New Antenna Design for Hyperthermia Treatment of Human Head

Maged Aldhaebei and Ibrahim Elshafiey
Department of Electrical Engineering
King Saud University
Riyadh, Saudi Arabia
431106415@student.ksu.edu.sa and ishafiey@ksu.edu.sa

Abstract—A study is presented to implement new ultra wideband Vivaldi antenna for hyperthermia treatment of human head. The proposed antenna has overall size 82x92x1.6 mm. The new antenna design is compared with original Vivaldi antenna structure, and the results are presented, showing that the new antenna performs better in terms of the return loss parameter, while enhancing the distribution of the specific absorption rate SAR inside the head. The performance of the original and new antenna design is tested corresponding to four background materials: air, oil, water and brain simulating liquid. Results illustrate the potential of this structure for hyperthermia-treatment applicator design.

Keywords—Vivaldi Antenna; Hyperthermia Treatment; UWB Technology; SAR

I. INTRODUCTION

Around 3-5% of cancer patients worldwide have tumors in the head and neck region [1, 2]. Brain cancer is one of the fatal types of cancer. The treatment plans involve surgery, chemotherapy, or radiation therapy, where each technique has its own negative aspects [3].

New techniques based on hyperthermia treatment can reduce the limitations and side effects associated with the currently used treatment modalities. In hyperthermia treatment the heat is applied to small tumor regions to reduce cell vitality by increasing temperature in the range of 40°-45°C [4].

There are three major methods for generation of local hyperthermia: external, luminal and interstitial [5]. Non-invasive hyperthermia using external applications is very attractive to clinical applications. However, technical challenges hinder the progress of hyperthermia and the confinement of thermal energy into tumor locations [6] and [7]. Another challenge of hyperthermia treatment is the difficulty to deliver energy into deep tumors.

Several studies have proposed techniques for non-invasive hyperthermia applicators to heat superficial tumors [8-10]. Heating techniques have been proposed to heat brain tumor [11]. Some examples are radio frequency (RF) capacitive heating applicators, annular phased applicators and coaxial transverse electromagnetic (TEM) applicators. Some of these methods have been in practical use. However, efficient heating localization has not yet been realized [12].

A promising solution to handle these problems is the use of ultra-wideband UWB systems. With extended-bandwidth, enhancement in localization of energy in deep tumor can be achieved. Low frequency ranges can be utilized for penetration of energy to deep tumor location and higher frequencies are utilized for confinement of energy with high precision [13].

Moreover, low profile antennas in the lower microwave range have received much attention in the recent years for medical applications. In order to improve the heat delivery to the tumor, a flexible tumor-specific applicators have been proposed [14, 15]. The goal is to develop an external applicator that is capable of modifying the focus size depending of the tumor position and volume. The importance of the foci-spot size adjustments comes from the ability to restrain hot spots near the tumor, which are difficult to suppress. An adaptation of the heating pattern can be realized by varying the operating frequency of the antennas [16].

This research seeks to implement new UWB Vivaldi antenna for use as an external applicator for hyperthermia treatment of brain tumors. The design depends on original structure presented in [17]. The return loss of the original and new antenna applicators corresponding to four background is presented. SAR distribution is investigated, corresponding to the two antenna with human head computation phantom. The advantages shown of the developed antenna include wide bandwidth, symmetrical beam widths, high directivity, low profile and ease of fabrication.

II. ANTENNA DESIGN

The antipodal configuration presented in [17] is created on a dielectric substrate with two-sided metallization. This structure has been proposed for medical imaging system in [18]. The overall size of the antenna is of 82x94x1.6 mm, and the substrate has dielectric permittivity 4.3. Fig. 1 shows illustration of the original antenna.

In the new design three disks are removed from the ground planes and the stripline as shown in Fig. 2. The radii of those three disks are 8 mm, 4 mm, and 2 mm, respectively. Initial design that depended on equal radii did not show improvements in performance. The current design implemented a ratio of two of disk diameters of adjacent disks. The disks are aligned in the ground planes and the stripline. Shift of the disk axes between ground and stripline planes showed deterioration in performance.

The overall size of the antenna is reduced to 82x92x1.6 mm, and the new structure showed enhancement in the performance of the antenna.

III. ANTENNA SIMULATION RESULTS

External heating of deep tumors in human head can be achieved by operating in the lower frequency ranges.
Extending the operation frequency to low frequency values, while keeping the antenna size reasonably small can be achieved by controlling the background medium. Four background materials are investigated including: air, oil, water and brain simulating liquid, with permittivity values of 1, 2.5, 78.4 and 40, respectively. Simulations are performed under CST microwave studio simulator [19].

Fig. 1. Structure of the designed original Vivaldi antenna. Dimensions are in mm.

Fig. 2. Structure of the designed proposed antenna. Dimensions are in mm.

The original and new Vivaldi antenna return-loss are estimated for different background materials. The results of S11 for air and oil background of the original Vivaldi are shown in Fig. 3., whereas the S11 of the water and brain simulating liquid are shown in Fig.4. S11 of the new structure, corresponding to air and oil backgrounds are shown in Fig. 5. Results corresponding to water and brain simulating liquid backgrounds are show in Fig. 6. The results reveal that the brain simulating liquid background provides superior results, and thus it was chosen for the simulation of the antenna with the human head phantom shown next.

Fig. 3. S11 parameter for the original antenna, in air and oil background.

Fig. 4. S11 parameter for the original antenna, in water and brain simulating liquid background.

Fig. 5. S11 parameter for the proposed antenna structure, in air and oil background.
IV. ANTENNA APPLICATOR WITH HUMAN HEAD PHANTOM

The SAM head phantom is used to evaluate the performance of the two applicator antennas. The head phantom shown in Fig. 7 is represented by two-layered average human head model. The brain is enclosed by a skull of relative permittivity of 3.7 and electrical conductivity of 0.0059 S/m. The brain model has relative permittivity of 38.836, electrical conductivity of 0.595 S/m and mass density of 1043 kg/m$^3$. These values are close to the brain white matter [20].

The tumor model is represented by a sphere at a distance of 75 mm from the outer boundary of the phantom. The tumor has radius of 10 mm, with properties of relative permittivity of 63.259 and conductivity of 1.21 S/m. In all simulations, the distance between head phantom and antenna is kept at 1 mm and background material is set to fluid with relative permittivity of 40.

The return loss of the two applicators with and without SAM head phantom is shown in Fig. 8 and Fig. 9, respectively.

The directivity of the antenna describes the radiation pattern. The antenna can radiate better in some directions than others. Fig. 10 to Fig. 13 show the directivity of the original and new antenna at two frequencies 433MHz and 1372 MHz.
The results show that the original antenna is better in performance in the low frequencies only and the new antenna is working in both higher and lower frequencies. This is suitable for hyperthermia treatment. SAR control is highly frequency dependent and requires sufficient resolution (high frequency) but also sufficient penetration of the EM waves (low frequency). Moreover, the two antenna models are suggested for use using phased-array techniques, to provide operation in low and high frequency ranges, simultaneously.

The penetration of energy inside SAM head phantom utilizing software CST of original and new antenna for 433 MHz and 1372 MHz are shown in shown in Fig. 14 and Fig.15, respectively.

![Fig. 11. The farfield directivity absolute at frequency=433 MHz of the original antenna.](image1)

![Fig. 12. The farfield directivity absolute at frequency=1372 MHz of the original antenna.](image2)

![Fig. 13. The farfield directivity absolute at frequency=433 MHz of the proposed antenna.](image3)

Fig. 14. The farfield directivity absolute at frequency of 1372 MHz of the proposed antenna.

Fig. 15. SAR distribution inside SAM head phantom at frequency 433 MHz using original antenna.

Fig. 16. SAR distribution inside SAM head phantom at frequency of 866 MHz using original antenna.

Fig. 17. SAR distribution inside SAM head phantom at frequency of 433 MHz using proposed antenna.
In this paper, a design of new UWB antipodal Vivaldi antenna is developed to achieve enhanced performance for hyperthermia treatment. The structure depends on removing three disks in the ground and stripline of the original antenna. The antenna size is reduced compared to the original antenna, and the bandwidth is enhanced. The design is suggested for use with the original antenna model using phased-array techniques, to provide operation in the low frequency ranges to achieve large penetration in the tissue, and at high frequency ranges to achieve more energy localization into tumor position. Results reveal the performance of the antenna is suitable to enhance the hyperthermia treatment by improving the localization of the specific absorption rate at the tumor location.

ACKNOWLEDGMENT

This research work is supported by the National Plan for Science and Technology (NPST), Kingdom of Saudi Arabia, under project number: 10-ELE996-02.

REFERENCES