DEVELOPMENT AND CHARACTERIZATION OF A SMALL-SCALE CONDUCTIVITY PROBE

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DECLARATION

I hereby declare that this thesis, submitted to Universiti Malaysia Sabah as partial fulfillment of the requirements for the degree of Bachelor (Hons) Computer Engineering, has not been submitted to any other university for any degree. I also certify that the work described herein is entirely my own, except for the quotations and summaries sources of which have been duly acknowledged.

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2nd July 2015

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ABSTRACT

Device manufacturers are constantly challenged by e water system manufacturers and end-users to constantly develop the water purification technology. As a more reliable, repeatable, portable and accurate conductivity is needed. The availability of a new system-on-chip fully integrated AD5933 which might allow the implementation of minimum size instrumentation for electrical conductivity measurement. The design of a two-electrodes probe adapting impedance measurement chip AD5933 for conductivity point measurement is presented in this thesis. The probe is designed for conductivity point measurements through the placement of the two electrodes outside the probe where the medium flows which associated control circuitry. Two electrodes serve as the current injector and collector in a currentless fashion. The cells are compared and repeated conductivity measurements on tap water are measured are also presented in this project. Finally, the conductivity probe is compared against the common commercial probe for evaluating conductivity of tap water. The circuit has shown a good measurement accuracy on various test. The two electrode system associating with AD5933 has been successfully characterize the point conductivity probe using the sample of tap water with different concentration. Experimental result covered by this point conductivity probe impedance system ranges from 4.14 mS/cm to 16.1 mS/cm.

ABSTRAK

Pengeluar peranti sentiasa dicabar oleh pengeluar sistem air dan pengguna akhir untuk sentiasa membangunkan teknologi penulenan air. Permintaan terhadap pengukuran kekonduksian yang boleh diharap, diulang, mudah alih dan tepat semakin meningkat. Dengan adanya AD5933, sistem-dalam-cip baharu yang bersepadu sepenuhnya memungkinkan pelaksanaan peralatan saiz minimum bagi pengukuran kekonduksian. Suatu reka bentuk probe dua elektrod disesuaikan dengan cip pengukuran halangan AD5933 untuk mengukur titik kekonduksian akan dibentangkan dalam tesis ini. Probe ini direka untuk pengukuran titik kekonduksian menerusi penempatan kedua-dua elektrod di luar permukaan probe di mana medium pengaliran berkait dengan litar kawalan. Kedua-dua elektrod berfungsi sebagai penyuntik dan pengumpul arus. Sel-sel dibandingkan dan ukuran kekonduksian berulang menggunakan air paip juga turut dipersembahkan dalam projek ini. Akhir sekali, probe kekonduksian dibandingkan probe komersial biasa untuk menilai kekonduksian air paip. Litar ini telah menunjukkan ketepatan pengukuran yang baik dalam pelbagai ujian. Sistem dua elektrod bersekutu dengan AD5933 telah berjaya mencirikan probe titik kekonduksian menggunakan sampel air paip dengan kepekatan yang berbeza. Hasil eksperimen yang diliputi oleh probe titik kekonduksian sistem halangan ini adalah antara 4.14 mS/cm dan 16.1 mS/cm.

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LIST OF ABBREVIATIONS

AC	Alternate Current
C	Conductivity
CIP	Clean-in-Place
cm	Centimeter
dc	Direct current
DDS	Direct Digital Synthesizer
DFT	Discrete Fourier Transform
G	Conductance
Hz	Hertz
I	Electrical current
I^2C	Inter-Intergrated Circuit
IC	Integrated circuit
I_{in}	Input Current
K	Cell constant
k	Kilo
K_C	Contaminant conductivity
K_H	Maximum sample conductivity
K_L	Minimum sample conductivity
M	Mega
m	Meter
mho	Siemens
mm	Millimeter
NaOH	Sodium Hydroxide
p	Pico

PEEK	Polyether Ether Ketone
PVDF	Polyvinylidene Difluoride
R	Electrical resistance
R_{FB}	Feedback resistor
S_D	Sensitivity per volume sample
TDS	Total Dissolved Solid
V_{in}	Input Voltage
vol	Volume
V_{out}	Output Voltage
Vpp	Amplitude voltage
Z	Impedance
µ	Micro

LIST OF SYMBOLS

%	Percent
I_x	Complex current
Z_x	Unknown Impedance
a_0	Constant
a_1	Regression coefficient
k'	Cell constant
k_c	Cell constant
$\bar{x}$	Mean of x
$\bar{y}$	Mean of y
y'	Predicted reciprocal of conductivity
°C	Degree Celsius
Σ	Sum
Ω	Ohm
A	Surface Area
S	Siemens
U	Electrical voltage
d	Distance
e	Estimated error
l	Length
x	Average impedance
y	Reciprocal of conductivity
γ	Specific Electrical Conductance
ρ	Electrical Resistivity
σ	Conductivity

ϕ Phase

CHAPTER 1

INTRODUCTION

1.1 Project background

The measure of the capability of the water to pass or carry an electrical current is known as electrical conductivity. The current flowing in the liquid varies from that in the metal conductors in which it must be carried by ions. The presence of inorganic dissolved solids such as chloride, sulphate, phosphate and nitrate affected the conductivity of water. The temperature of the solution is also affecting the conductivity where the higher the temperature of the water, the higher the conductivity.

The reciprocal of electrical resistivity is the electrical conductivity. In 1971, General Conference on Weight and Measures adopted the unit "siemens" (symbolized by the capital letter S) which is named after Warner von Siemens, the 19th century German inventor and entrepreneur in the electrical engineering area, as an SI derived unit rather than using the units $\Omega^{-1}m^{-1}$. Now then siemens per meter becomes the unit for electrical conductivity.

Table 1 Electrical Conductivity Measurement Units

Measurement	Units
resistance conductance	ohm siemens·mho
resistivity conductivity	ohm siemens·cm^{-1}, ohm·cm^{-1}

Many fields of application including environment monitoring, agriculture, medical, biomedical and etc. are using conductivity measurement. Conductivity measurement is a quite good evaluation of quality control. Few examples on the application of conductivity measurement comprises feed water purify monitoring, quality control of drinking water and process water. Conductivity measurement comprises a wide diversity of solution conductivity. The measurement of conductivity is a hasty and affordable way to determine the ionic strength of a solution with a non-specific reading proportional to the combined effect of all ions present.

In the laboratory or field, a conductivity probe is used in measuring the solution conductivity. The existing method to measure the electrical conductivity of water utilizing conductivity probe is based on the measurement of the resistance of a column of water of accurately known dimension and does not require a water of known conductivity (Jones, 2012).

Due to low demand on sample preparation and high accuracy, the electrical conductivity water is studied using two-electrodes point probe characterization in this project. In order to adapt the situation, the spacing between the two-electrodes point conductivity probe must be reduced to micro-scale to obtain expected sensitivity (Petersen et al., 2002). Systems with long-range conductivity variations are particularly suited with two-electrodes point probe compared to the electrode spacing. Two electrodes serve as the current injector and collector in a currentless fashion. Measurement errors can be practically eliminated using this method due to contact resistances between the electrodes and the sample (Smits, 1958). Since the effective depth of probing in a homogenous sample is approximately proportional to the inter-electrode spacing, the small electrode spacing gives the advantage of higher sensitivity to the surface layer.

1.2 Problem Statement

Conductivity measurement have been widely used in industry to determine the passive electrical properties and used for practical application such as impedance tomography. As the advancement of technology, more effort has been made to apply conductivity measurement techniques to micro scale, with many promising applications such as conductivity sensor in water quality monitoring. The measuring electrodes can be easily reduced to micro scale and result in reduction of the intrusion yet the whole equipment still remain large and inconvenient for portable. Moreover, conductivity measurement for point measurements with localized high accuracy and more precision is on high demand. Hence, a small and portable point conductivity probe processing system which uses an impedance measurement chip AD5933 will be study.

1.3 Project Aim

The focus of this project is to design a small-scale two-electrodes conductivity probe for point measurement. The work aim is to develop and characterize a prototype for conductivity point measurement based on a two-electrode conductivity probe.

1.4 Project Objective

In order to achieve the aim of this project, the following objectives have been set:

i. Design a small-scale conductivity probe for point measurement following the existing conductivity probe measurement system.

ii. Calibrate and characterize the small-scale conductivity probe following the existing conductivity probe measurement system.

iii. Test and troubleshoot the small-scale conductivity probe.

1.5 Project Scope

The scope of this project is limited to the liquid to acts as the medium for conductivity. Besides, the size of the point conductivity probe to be designed must be less than the conventional conductivity probe of the size of 1 cm^3. Moreover, the point conductivity probe is designed for working frequency of 10 kHz.

1.6 Report Organization

This thesis consists of five chapters including this chapter. The organization of this thesis is as follows:

Chapter 2 provides a literature review of the approaches, theories, techniques and application related to the conductivity. It includes the previous conductivity probe design which involves the current source, voltage measure and phase sensitivity. Recent research from other researchers who contributed ideas to this research is also reviewed here.

Chapter 3 is the description of the design of the point conductivity probe by adapting AD5933, explaining how the overall of the whole probe has been designed and developed. This chapter also described the characteristics of the probe and how the system works on.

Chapter 4 describes the presentation and discussion of the simulated result. This chapter also included the details of calibration of the part of the system and discuss all the result obtained from this work.

Finally, Chapter 5 concludes the entire research work done. Here, the discussion is also made to determine the level of achievement of the proposed solution is already fulfilled the goals that have been targeted in this research. It is also seen, a summary of the contributions of this research. Finally, future work and research directions are also discussed here.

CHAPTER 2

LITERATURE REVIEW

2.1 Chapter overview

This chapter discussed the overview and a basic research of the conductivity probe and measurement theory in the extent to proceed with the project. The existing conductivity probes are being studied and several existing properties need to be investigated thoroughly. The applications of the conductivity probe measurement are reviewed and the designed structures are studied in order to ease the development of the project.

The conductivity probe is widely used in different measurement technique and the general ideas of the measurement technique are being studied for future references and ease the development of the project. Appropriate techniques on developing a probe and measurement system also being acknowledged and can be applied throughout the project. The literature review gives the conclusion for the way of designing the probe and determining the conductivity measurement.

2.2 Existing Conductivity Probe

The conductivity probe can be used to measure either the conductivity or the total ion concentration of the aqueous samples being tested. One of the easiest ways environmental tests of testing the aquatic samples is through conductivity. This quickly determines the total concentration of ions in the sample yet does not tell the specific ions that are present as shown in Figure 2.1.

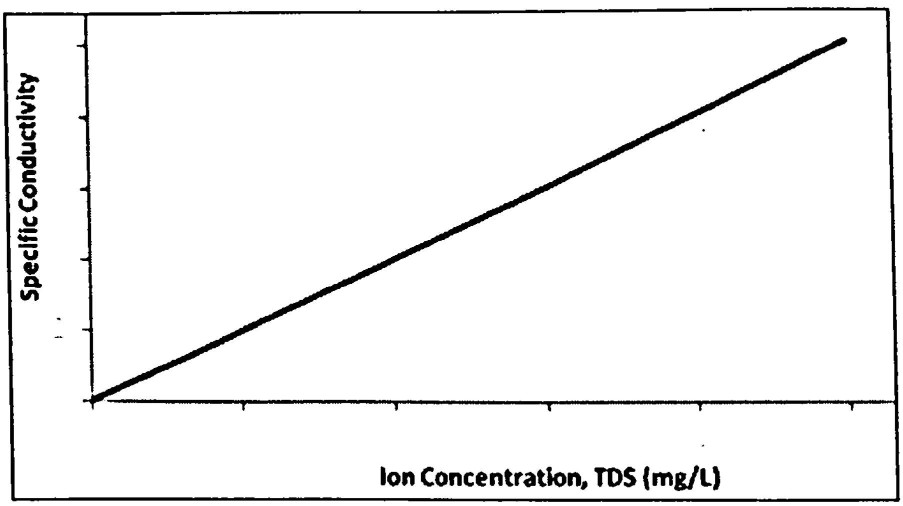

Figure 2.1 Relationship between Conductivity and the Concentration of Ions (Conductivity probe, 2010)

Nowadays, the conductivity probe mostly uses cell measurement method to determine the conductivity level. The conductivity probe measures the conductivity which is the ability of the solution to conduct an electric current which flows by ions transport between the two electrodes. Hence, the increased in concentration of ions in the solution will result in the increased of conductivity values. Actually, the conductivity probe is measuring the *conductance* which defined as the reciprocal of resistance where the resistance is being measured between two points regardless either the shape or the volume with specific resistivity of the sample being measured as shown in Figure 2.2.

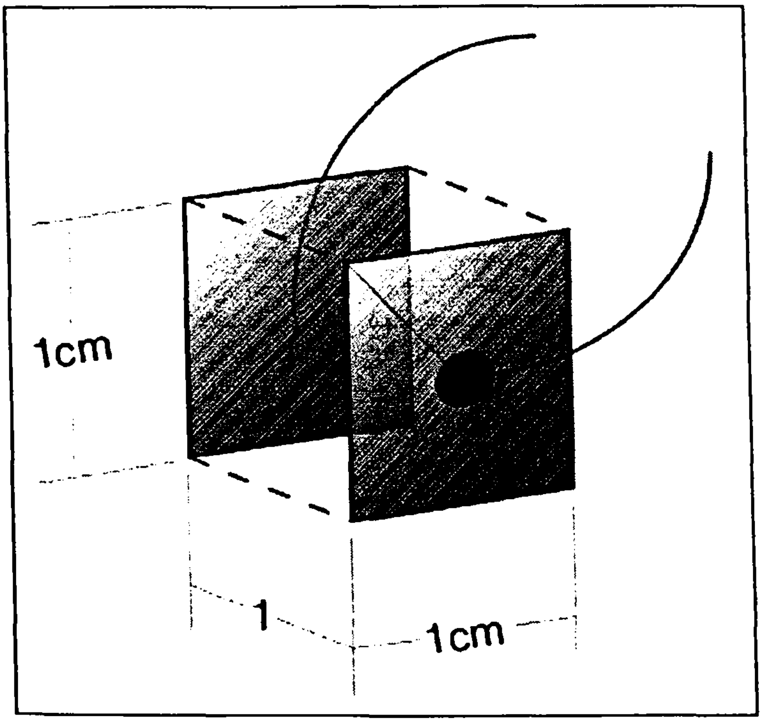

Figure 2.2 Cell Electrodes (Hunt, 1995)

The conductivity, C, can be found by using the following formula:

$$C = G \cdot k_c \tag{2.1}$$

where G is the conductance and k_c is the cell constant. The cell constant for a probe is determined using the formula:

$$k_c = \frac{d}{A} \tag{2.2}$$

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