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Impedance Influence Analysis on Multi Spectral Capacitive Sensor

Melinda Melinda^{1,2}, Agus Santoso Tamsir¹, Sarah Afifah¹, Dadang Gunawan¹

¹Electrical Engineering Department, Engineering Faculty, Universitas Indonesia
Depok, Jawa Barat, Indonesia, 16424

²Electrical and Computer Engineering Department, Engineering Faculty, Syiah Kuala University
Darussalam, Banda Aceh, Indonesia, 23111

melinda@unsyiah.ac.id, tamsir@ee.ui.ac.id, sarah.afifah@ui.ac.id, guna@eng.ui.ac.id

Abstract— Electrochemical Impedance Spectroscopy (EIS) has been a well-known method that popularly used in creating a high sensitivity of the sensor. This detection method uses a multi-spectral approach, complex data analysis, a relatively fast and also accurate measurements. We describe the method of sensing using a multi spectral capacitive sensor (MSCS) which has based on the EIS principal. Results analyses were done for 150 data sets that have been taken from pure water using MSCS. The output of this sensor is shown in a 3D (Dimension) image which is known as HHF (High High-Fluctuation) and also represents the amplitude of fluctuation in noise spectral frequency. In this study, we manage to define the effect of impedance in the sensor system to the output with such qualitative and quantitative observation. There are two types of impedance used, which are 3.3 M Ω , and 8.2 M Ω , respectively. The result will reveal the amplitude values. Hence, it is easier to observe the fluctuation value and consistency value of the material measured.

Keywords—Amplitude of Fluctuation; segmentation; influence of impedance

I. INTRODUCTION

Capacitive sensing has been through a progressive development in the world of sensors that is commonly applied in various technology industries, including biomedical engineering [1]. Various methods can be used in a capacitive sensor, a well-known method generally used is impedance spectroscopy (IS)[2][3].

Impedance spectroscopy is a field of observation related to the electrochemical field. There are three approaches that are often used in IS: transient signals, single frequency, and noise signals. Research related to the identification of aqueous materials has been widely applied to all three approaches. Firstly, the research of single frequency of impedance spectroscopy that had been done in the references of [4-8] aim to measure and to show the impedance response results.

Brabants had proposed a model of commercially equivalent circuits of lithium-ion cells based on the principle of EIS [4]. This model can predict the difference of battery output potential during system rotation. The same action was also done by [13], by utilizing lithium-ion batteries that the results show the estimation of phase shift is better than magnitude [5]. Furthermore, Zhu had proposed a procedure for obtaining data

in a wide range of frequencies ranging from 1 MHz - 10MHz which offers maximum results [6]. While, Volkmann had performed EIS measurements that can monitor the performance of the membrane and require further improvement for higher concentrations [7]. Lastly, Siao also had monitored by using EIS [8].

Research used transient signals such as references [9-10] have predicted EIS spectra and have provided the resulting response. The third approach is to apply a white noise signal developed in references [11-13] that analyse some the chemical effects using the EIS method. Study conducted by [11], which had analysed the effect of ZnO particle nano on several different concentrations in epoxy coating anti-corrosion activity in NaCl solution by using EN and EIS methods. The contribution obtained is ZnO nano particles can be observed in coatings, especially ZnO in high concentrations. Furthermore, study [12] demonstrated a two-time-frequency technique that was resulted in an effective solution for removal trends. All measurements were performed with computer control compactstat of Ivium technology that worked on zero resistance of ammeter and potentiometer. The result had shown a consistent value for residual power of the (potential) signals. Next, the study was conducted by reference [13]. Study had monitored the performance layer using the ENA by observing the trends of various experimental parameters and had conducted analysis in time and frequency domain. Here, they connected ZRA to sample using multiplexer and then measured the impedance.

Multi spectral capacitive sensor is a molecule sensing system which is based on impedance spectroscopy. We conduct the research to determine the ability of this sensor in sensing of a certain liquid which has been prepared in advanced. Moreover, we expect the sensor to be able to identify the content of a material without needing a direct contact to the material. Hence, it does not harm the material.

The current study is to create a multi spectral capacitive sensor that has quite similar approaches such as impedance white noise spectroscopy developed in the previous study [14-15]. The multi spectral capacitive sensor is a tool that works based on observations on the fluctuations represented by the average statistical quantities and the standard deviations of noise spectra observed in a large number of data sets. This

research is kind of a frontier project because of the new approach applied. Also, this study was conducted to determine the ability of the sensor to identify molecules in certain substances, from pure water, chemical mixtures and oils. The final product is expected to be a device that can detect or can identify the content of a substance without direct contact between the sensor and the substance tested. Hence, it does not destruct the properties.

The study is going to describe the MSCS system, which works in especially the effect of resistive impedance in the system. It is expected to create the amplitude of fluctuation that is helpful to observe the changes of material fluctuation pattern that have been done previously by [1].

Data processing is done automatically via PC using Matlab software into 3D (dimension) shape of the graph. From this graph, we predict that there are some noticeable changes of fluctuation patterns from the material tested. In other word, we can determine the working point in this the MSCS system. The frequencies used in this study are in the low frequency range of 1 KHz to 1 MHz. This is because, at low frequencies it is easier to generate frequency and also better for noise. Thus, we assume that low frequency is predicted to have more noise. However, this noise is the desired noise, which can display fluctuations or prominent changes that occur in the material being measured.

This study can be divided into several stages. It is starting from the introduction of some studies that had been done previously. Then, we discuss about the multi spectral capacitive sensor system used in this study. The next section, we propose the methods used and proceed with some results and analysis obtained.

II. MULTI SPECTRAL CAPASITIVE SENSOR (MSCS)

In order to comprehend the effect of impedance to the output of MSCS, it is required to understand the system of this kind of sensor. MSCS is a sensor device, which we made in this study in order to sense the changes of material that is in a molecular scale. This sensor is based on the principal of impedance spectroscopy (IS). Therefore, it has the ability not to harm the molecules which are being detected. Furthermore, we create this sensor to measure a tube which is surrounded by four electrodes divided by 90° that is a grounding electrode standing among them. Moreover, these four electrodes are divided in two pairs. First pair is connected to a main input and a set Impedance. Then, the second pair is connected to a disruptive input and the same impedance as the main input.

Main input is connected to 26 Volt peak to peak, with the frequency change sequentially in a specified range, while the disruptive input is connected to a specified Volt input peak to peak with a set of frequency. Electrical field that is created by each input then create Coulomb forces that affect the molecules inside. Therefore, it is going to produce movements of ions, which then affect the amplitude and generate the fluctuation. Disruptive frequency produces more patterns of the movements, therefore increasing the variable can be observed. The scheme of upside view of the MSCS can be figured out in the fig. 1.

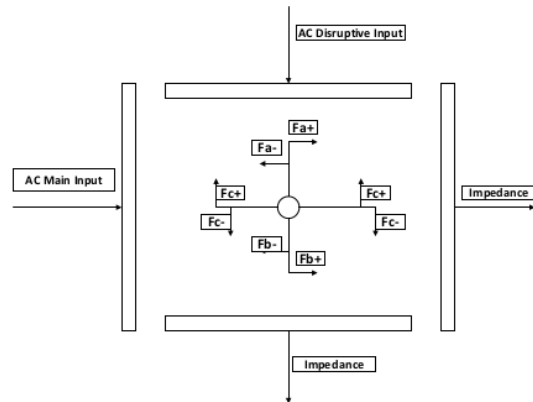


Fig. 1. Upside View of Multi-frequency Capacitive Sensor

A. Multi Spectral Capacitive Sensor System

In order to fulfil the standard of this sensor, we try to use supportive system. Then, the system is formed by providing the input needed and also present a more accurate output. Clearly, the MSCS supporting system can be seen in the fig 2.

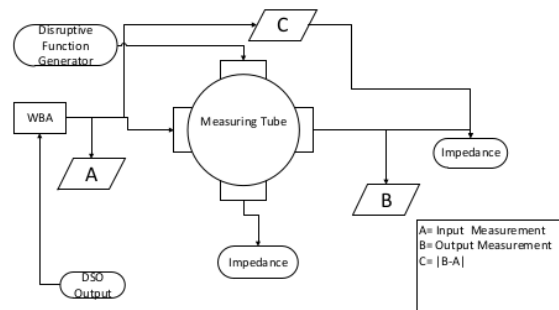


Fig. 2. MSCS Supporting Systems

We apply the DSO (Digital Storage Oscilloscope) to generate the input as well as reading the output and then it stores the output of the sensor that is processed in the next stage. We prefer the DSO because it can be easily controlled from a personal computer by using Matlab program that has been integrated. However, the output of the DSO is really small, which can only generate 2 Volt. By considering this condition, we use a wide band amplifier (WBA) that can amplify the input signal from the DSO.

B. Resistive Impedance Effect in MSCS

Resistor is a component that is used to block or limit electrical current that flows in an electronic circuit. In order to define the effect of resistive impedance to the sensor, an understanding of resistive impedance is needed. Data from EIS generally are analysed by comparing it with an equivalent electrical circuit. Most circuit elements in this model are general electronic components, such as resistor, capacitor, and inductor.

TABLE 1. IMPEDANCE IN CIRCUITRY

Component	Current Voltage	Impedance
Resistor	$E = IR$	$Z=R$
Inductor	$E = L di/dt$	$Z=j\omega L$
Capacitor	$E = C dE/dt$	$Z=1/j\omega C$

Based on Table 1, it can be seen that the impedance of a resistor is independent to frequency and only consist of real components, whereas capacitor and inductor consist of imaginary components. In this states, the current that flows through a resistor always has the same phase with the voltage.

III. RESEARCH METHOD

A research has been done on the same materials, which is pure water fused with 5 Molar Hydrogen Chloride (H_2O+HCl 5M) and the parameters research are described in Table 2. The changing variables are the impedances that are connected to main and disruptive pair electrodes. Main input used is a result from WBA with a value of 26 Volt. Furthermore, the changing frequencies through DSO are changed periodically, ranged from 1KHz to 1MHz, which have been specified previously [1].

TABLE 2. PARAMETERS RESEARCH

Material used	Changed Variables Impedance	Fixed Variable		
		Main Input	Input	Data Sets
H_2O+HCl (5M)	3.3 M Ω	26V / 1KHz-1MHz	0 V	150
H_2O+HCl (5M)	8.2 M Ω	26V / 1KHz-1MHz	0 V	150

Even though the study has prepared a system with a disruptive input, it is applied without using the disruptive input. Therefore, the voltage is set to be 0 Volt. Thus, this circumstance decreases the sensitivity of the system. However, it does not affect the amplitudes that are observed in this study.

We do the observation of the value of MF (Mean Fluctuation), HF (High Fluctuation) and HHF (High High Fluctuation). MF expresses the mean value that is taken from the data certain frequencies. However its fluctuation is really insignificant, therefore it is quite difficult to observe. Considering that, we try to observe the HF, which is the multiplication of the MF value and the standar deviation, but the fluctuation is still not preferred. The formula of HF is show as follow:

$$HF = \mu \cdot \sigma \quad (1)$$

Lastly, HHF is defined with the formula as follow:

$$HHF = \mu_{(HF)} \cdot \sigma_{(HF)} \quad (2)$$

HHF is the multiplication of the mean value from HF and the standard deviation from HF. From this formula, we gain the value of the fluctuation is clear enough to be seen. So, when the changes occur to the material tested, it can be observed through the sensor. Moreover, we hypothesize the

changes of impedances that affect the fluctuation of the HHF. Thus, it makes this fluctuation event quite easier to observe.

In addition, we analyse those values above are in the spectral noise frequency of an impedance spectroscopy. Generally in EIS, the value that is being observed is only the main frequency domain, a result from Fourier transform. This circumstance is going to differentiate the research that has been done with previous research. This method also observes a change in amplitude in a range of frequency of noise spectral around the main frequency.

The next analysis is to use the value of variance to mean (VMR) ratio based on the following equation [16]:

$$VMR = \frac{\sigma_{HHF}^2}{\mu_{HHF}} \quad (3)$$

The VMR equation (4) is required to obtain consistency value and to analyze the peak amplitude value of the measured material.

IV. RESULT AND DISCUSSION

After doing the processing method that has been determined in the previous stage, 3D image result can be seen in the fig.11 and fig. 4. These graphics consist of main frequency as the Y axis, spectral frequency as the X axis, and voltage amplitude which is defined by different colors representing the Z Axis. The parameter research used in this study is based on Table 2. Fig. 3 represents the voltage amplitude fluctuation of H_2O+HCL (5M) using 3.3 M Ω of resistance. This amplitude fluctuation can be seen in the colors alteration based on the information beside the image. HF and HHF are going to be observed in order to see the changes that occur if any changes happen to the material.

Based on Table 3, data can be gained from the image, where at a certain frequency the highest amplitude of HHF appears. This is needed to define in which frequency is affected when there is a change in the material. Based on the Table 3, the highest amplitude of HHF can be seen in the 28th segment, at main input of 700 KHz, and noise spectral of 10.1013 MHz, with amplitude of 81.6265 Volt. The result values in Table 3 are expected to represent the changes observation that can happen in certain significant segment. In addition, these differences of amplitude in each frequency are caused by movements of ion inside of the materials. A distinct range between a positive ion and negative ion create higher potential differences hence increasing the voltage amplitude of the materials. It is worth noting to assume that in the 28th segment, there has been considerable fluctuation that shows a higher value of amplitude when compared to some other segments.

Moving on to fig. 4, it clearly shows the result of the same material which uses an impedance of 8.2 M Ω . Visually observed, it is seen that there is a difference in the amplitude of fluctuation. Interestingly, if it is compared to the result of fig. 3, a quite significant change can be seen in the amplitude

differences in HF and HHF. These changes that we can observe is quite more vivid color of higher amplitude seen in the graphic, hence it will make it easier to observe the pinpoint location of changes that may occur when a change occurs to the material, even if it is in molecular level.

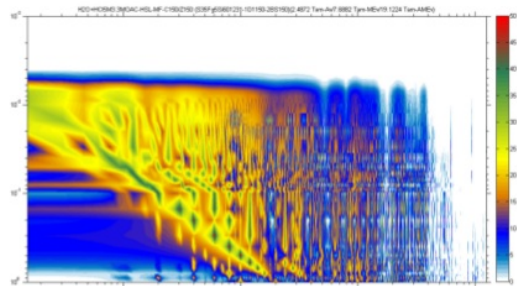


Fig. 3. (a). 3D Image MF of H2O mixed with HCl at 3.3 MΩ

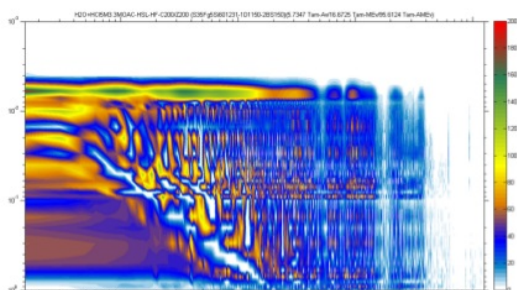


Fig. 3. (b). 3D Image HF of H2O mixed with HCl at 3.3 MΩ

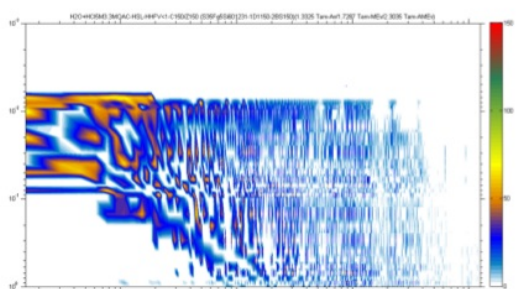


Fig. 3. (c). 3D Image HHF (VMR<1) of H2O mixed with HCl at 3.3 MΩ

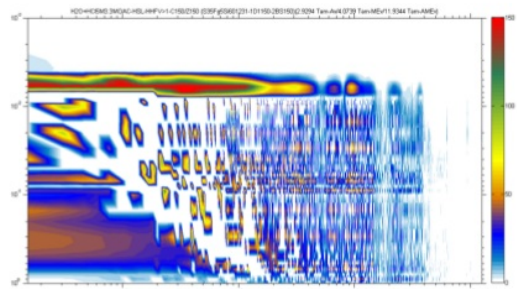


Fig. 3. (d). 3D Image HHF (VMR>1) of H2O mixed with HCl at 3.3 MΩ

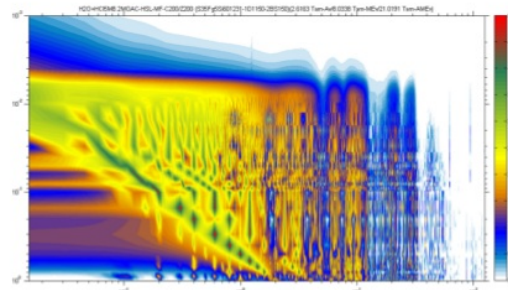


Fig. 4. (a). 3D Image MF of H2O mixed with HCl at 8.2 MΩ

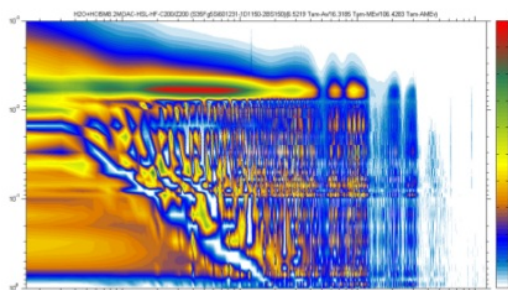


Fig. 4. (b). 3D Image HF of H2O mixed with HCl at 8.2 MΩ

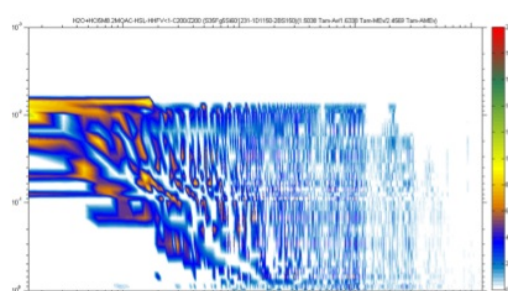


Fig. 4. (c). 3D Image HHF (VMR<1) of H2O mixed with HCl at 8.2 MΩ

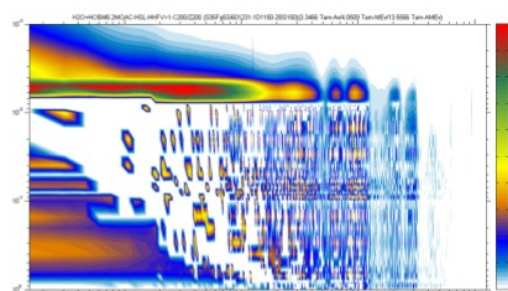


Fig. 4. (d). 3D Image HHF (VMR>1) of H2O mixed with HCl at 8.2 MΩ

Table 4 defines the data from fig. 4. As expected from the hypothesis, an increase of impedance leads to an increase of voltage, and these changes only affect the signal that are supposed to be read. By doing so, the difference of amplitude

between main signal and ignored signal are quite high thus making it easier to be observed. However, the highest amplitude of 111.824 V exist in the 8th segment, while previously in the 3.3 M Ω , the 8th segment is only considered as third highest of amplitude. Furthermore, the 12th segment in 3.3 M Ω holds the highest amplitude and the lowest amplitude is around 83.29 V. Because of this anomaly, another factor is being observed, this factor is shown in fig. 5.

TABLE 3. THE RESULT OF VOLTAGE AMPLITUDE SEQUENCE IN 3.3 M Ω

No	Segment	Frequency (MHz)		HHF Amplitude (V)
		Main Frequency	Noise Spectral	
1.	28	0.700	10.1013	81.6265
2.	8	0.007	0.0916	79.3185
3.	28	0.700	8.4991	78.3731
4.	9	0.008	0.4883	75.5359
5.	28	0.700	8.3008	72.6836

TABLE 4. THE RESULT OF VOLTAGE AMPLITUDE SEQUENCE IN 8.2 M Ω

No	Segment	Frequency (MHz)		HHF Amplitude (V)
		Main Frequency	Noise Spectral	
1.	8	0.007	0.1678	111.8247
2.	16	0.050	0.1526	99.3645
3.	28	0.700	8.4991	94.5588
4.	13	0.020	0.0610	90.4493
5.	9	0.008	0.1678	88.0320
6.	28	0.700	10.1013	83.2932

Furthermore, based on the result of amplitude values in the Table 3 and Table 4, it is reasonable to discuss that the result of voltage amplitude sequence in 8.2 M Ω is in Table 4 performs quite good performance compared to the result of voltage amplitude sequence in 3.3 M Ω .

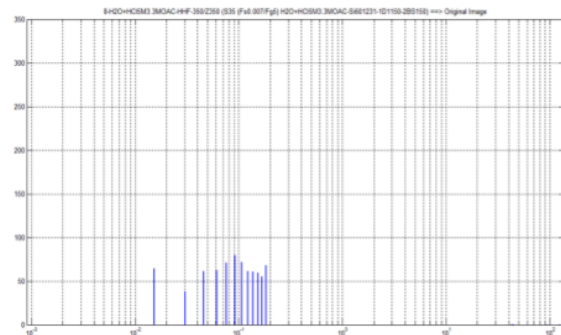


Fig. 5. (a). Amplitude of segment 8 of 3.3 M Ω

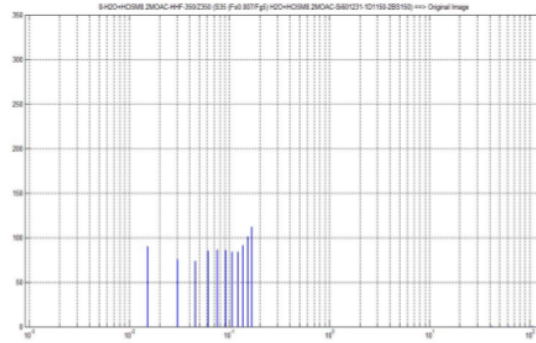


Fig. 5. (b). Amplitude of segment 8 of 8.2 M Ω

Fig. 5 represents the voltage of amplitude at 8th segment, or at frequency of 7 KHz with spectral frequency as x Axis. This graphic can clarify that the changes that have been made by increasing the impedance, does not affect the voltage amplitude at each spectral frequency. Furthermore, we can investigate from the data that relate to the main function of the sensor.

The occurrences changes indicate that the fluctuating consistency of the use of impedance values of 3.3 M Ω and 8.2 M Ω then the fluctuation consistency value will increase as well. Moreover, previously the value of consistency was at 61.31% and is now 94.35%. This consistency value is obtained by using (4), which is represented by the VMR value. Obviously, the values obtained determine good results and has almost reached the consistency standard of 99%.

V. CONCLUSION

This study shows that the increase of impedance value given to the sensor system can produce higher amplitude output value than before. In other words, it can be said that the amplitude range increases then its amplitude fluctuations will be easier to observe.

It is also shown that in the spectral range of frequencies against the graph of the voltage amplitude. There is not every frequency will change the amplitude values, and these results are in a segment change with the highest amplitudes. But changes in the highest amplitude segments do not affect the increased of fluctuations value, which in turn can assist observation of the data resulted. Future work of this research is the use of perturbation frequency, in order to increase the consistency level of this sensor.

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