Combination of C and T slot Antenna at 915 MHz for Hyperthermia Application

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***Abstract*—In this paper, the design and the analysis of a microstrip slotted antenna are proposed for the Hyperthermia application. The proposed antenna has a size of 110x110x1.6 mm^3 with a frequency of operation of 915 MHz. Simulation of this antenna is in HFSS 2020R1 software, based on FEM. FR-4 substrate with relative permittivity of 4.4 and thickness of 1.6 mm material is used. The proposed antenna structure was simulated with a combined single-layer human tissue model as well as a multi-layered tissue model. The specific absorption rate (SAR) is achieved for different distances irrespective of wavelength and the obtained results are within the limits of the IEEE standard.**

***Index Terms*—Tissue Equivalent Liquid (TEL), Multi-layered phantom, Hyperthermia applicator, specific absorption rate (SAR).**

I. INTRODUCTION

The major state of research on microwave antennas for scientific applications has targeted generating hyperthermia for scientific remedies medical and tracking various physiological parameters [1], [2]. Antennae used to raise the temperature of cancerous tissue are placed inner or outer side of the patient's body, and the kinds of antennae depend on the location. For example, waveguide or low-profile antennae are placed externally whereas monopole and dipole antennae transformed from a coaxial cable are designed for inner use [1].

Hyperthermia is a healing technique used to elevate the temperature of a localized vicinity of the frame/body. In cancer remedy, it is frequently used with chemotherapy and radiation therapy. The applicator is optimized to non-invasively couple the electromagnetic strength to the skin of different patients for superficial cancer treatment in conjunction with the ionizing or chemotherapeutic application. The directed power is used to raise the temperature of the cancerous tissue by some tiers to approximately 40 44 without detrimental to the encircling wholesome tissue. RF/microwave radiation era for hyperthermia in cancer patients has been studied for such localized heating [3], [4]. The heating technique and its effectiveness are a feature of the applicator type, size, implemented field polarization, frequency, power level, proximity to the skin, and the conformability of the applicator to the skin surface. Moreover, the energy absorption depends on the electrical properties of the biological tissue, this might have nonlinear frequency and temperature-dependent dielectric properties. Conveniently, the applicator needs to be mild weight, bendy, compliant, and also small. The mild weight of the applicator should help avoid putting pressure on the tumor and changing its shape. The flexibility could facilitate its adaptability to diverse regions of the body. Placing the applicator near the tissue might grow energy coupling to the tissue, however, could significantly degrade the performance of the radiating element, which has been a difficult design problem.

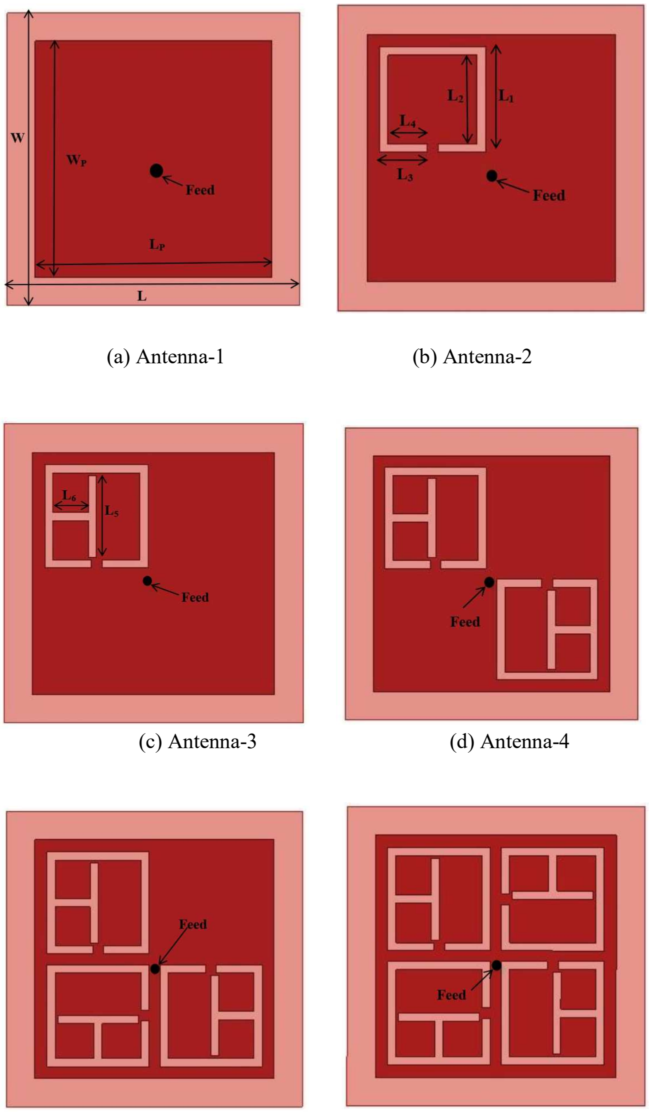
Regardless of extreme research efforts in current years, hyperthermia cancer remedy keeps remaining as the concern of studies engrossment for scientists and engineers all over the world. Microwave hyperthermia can warm the cancerous tumor effectively as it can effortlessly be focused within the tumor region. External microwave antenna applicators are designed and optimized to non-invasively couple microwave energy through human skin to kill cancer cells. The directional microwave energy is used to raise the temperature of cancer cells by some stage inside the range of 41–45 °C [5], even as the temperature required for normal tissue is less than 41 °C.

In this paper, a combination of C and T slots with a phase shift of 90 degrees symmetrically placed in all quadrant microstrip patch antenna was designed to operate at the ISM band of 915 MHz. The proposed antenna is simulated with single-layered TEL as well as a multi-layered phantom.

II. MATERIAL AND METHODS

A. *Antenna Design*

In this paper, a microstrip antenna has been proposed to operate resonance frequency at the ISM band (915 MHz) for the treatment of hyperthermia. This proposed structure is simulated with a dielectric FR-4 substrate of dimension 110x110x1.6 mm^3 with a ϵ_r of 4.4 and a tanδ of 0.02. Power is fed by using a 50-ohm coaxial probe. Fig.1 shows the evaluation process of the proposed structure. To get the ISM band of 915 MHz with improved reflection coefficient without increasing the size of the structure, Four C slots and Four T slots on top of the patch with 90-degree angular clockwise rotation starting from the second coordinate. The reflection coefficient plot of antenna-1 is shown in fig.3 and the result is tabulated in Table IV. For the improvement of characteristics at 915 MHz of the proposed structure optimization is considered in different iteration processes and it is shown in fig. 1(a) to fig.1(f). The geometrical parameters of the proposed structure are shown in Table I.



(a) Antenna-1 (b) Antenna-2

(c) Antenna-3 (d) Antenna-4

(e) Antenna-5 (f) Proposed antenna

Fig.1. The geometrical configuration of the proposed antenna.

TABLE I Geometrical Parameters of the proposed antenna

Parameter	Value (mm)	Parameter	Value (mm)
L	110	L_2	32
W	110	L_3	17
L_P	89	L_4	14
W_P	89	L_5	30
L_1	38	L_6	13

B. *TEL and multi-layered phantoms tissue model*

A planar single-layered tissue equivalent phantom and multi-layered phantom (skin, fat, and muscle) were used to analyze the performance of SAR at different distances from the antenna. As per IEEE standard multi-layered phantom tissue model with water bolus shown in Fig.2. Water bolus layered has different significances for taking into consideration like it makes the EM field transmission into the phantom with less reflection from the surface, it is also used for cooling down the skin layer at constant temperature and one more interesting function of water bolus layer is to protect the EM field radiation at a safety level.

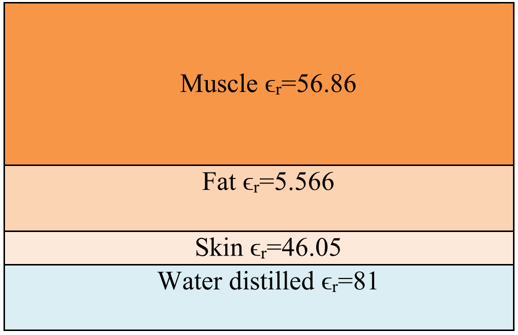


Fig.2. Three-layered phantom tissue model

The model overloads the antenna fields and provides the main SAR pattern due to the combined strength. Table II and Table III define the dielectric parameters of permittivity (ϵ_r), conductivity (σ S/m) [6], [7], and density (ρ Kg/m^3). The size of each cubical phantom is 190x130x100 mm^3 taking into consideration.

TABLE II Dielectrics parameters for the size of single-layered tissue equivalent material at 915 MHz

Material	Permittivity (ϵ_r)	Conductivity (σ, S/m)	Mass density (ρ, Kg/m^3)	Phantom Tissue L×W×H (mm^3)
TEL	63.3	0.472	1100	190×130×100

TABLE III Dielectrics parameters for the size of the multi-layered tissue phantom at 915 MHz

Material	Permittivity (ϵ_r)	Conductivity (σ, S/m)	Mass density (ρ, Kg/m^3)	Phantom Tissue layer thickness h(mm)
Water distilled	81	0.0002	1000	5
Skin	46.05	0.702	1100	0.4
Fat	5.56	0.041	916	15
Muscle	56.86	0.805	1041	84.6

C. *Methodology*

The architecture process was initiated with the use of the Ansys version 2020R1 designer, a 2-D FEM-based application [8]. Previously this antenna was designed without tissue phantom. Then take a single-layered TEL phantom with a thickness of 100 mm, placed from the antenna to the minimum wavelengths at 20.5 mm (λ/16), 41 mm (λ/8), and 82 mm (λ/4). A similar kind of procedure was applied with a multi-layered phantom having a particular specified thickness of each layer.

III. RESULTS AND DISCUSSION

A. *Reflection coefficient (S_{11})*

Fig.3 shows each step of the reflection coefficient of the proposed antenna without phantom at 915 MHz which is -19.18 dB. Fig 4 to Fig.6 shows the simulated reflection coefficient with each Phantom at λ/16, λ/8, and λ/4 distances respectively. The differences in reflection coefficient due to TEL Phantom and multi-layered phantom at λ/16, λ/8, and λ/4 distances from the antenna at 915 MHz are summarized in Table IV.

TABLE IV Comparison of TEL and Three-layered Reflection Coefficient

Distance b/w antenna and Phantom	Simulated S_{11}(dB) with TEL	Simulated S_{11}(dB) with three layered
λ/16	-18.34	-17.67
λ/8	-17.75	-16.61
λ/4	-16.34	-16.66

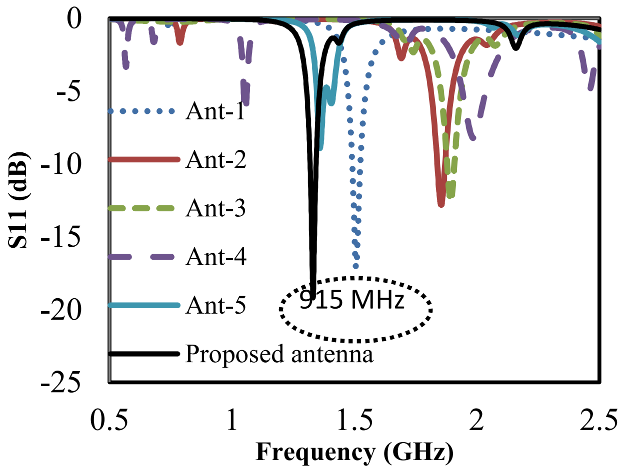


Fig.3. Simulated S_{11} of all steps

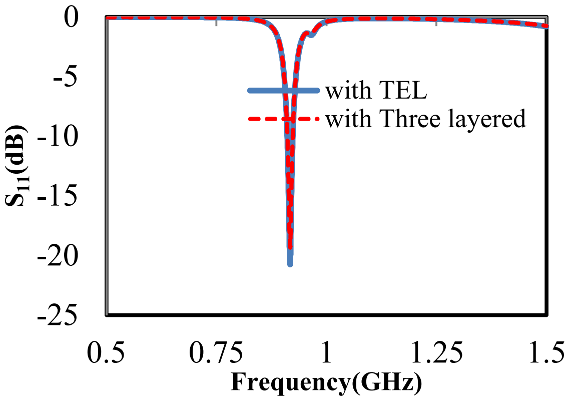


Fig.4. Simulated S_{11} at λ/16 distance b/w antenna and phantom

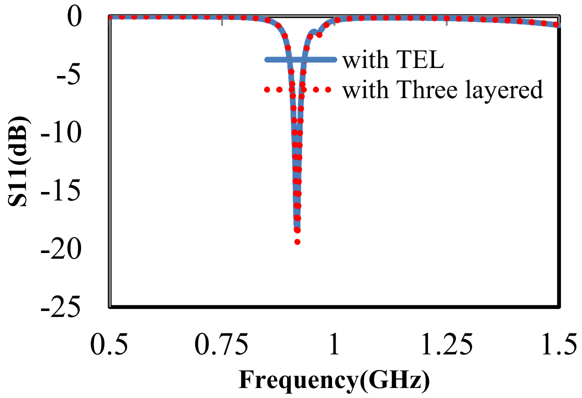


Fig.5. Simulated S_{11} at λ/8 distance b/w antenna and phantom

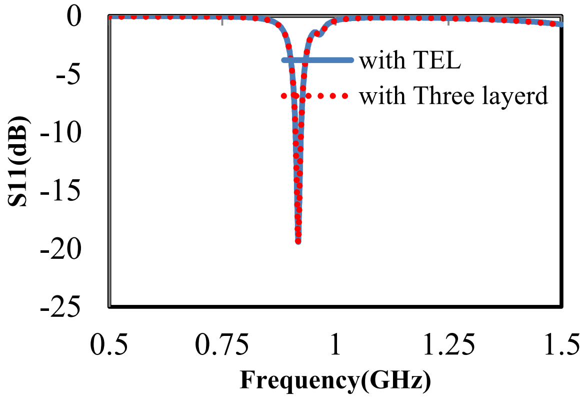
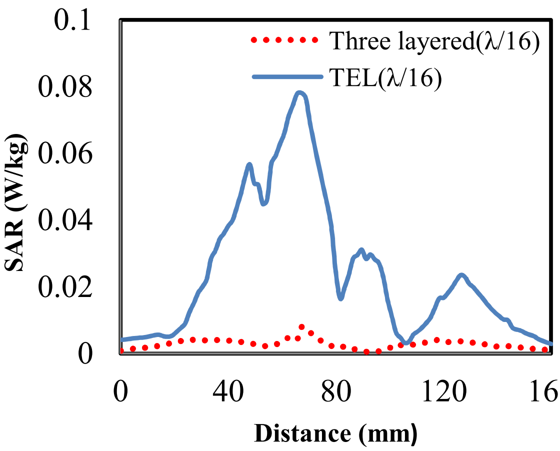


Fig.6. Simulated S_{11} at λ/4 distance b/w antenna and phantom

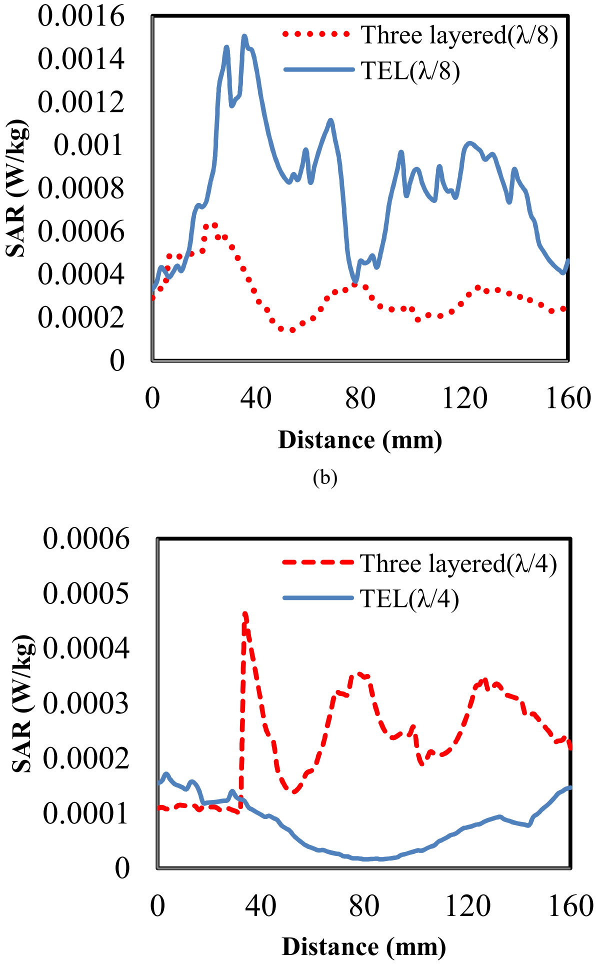
B. *Specific Absorption Rate (SAR)*

The SAR is the amount of power deposited in the tissue by radiofrequency irradiation per unit mass, measured in W/kg. And it is calculated by using the formula given in equation (1). Simulated SAR results are summarized in Table V. We have taken three different cases for SAR calculation, Fig. 7(a), 7(b), and 7(c) show the SAR value along the x-axis penetration depth when both phantoms are placed at λ/16, λ/8, and λ/4 distance from antenna respectively.

$$SAR = \frac{\sigma E^2}{2\rho} \quad (1)$$



(a)



(b)

(c)

Fig.7. Simulated SAR value along the x-axis variations.

From Table V, it can be concluded that SAR is the nonlinear function w.r.t. distance. In the case of the TEL phantom at 915 MHz SAR is 0.08 W/kg when the phantom was at λ/16 from the antenna. In the case of the multi-layered phantom at 915 MHz SAR is 0.01 W/kg when the phantom was at λ/16 from the antenna.

TABLE V Simulated SAR value along the x-axis variations

Phantom Detail	Distance b/w antenna and Phantom (d) in cm	SAR W/Kg
TEL	λ/16	0.08
	λ/8	0.0015
	λ/4	0.0002
Three layered	λ/16	0.01
	λ/8	0.0006
	λ/4	0.0004

IV. CONCLUSION

In this work, a low-profile microstrip slot patch antenna for hyperthermia application has been designed at 915 MHz. The antenna performance is compared at different distances from the phantom model using FEM modeling. SAR and reflection coefficient have been evaluated. The value of SAR lies in the permissible limit of the exposed body as stated by IEEE standard.

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