Electromagnetic modelling of a parallel-plate waveguide applicator irradiating an inhomogeneous lossy medium

Luc Martens[1], Niels Faché[1], Daniël De Zutter[1], and Carlos De Wagter[2]

[1]Lab. of Electromagnetism and Acoustics, Univ. of Gent, Sint-Pietersnieuwstraat 41, B-9000 Gent, Belgium, [2]Department of Radiotherapy and Nuclear Medicine, Univ. Hospital of Gent, Belgium

ABSTRACT

An integral method is presented to correctly calculate the mutual coupling between a parallel-plate waveguide applicator and an inhomogeneous lossy structure. The aperture field and hence the electromagnetic absorption in the biological structure is a result of this coupling. The results are presented for the TE_1-mode excited parallel-plate waveguide applicator. The possibility of changing the electromagnetic absorption in the biological structure by introducing a dielectric material in the waveguide is investigated.

I. INTRODUCTION

In a hyperthermia treatment, the biological tissues are placed in the near field of the electromagnetic (EM) sources. One of the most frequently used hyperthermia EM-sources, is the waveguide applicator. Because the biological tissue is in the near field of the applicator, the field, scattered by the tissue, will change the aperture field of the applicator and the electromagnetic absorption. Up to now, only waveguide applicators irradiating homogeneous or layered biological media were modelled [1][2][3]. In this paper, an integral equation method to model a parallel-plate waveguide applicator irradiating a realistic inhomogeneous biological tissue is presented. A new feature of the developed software is the possibility to design new applicators by introducing inhomogeneous dielectric materials in the waveguide.

II. INTEGRAL EQUATION METHOD

Figure 1 shows the configuration. A parallel-plate waveguide applicator with aperture width a, irradiates an inhomogeneous lossy tissue. In the waveguide, an inhomogeneous dielectric material can be placed in order to influence the absorbed power distribution in the biological tissue. The applicator is excited by the TE_1-mode of the parallel-plate waveguide. The width of the waveguide and the frequency is chosen in such a way that only the lowest TE_1-mode propagates in the waveguide.

The field, scattered by the lossy inhomogeneous tissue is modelled by polarisation currents. The electrical field in the biological tissue can be written as a function of the aperture field and the polarisation currents in the tissue:

$$E_z^r(x,y) = -\int_0^a E_z^a(y') \left[\frac{\partial}{\partial x'} G_f(x,y|x',y') \right]_{x'=0} dy' + j\omega\mu_0 \iint_{S_b} J_P(x',y')\, G_f(x,y|x',y')\, dS' \quad (1)$$

CH3141-9/92/0000-0243$01.00 © 1992 IEEE

IF1

$G_f(x,y|x',y')$ is the Green's function of the two-dimensional half free space with short circuited wall at x=0 where G_f is zero. S_b refers to the lossy inhomogeneous tissue. $J_P(x',y')$ is the polarisation current distribution in the tissue and $E_z^a(y')$ is the aperture field. The superscript r refers to the half plane x >0.

The electrical field in the waveguide follows from the incident field (= TE_1-mode) in the waveguide, the aperture field, and the field due to the polarisation currents in the dielectric material placed in the waveguide:

$$E_z^l(x,y) = E_z^{inc'}(x,y) + \int_0^a E_z^a(y') \left[\frac{\partial}{\partial x'} G_w(x,y|x',y') \right]_{x'=0} dy'' + j\omega\mu_0 \iint_{S_d} J_P(x',y')\, G_w(x,y|x',y')\, dS' \quad (2)$$

$G_w(x,y|y',y')$ is the Green's function of the homogeneous filled short-circuited waveguide. $E_z^{inc'}$ is the electrical field of the lowest mode and its reflection on the short circuit. S_d refers to the dielectric in the waveguide and the superscript l to the half plane x<0.

The electromagnetic problem is completely defined if the continuity of the tangential component of the magnetic field ($H_y = \frac{1}{j\omega\mu_0}\frac{\partial}{\partial x}E_z$) is applied in the aperture:

$$\left[\frac{\partial}{\partial x} E_z^r(x,y) \right]_{x=0+} = \left[\frac{\partial}{\partial x} E_z^l(x,y) \right]_{x'=0-} \quad 0<y<a \quad (3)$$

(1), (2) and (3) are three coupled integral equations. In (1) and (2) E_z^r and E_z^l in the lossy medium and the dielectric material respectively can be written as a function of the respective polarisation currents. These fields are determined by solving (1), (2) and (3) for the unknown polarisation currents using the moment method and the point matching technique. The specific absorption rate (SAR) distribution in the lossy tissue is calculated from the formula $\sigma(x,y)|E_z^r(x,y)|^2/2$.

III. RESULTS

In figure 2, two examples of waveguide applicators loaded with dielectric wedges irradiating a muscle tissue at 433 MHz are shown.

The SAR-distribution is given in dB with respect to the maximum SAR-value near the surface of the muscle tissue. The two dielectric wedges are used to change the SAR-distribution in the muscle tissue. From the SAR-distribution results, we note that is possible to achieve respectively smaller and broadened absorption compared to the results of the homogeneously filled waveguide. The penetration depth of the SAR-distribution is unchanged.

IV. CONCLUSION

Starting from three coupled integral equations, it is possible to correctly calculate the mutual coupling between an inhomogeneous biological tissue and a parallel-plate waveguide. By introducing dielectric materials in the waveguide, it is possible to design new waveguide applicators in order to change the SAR-distributions in the biological tissue. An example of a waveguide applicator with two types of wedges has been presented. Although it was possible to change the width of the SAR-pattern, changes in the penetration depth were not achieved.

V. REFERENCES

[1] Antolini, R., G. Cerri, L. Cristoforetti, and R. De Leo, "Absorbed Power Distributions from Single or Multiple Waveguide Applicators during Microwave Hyperthermia," *Phys. Med. Biol.*, vol. 31, no. 9, pp. 1005-1019, 1986.

[2] Nikita, K.S., and N.K. Uzunoglu, "Analysis of the Power Coupling from a Waveguide Hyperthermia Applicator into a Three-Layered Tissue Model," *IEEE Trans. Microwave Theory Techn.*, MTT-37, no. 11, pp. 1794-1801, 1989.

[3] Okoniewska, E., M. Okoniewski, and P. Debicki "Relative $\sigma|E|^2$ Heating Patterns in Multilayered Biological Tissues Exposed to a Cylindrical waveguide Applicator," in *Proc. of IEE Sixth Intern. Conf. on Antennas and Propagation, Part 1: Antennas*, Warwick, pp. 416-420, 1989.

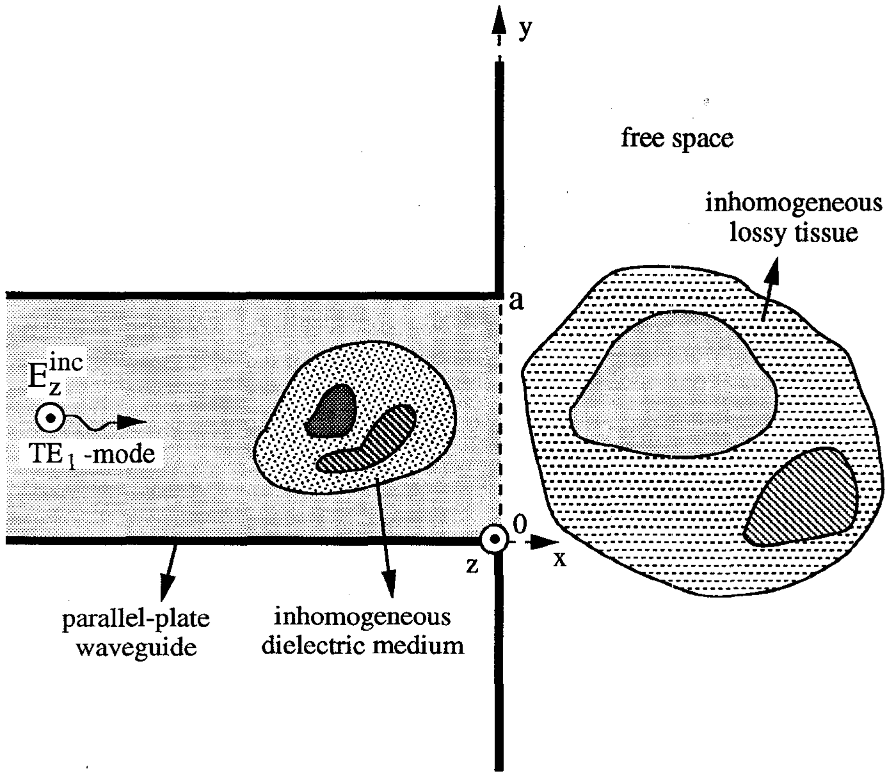

Fig. 1: parallel-plate waveguide applicator irradiating an inhomogeneous lossy medium

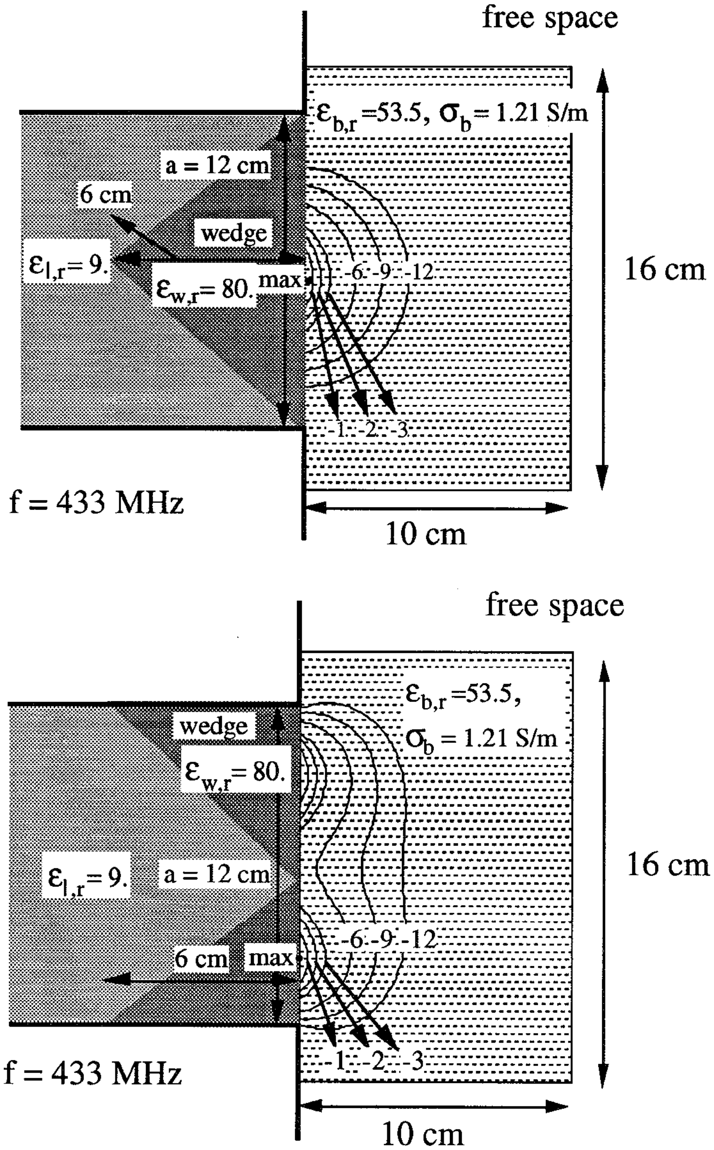

Fig. 2: SAR-distributions for the waveguide applicator loaded with two types of wedges