Zeroth-order Mode Resonator Metamaterial Applicators for Superficial and Deep Local Microwave Hyperthermia

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Abstract— Paper deals with our new results in the field of applicators used for microwave regional thermotherapy, like, e.g., cancer treatment, physiotherapy, etc.. New type of applicator based on Metamaterial technology especially with zeroth order resonances will be introduced. The main aim of this work is to verify whether EM wave penetrating into the biological tissue can have good SAR homogeneity and depth of penetration approaching to theoretical limit.

1. INTRODUCTION

Aim of this paper is to verify whether a metamaterial structure can be used as applicator for hyperthermia treatment. For this experiment antenna is adapted from [1] with respect to required quality. Applicators for hyperthermia treatment have to be design in such a way they produce suitable shape of radiated electromagnetic wave. For local and deep local treatment electromagnetic plane wave can would by suitable because it ensures:

- the best penetrating depth,
- the best homogeneity of SAR.

2. DESIGN OF THE APPLICATOR

The applicator is proposed (shown in Fig. 1) is based on microstrip technology which allows very thin and low profile applicator construction. The input impedance of this structure at the operating frequency is approx. 5 ohms [2, 3]. To improve applicator reflection coefficient, a $\lambda/4$ impedance transformer is used. The length of the impedance transformer is 107 mm. The impedance transformer increases the applicator overall dimensions from 80 mm (without the impedance transformer) to 187 mm (the impedance transformer included). The longitudinal dimension of the applicator can be decreased by using a double layered dielectric substrate with the impedance transformer on the other side. The inductive microstrips are grounded by capacitors. The interdigital capacitor for this design consists of four fingers. The length of each finger is $L_f = 18$ mm, length of the inductive part is $L_{ind} = 41$ mm, length of the unit cell $L = 22$ mm, and dimensions of grounded capacitor are $16 \times 13\,\text{mm}^2$.

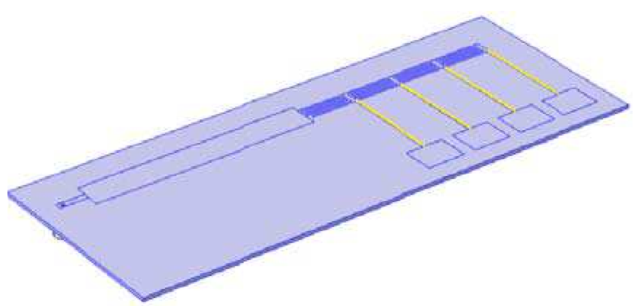

Figure 1: Aperture view of Applicator 2 based on microstrip technology. Applicator dimensions are $187 \times 56\,\text{mm}^2$ for a substrate thickness of 1.5 mm.

Table 2 lists the effective field size (EFS) for three different depths in muscle tissue-equivalent phantom. EFS (Active Element) is defined as irradiated area/active element area and EFS (Applicator) irradiated area/ground plane area. EFS is numerically estimated for three different levels of SAR, namely 25%, 50% and 75%. All SAR levels are normalized to the maximum SAR in the 1 cm deep plane.

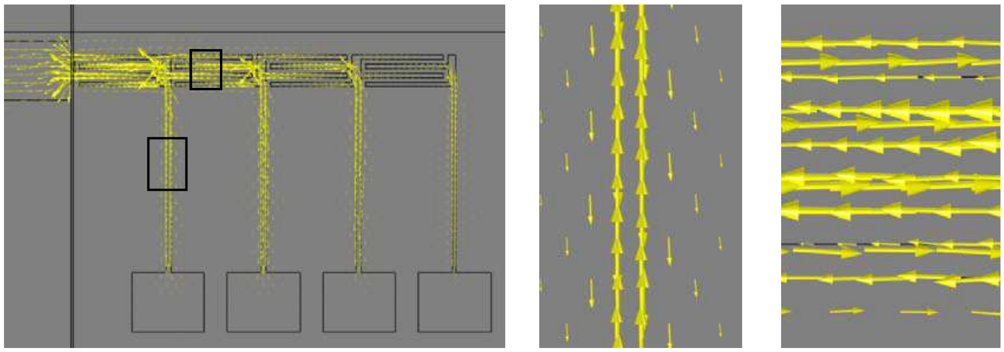

Figure 2: (a) Surface current density (at some time instant) represented by yellow arrows on the surface of metallic parts of Applicator. (b) Currents flowing from bottom to top are on the antenna structure whereas currents with the opposite orientation are currents on the ground plane underlying the 1.5 mm thick substrate. (c) Detail of one interdigital capacitor where currents flowing from right to left are currents on the interdigital capacitors and the current flowing from left to right are the currents on the ground plane.

Table 1: Dielectric properties (@434 MHz) of materials considered in numerical models.

Material	FR4 [5]	De-ionized water (20°C) [6]	Muscle tissue [4]
Relative permittivity ε_r [-]	4.2	80.1	57
Equivalent conductivity σ_e [S/m]	0.0016	0.047	0.81

Table 2: Dependence of effective field surface and depth.

Penetration depth in muscle tissue (cm)	Level of SAR (%)	Irradiated area $\geq$ SAR% (cm^2)	EFS (Radiating element) (%)	EFS (Applicator) (%)
1	75	16	33	24
	50	37	77	55
	25	64	133	95
2	50	1	2	1
	25	31	64	46
3	25	3	6	4

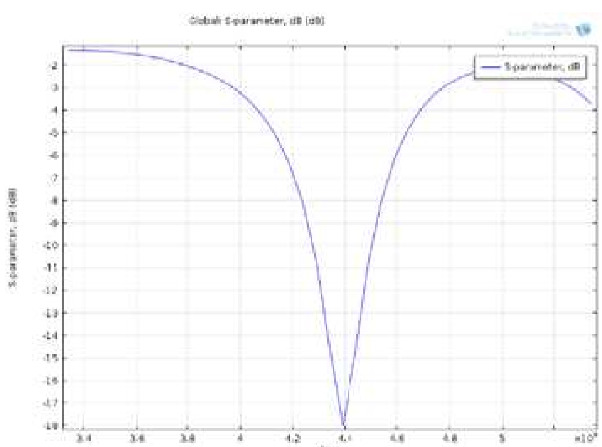

Figure 3: Reflection coefficient of Applicator which is matched by the impedance transformer.

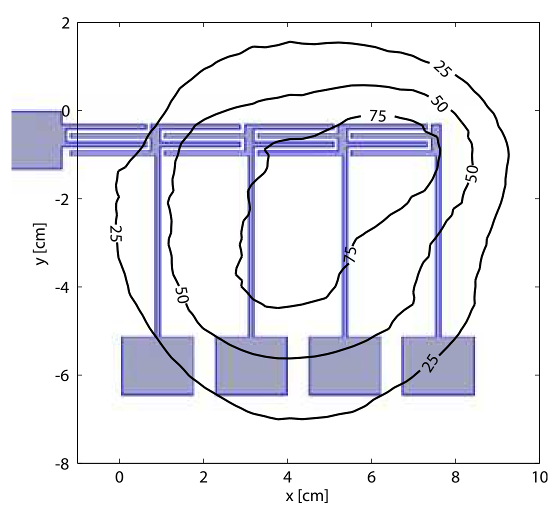

Figure 4: Power deposition pattern 1 cm deep in muscle phantom from Applicator 2 prototype.

3. 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 this structure and verify the promising simulation results experimentally.

ACKNOWLEDGMENT

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