Orthogonally Rotated Radiating Array for Improving Heating Uniformity in Hyperthermia System

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***Abstract*—An orthogonally rotated radiating array applicator is proposed to enhance the therapeutic suitability of superficial hyperthermia treatment system. The proposed applicator provides an optimal heating effect to widely distributed tumors by configuring the orthogonal arrangement of radiating elements. Each element causes a destructive interference of electromagnetic field at the center of the array applicator, so as to prevent an overheating at the central region. The electric field and the specific absorption rate (SAR) are evenly formed with a circular-shaped distribution, which allows for the uniform heat deposition on the therapeutic area. The achieved ETA ratio is 152.6 %, corresponding to 44 % increase, as compared with the single element operation. The proposed hyperthermia applicator not only leads to a wide therapeutic coverage by the orthogonally rotated array configuration, but it also satisfies the thermal requirement for tumor necrosis.**

Keywords—Microwave Antenna Array, Tumor Treatment, Superficial Hyperthermia, Heating Uniformity.

I. Introduction

A hyperthermia takes advantage of the thermal interaction with malignant tumors, which leads to a cell-destruction and necrosis of tumors exposed to temperatures higher than 43 °C. By applying heat to the tumor cells alone, a hyperthermia system provides not only a comfortable treatment environment without surgical incisions or damages to normal tissues [1]-[2], but also a synergistic method used with radiation oncology or chemotherapy [3]-[4]. To improve the therapeutic effect of superficial hyperthermia system, a heat must be evenly formed on the therapeutic area, and the system prevents an overheating in a specific point. As well as, the hyperthermia applicator should provide a high-SAR into a treatment area. As for the previous work [5], we studied about the array applicator for improving the effective treatment area in a hyperthermia system. However, the applicator mentioned in [5] has low-SAR, which degrades the treatment effect. In this paper, a radiating array applicator is proposed for improving the heating uniformity in superficial hyperthermia system. And the design of the radiating element is also proposed for the enhancement of the SAR performance. By applying the orthogonally rotated feeding configuration to the radiating array, the proposed applicator lead to a suitable EM field distribution at the desired therapeutic target. The heating performance is verified by the definition of ETA for the reasonable comparison of treatment area [6].

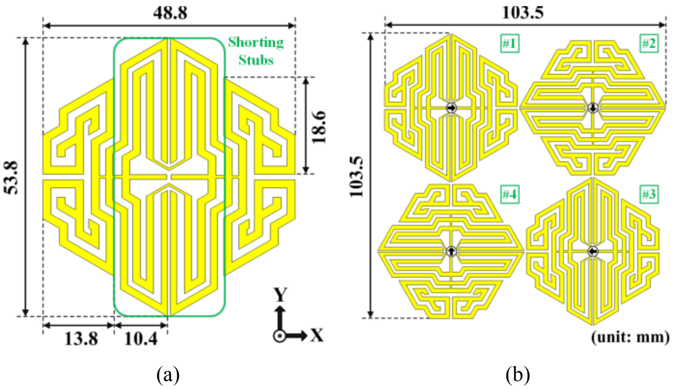

Fig. 1. Geometry of the proposed hyperthermia applicator; (a) Radiating element and (b) Orthogonally rotated radiating array.

II. Design of Proposed Hyperthermia Applicator

A hyperthermia applicator should be compactly designed to be suitable for use as a human treatment. As well as, the electromagnetic (EM) energy should be well transmitted into the human body. For supporting EM energy transmission, the proposed applicator is verified by the previous experimental setup and evaluation procedures [6]. The experiment composed of the radiating applicator, the water-bolus, and the phantom as a model for the human body.

A. Design of the Radiating Element

The geometry of the proposed radiating element, based on modified dipole design, is shown in Fig. 1(a). The proposed element is composed of the multi-branched strips and shorting stubs at the center of the element geometry. The symmetrical design of the radiating element provides the uniformity of electric field formed in human body, which can improve the heating uniformity in experiments for the array applicators. The multi-strip lines support the intensive current distributions by configuring with the strip lines in which an electric field are intensively distributed on the center of the radiating element, so as to generate high SAR at the center of the therapeutic area. As for the hyperthermia treatments, the high-SAR can improve the therapeutic effectiveness according to the bio-heat equation [1]. The shorting stubs allow for the impedance matching at 433 MHz. The radiating element is printed on FR-4 substrate (ε_r = 4.3 and tanδ = 0.025) with a 1-mm thickness.

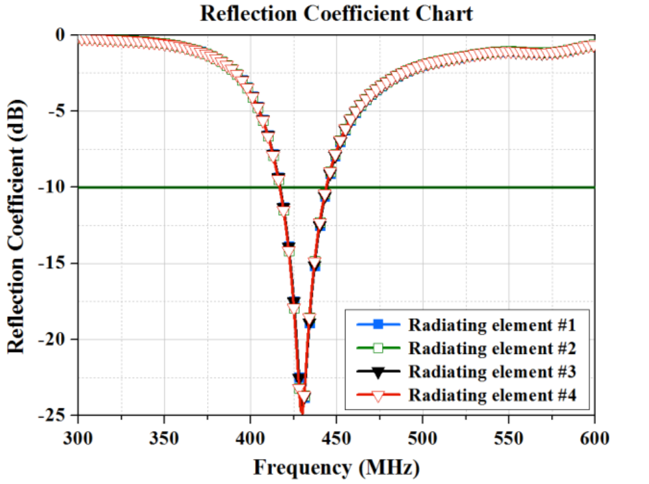

Fig. 2. Reflection coefficient chart of the proposed applicator.

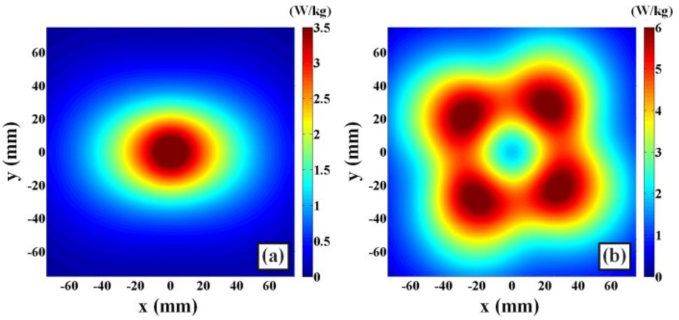

Fig. 2. 1g-averaged SAR (SAR_{1g}) distribution of proposed applicator; (a) Single radiating element and (b) Orthogonally rotated radiating array.

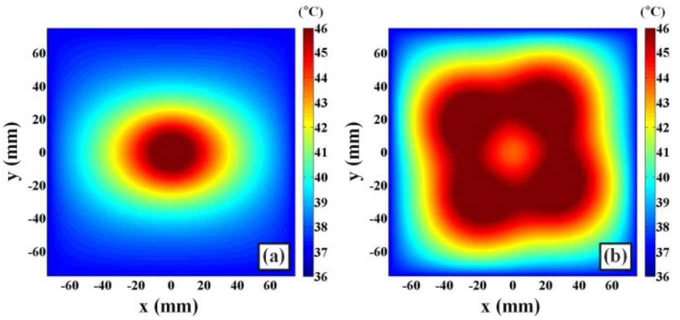

Fig. 3. Temperature distribution of proposed applicator; (a) Single radiating element and (b) Orthogonally rotated radiating array.

B. Orthogonal Arrangement of Radiating Elements

The configuration of 2×2 array applicator is presented in Fig. 1(b). Each element is arranged by a sequentially rotated direction and the simultaneous input signals are applied to all elements. The orthogonally rotated arrangement leads to the destructive interference by creating 180° phase differences between two co-polarized groups of 1st, 3rd and 2nd, 4th elements. Whereas, the co-polarized arrangement for all elements induces the constructive interference, which causes over-heat at the center. And also, it can degrade the uniformity of heating effect. The destructive interference of proposed applicator assists in broadening the heating area and preventing the overheating at the center of the array. The reflection coefficients of elements are also profited by configuring with the perpendicular polarization between adjacent elements.

III. Result and Discussion

As shown in Fig. 2 and 3(a), the proposed radiating element exhibited stable performance at 433 MHz with low reflection coefficient and SAR_{1g} of 3.83 W/kg. The multi-strips of the proposed radiating element lead to the intensive electric field at the center of the element, so as to generate high SAR at the center. The configuration of the orthogonally rotated array causes the broadening of EM energy absorption of Fig. 2(b). The peak SAR_{1g} of 6.25 W/kg occurs at each center of elements, while the destructive interference occurs at the center of the array. The heating effect is analyzed by the bio-heat equation, which includes the temperature increase by the SAR, blood circulation, and heat conductivity [1]. For reasonable comparison of the ETA, the excitation powers are applied differently to the experiments for Fig. 4(a) and 4(b) in order to equalize the maximum temperature rise. The RF signals are applied to the radiating elements with the powers of 37 dBm for single element in Fig. 1(a) and 34.8 dBm for rotating array elements in Fig. 1(b). The heating effect of Fig. 4(b) spreads by the heat diffusion of the blood circulation effect, whereas the single element generates the heat of Fig. 4(a) at the center. The ETA is regarded as an area that is heated to more than 7 °C above the human body heat within one hour of heating, and the ETA ratio is the size ratio between the ETA and the aperture size of the applicator. The ETA is determined on condition that the maximum temperature is equalized to 10 °C. The ETAs of 1433 mm^2 and 8175 mm^2 and the ETA ratios of 108.6 % and 152.6 % are achieved in experiments for single element and rotating array, respectively. By configuring the proposed orthogonal rotated array, the heating effect allows for the thermal requirement to a wide area, corresponding to 44 % increase in comparison to the single element operation.

IV. Conclusion

A microwave radiating array applicator is proposed for the treatment of superficial tumors. This applicator not only induces the high specific absorption rate (SAR) into the human phantom for effective treatment in hyperthermia system, but it also provides the uniform heating effect to a wide treatment area by configuring the orthogonally rotated arrangement of radiating elements. The proposed radiating array applicator allows for the high heating uniformity, which corresponds to

44 % increase as compared with the ETA ratio of the single radiating applicator. As well as, it is possible to prevent the overheating by the sequentially rotated fed design, so as to cause the destructive interference at the center of the array applicator. The proposed applicator which is composed of the microwave radiating element and the orthogonally rotated array configuration can be expected to provide the uniform heating effect to tumors formed over a wide area, and can be suitable for use as a treatment for skin tumors in superficial hyperthermia system.

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