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# Microwave Ablation Antenna Design: Interaction of Microwaves with Liver Tissue

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**Abstract**: Microwave and radio frequency (RF) energies have been used to treat tumors, cancer, arrhythmias etc. The prime goal of ablation technology is to kill the liver tumor while preserving the healthy liver tissue. Microwave ablation (MWA) is a new challenging multidisciplinary technology for the treatment of cancer that has propelled the scientist and technologist to develop the novel microwave antennas to destroy the deep seated tumors. Before designing any novel antenna the preliminary approach is to explore the design requirement of the antenna with respect to a particular application. In this research paper author has explored the interaction of microwaves and the design requirements of miniaturised interstitial microwave antennas for liver tumor.

**Keywords**: Microwave ablation (MWA), Specific Absorption Rate (SAR), Reflection Coefficient, Antenna

## I. INTRODUCTION

Microwave ablation (MWA) uses microwave frequencies, 915 MHz and 2.45 GHz to heat the tissue to lethal temperatures. With the development of the applications of microwaves in MWA, microwaves are used to treat larger and deep-seated tumors in shorter period of time with less complication.
Many advantages of microwave ablation over other ablative therapies have driven researchers to develop innovative interstitial microwave antennas to effectively treat deep seated, nonresectable hepatic tumors.

Although different types of antennas have been proposed for MWA for the treatment of liver tumor, but researchers have primarily focused on thin, coaxial-feed line-based interstitial antennas.

With recent improvements in the newly designed antennas, their capability to deliver a large amount of electromagnetic power in more localized patterns, and less backward heating have proven that, MWA antennas are more suitable for various kind of thermal ablation treatments [1].

Although clinical tests are battle field for evaluating the performance of these devices, but are risky, expensive, time consuming, and limited in scope. Computational methods for the simulation of microwave ablation treatment are invaluable tools.

The complex geometries and tissue properties involved in simulation of MWA, especially blood perfusion, make computer simulations an ideal choice over analytical solutions which require many simplifying assumptions. Hence the design of antenna based upon, the dimensions of antenna and penetration depth are of primary importance [2].

## II. INTERACTION OF MICROWAVES WITH TISSUE AND ITS HEAT ABSORBTION

The electric and magnetic fields E and H were originally defined to account for forces; hence, the fundamental interactions of E and H with biological tissue are the forces exerted on the charges in the tissue.

The electric fields are associated with forces in the presence of electric charges whereas the magnetic field exists as a result of the movement of electric charges (electrical currents) [3]. These propagation and absorption of microwaves in tissue is basically governed by Maxwell's equations.

However, the interaction of microwaves with tissue is actually more complicated, because, time varying electric field creates induced dipoles, aligns the existing dipoles within the material, alters the bound-charge orientation, and forces the electric charges to form electric currents.

Three parameters are defined to describe these effects macroscopically, namely permittivity, conductivity and permeability [4]. In general, biological materials are composed of a complex mixture of water, ions, polar and non-polar molecules, proteins, lipids and others.
Characteristics of the dielectric properties of such complex materials are heavily dependent on their actual composition and the environment, as well as EM frequency and temperature.

Once the electric field goes straight through the body tissues, the electromagnetic energy turns into heat due to dielectric losses. This means that, as long as the electric field travels across the human body, it decreases its energy and increases the temperature in surrounding tissues. The transportation of thermal energy in biological tissue is a complex process, the increase in temperature within the

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human body when electromagnetic energy is present is influenced by other phenomena such as conduction, convection, radiation, metabolism heat generation, thermal migration, blood perfusion, tissue water evaporation, condensation, etc.

It is very difficult to study such a complex process; especially when behavior of tissue is unpredictable, at high temperatures. Unfortunately, MWA is one of the thermal ablative technologies which heats the tissue to a high temperature enough for all the phenomena to happen

The specific absorption rate (SAR) is used in dosimetry to denote the transfer of energy from the EM fields to biological tissue (rate of energy deposition per unit mass of tissue).

The SAR is defined as the rate of change of energy absorbed by charged particles within an infinitesimal volume at that point within an absorber, averaged by the mass of that small volume or the rate at which energy is deposited in any kind of material per unit of mass; that is, the power absorbed by the tissue per unit of mass.

Thus, SAR is the parameter employed to quantify the electromagnetic magnitudeand its absorption inside biological tissues. In other terms, SAR can be seen as the velocity at which the human body absorbs the electromagnetic energy [5].

$$SAR = \frac{\partial w/\partial t}{\rho} \qquad (1)$$

However, the rate of change of energy $\partial W/\partial t$ is equivalent to power density (P). Hence the above equation can be rewritten as:

$$\mathrm{SAR} = \frac{\mathrm{P}}{\rho} \qquad (2)$$

Re-formulated equation to relate the SAR to internal E fields becomes:

$$\mathrm{SAR} = \frac{\sigma}{\rho}|\mathrm{E}|^2 \qquad (3)$$

Where $\rho$ is the electric charge density, $\sigma$ is the electric conductivity, E is the electric field intensity. The scope of the SAR evaluation includes virtually all RF transmitting devices that are used in close proximity to the human body and transmit more than 20 mW of RF power [6]. The relationship between SAR and the resulting temperature rise is quite complex, and is dependent on many parameters.

The traditional continuum heat-sink model, developed by Pennes [7], was found to give remarkable accurate results in many circumstances. For heat transfer in the tissue, the temperature profile in tissue during ablation is obtained by solving a bioheat equation. Hence Pennes bioheat equation is the most widely used bioheat equation for modeling thermal therapy procedures.

The Pennes' Bioheat equation effectively describes how heat transfer occurs in biological tissue and evaluates the rate of change of temperature due to the heat absorption.

$$\rho c \frac{\partial \mathrm{T}}{\partial t} = \nabla \cdot k \nabla \mathrm{T} + SAR - \rho_{b1} c_{b1} w_{b1} (\mathrm{T} - \mathrm{T}_{b1}) \qquad (4)$$

Where T is the tissue temperature (K), $\rho$ is the charge density for tissue (kg/m3), c is specific heat capacity (J/kg.k), k is thermal conductivity (W/m.k), $\rho_{b1}$ is blood density (kg/m3), $c_{b1}$ is the specific heat capacity of blood (J/kg.k), $w_{b1}$ is blood perfusion rate (kg/m3.s), $\mathrm{T}_{b1}$ is blood temperature (K), SAR is the microwave power per unit volume applied by MWA (W/m3).

The major physical phenomena considered in the Bioheat equation are microwave heating and tissue heat conduction. Heat conduction between tissue and blood flow in tissue is approximated by the term $\rho_{b1} c_{b1} w_{b1} (\mathrm{T} - \mathrm{T}_{b1})$ in the above equation. Heat radiation and metabolism heat generation are assumed to be minimal during MWA and are ignored [8].

Since the Bioheat equation modeling of the heat transfer in perfused tissues cannot account for the actual thermal equilibration process between the flowing blood and the surrounding tissue, hence it does not cover convective heat transfer, tissue water evaporation and water vapor condensation. Although new models based on a more realistic anatomy of the perfused tissue are developed, but due to the lack of experiment grounding and inherent complexity, the Pennes model is still the best practical approach for modeling Bio-heat transfer in living tissue. When applied under valid conditions, the Bioheat equation has proved to be a viable approximation for heat transfer in biological tissues [9-13].

The efficiency of antenna may be depicted by reflection coefficient S11, which can be expressed logarithmically as in equation 5. The frequency, at which the reflection coefficient is minimum, is referred as resonant frequency and should be approximately same as the operating frequency of the microwave generator used. Antennas operating with high reflection coefficients (especially at higher power levels) can cause overheating of the feed line, possibly leading to damage of the coaxial line or of the tissue due to the thin outer conductor.

$$\mathrm{S11} = -10\ \mathrm{Log}_{10} \frac{\mathrm{P_r}}{\mathrm{P_{in}}} [\mathrm{dB}] \qquad (5)$$

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## III.DESIGN REQUIREMENT OF MWA ANTENNA

It is desirable for the MWA antenna to satisfy the following performance characteristics: i) The antenna applicator diameter (3.5 mm) should be small ii) The inner conductor, outer conductor, dielectric, slots, choke, sleeve etc. must have optimum coupling in between. iii) The antenna must be efficient in term of reflection coefficient S11 (< −10 dB) over a wide frequency range.

The tradeoffs between antenna size, impedance matching and reflection coefficient are of primary importance [14]. The transmission line theory explains the relationship between the impedances. The outer conductor, surrounding dielectric of the catheter, and conductive tissue can be thought of as a lossy transmission line. Then, using the knowledge that the input impedance of a transmission line is equal to

$$Z_{in} = jZ_0 \tan(\beta h + j\Theta h) \qquad (6)$$

where Z0 is the characteristic impedance of the segment, β is the wave number, and h is segment length with the terminal function Θh=0 for an open-ended segment and for a short-circuited segment, the impedance of the segments above and below the gap/slot/choke can be determined.

From this expression, the total impedance of a coaxial-fed interstitial antenna having two segments (A and B) can be written as the sum of the individual input impedances of segments A and B

$$Z_d = Z_{inA} + Z_{inB} \qquad (7)$$

where ZinA and ZinB correspond to the extensor region and insertion region and Zd is the impedance seen at the gap. A symmetric segment lengths with respect to λeff yields excellent matching to the 50 Ω feed line and good power transfer.

Antenna geometry parameters, the slot spacing, choke offset, choke length, floating sleeve length, etc, are chosen based on the effective wavelength in bovine liver tissue at 2.45 GHz, calculated using equation [15]:

$$\lambda_{eff} = \frac{c}{f\sqrt{\epsilon_r}}[m] \qquad (8)$$

where c is the speed of light in free space (m/s), f is the operating frequency of the microwave generator (2.45 GHz), and εr = 43.03 is the relative permittivity of bovine liver tissue at the operating frequency; this yielded the effective wavelength of approximately 19 mm (18.6 mm).

The Equation only provides a very crude approximation for the design [16]. Generally slot spacing, choke offset, choke length, floating sleeve length correspond to 0.25λeff, 0.5λeff, and λeff respectively, which are chosen to achieve localized power deposition near the distal tip of the antenna.

## IV. CONCLUSION

In this paper, the fundamentals of bioelectromagnetics have been presented. The interaction of microwaves with tissue has been explained with the aspect of the Maxwell equation, complex permittivity, SAR, S11, and bioheat equation.The thermal responses of biological tissues during MWA have been explained for the evaluation of energy absorption in the exposed targets. The design requirements of coaxial MWA antenna based upon thetradeoffs between the size of coaxial antenna, its impedance matching between inner and outer conductor with respect to operating frequency and reflection coefficient has also been deliberated.

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