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Design of a Bow-Tie Antenna for Hyperthermia Applications

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Abstract

This paper presents a Bow–Tie antenna designed to serve as the basis element in a phased-array hyperthermia applicator. The antenna operates at 900 MHz to achieve deep tissue hyperthermia. The antenna is compact with 36 by 30 mm substrate dimensions. Radiation characteristics are improved by optimizing the shape of the patch element and adding symmetric corrugations to the patch element. Corrugations and shorting pins were used to increase the current path to minimize the antenna dimensions. The radiating element of the antenna is directly in contact with a lossy layered medium which also aids the obtained compact antenna dimensions,

Introduction

Clinical studies show that hyperthermia added to radiation therapy or chemotherapy substantially improves treatment outcome [1–2]. During a hyperthermia treatment, the tumor temperature is elevated to between 40 C and 45 C for 60 min. The temperature rise in the body can be obtained from the dielectric or mechanical losses from applied electromagnetic or ultrasound waves, respectively. Traditionally, for treatment of deep-seated tumors, an applicator holding multiple antenna elements arranged in circular or elliptical array is used. The constructive wave interference to heat the tumor is controlled by changing the amplitudes and phases at the feed points of the antennas.

The vast majority of deep hyperthermia applicators were developed to operate at single frequencies around 100 MHz [3–4]. Unfortunately, the large wavelengths at these frequencies, do not give the centimeter-scale spatial control, needed to compensate for vascular cooling in living tissues and to deal with small anatomical structures. In order to improve the specific absorption rate (SAR) distribution in the treated area, the recent trend in hyperthermia is to utilize applicators holding a number of antennas that operates at higher frequencies. It has been clinically demonstrated that an applicator operating at frequency 900 MHz can adequately heat tumors in the head-and-neck region (H&N) [5]. More recently, a study done by the same group as in [5] showed that increasing the number of antennas from 12 to 20 improves the heat delivery in challenging tumor locations such as the nasal cavity [6]. In order to improve the heat delivery further, the reported studies have introduced the optimal frequency as a treatment planning parameter, which can be specified for each patient and each tumor position. While utilizing higher frequencies is beneficial for treatment of small tumors as it reduces the focal spot size, the low frequencies are preferable in the case of large or deep-seated tumors. A Also, the applicator should consist of 12–20 antenna elements placed in multiple rings.

In this work, we present a novel antenna design to act as an element of such an array. An ideal antenna for this purpose should be directional, with reflection coefficient better than −10 dB. preferably have a symmetrical radiation pattern and be of small size. Most of the antennas such as [7-8] are large in size and bulky. Bow-Tie antenna is known to provide a directional radiation pattern with high $E_{\parallel}/E_{\perp}$ ratio over a good frequency band along with the small dimensions. In this work, we extend the original Bow-Tie design by adding a corrugation on the radiating arms and by shaping the radiating arms of the antenna. The antenna was designed to radiate towards layered breast tissue and was simulated in Computer Simulation Technology (CST) software. A water bolus was also included in the design as a cooling system to prevent the skin from overheating. The remainder of this paper describes the antenna design and simulation results.

Antenna Design

The dimensions of the Bow-Tie antenna were calculated considering an antenna operating air medium. The antenna dimensions are then gradually optimized by adding layered lossy media. To further minimize the antenna, symmetrical corrugations and shorting pins were added to the Bow-Tie design. These two techniques are frequently used to obtain an electrically longer structure. Note that there is a need to increase the number of antennas surrounding the breast tissue to achieve deep tissue heating; therefore, minimization of the antenna is vital. The top-view of the antenna along with the final dimensions are shown in Figure 1.

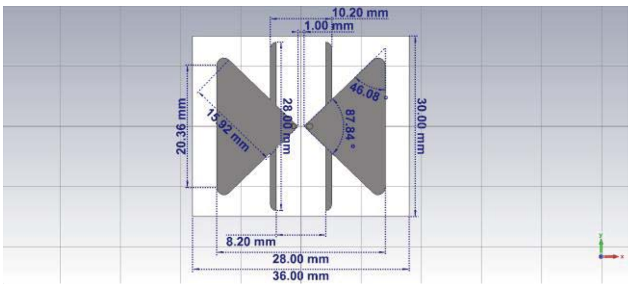

Figure 1. Top-view of the final Bow-Tie antenna optimized to operate while radiating towards lossy tissue.

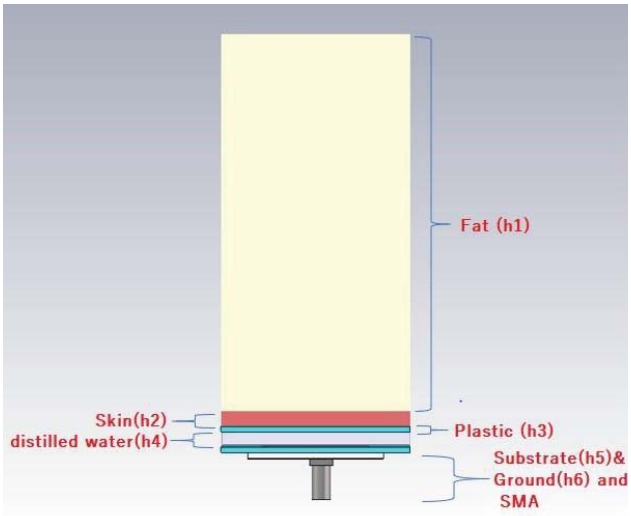

Figure 3. Bow-Tie antenna model radiating towards layered medium with distilled water bolus, skin, and fat.

Table 1. Shows the dielectric properties and the height of each layer in the design.

Layer	Relative Permittivity	Conductivity (s/m)	Thic-kness (mm)
Fat (h1)	5.3	0.10	100.0
Skin (h2)	38	1.4	4.0
Plastic (h3)	2.8	0.01	1.5
Distilled water(h4)	78.4	1	4.0
Substrate (h5)	2.2	1	1.6

For the substrate design RT duroid 5880 has used instead of RF-4 for different reasons such Low electrical signal loss, Lower dielectric loss and Improve impedance control. A total of four pins were used to short the antenna patch elements with the ground plane. This effects the impedance and capacitance of the antenna enabling the low-frequency operation. These design approach enabled a 50% decrease in dimensions. Figure 2 shows the antenna design which include the layered breast mimicking phantom (skin and fat) also the water bolus. Table 1 show the Dielectric properties and the height of each layer in the design. Note that the antenna patch element was immersed inside the water bolus. The antenna was simulated by varying the layered breast phantom dimensions where the antenna was still working under -10 dB for reflection coefficient. The antenna was fed with center feeding SMA where a gap between the SMA and the ground left to prevent and distortion in the radiation signal. For the cooling system we changed the plastic and the water thickness by using sweep parameter in CST and the best results fixed with 1.5 mm thickness of plastic layer and 4.0 mm thickness of the distilled water.

Results and Discussion

The target in this design is to make the antenna work in low frequency (900 MHz) also the dimensions of the antenna should be small enough to meet the application requirements. The most challenging aspect of this antenna design was to match the impedance between the feeding line and the antenna patch element. Figure 3 shows the S-parameter response of the optimized design. Since the antenna is designed to radiate towards a lossy medium the gain was close to 0.26 and the radiation pattern is good enough to be control and guide toward the tumor by changing the phase of the antenna. Figure 4. shows the gain and the radiation of the antenna.

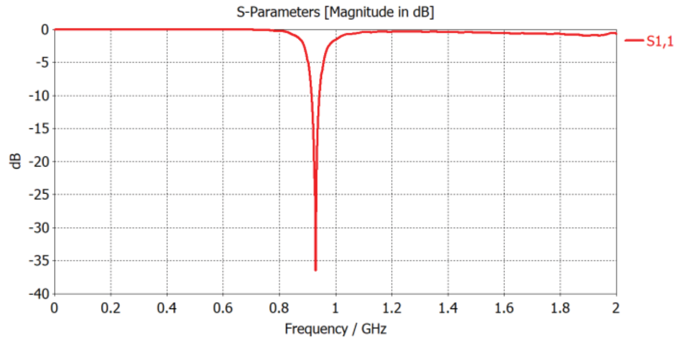

Figure 3. Simulated S-parameters response of the opimized Bow-tie antenna radiating towards the lossy medium.

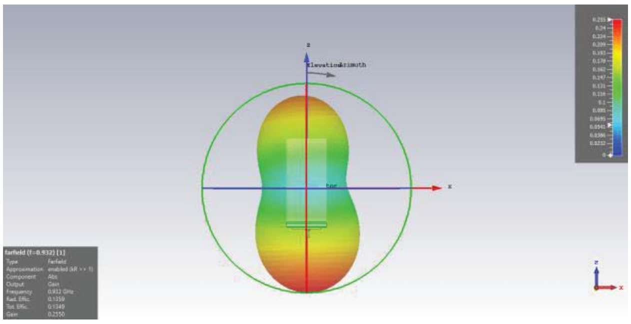

Figure 4. Simulated gain and radiation characteristics of the Bow-Tie antenna.

Conclusions

In this paper, we presented a Bow-Tie antenna design to serve as the basis antenna element in a hyperthermia phased-array applicator. Matching in the desired operation frequency is achieved by appropriately shaping the radiating arms of the antenna and also by including corrugations as well as short pins. These design elements significantly improved the energy delivery in the treated area. The antenna was simulated with a breast phantom with height equal to 104.0 mm and cooling system equal to 7.0 mm. All these results encourage us to take our work to a further step and to improve the bandwidth of the operating frequency. The final design will be fabricated and tested with a layered breast tissue mimicking phantom.

Acknowledgements

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