Dual Coaxial slot antenna for Interstitial Microwave Hyperthermia

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Abstract— Microwave Hyperthermia is type of treatment of cancer tumors in which the body tumor is exposed to slightly higher temperature than the body in order to kill the cells or make it sensitive to radiation for certain anti-cancer drugs. To focus the heat into the tumors antennas or applicators are required, here coaxial slot antenna has been discussed for interstitial application in hyperthermia. The model was designed and simulated in CST studio suite and the SAR and temperature distribution of the antenna shows very well matching between theoretical and calculated results. The temperature around the tip is 55-60 degree celcuis which shows that the antenna can be effectively used for heating the tumors deep inside the vicinity.

Key words: Microwave Hyperthermia (MWH), Applicator, Specific Absorption Rate (SAR), MAFIA, FIT, FEM

I. INTRODUCTION

A. Microwave Hyperthermia:

Cancer is the number one cause of death and mortality in the 21st century, according to the report of World Health Organization (WHO) up to 2013 there has been 14.5 million new cases of cancer and about 8.5 million deaths related to cancer. The number of new cancer cases is expected to rise by about 70% over the next twenty years. Among men the most common sites of cancer diagnosed in 2013 were lungs, prostate, colorectum, stomach and liver cancer. Among women are breast, colorectum, lungs, cervix and stomach cancer.

There are many types of treatment and surgeries available for cancer they are surgery, chemotherapy, radiation therapy, targeted therapy, immunotherapy, stem cell transplant, photodynamic therapy, blood product donation, transfusion and microwave hyperthermia. The treatments other than hyperthermia has some negative side effects on the body. Therefore MWH is the upcoming major subject of interest of inquisition biological effects and its application on treatment of tumour and cancer.

Hyperthermia is a thermal therapy, is a type of cancer treatment in which the tumor of the body is exposed to slightly higher temperature than the normal body temperature [1] (up to 42-45 degree celcius). The research it has been shown that high temperature can damage the proteins and structures within cells and due to which there is shrinkage in the size of the tumor, it uses non-ionizing radiation therapy that can substantially improve results for cancer treatment [2]. The cancer cells are more responsive to hyperthermia effects than the healthy cells because of high rate of metabolism [3]. The basic principle of MWH is to apply microwave power to the tumor tissue through a microwave applicator that is antenna. The power of the EM waves is absorbed by the tissue and heats it, resulting in excitation and oscillation of the polar molecules and causing frictional heating, which results in cell death.

B. Types of Hyperthermia:

There are different methods through which the transfer of heat energy can take place into the body, namely local hyperthermia, regional hyperthermia and whole body hyperthermia

1) Local Hyperthermia:

Local body hyperthermia is used to expose a small area of tumor about 5 cm area to very high temperature. It involves heating the cells with very high temperature. The heat may be applied to the tumors using the following techniques

1) External approaches are used to treat tumors that are in or just 2cm below the skin. The applicators are fixed around or near the appropriate region, and wave energy is focused on the tumor to raise its temperature.
2) Intraluminal or endocavitary methods may be used to treat tumors within or near body cavitites, such as the esophagus or rectum. Probes are placed inside the cavity and inserted into the tumors to deliver energy and heat the area directly.
3) Interstitial technique are used to treat tumors deep inside the body, such as brain tumors. This technique allows the tumor to be heated to higher temperature than external techniques. Under anesthesia, probes or needle are inserted into the tumor. The ultrasound imaging technique is used to make sure the probe is properly inserted into the tumor. The heat source is then inserted into the probe and the tumor is heated through EM waves.

2) Regional Hyperthermia:

In this type different approaches are used to heat large areas of tissue, like cavity, organ of limbs. In this external applicators are used for deep tissue which are positioned around the body cavity and organ to be treated and the energy from the applicators is used to increase the temperature of that area [4].

3) Whole Body Hyperthermia:

This type of treatment is used to treat the cancer which is spread out all over the body. Thermal chambers or warm water blankets are used to raise the temperature of body above normal up to 45 degree celcius [4].

Many different antenna design for interstitial applications have been proposed by different author at different frequencies, the designs were optimized and verified. For heating tumors which are under the body for about 10-15 cm deep, coaxial based antennas are very effective for MWA application because of their small dimensions, low cost and effective input power. Coaxial antennas differ in many ways on the basis of dimension at a particular frequency, the input power level which it can handle and giving effective output, shape and size of tumor and its depth, etc. Backward heating is one of the major problems for MWA in the interstitial type of application, back heating occurs along the coaxial feed line of the antenna or applicator. This backward heating causes damage

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to the tissue outside the desired treatment region which may lead to burning of the skin during percutaneous treatment.

Several types of coaxial-based antennas, including the coaxial slot antenna [7,8], coaxial dipole antenna [5,6], coaxial cap-choke antenna [9]. Many researchers are doing effort to develop the less invasive interstitial antennas for microwave ablation for treating the cancer tumors. These antennas are capable of focusing the EM wave and producing highly localized patterns of electromagnetic power deposition in the tumors.

In part II the geometry of coaxial slot antenna is described. In part III thermal characteristics of the antennas has been investigated using Finite integration technique. In part IV the Results were discussed. Finally, conclusions are presented in part V.

II. DESIGN OF APPLICATOR

The author has been studying coaxial antennas for minimal invasive microwave thermal therapies. The below Fig.1 shows the geometry of the coaxial slot applicator [10]. The operating frequency for the applicator is 915 MHz, which is one of the ISM (Industrial, Scientific and Medical) frequencies. The coaxial slot applicator is made of thin semi-rigid coaxial cable. There are two slots made on the outer conductor of the applicator and the tip is short-circuited. The spacing of the slot is taken as lambda/4 and lambda/8 respectively [10] for power deposition near the slots of the antenna for effective radiation.. The effective wavelength can be mathematically calculated using equation 1,

$$\lambda = \frac{c}{f\sqrt{\varepsilon_r}} \text{ (m)} \qquad (1)$$

Where, c is the speed of light in free space (m/s), f is the operating frequency of the generator (915 MHz), and ε_r=54.997 is the relative permittivity of the muscle at the operating frequency. The inner conductor is constructed using silver coated copper wire, the dielectric used is a low-loss Teflon (PTFE). The outer conductor is made of copper with two ring slots on it at lambda/8 and lambda/4 distance from the tip, which has a width of 1mm for Microwave propagation into the tissue.

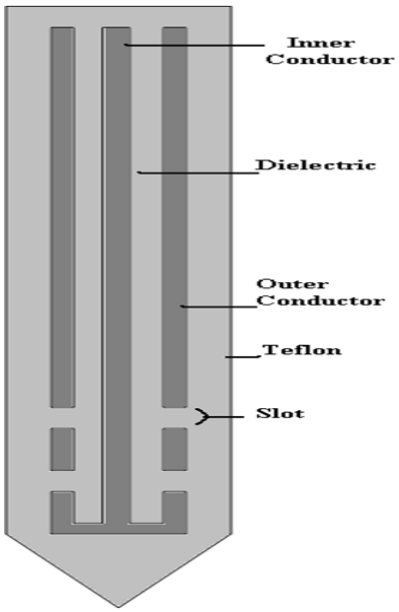

Fig. 1: Structure of the applicator Geometrical dimension of the applicator in mm

Parameter	Value
Radius of inner conductor	0.255
Radius of Dielectric	0.84
Radius of outer conductor	1.1
Radius of catheter	1.125
Length of tip	2
Material	Relative Permittivity
Inner dielectric of coaxial cable(Teflon)	2.03
Catheter dielectric constant	2.60
Muscle tissue	54.997

III. THERMAL CHARACTERISTICS OF ANTENNA

For the simulation of the proposed applicator the software package used is CST Studio suite, which is based on MAFIA where MAFIA stands, "solving Maxwell equations using finite integration algorithm technique. The simulation is carried out in 2D axial symmetric model to minimize the computation time and to give good resolution and preserving the full 3D nature of the fields. The software allows us to specify the geometry of the applicator and then solves the Maxwell's equations and Pennes bio-heat equation in the surrounding tissue.

In the paper the temperature distribution of the array of applicator is to be analyzed by numerical simulations. The important factor to calculate the absorption of heat in the human body is the SAR that is specific absorption rate [11].

The SAR is a measure of rate at which the energy is absorbed by the body or the tissue when it is exposed to electromagnetic radiation, its unit is watts per kilogram (W/kg). The SAR can be calculated at any position.

Mathematically:

$$\text{SAR}=\frac{\sigma}{\rho}E^2 \text{ (W/kg)}$$

Where σ is tissue conductivity (S/m), ρ is tissue density (kg/m^3) and E is the electric field (rms) (V/m). The SAR pattern of a particular antenna causes the temperature of the tissue to rise, but it does not specify the final tissue temperature. Next, we analyze temperature distribution in the tissue using the SAR values calculated by MAFIA technique in CST studio suite. The bio-heat transfer equation is given by

$$\rho c\frac{\partial T}{\partial t}=\nabla\cdot(k\nabla T) -\rho\rho_b c_b F (T-T_b)+\rho.\text{SAR} \qquad (2)$$

Where T is tissue temperature, t is the time, ρ is the density,

C is the specific heat, k is the thermal conductivity, ρ_b is the density of blood, c_b is the specific heat of the blood, T_b is the temperature of blood, and F is the blood flow rate.

IV. RESULTS AND DISCUSSION

The above geometry of the applicator has been constructed in CST studio suite, which is based on finite integration technique (FIT). This technique uses a spatial discretization scheme on the coaxial slot antenna to numerically solve the electromagnetic field problems in frequency and time domain. The mesh cells consists of 161359 cells which are dense near the end point of the applicator, where the temperature is to be found out.

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The SAR pattern of the applicator simulated in CST studio suite is shown in Fig23 and the plot of the SAR is in dB. The thermal model of the applicator of the applicator was found using the post processing option in CST studio suite. The SAR value shows the how much heat the body can absorb per kg when the applicator or the antenna is applied in the vincinity of the tumor. Fig 3 shows the temperature distribution of the applicator near the tip, the temperature is near about 55-60 degree celcius. For MWH the temperature around the tip should be around in the range of 40-45 degree celcius, here it is around 55 degree celcius which is very good. The temperature distribution can be controlled by the incident power to the applicator or antenna, here the applied power is around 10 W, if the power is decreased the temperature around the tip can also be decreased and controlled in the range of 40-45 degree celcius. Hence this applicator can be used to heat the tissue which are located deep inside.

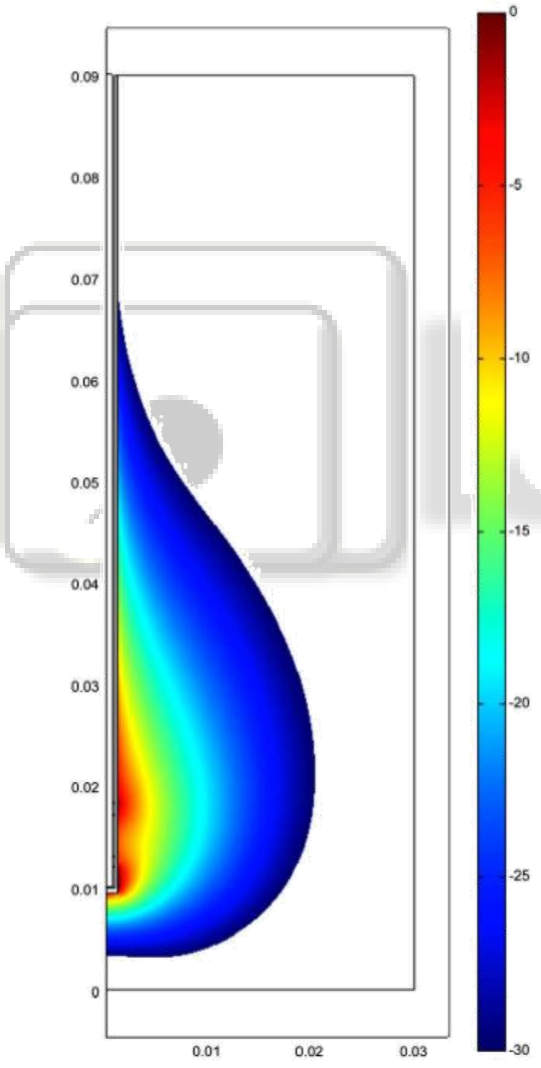

Fig. 2: SAR pattern of the coaxial slot antenna in dB.

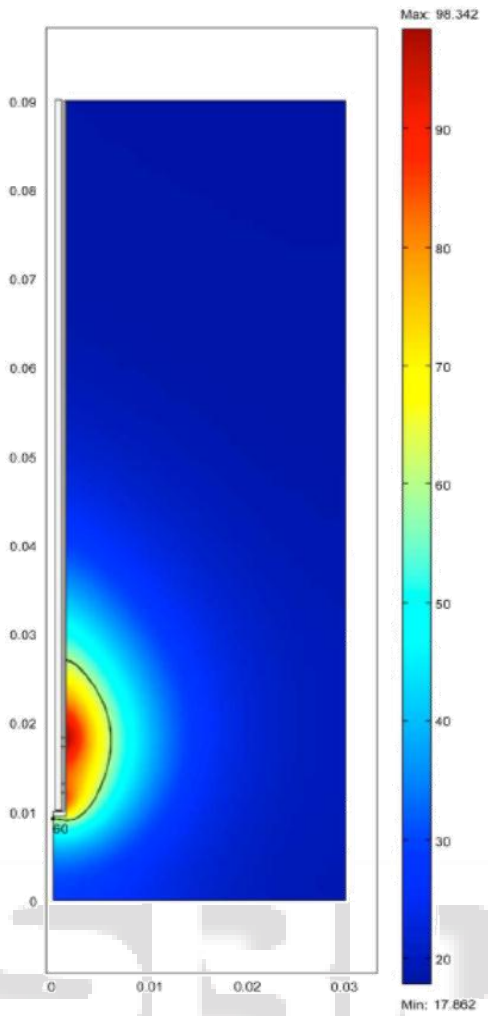

Fig. 3: Temperature distribution near the tip (about 60 degree celcius)

V. CONCLUSION

We have designed a coaxial slot antenna for interstitial Microwave Hyperthermia, the dimension of which was calculated at 915 MHz, the geometry was constructed in the CST studio suite software and it was simulated. The results, SAR distribution and the temperature distribution of the antenna were calculated. Furthermore, the temperature distribution of the antenna is around 55-60 degree celcius which shows that the above antenna can be used to heat the tumors which are deep inside the body.

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