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Antenna Design Considerations for High Specific Absorption Rate in Local Hyperthermia Treatment

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Introduction

Clinical trials are being conducted across the world to determine the effectiveness of hyperthermia as a cancer therapy. It has been shown to be an effective treatment for some cancers in combination with radiotherapy, chemotherapy, or both [1-2]. The effectiveness of hyperthermia treatment is related to the temperature achieved during the treatment [1], which can be provided by ultrasound or microwave techniques. If microwaves are used, the effectiveness is related to the specific absorption ratio (SAR).

Both local hyperthermia and whole-body/regional hyperthermia are used to treat superficial or subcutaneous tumors and systemic/regional cancers, respectively. The main requirement for local hyperthermia is the delivery of electromagnetic energy from a small efficient applicator, which is placed in close proximity to the tumor area, sometimes using interstitial techniques/arrays [3].

An understanding of the antenna design, when in close proximity to human tissue leads to improved hyperthermia techniques. In order to prevent significant antenna detuning, and the consequent mismatch and reduced coupling to the body, the body proximity effects must be considered when designing the antenna. One method to achieve this is by optimizing the impedance matching when in proximity to the tissue. However, this method may suffer from reduced delivery when the antenna-to-tissue distance varies. These applicators may have efficient delivery only at a fixed distance and completely detune when the distance changes. An improved design method is to develop the antenna to have good impedance matching in the presence of tissue and also to have resilience to distance-dependent antenna detuning.

One of the frequencies used clinically is 434 MHz. It is a reasonable compromise between antenna size/efficiency and penetration depth. Resonant circular loops, dipoles and microstrip patches have been used for this purpose [4]. Resilience to detuning can be effected using methods such as stepped impedance matching, broadbanding and the use of geometries which enable mode alteration with change of distance. The other requirement is miniaturization, which is always a challenge for antenna designers. In this paper, the design of a miniaturized antenna which provides efficient deposition of energy and resilience to detuning is described.

Antenna Design

The basic element chosen is a microstrip patch antenna, but different miniaturization techniques have been used in the design of this applicator. The annular-ring geometry provides considerably smaller size geometry than the circular patch for the same operating frequency. The addition of groundplane slots and the concentric circular patch further miniaturises the element [5]. These techniques enable the antenna to be fabricated

on a small 130 mm x 130 mm groundplane. The laminate used is Taconic RF-35 of thickness 2.97 mm (relative permittivity 3.5 and loss tangent 0.0018). A short parametric study follows. In order to provide best matching and highest SAR, a planar 3-layered tissue model is employed [6-7] and shown in Figure 1. The model parameters are: Skin layer thickness, S : 1.3 mm, permittivity: 46.059, conductivity: 0.702 S m^{-1} , mass density: 1100 Kg m^{-3} ; Fat Layer thickness, F : 15 mm, permittivity: 5.566, conductivity: 0.042 S m^{-1} , mass density 916 Kg m^{-3} ; Muscle layer thickness, M : 83.7 mm, permittivity 56.865, conductivity 0.805 S m^{-1} , mass density 1041 Kg m^{-3} . The proposed antenna is shown in Figure 2, and the optimized dimensions in body proximity are as follow: $L_1= 120\text{mm}$, $L_2= 114\text{mm}$, $sw= 8.0\text{mm}$, $SR= 12\text{mm}$, $R_1= 62\text{mm}$, $R_2= 51\text{mm}$, $R_3= 38\text{mm}$. Feed Point (38mm, 38mm), considering the centre of the circular patch as the rectangular coordinate system origin.

The cross slots in the groundplane, not only enable miniaturization, but also provide wide bandwidth and resilience to proximity detuning. Figure 3 illustrates that the slot width can be used to increase bandwidth and Figure 4 shows the S_{11} behavior as the distance antenna-tissue, L , varies. For the antenna in proximity to the layered model, ($L=2.5\text{mm}$), the return loss is better than 30dB at 434MHz. The 10 dB return loss bandwidth is about 84MHz from 387MHz to 471 MHz and antenna has circular polarized characteristics as shown in Smith chart in Figure 5. The maximum SAR is 2.36W/kg averaged over 1g of tissue volume. Figure 6, shows the SAR value at the different tissues interfaces and the maximum axial-ratio (AR) for the various antenna-tissue distances. It was seen that the polarisation is mainly circular when in close proximity to the model and becomes elliptical as the distance increases. Circular polarization (CP) performance corresponds with highest values of SAR.

Conclusion

The design of a miniaturised low-profile efficient hyperthermia applicator is presented. The efficiency is attributed to small size, resilience to detuning and wide bandwidth. The antenna provides a high value of SAR and is well matched to tissue, even at close distances.

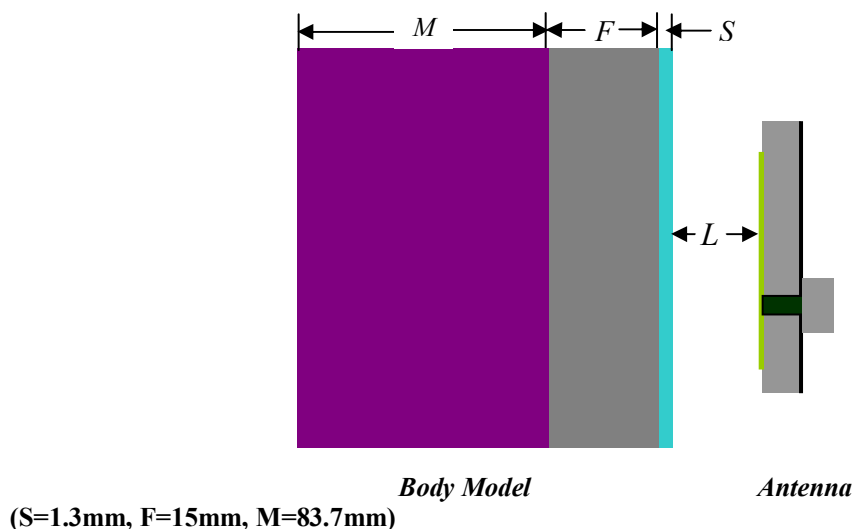


Figure 1. Arrangement of antenna and 3-layered tissue model

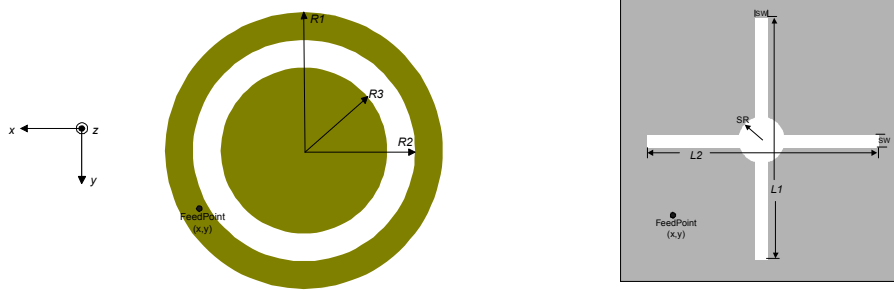


Figure 2. Geometry of the antenna showing annular patch and cross slot in groundplane.

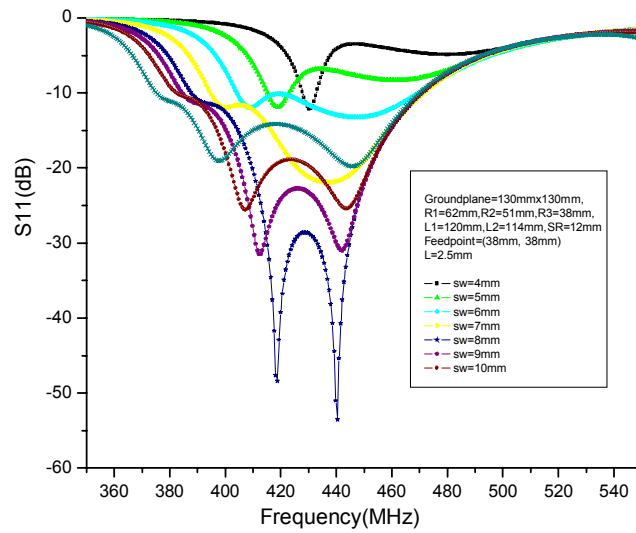


Figure 3. Simulated S11 for different slot widths sw in the presence of 3-layer tissue model.

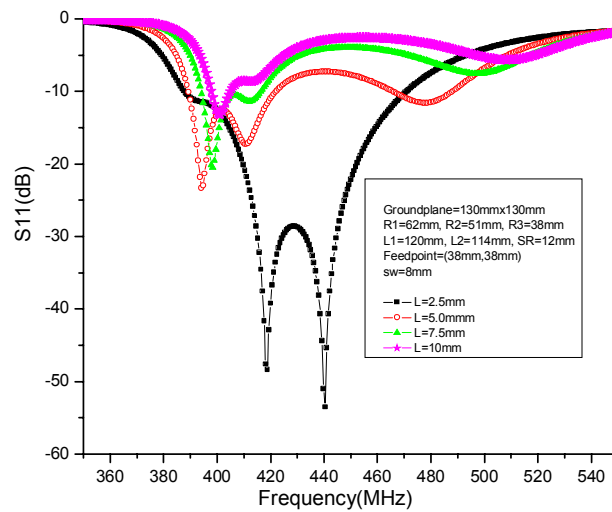


Figure 4. Simulated S11 for different distance between antenna and layered tissue model.

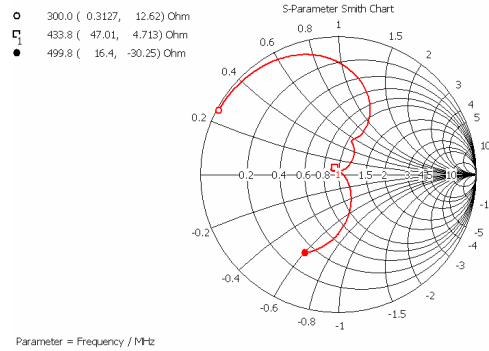


Figure 5. Simulated Smith chart showing CP for antenna at 2.5 mm from tissue

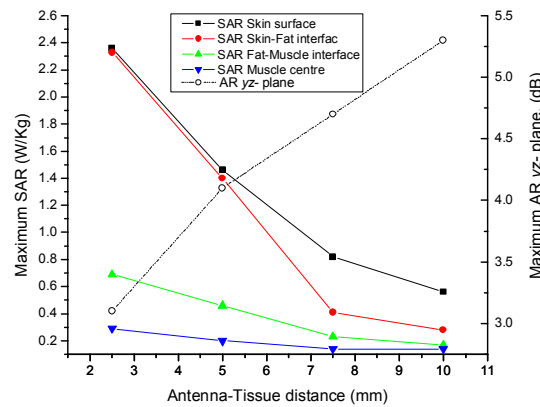


Figure 6. Maximum SAR and Axial-Ratio for different layer interfaces and distances

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