Simulation of Single Channel Magnetic Induction Tomography for Meningitis Detection By Using COMSOL Multiphysics

Aiman Abdulrahman Ahmed¹, Zulkarnay Zakaria*, Marwah Hamood Ali², Anas Mohd Noor¹, Siti Fatimah Binti Abdul Halim¹, Ahmad Nasrul Norali¹, Jaysuman Pusppanathan³, Ruzairi Abdul Rahim⁴

¹ Biomedical Electronic Engineering, Faculty of Electronic Engineering Technology, Universiti Malaysia Perlis, Arau, Perlis, 02600, Malaysia.
² Faculty of Dentistry, University of Science and Technology, Sana’a, Yemen.
³ Sport Innovation & Technology Centre (SiTC), Institute of Human Centered Engineering (iHumen), Universiti Teknologi Malaysia, Skudai, 81310, Johor, Malaysia.
⁴ School of Electrical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Skudai, 81310, Johor, Malaysia

*zulkarnay@unimap.edu.my

Abstract. Meningitis is an inflammation of the meninges and the most common central nervous system (CNS) due to bacterial infection. Numbers of children who have bacterial meningitis are still high in recent 15 years regardless of the availability of newer antibiotics and preventive strategies. This research focuses on simulation using COMSOL Multiphysics on the design and development of magnetic induction tomography (MIT) system that emphasizes on a single channel rotatable of brain tissue imaging. The purpose of this simulation is to test the capability of the developed MIT system in detecting the change in conductivity and to identify the suitable transmitter-receiver pair and the optimum frequency based on phase shift measurement technique for detecting the conductivity property distribution of brain tissues. The obtained result verified that the performance of the square coil with 12 number of turns (5Tx-12Rx) with 10MHz frequency has been identified as the suitable transmitter-receiver pair and the optimum frequency for detecting the conductivity property distribution of brain tissues.

1. Introduction

Bacterial meningitis is a mortal disease in most conditions (90%) around the pre-antibiotic era [1],[2]. The possibility of being infected by meningitis will increase if the skull got injured [3]. The first efficient therapeutic intercession in bacterial meningitis bringing in reducing of death rate to 25% by installation of immune plasma supplemented immediately [4]. Epidemiological studies shown that there are several risk factors for bacterial meningitis which can attack anyone at any age, newborns, young children and young adults [5],[6].

Magnetic Induction Tomography (MIT) is preferred for imaging of biological tissue due to its non-invasively predicting and diagnosing the lesions that does not produce a hazard to human health rather than invasive technique. MIT is robust, contact-less and electrode-less technique which can be operated at a lower frequency. The interest of MIT is on the passive electromagnetic properties (PEP) that are conductivity ($\sigma$), permittivity ($\varepsilon$) and permeability ($\mu$). However, in this research conductivity property has been chosen as it is the dominant property in biological tissue [7],[8].
2. Principles of Magnetic Induction Tomography (MIT)

MIT is an imaging modality which applied the magnetic induction principle which consist of excitation coil (Tx), receiving coil (Rx), electronic circuits (amplifier, filter, conditioning circuit, etc.) and personal computer for image reconstruction algorithm. As shown in Figure 1, excitation field generated at the Tx, travels across the region of interest (ROI) where the object under investigation (biological tissue) is located. As a reaction to this excitation field, eddy current is induced within the tissues. This eddy current then generates its own field known as perturbation field or also known as secondary field or eddy current field. This secondary field is the interest at the Rx as it contains the information of the PEPs of the tissues [9],[10],[11] where in this research the focus in given to only conductivity property. The suitable frequency for MIT applications is within the Beta-dispersion region range [1][2][3].

![Figure 1. Magnetic induction tomography principle. [9]](image)

MIT operating principle of MIT is based on electromagnetic theory, which follows Maxwell law [11][14][15] which is shown in equation (1-4):

\[ \nabla \times \mathbf{H} = (\sigma + j\omega \varepsilon) \mathbf{E} \]  \hspace{1cm} (1)

\[ \nabla \times \mathbf{E} = -j\omega \mathbf{B} \]  \hspace{1cm} (2)

\[ \nabla \cdot \mathbf{D} = \rho \]  \hspace{1cm} (3)

\[ \nabla \cdot \mathbf{B} = 0 \]  \hspace{1cm} (4)

3. Simulation Using COMSOL Multiphysics

Simulation of the MIT system is using COMSOL Multiphysics software. The specification of transmitter Tx and receiver, Rx are shown in Table 1 and Table 2 respectively. Two types of transmitter and receiver have been simulated that are circular type (cir) and square type (sqr). For transmitter the difference is only on the diameter but with the similar number of turns, however for receivers, each types consist of 8 and 12 numbers of turns with diameters of 4.8 and 5.2 cm.

| Table 1. Transmitter design specification |
|------------------------------------------|
| Parameter          | TXcir5 | TXsqr5 |
| Diameter (cm)      | 4      | 4.2    |
| Number of turns    | 5      | 5      |
Table 2. Receiving coil, Rx design specification

| Parameter       | RXcir8 | RXcir12 | RXsqr8 | RXsqr12 |
|-----------------|--------|---------|--------|---------|
| Diameter (cm)   | 5.2    | 4.8     | 5.2    | 4.8     |
| Number of turns | 8      | 12      | 8      | 12      |

3.1. Two-Dimensional Model
Single channel MIT with 2D brain model is shown in Figure 2. The model is developed according to the tabulated parameters in Table 3 based on study by F. González [14][15].

![Diagram of brain-magnetic system 2D model](image)

Figure 2. The brain-magnetic system 2D model

Table 3. List of 2D model parameters

| Parameters                  | Values |
|-----------------------------|--------|
| Diameter of brain (cm)      | 12     |
| Diameter of tumor (cm)      | 1      |
| Frequencies used (MHz)      | 2-10   |

Figure 3 shows the simulation of excitation field of the transmitter for the meningitis effected brain tissue with circular and square transmitter based on the developed model as shown in Figure 2.
Figure 3. The excitation for the transmitter coil with the meningitis, (A) 12 turns of circular coil and (B) 8 turns of circular coil, (C) 12 turns of square coil and (D) 8 turns of square coil

4. Result

4.1 Phase shift with varying frequency based on normal brain tissue conductivity and varying conductivity of meningitis for different coils and number of turns.

i) Circular coil (TXcir5-RXcir12)

![Phase Shift Vs Frequency](image)

Figure 4. Phase shift for TXcir5-RXcir12
ii) Circular coil (TXcir5 - RXcir8)

![Figure 5. Phase shift for TXcir5 - RXcir8](image)

iii) Square coil (TXsqr5 - RXsqr12)

![Figure 6. Phase shift for TXsqr5 - RXsqr12](image)

iv) Square coil (TXsqr5 - RXsqr8)

![Figure 7. Phase shift for TXsqr5 - RXsqr8](image)

Figures 4 - 7 showed plots of the phase shift with varying frequency for the four coils and varying conductivity of meningitis. The graphs shown that the higher the conductivity, the higher phase shift will be produced. Higher conductivity reflects seriousness level of meningitis.
4.2 Comparison between the performances of the four coils based on the relationship between the phase shift and the conductivity range for each frequency value.

![Figure 8. Phase shift for different circular and square types of coils](image-url)
Figure 8 shows the performance of each coil among the four coils used based on the relationship between the phase shift and the conductivity range for the normal brain tissue and the meningitis. Graphs show that RXsqr12 has the highest performance compared to the other three coils.

The values of the phase shift that have been calculated based on the values of the voltage gotten from simulation by COMSOL5.0 with varies frequency for the normal brain tissue conductivity (10.92 mS/cm) and the meningitis conductivity range (15.92-35.97mS/cm) for RXsqr12 are shown in table 4.

Table 4. The calculated value of the phase shift with varies frequency and conductivity values.

| No | Conductivity (mS/cm) | Frequency (MHz) |
|----|---------------------|-----------------|
|    |                     | 2              | 4              | 6              | 8              | 10             |
| 1  | 10.92               | 91.4561        | 95.7211        | 102.3063       | 110.9764       | 121.3472       |
| 2  | 15.95               | 93.1242        | 101.4332       | 114.2128       | 130.1158       | 147.9261       |
| 3  | 20.99               | 96.2131        | 108.8324       | 128.7411       | 152.1492       | 165.5684       |
| 4  | 25.94               | 97.6533        | 117.6562       | 144.9246       | 166.4194       | 186.2534       |
| 5  | 30.93               | 100.5675       | 127.4516       | 162.9667       | 181.4135       | 189.3951       |
| 6  | 35.97               | 103.9783       | 137.9291       | 162.9667       | 181.4135       | 189.3951       |

The result of 10MHz frequency and RXsqr12 has been considered as the best frequency and coil respectively.

5. Conclusion

In this project, the objective is to identify suitable frequency and Tx-Rx pair for optimum signal detections is achieved. The result identified that 10MHz frequency and RXsqr12 has been considered as the suitable transmitter-receiver pair and the optimum frequency for detecting the conductivity property distribution of brain tissues.

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References

[1] Casemore D P, Armstrong M and Sands R L 1985 Laboratory diagnosis of cryptosporidiosis, J. Clin. Pathol. 38 12 1337–1341.
[2] Kornelisse R F 1996 Bacterial meningitis and sepsis in children: Clinical aspects and host response Rotterdam: Erasmus Universiteit Rotterdam, Afd. Kindergeneeskunde.
[3] Sell S H 1987 Haemophilus Influenzae Type b Meningitis: Manifestations and Long Term Sequelae, Pediatr. Infect. Dis. J. 6 8 775–778.
[4] Hussain I H M, Ali S, Ong L, Choo K, Musa M, and Teh K 1998 Haemophilus Influenzae meningitis in Malaysia, Pediatr. Infect. Dis. J. 17 9 189–190.
[5] Basri R, Zueter A R, Mohamed Z, Alam M K, Norsa’adah B, Hasan S A, Hasan H, and Ahmad F 2015 Burden of bacterial meningitis: a retrospective review on laboratory parameters and factors associated with death in meningitis, Kelantan malaysia, Nagoya J. Med. Sci. 77 59–68.
[6] McNeil H C, Jefferies J M and Clarke S C 2015 Vaccine preventable meningitis in Malaysia: epidemiology and management Expert Rev Anti Infect Ther. 13 6 705-14.
[7] O’Toole M D, Marsh L A, Davidson J L, Tan Y M, Armitage D W and Peyton A J 2015 Non-contact multi-frequency magnetic induction spectroscopy system for industrial-scale bio-impedance measurement, Measurement Science and Technology 26 3 17.
[8] Griffiths H 2001 Magnetic induction tomography, Meas. Sci. Technol. 12 2 1126–1131.
[9] Zakaria Z, Rahim R A, Mansor M S B, Yaacob S, Ayob N M N, Muji S Z M, Rahman M H F and Aman S M K S 2012 Advancements in transmitters and sensors for biological tissue imaging in magnetic induction tomography, Sensors 12 7126–7156.

[10] Luo H J, He W and Xu Z 2012 Preliminary Results on Brain Monitoring of Meningitis Using 16 Channels Magnetic Induction Tomography Measurement System, Prog. Electromagn. Res. 24 57–68.

[11] Marmugi L and Renzoni F 2016 Optical magnetic induction tomography of the heart, Scientific Reports 6 23962.

[12] Li X, Yu K and He B 2016 Magnetoacoustic tomography with magnetic induction (MAT-MI) for imaging electrical conductivity of biological tissue: A tutorial review, Physics in Medicine and Biology 61 18 249–R270.

[13] Deng Y and Liu X 2011 Electromagnetic imaging methods for nondestructive evaluation applications, Sensors 11 12 11774–11808.

[14] González C A, Silva J G, Lozano L M and Polo S M 2012 Simulation of Multi-Frequency Induced Currents in Biophysical Models and Agar Phantoms of Breast Cancer, Journal of Electromagnetic Analysis and Applications 4 8 317–325.

[15] González C A, Rojas R and Rubinsky B 2007 Circular and magnetron inductor/sensor coils to detect volumetric brain edema by inductive phase shift spectroscopy: a sensitivity simulation study IFMBE Proceeding 17 4 315–319.