

SIMULATION OF SINGLE CHANNEL BIOLOGICAL TISSUE SPECTROSCOPY USING COMSOL MULTIPHYSICS

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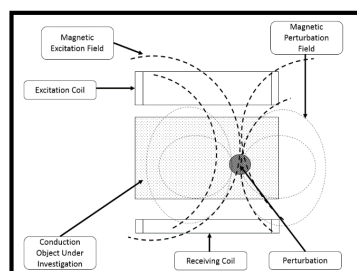
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Graphical abstract



Abstract

The enhanced ability to detect accurate location and measure the depth of a metal inside a biological tissue is very useful in the assessment of medical condition and treatment. This manuscript proposed a solution via the measurement of the tissue properties using magnetic induction spectroscopy (MIS) method to describe the characterization of biological soft tissue. The objective of this study is to explore the viability of locating embedded metal inside a biological tissue by measuring the differences the biological tissue electrical properties using principle of Magnetic Induction Spectroscopy (MIS). Simulation is done using COMSOL Multiphysics software for accurate information on the involved parameters for both metal and biological tissues. Simulation has confirmed that MIS capable of detecting and locate embedded metal inside a biological tissue.

Keywords: Magnetic Induction Spectroscopy (MIS), Foreign Metal, Phase Shift, Biological Tissue, COMSOL Multiphysics software

Abstrak

Penambahan kebolehan pengesanan ketepatan lokasi dan mengukur kedalaman logam dalam tisu biologi sangat berguna dalam pengesanan kondisi perubahan dan rawatan. Manuskrip ini mencadangkan satu penyelesaian melalui pengukuran sifat-sifat tisu menggunakan kaedah spektroskopi induksi magnet dalam menggambarkan ciri tisu biologi lembut. Objektif pengkajian ini adalah untuk meneroka keberdayaan dalam menentukan lokasi logam terbenam dalam tisu biologi perbezaan sifat-sifat elektrik tisu tersebut melalui teknik Spektroskopi Induksi Magnet (MIS). Simulasi dilaksanakan menggunakan perisian COMSOL Multiphysics bagi memberikan nilai tepat parameter-parameter yang terlibat untuk kedua-dua logam dan tisu biologi. Simulasi mengesahkan bahawa MIS berupaya mengesan dan menentukan lokasi logam terbenam dalam tisu biologi.

Kata kunci: Spektroskopi Induksi Magnet (SIM), Logam asing, Beza fasa, Tisu biologi, Perisian COMSOL Multiphysics

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1.0 INTRODUCTION

Foreign materials which are buried inside biological tissue due to an accident or gunshot could damage the surrounding tissue. This can be a surgical challenge due to infection and immunological response. It is possible that the eroded metal splinter could enter the bloodstream. Then, the fragments could lodge in any part of the body which later can cause infection and pain. Therefore, the doctors would have to know the location of the fragments before taking it out [1-4].

Magnetic Induction Spectroscopy; (MIS) is suggested as the best way for non-invasive or passive detection of the metal by using a multiple-frequency and induced magnetic fields which is applied through the system to get different output wave due to the interaction between different materials through the biological soft tissue. The interaction is referring to the measurement of radiation intensity as a function of wavelength [4, 5]. Figure 1 shows the principle of a typical MIS system.

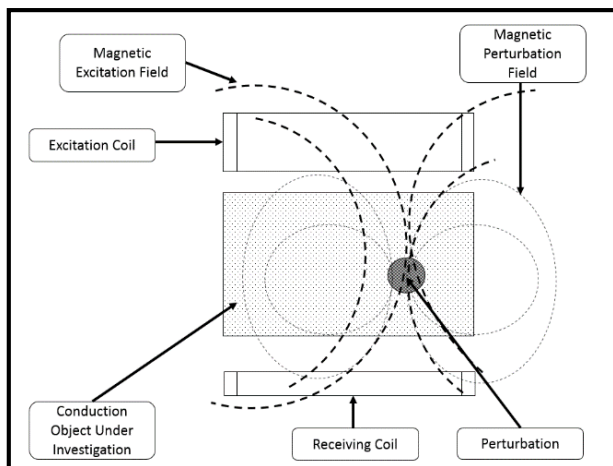


Figure 1 The principle of MIS

By studying the wavelength and the radiation intensity, it is possible to identify the tiny fragments of the metal in biological soft tissues and their reactions. This could serve as the first order clinical warning for the metal detection in the biological tissues. The design of a single channel biological tissue spectroscopy using COMSOL Multiphysics software refers to the MIS system which gives a value of spectroscopic conductivity information to use it to measure several types of material inside a piece of biological tissue.

2.0 MODELING PARAMETERS

COMSOL Multiphysics software is used for modelling and simulating the system which is the Single Channel Biological Tissue Spectroscopy to get the correct location of any foreign metal which burnt

inside a biological tissue. The simulation is performed on a single channel biological tissue spectroscopy, and we have design it via the principle of Magnetic Induction Spectroscopy by single channel and biological tissue.

2.1 Parameter of Transmitter and Receiver

Since we use the coils to generate the magnetic field, we specify the properties of the coils which important to generate strong magnetic field to cross the biological tissue and detect the properties of the sample by using the principle of Magnetic Induction Spectroscopy. Table 1 show the different parameter for the coils.

Table 1 The Different Parameter of the Transmission Coil and Receiver Coil

No.	Parameters	Excitation Coil	Detection Coil
1.	The number of turns	50 turns	50 turns
2.	The current applied	1A	1A
3.	The frequency range	1MHz -20MHz	1MHz -20MHz
4.	The diameter of wire	0.1 mm	0.1 mm
5.	The diameter of coils	2 cm	2 cm
6.	The distance from the coils to the tissue	1 cm	1 cm

2.2 Modelling using COMSOL Multiphysics

By using COMSOL Multiphysics, the excitation coil (EXC) is designed to produce a magnetic field across a sample which contains a small metal inside it. The magnetic field should be always in the form of perturbation of voltages and it is induced in receiver coil (REC) [5]. The signal will be simulated and modelled by using COMSOL Multiphysics. Magnetic Induction Spectroscopy requires an alternating magnetic excitation field to make the measurement of radiation intensity from the excitation coil (EXC) to the biological soft tissue under investigation. Whereas, the changing in the complex conductivity will make a change in the relative magnetic permeability in the output, caused by the perturbation due to the radiation intensity coupled from the interaction between matter and radiated energy as a function of wavelength in the object under investigation [2],[6-11]. Figure 2 show the mean part of the system designed are the coils and the sample which the muscle as example of biological soft tissue and the air around the system for accurate result.

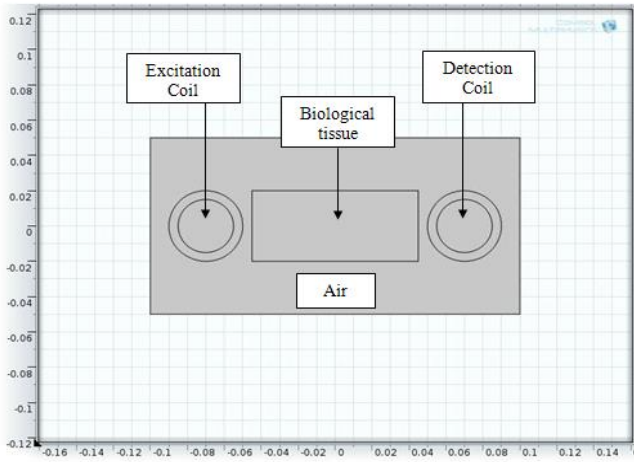


Figure 2 The main part of the system design

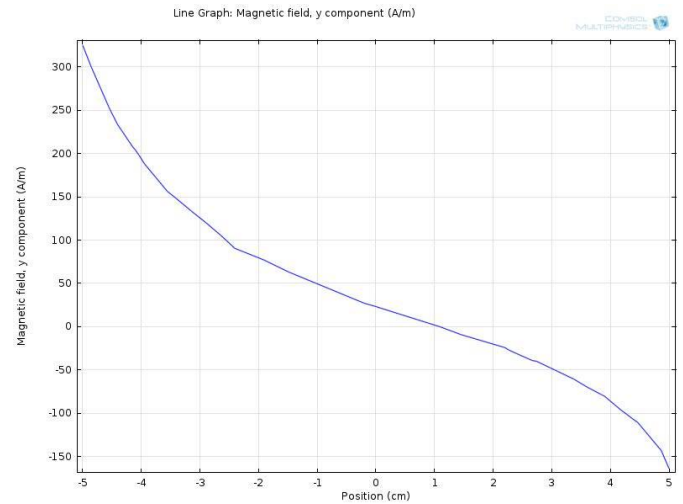


Figure 4 The result graph of the simulation

3.0 RESULTS AND DISCUSSION

3.1 Simulation without Tissue Sample

Since the result is not accurate especially when we increase the frequency range, we have tried to simulate a single channel with a new design which two coils, one is the excitation coil and the other one is detecting coil in circular shape, and the air is our medium. The simulation done by generating the magnetic field and catch the signal wave in the detector and use it for analysed the change on its magnitude after specify and add the biological tissue in the medium. The simulation was done through different frequency in the range of (1MHz – 20 MHz). Figure 3 show the simulation with air medium, and frequency range of 5 MHz and the result graph of the system as shown below in Figure 4.

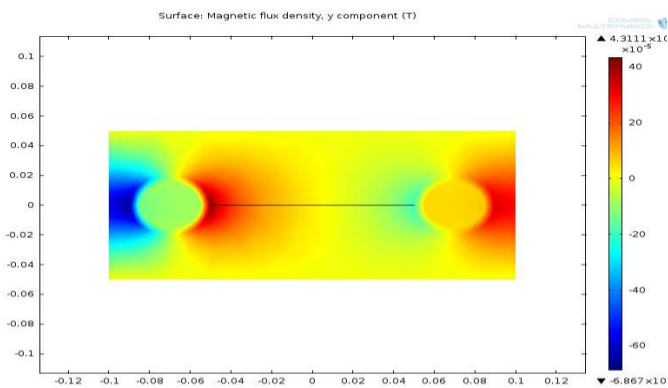


Figure 3 Electromagnetic field pattern of the simulation

3.2 Simulation with Tissue Sample

The simulation of the Single Channel Biological Tissue Spectroscopy using COMSOL Multiphysics requires a different parameter to identify different properties of the object (metal) and the biological tissue and the application of the magnetic induction frequency. Therefore, the output will give a phase shift on the signal which can be used to identify the samples.

After we set up the different parameter and properties of the biological tissue and using (muscle) as our sample, we specify the properties of the coils which important to generate strong magnetic fields to cross the muscle tissue and detect the properties of the sample by using the principle of Magnetic Induction Spectroscopy.

The Excitation coil contain of 50 numbers of turn which the best choice because, we have found that is impossible to generate strong magnetic fields with high frequency in the range of (1MHz-20MHz) to cross hard material such as biological tissue, and got good reading for the resulting wave in the detector.

The Detector coil comprises of 50 numbers of turns which the minimum requirement for our system to be able to detect the small change on the wave or the shift cause in the magnetic field which happen due to the shocked when the biological tissue contain any metal inside it. This winding results in a uniform magnetic field between the coils with the primary component parallel to the axis of the two coils. The uniform field is the result of the sum of the two field components parallel to the axis of the coils and the difference between the components perpendicular to the same axis.

To produce a strong magnetic field in the Excitation coil we added a current which required to flow in the Excitation coil and detection coil as well, and through some experiment which we were trying to choose the best and the minimum current, we found that the system need 1A of the current in the

Excitation coil and 0.5A in the detection coil.

An electric current is passed through the primary (Excitation coil), creating a magnetic field. Because of the common core, most of the primary's magnetic field couples with the secondary winding. The primary behaves as an inductor, storing energy in the associated magnetic field. When the primary current is suddenly interrupted, the magnetic field rapidly collapses. This causes a high voltage pulse to be developed across the primary terminals through electromagnetic induction because of the large number of turns in the primary coil.

Since we have chosen the range of the frequency are from (1MHz) to (20MHz), we did the simulation of the single channel biological tissue spectroscopy by 5 different frequencies which (1MHz, 5MHz, 10MHz, 15MHz, 20MHz) to compare between them and choose the best range of frequency which be able to use to detect any metal in the biological tissue sample.

Our simulation is going through different condition, the first one is the excitation coil and the detection coil and through the air medium to see the shape of the magnetic field as result in the detection coil. This stimulation has gone through the different type of frequency to do the comparison between them in this first condition.

The second condition is set up when the biological tissue which we choose the muscle as our sample in the middle between the excitation coil and the detection coil in the distance of (-0.045m) and (0.045m) in the x-axis. After applying a different range of frequency, we saw the shape of the wave of the magnetic field in the detector after crossing the biological tissue.

The third condition when specify a piece of metal have a length of (0.01 m) in a specific area which known in the distance between the excitation coil and the detection coil, from different material inside the biological tissue. In this case we choose three areas to study and did the simulation to detect the metal in different area and saw the output wave of the magnetic field as result in the detection coil.

We choose the first distance at x-axis at the point of (-0.035 m, 0 m) of the whole distance in the biological tissue and try two different materials which copper and iron, and see the difference and the similarity in our result. And the second area is in the distance of (0 m, 0 m), which in the middle of the biological tissue and with the same size of (0.01m) with the different material. The third area is in the distance of (0.035 m, 0 m), near the detection coil.

The result which I got from the stimulation containing the value of the flux density in each experiment which very important to identify the maximum and minimum flux, thereby to identify the distance of any tiny fragments of the metal in biological soft tissue. Flux means something quite different physics than it does in everyday conversation. In physics, the flux through an area is simply a measure of the number of field lines passing through an area, for instance, we could have

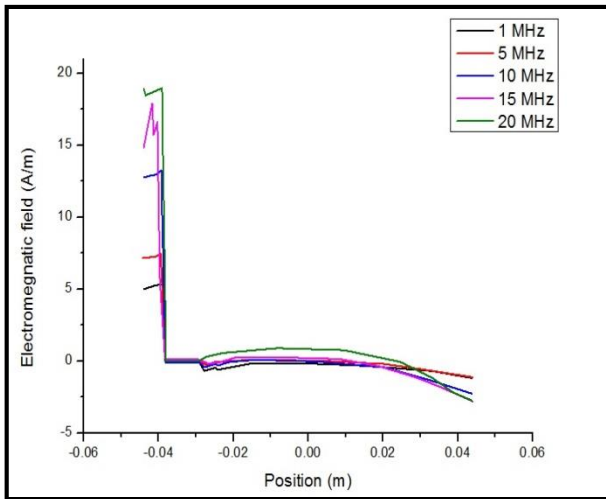
defined an electric flux, a measure of the number of electric field lines passing through an area, in a way analogous to the following definition of magnetic flux.

Regarding the meshing limitations and sharp boundary problems, we tried to smoothen sharp corners in the design of the muscle tissue and the coils, especially when we applied high frequency. A current carrying coil (excitation coil) is located in front of the muscle tissue to generate the primary magnetic field. Multiple parameters in the medium are changing while changed the place of the metal, such as geometry and size of the muscle, dimensions of the metal and electrical conductivity and permittivity of the muscle tissue. In addition, since obtaining the convenient location of the coil regarding to the biological tissue is of great interest, especially for safety issues and compatibility with national and international standards, coil distance from the body was defined as a variable parameter. The values of the passive electrical properties for a frequency range of 1 MHz- 20 MHz has been obtained from the client/server approach consists in the centralized management of the tissue parameters.

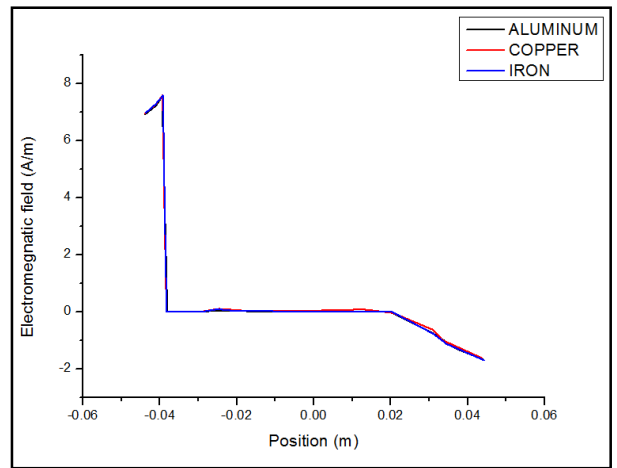
From this result, we can see the different graph acting when we apply different frequency from the range of (1MHz – 20MHz). Therefore, to increase the ability for detecting the metal is increasing with more frequency applying in the magnetic field. Thereby, the best result from the highest frequency which can apply.

It was found that the highest frequency produced the highest EMF value and with the smooth measured signal. In terms of EMF pattern, all frequencies produced almost the same, but a slightly small difference at the centre region of tissue. At the front-end region of the tissue the difference was somehow obvious as these both end regions were located nearer to the transmitter and receivers, which were more sensitive compared to the central region.

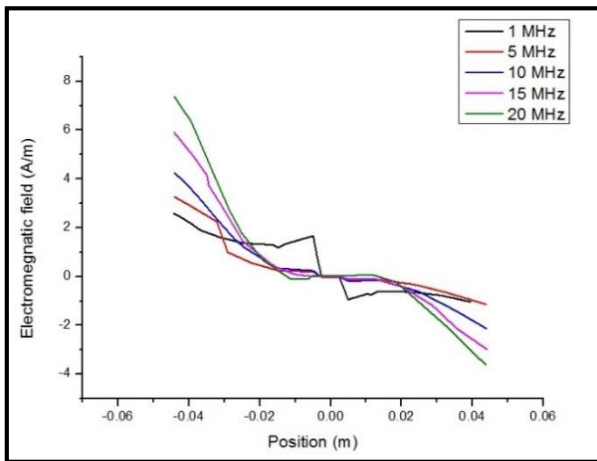
The signal is divided into two parts, positive region and negative region. Positive region started from the transmitter to the center while negative region starting from centre towards the receiver. The negative region exists as the secondary field generated by the receiver opposed the direction of the primary field. However the maximum negative value is smaller compared to the primary, as the supplied current is smaller (primary current is 1 A and secondary current is 0.5 A).



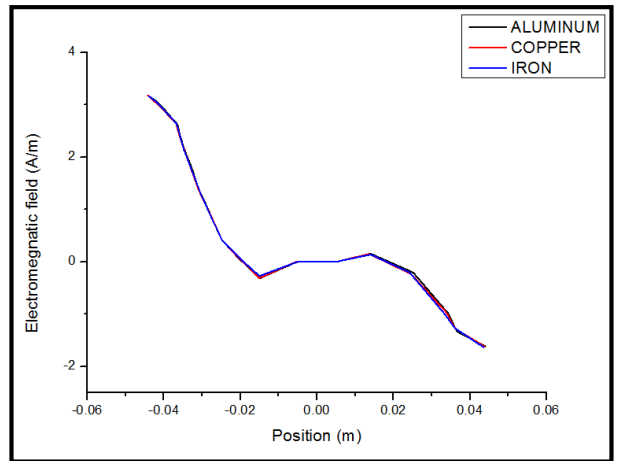
(a)



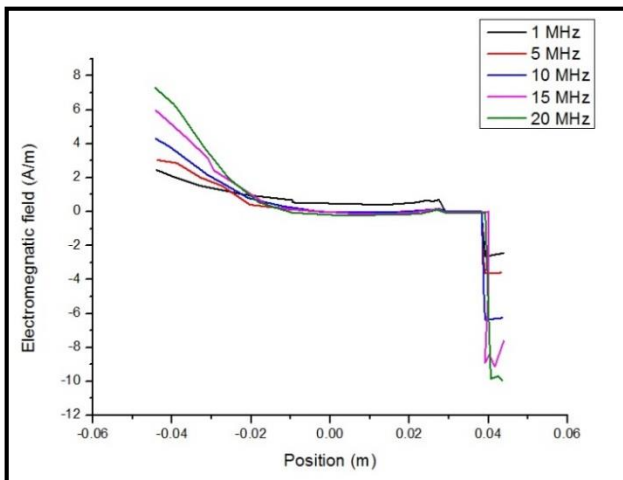
(a)



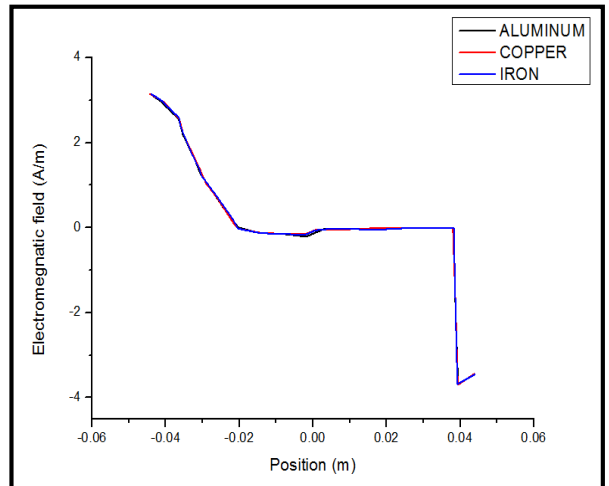
(b)



(b)



(c)



(c)

Figure 5 The EM field pattern in the muscle tissue when different metals are inserted using 1MHz - 20 MHz frequency. (a) $x = -0.035$, (b) $x = 0.000$ and (c) $x = +0.035$

Figure 6 EM field pattern in the muscle tissue when different metals are inserted using 20 MHz frequency. (a) $x = -0.035$, (b) $x = 0.000$ and (c) $x = +0.035$

Figures 5, a, b, and c and Figures 6, a, b, and c show the simulation results of three metal samples (copper, aluminum and iron) exist in muscle tissue. Frequency of 20 MHz frequency has been chosen because this frequency has produced the best EMF compared to other tested frequencies. It was found that, the region where the metal sample exists is significantly changed from the early value, but maintains the value starting at the first point of sample exist until the end. This is due to the very high secondary field signal generated by the metal samples compared to the secondary signal from the muscle tissues. These secondary field opposed the transmitted primary field, thus measured resulting EMF field was significantly reduced. The EMF patterns for all the simulated samples were same. This shows that any metal objects produced very high secondary field compared to the one generated by muscle tissues.

4.0 CONCLUSION

As a conclusion, as far as this stimulation is concerned, the results suggest that MIS has the potential to detect early foreign materials inside a biological soft tissue and gathering several information which can be useful for the assessment of medical condition and treatment. Graphs for the wave in the detector to prove that (MIS) can be proposed to be an alternative method as the best way for non-invasive or passive detection of the metal by using a certain-frequency and induced magnetic fields which is applied through the system to get different output wave due to the interaction between different materials through the biological soft tissue. Both metals and the biological soft tissue have their own properties and it is important to realize that the overall biological response of host

tissue to foreign material in the human body is problematic.

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