Microwave Applicators for Medical Applications: Imaging and Thermotherapy Treatment

Jan Vrba

***Abstract* - Paper deals with our new results in the field of waveguide and intracavitary applicators used for microwave thermotherapy, like e.g. cancer treatment, physiotherapy, benign prostatic hyperplasia (BPH) treatment, etc.**

I. INTRODUCTION

In our contribution we describe waveguide and intracavitary applicators working at 70, 434 and 2450 MHz see ref. [1 to 6]. These applicators were used here in Prague for the treatment of more then 500 cancer patients with superficial or subcutaneous tumors (up to the depth of approximately 4 cm). Now, following new trends in this field, we continue our research in important direction of deep local and regional applicators.

II. WAVEGUIDE APPLICATORS

For the deep local thermotherapy treatment we develop above all waveguide type applicators based on the principle of evanescent mode waveguide, which is our specific solution and original contribution to the theory of microwave hyperthermia applicators, see ref. [5, 6]. This technology enable us:

- to design applicators with as small aperture as necessary also for the optimum frequency range for deep local and/or for regional thermotherapy treatment (the frequency band between 27 and 70 MHz).
- using our technology we need not to fill the applicator by dielectric (necessary for deep penetration into the biological tissue - i.e. up to 10 centimetres under the body surface).
- two to four of such applicators can be also used for regional treatment.

Waveguide type applicators are often used in the local external hyperthermia treatment of cancer and other modifications of microwave thermotherapy as they offer very advantageous properties, above all:

- depth of penetration of the EM energy approaching the ideal case of plane wave,
- low irradiation of the energy in the vicinity of the hyperthermia apparatus,
- very good impedance matching, i.e. perfect energy transfer to the biological tissue.

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 approx. 1000 MHz) the depth of effective heating *d* is above all a function of frequency *f* (skin effect),
- bellow approx. 100 MHz *d* is the dominantly function of the diameter *D* of applicator aperture ($d = 0.386\ D$).

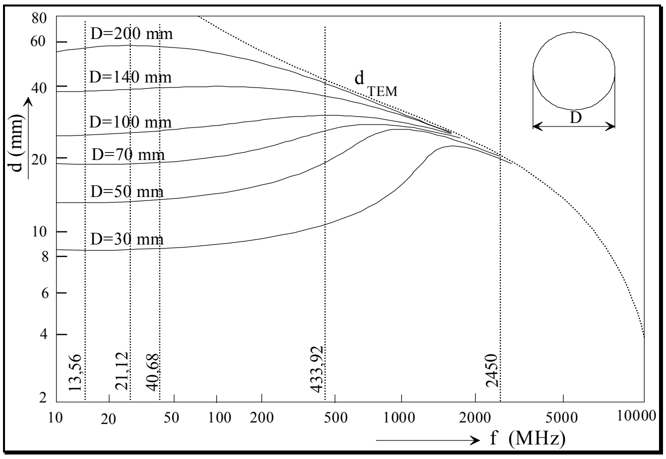


Fig. 1. Effective depth of heating d for external waveguide applicator with respect to frequency f [MHz] and diameter of aperture D [mm].

One of our project was comparison of Evanescent Mode Waveguide Applicator with a reference Waveguide Applicator. The both applicators have aperture dimensions of 18 x 12 cm and are operating at 434 MHz. Evanescent Mode Applicator is a waveguide, which is excited under cut off frequency. Inserting a capacity and inductive element + inductive wave admittance of TE mode we can build up band pass filter for operating frequency. Reference Waveguide Applicator is filled by dielectric with for decreasing the cut off frequency. For good knowledge of SAR distribution is necessary to measure thermal increments in high enough number of points in front of applicator aperture. Fig. 2 and 3 give results of measurements resp. calcultations of SAR for the case of reference wave guide applicator, Fig. 4 then shows SAR distribution for the case of Evanescent mode applicator.

Another of our research interests is to study what happens, when the frequency *f* of hyperthermia apparatus is either very different (much higher or much lower) from the cut-off frequency f_c of the used waveguide applicator or very near (even

Czech Technical University in Prague, Dept.of EM Field,
Technická 2, 16627 Prague, Czech Rep.,
e-mail : Vrba@feld.cvut.cz

equal) to this cut-off frequency f_c. This happen when either the hyperthermia apparatus is tunable in broader frequency range or the cut-off frequency f_c of the applicator is changed by different dielectric parameters of various types of biological tissues near to heated locality.

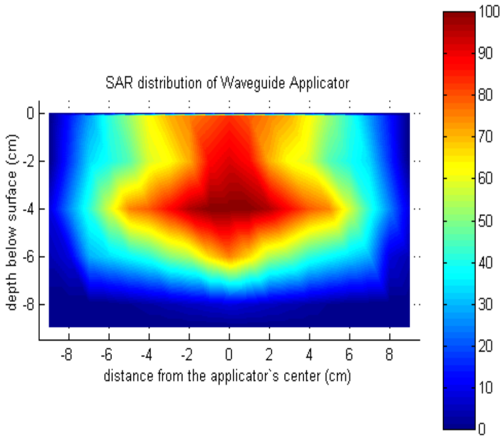


Fig. 2. Measured SAR distribution of a passband Waveguide Applicator

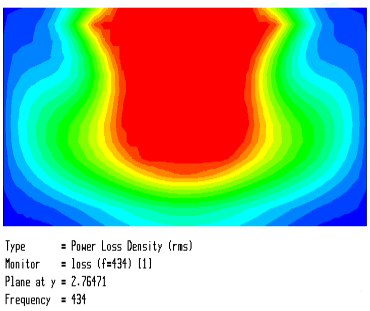


Fig. 3. Calculated SAR distribution of a passband Waveguide Applicator

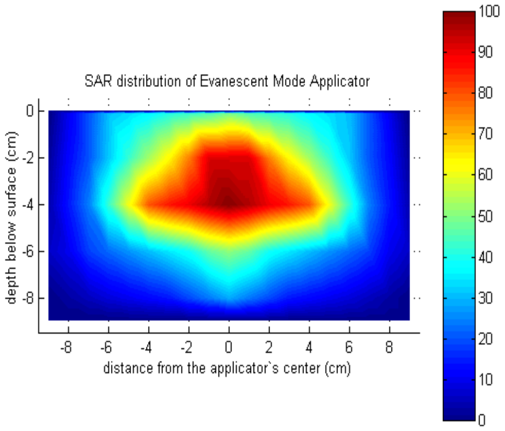
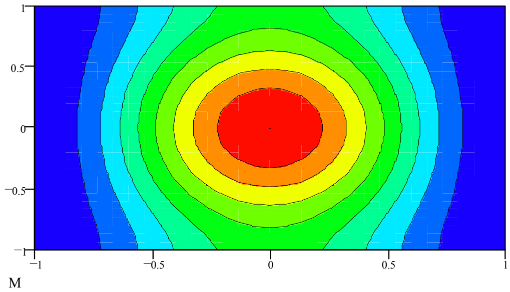


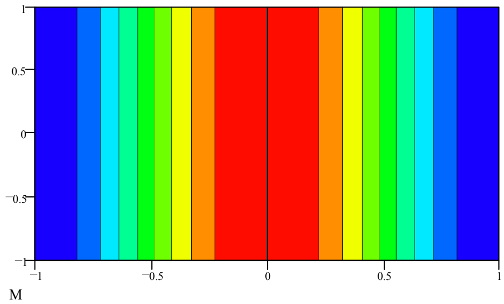
Fig. 4. Measured SAR distribution of Evanescent Waveguide Applicator

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 3 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. 5a+b.
- 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. 6.



(a)



(b)

Fig. 5a+b . SAR in the aperture of applicator.

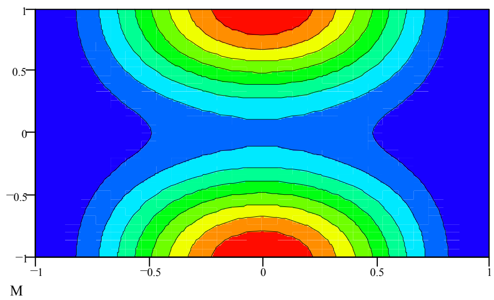


Fig. 6. Calculated SAR in the waveguide aperture.

Evaluation of hyperthermia applicators in the water phantom means to measure the electromagnetic field power distribution in front of the aperture of this applicator. The E-field distribution can be measured by the dipole antenna. The length of this antenna must be smaller then $\lambda/4$ (λ is the wavelength of measured field in this media). The voltage induced in this antenna supply the LED. The optical signal from the LED is leaded by the optical fiber outside the phantom to the optical detector. The scheme of the described system for microwave applicators evaluation is shown in the figure 1.

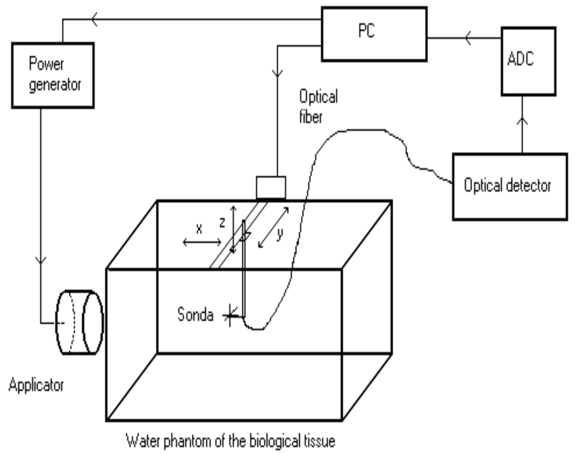


Fig. 7. Apparatus for evaluation of applicators.

The output voltage from the optical detector is measured by the voltmeter or is converted by the ADC to the digital form and processed by the computer.

III. INTRACAVITARY APPLICATORS

Costs and risks associated with clasical BPH treatment (TURP and open surgery) have promoted the development of minimally invasive methods. Microwave thermotherapy, varying forms of laser treatment, transurethral needle ablation, etc. have all been developed in the 1990s. The underlying principle behind these methods is to coagulate prostatic adenomatous tissue by means of heat. Of all the available minimal invasive treatment modalities, transurethral microwave is one of the most wide spread at present [1].

We have investigated basic types of microwave intracavitary applicators suitable for BPH treatment, i.e. monopole, dipole and a helical coil structures. These applicators are designed to work at 915 MHz. In the conference contribution we would like to discuss it's effective heating depth, based on the comparison of the theoretical and experimental results. Basic mechanisms and parameters influencing (limiting) heating effective depth are described and explained in ref. [2, 3].

The basic type of intracavitary applicator is a monopole applicator. The construction of this applicator is very simple, but calculated and measured „Specific Absorption Rate" („SAR") distribution along the applicator is more complicated, than has been the first idea. „SAR" can be measured either in water phantom or by infrared camera. During measurements of SAR along the applicator we have found, that typically there is not only a one main „SAR" maximum (first from the right side), but also a second and/or higher order maximas can be created, being produced by outside back wave propagating along the coaxial cable, see Fig. 8.

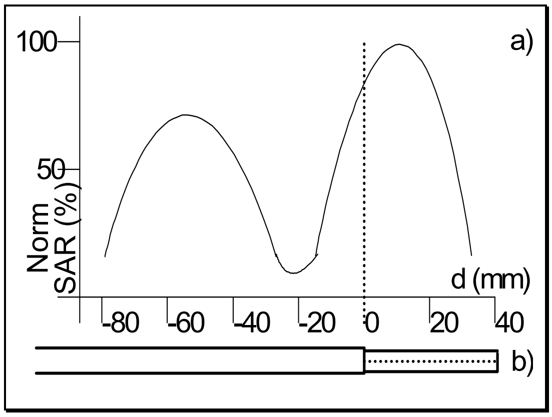


Fig. 8. Monopole applicator

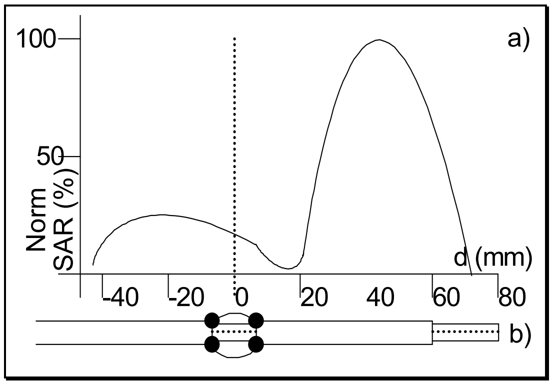


Fig. 9. Dipole applicator

In Fig 9. the „SAR" distribution improvement (i.e. reduction of second maximum) can be noticed for the case of dipole like applicator. To eliminate this second maximum and optimise the focusing of „SAR" in predetermined area of biological tissue needs to use the helical coil antenna structure. After coil radius and length optimisation we have obtained very good results of „SAR" distribution, see Fig. 10 and 11. Some problems can be with the antenna self-heating, but it can be reduced by cooler at the end of applicator tip.

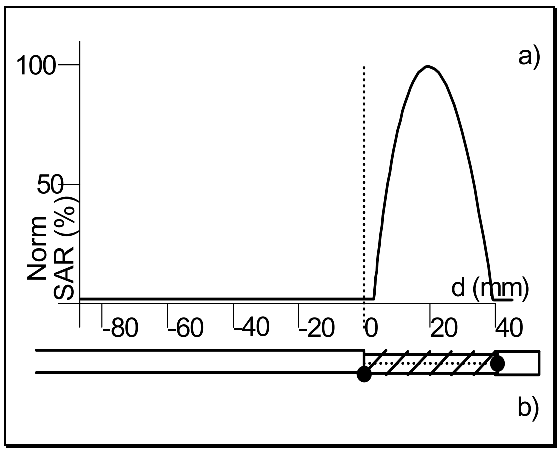


Fig. 10. Helical coil applicator

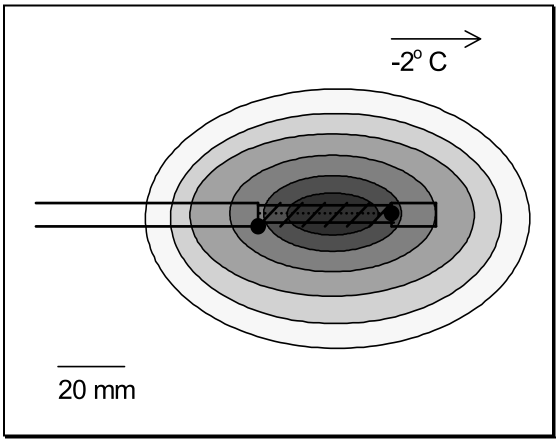


Fig.11. Temperature field around the helix

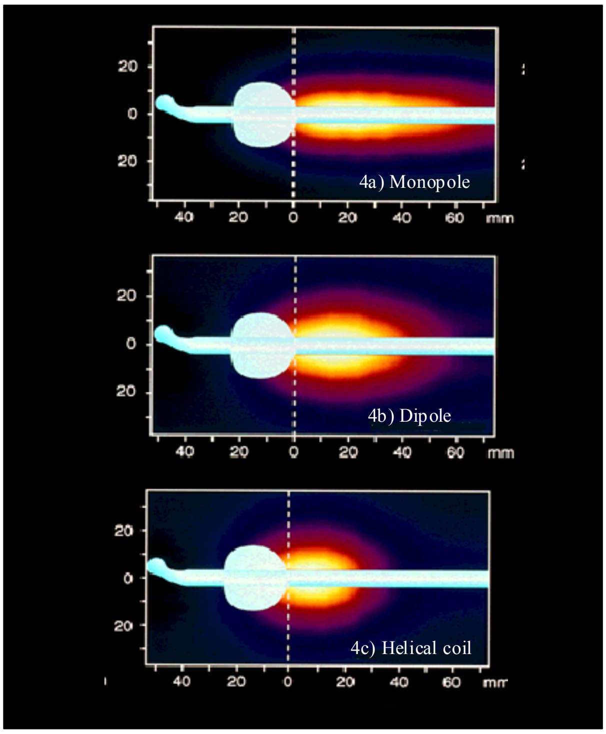


Fig 12. The heating pattern obtained for different antennas:
- the monopole (a),
- the dipole (b),
- the helical coil (c).

In Fig 12 there is the typical measured heating pattern of monopole (a), dipole (b), and helical coil antennas (c). Note the long back heating tails with a monopole antenna (Fig 12a) which is caused by microwave currents that flow backwards along the cable and cause the feeding cable to radiate. The radiation pattern from a dipole antenna (Fig 12b) is generally well confined without any excessive backheating. The dipole antenna is suitable for prostates with axial length > 40 mm. The helical coil antenna (Fig 12c) has the shortest and most focussed heating and would be the choice for small prostates, 25 – 40 mm in length.

The pattern is colour-coded according to a linearly decreasing scale of white-yellow-red, where white is the maximum temperature. A diagrammatic catheter is inserted in each figure; the orientation of the bladder neck in a patient is indicated by a dashed line.

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 and intracavitary applicator design and optimisation,
- innovate the system for the applicator evaluation (mathematical modelling and measurements)
- develop system for regional treatment.

References

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Acknowledgement: This research is supported by Czech Research Programme: „Transdisciplinary Research in the Area of Biomedical Engineering II“ and by Grant Agency of the Czech Republic, project: „Microwave Imaging for Biomedical Applications“ (102/05/0959).