Aperture Resonances of Microwave Applicators for Thermoherapy

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Abstract

This paper deals with our new results in the field of external applicators used for local microwave thermotherapy, like e.g. cancer treatment, physiotherapy, etc. We will focus here on a very special problem of aperture and water bolus resonances - a phenomenon, which can significantly deteriorate SAR and temperature distribution in the treated area and so significantly complicate the treatment of cancer patient.

I. Introduction

In our paper we describe specific aspects of external local applicators, usually working at 70, 434 and 2450 MHz**.** These applicators were used here in Prague at Institute of Radiation Oncology for the treatment of more then 1000 cancer patients with superficial or subcutaneous tumours (up to the depth of approximately 6 cm).

We have studied waveguide applicators heating pattern for the aperture excitation at above and at under the cut-off frequency. It has helped us to get analytical approximations of the electromagnetic field distribution in the treated area of the biological tissue. In the Fig. 1 there is one of very important results - diagram showing the theoretical depth of heating d as a function of the used frequency f and of the aperture diameter D of the applicator. The most important results for the effective heating depth d can be characterised as follows:

- at high frequencies (above 1000 MHz) the depth of effective heating d is a function of frequency f ,

- bellow 100 MHz d is the dominantly function of the diameter D of applicator aperture ($d = 0.386\ D$).

Local microwave applicators can be either directly coupled to treated area, or they can be coupled through the so called water bolus (i.e. plastic sac).

II. Resonances in the aperture of waveguide applicator

In our contribution we would like to discuss what happens, when the frequency f of hyperthermia apparatus is either very different (much higher or lower) from the aperture resonance frequency f_r or very near (even equal) to the aperture resonance frequency f_r of the used waveguide applicator. This special case of our interest can happen when either the hyperthermia apparatus is tunable in broader frequency range or the aperture resonance frequency f_r of the applicator is changed by different dielectric parameters of various types of biological tissues.

There is a substantial difference between the two ways of the waveguide applicator excitation (i.e. above or under the aperture resonance frequency f_r) and in the propagation and „behaviour“ of the EM field inside such applicator also. Basic differences would be explained during the presentation.

For the following discussion we have chosen the case of the rectangular applicator with a flange. But similar results is possible to obtain for other important cases like e.g. rectangular applicators without flange or for the family of circular applicators

In Fig. 1, a simple sketch of electric field strength line of the electromagnetic field irradiated from waveguide applicator is shown. It is the basis of our analysis of SAR distribution in front of the aperture of waveguide applicator, radiating into the heated biological tissue. Formulas describing the electric field distribution are given in the right side of this figure.

Waveguide flange is in our approach considered as an electric wall, dashed line going into the biological tissue determines the magnetic wall of our model. The distance between these walls determines the aperture resonance frequency f_r of the applicator aperture. Of course, f_r is influenced by the tissue permittivity also.

Let us take into account the area of biological tissue surrounded by electric and magnetic walls. Then the hybrid waveguide mode HE_{11} (i.e. the lowest possible one) can be defined and excited in the biological tissue in front of applicator aperture and can be specified by the case

$$m = n = 1\ .$$

In fact, it is a linear superposition of the modes TE_{11} and TM_{11}. Higher order modes can be suppressed by the suitable construction of the applicator. Moreover these modes do not penetrate so deep in the tissue, therefore we need not to take them into account in our analysis.

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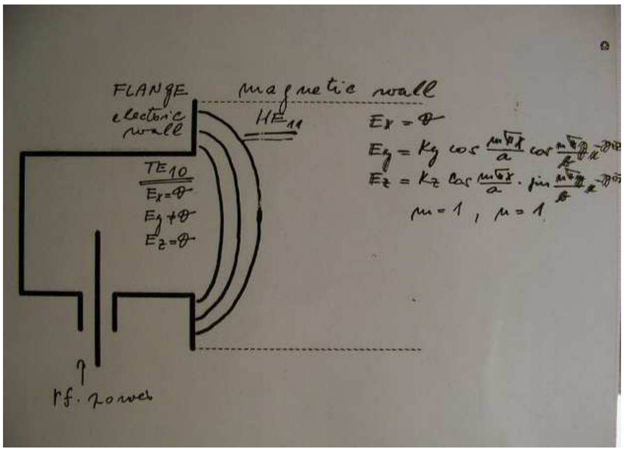

Fig. 1. Schematics of the applicator radiating into the biological tissue.

Figures 3a to 3c show the change of the SAR in front of the applicator aperture as a function of working frequency f of the hyperthermia apparatus with respect to the f_r. There is big difference between f and f_r in the case shown in Fig. 3a, instead both frequencies are very near each to other in the figure 3c (the difference between f and f_r is going down through the figure series). More detailed description of this theory of the waveguide applicator SAR analysis and more figures we will offer during presentation.

The results we would like to describe in our contribution are important from theoretical point of view of the knowledge about the general properties of the waveguide applicators. And are very important also for the treatment - our results demonstrate very substantial changes of SAR distribution in the treated biological tissue. If f is going to f_r then so called hot spots complicating the treatment can arise. Waveguide flange is considered as an electric wall, dashed line going into the biological tissue determines the magnetic wall of our model.

Let us take into account the area of biological tissue surrounded by electric and magnetic walls. Then the hybrid waveguide mode HE_{11} (i.e. the lowest possible one) can be defined and excited in the biological tissue in front of applicator aperture (it is a linear superposition of the modes TE_{11} and TM_{11}). Higher order modes can be suppressed by the design of the applicator. Following cases describe the change of the SAR in front of the applicator aperture as a function of working frequency f of the hyperthermia apparatus with respect to the f_c:

- if there is enough big difference between f and f_c , then homogeneous heating of the treated area can be expected - see Fig. 3a,
- if the both frequencies are very near each to other (difference between f and f_c is going down), then overheating (hot-spots) out of the treated area can arise - see Fig. 3b.

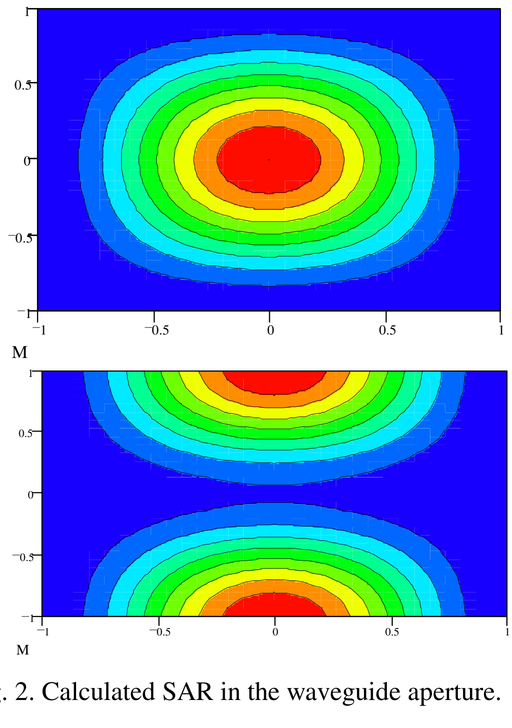

Fig. 2. Calculated SAR in the waveguide aperture.

III. Water bolus

Often waveguide applicator is not coupled directly to the biological tissue, but between its aperture and treated are a so called water bolus is being placed. We have studied the influence of water bolus on SAR and temperature in the treated area.

In general, water bolus can often improve both SAR and temperature distributions in the treated area. But sometimes volume resonances can occur and in such case heating pattern can deteriorate significantly. To prevent that, we need to study conditions of excitations of resonant modes inside water bolus and in the applicator aperture. Superposition of these mode can give very surprising EM field and temperature distribution in the treated area.

IV. Conclusions

Microwave thermotherapy is successfully applied in clinics in the Czech Republic. Technical support is at present from the Czech Technical University in Prague. Our goal for the next technical development is:

- improve the theory of the local applicators design and optimisation,
- innovate the system for the applicator evaluation (mathematical modelling and measurements)