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Fundamental study on jaundice assessment using magnetic Induction Spectroscopy Technique

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ABSTRACT

This paper discusses the new method in jaundice assessment using magnetic induction spectroscopy (MIS) technique. Through this method, MIS technique is focused on a phase shift measurement. It was studied by conducting an experiment and using iodine solution as a measuring sample. The concentrations value of measuring sample is mimicked to the concentration of bilirubin in the baby's blood (biological tissue). This research was done by implementing circular coil and the samples were measured by MIS circuit. The MIS system operates at a frequency below 10MHz. The highest frequency which is 10MHz has greater phase shift compared to 2MHz, 4MHz, 6MHz, and 8MHz. Unfortunately, measured phase shifts are fluctuated and inconsistent due to the external interference. Though MIS circuit has been covered by an aluminum box to minimize the interference which is an external electromagnetic field from entering measurement region, it did not eliminate the whole effect. The system still can be affected by some conductive materials which placed close to measurement region. Other than that, an electrical field (capacitive coupling) also contributes to fluctuated results. This kind of signal occurred between the transmitter coil and receiver coil where the contamination can be very significant when the measured sample have low electrical conductivities that less than 3 Sm-1. Hereby, MIS circuit should include electric field shielding to eliminate unwanted signal in the system and the measured sample should consider the electrolytes solution.

Keywords:
External interference, Jaundice, Magnetic induction spectroscopy, phase shift

1. Introduction

Neonatal jaundice or neonatal hyperbilirubinemia is caused by overproduction of bilirubin in newborn infants. The reason is that some of the baby's liver has limited ability to collect and

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excrete bilirubin. Bilirubin's production begins from the derivation of heme where it is present in hemoglobin [1]. When hemoglobin removes iron and globin from its molecule, carbon monoxide is released and produces a green pigment which is biliverdin. Then, biliverdin converted to bilirubin by enzyme biliverdin reductase [2] as shown in Figure 1. The majority of new-born infants develop jaundice during their first week of life, then the jaundice level is decreased gradually and the babies do not require any treatment.

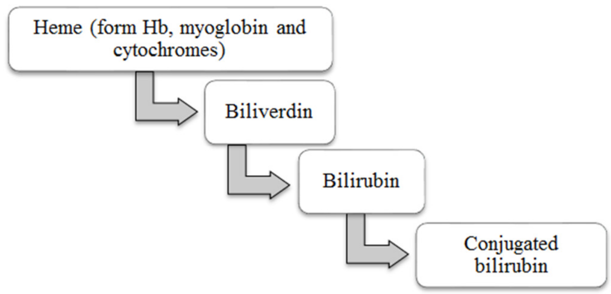

Fig. 1. Steps of bilirubin production [3]

Somehow, in several cases, if total serum bilirubin (TSB) in newborn infants is greater than 12.9 mg/dL which is reached a serious level, the infants need more attention and should be routinely monitored by neonatal nurses [4, 5]. Therefore, a common method which is heel puncture is used to measure TSB level in newborn infants. This method is performed on newborn infants that haven't started walking or aged less than a year old. Unfortunately, this method has some limitations where neonatal nurses should avoid from puncture through the previous site of the baby's heel because if this happens, it may spread the infection to the baby's skin due to small cuts on their heels [6]. Besides that, neonatal nurses also need to be careful with the baby's heel in order to avoid from puncturing the heel area deeper than 2.0 mm, which can cause osteomyelitis [3]. Based on Figure 2, it shows blood sample taken from baby's heel through heel puncture method.

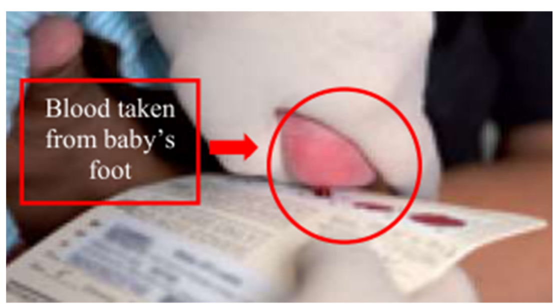

Fig. 2. Blood sample was taken from baby's heel [6]

Having known this issue, in this research, a new method of non-invasive technique has been introduced which is by introducing magnetic induction spectroscopy (MIS) technique to overcome the weakness of invasive method. Through the non-invasive method of MIS, it yields magnetic field and the phase shift between primary field and secondary field is calculated. Phase shift measurement technique has been applied in many low conductivity applications such as low conductivity solution and biological [7, 8]. Therefore through this research, a fundamental study of MIS technique to detect jaundice level which applies phase shift technique during measurement will be studied. The phase shift between the reference signal and the measurement signal will be analyzed to determine the capability of the developed system.

2. Experimental Method

For the fundamental study of MIS system, five different concentrations of samples solution (iodine solution) that is similar to the concentration of bilirubin in the baby's blood have been prepared. The sample solution acts as biological tissue which is bilirubin in the baby's blood. All the solutions have different electrical conductivities as shown in Table 1. Iodine solution is used to resemble the bilirubin because iodine solution is a nonpolar substance and produce bright yellow color [9] as a bilirubin [10].

Table 1
Concentration and Electrical Conductivity of Sample Solution

Iodine Concentration (µmole/L)	Electrical Conductivity Sample Solution (µS/m)
85.0	2.147
170.0	3.436
255.0	4.936
290.0	5.766
331.5	6.716

Through this experimental study, molarity formula is used to calculate required volume of iodine solution as represents in equation (1).

$$M_1V_1 = M_2V_2 \tag{1}$$

where M_1 represents molarity of iodine stock and followed by V_1 which represents the required volume of iodine. While M_2 represents molarity of bilirubin and V_2 is the container's volume. The concentration of sample solution is started from 85.0 µmole/L because neonatal jaundice starts to appear on baby's skin when bilirubin concentration reaches 85.0 µmole/L. While, when bilirubin concentration keeps rising and reach 255.0 µmole/L, then the yellow tone will appear on palms and soles. Somehow, the serious level of jaundice is at 331.5 µmole/L, where at this level, the newborn infant requires more attention [11].

2.1 Experimental Design

Through this research study, copper wire has been chosen as a sensor coil because it is highly conductive. Copper can be easily formed, fabricated, soldered and have high performance [12]. Circular coil on the transmitter (T_x) and receiver (R_x) as shown in Figure 3 is used as a sensor coil because it has a feasible configuration for an easy and practical application.

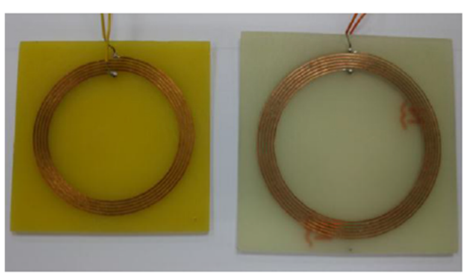

Fig. 3. Fabricated circular coil of the transmitter (T_x) and receiver (R_x) coils

Other than that, circular coil also adaptable to phase shift application because it exhibits high efficiencies with and without phase shift [13]. A number of turns of T_x coil are five turns (single sided) and twelve turns (double sided) for R_x coil. The reason is that it has a good sensitivity [14]. The circular coil is fabricated on PCBs and has been implemented in the experiment. The diameter of the copper coil is 1 mm [15].

The experiment was conducted with five different concentrations of sample solution by placing the sample between T_x and R_x coils as illustrated in Figure 4.

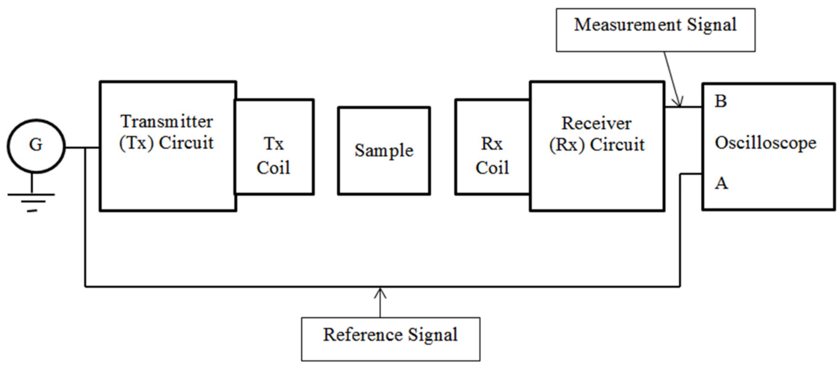

Fig. 4. System Setup Diagram

Once MIS circuit has been set up as shown in Figure 4, then five volts of DC power supply is supplied to the circuit. This system can operate at a frequency below 10 MHz. This is because when frequency beyond 10 MHz is given, it will decrease the stability of the system and interruption of the signal will occur [16]. Through the experiment, T_x coil excites when transmitter circuit is supplied by alternating current. The magnetic field generated through the sample, thus eddy current induced in the sample. After that, an eddy current is detected by R_x coil and the collected signal is propagated in phase detector circuit. Thereafter, the reference signal and measured signal are two output signals that are obtained from the measurement. The data obtained from these output signals are used to investigate the different concentration of samples with the measured secondary field.

3. Results and Discussion

The experiment's measurement was conducted with operating frequency from 2 MHz to 10 MHz which is applicable to excite the T_x coil and penetrate the sample that was placed between the T_x and R_x coils. It can be seen that from Figure 5, phase shift value of 10 MHz is greater than 2 MHz, 4 MHz, 6 MHz and 8 MHz. This is due to the current that easy to pass through the sample (biological tissue) when high frequency applied whereas when low frequencies applied the current have difficulty to pass through the sample. Nevertheless, the phase shift results fluctuate.

Referring to the previous research studies by Jin *et al.* [17], when electrical conductivity of the concentration increased, the phase shift gets higher. Unfortunately, the result obtained does not follow the expected trend and the measured phase shifts were fluctuated and not stable. The external electromagnetic field can act as an external interference, thus the prototype of MIS circuit was covered by an aluminum box to minimize such interference from entering the measurement region. This step shows that the interference can be minimized yet not completely eliminated [16]. Besides that, the system still can be affected by some conductive materials or magnetic objects [16] which are placed close to the measurement region. Other than that, electromagnetic interfaces such as electrical power and human body also influence the measurement region in MIS circuit.

Thereby, it causes inconsistency in data collection. Based on the previous researcher by Mahdavi *et al*. [18] in MIS system has two kinds of the signal which are a magnetic field and electric field. Through this experiment, an electric field acts as an unwanted signal when the sample to be measured has low conductivity. It produces large errors in the data collection. This kind of signal only acquired in the application of vital sign such as breathing monitors. Nevertheless, MIS circuit that used to measure secondary field in Rx coil in this research has no electric field shielding.

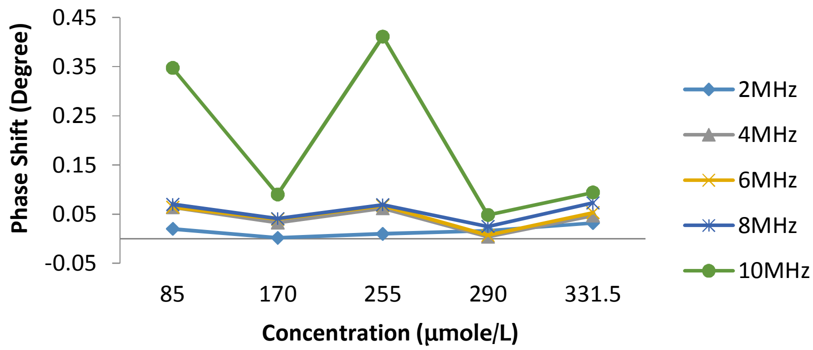

Fig. 5. Phase shift results

Hereby, the circuits have high possibility to produce errors. Thus, capacitive coupling occurs between Tx coil and Rx coil where the contamination can be very significant when the measured sample has low conductivities which are less than 3 Sm^{-1} [19]. The electric field shielding that has been suggested by Goss *et al*. [19] is a star-pattern shield which needs to be constructed on printed circuit board as shown in Figure 6, then place in front of the Rx coil. Therefore, electric field shielding should be included in MIS circuit to eliminate unwanted signal in the system [19].

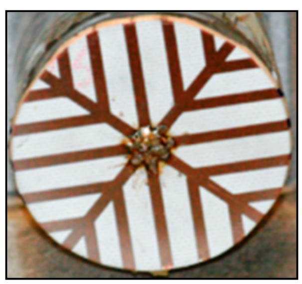

Fig. 6. PCB Star Shield [19]

Other than that, in order to overcome these problems, iodine solution also should be added with 0.9% of saline solution which is equal to 0.154 M of sodium chloride solution (NaCl). According to previous researcher Davila *et al*., 0.9% of NaCl aqueous solution is the important electrolyte solution in the human body. 0.9% of NaCl solution has two types of ions which are Na+ and Cl-. These ions are the most abundant ions in the electrolytes solution [20] which is extracellular compartments in the human body. It was dominated by 140 mEq/L of sodium and 100 mEq/L of chloride [21]. Therefore, the aqueous solution is required in the measured sample solution.

4. Conclusion

As a conclusion, 10 MHz of experimental MIS system has been developed as the first stage towards a non-invasive technique in jaundice assessment. Megahertz frequency is significant in MIS system in order to get a high signal in the secondary magnetic field. It proved that only high-frequency range can cause the current to pass through the cell membrane. The reason behind this is the cell membrane in biological tissue acts as an insulator which prevents current from entering the cell at low frequency. Therefore, these higher frequencies, with their resulting larger phase shift, may be suitable. It was found that MIS system is very sensitive to an external interference and conductive material because phase shift measurement was affected by the interference. For future works, full capabilities of MIS system for jaundice assessment need to be studied.

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