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Simulation of Single Channel Magnetic Induction Spectroscopy for Fetal Hypoxia Detection

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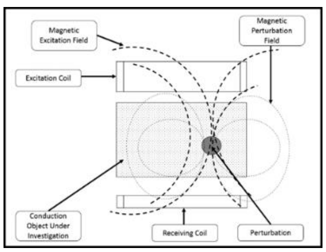
Graphical abstract



Abstract

Conventional fetal scalp blood sampling (FBS) need an invasive measurement to detect fetal hypoxia in fetus. This paper describe non-invasive technique employing single channel magnetic induction technique. The simulation was done to determine the best range of frequency value to detect biological tissue and tested with different value of conductivity value.

Keywords: Fetal blood sampling; single channel magnetic induction spectroscopy

■1.0 INTRODUCTION

pH is a level of the acidity or alkalinity of a water solution. The acidity or alkalinity of a water solution is constrained by the relative number of hydrogen ions (H+) or hydroxyl particle (OH) present. Acidic solutions have a higher relative number of hydrogen ions, while alkaline or basic solutions have a higher relative number of hydroxyl particle.[1,2] The retention of the hydrogen and hydroxyl can vary over 15 orders of magnitude in water as shown in Figure 1.

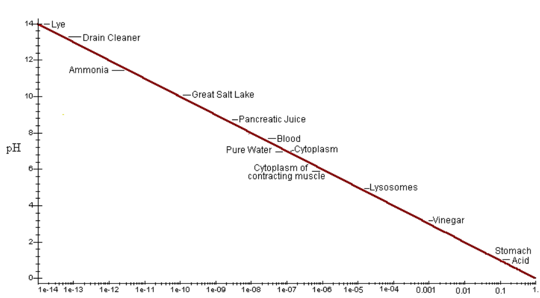


Figure 1 pH values of acid and alkali

1.1 Fetal Hypoxia

Fetal hypoxia or intrauterine hypoxia is the condition occurs when the fetus is deprived of an sufficient supply of oxygen.[3] One of the techniques to determine this fetal hypoxia is fetal scalp sampling. This procedure performed when is in active labor to determine whether the baby is getting enough oxygen.[4] The purposes of this testing is to prevent unnecessary intervention by investigation of pH and lactate values of fetal blood when there is suspicion of fetal compromises.

Fetal scalp testing is a common test used before the mother giving birth to determine the oxygen level of the baby through blood pH. This test is important because it will determine whether the fetal is ready to be delivered as well as to find the most suitable technique to deliver the baby, either normal birth or caesarean.[5,6] Conventional technique for this test requires the doctor to slice the fetal scalp a bit using forceps and draw the blood from there.[7] The blood then taken to the lab for analysis which consuming times.[8] This method may lead to continue bleeding in fetal scalp and swollen, which is very dangerous to the fetal, besides arise trauma to the mother. Besides that, the analysis of pH requires a relatively large amount of blood (30-50 µl), and sampling failure rates of 11-

20% have been reported.[9] Thus, non-invasive technique is proposed as an alternative to this conventional method.

1.2 Magnetic Induction Spectroscopy

For the non-invasive technique, single magnetic induction setup is suggested as the best way to detect low conductivity of biological tissues. This single channel spectroscopy consists of one transmitter and one receiver. The AC signal is supply to transmitter and generate primary field. After the fields penetrate into the object with conductivity, eddy current will induced. The object will produce secondary field, which weakens the original primary field, due to Lenz' Law.[10] This secondary field will receive by receiver.[11] The eddy current produced because of the Faraday's Law of Induction, where time-varying magnetic field, H induces and electrical field E. Figure 2 shows the principle of a typical magnetic induction system (MIS).

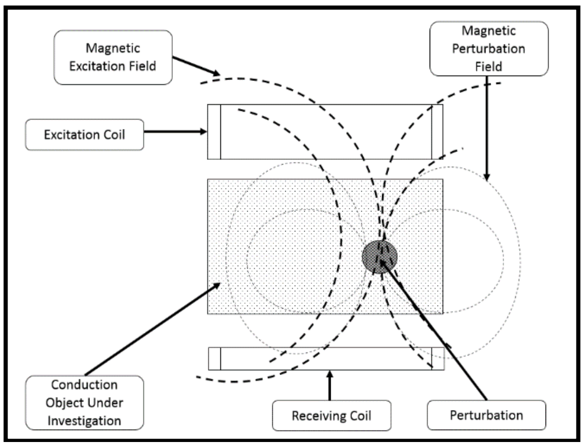


Figure 2 Magnetic induction spectroscopy setup[11]

2.0 LITERATURE REVIEW

In the previous studies, we have seen that measuring induction based on the phase shift approach could be used as an alternative technique to detect the biological soft tissue and metal debris.[12] The phase shift approach is sensitive to the phase delay when propagates through the biological soft tissue in the time domain and broad range of frequencies.

Numerous researches concentrate on using different method to simulate the interaction between matter and radiated energy, however the Magnetic Induction Spectroscopy (MIS) is preferred as it eliminates some difficulties of the use of fully non- contacting inductive coupling between the sensor and the sample or in this case biological tissue.[13]

Hevia–Montiel et *al* applied MIS Setup to detect early breast cancer. They suggested that the utilization of tissue bio impedance estimations by multiple frequency magnetic fields as a valuable alternative to detect non-inversely breast neoplasm and MIS was used to measure the electrical properties of tissue at different frequencies.[14]

Min *et al* [15] calculated and measured of induced current density inside human body under 60 Hz extreme low frequency magnetic field.

Simulation of multi-frequency induced current was done by Cesar *et al*.[16] Their aim was to assess analytically and experimentally the inductive phase shift as a function of multi-frequency induced in breast cancer condition. The magnetic induction method was used to anticipate the inductive phase shift as a function of the bulk electrical properties in typical breast volumes with tumors in particular positions.

3.0 METHODOLOGY

COMSOL Multiphysics is choosing to design the Magnetic Induction to detect blood in fetal scalp. The simulation is performed on a single channel biological tissue spectroscopy. The flow chart of methodology is shown Figure 3.

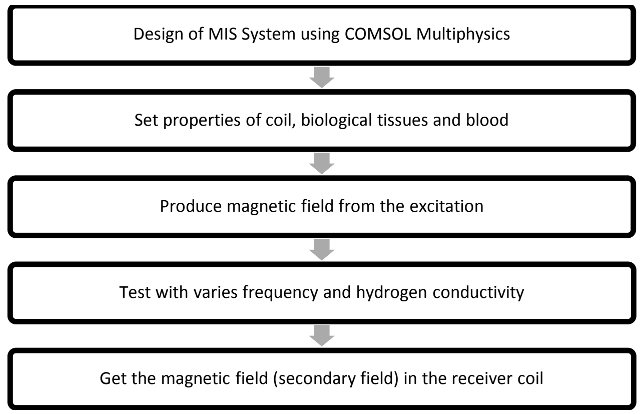


Figure 3 Flow chart of the project

The coil is used to generate magnetic field and specification of it is very 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. Therefore, we used 50 turns coil for both transmitter and receiver and applied 1 A for the transmitter coil and 0.5 A for receiver coil. The detail specification is shown in Table 1.

Table 1 Properties of the coil

No	Properties	Transmitter Coil	Receiver Coil
1	Number of turns	50 turns	50 turns
2	Current Applied	1 A	0.5 A
3	Diameter of the coil	0.009m	0.009m
4	Diameter of the wire	1mm	1mm

The properties of the material consist of biological tissues and blood.[17–19] The range of the frequency in this simulation is 1 MHz until 25 MHz. This range is choose to compare prove that the induced current in the secondary coil or receiver will increase with increasing frequency.

By using COMSOL Multiphysics, the transmitter is designed to produce a magnetic field across a sample which contains a biological tissues and blood in it. The magnetic field must in the form of perturbation of voltages and it is induced in receiver coil.[20] 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 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.[11,21,22] Figure 4 show the main part of the system designed which are the coils, sample and the air around the system for accurate result.

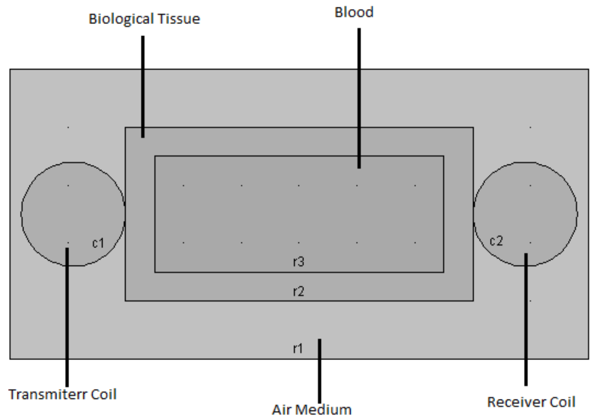


Figure 4 The design of MIS setup

4.0 RESULT AND DISCUSSION

4.1 Simulation without Tissue Sample

Before testing with biological tissues and blood, we have tried to simulate a single channel Magnetic Induction Spectroscopy by generating magnetic field in the excitation coil and detect the signal in the receiver. The simulation was done through frequency range from 1 MHz until 25 MHz. Figure 5 shows the simulation in air medium with frequency of 10 MHz and the magnetic flux density is plotted as shown in Figure 6.

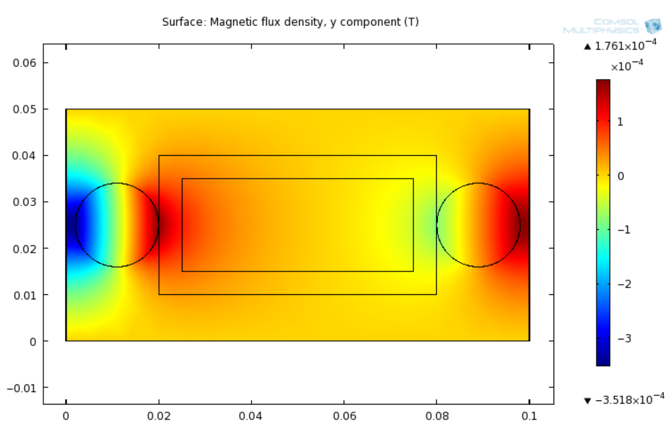


Figure 5 Suface plot result in air medium

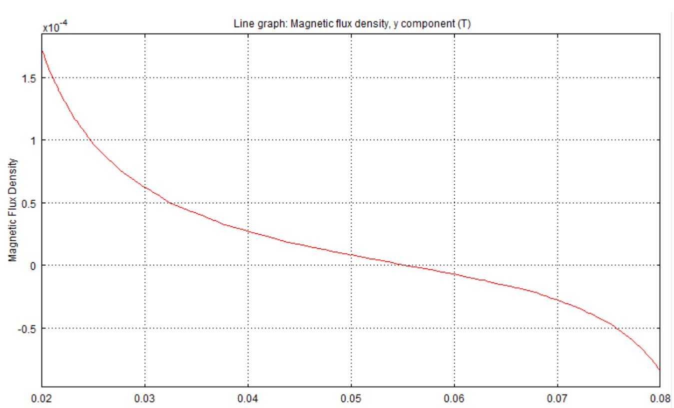


Figure 6 Simulation result in air medium

4.2 Simulation with Tissue Sample

The stimulation begins with dielectric definition of each material that we used which are skin as biological tissue and blood. After that, we specify the properties of the coils which are very important to generate strong magnetic field. The ranges of frequencies are between 1 MHz to 25 MHz. The magnetic field that produce for each frequencies is acquire and plot to compare the best range of frequencies to detect blood in underneath the skin. The result the simulation is shown in Figure 7.

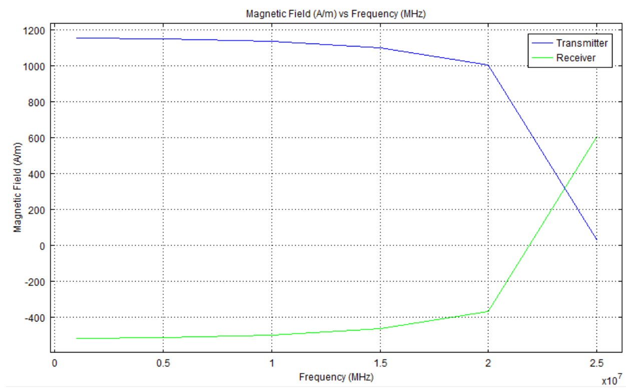


Figure 7 Simulation result with biological tissue and blood

From the result, the magnetic field in receiver circuit is increase when the frequency is increase. Therefore, it's proving that more higher the frequency that apply to the system, it induces more secondary field.

It was found that the highest frequency produced the highest EMF value and with smooth measured signal. In term of EMF pattern, all frequencies produced almost the same but with slightly small different at the center 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 center region.

Then, the model is tested by layer by layer simulation. First, we do simulation with only skin layer, and then continue with biological tissue and blood layer. Lastly, the combination of skin layer and blood layer with hydrogen. The result as shown in Figure 8.

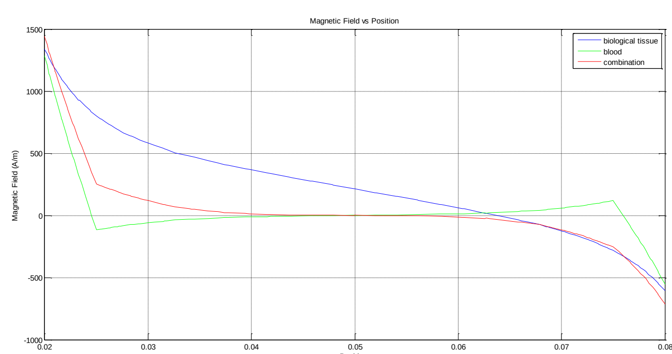


Figure 8 Simulation result layer by layer

With 15 MHz as the chosen frequency, the simulation is continue with simulation with hydrogen properties is add into the blood.[23] The hydrogen is chosen because pH is hydrogen dependent. The conductivity of hydrogen material is adjusted to few values. The result acquire is shown in Figure 9.

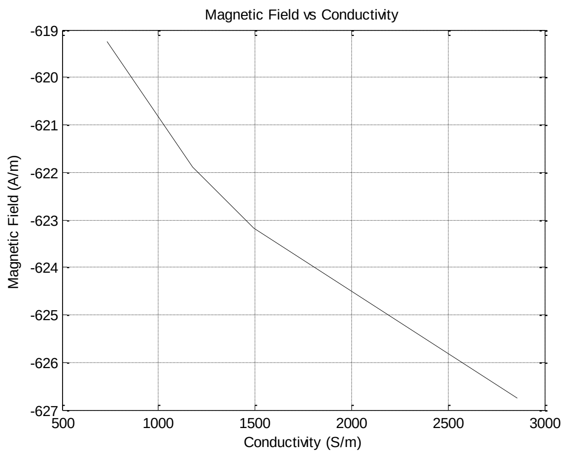


Figure 9 Simulation result with different conductivity

The magnetic field that gains in the receiver is in negative value. This negative region exists because the secondary generated by receiver coil opposed the direction of primary field. So, from the result, we can see that the secondary field that generated in receiver is increase with increasing value of conductivity which in our case, the conductivity value of hydrogen is assume as the pH value. The higher the hydrogen conductivity, the higher pH value.

5.0 CONCLUSION

As conclusion, the MIS Setup can be used to detect biological tissue and blood in human. The range of frequency must be high to increase the induced field or secondary field. The eddy current induced based on the conductivity in material. The conductivity of hydrogen is choose because pH is hydrogen dependent and the magnetic field receive in the receiver is increase as the conductivity is increase. Hence, the MIS system is can used to determine fetal hypoxia symptom in the fetus.

Acknowledgement

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