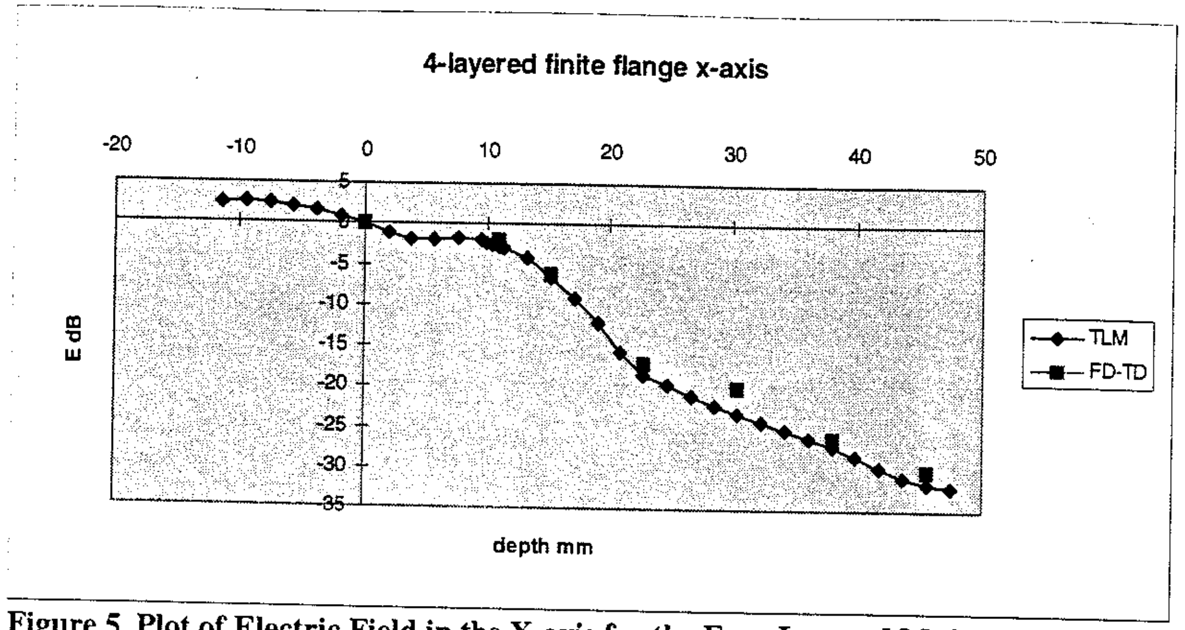

Figure 5. Plot of Electric Field in the X-axis for the Four Layered Medium