A Compact Microwave Patch Applicator for Hyperthermia Treatment of Cancer

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***Abstract*— Design and development of a compact microstrip C-type patch applicator for hyperthermia treatment of cancer is presented. The patch antenna is optimized for resonance at 434 MHz, return loss (S_{11}) better than -15dB and co-polarized electric field in tissue. Effect of water bolus thickness on power delivery is studied for improved power coupling. Numerical simulations for antenna design optimization carried out using EM simulation software, Ansys HFSS®, USA were experimentally verified. The effective field coverage for the optimized patch antenna and experimental results indicate that the compact antenna resonates at ISM frequency 434 MHz with better than -15 dB power coupling.**

I. Introduction

Hyperthermia treatment of cancer involves selective elevation of tumour temperature to 39-45^{0}C to induce cell kill and other beneficial reversible cell damages that sensitize radiation and chemo therapy. As device physical size and power deposition at a given depth decreases with increasing frequency, electromagnetic heating devices operating from 8 till 915 MHz have been proposed for hyperthermia treatment of cancer [3-5]. In this work we present a compact patch antenna at 434 MHz for treating disease extending 3-4 cm from skin. The proposed antenna is relatively smaller than the dielectric loaded horn, CFMA and patch antennas proposed for hyperthermia treatment of cancer at 434 MHz [6-8]. Numerical simulations were carried out to simulate near field interaction between patch antenna and biological tissue, since the analytical equations hold good only for free space radiation. Section II presents the 3D numerical model of the hyperthermia applicator, C-type patch antenna design and optimization. Section III presents the simulation and experimental results. Section IV concludes this work.

II. Methodology

A. 3D Numerical Model

The numerical model consists of a C-type metal patch on a dielectric substrate of height, h and permittivity, ε_s fed by a coaxial probe with feed position (x_f , y_f) defined with respect to patch corner and irradiating a 10 cm thick planar muscle tissue through deionized coupling water bolus. The patch is located in a cylindrical metal cavity to minimize its sensitivity to variation in tissue load and surrounding environment.

B. Patch antenna design

Fig. 1 illustrates the side view of the patch applicator developed for hyperthermia treatment at 434 MHz. A low loss high permittivity substrate was chosen for antenna size reduction at 434 MHz. Reactive loading of the patch using shorting pin further reduced the applicator size. The dimensions of the C-type patch, substrate (h), superstrate (h_1) and feed position (x_f , y_f) were optimized for ε_s =78 and resonance at 434 MHz. The 3D model of the applicator with C-type patch was designed using EM simulation software, HFSS® (Ansys, USA). Table 1 lists the electrical properties used in the numerical simulations. HFSS® solves Maxwell's time harmonic vector wave equation with source $\nabla \times \mu^{-1} \nabla \times \vec{E}(r) - \omega^2 \varepsilon \vec{E}(r) = i\omega \vec{J}(r) - \nabla \times \mu^{-1} \vec{M}(r)$ where $\vec{E}$ is the Electric field Vector, ε and μ is the permittivity and permeability of the substrate, $\vec{M}$ is the magnetic current density and $\vec{J}$ is the current impressed on the probe fed patch in the 3D computational domain with perfectly matched layer boundary condition and TEM wave excitation at the coaxial feed. The time harmonic vector electric field calculated by HFSS® is used to compute specific absorption rate (SAR), $\sigma|\vec{E}|^2/2\rho$ where σ is tissue conductivity and ρ is tissue density. Metal structure in the patch applicator and coaxial feed connector were given properties of copper (perfect electric conductor, PEC). Coaxial feed of the patch antenna was excited using wave port option in HFSS which simulated TEM propagation in the feed cable.

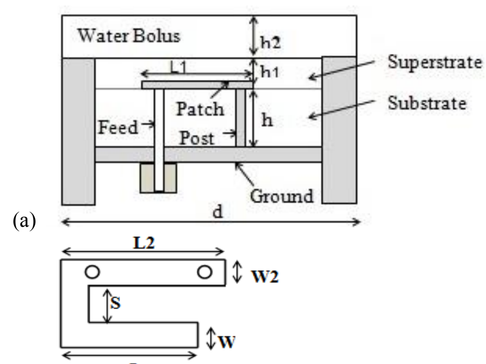

Figure 1. Illustration of the compact patch applicator (patent pending) (a) applicator cross sectional view (b) top view of C-type patch.

Several parametric sweeps were carried out on the length, width, and height of the patch, feed position, bolus thickness, substrate height and cavity height for resonance at

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434 MHz. Table 2 lists the range considered for the parametric sweep.

TABLE I. ELECTRICAL PROPERTIES OF MODEL DOMAIN

S.No	*Materials*	*Relative permittivity*	*Conductivity (S/m)*	*Loss Tangent*
1	Substrate	11.9	0	0.003
2	PEC (metal)	1	$1x10^{30}$	0
3	Deionized water	78	0.00	0.025
4	Air	1.006	0	0
5	Muscle	56	0.8	0.5587
6	Aluminum	1	$38x10^{6}$	0.001
7	Teflon	2.1	0.00046	0.001

TABLE II. ANTENNA DESIGN PARAMETRIC VARIATIONS

S. No.	*Physical dimensions*	*Range(mm)*
1	Patch Length L L_2	19-21 21-22
2	Substrate height	9 -11
3	Patch Width	2-3.5
4	Feed position from origin x_f y_f	 3-9 6.3
5	Bolus	20-50
6	Aluminum	0.5-2

III. RESULTS AND DISCUSSION

A. Simulation Results

Fig. 2 shows the antenna return loss over 350-500 MHz as patch length was varied from 20 to 60 mm for W=3mm, h =10mm, (x_f , y_f) =(3,6.3) mm, x_{short} =19mm, s =2.8mm. From Fig. 2 we observe that the resonance shifts to lower frequencies as the patch length increases. This is because the maximal linear dimension of the patch (L) determines the resonant frequency of the patch (f_0). From Fig. 2 the length of the antenna was fixed at 20 mm for resonance at 434 MHz. Following the parametric sweep, optimal antenna dimensions and feed position were determined for applicator fabrication. Thus, the optimal design of the C-type patch was fixed as L =20mm, L_2 =22mm, s =2.8mm, W =3mm, W_2 = 3mm, x_f =3mm, y_f =6.3mm, x_{short} =19mm, h =10mm, h_1 = 40mm. The size of the proposed patch is smaller than the rectangular patch antenna in [8] due to reactive loading with a shorting pin. Furthermore, the proposed applicator is less susceptible to external environment due to the presence of metal cavity. Fig. 3 shows the simulated (SAR) for the optimized C-type applicator calculated at varying depth in the muscle tissue. The SAR pattern is normalized with respect to the maximum value recorded in the measurement planes. The effective field coverage defined as the surface area with SAR value ≥50% of the maximum SAR was calculated for the optimized patch antenna. Fig. 3 indicates that the power deposition pattern of the 22x8.8 mm patch is 34 square cm and the pattern looks same far away from the tissue surface.

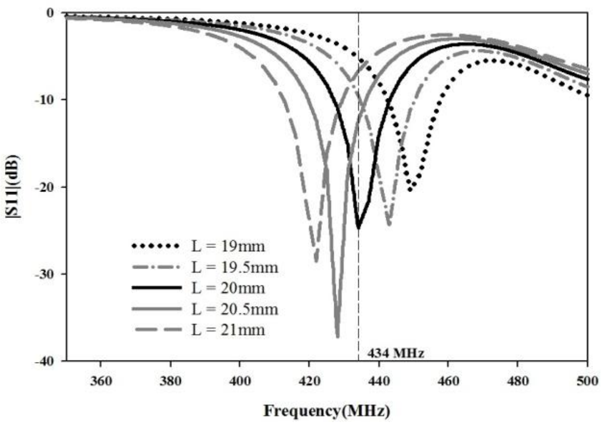
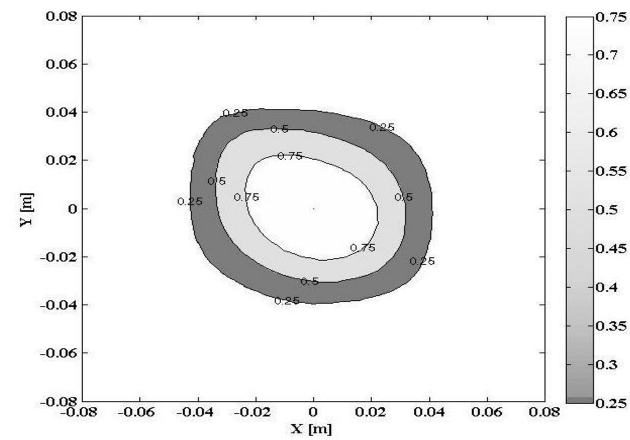
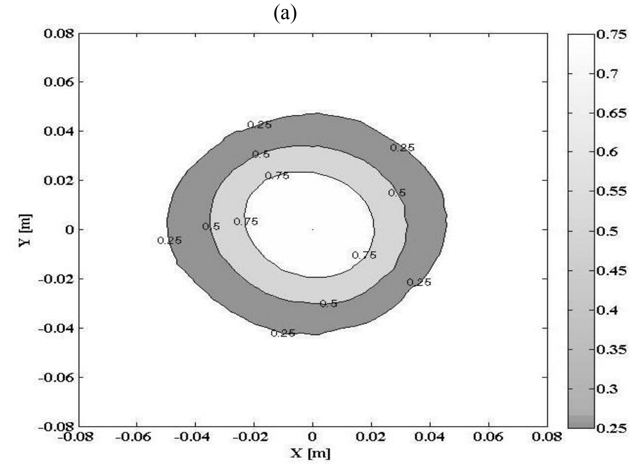


Figure 2. Simulated return loss (S_{11}) of the compact C-type patch applicator for varying patch length (L).Antenna resonance shifts to lower frequencies with increasing patch length and L=20mm resonates at 434 MHz.



(a)



(b)

Figure 3. SAR pattern normalized with the maximum value in muscle tissue at various depth (a) 10mm and (b) 30mm

B. Experimental Results

The designed antenna was fabricated to accommodate a variable volume coupling water bolus. The dimensions of the fabricated applicator are 60mm outer diameter and 12 mm height. Picture of the fabricated patch applicator without the coupling bolus is shown as an inset in Fig. 4. Fabricated applicator performance was tested on a tissue mimicking phantom using Agilent vector network analyzer E5071C.

Experimental return loss was recorded for the compact C-type patch applicator for varying thickness of the coupling deionized water bolus. Fig. 4 shows the comparison between experimental result and numerical simulations. It should be noted that the power coupled to the tissue mimicking phantom varies with bolus thickness. This was confirmed with the numerical simulations obtained for varying bolus thickness (Table II, simulations not shown here). From Fig. 4 it is observed that the experimental result resonates slightly at a higher frequency however, the return loss at 434 MHz is better than -10 dB for both measurements.

Manufacturing errors during applicator fabrication were ruled as it was fabricated with 25μm precision. Thus, the fabricated applicator was simulated with varying electrical properties for the deionized water in the coupling bolus – ranging from 70-80. Shift in antenna resonance to higher frequency was observed with a small variation in the electrical property of the deionized water as shown in Fig. 5. Thus, the reason for deviation in the measurement was clarified using numerical simulations.

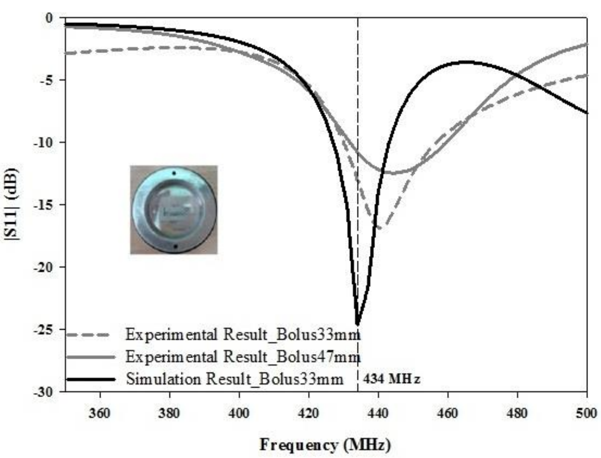


Figure 4. Return loss measured for C-type patch on a tissue mimicking phantom. Applicator picture is shown as inset.

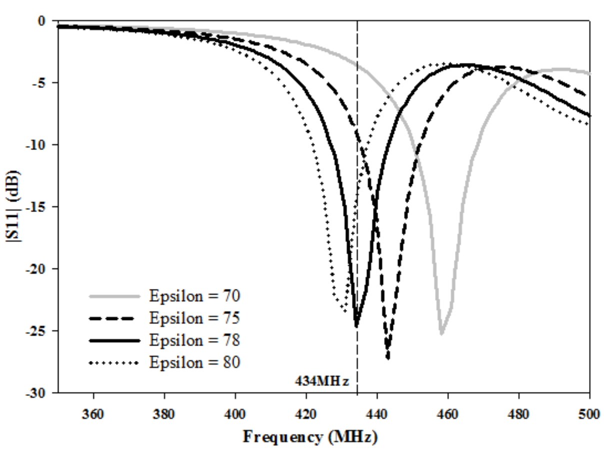


Figure 5. Epsilon variation of the C-type patch of patch antenna

IV. Conclusion

A compact 434MHz patch applicator is developed for hyperthermia treatment of cancer. The size of the radiating patch is significantly reduced using high dielectric substrate and reactive loading with shorting pin. Experimental results indicate that the 434 MHz applicator can be used to treat superficial disease of 34 sq. cm and extending as deep as 3-4 cm from tissue surface.

Acknowledgment

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