Microwave Coaxial Antenna for Cancer Treatment: Reducing the Backward Heating Using a Double Choke

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Abstract— **In this paper, we focus on the so-called backward heating problem, which appears when coaxial-type antennas are used to treat certain types of cancers. The aim of this study is to reduce the surface currents propagating along the outer conductor of the antenna that lead to a higher Specific Absorption Rate (SAR) and overheat the healthy tissues. Our study shows that the use of a double-choke can lead to a lower SAR compared to the case of a single one. We also demonstrate that the use of a periodic structure does not help to further improve the SAR-level along the antenna.**

Keywords— Microwave Coaxial Antenna, Microwave Cancer Ablation, Surface Current

I. Introduction

Over the last decades number of people afflicted with cancer has seen a dramatic increase. According to the World Health Organization (WHO), cancer is the leading cause of death worldwide today. In the year 2012, the number of deaths caused by cancer already reached 8.2 million. Among others, the most common cause of cancer death are cancer of the lungs and liver, claiming 1.59 million and 745,000 deaths, respectively [1].

The most widely used cancer treatment techniques are surgery, chemotherapy and radiotherapy. However, these techniques have some drawbacks and limitations. For example, only 25% of the patients are candidates for surgery, and the radiotherapy can treat only 1-2 cm of the targeted area [2]. As for chemotherapy, it has many physical and non-physical side effects that affect the life of patients [3].

The microwave ablation technique has attracted increased attention in recent years, owing to its ability to heat much larger lesion size within a shorter treatment time. Microwave ablation treatment is performed by using a tiny interstitial antenna, which allows radiating the electromagnetic energy into the tissue through an aperture positioned at its end. The most common applicator is of coaxial type classified as dipole, monopole or slot antenna [4]. Although these antennas have several important advantages, such as increased power deposition near the aperture in a shorter treatment time, they have drawbacks that prevent them to be considered as an alternative to the RF ablation, which has witnessed extensive use in recent years. Indeed, the electromagnetic power is not only deposited near the aperture (or slot) but also all the way along the interstitial antenna toward the feed point. This phenomenon can be primarily associated with the surface currents that travel along the outer conductor of the coaxial antenna and cause an overheating of the healthy region adjacent to the coaxial line. As can be seen from the discussion presented in the subsequent sections, considerable research has been carried out in attempts to reduce the backward-heating problem and thereby increase the radiation properties of the antenna. For example, in [5] and [6] the authors have proposed to use cap-chokes or sleeves to impede the propagation of the surface current. Although the results obtained were somewhat promising, it was found that the surface currents were not completely suppressed and the overheating problem was not entirely eliminated.

In this work, we present a new approach to reducing the surface currents along the antenna and to maximizing the SAR, referred to hereafter as max(SAR), in the vicinity of the slot. We show that we can significantly reduce the SAR along the antenna while the max(SAR) becomes higher—which is our desired goal--by adding a second choke which is appropriately oriented to help achieve our goal. In addition, we also investigate the use of periodic structures that are widely used in the electromagnetic community to reduce the surface currents flowing along the catheter. The results show that, the use of periodic structures do not significantly contribute to the reduction of the SAR, or the level of excitation of the surface currents along the antenna, as compared to the case of the double-choked structure proposed herein.

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II. MICROWAVE ANTENNAS

A. Antenna Design

To-date, much of the research on microwave ablation therapy has focused on antenna design. We define as antenna the entire structure beyond the flexible power delivery cable, i.e., the applicator comprising of the shaft and the radiator section at the distal end. The overall aim of this research has been to obtain highly localized power deposition in the tissues with lesions possibly as large as the size of the tumor. As is well known for all antennas, good radiation is possible only if the reflected power from the antenna, i.e., the return loss at the frequency of operation is relatively low. Otherwise, the reflected power would heat up, and cause damage not only to the antenna, but also to the healthy tissue around it.

Several antenna designs have been proposed to achieve these goals. For examples, monopoles [7], dipoles [8], triaxials antennas [9], coaxial slot antennas [10], loops [11], helical antennas [12], etc., have been investigated.

Due to their simple design, coaxial slot antennas are the most widely used antennas. The electromagnetic energy is radiated through the small annular aperture (slot) positioned close to the end of the antenna. However, despite the low return loss and acceptable radiation pattern, these antennas suffer from unwanted backward heating along the antenna. The subsequent section is dedicated to this very well known issue that limits the use of microwaves energy as a cancer treatment technique in clinics.

B. Backward Heating

The backward heating along the antenna can be attributed to three different types of sources. The first one is the heating of the antenna due to the high-power energy propagation in the antenna. A solution to this problem could be the use of an antenna with a larger diameter, in order to increase the maximum power handling capability. However, this can also increase the risk of complication such as bleeding during the operation due to the invasive nature of the applicator. In fact, the designed antenna must be interstitial intended for percutaneous application. The second source of excessive heating is due to heat conduction from the ablated zone along the antenna. Finally, probably the most important source, which is related to the antenna design, is the phenomenon of backward-heating, which originates from the aperture while it contributes to the radiation of energy in the tissues [13, 14].

To prevent this type of excessive heating, clinics employ a variety of approaches--they often use antenna cooling systems, for instance. Water or gas-cooled antennas also can be utilized to prevent unwanted heating [15]. In this work we focus on the backward heating phenomenon, caused by the aperture which creates surface currents on the outer conductor of the antenna. Descriptions of different ways to address this issue can be found in the literature. Choked antenna [16], cap-choked antenna [5], sleeve antenna [6], floating sleeve antenna [17], are among the most cited designs.

A choke is a metallic jacket, which surrounds the outer conductor of the coaxial antenna. It is electrically connected to the outer conductor to reduce the reflected surface wave. In [18], the authors have proposed the use of a choke on a transmission line (coaxial cable) terminated by a λ/4 dipole, which serves as the feed for the reflector. With a length of about λ/4, the choke presents an infinite impedance at its open end to confine the currents on the outer conductor to the region between the choke and the end of the line. The same structure was used for microwave ablation antenna. Authors in [8] employed a choke around a coaxial transmission line terminated by a dipole-type antenna. They showed that the λ/4 long choke is capable of concentrating the power independent of the insertion depth of the antenna into the tissues. In [19], the same choke was used along with a disk at the end of the dipole. This enhances the radiating power in the forward direction by reducing the reflected backward power. To avoid an increase in the size of the applicator, caused by the insertion of the choke, the authors in [20] proposed the use of a biopsy needle to introduce the antenna into the tissue as the metallic wall of the choke. The authors pointed out that this solution not only enables us to reduce the unwanted reflected power, but also to adjust the length of the choke in order to compensate for possible mismatch during the operation. Further information on the optimization of choked antennas can be found in [21].

To further improve the power radiated into the region of interest, the authors in [5] have used a cap at the end of the antenna tip in addition to the choke.

III. THE PROPOSED STRUCTURE

Our proposed structure consists of a coaxial slot antenna onto which we have added the chokes, as shown in Fig. 1. The dimensions of the antenna and the position and size of the slot are directly taken from [22]. The overall antenna along with the biological tissue, which is the liver in this case, has been simulated using the commercial software, HFSS. The physical parameters of the liver such as the dielectric constant and the electrical conductivity and those of the antenna with the catheter are summarized in Table 1.

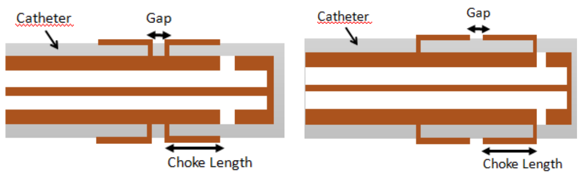

Fig.1: Double choked antennas, FW-RW (left), RW-FW (right)

As mentioned earlier, choked antenna design has been investigated extensively so far. In the literature, the choke is used with its aperture facing either the coaxial line or the slot of the antenna. We decided, in this work, to combine both of the design, and hence we show that their proper combination allows higher performance of the antenna. The following nomenclature is used: the FW abbreviation, standing for "forward", is preferred when the choke is facing the slot; otherwise RW abbreviation, standing for "reversed", is adopted. In Fig.1, two combinations of the chokes are presented: FW-RW and RW-FW. In these designations, the first abbreviation is used for the closest choke to the slot of the antenna. To show the performance of the new antenna, we studied the effect of the gap between the two chokes and also the effect of the choke length. The SAR and the max(SAR) are calculated at a distance of 1.5 mm from the catheter surface. The results are presented in Fig. 2 – 5. The SAR along the antenna is calculated at 30 mm from the excitation side of the antenna.

TABLE I. PHYSICAL CONSTANTS

Quantity	*Value*
Dielectric constant of the liver	43.03
Electrical conductivity of the liver	1.68 S/m
Dielectric constant of the catheter	2.2
Dielectric constant of the coaxial antenna dielectric	2.2

The results in Fig.2 and Fig. 3 are obtained by fixing the choke length and varying the gap size. Fig. 2 reveals that in the case of the FW-RW combination, except for large values, the gap has no significant effect on the SAR along the antenna. It is also seen that, for the RW-FW combination, the SAR value at the same point is highly dependent on the gap between the two chokes. A possible explanation for that behavior could be the fact that when the surface current is flowing from slot toward the choke, it sees an open circuit with very high impedance in the case of the FW-RW combination. This means that, whatever the capacitance value—the gap is similar to a capacitance—, that contribution to the high impedance presented by the FW choke is very small.

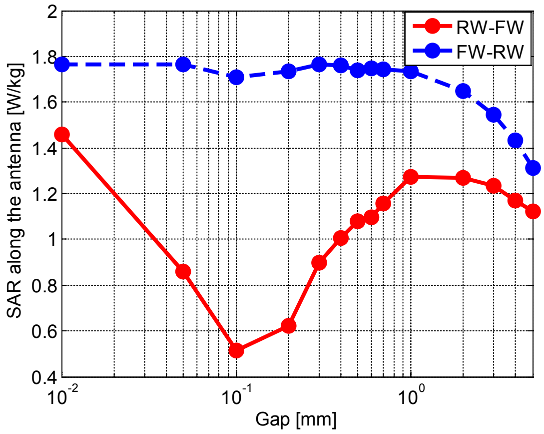

Fig.2: Effect of the gap between chokes on the SAR at some point along the antenna.

However for the RW-FW combination, the impedance seen by the current is directly dependant on the capacitance between the chokes. For an optimal value of the gap the SAR that we want to minimize reaches its minimum. One can also notice that for the same gap value, the max(SAR) is reaching its maximum value, which is exactly our desired goal (Fig. 3).

For the optimal value of the gap, where the SAR is lowest, the SAR at 30 mm along the antenna with the RW-FW combination is about 71% lower than with the FW-RW combination. On the other hand, for the same optimal gap size the max(SAR) is about 10% higher for the RW-FW combination.

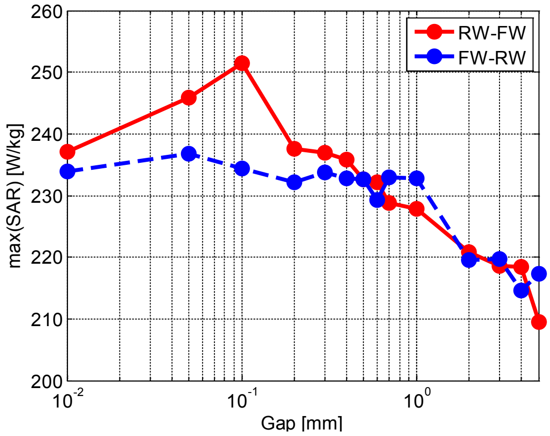

Fig.3: Effect of the gap between chokes on the max(SAR).

The higher performance of the RW-FW combination is also confirmed by analyzing the effect of the choke length (Fig. 4 and Fig. 5). The data presented in these plots have been obtained by fixing the gap size and varying the choke length. The optimal length of the choke where the SAR is lowest is about $\lambda_{eff}/4$. λ_{eff} is the wavelength in the tissue. This choke length corresponds to the value that is commonly used in literature [4]. For the combination RW-FW, the optimal value of the choke length leads to an SAR of about 67% lower than with the single choke structures. For the same choke length, the max(SAR) with the RW-FW combination is always higher (about 10%) than with the single chokes and the FW-RW combination.

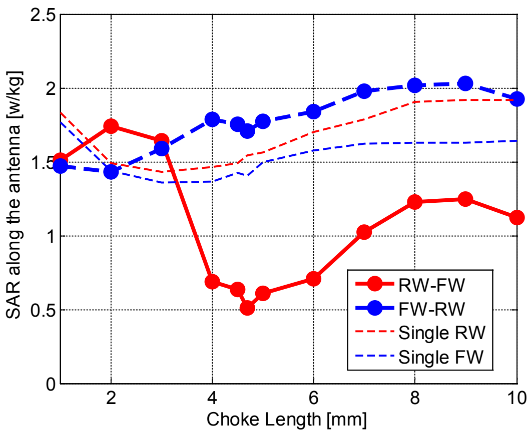

Fig.4: Effect of the choke length on the SAR along the antenna.

Finally, the antenna catheter was covered by periodic choke structure. The SAR along the antenna (at 30 mm) is plotted versus the frequency (Fig. 6) and compared with reference antenna – that has no choke-- and the antenna with a single RW-FW structure. It is shown that the periodicity does not improve the SAR even though it is lower than that of the reference for all frequencies.

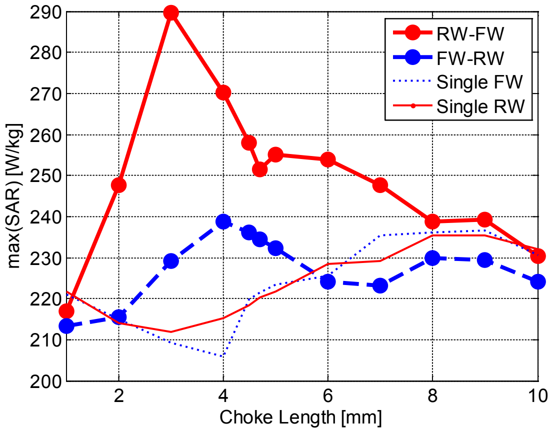

Fig.5: Effect of the choke length on the max(SAR).

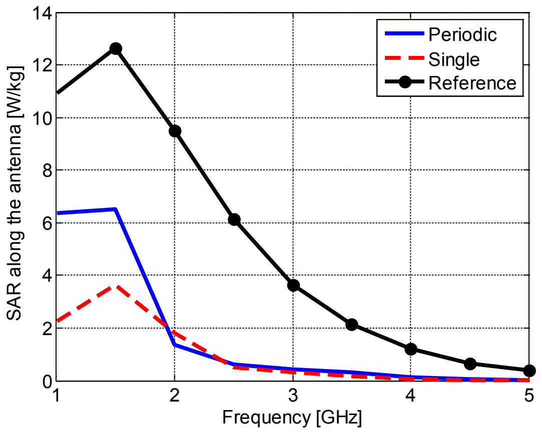

Fig.6: SAR along the antenna vs. Frequency

IV. CONCLUSIONS

Different combinations of two chokes of same lengths have been investigated to reduce the SAR along the antenna and to increase the energy absorption in front of the slot of a coaxial antenna for microwave cancer ablation therapy. Results show that when properly combined (orientation, length and gap size), further improvement can be obtained in term of the performance of the antenna. It has been also showed that the periodicity does not have any effect on the SAR along the antenna. Additional results, especially for the periodic case, will be included in the presentation.

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