# pH Estimation of Fetal Scalp Blood using Magnetic Induction Spectroscopy Technique

**By**


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## LIST OF ABBREVIATION

| | |
|---|---|
| ABS | Acrylonitrile Butadiene Styrene |
| CHCM | Contra Hemisphere Cancellation Method |
| CTG | Cardiotocography |
| DRBEM | Dual Reciprocity Boundary Element Method |
| EM | Electromagnetic |
| FBS | Fetal Blood Sampling |
| FHR | Fetal Heart Heart |
| GUI | Graphical User Interface |
| HC*l* | Hydrochloric Acid |
| MATLAB | Matrix Laboratory |
| MIPS | Magnetic Inductive Phase Shift |
| MIS | Magnetic Induction Spectroscopy |
| MIT | Magnetic Induction Tomography |
| NaCl | Sodium Chloride |
| NaoH | Sodium Hydroxide |
| PCB | Printed Circuit Board |
| PEP | Passive Electrical Properties |

| | |
|---|---|
| pH | Potential of hydrogen |
| RMSE | Root Mean Square Error |
| ROI | Region of Interest |
| Rx | Receiver |
| STAN | ST Segment Analysis |
| Tx | Transmitter |

## LIST OF SYMBOL

| | |
|---|---|
| Ω | Ohms |
| $\mu$ | Permeability |
| $\varepsilon$ | Permittivity |
| $\sigma$ | Conductivity |
| $CO_2$ | Carbon Dioxide |
| $H^+$ | Hydrogen ion |
| $OH^-$ | Hydroxyl ion |
| $pCO_2$ | Partial pressure of carbon dioxide |
| V | Voltage |

**Penganggaran pH Darah Kulit Kepala Janin Menggunakan Teknik Magnetik Induksi Spektroskopi**

## ABSTRAK

Tesis ini menerangkan tentang pengenalan teknik baru bagi penganggaran pH kulit kepala janin menggunakan teknik aruhan magnet. Teknik aruhan magnet adalah satu pendekatan yang bukan invasif yang menggunakan medan magnet untuk menentukan sifat-sifat elektrik pasif sesuatu bahan. Hubungan di antara signal yang diterima di penderia penerima dengan nilai pH telah dikaji. Perisian COMSOL digunakan untuk simulasi reka bentuk kuar penderia. Simulasi dilakukan dengan beberapa parameter seperti julat frekuensi, geometri penderia, bilangan lilitan dan jarak antara penderia pemancar dan penerima. Ini dilakukan untuk menentukan reka bentuk teknik aruhan magnet yang sesuai untuk diaplikasi dalam pengukuran pH model kulit kepala janin. Keputusan yang terbaik daripada setiap parameter akan digabung untuk menjadi reka bentuk muktamad, dan dibuat dalam bentuk peranti. Persamaan matematik diperoleh untuk menunjukkan hubungan di antara voltan dan pH. Hasil kajian menunjukkan bahawa teknik aruhan magnet mampu untuk mengesan perubahan pH dalam darah kulit kepala janin. Julat frekuensi yang digunakan mestilah berada dalam lingkungan MegaHertz untuk meningkatkan pengeluaran medan teraruh. Gegelung bulat dipilih sebagai sensor geometri paling sesuai kerana boleh mengenalpasti perubahan kecil hidrogen dalam darah kulit kepala janin. Jarak antara gegelang pemancar dan penerima adalah 0.08 mm kerana kekuatan medan magnet berkurang dengan penambahan jarak. Peratusan ralat yang diperoleh daripada ramalan persamaan matematik adalah kurang daripada 1% dan nilai minimum korelasi yang diperoleh antara signal teraruh dan pH adalah 0.9190.

**pH Estimation of Fetal Scalp Blood using Magnetic Induction Spectroscopy Technique**

## ABSTRACT

This thesis describes the development of fetal scalp pH estimation utilizing magnetic induction spectroscopy technique. Magnetic induction spectroscopy is a non-invasive approach that applies a magnetic field to determine the passive electrical properties. The relationship of the induced signal at the receiver and fetal scalp pH value was investigated. COMSOL Multiphysics® software was used to simulated sensor probe design. The simulation was done with several parameters such as frequency range, sensor geometry, number of turns and distance between transmitter and receiver coil to determine the suitable single channel magnetic induction spectroscopy technique for fetal scalp pH measurement design. The best result from parameters simulation was combined and finalized to be final sensor design. Then, the hardware was develop according to the simulation result. Mathematical equation was derived to show the relationship between voltage and pH. The result shows that the magnetic induction spectroscopy was capable to detect pH changes in the fetal scalp blood mimic model. The frequency range must be in the range of MegaHertz to increase the production of induced field. Circular coil was choose as the most suitable sensor geometry due to its sensitivity to detect smallest hydrogen conductivity changes in fetal scalp blood mimic model. The distance between the sensing coils of 0.08 mm was better than 0.1 mm because the strength of the field decreases with increasing distance from the wire. The error percentage acquired from prediction mathematical equation was less than 1% and the correlation obtained between the induced signal and pH was greater than 0.9190.

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

This chapter is an introduction to the research. In this chapter, explanation on the pH measurement and magnetic induction spectroscopy will take place. The problem statement and the scopes are also briefly explained in this chapter.



## 1.2 Introduction to pH Measurement, Magnetic Induction Spectroscopy and Phase Shift

Potential of hydrogen (pH) measurement is important in many areas of applications. pH can be defined as a degree of acidity or alkalinity of the solution. This pH value is limited by the value of hydrogen or hydroxyl ions presents in a solution. The acid solution consists of a higher relative number hydrogen ions, whereas alkaline or basic solution consists of higher relative number of hydroxyl ions (David, 2003; Filomena Camoes, 2010). The retention of the hydrogen and hydroxyl can vary over 14 orders of magnitude in water, where 1 to 6.99 is indicated as acid, 7 is neutral and 7.1 to 14 is alkaline as shown as in Fig 1.1. A simple pH indicator uses a colour as the indicator or preferences to determine the pH value.

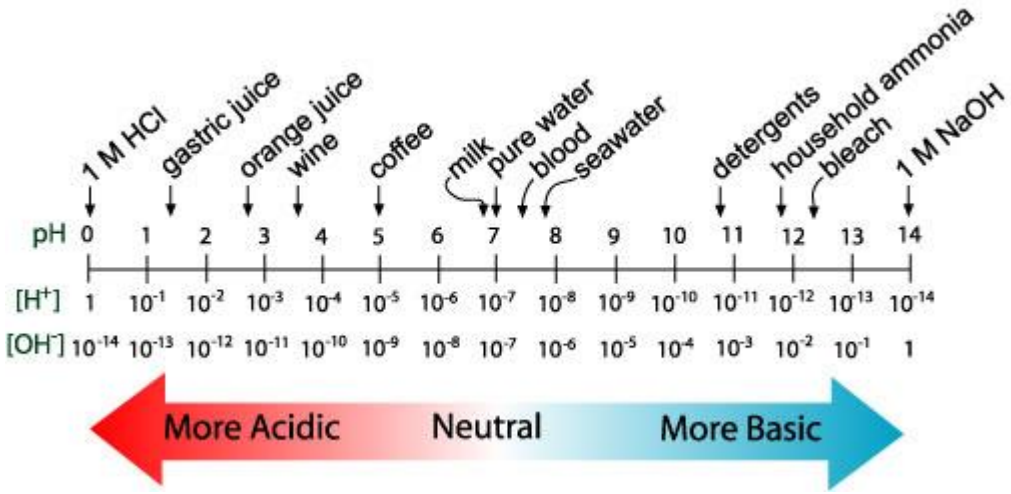


Figure 1.1: pH range (Bishop, 2013)



A pH meter is basically a voltmeter with high input impedance which assesses the voltage of an electrode. This electrode is sensitive to the hydrogen ions concentration, relative to another electrode which displays a constant voltage. The increase of acidity leads to greater voltage, thus causing the reading of pH meter to decrease. Therefore, an increase of hydroxyl ions indicates an increased alkalinity, causing a decrease in voltage reading.

The Magnetic Induction Spectroscopy (MIS) is a non- invasive technique which claims uses of a magnetic field to determine or aiming on the passive electrical properties (PEP) such as conductivity (σ), permittivity (ε) and permeability (μ) of biological tissues at difference frequencies (Dávila, Gutierrez, & Blanco, 2012). Originally, MIS is known as single channel multi-frequency Magnetic Induction Tomography (MIT) system. Previously, MIS system was used by 'Graz Austria Group' to measure the conductivity spectrum of biological tissue ( Hermann Scharfetter et al., 1999; Hermann Scharfetter, Casañas, & Rosell, 2003; Hoe, 2011;). This non-invasive technique is preferable on measuring of pH due to the detection of the electrical properties without contact to the solution will reduce the time of measurement. The common practice of pH yields slower

response in obtaining the result. MIS is a passive detection that can detect an object by using a multiple-frequency and induced magnetic fields which are applied through the system to get different output wave due to the interaction between different materials through the samples.

The phase shift or phase angle is the time relationship of two periodic signals of the same frequency. The phase or the relative phase different of these periodic signal can be measured if both were derived from a synchronous source, as shown in Fig 1.2.

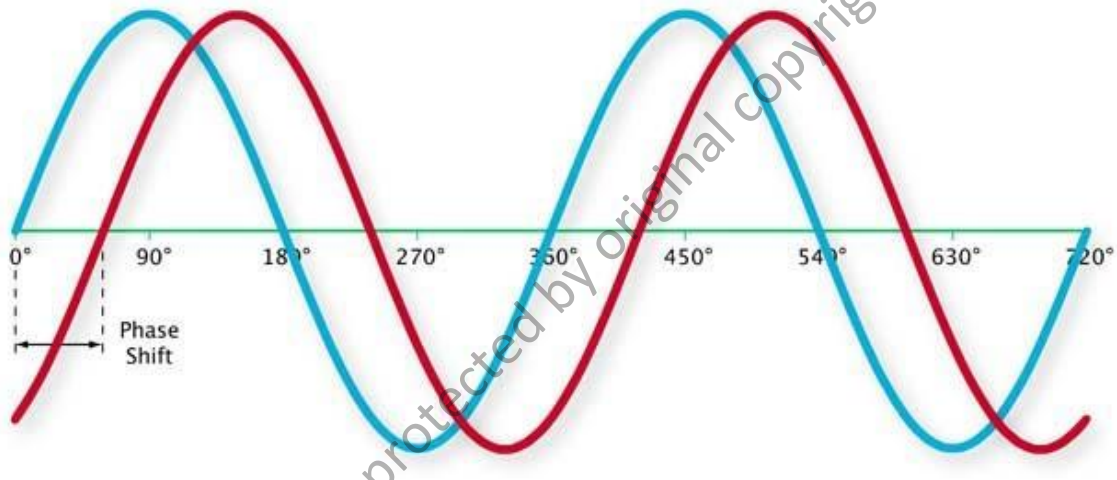




Figure 1.2: Phase shift signal

Figure 1.2 shows the case for a single-tone sinusoidal wave. Phase measurement or a periodic signal which has extra harmonic or frequency components present, such as multi-tone signals, can also be determined. The magnitude and phase of a multi-tone signal can be calculated by the Fourier transform method which provides a very convenient method to determine the relative phase for all frequency components simultaneously.

## 1.3 Problem Statement

The intrapartum estimation of fetal well-being presents a challenge to the obstetrician (Henderson & Ecker, 2003). The fetus depends on themother for the placental exchange of oxygen and carbon dioxide. Disruption during the exchange process can cause fetal hypoxia, which may lead to acidosis (Bobrow & Soothill, 1999) and in worst case, it will cause complete disruption of maternal – fetal gas exchange, such as cord prolapse and placenta abruption which can lead to neonatal encephalopathy (Kendall & Peebles, 2005). Several techniques may use to evaluate this condition including direct analysis of fetal blood acquired from scalp sampling or fetal blood sampling.

Fetal blood scalp sampling (FBS) is a common test utilized before the mother giving birth to determine the oxygen level of the infant through blood pH. This test is crucial in order to determine whether the fetal is ready to be delivered. Besides that, it helps to identify the suitable technique to deliver the baby, either by normal birth or caesarean method ( Jørgensen & Weber, 2014b; Holzmann, Wretler, Cnattingius, & Nordström, 2015). However, this method needs a small incision on the fetal scalp and the drop of blood is collected using a thin heparinized capillary tube (Women and Newborn Health Service, 2008). The blood then taken to the lab for analysis and the median time taken for the test was 18 minutes had been reported (Tuffnell, Haw, & Wilkinson, 2006; Annappa, Campbell, & Simpson, 2008). Although blood sample may be safely retrieved from the scalp during labor, pitfalls may occur during this invasive method, such as inadequate incision, which may lead to continuing bleeding and infection at the puncture site (Carbonne & Nguyen, 2015). Current FBS method also may leave the bruise and scar at the baby scalp and not suitable to the mother with an infection such as HIV or Hepatitis B (Kaneshiro & Zieve, 2012). Besides that, the analysis of pH requires a relatively large

amount of blood (30µl-50µl) (Wiberg-Itzel et al., 2008) and sampling failure rates of 10% have been reported (Carbonne & Nguyen, 2016). Considering the risks of the current FBS method, new FBS method by employing magnetic induction spectroscopy (MIS) technique through phase shift approach is introduced which can be done without incision at the fetal scalp.

### 1.4 Objectives

1. To design and simulate suitable single channel magnetic induction technique for fetal scalp measurement.
2. To investigate the relationship between produced voltage at the receiver over the pH value of the solution of interest through an application of magnetic induction technique.
3. To assess fetal scalp pH estimation employing magnetic induction spectroscopy technique by using an acid solution to mimic pH blood.



### 1.5 Scopes

The scope of this research was to design and simulate MIS system to detect fetal pH measurement by using COMSOL Multiphysics® version 5.0 (2014). This single channel consists of one transmitter coil (Tx) and one receiver coil (Rx). The applied frequency was in the range of 2 MHz to 20 MHz to increase the production of the induced field. For hardware parts, the Multisims software version 12.0 (2012) was used to simulate the

circuit design. The circuit is then printed into PCB board to do the measurement. The pH solution of an acid sample was used to mimic the pH of the blood. The range of pH was from 7.0 to 7.4 to cover all three stages of FBS condition which are Acidemia, Pre Acidemia and Normal.

## 1.6 Thesis Organization

The thesis is separated into five chapters. Chapter 1 of this thesis describes the introduction part of the research. The purposes of this chapter are to give a brief introduction to the reader's to understand what they will go throughout this thesis and what they can expect in this investigation. It consists of the problem statement, objectives and scope of this research conducted.

Chapter 2 explained the literature review collected to conduct this investigation. This chapter intends to give some review to the readers about the scope of the research that has been done. This chapter includes current technology of pH measurement, current technology of fetal blood sampling, magnetic induction spectroscopy, phase measurement and also Bohr Effect.

Chapter 3 explicates about the methodology to be used in this research. This chapter is divided into two parts, simulation of single channel MIS measurement by using COMSOL Multiphysics and development of hardware measurement. At this chapter, readers would be able to recognize the method that is used in order to achieve the objective of this research.

Chapter 4 presents the results and discussions obtained from this investigation. This section is also divided into two parts, simulation results and data collection results. The discussion will be based on the results obtained to support the objectives.

Chapter 5 provides the conclusion of this thesis. In this chapter, readers can find the summarization obtained throughout the research.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter discussed the current technology of the pH measurement, fetal scalp sampling, phase measurement and a background review of magnetic induction spectroscopy. These include the previous research that has been done and the current application.



## 2.2 Current Technology of pH Measurement

Non-invasive technique for measuring the pH value had been researched with several methods. For example, magnetic resonance spectroscopy, optical technique and fluorescent technique (Kimball, Furlong, Us, & Pierskalla, 2005).

In medical field biological processes, the human body require a narrow range of pH for normal condition, where significant changes in pH from this range may be life threatening (Kimball et al., 2005). Thus an accurate and stable pH measurement system should be researched to overcome these issues. One of the methods that had been proposed is by using a hyperpolarized carbon dioxide and bicarbonate as a medium to measure the intracellular pH in the heart. The implementation of magnetic resonance spectroscopy (MRS) to measure the pH value of the blood in the heart have been studied by Marie et al. However, there are limitation on this method which is hyperpolarized medium not directly distinguish between the metabolites that are located in the intracellular and also in the extracellular spaces (M. A. Schroeder et al., 2010). In addition, the previous study

stated that a cardiac pH in vivo measurement using MRS is not possible due to 2, 3-diphosphoglycerate (2, 3-DPG) in the ventricular blood contaminates the myocardial inorganic phosphate peak. This is not suitable to be utilized in real time measurement of a pH in human intracellular.

In another method, fiber optic fluorescence sensor can be measured a pH value from the platelets concentration. This method uses a non-invasive fluorescence reader and was tested using Blood Gas Analyzer. This test is a syringe-based sample and with some parameter measurement and the setup is shown in Fig 2.1. The pH sensor on this system was determined the pH in both phosphate-buffered salines and in platelets concentration. The accuracy of the sensor determined instead of pH value. In comparison to colorimetric, the fluorescent pH indicator has advantages based on sensitivity and it has been immobilized on solid support. Thus, the advantage of this feature is used to develop the fiber optic sensor to calculate the pH blood value (Reed et al., 2009).



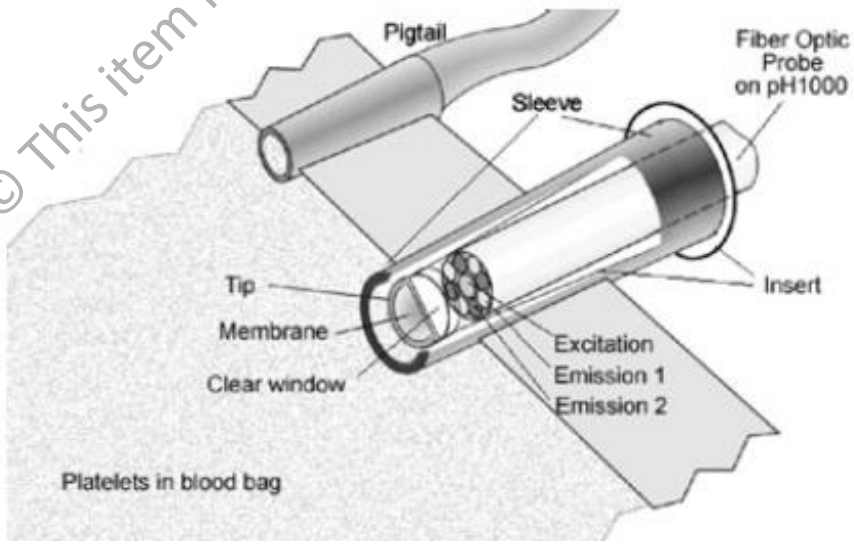


Figure 2.1: System of the fiber optic sensor (Reed et al., 2009).