APPLICATOR FOR TREATMENT OF DEEP SEATED TUMOURS

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Abstract: A model of a new type of applicator for microwave thermotherapy, compatible with non-invasive thermometry was developed and evaluated. The goal of this paper is to validate theoretical assumptions for using the applicator in regional thermotherapy. Radiating elements of this applicator are 8 inductive loops tuned to resonance by capacitive elements. Details of the applicator's realization and ability to focus electromagnetic (EM) energy in the phantom of biological tissue by employing various number of elements are presented. Possibilities of focusing EM energy in an arbitrary part of phantom of biological tissue using phase and amplitude shift at the feed-points of the elements are described. Preliminary measurements of the model and comparison with simulated results are made. Further refinement of numerical models and measuring methods are necessary.

Introduction

Regional thermotherapy is one of the domains of microwave thermotherapy in the field of complex cancer treatment. This technique is presently used as an adjuvant to the radiation therapy in the treatment of certain types of cancers. The goal of hyperthermia treatment is to raise the temperature of a localised cancerous tumour to a therapeutic level without overheating surrounding normal tissue. The effective temperature range of hyperthermia is 39-44°C. In hyperthermia applications, adequacy of efficient treatment can be related to the extent to which the tumour is enclosed by surfaces with 50% of SAR (Specific Absorption Rate) produced by applicator.

The SAR distribution within a patient is governed by the interaction of the irradiated electric field with the patient's tissues. This interaction is rather complex due to the inhomogenous dielectric properties of the tissues. Moreover in the treatment of deep seated tumours its definition is very complicated due to the cooling produced by significantly varying blood perfusion rates within the heated volumes.

One approach for providing the deep hyperthermia is to use an array of radiators placed in a circumferential array about the patient, relying on constructive wave interference to selectively heat the tumour. The depth of the heating depends on the frequency of the generated waves, which is moving between 27 - 434 MHz.

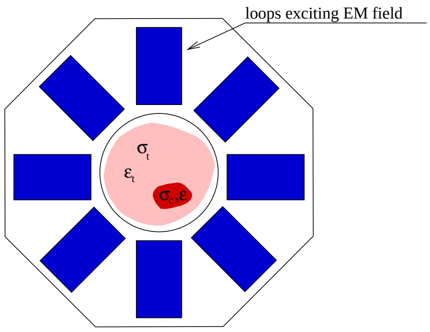

Figure 1: Set up of proposed regional applicator (8 inductive loops)

Applicator design

The applicator consists of an array of the radiators oriented around the patient, which distributes the EM energy into the body. Having an excellent compatibility of the applicator with non-invasive temperature measurement system (ultrasound or MR) is a fundamental condition for our project. Hence we have to use non-magnetic metallic sheets of minimized dimensions to create the conductive elements of the applicator. Therefore the applicator itself is created by 2 - 8 inductive loops tuned to resonance by a capacitive element. The size of identical elements sets resonance frequency [1].

$$f = \frac{1000}{2\pi\sqrt{LC}} \tag{1}$$

where L is the induction of the rectangle loop and C is the capacitance of the slab capacitor.

Dimensions of these resonant loops were designed by our software, developed for this purpose.

The EM field is excited by the rotary loop, as shown in 2a, which is composed of two threads, that represent the excitation of the magnetic field. The direct connection of the loop and the coaxial cable is not convenient. The reason is that the impedance matching of the applicator varies too sensitively with position of the coaxial cable.

Impedance matching between 50 Ω coaxial line and the complex impedance of the biological tissue as well as mutual coupling between resonant loops could be adjusted to optimum. With respect to the use of relatively high level of power, it is necessary to obtain a reflection coefficient that is better than 13 dB.

The applicator operates at 434 MHz and focuses EM

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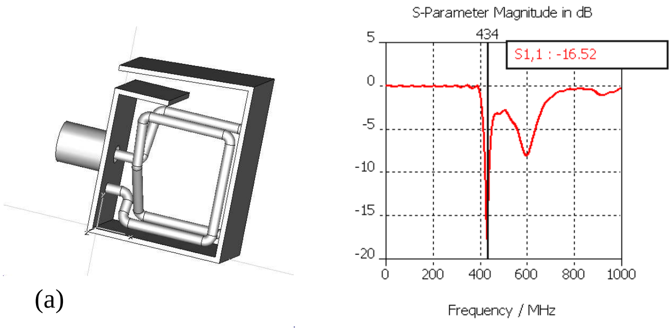

(a)

(b)

Figure 2: (a) Element of regional applicator. (b) Impedance matching of the element.

fields in parts of the body, which have diameters of 10-15 cm.

The numerical experiments

In this section numerical simulation results of EM field absorption in the phantom of biological tissue are shown. The phantom has a diameter of 10 cm and same dielectric parameters as a muscle tissue ($\varepsilon_r = 56, \sigma = 0.8\frac{S}{m}$). Between the phantom and radiating elements a water bolus with a thickness of 1 cm is placed.

Water bolus is a dielectric layer inserted between the applicator and the treatment area. The necessity of using water bolus with any microwave hyperthermia applicator is not a debated fact. It is used to obtain better contact between the applicator and uneven surfaces of the human body. Water bolus also allows modification of the thermal profile on the body surface and eliminates hot spots originating on the surface. The hot spots are expressed at places with very high level of absorbed energy. This incidence of hot spots could be reason for the patient's burns.

All results from the simulation describe the distribution of the SAR, which has very good correlation with temperature increases according to

$$SAR = c\frac{\Delta T}{t} = c\frac{T2 - T1}{t} \qquad (2)$$

where T1 and T2 are the temperatures before and after heating, respectively. t is the period of heating and c = 3000 $\frac{J}{Kg \cdot K}$ is the heat capacity of the agar phantom.

Mathematical description of EM field distribution around the applicator is too complicated even for short introduction. Hence we do not mention it here. One can find complete analysis of this problem in [2] here.

Focusing of SAR in the center of phantom of biological tissue

In the most simple configuration, when we use two excited elements, the distance between them is too long and the resultant focusing of the EM field is quite mild. The distribution of SAR is in the best case less than boundary value for effective treatment. Thus, that type of applicator is unapplicable for sufficient treatment.

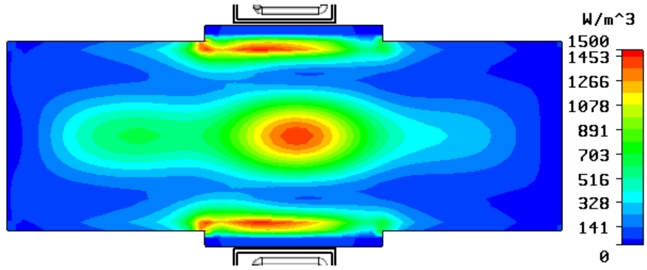

Figure 3: SAR absorbed in phantom along axis z by using 4 elements

Better results were obtained by applying four elements situated symmetrically around the phantom. We achieved symmetrical SAR distribution in the z axis cut. Simulation shows very good focusing of the EM energy at the center of the phantom, where 90% of SAR on the surface of the phantom is achieved.

Finally, we used an applicator containing eight elements. The level of absorbed energy (Fig. 4) was sufficiently large such that this applicator could be used for efficient treatment of parts with diameter betwwen 15 - 20 cm. Additionally, the focusing of the EM power was better and the distribution of SAR was more homogeneous than in the previous case.

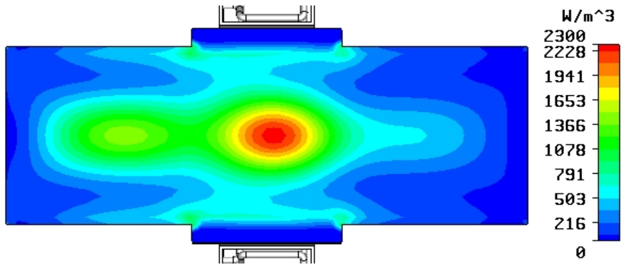

Figure 4: SAR absorbed in phantom along axis z by using 8 elements

However, as the SAR was high in a large area, certain parts of the body may get overheated. Accumulated energy was clearly caused by the connectors of the elements. Thus connectors of the elements were displaced for reducing this area (Fig. 5a). Figure 5b depicts that the area of focus was separated into a main area and two additional areas on the sides of the phantom. This was evoked by a basic principle of the phantom, which was acting on as a resonator structure. Despite this fact, that maximum SAR level are insignificant and in practice will be limited by distribution of heat. We are dealing continually with this problem.

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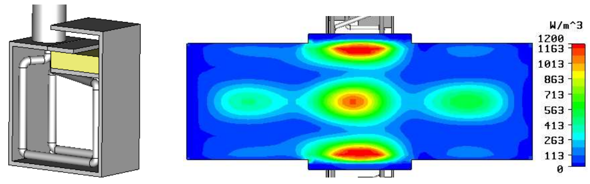


(a) (b)

Figure 5: (a) Design of radial excitations element. (b) SAR absorbed in phantom along axis z by using 4 radial excitations elements

Focusing of SAR in the arbitrary part of the phantom of biological tissue

The most important attribute of engineered applicator is the ability to vary the location of the focused EM energy in an arbitrary part of the body. For this purpose, we can use two techniques for feeding the exciting elements. One of them is by feeding certain elements with signals with higher amplitude (amplitude shift). The other method is to feed certain elements by signals with unequal phase (phase shift).

Figure 6 depicts the SAR distribution in the phantom for diverse cases of feeding of four elements. In case 6a), the element number one is fed by double amplitude compared to other elements and for case 6b), the phase shift of $\frac{\pi}{2}$ for the same element is used. Apparently, by using amplitude shift, focusing of EM energy comes close to elements with higher amplitude of feeding, whereas by using phase shift, it is the converse case. In both cases, the peak location of the SAR is displaced slightly. On the other hand, the absorbed energy in large regions is now nearly zero. This help in protecting various parts of the body against overheating.

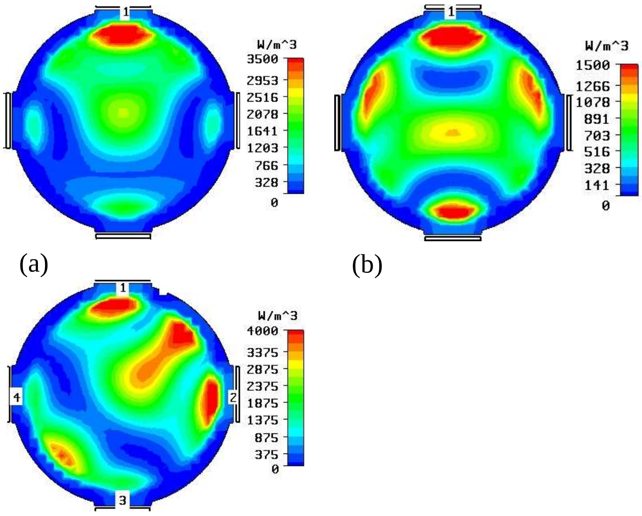
In case 6c), attributes of previous cases are employed. Thus, element number 1 and 2 are fed by signals with double amplitude compared to remaining ones, while elements number 3, 4 are fed by signals with phase shift $\frac{\pi}{2}$. Clearly, displacement of the peak locations of SAR between elements 1 and 2 has been achieved.

Employing four excitation elements affords a limited alternation. On the other hand, it provides us elemental behavior of the system by using amplitude and phase shifts at the feed-points of the elements. We can use acquired experience for more realistic experiments, where all eight elements of the applicator are employed.

In case 7a), when double amplitude at the feed-points of elements 2, 3 was employed, only a slight move in the peak of the SAR arises. Distribution of SAR on the surface of the elements fed by the signal without amplitude shift achieves neglectable values, which is favorable.

An opposite situation arises in case 7b), where two adjacent elements are fed with phase shift π. The center of focusing is moved in the direction from the elements fed with the phase shift. The level of focusing energy is lower than SAR distribution on the surface.

In case 7c), both effects are combined. Element numbers 2 and 3 are fed by signals with double amplitude and element numbers 6 and 7 are fed by signals with phase shifts of π. Compared to previous cases, the center of focusing energy is moved to the required area and the SAR absorbed on the surface of the phantom achieves acceptable values. However, SAR distribution is spread over large areas of the phantom.



(a) (b) (c)

Figure 6: SAR absorbed in phantom along axis x by using 4 excitations elements. Numbering of elements in all figures is according to figure (a). Amplitude shift means double amplitude of feeding of element compare to others, Phase shift means phase shift of feeding of element. (a) Element no. 1: Amplitude shift. (b) Element no. 1: Phase shift $\frac{\pi}{2}$. (c) Element no. 1, 2: Amplitude shift; Element no. 3, 4: Phase shift $\frac{\pi}{2}$

The SAR is more focused in cases, where shifts in the feed-points of more elements are used. The most favorable SAR distribution occurs in cases 7e) and 7f), where element numbers 1 and 2 are fed by signals with double amplitude, element numbers 5 - 8 fed by signals with phase shifts of π, element numbers 1 - 4 fed by signals with double amplitude, and others by signals with phase shifts of π, respectively. Negligible amount of energy is absorbedon the surface, which in practice will be limited by distribution of heat.

Results achieved by simulations show, that the designed applicator is usable for treatment of tumours seated in arbitrairly deep of area. We recommend using a combination of both techniques, phase and amplitude shift in feed-points, for focusing of energy in an arbitrary part of the body.

The experimental measurement

Measurements were carried out in Bulovka Hospital in Prague. The experiment setup shown in Figure 8. A generator from thermoterapeutic apparatus Lund system 4010 was used. Agar phantom of muscle tissue ($\varepsilon_r = 56, \sigma = 0.8 \frac{S}{m}$) with a diameter of 10 cm and

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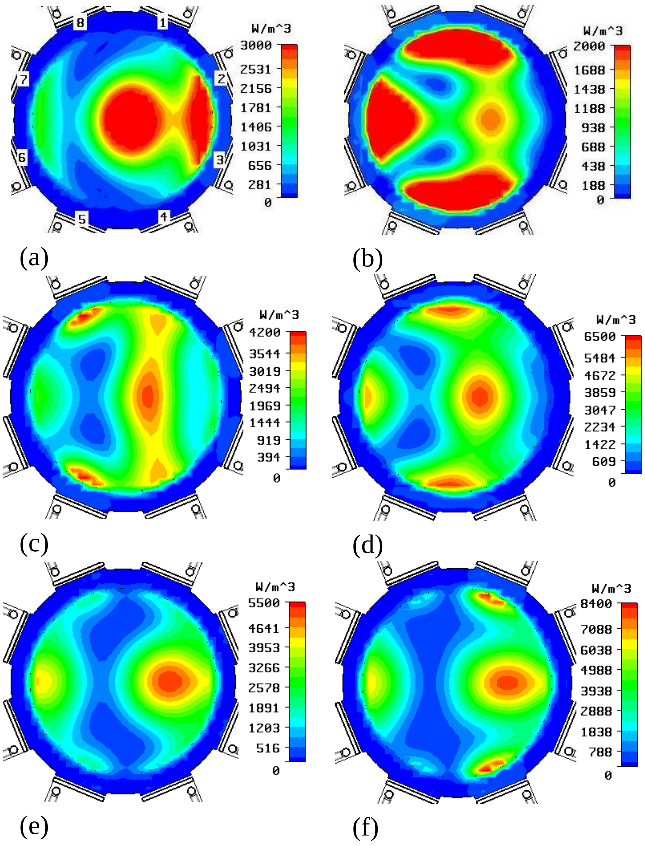

Figure 7: SAR absorbed in phantom along axis x by using 8 excitations elements. Numbering of elements in all figures is according to figure (a). Amplitude shift means double amplitude of feeding of element compare to others, Phase shift means phase shift of feeding of element.(a) Element no. 2, 3: Amplitude shift. (b) Element no. 6, 7: Phase shift $\frac{3\pi}{2}$. (c) Element no. 2, 3: Amplitude shift, Element no. 6, 7: Phase shift π. (d) Element no. 1 - 4: Amplitude shift, Element no. 6, 7: Phase shift π. (e) Element no. 1, 2: Amplitude shift, Element no. 5 - 8: Phase shift π. (f) Element no. 1 - 4: Amplitude shift, Element no. 5 - 8: Phase shift π.

length 15 cm was exposed to the applicator containing 4 primal designed elements (Fig. 2a). A water bolus with a thickness of 1 cm between the phantom and the radiating elements was placed. Coupling between the coaxial feeder and resonant loops, as well as a mutual coupling between resonant loops could be adjusted to an optimum by a microwave network analyser. Duration of exposure was 10 minutes, the input power was 100 W, and the reflected power was 9 W. Before excitation the agar phantom was split. Immediately after excitation a pictures of both halves was made using a thermocamera, as shown in Fig. 9.

Focusing of EM energy in the middle of the phantom achieves the same level of heat distribution on the surface of the phantom as well as during numerical simulations. However, maximum temperature is situated in frontal parts of the phantom, and not under the elements as we expected. Clearly, it is caused by situating of the

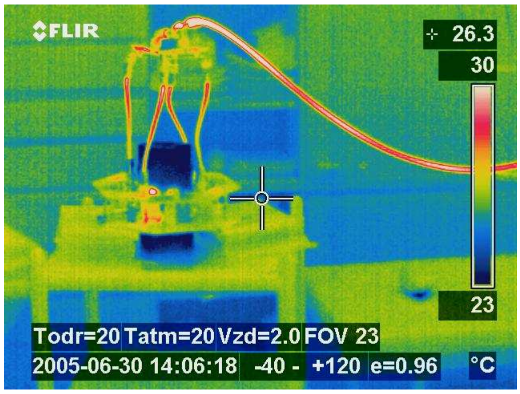

Figure 8: Setup of experiment - thermogram

coaxial cables closely to the phantom. Figure 8, acquired during the excitation, shows high level of energy passing through the cables. We registered similar behavior of system even during simulations, when excessively long feed cable situated close to phantom was used.

The SAR distribution is asymmetrical. This is probably caused by combination of slightly asymmetrical position of exciting elements and uneven impedance matching of the elements. Impedance matching between 50 Ω coaxial line and complex impedance of the biological tissue of each element was provided. But during composition of the whole applicator, slight mistuning of an element may have ocurred. After composition only impedance matching of the whole applicator was checked. The fixation of the phantom during the experiment was also incomplete. The phantom has gelatinous character and this has probably occured during exposure due to its motion.

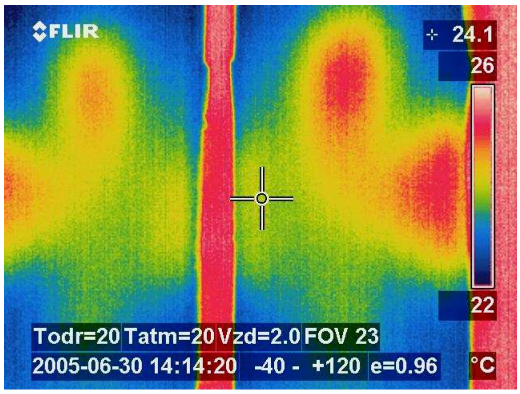

Figure 9: Distribution of heat in phantom after 10 minutes excitation. Applicator contains 4 elements.

Conclusions

In this paper we have discussed a new model of regional applicator for treating deep-seated tumours in neck and limbs, which is compatible with non-invasive thermometry utilizing various number of radiators.

We attain very good focusing of the EM energy by using 4 and 8 radiating elements. Especially, in the case of an applicator containing 8 elements the distribution of SAR is extremely favorable. However, the SAR was absorbed in a large area and could inflict overheating of an adjacent part of the body. We displaced connectors of elements for reducing this area and we are dealing continually with this problem.

We have solved the problem of situating the focused EM energy in an arbitrary part of the body by using amplitude and phase shift at the feed-points of elements. Employing four excitation elements affords a limited alternation, nevertheless it confirms expected elemental behavior of the system by using amplitude and phase shifts. More realistic experiments, where by all eight elements of the applicator are used, shows very good applicability for treatment of tumours placed in arbitrary parts of the body. Employing a of combination of both techniques, phase and amplitude shift at the feed-points of elements, leads to more focused shape of SAR distribution and eliminates the SAR distribution on the surface of the phantom.

Simulated results were verified by real measurements using a thermocamera. Asymmetrical profile of heat distribution was caused by imperfect impedance matching of one of the elements. However, the measured and simulated data are in coherence with each other.

We believe that this is a good initial step with promising results which encourages us to make more realistic tests.

Acknowledgement

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