Development of Microwave System for Tumor Ablation and Imaging

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Abstract— **This paper presents a research that aims at developing a system for microwave imaging and hyperthermia ablation of brain tumors. The system depends on a MIMO array of microstrip antennas to be mounted on the head. An L-band antenna is designed to increase the power radiated toward the human and increase the SAR values in the tumor. The size reduction is achieved by adding a high dielectric layer just above the antenna. The antenna is made of a short-circuited- slotted triangle on a thick foam substrate to enhance the bandwidth. A directional coupler is designed for use in exciting the antenna and collecting the reflected signal. This allows the achievement of imaging and hyperthermia treatment functionality, simultaneously. S-parameters are monitored of four antennas installed on a tank filled with a brain simulating liquid in the presence and absence of an anomaly. Results are presented of the simulations and the experimental measurements.**

Index Terms— **Hyperthermia treatment; Microwave imaging; Microstrip antenna arrays; Directional couplers**

I. Introduction

Cancer is expected to be the leading cause of death worldwide [1]. Three techniques are currently used against cancer for tumor ablation based on surgery, chemotherapy, and radiotherapy [2]. Each of these techniques has its own drawbacks and an emerging tool based on hyperthermia is currently gaining interest within the research community.

Heating devices used in hyperthermia can be categorized into: external, intraluminal, and interstitial types. External applicator devices are the easiest to be dealt with, but they pose challenges to get the energy deposited into deep and confined tumor locations. This research proposal aims at designing a preclinical hyperthermia treatment system that is capable of conducting imaging.

Various techniques have been proposed for producing localized or regional hyperthermia, and each of these techniques has its inherent advantages and disadvantages. Antenna designs as single elements and conformal arrays have achieved wide progress in the application of microwave hyperthermia treatment of tumors.

The purpose of this research is to design a multi-input multi-output MIMO system to localize microwave energy in tumor locations and collect the reflected energy for the imaging process. Fig. 1 shows a set of elements mounted on the head. Practically, the antennas can be mounted on a helmet appropriate to the head size to be worn by the patient. A directional coupler is designed here for use in exciting the antenna and collecting the reflected signal. This allows the operation of imaging and hyperthermia treatment simultaneously. Antenna and coupler design optimization is performed under IE3D [3] and SEMCAD-X [4]. Details are presented next.

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II. Antenna Design

Low profile antennas in the lower microwave range (L-band) have received much attention in the past ten years for handset wireless applications. Microstrip antennas are the best candidate for these applications. The size of the conventional microstrip antennas is relatively high at these frequencies. Several techniques have been suggested to reduce the size of these antennas such as: adding a short circuit at one end of the patch [5]; using high dielectric constant substrate [6]; shaping the conventional patch structures by cutting slots or slits in the radiating patch [7]; and various combinations of the above mentioned techniques [8]. Microstrip antennas usually suffer from bandwidth (BW) limitation. The bandwidth can be increased by adding lossy-elements or increasing the substrate height that leads to families of planar inverted-F antenna (PIFA).

PIFA antenna has become the most common type used for mobile handsets in L-band. The design objective of these antennas is to reduce the radiation toward human head. In other word is to decrease the specific absorption rate (SAR) [9] and [10]. In this case, the antenna performance, especially the matching parameter (S11) should have minimum effect by the human body. On the other hand, inverting the antenna performance by increasing SAR values provides a useful tool in new applications related to microwave imaging and hyperthermia treatment of brain tumors. The objective, in this case, is to increase the power radiated toward the human and enhance the SAR values in the tumor. The challenge is to design physically small size antenna that is operable at low frequency with possible sufficient penetration. Reducing antenna size allows the use of an array on the head, providing a MIMO system that is capable to radiate concentrated power into the head and collect most of reflected radiation.

More size reduction can be achieved for imaging applications by adding a high dielectric layer just above the antenna. The best layer suitable for this application is found to be fresh water. Fresh water plays another important role to reduce the effect of the human body on the antenna operating frequencies.

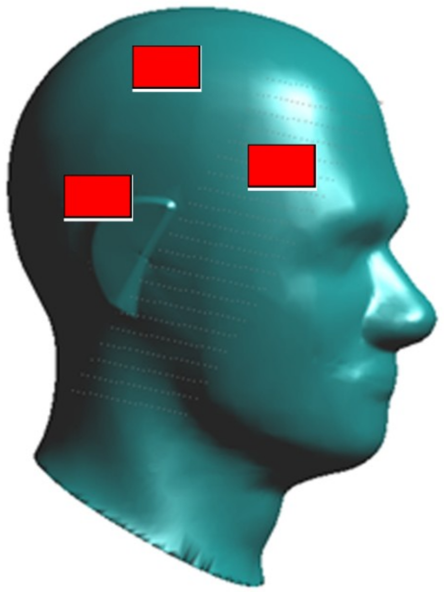

Fig. 1. Illustration of proposed configuration

A promising triangular shape is suggested in [11] and [12]. The geometry of the original antenna is modified by including the foam layer between two substrates with higher ε_r as shown in Fig. 2. The upper layer triangle has the size dimensions shown in Fig. 3. The ground layer is a conductor from one side, while the side that is adjacent to the foam materials is free from copper. The antenna is fabricated on the upper layer of the substrate, while the other side of the layer is free from conductor.

After assembling the antenna, probe-feed is added, as shown in Fig. 3. The measured reflection coefficient for the assembled antenna is shown in Fig. 4. The resonance frequency is 2.15 GHz with fractional bandwidth (FBW) of 11.62% (for S11<-10dB).

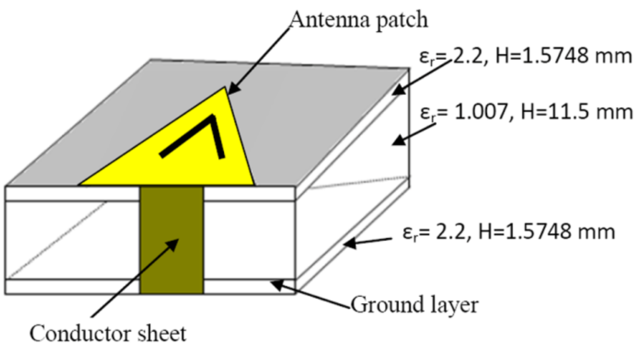

Fig. 2. Geometry of the antenna

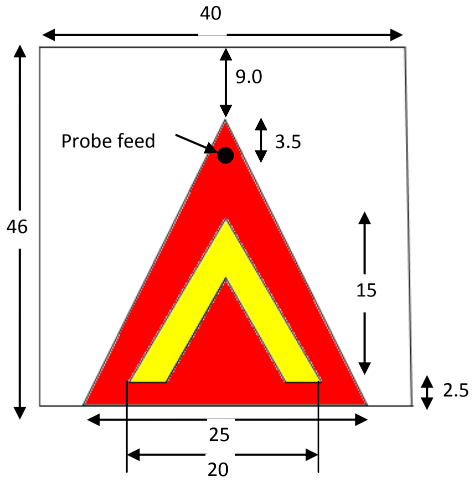

Fig. 3. The dimensions for the triangle antenna in the upper layer. Dimensions are in mm.

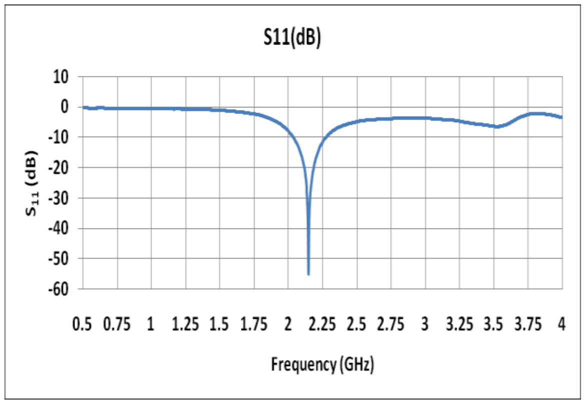

Fig. 4. The measured Reflection Coefficient for the assembled antenna

III. COMPACT WIDE-BAND BRANCH LINE COUPLER

The antenna is fed through a line coupler. The branch line coupler is one of the most popular hybrid implementations for microwave circuits. The single-section branch line coupler suffers from narrow bandwidth characteristics, and such problem can be solved by using multi-section branch line coupler. The multi-section design produces a large size coupler. Good fabrications tools are also needed to implement very small width dimensions, mandated by the high microstrip impedance.

Several solutions have been suggested to the challenges of designing directional coupler [13] and [14]. Some techniques use multilayer substrate materials, which usually lead to complex designs. Other approaches depend on the use of lumped parameters, which suffer from limited frequency ranges. A cascaded branch line coupler is suggested here, with four branch lines to achieve a fractional bandwidth of 60%, as shown in Fig. 5. The design parameters are [15]: Z_{c1}=53.94 Ω, Z_{c2}=58.31 Ω, Z_{c3}=Z_{c4}=142.86 Ω, $\theta_1 = \theta_2 = \theta_3 = \theta_4 = 90^o$.

This coupler is designed on (ε_r=4.0, h=1.57 mm) at the operating frequency of 1-GHz. The overall size is 139 x 50 mm. The coupler section is zigzagged such that the overall size is reduced to 95 x 31.5 mm, Fig. 6.

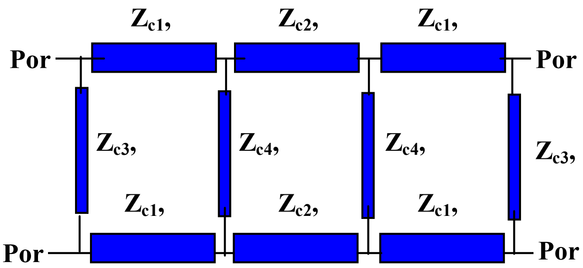

Fig. 5. Conventional branch line coupler with four branch lines.

The coupler size can be reduced to small size by replacing each λ/4 section to a T-section or a Π-section. The simulated S-parameters are shown in Fig. 7 (a), while the measurement S-parameters are shown in Fig.7 (b). The measured coupling parameters S_{21}, S_{31} are (-3±1 dB) in the frequency band (0.8-1.6 GHz), while the reflection coefficient S_{11} and the isolation coefficient S_{14} are nearly less than (-6 dB) in this operating frequency band.

IV. Experimental Setup

The experimental setup for SAR measurements is based on DASY-5 system manufactured by SPEAG [16]. The system implements a Staubli six-degree-of-freedom robot, a head phantom, measurement sensors, and the head simulating liquids. SAM-type phantom is implemented in the system. The phantom incorporates a lossless simulated ear, and is filled with human brain simulating liquid corresponding to the tissue parameters at the frequency of interest. SAR probes specially designed for use in liquids with high permittivity values are used.

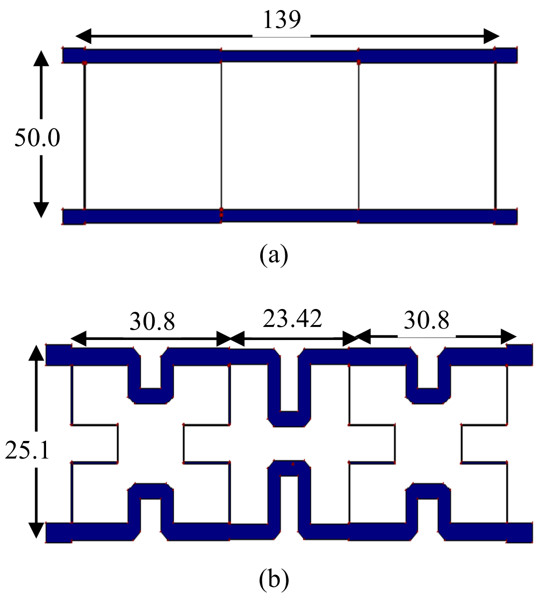

Fig. 6. Conventional cascaded branch line coupler and zigzag cascaded branch line coupler (b). Dimensions are in mm.

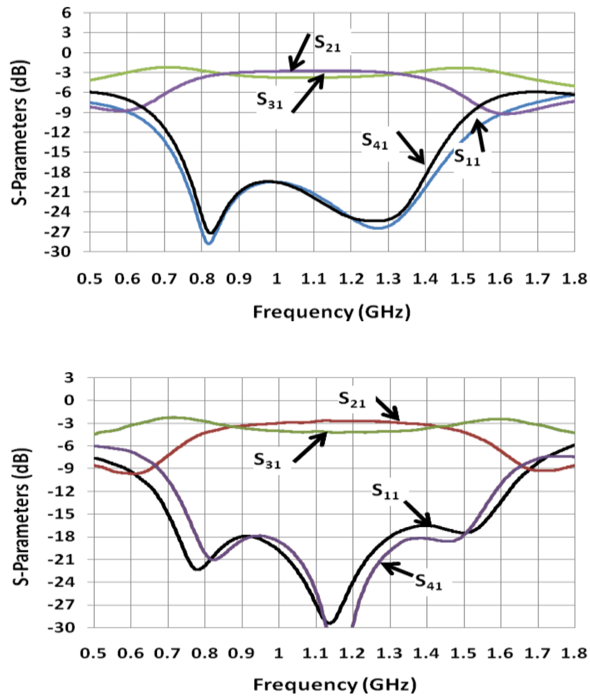

Fig. 7. Simulated S-Parameter (top) and measurements (bottom) for the cascaded zigzag branch line coupler

The probes are calibrated for the liquids corresponding to the frequencies of interest. Signal generator (Hittite HMC T2100) is used to drive the antenna with CW of 2.1 GHz and power of 24dbm. The nearest available HSL (head simulating liquid) of 1.95 GHz is used in SAM phantom with conductivity of 1.41 S/m and permittivity of 39.7. Dosimetric E-field probe (EX3DV4) is used to measure the electric fields inside the liquid by the help of the robot for precise positioning. In performing the measurements, an area scan is first performed over the section of phantom to find the hot spot followed by a zoom scan according to (IEEE/IEC/ANSI C63.19-2007).

For area scan: grid size is (120 x 110) mm, step size is 15-mm in x,y direction. The average SAR over 1-g is 7.11 mW/g, and the average over 10 g is 3.24mW/g. The readings are obtained by Motorola fast SAR calculation algorithm. For zoom Scan extent is 30 x 30x 30 mm, step size: 5 mm, average over 1-g is 6.47 mW/g, and averaged over 10 g is 2.95mW/g.

The antennas are arranged face to face at the surface of a container containing the human head liquid simulator. The antennas are positioned such that element 1 and 4 are on one side and the other elements (2 and 3) are on the opposite side. Each two element on one side are separated by about 20 mm.

The measurement is carried out such that antenna 1 is connected to port 1 of the network analyzer and one of the other ports is connected to port 2 of the network analyzer. Anritsu network analyzer is used in these measurements. The rest two ports are connected to 50-ohms terminations. S_{11} represents the reflection coefficient of antenna 1, S_{21} represents the transmission coefficient from antenna 1 to antenna 2, S_{31} represents the transmission coefficient from antenna 1 to antenna 3, and S_{41} represents the coupling between the two adjacent antennas 1 and 4 located at one side.

Fig. 8 shows S_{11} with liquid only and with liquid along with the anomaly body. The frequency of operation for -10 dB BW is approximately from 2 to 2.3 GHz. The percentage change of S_{11} and S_{41} are also given in Fig. 8. The percentage change in S_{31} is given in Fig. 9. This shows how the existence of tumor will affect these measurements, which makes this technique promising for human tumor detection.

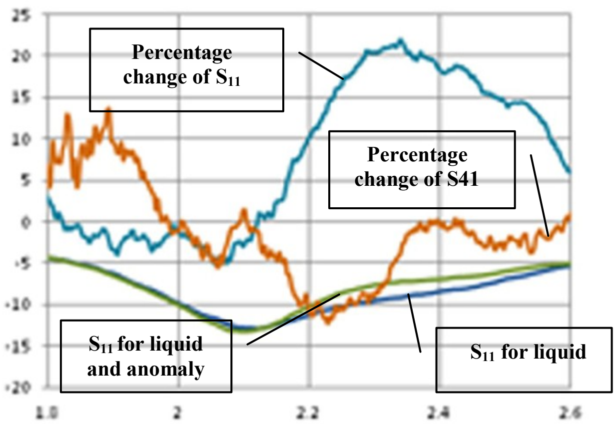

Fig. 8. Measurement results: S_{11} in dB, and the percentage change of S_{11} and S_{41}

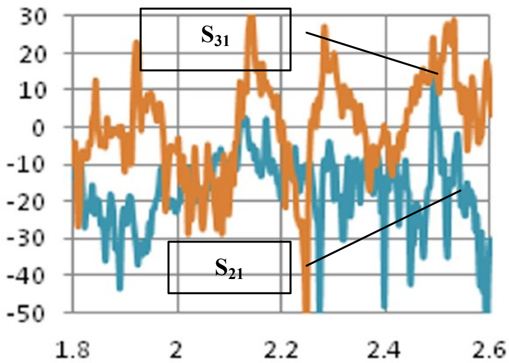

Fig. 9. Measurement results: percentage change of S_{21} and S_{31}

V. CONCLUSIONS

A system is presented for use in microwave hyperthermia ablation and microwave imaging of brain tumors. Small size antenna is used to allow implementation of multiple antennas array. An L-band antenna is designed to increase the power radiated toward the human and increase the SAR values in the tumor. Reflected signals are collected using a coupler in order to monitor the tissue,. Presented simulation and experimental results illustrate the effect of an anomaly on the s-parameters.

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