Metamaterial-Applicators for Microwave Hyperthermia Treatments

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Index Terms—MTM, Zeroth-Order Mode Resonator, Applicator Array

I. INTRODUCTION

This paper characterizes three novel microwave applicators based on zero-order mode resonators for use in hyperthermia treatment of cancer. The radiation patterns are studied with numerical simulations in muscle tissue-equivalent model at 434 MHz. The relative performance of the applicators is compared in terms of reflection coefficient, current distribution, power deposition (SAR) pattern, effective field size in 2D and 3D tissue volumes, and penetration depth [1]. One particular configuration generated the most uniform SAR pattern, with 25% SAR covering 84 % of the treatment volume extending to 1 cm depth under the aperture, while remaining above 58% coverage as deep as 3 cm under the aperture. Recommendations are made to further optimize this structure.

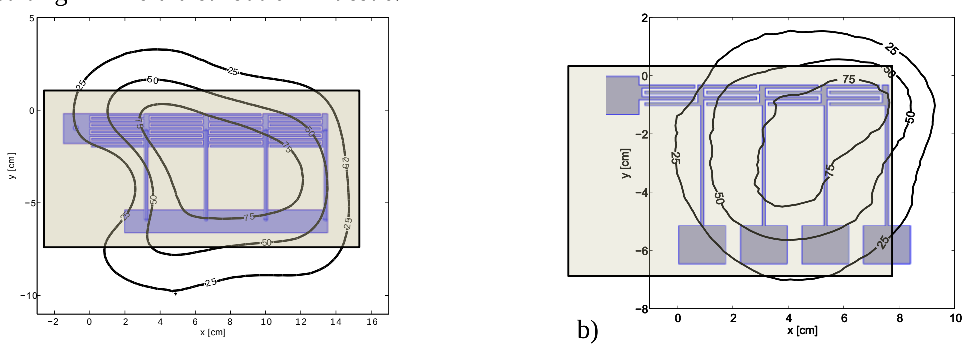
Recent advances in metamaterial (MTM) Zeroth-Order mode resonators (ZOR) have shown potential to improve the homogeneity of electromagnetic (EM) power deposition and the depth of EM wave penetration in human tissues [2]. In addition, this MTM-ZOR technology allows the development of electrically small applicators, which can work without filling the inner structure with high dielectric material (usually water), as required by traditional waveguide structures. The absence of water facilitates compatibility with magnetic resonance equipment, which is desirable for use as a 3D thermometry system to monitor and control hyperthermia treatments.

II. METHODS

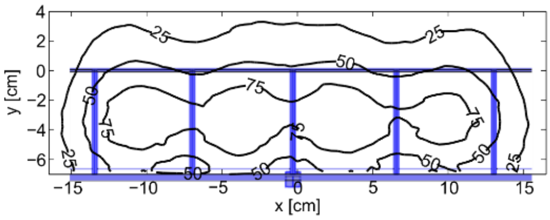
MTM ZOR applicators are introduced and relevant properties of the applicator itself as well as several array arrangements of the ZOR antenna for hyperthermia cancer treatment are investigated by means of numerical simulations. The simulations were performed using a multiphysics simulation software COMSOL Multiphysics. Relative performance of the array applicators is compared with respect to the homogeneity of power deposition induced in numerical muscle tissue-equivalent phantoms.

III. SIMULATIONS

Three novel MTM applicators were designed for hyperthermia treatments at 434 MHz based on similar ZOR working principles. By exciting the zero-order mode, current density vectors are generated in the tissue facing inductive components of the applicators with approximately the same magnitude and phase. The radiated contributions from all inductive parts of the applicator are constructively added as they exit the front aperture of the applicator and combine in phase in tissue. This allows the Huygens principle to be applied to describe the resulting EM field distribution in tissue.



a) b)



c)

Fig.1. applicator design and power deposition pattern in 1 cm deep in muscle model using applicator 1, 2 and 3 respectively. The first proposed applicator a) is based on micro-coplanar technology. The second proposed applicator b) is based on microstrip technology. This design allows the development of very thin and low profile applicators, which are more convenient for some clinical sites. The third analyzed applicator c) was already proposed in [3], where its radiation patterns were only briefly characterized.

IV. CONCLUSION

This investigation demonstrates that two applicators have relatively slow change of EFS at different depths in tissue and thus appear suitable for well controlled deep heating of tissue under the MTM applicators. The ultimate choice for the applicators use in microwave hyperthermia will integrate easy of design and penetration depth, where some applicators might be more suitable for deep targets (applicator 1 and 3) and others for superficial targets (applicator 2), such as chest wall breast cancer recurrence. Thanks to a MTM phenomenon where the resonator can be smaller than multiples of a half-wavelength, the regional system can consist from more applicators than the already known systems. The next step towards practical use of these structures is to create antenna array configurations that allow heating large areas, such as chest wall recurrence of breast cancer, or alternatively to improve focused heating of deep targets like pancreas or bladder.

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