Closed-Loop System for Microwave-Induced Hyperthermia

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Abstract— **Microwave technology is now widely used in a variety of medical applications such as cancer treatment and diagnostics. This paper describes the structure of a novel hyperthermia system for biomedical research. The software Ansoft HFSS was used to design a rectangular waveguide applicator. A closed-loop is presented in order to control the output power of the system by the temperature measured on the sample. Initial results from experimental testing are presented. In these results, it is shown that the water temperature can be increased from 21°C to 40°C in 12 minutes. As a result, it has been tested that the system works properly. The next step will be to apply the system to melanoma cancer cells.**

Keywords-superficial tumor; hyperthermia; microwave; loop; feedback; temperature; control.

I. INTRODUCTION

Hyperthermia denotes a treatment for cancer patients providing heat to body tissue (between 40-44ºC) for a specific period of time [1]. Previous evidence suggests that high temperatures such as the ones reached using this therapy can destroy cancer cells, normally with least harm to the healthy tissues [2]. Due to this fact, over the past decade most research in cancer treatment has emphasized on the use of hyperthermia combined with other therapies such us radiotherapy and chemotherapy. For instance, it has been demonstrated that tumor cells could become more vulnerable to radiation and areas not reached by radiation alone could be affected when hyperthermia is used with radiotherapy. Regarding that, a number of researches have reported that the use of these treatments together has shown a considerable diminution in tumor size. [1]-[3].

To this date three hyperthermia methods have been developed and introduced: local, regional and whole-body hyperthermia. In our study we choose local hyperthermia since one of the aims of this project is to develop a novel microwave hyperthermia system that will be used as a reference for following studies focused on melanoma cancer research and treatment [4]. The main reason why the local therapy was considered the best option to treat this disease is that local hyperthermia offers an effective way of treating tumors located in or close to the skin such as melanoma. By using this method, applicators are placed next to the affected area of the body in order to concentrate the energy on the cancer cells and increase its temperature. The way heat is induced can vary depending on the position and the magnitude of the tumor. Regarding this issue, different techniques can be applied for different situations such as infrared radiation for the whole-body, radiofrequency radiation for more profound positioned tumors or microwave radiation for skin-deep tumors. Taking into account that this study is focused on superficial hyperthermia research and treatment, a microwave applicator was selected [4], [5].

Up to the present, several hyperthermia systems have been developed. These structures usually include heavy and costly components such as a microwave generator or a power meter [5], [6]. In general, there is a demand for lighter, more compact and cheaper systems and for this reason, the main purpose of this project is to establish a new hyperthermia system for treating superficial tumors that best suits these characteristics. The system primarily targets in-vitro research although the RF chain can be used with another RF applicator more suitable for in-vivo exposures. In terms of the advantages of the system we can say that it has accurate temperature control by the use of a feedback loop, homogeneous heating of the sample and rapid temperature rise. The design of a waveguide applicator and a closed-loop to control the power levels depending on the temperature measured in real time have been presented. Finally, in order to validate the functionality of the system, a flask containing water is introduced into the applicator.

II. HYPERTHERMIA SYSTEM

A. Identification of the components

The frequency band chosen to operate is the ISM band of 915 MHz since it is one of the most commonly used in microwave hyperthermia [5]. For this reason, we selected components that are able to work between 0.9 and 1 GHz. In terms of the output power of the system, it was calculated that a maximum power of 50 dBm was sufficient to achieve a water temperature of 45ºC inside a flask of 0.09 m diameter and 0.02 m height in a short period of time.

As shown in Fig. 1 the hyperthermia system is composed of a voltage-controlled oscillator or VCO (ZX95-1015+, Mini-Circuits) whose signal frequency is controlled by a voltage input, an attenuator to control the power of the signal (ZX73-

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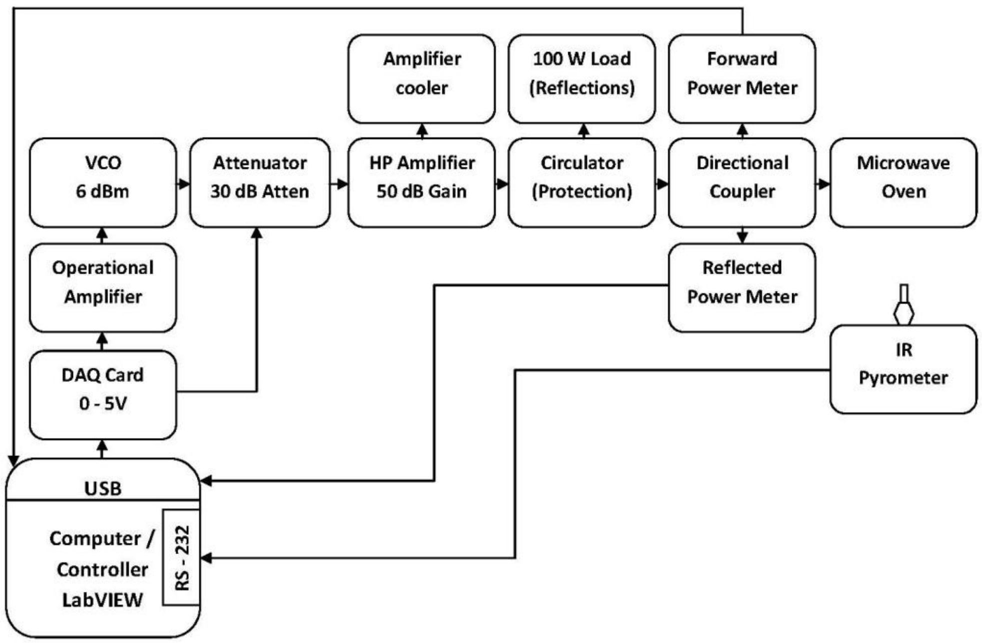

Figure 1. Block diagram of the necessary components to drive the microwave induced hyperthermia system.

2500+, Mini-Circuits), a high-power amplifier with a maximum gain of 50 dB (ZHL-100W-13+, Mini-Circuits), an isolator formed by a circulator (JCC0900T1000N20-HER, JQL Electronics) and a 100W load (TN060M-100W, RF Components) for protecting the amplifier from reflected signals, a dual directional coupler (C2-A12, RF Components) connected to two power sensors (PWR 4GHS) to calculate the forward and backward power flow and a microwave applicator, which is a rectangular waveguide [7]. The design of the cavity will be presented in the next section.

B. *Closed-loop*

All the system parameters such us frequency, output power and temperature can be monitored from a personal computer or PC. The software chosen for this purpose was LabVIEW (National Instruments).

First of all, in order to connect the VCO to a PC to be able to adjust the frequency from LabVIEW, a data acquisition card or DAQ was required. As the maximum output voltage value of this card is 5V (see DAQ datasheet) and the voltage necessary to choose a frequency of the ISM band of 915 MHz on the VCO is around three times greater than 5V (see VCO datasheet), the card was connected to a 3 dB gain operational amplifier (LN324AN) and the output of this one to the VCO. The DAQ card is connected to the PC via USB.

Secondly, the control of the power is accomplished by the use of the attenuator, which is connected to the PC using the same DAQ card. Additionally, the power reflection coefficient is calculated with the use of the backward and forward power flow obtained by the sensors. This coefficient will be used to further enhance control of the temperature.

Finally, the temperature is measured by a pyrometer (CT84-02, Sensortherm), which is positioned at the top of the cavity with the lens focused to the flask containing the water. This pyrometer is also connected to the PC via RS-232. As a result, the system provides real time display of the temperature at the same time that this temperature is used to control the power levels. The functionality of the closed-loop is follows: while the measured temperature is lower than requested, the attenuator should be reducing the attenuation to increase the power level until the target temperature is achieved. In the same way, when the measured temperature is higher than requested, the attenuator should increase the attenuation to reduce the power.

III. DESIGN OF THE APPLICATOR

A. *Cavity shape*

In the design of the applicator, several requirements were taken into account. As our aim is to validate the functionality of the hyperthermia system by heating water introduced in a flask, we decided to locate the flask inside the cavity. In order to achieve that, the applicator is formed by two rectangular aluminum waveguides that have a different width, as shown in Fig. 2, so that a rohacell layer could be placed between the two cavities. The reason why the rohacell was chosen is that its permittivity value is similar to the air permittivity. Thanks to this structure, it is possible to position the flask over the rohacell. Furthermore, the top of the shortest cavity can be removed in order to take out the flask and change the sample. there is a hole at the top of this cavity for the pyrometer to measure the temperature. Finally, an N-type connector was set

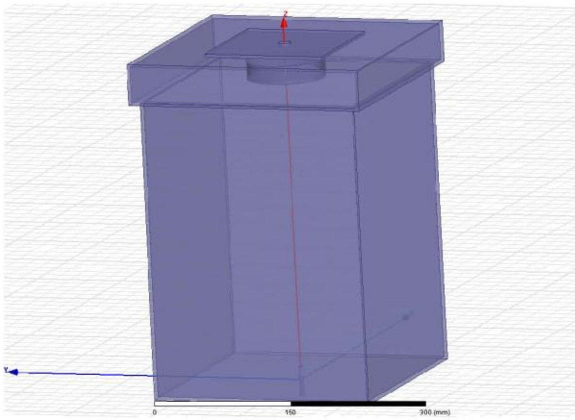

Figure 2. Microwave oven design including a cylindrical flask containing samples at the top cavity.

at the bottom of the largest cavity in order to connect the system to the applicator.

B. *Calculation of the dimensions*

The height of the applicator (d) has been obtained using the equation that calculates the resonant frequency of a TM_{mnl} mode [8] taking into account that we wanted to achieve the second transverse mode TM_{111} in correspondence of the working frequency. The value of the other two dimensions (a, b) was established as 0.25 m to be able to introduce flasks with different shapes and sizes and check the uniformity of the fields. As the cavities are filled with air, the value of the permittivity is 1. Finally, we obtained a height value of 0.37 m.

C. *Electric field distribution*

Before fabricating the applicator it was designed using the software Ansoft HFSS. Due to the fact that the inner conductor of the N-Type connector is inside the cavity, it was necessary to change the length of it in order to improve the impedance matching.

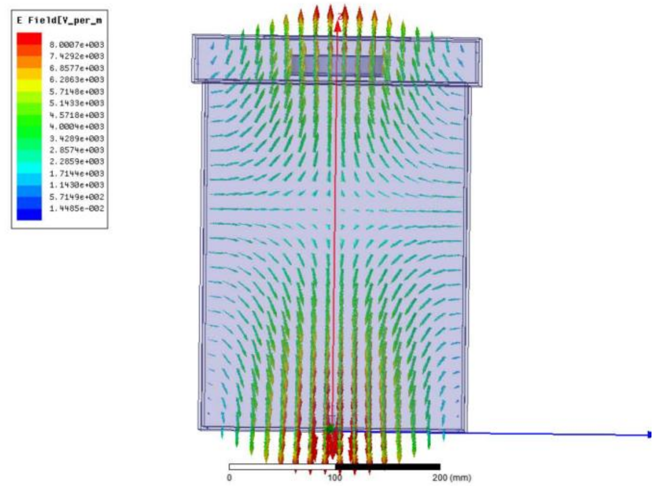

Figure 3. Simulated electric field within the oven cavity (TM mode).

In terms of the electromagnetic mode, it is shown in Fig. 3 that the TM_{111} mode was accomplished. Furthermore, it was tested that the distribution of the electric field between the two cavities was considerably uniform. Although the power is a bit stronger in the middle of the flask than at the edges.

IV. INITIAL RESULTS

Once the applicator was manufactured, the S_{11} parameter was measured by using a vector network analyzer or VNA. The comparison between the simulated and the measured S_{11} parameter is shown in Fig. 4.

Concerning the validation of the system functionality, some initial results have been obtained as shown in Fig. 5.

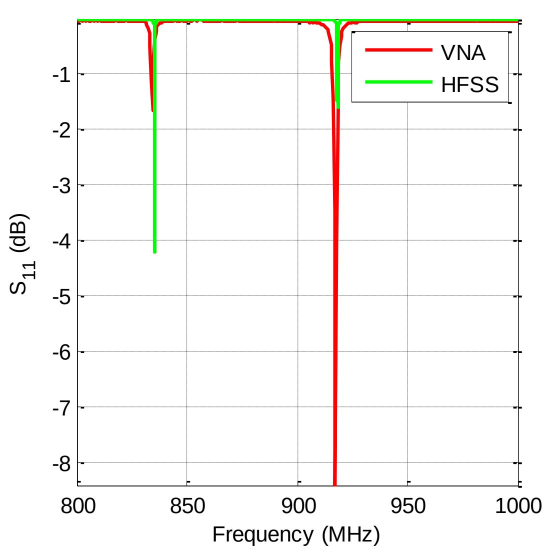

Figure 4. Comparison between the S_{11} parameter obtained by simulation (HFSS) and measurement (VNA) for the microwave oven.

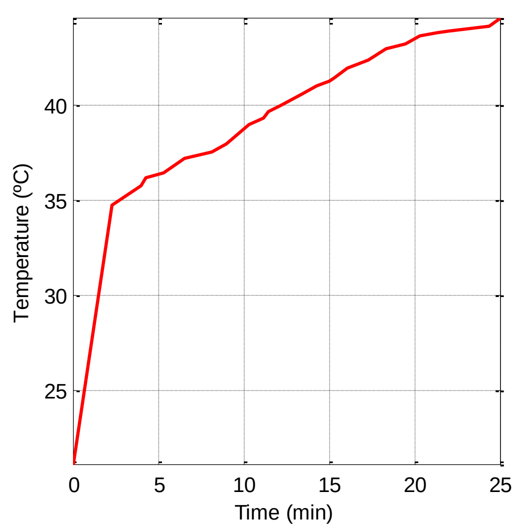

Figure 5. Measured temperature of the sample (water in this case) while the system is working at the resonance frequency (second mode).

Figure 6. System in the laboratory

V. CONCLUSION

A novel hyperthermia system has been presented in this paper. After choosing all the components that form the system, a waveguide cavity was designed with HFSS and manufactured afterwards. It has been shown in Fig. 4 that the measured resonance frequency is the same as the simulated one. The difference between them is the matching, the results measured show a better matching than the ones simulated. That could be attributed to the fact that the manufactured applicator takes into account other physical factors that the simulated one does not. Furthermore, it is shown in the same figure that two electromagnetic modes are propagating in the range from 0.8 MHz to 1 GHz. Due to the fact that the second mode (917 MHz) has a better matching than the first one (835 MHz), this was the one selected for our system.

Regarding the temperature results seen in Fig. 5, it is shown that around 12 minutes are required to increase the temperature of the water from 21ºC to 40ºC and 22 minutes to increase it up to 44ºC. As the temperature needed for the hyperthermia treatment is located between these values, a feedback loop is used in order to control the output power of the system in terms of the temperature. The functionality of this feedback loop consists of increasing the value of the power of the system if the temperature is lower than the value required for the treatment and decreasing it if the temperature is higher than required. Afterwards, the system will be used in melanoma cancer cells.

REFERENCES

[1] Hildebrandt B, Wust P, Ahlers O, et al.," The cellular and molecular basis of hyperthermia", Critical reviews in Oncology/Hematology, 43(1), pp. 33–56, 2002.

[2] Van der Zee J., "Heating the patient: a promising approach?", Annals of Oncology, 13(8), pp. 1173–1184, 2002.

[3] Wust P, Hildebrandt B, Sreenivasa G, et al., "Hyperthermia in combined treatment of cancer", The Lancest Oncology, 3(8), pp. 487–497, 2002.

[4] X. Yang, J. Du, Y. Liu, "Advances in hyperthermia technology", Engineering in Medicine and Biology 27th Annual Conference, September, 2005.

[5] P. Togni, J. Vrba, and L. Vannucci, "Microwave applicator for hyperthermia treatment on in vivo melanoma model", Med. Biol. Eng. Comput., 48, pp. 285–292, 2010.

[6] O. A. Arabe, P. F. Maccarini, E. L. Jones, G. Hanna, et al., "A 400 MHz hyperthermia system using rotating spiral antennas for uniform treatment of large superficial and sub-surface tumors", 2007.

[7] S. Kumar Pauvuluri, M. Ferenets, G. Goussetis, M. P. Y. Desmulliez, T. Tilford et al., "Encapsulation of Microelectronic Components Using Open-Ended Microwave Oven", IEEE Transactions on Components, Packaging and Manufacturing Technology, vol. 2, No. 5, May 2012.

[8] D. M. Pozar, "Microwave Engineering", Fourth Edition, chapter 6.3, p. 286, equation (6.40), 2012.