TECHNICAL EQUIPMENT FOR RESEARCH OF EM FIELD AND BIOLOGICAL SYSTEMS INTERACTIONS

J. Vrba*, L. Vannucci**, P. Peschke***, F. Vožeh[+], M. Vojtíšek[++], J. Kubeš[+++], J. Herza*, J. Cvek*, T. Dřížďal* and R. Zajíček*

*Czech Technical University in Prague, Department of Electromagnetic Field, Prague, Czech Republic
**University of Pisa + Institute of Microbiology, Czech Academy of Sciences, Prague, CR
*** German Cancer Research Institute, Heidelberg, Germany
[+]Charles University, Medical Faculty, Plzeň, Czech Republic
[++]Czech Institute of Health, Prague, Czech Republic
[+++]Institute of Radiation Oncology in Prague, Hospital Bulovka, Czech Republic

vrba@fel.cvut.cz

ABSTRACT: Research of interactions between em field and biological systems is of growing interests elsewhere. Also here in czech republic there are several groups working in this field, often in international co-operations. We will describe here mainly basic technical equipment developed for 5 different research projects in the discussed area of interactions of em field and biological systems.

Introduction

In present time four research institutions here in the Czech Republic run research projects focused on studies of interactions between EM field and biological systems. These institutions are technically supported by Dept. of EM Field of the Czech Technical University in Prague. In this contribution we would like to give more details about that projects and obtained technical results (i.e. description of developed exposition systems).

Three of discussed projects (1 in Germany and 2 here in Czech Republic) are basic research for simulation of the microwave hyperthermia treatment. Other two projects (both in Czech Republic are focused on simulation of the case of exposition by mobile phone.

In the modern view, cancer is intended as a complex illness, involving the cells that undergo to transformation, their environment, and the general responses at biochemical and biological levels induced in the host. Consequently, the anti-cancer treatment protocols need to be multi-modal to reach curative effects. Especially after the technical improvements achieved in the last 15 years by bio-medical engineering, microscopy devices, and molecular biology methods, the combinations of therapeutic procedures are growing in interest in basic and clinical research.

The combination of applied biological research together to the physical sciences can offer important perspectives in anticancer therapy (e.g. different methodologies and technical devices for application of energies to pathological tissues).

The modern bioengineering knowledge applied to traditional tools, as the microscopy, has largely renewed and expanded the fields of their applications (e.g.: *in vivo* imaging), pushing the interest for direct morpho-functional investigations of the biomedical problems.

Waveguide applicator

Very good results of EM field expositions in biological experiments can be obtained by simple but efficient waveguide applicators, see example in Fig. 1.

Waveguide offer a very big advantage – in approximately of fifty percents of its aperture the irradiated electromagnetic field is very near to a plane wave, which is basic assumption for good homogeneity of the heating and optimal treatment penetration.

Here described system is being used (shared) for research projects by two two institutions (Institute of Radiation Oncology in Prague and Institute of Microbiology of the Czech Academy of Sciences).

Figure 1: Waveguide applicator for biological experiments.

Aperture of this waveguide is 4.8 x 2.4 cm and it is excited at frequency 2.45 GHz. Effective heating is in the middle of the real aperture – its size is approximately 2.4 x 2.4 cm. Waveguide is filled by teflon to reduce its cut-off frequency. Power from generator is possible to control from 10 to 180 W, in these experiments we work between 10 and 20 W mostly.

Evaluation of waveguide applicator

To evaluate this applicator from technical point of view we made a series of experiments, see e.g. Fig. 2, where you can see example of measurement of temperature distribution by IR camera.

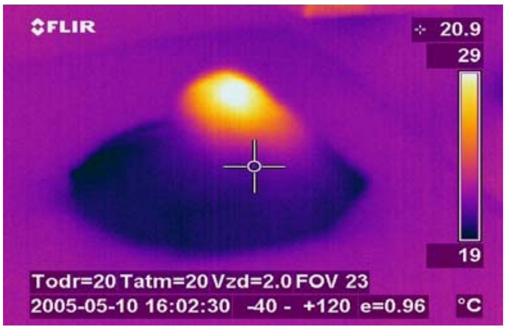

Figure 2: Temperature distribution obtained on surface of a model of mouse.

Here you can see temperature distribution obtained on surface of a model of mouse made from agar – with a simulated tumour on mouse back. Experiment has been done by heating phantom during 2 minutes delivering a power of 10 W. Maximum of temperature increase has been found approximately 10 ^{o}C. Similar results with different increase in temperature we have got also in other technical experiments on phantom or live mouse when power or heating time was changed.

Next figure (3) gives example of temperature increase on the surface of the phantom and 1 cm in that phantom. Temperature was measured by our 4-chanel thermometer. In this case with two thermoprobes.

Heating here is scheduled to 9 times repeated 30 s of heating and 30 s pause. Difference in temperature on the surface and under it is on the level of 1^{o}C. That means very good homogeneity of temperature distribution in the treated area during planned biological experiments.

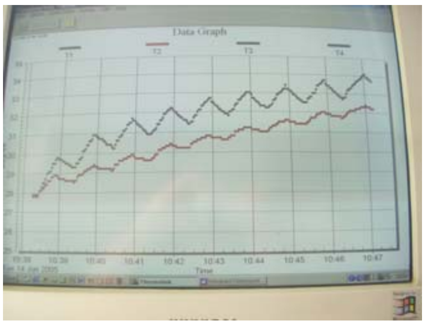

Figure 3: Temperatures during experiments.

Array applicator

The main goal of the planned biological experiment is a hyperthermia treatment of the experimentally induced pedicle tumours of the rat to verify the feasibility of ultrasound diagnostics and magnetic resonance imaging respectively to map the temperature distribution in the target area of the treatment. That means to heat effective volume of approximately cylindrical shape (diameter approx. 2 cm, height approx. 3 cm). Temperature to be reached is 41 ^{o}C or more (i.e. temperature increase of at least 4^{o}C from starting point 37 ^{o}C), time period of heating is 45 minutes.

Considering the necessary effective heating depth for the planned experiments, we have found 915 MHz to be suitable frequency. As an excellent compatibility of the applicator with non-invasive temperature measurement system (ultrasound or NMR) is a fundamental condition for our project, we should have to use non-magnetic metallic sheets of minimised dimensions to create the conductive elements of the applicator. Therefore the applicator itself (see Fig.4) is created by two inductive loops tuned to resonance by capacitive elements [4,5]. Dimensions of these resonant loops were designed by our software, developed for this purpose. Coupling between coaxial feeder and resonant loops (not shown in Fig.4) as well as a mutual coupling between resonating loops could be adjusted to optimum by microwave network analyser.

The position of the loops is fixed by perspex holder. There is a special cylindrical space for experimental animal in lower part of this perspex holder. As the heated tissue has a high dielectric losses, both loops are very well separated and so no significant resonance in heated area can occur. From this follows, that either the position of the loops with respect to heated area or the distance between the loops is not very critical.

First measurements to evaluate the basic properties of the discussed applicator were done on agar phantom of muscle tissue:

- evaluation of basic microwave properties (transfer of EM energy to the tissue, reflections),
- evaluation of compatibility with US and NMR,
- calculation and measurement of SAR and temperature distribution and its homogeneity.

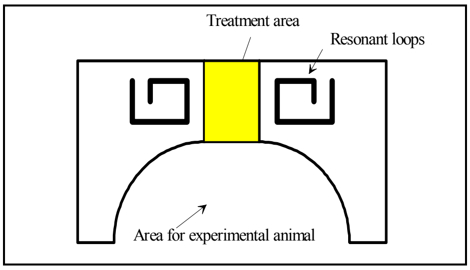

Figure 4: Arrangement of discussed microwave hyperthermia applicator.

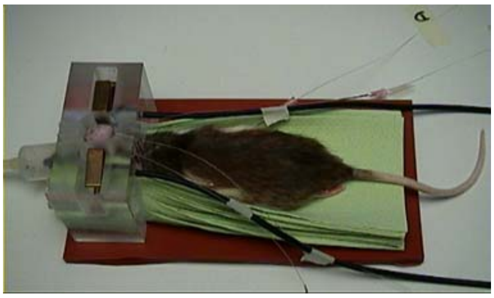

Figure 5: Photograph of the discussed applicator

Exact tuning of the resonant loops to frequency 915 MHz has been easy and we could optimise the coupling between the coaxial feeder and resonant loops as well, reflection coefficient less than 0.1. We have tested the power to be delivered to the applicator to obtain sufficient temperature increase (approximately 4 ^{o}C in less than 5 minutes is required). With power 10 W delivered to each loop for period of 2 minutes we succeeded to obtain the temperature increase of approximately 7 ^{o}C. To keep the increased temperature for a long time, 2 W in each loops were sufficient. Similar values were obtained during first experiments on rats also. Even with higher level of delivered microwave power we did not observe the change of resonant frequency (caused by increased temperature of the loops).

This applicator has been developed for German Cancer Research Institute in Heidelberg. And it is being used there for a series of animal experiments to study effect of hyperthermia on tumours and possibility to combine hyperthermia with chemotherapy etc.

Compatibility of this applicator with a Magnetic resonance unit (MR) has been studied and it has been demonstrated.

We have tested the influence of the applicators on US diagnostics and NMR imaging and the result of this evaluation shows very good compatibility. Only a negligible deterioration of the US images have been observed when the incident power was kept under 100 W.

Details about influence of microwave power on MR imaging are given in Fig. 6. We can see here a sequency of images of the discussed applicator made by MR unit for four different cases. First case (upper left) is image for the case without power excitation of the applicator. Second case (left down) a power of 10 W has been delivered to each loop. We can see quite clear configuration of the applicator set-up. Third case (upper right) gives situation when 20 W has been delivered to each loop. Slight noise but still quite a clear configuration of the applicator set-up can be observed. Fourth case (right down) gives situation when 40 W has been delivered to each loop. In this case noise disturbed the possibility to observe the configuration of the applicator.

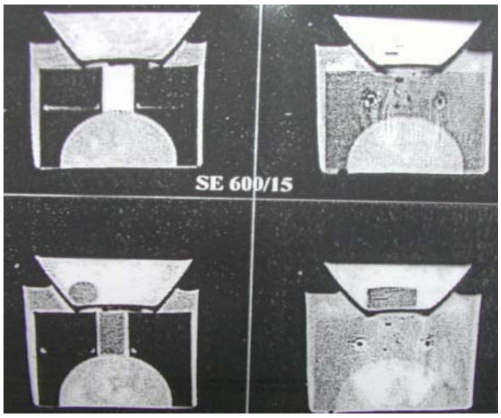

Figure 6: MR images of the discussed applicator.

In theoretical and experimental evaluation, the grade of homogeneity of the temperature distribution in the target area has been tested, see the Fig. 7. Our mathematical approach is based on idea of waveguide TM_{01} mode excited in the agar phantom under the given conditions (see the dashed lines). Measurement of SAR (full lines) has been done on agar phantom of the muscle tissue. Very good agreement have been obtained when verifying these results numerically by software product FEMLAB (Fig. 8).

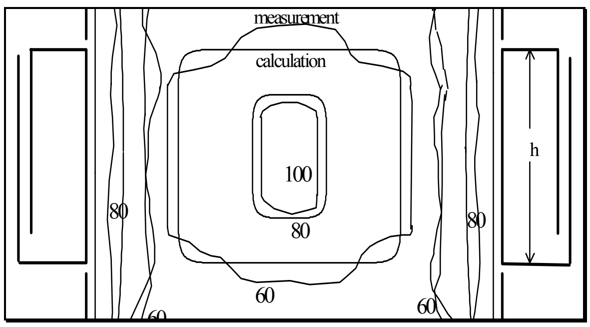

Figure 7: Normalised SAR distribution (calculated and measured) in the heated agar phantom.

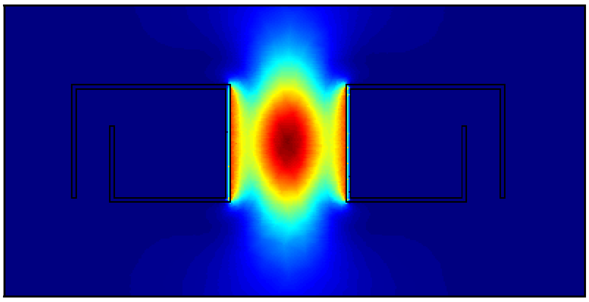

Figure 8: Numerical SAR analysis made by software product FEMLAB

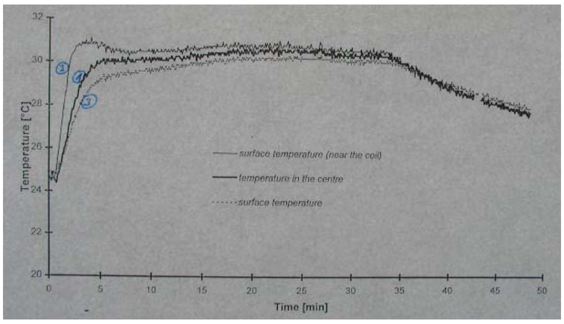

Figure 9: Temperature measurements.

In Fig. 9. we can see temperature vs. time measurement in the case of agar phantom inserted in the studied applicator.

Next figure shows experimental setup of applicator and simple exposure chambers installed at Medical Faculty of Charles University in Pilsen.

Figure 10: Exposure system for research of EM field and biological system interactions.

Conclusions

In this paper we have described basic microwave technical equipment for biological experiments, i.e. waveguide applicator and so called array applicator, including its basic evaluations.

As a novel results of our work we could mention that the new types of microwave applicator for basis biological research of cancer treatment and EM field interactions with biological systems have been developed and evaluated. Evaluation procedures have shown, that this applicator is a very effective heating structure and a compatibility with US and MR has been approved as well.

Having approved these applicators in animal experiments, we are now working on development of their clinical versions to be used in clinical praxis soon.

Acknowledgements

This work was supported by the Czech Academy of Sciences, Institutional Research Concepts No. AV0Z50200510: "Hyperthermia and anticancer immunomodulation, morpho-functional study of micro-environmental interactions in melanoma model".

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ISSN: 1727-1983