FINITE-DIFFERENCE-TIME-DOMAIN SIMULATION OF INSULATED MONOPOLE IN BRAIN TUMOR HYPERTHERMIA TREATMENT

LEE CHIA WUI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

NOVEMBER 2015

To education in science

ACKNOWLEDGEMENT

The completion of this thesis has involved help from many peoples and academician. In particular, I wish to express my sincere thanks to my supervisor Dr. You Kok Yeow for his guidance. Without his guidance, this thesis would not have been the same as presented. Special thanks to Librarian at University Teknologi of Malaysia (UTM) for supplying the relevant literatures. My sincere appreciation also extends to all my colleagues and others who have provided assistance. Last but not least, I am grateful to my family members.

ABSTRACT

Hyperthermia treatment has been used to treat brain tumor diseases where conventional surgical removal is invasive and poses threat to a patient. The treatment technique is to apply microwave energy which transforms into heat on the target tumour without overheating surrounding healthy tissue. The insulated monopole has proven to be suitable as an applicator in hyperthermia treatment whereby its thin slot form and small cross section area allows it to reach deep seated brain tumour. Nowadays, simulation is used to evaluate insulated monopole design. However, existing commercial simulators are difficult to learn and operate. In this study, a simple and user friendly finite-difference-time-domain (FDTD) based simulator written in MATLAB codes is developed for hyperthermia brain tumour treatment. Using the developed simulator, electric field, specific-absorption-rate (SAR) distribution and reflection coefficient of two designed insulated monopoles have been studied. The first designed insulated monopole is a simple insulated monopole with thin air gap. The second design is a multi-layer insulated monopole used to treat large deep-seated brain tumour. The resulting electric field and SAR distribution were compared and validated against analytical solutions and commercial simulator's results, respectively. The simulator's result was found to be more accurate with less reflection at the wave scatter boundary when complex frequency shifted perfectly matched layer (CFS-PML) absorbing boundary condition was used. And the optimal parameters of the absorbing boundary condition CFS-PML in reducing computation cost were identified to be 10 layers with the degree of polynomial, $m = 4$.

ABSTRAK

Rawatan hipertermia telah digunakan untuk merawat tumor otak di mana kaedah pembedahan konvensional adalah invasif dan membahayakan pesakit. Rawatan ini menggunakan tenaga gelombang mikro untuk menjanakan tenaga haba supaya memanaskan tumor tanpa memanaskan tisu yang sihat di sekelilingnya. Ekakutub tertebat adalah peranti yang sesuai digunakan sebagai aplikator dalam rawatan hipertermia. Ini disebabkan aplikator tersebut mempunyai keratan rentas yang kecil dan terpencil di mana ia dapat mencapai kedudukan tumor yang terletak dalam rongga otak. Kini, ekakutub tertebat biasanya direka dengan menggunakan simulator. Tetapi, simulator komersial sedia ada sukar dioperasikan dan dipelajari. Dalam kajian ini, simulator yang mudah dan mesra pengguna berdasarkan kaedah perbezaan-terhingga-domain-masa (FDTD) telah dibina dengan menggunakan kod MATLAB. Dua jenis ekakutub tertebat telah direka dan dikaji dengan simulator tersebut dan prestasinya ditentukan berdasarkan taburan medan elektrik, taburan kadar-penyerapan-tentu (SAR) dan pekali pantulan masing-masing. Bentuk ekakutub pertama adalah ekakutub tertebat yang asas dengan lapisan udara di tengah. Bentuk ekakutub yang kedua ialah ekakutub tertebat berbilang lapisan yang diguna untuk merawat tumor otak yang besar dan letak dalam. Penyelesaian simulasi seperti taburan medan elektrik dan SAR telah dibandingkan dengan penyelesaian beranalisis dan kaedah unsur terhingga dan didapati lebih tepat disebabkan pengunaan lapisan padanan sempurna teranjak frekuensi kompleks (CFS-PML) yang mengurangkan pantulan di sempadan serakan gelombang. Parameter optimum yang dikenal pasti untuk CFS-PML dalam mengurangkan kos pengiraan komputer adalah 10 lapisan pada darjah polynomial, $m = 4$.

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LIST OF ABBREVIATIONS

ABC	-	Absorbing Boundary Condition
CFS	-	Complex Frequency-Shifted
CPML	-	Convolutional Perfectly Matched Layer
EM	-	Electromagnetic
FEM	-	Finite Element Method
FDM	-	Finite Difference Method
FDTD	-	Finite Difference Time Domain
MoM	-	Method of Moments
PDE	-	Partial Differential Equation
PEC	-	Perfect Electric Conductor
PML	-	Perfectly Matched Layer
SAR	-	Specific Absorption Rate
TEM	-	Transverse Electromagnetic
TM	-	Transverse Magnetic
UPML	-	Uniaxial Perfectly Matched Layer

LIST OF SYMBOLS

ε	-	permittivity
σ	-	conductivity
E	-	electric field
H	-	magnetic field
B	-	magnetic flux density
D	-	electric flux density
J	-	electric current density
ρ	-	electric charge density
k	-	complex wavenumber
Z	-	characteristic impedance
q	-	electric charge per unit length
p	-	density
λ	-	wavelength
Γ	-	reflection coefficient
C_p	-	Heat Capacity
K	-	Thermal conductivity
ω	-	volumetric perfusion rate
T	-	Temperature

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

In medical field, hyperthermia treatment has been seen as a better alternative treatment to tumor disease (Moroz *et al.*, 2002). Conventional practicing treatment such as surgical operation, chemotherapy and radiotherapy leave side effects to patient, as it is not localized on the tumor and rather toxic in the process. Hyperthermia treatment on the other hand is the opposite, where thin needle shape of insulated monopole antenna is penetrated into the target tumor tissue through skin and electromagnetic wave is radiated to produce heat as shown in Figure 1.1. Eventually, the surrounding temperature of tumor tissue cell increased to the therapeutic temperature between 42 and 45 °C for the purpose of destroying cancer tumor cells (Guojun *et al.*, 2010).

For hygienic purpose, near lossless dielectric material is used to cover the conductor of the bare monopole antenna. In the process of the treatment, temperature near to the antenna can reach 100 ℃. Air gap is introduced between the conductor and the tumor cells to protect the antenna.

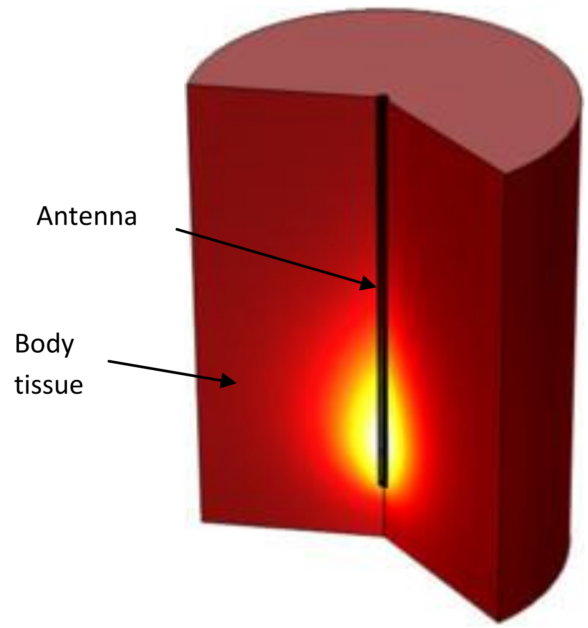

Figure 1.1: 3-D cross sectional view of thin monopole antenna radiating wave to produce heat.

In hyperthermia study, the primary interest is the near field close to the antenna where most of the heating takes place. Different design configuration of the monopole and Radio frequency (RF) or thermodynamic parameters will produce different heat distribution. Due to complexity of configuration of monopole antenna (multilayer insulated monopole antenna), researchers nowadays use simulator to calculate the heat distribution in preliminary design stage of antenna. In this study, finite difference time domain (FDTD) is employed to study the electromagnetic field and specific absorption rate (SAR) distribution produced by the insulated monopole. FDTD has the advantages of being simple to implement and capable of wideband analysis compare to other method such as finite element method (FEM) and Method of Moment (MoM). Detail description of FDTD will be available in Chapter 2. On the other hand, finite difference method (FDM) is subsequently used to calculate the heat distribution using SAR distribution as heat source.

The research work is divided into two parts. The first part is to validate the computational result by studied simulator with the calculated result from the analytical method and commercial software. The model used in the validation is a simple one layer insulated monopole and the validated result includes electric field distribution, input impedance, and heat distribution which are the essential parameters in brain tumor hyperthermia treatment (Ahn *et al.*, 2005). In the second part, the studied simulator is used to design multi-layers insulated monopole and calculated performances are validated using commercial software, so-called COMSOL Multiphysics.

1.2 Problem Statements

Recently, most of the commercial simulators are catered for multidisciplinary purpose due to competitive market. Thus, this kind of simulator has a lot of parameters or constant values are required to be properly defined before performing the simulation. In this study, a simple, accurate and user friendly graphical-user-interface (GUI) FDTD-based simulator particularly for insulated monopole will be developed for hyperthermia brain tumor treatment.

Brain tumors are among the most difficult forms of cancer to treat as brain tumor can be large and deep seated in brain cavity. The insulated monopole is an appropriate selection to treat brain tumor with hyperthermia technique since it is long, thin and small in cross sectional area to reach the targeted tumor. Furthermore, the monopole antenna’s return loss has to be low to achieve the maximum energy transfer to the brain tumor from the monopole.

Besides, deviation between experimental result and simulation result in open-ended FDTD simulations caused by reflected outgoing electromagnetic waves from computational domain’s boundary is also improved in this study.

1.3 Objectives of the Study

Create FDTD-based GUI simulator using MATLAB to solve the insulated monopole problems. The 2-D studied simulator is particularly used to simulate insulated monopole in brain tumor for hyperthermia application.

On the other hand, the sub-objective of this study is to identify the optimal parameters of the absorbing boundary condition-CPML used in FDTD in order to improve the accuracy of the simulation.

1.4 Scopes of the Study

Scope of this study can be broken down as:

i. To review analytical method, FEM and FDTD methods in solving insulated monopole's problem and identify their advantages and disadvantages.
ii. To validate the accuracy of studied simulator and improve it by reducing the reflection from the boundary.
iii. To determine electric field and heat distribution radiated by insulated monopole in brain tumor hyperthermia application using studied FDTD-based simulator.
iv. To use parameters from available published *ex-vivo* experimental work (Ahn *et al.,* 2005) in simulation work. Experimental work will not be part of the study.

1.5 Motivation of the Work

Recently, hyperthermia treatment has been proven to be capable and reliable to treat cancer tumor (Sterzer, 2002). Therefore, this project is held to contribute in respective field especially in brain tumor treatment. In fact, the hyperthermia treatment performance can be referred to the numerical simulation result without actual build of the treatment system.

However, electromagnetic field and heat distribution simulations involve both complex mathematics and numerical computation that are difficult to comprehend and master. Through this work, better understanding of the underlying can be gained and eventually improves simulation accuracy. Improving accuracy in simulation will decrease the cost in designing applicator for hyperthermia treatment and deliver better guarantee of its use.

1.6 Thesis Outline

The thesis is divided into 6 chapters. Chapter 2 reviews history and theoretical background of analytical and numerical method on insulated monopole. Advantages and disadvantages between FDTD and FEM are also compared. Next, different designs of insulated monopoles used as applicator in hyperthermia treatment are presented. Finally, brief theoretical background of absorbing boundary condition used to absorb scattering electromagnetic waves at the boundary is outlined.

Chapter 3 describes the methodology used to develop the FDTD-based simulator. MATLAB codes on source excitation, post processing, SAR and heat distribution calculations are presented. Assumption and boundary conditions used are mentioned.

Chapter 4 discusses the validation results of developed simulator with analytical method and commercial software. The optimized parameters for absorbing boundary conditions to reduce computation resource are also addressed.

Chapter 5 presents the application of developed simulator on multi-layer insulated monopole used in brain tumor hyperthermia treatment. The validation of simulated result with commercial simulator, namely COMSOL Multipyhsics 4.2, is also presented.

Chapter 6 concludes this project and presented future work recommendation to further reduce the differences between simulation result and experimental result in brain tumor hyperthermia.

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