Novel Microwave Applicators Inspired by Metamaterials for Hyperthermia Treatment of Cancer

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Abstract— In this paper, novel microwave applicator prototype based on zero-order mode resonator is proposed for use in hyperthermia treatment of cancer. The ability of applicator to homogenously irradiate muscle tissue-equivalent phantoms is demonstrated with results of numerical simulations and relative performance of the applicators is compared.

1. INTRODUCTION

Based on previous research [1], it can be stated that metamaterial (MTM) Zeroth-Order mode resonators (ZOR) can provide improved thermotherapy for cancer in several ways, by improving the homogeneity of electromagnetic (EM) power absorption, the depth of EM wave penetration, and offering the possibility of either homogeneous treatment of very large areas or conversely focusing EM power into well-defined small areas [2]. New capabilities include, among others, the creation of electrically small applicators that can work without water filling. This could facilitate the delivery of microwave hyperthermia treatment simultaneous with 3D monitoring of temperature distribution in the patient with Magnetic Resonance (MR) thermal imaging. Another advantage of MTM technology is that this phenomenon enables the creation of a special kind of resonator whose physical length is completely independent of the classical resonance condition (wavelength). This allows us to design the applicator with dimensions matching the clinical need and as a result of the spatial arrangement of MTM resonators we are able to radiate an almost perfect electromagnetic plane wave into the treated area. This improvement in wave propagation produces the advantage of optimizing homogeneity of power deposition within the target tissue region resulting in an improved temperature distribution throughout the treated area.

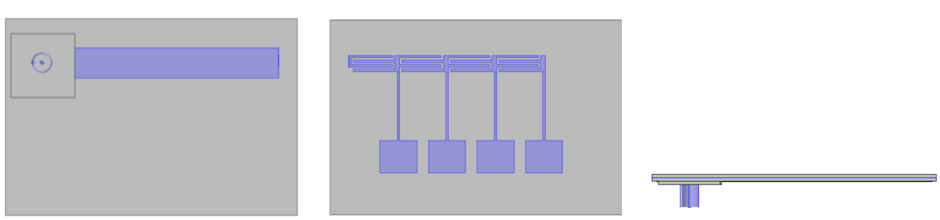
The applicator is designed for use at 434 MHz. Thanks to the excitation of zero-order mode, vectors of surface current density in all inductive parts of the proposed applicators show approximately the same magnitude and phase. The radiated contributions from the all inductive parts of the applicator are in good superposition 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.

2. APPLICATOR DESIGN

Applicator design 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 antenna structure consists of 4 inductive strip radiators ($L_{ind} = 41$ mm) that extend from the four finger interdigital capacitors ($L_f = 18$ mm) to the grounded capacitive plates with dimensions of $16 \times 13\,\mathrm{mm}^2$. The separation of radiators corresponds to the length of the unit cell and is $L = 22$ mm. The input impedance of this structure at the operating frequency 434 MHz is approximately 5 Ω.

3. APPLICATOR EVALUATION

In the numerical simulation, applicator radiates into the homogeneous muscle tissue-equivalent model through a layer of deionized water of 1 cm thickness representing a water bolus. Figure 2(b)



(a) (b) (c)

Figure 1: (a) Feeding part of the applicator, (b) applicator aperture facing the patient, (c) applicator profile.

shows the COMSOL Multiphysics simulated power deposition distributions induced in muscle 1 cm under the tissue surface. Plotted contours circumscribe the regions of 75, 50 and 25 percent of maximum absorbed power in tissue at that depth.

The applicators are also characterized in terms of temperature distributions induced in a homogeneous muscle tissue load, using 2D cross section metrics. Effective heating is considered to be tissue temperatures above 41°C with a maximum tissue temperature of 45°C. 2D temperature distributions are evaluated in 3 planes from the 1–3 cm depth, and are quantified as Effective Thermal Area above 41°C (ETA_{41}), here defined as the ratio of area enclosed by the 41°C contour in a given plane divided by the footprint area of the radiating aperture.

For best special arrangements we take into consideration several applicator settings. The initial design is in the Figure 5(a) where the radiating structure and impedance transformer are in the same plane. The applicator impedance is about 5 ohms the impedance transformer is needed to match the connector to antenna. Since such an arrangement is not practical for clinical needs the

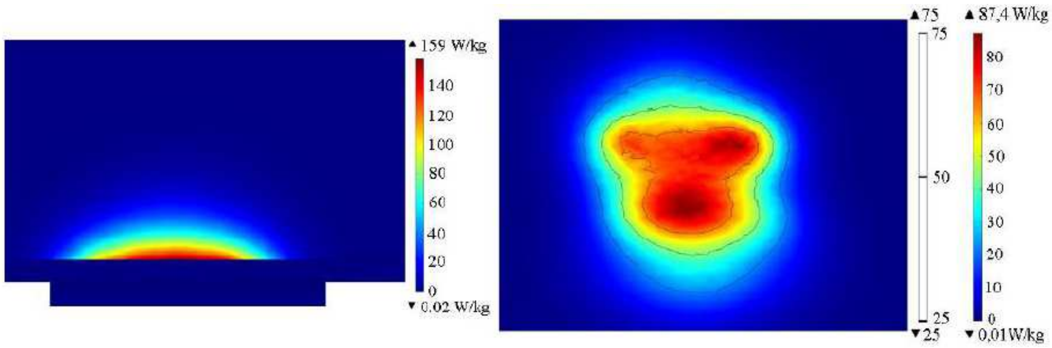


Figure 2: Power deposition pattern perpendicular to applicator aperture and in 1 cm deep in muscle model, respectively.

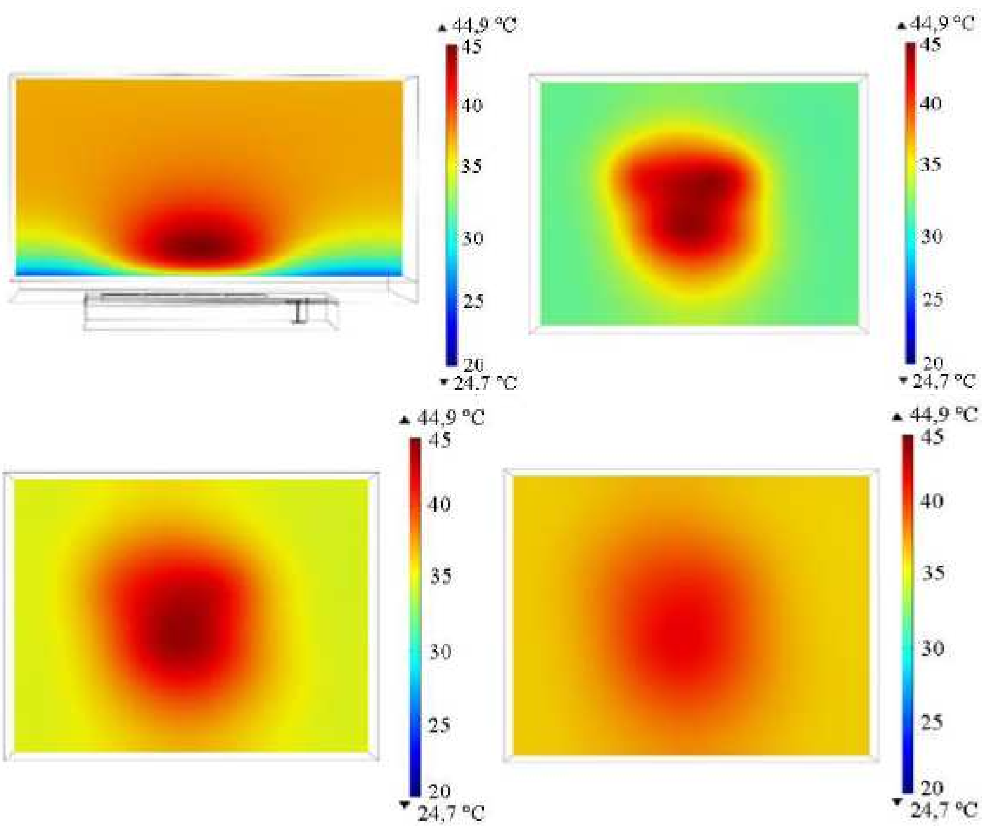


Figure 3: Temperature distribution perpendicular to applicator aperture and in 1, 2 and 3 cm deep in muscle model, respectively.

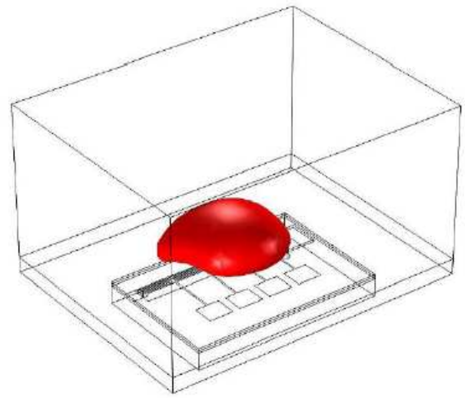


Figure 4: Spatial arrangement of temperature above 41°C in the muscle equivalent phantom model.

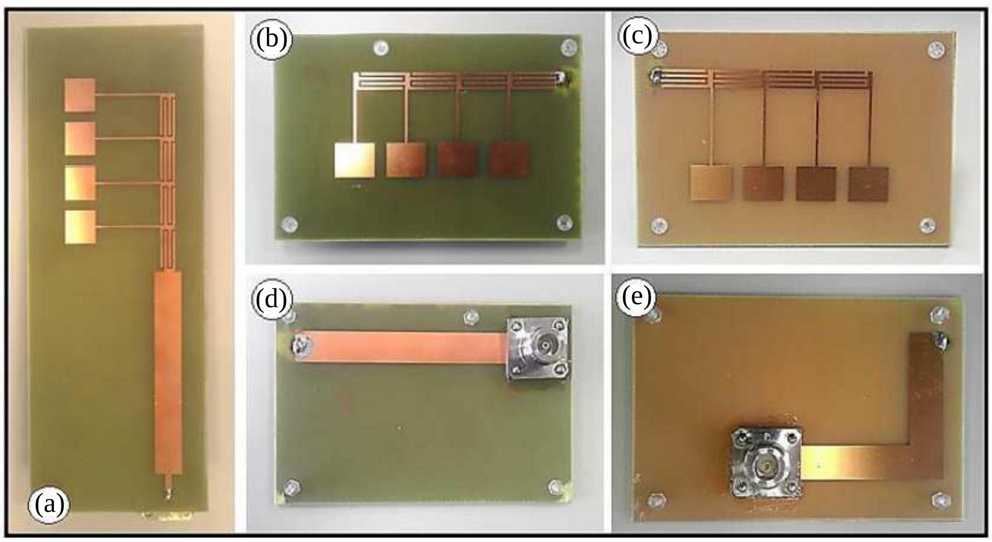


Figure 5: 3 types of applicators on (a) one single substrate and double layered substrates. In (c) and (e) is the impedance matching and on (b) and (d) there is an aperture facing the area to be treated.

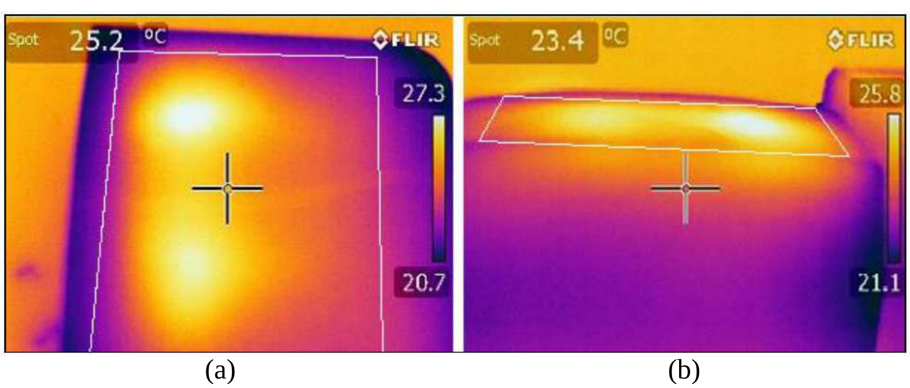


Figure 6: (a) Surface heating and (b) deep heating. Applicator aperture is highlighted by white lines.

applicator was redesigned on double layered substrate.

4. APPLICATOR CHARACTERISTICS VERIFICATION

For verification of radiation characteristic the heating of agar phantom was done. The applicator was excited by 100 W for 60 second.

5. CONCLUSIONS

New MTM structures with capability of creating plane wave to be radiated into the biological tissue were introduced in this paper. It has been demonstrated here that EM wave penetrating into the biological tissue had very good SAR homogeneity and depth of penetration approaching theoretical limit. Our future plans will be to do an experiment with the matrix of this structure and verify the promising simulation results experimentally of larger area.

ACKNOWLEDGMENT

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