Redesign of 434 MHz Cavity Backed Patch Antenna for Hyperthermia Treatment of Cancer

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Abstract

Studies have shown that increasing tumor temperature in the range of 40-44 °C for a duration of 60 minutes (hyperthermia treatment) increases the efficacy of chemotherapy and radiotherapy. In this work, we redesigned a water-loaded cavity-backed C-type patch antenna operating at 434 MHz Industrial, scientific and medical (ISM) band for use as a near field radiating element in a phased array applicator for targeted heating of deep-seated breast tumors. The redesigned antenna has more than 90% power coupling, −10 dB bandwidth of 16.10 MHz and antenna measurements in muscle tissue mimicking phantom are in good agreement with required design parameters.

1. Introduction

Many clinical trials have shown increasing tumor temperature in the hyperthermia treatment (HT) range (40-44 °C) for a duration of 1 hour increases the efficacy of chemotherapy and radiotherapy [1, 2]. Selective heating of cancerous tumors can be achieved using microwaves as tumors have high water content. Microwaves can be focused at malignant tumors using near-field antennas. Antennas that are used for HT can be classified as non-invasive and invasive types [3]. Invasive applicators are used to heat specific locations where achieving non-invasive targeted heating is difficult such as rectal cancer. To avoid contact between the tissue and the near field antenna, catheters are used to hold the coaxial antennas used for invasive tissue heating [4]. But due to the invasive nature, such applicators are not suitable for all cancer sites. Non-invasive antennas such as microstrip antennas provides low cost and compact option for electromagnetic (EM) heating of biological tissues.

Rectangular patch and spiral antennas operating at 434 MHz and 915 MHz, respectively demonstrated the ability to heat deep seated tumors [5, 6]. Antennas operating at 434 MHz offers large penetration depth and field size which are required for locally advanced large deep-seated tumors. This operating frequency is also an ISM band in India. As the near field antennas are designed to radiate towards the tissue, the radiated field strength is relatively low which removes the requirement of a Faraday cage for the end clinical application. A circular cavity backed water loaded patch antenna was reported in our earlier work [7] which was later miniaturized into a rectangular cavity backed patch antenna for near field phased array design [8]. The cavity backing provided stable resonance compared to the low profile microstrip patch and slot antennas. The dielectric properties of body tissues has wide variations and the bulk dielectric property is characterized as a lossy high dielectric load which in the near field of an antenna can detune the antenna resonance. Microwave antennas used for hyperthermia treatment of cancer has to be in the near field of the human body to reduce distance related losses and deposit the highest possible specific absorption rate (SAR) at the tumor. Selecting the optimum distance between the human body and antenna is a critical task for clinical applications. In this work, we redesigned a water loaded cavity backed C-patch antenna operating at 434 MHz [7, 8] for non-invasive heating of deep-seated tumors in breast, neck and lower extremities.

2. Redesigned cavity backed patch antenna

2.1 EM simulations

EM simulations were carried out in a finite element method (FEM) based commercial solver Ansys HFSS (Version 2021 R1) to obtain the E-field distribution in the computational domain. The EM simulation solves the vector wave equation. The cavity-backed patch antenna was probe fed and a frequency sweep from 420 MHz to 450 MHz for 1 W of input power was performed. A radiation boundary box which contains the computational domain to absorb the outward radiated EM waves was defined. The dielectric properties of materials used in EM simulation are listed in Table 1.

Table 1. Material properties used in simulations [8].

Material	**Relative permittivity (ε_r)**	**Conductivity σ (S/m)**	**Density ρ (kg/m³)**
Aluminum	1	38×10^6	2689
Deionized water	78	0.04	1000
Acrylic	3.4	0	1000
Teflon	2.1	0.0005	2250
PEC	1	1×10^{30}	1000
Muscle	56	0.83	1000

Dielectric properties such as conductivity, relative permittivity, and loss tangent of deionized (DI) water for the frequency range 420 to 450 MHz used in the EM simulation were measured using dielectric assessment kit (DAK) V 3.0 (Schmid & Partner Engineering AG) (shown in Figure 1). Figure 2 shows the 3D model of the cavity-backed patch antenna embedded inside the acrylic sheet with water bolus and muscle phantom used in the EM simulation. Water bolus of thickness 40 mm acts as a coupling medium between muscle phantom and cavity-backed patch antenna.

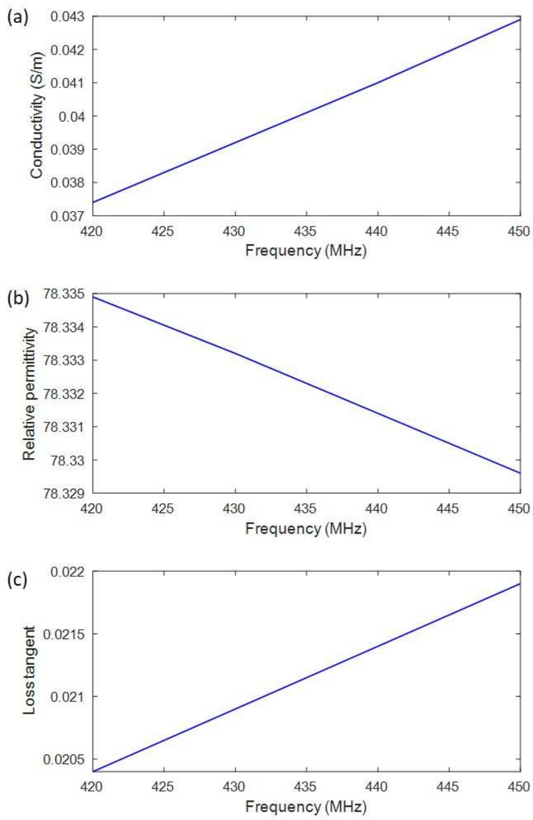

Figure 1. Dielectric properties (a) conductivity, (b) relative permittivity, and (c) loss tangent of DI water measure using DAK.

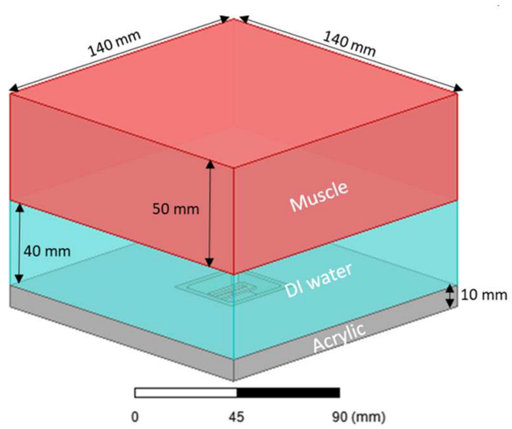

Figure 2. 3D model of the cavity-backed patch antenna embedded inside the acrylic sheet with water bolus and muscle phantom.

2.2 Cavity backed C-patch antenna design

Figure 3 shows the 3D numerical model of our cavity backed C-patch antenna along with feed, shorting post, cavity and patch dimensions. Antenna cavity and C-patch was assigned material properties of aluminum. The patch dimensions were optimized to obtain an antenna with reduced antenna and cavity size. The metal cavity enclosure was provided to shield the patch antenna from finite ground plane effects and to achieve stable resonance at 434 MHz. DI water was used as substrate and superstrate of the cavity backed patch antenna. DI water was selected as it offers high permittivity which helps to obtain a compact antenna design and also helps to maintain the antenna temperature during hyperthermia treatment. As the load for our antenna is biological tissue which consists of 70% water, DI water as substrate also improves EM coupling between our antenna and tissue load. The cavity backed patch antenna was optimized to achieve the following design parameters:

- stable resonance at 434 MHz (ISM) frequency,
- bandwidth (−10 dB) of at least 10 MHz,
- predominantly tangential electric field to the tissue in order to minimize the tissue heating.

The cavity height (h) was varied from 6 to 16 mm and its influence on specific absorption rate (SAR) deposited at 5 mm depth of muscle phantom was measured. The influence of water bolus thickness on power reflection coefficient of redesigned cavity-backed patch antenna was numerically studied by varying the water bolus thickness from 5 to 40 mm in steps of 5 mm.

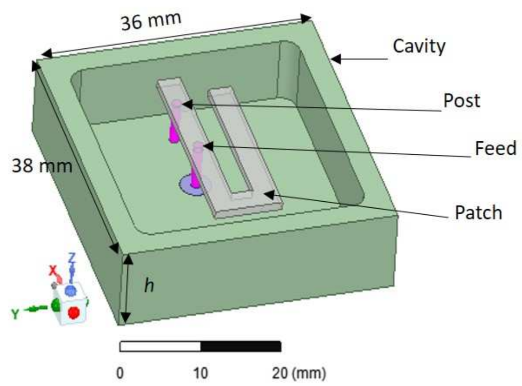

Figure 3. 3D numerical model of cavity backed C-patch antenna.

3. Results and discussion

Figure 4 shows the average SAR calculated at 5 mm depth in tissue plane for varying cavity height. It can be observed that the average SAR is the maximum for 10 mm high cavity. Based on the simulation results, cavity backing with 10 mm height was chosen for the PA applicator. Figure 5 shows the power reflection coefficient of redesigned cavity-backed patch antenna for varying water bolus thickness. For all water bolus heights, more than 90% power is coupled at 434 MHz which shows that the redesigned cavity-backed patch antenna offers significantly less reflected power to the power amplifier even in case of patient movement during the HT. The bandwidth (−10 dB) of cavity backed patch antenna for cavity height and water bolus height of 10 mm, and 40 mm respectively was 16.10 MHz. Figure 6 shows the normalized SAR distribution induced by cavity backed patch antenna in the muscle at 5 mm depth.

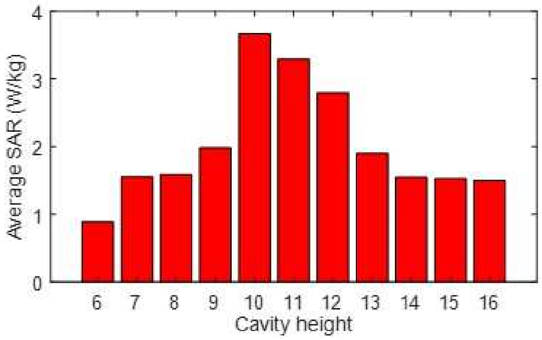

Figure 4. Average SAR at 5 mm depth in the tissue plane for varying cavity height.

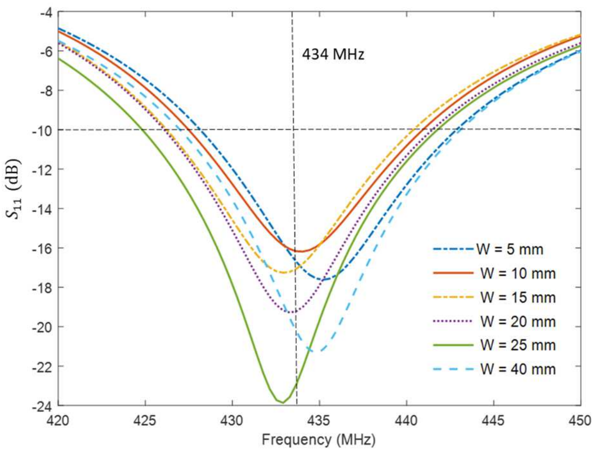

Figure 5. Power reflection coefficient of cavity-backed patch antenna for varying water bolus thickness.

Figure 6(a) shows the vector E-field distribution inside the water bolus and muscle phantom. Figure 6(b) shows the current density distribution on the C patch at 434 MHz. As the current density induced on both the arms of the patch is linear, the patch antenna maintained a predominantly tangential E–field in the tissue (Figure 6). The re-designed patch antenna occupies one third the volume of the existing antenna used in the phased array applicator without compromising on the power deposition characteristics. This is a significant savings in terms of space and will enable us to design a compact phased array applicator for HT of deep-seated tumor.

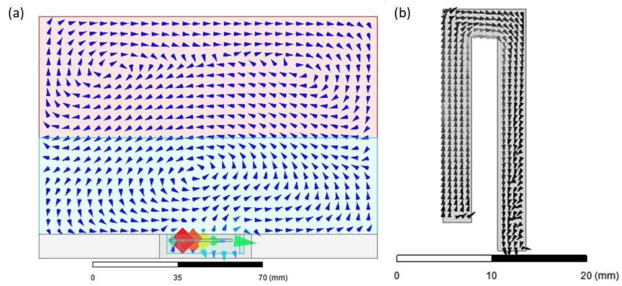

Figure 6. (a) E-field distribution inside water bolus and muscle phantom. (b) Current density distribution in the C-patch at 434 MHz.

4. Conclusion

A reduction of 30% in the volume of the antenna was achieved without any compromise in the antenna performance compared to our existing cavity-backed patch antenna [8]. Simulation results of the redesigned cavity-backed patch antenna show stable resonance at 434 MHz with −10 dB bandwidth of 16.10 MHz. The simulation results show that the redesigned antenna could be used as a radiating element for design of phased array applicator for HT of deep-seated tumors.

5. Acknowledgment

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7. References

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