Array of Spiral Applicators for Local Thermotherapy

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Abstract— This article deals with the design and testing of planar microwave two-wireArchimedean spiral applicator. Applicator is designed to work on the frequency $f = 434\,\text{MHz}$, aperture has a size of $35\,\text{mm} \times 35\,\text{mm}$ and its matrix composition consists of the five applicator of the same type. In this case, aperture has a size of $100\,\text{mm} \times 100\,\text{mm}$. Design simulation and the simulations of Specific Absorption Rate distribution are created in program CST MICROWAVE STUDIO 2009. Final evaluation of construction solution is established on SIXPORT for S_{11} coefficient and evaluation of SAR distribution is evaluated by infrared camera FLIR P25.

1. INTRODUCTION

Nowadays the use of microwave thermotherapy is a common part of the clinical hyperthermia oncology treatment. Thus, the paper deals with the prospective type of microwave planar applicator for thermotherapy. The discussed applicator is Archimedean two-wire spiral applicator. We are mainly interested in the shape of radiated power from the aperture and the depth of effective penetration of the biological tissue. This two main parameters have the crucial impact on the process of hyperthermia oncology treatment. Thus, we want to irradiate the cancerous tissues with the predictable doze of microwave radiation. This is reason why we are running the simulations of this above mentioned microwave thermo therapeutic applicator not only for the impedance matching to the biological tissue, but also for the shape of radiated power from applicator aperture together with the determining the depth of effective penetration. Numeric verification of SAR distribution is calculated in homogenous plane phantom having electrically the same parameters as the biological tissue.

2. THERMAL EFFECTS ON TISSUE

Hyperthermic effects on living organism are not that simple matter [1] as it can be seen but here comes a variety of factors to deal with. We can divide them into two major groups; effects caused by blood flow in the tissue and effects of the heat shock proteins (HSP). On cellular level we can describe the heat shock proteins as agents which are protecting the cells and the whole organism from lethal hyperthermia expositions.

In mammals the effects of higher temperatures (up to 43°C) cause cellular damage caused by a denaturation of proteins. When this happens the cell protheo synthesis is terminated and apoptosis is induced.

Physiologically the thermal exposition in mammals happens together with fever when heat shock proteins come to action, this supports the hypothesis that the heat shock proteins are protecting the cells against high temperatures. In fact we still know very little about heat shock proteins as the fever sicknesses are as old as the humankind.

Other very important physiological parameter influencing tissue response to heat is the blood flow. At higher temperatures blood perfusion increases in many tumors and this effect is dependent on heating time, temperature and also tumor structure. Blood flow increases to improve tumor oxygenation, but in most cases it is not sufficient because the increased consumption of oxygen in heated tissue. When heating is terminated, blood perfusion and oxygenation slowly recover and how quickly this occurs appears to be tumor-specific. Similar physiological effects occur in normal tissues, but normal tissue has more sophisticated vascular structures to help the tissue deal with the higher temperatures. Heating tumors to higher temperatures typically causes a increase in perfusion during heating which is followed by vascular collapse and if sufficient, this will lead the tumor to necrosis. The speed and degree of vascular collapse depends on heating time, temperature and, of course, on the tumor.

The tumor vascular supply can also be exploited to improve the response to heat. Decreasing blood flow, using physiological modifiers or longer acting vascular disrupting agents prior to the initiation of heating can both increase the accumulation of physical heat in the tumor, as well as increase the heat sensitivity of the tumor.

3. HYPERTHERMIA ONCOLOGY

Hyperthermia, also called thermotherapy, is a type of cancer treatment [2] in which body tissue is exposed to high temperatures (up to 43°C). It has been shown that high temperatures can damage and kill cancer cells, usually with lower injury to normal tissues. Damaging proteins and structures within cells is causing death of cancer cells by damaging proteins and their inner structures.

Hyperthermia is often used with other forms of cancer therapy, such as chemotherapy and radiation therapy. Hyperthermia may make some cancer cells more sensitive to radiation or harm other cancer cells that radiation cannot damage and it can also enhance the effects of certain cytostatics.

There are two main streams in hyperthermia thermotherapy depending on the area of the human body where the heat was applied. Thus, we have a local hyperthermia application and a whole body application.

In local hyperthermia, heat is applied to a small area, such as a tumor, using techniques that deliver energy to heat the tumor. Different types of energy may be used in this case including radio frequency, microwave, or ultrasound.

Depending on the tumor location, there are several approaches to local hyperthermia: External approaches are used to treat tumors in superficial area, which means that the tumors are not more than 30 mm below the skin. External applicators are often positioned around or near the appropriate region, and energy is focused on the tumor.

The internal method may be used to treat tumors close or near body cavities, such as the esophagus or rectum. Intracavitary applicators are placed inside the cavity and inserted into the tumor to deliver energy which dissipates into heat in the desired area.

Interstitial techniques are used to treat tumors deep within the body, such as brain tumors. This technique allows the tumor to be heated to higher temperatures than external techniques. Under anesthesia, intracavitary applicators are inserted into the tumor. Imaging techniques, such as ultrasound, may be used to make sure the probe is properly positioned within the tumor.

To ensure that the desired temperature is reached, but not exceeded, the temperature of the tumor and surrounding tissue is monitored throughout hyperthermia treatment. Using local anesthesia, the doctor inserts small needles with tiny thermometers into the treatment area to monitor the temperature. Imaging techniques, such as computer tomography, may be used to make sure the probes are properly positioned.

4. PLANAR APPLICATOR

Two-wire Archimedean spiral applicator configurations shown in Fig. 1, when properly excited, have been shown to be circularly polarized radiators with wide broadband characteristic with respect not only to input impedance but also to radiation pattern. In practice, the configuration is excited from a transmission line connected to the center terminals of the configuration.

Such energized two-wire Archimedean spiral radiates a broad circularly polarized beam to each side of the spiral. Each radiated beam is normal to the plane of the spiral Accordingly, the radiated beams are identical except that the rotational sense of polarization of the radiated field on one side is the opposite of that on the other.

In most applications it is desirable that the spiral radiate to one side this is accomplished by appropriately backing the spiral on one side by a ground plane.

The matrix composition (see Fig. 2) of the two-wire Archimedean spiral applicators is a very useful when we want to irradiate the larger area, which can be useful for example treating the tumors in thoracic region.

5. SIMULATIONS

There has not been any rigorous theory to explain the spiral applicator. However, the following explanation of the radiating mechanism of the two-wire Archimedean spiral is offered through the experimental observations. The point of view taken is that the two-wire spiral applicator be haves as though it were a two-wire transmission line which gradually, by virtue of its spiral geometry, transforms itself into a radiating structure or antenna.

It is well known that a two-wire transmission line, of narrow spacing relative to wavelength of any length, yields a negligible amount of radiation when excited at its terminals. This is due

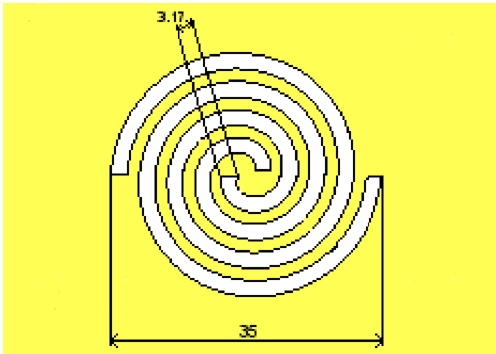

Figure 1: The scheme of the two-wire Archimedean spiral applicator.

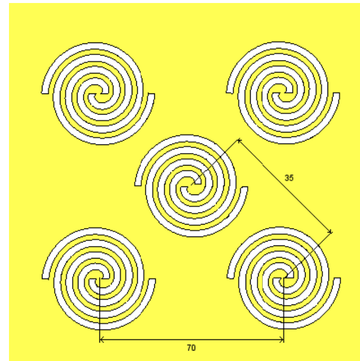

Figure 2: Matrix composition of five Archimedean spiral applicators.

to the fact that the currents in the two wires of the line at normal cross section are always 180' out-of-phase so that radiation from one line is effectively cancelled by the radiation from the other.

Simulations for this applicator have been done in the simulator of electromagnetic field CST MICROWAVE STUDIO 2009. This simulator uses a FDTD method to solve problems related to the electromagnetic field.

The one of the main objectives of the simulations was to find an impedance matching the thermo therapeutic applicator to the biological tissue with the required parameter $S_{11} < -15\,\mathrm{dB}$. As shows the Fig. 3, the best impedance matching the applicator was found with the width of the applicators arms 3.17 mm. Impedance matching in this case was $S_{11} = -24.8\,\mathrm{dB}$.

To sum up, after modeling the first shape of the applicator's body and setting the parameters of transient analysis with the proper field monitors, the first results have been obtained. When setting the cells mesh we have to be very careful and add sufficient discretization density of cells when it's needed; otherwise the results will not be so good. As the lowest discretization with sufficient outcome we can assume the density of 35 discretization lines per wavelength.

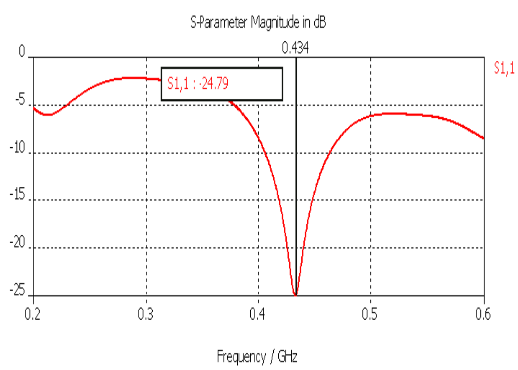

Figure 3: Impedance matching of two-wire Archimedean spiral applicator in wide range of frequencies.

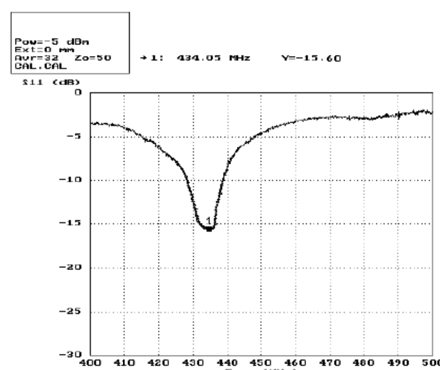

Figure 4: Impedance matching of two-wire Archimedean spiral applicator determined by measurement on SIXPORT.

The depth of effective penetration of the biological tissue is determined using the simulator of electromagnetic field SEMCAD BERNINA 13.4 and the depth is $d = 17\,\mathrm{mm}$.

6. RESULTS

Our main aim was to discuss the matrix composition of the two-wire Archimedean spiral applicators. From the results based on the simulations in simulator of electromagnetic field CST MICROWAVE STUDIO 2009, assume that this setup is the most suitable applicator for the superficial thermotherapy covering the largest area of tissue. Effective field size of the single applicator is 63% [3]. The measured impedance matching to the biological tissue is presented in Fig. 4. When composed together in the shape of five spiral applicators, this setup is capable of effectively heating the superficially located tumors.

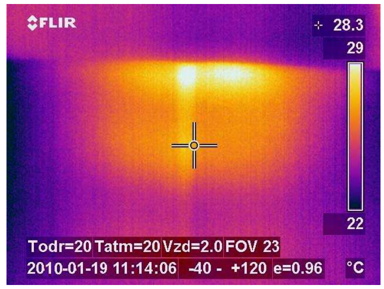

Figure 5: The thermal image of the SAR distribution in the agar phantom of the biological tissue, determined using the thermo camera FLIR P25.

7. CONCLUSIONS

As shown on previously presented results, the applicator is suitable for clinical practice where it can be used as a part of local superficial hyperthermia treatment. For a brief revision, the basic parameters of this applicator are: effective area of the aperture 63%, depth of effective penetration $d_{1/2} = 17\,\mathrm{mm}$ and, naturally, the value of reflection coefficient $S_{11} = -15.6\,\mathrm{dB}$.

From the thermal image as shown on Fig. 5 we can assume that the constructed applicator is capable of heating superficially located tissues.

REFERENCES

1. Horsman, R. M., "Tissue physiology and the response to heat," *International Journal of Hyperthermia*, Vol. 22, No. 3, 197–203, 2006.
2. Falk, H. M. and R. D. Issels, "Hyperthermia in oncology," *International Journal of Hyperthermia*, Vol. 17, No. 1, 1–18, 2001.
3. Vorlicek, J. and J. Rusz, "Useful Matlab tool for radio frequency designer," *Technical Computing Prague 2009, Full paper CD-ROM Proceedings*, P. Byron Ed., Humusofts.r.o. & Institute of Chemical Technology, Prague, 2009.