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REFLECTION AND DIELECTRIC MEASUREMENT FOR SALINITY OF WATER USING MICROSTRIP LOOP ANTENNA AND DIELECTRIC PROBE

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ABSTRACT: This study was conducted to investigate the feasibility of loop antenna in gauging level of salinity of water via electromagnetic wave reflection. High salinity cause adverse effect to environment. When high levels salinity of water diffuse into soil, it declines values of land for human and animal consumption. These impacts can cause tremendous monetary lost because the restoration of impairments is extremely costly. Therefore, a reliable salinity detection system of water source is crucial. In this work, reflection measurement was conducted using loop antenna in conjunction with network analyser for water salinity detection. Dielectric probe will be then used for dielectric characterization due to different water salinity. It comes to learn that the different level of salinity of water exhibit different dielectric properties through reflection measurement. The increment of salinity leads to increment and decrement of dielectric constant and loss factor, respectively. Similar observation can be found in reflection coefficient.

Keywords: Loop Antenna, Salinity, Reflection Coefficient, Dielectric Properties, Water

1. INTRODUCTION

Salinity of water source is very crucial in determining the quality of our environment, either for residential purpose or habitat for flora and fauna. Salinity is referred to the quantity of salt in water which will affect its acidity. Disturbance of acidity of water may cause inconvenience to human race, flora and fauna. The prehistoric case during 2400ï 1700 B.C. in ancient Mesopotamia which cause several negative issues due to disturbance of salinity were occurred. Their negative effect, e.g. soil erosion, landslide, water pollution and some other environmental issues were even extended to disrupt civilization. The recent one is occurred in southern Iraq [1].

Agricultural activity is backbone of economy for certain ASEAN countries, e.g. Thailand, Malaysia, Indonesia, Vietnam and etc. The disruption of acidity of water can be extended to soil salinity. Water and soil for plantation and agricultural activity is closely related. Salinity of soil and water must be preserved at optimum salinity, in order to provide the best environmental condition for agricultural activity. Suffice to say, the salinity of water is not merely disrupt the ecosystem, but its effect may even connect to economy of an agricultural-based countries. As a result, a fast and accurate salinity detection method is required for precaution.

In this work, water in different degree of salinity which is presented in molarity will be characterized dielectrically by Agilent E8362B PNA Microwave Network Analyzer in conjunction with Agilent 85070E slim probe from 2 GHz to 20 GHz. In addition, complex reflection coefficient in terms of magnitude and phase are measured by using Agilent E8362B PNA Microwave Network Analyzer. However, measurement of loop antenna on salinity will be conducted within 2.3 GHz to 2.5 GHz where ISM band appear within this frequency range, i.e. 2.45 GHz. The relationship among the salinity, dielectric properties and reflection coefficient will be discussed.

1.1 Past Researches

Researches for salinity analysis have been conducted in recent years [2]-[3]. Immense number of publication can be found especially implementation of microwave method [4]-[5]. Kundra et al. (1992) [6] measure dielectric properties of milk due to effects of dissolved salts. Gadani et al. (2006) [7] proved the effect of salinity and frequency on dielectric constant where dielectric constant decreases when concentration of saline water increase. Whereas, increment of frequency cause decrement in loss factor. On the other hand, Thomas M. Dauphi et al. (1983) [8] reported that a salinometer which was designed with principle of the conductivity for ratio of sample to standard seawater in dual cell. Satellite was even used for complex dielectric analysis on pure and sea water [9].

1.2 Loop Antenna

In telecommunication industry, loop antenna is well known as one of the efficient receiver of radio signals if compare with other antennas, e.g. monopole antenna, dipole antenna, Uda-Yagi antenna and etc. It is due to its mobility, compatibility wide range of frequencies, and low electricity consumption. The performance of a loop antenna's performance is crucially determined by its design, specification and placement.

Loop antennas can be a wideband transmitter and receiver. It has high portability because it can be easily miniaturized [10] for many portable and small wireless devices. On the other hand, loop antennas are also low cost, ergonomic, and commonly used for various purposes, e.g. as antenna sensing system.

A loop antenna is made of a loop of copper as shown in Fig. 1. The loop antenna's capacitance is proportionally varies with operating frequency. In other word, the loop's capacitance increase with frequency and vice versa. The equivalent loop's capacitor maintains electric voltage by holding the deposited charge. Charge will be release and causes the flow of current after time constant, τ. It implies that the longer τ lead to higher efficiency of antenna to propagate the waves into free space. Lower frequency can be easily implemented in such a case. Albeit lower frequency cannot propagate farther, its signal of wave can be stronger.

2. METHODOLOGY

2.1 Samples Preparation

In this project, the saline water with different molarity is prepared for reflection-based saline water measurement. The sodium chloride (NaCl) with different quantity (weight) is dissolved in water, in order to prepare different molarity of saline water. The samples were prepared in molarity of 0.00 M, 0.34 M, 0.69 M, 1.03 M, 1.38 M, 1.72 M, 2.07 M, and etc. The molarity can be defined as the molar concentration that denotes the number of moles of a given substance per liter of solution. The formula for molarity can be expressed as

$$\text{molarity}\left(\frac{\text{mol}}{\text{L}}\right) = \frac{\text{mole of solute(mol)}}{\text{Volume of solution(L)}} \quad (1)$$

$$\begin{aligned} &\text{moles of NaCl(mol)} \\ &= \frac{1\,\text{mol}}{\text{Relative weight of NaCl(g)}} \\ &\quad \times \text{Weight of NaCl(g)} \end{aligned} \quad (2)$$

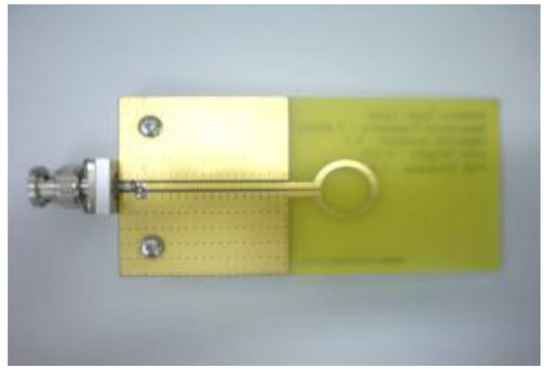

Fig. 1 Microstrip Loop Antenna.

2.2 Reflection and Dielectric Measurement

2.2.1 Reflection measurement

The reflection measurement for complex reflection coefficient using loop antenna is as shown in Fig. 2. Short, open, load, and known-thru standards (SOLT) in Agilent 85050B standard mechanical calibration kit are used for calibration prior to reflection measurement [11]. The calibration procedure is conducted to get rid systematic errors and drift errors.

During reflection measurement, the loop antenna which connects with Agilent E8362B PNA Microwave Network Analyzer is used to measure reflection coefficient in terms of magnitude and phase. The antenna was fully dipped in the various molarity of saline water. The measured magnitude and phase for various molarity of saline water as exhibit on PNA were recorded for analysis.

2.2.2 Dielectric measurement

Agilent 85070E slim probe (Fig. 3) is an open-ended type of dielectric sensor which works with Agilent microwave PNA for dielectric characterization in terms of dielectric constant (ε') and loss factor (ε'').

Calibration is conducted through slim form probe calibration short, pure water and free space. The method of measurement is similar with reflection measurement where the slim probe is dipped into saline water. Both ε' and ε'' will be computed through Agilent 85071E material measurement software. Both ε' and ε'' are needed to explain the measured complex reflection coefficient.

Fig. 2 Reflection measurement for salinity using loop antenna.

Fig. 3 Agilent 85070E slim probe [12].

3. RESULTS AND DISCUSSIONS

3.1 The Effect of Salinity on Dielectric Properties (Agilent 85052D Slim Probe)

Figure 4 and 5 illustrated the variation of dielectric measurement using Agilent 85052D slim probe in conjunction with PNA. Figure 4 indicates that the dielectric constant, Ůô of all saline water with different molarity decreases when frequency increase from 5 GHz to 20 GHz, overall. The incomplete polarization due to the delay of response to the change of applied field causes the decrement of Ůô. In addition, the measured dielectric constant for free space is as expected which present in unity.

In Fig. 5, the loss factor, Ůô shown constant in null value for free space. is merely almost level off when exceeding 15 GHz. It might due to the delay response of molecules in saline water to applied time-varying field. The synchronous polarization among the molecules in saline water reduce the friction occurred among molecules. The loss factor is determined by asynchrony of relaxation and operating frequency. The highly dispersion of relaxation frequencies among the molecules in saline water cause the asynchrony. The rotations of molecules due to time-varying applied field cause the friction. Subsequently, the heat is generated and dissipated. As a result, the loss factor for different molarity exhibit different gradient of trendline as shown in Fig. 4.

Generally, it can be observed from Fig. 4 that dielectric constant decreases when molarity of saline water increases. When Sodium Chloride (NaCl) dissolved in water, water molecules (H_2O) will bind with the molecule of NaCl to form hydrogen bonding. It increases the inertia of molecules. Subsequently, the mobility of water molecules is degraded and so for polarization. The mobility of these molecules is constraint during polarization and hence cause the descending of Ůô when molarity increases. Higher molarity implies less free water molecule. Hence, Ůô decreases when salinity (molarity of NaCl) in water increases. In contrast, Ůô increases with molarity of NaCl.

The dispersion of relaxation frequencies among bound molecules and free water molecules due to inertia increase the asynchronous of rotation. Hence, the rotational losses or friction among molecules rise up. It can be justified through Fig. 5 where Ůô increase with molarity of NaCl in saline water. However, it starts to be level off because most of the free water molecules have been bound by NaCl. It enhances the synchrony of all molecules during the polarization. Low dispersion of relaxation frequencies and operating frequencies might be the main reason for this phenomenon.

In addition, the higher molarity also exhibit lesser gradient. It is attributed to insufficiency of free water molecule. Pure water exhibit the highest Ůô due to the presence of free water molecule is high. It can be easily polarized when field is applied because the mobility of free water molecules has not been constraint. When free water molecule is bound with NaCl in solution, free water molecule loss its mobility and its inertia is high. Hence, it leads to low Ůô.

In the meantime, higher molarity also results lower gradient of Ůô over frequency. It is due to high inertia of bound molecules where these molecules lost its capability to polarize synchronously with operating frequency. Therefore, its Ůô is presented constantly in Fig. 4. Meanwhile, dispersion of frequency among the applied field, bound molecules and free water molecules are lead to variation of Ůô over frequency. At low frequencies, bound molecule which are major component in saline water are still capable to follow the oscillation of applied field. When frequency increases, they might be oscillate insignificantly because the frequency of oscillation is too high. Less friction among molecules are taken place, therefore, it exhibits lower gradient of Ůô over frequency range beyond 15 GHz.

3.2 The Effect of Salinity on Reflection Coefficient (Loop Antenna)

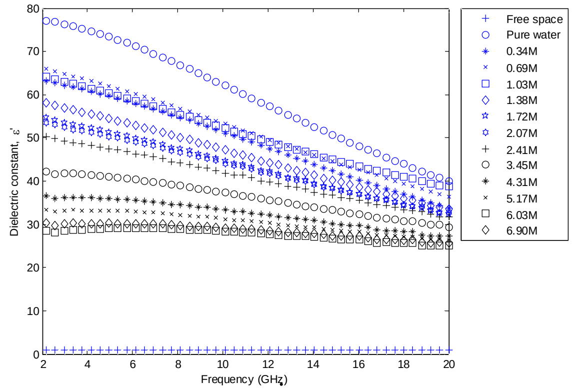

Fig. 4 The variation of dielectric constant over frequency for various molarity of saline water

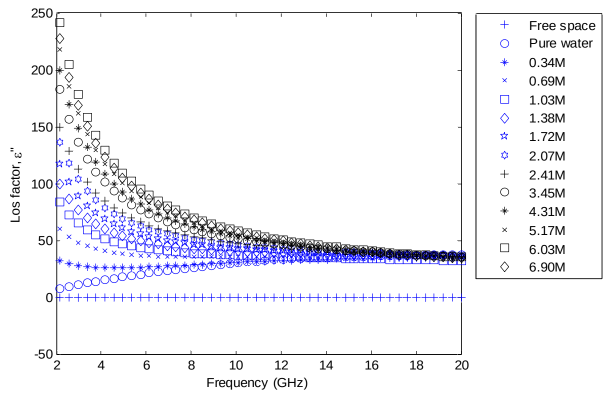

Fig. 5 The variation of loss factor over frequency for various molarity of saline water.

From Fig. 6, it can be observed that the magnitude of reflection coefficient decreases when frequency increases. Actually, it is in line with the variation of Ủδ over frequency as shown in Fig. 4. Reflection coefficient, Γ can be expressed as

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \qquad (3)$$

where Z_L is impedance of load/sample and Z_0 is a constant which refer to characteristic impedance of transmission line on loop antenna. In this work, Z_L is defined as impedance of saline water. Generally, Z_L can be expressed as

$$Z_L = j\frac{1}{\omega C} \qquad (4)$$

$$C = \varepsilon C_0 \qquad (5)$$

where ω is angular velocity and C_0 is capacitance for free space. If Z_L is closer with Z_0, Γ will show lesser. As a result, it can be deduced that the decrement of magnitude of reflection coefficient over frequency might due to approach of Z_L to Z_0. It can be explained by the mismatch impedance where the smaller $Z_L - Z_0$ at numerator of Γ as expressed in Eq. (3). The loop antenna is designed to drive the electromagnetic wave to propagate into free space. When the loop antenna was dipped into saline water, the propagation environment is different from the free space. It causes the reflection where it meets the mismatch impedance at interface of two media. The higher degree of mismatch implies the greater reflection is occurred. It can be inferred that when the dielectric constant decreases with frequency (Fig. 4), it leads to the decrement of mismatch impedance. Hence, it can be noticed that magnitude of reflection coefficient decreases over frequency too as shown in Fig. 6.

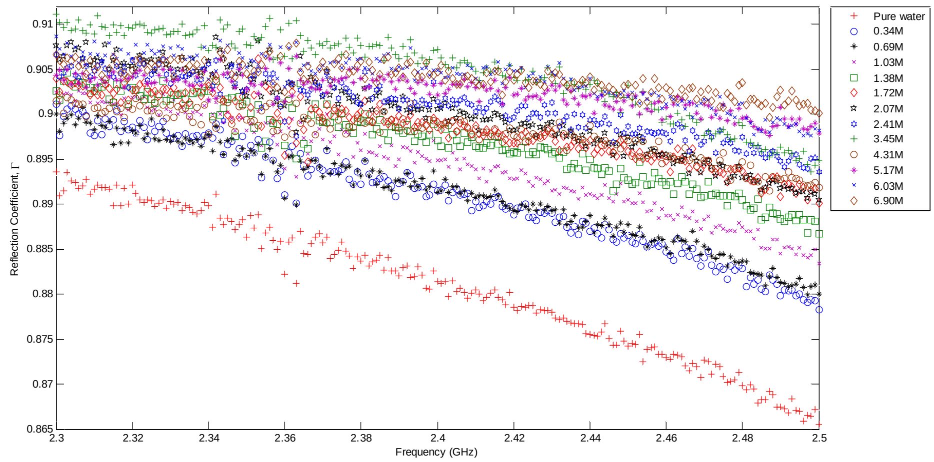

Fig. 6 The variation of magnitude of reflection coefficient over frequency.

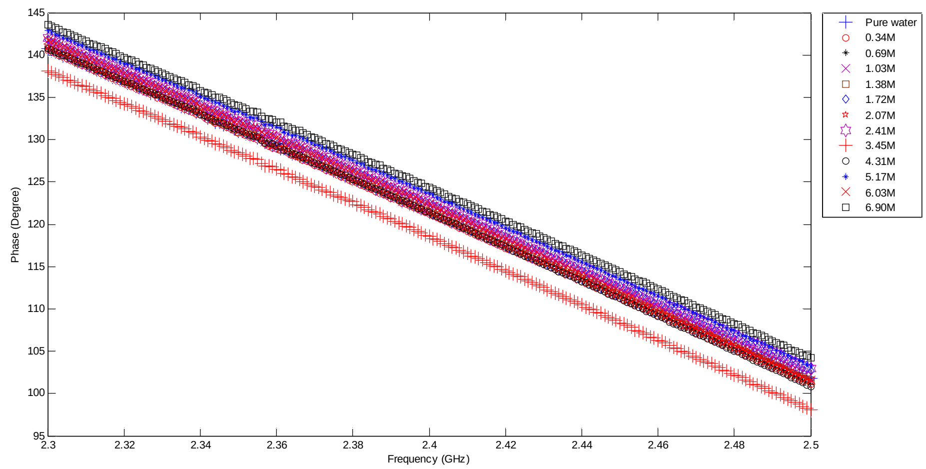

Fig. 7 The variation of phase of reflection coefficient over frequency.

Withal, phase of reflection coefficient plummet as frequency increases. It can be clearly seen in Fig. 7. The phase for all molarity of saline water cannot be distinguished significantly. It might due to the insignificant delayed time of incident wave and reflected wave. When the incident wave transmits from antenna impinges on interface, the time delay is occurred before reflection. In Fig. 7, time delay during the reflection on interface is mitigated over frequency. Therefore, the phase angle has shown decreases with frequency, as increment of frequency shorten time delay during the polarization. Time is delay because time is taken for process polarization. When the frequency increases, the dielectric constant decreases. The depth of wave from the interface to be reflected might be smaller. As a result, the resultant phase shift due to reflection on surface and internal depth of saline water will be smaller. Delayed time is closely related to the depth which the internal reflection occurred. It can be seen that depth for internal reflection does not change significantly over frequency.

4. CONCLUSION

A reflection-based microwave measurement system which consists of dielectric slim probe and loop antenna in conjunction with PNA is developed for the sake of salinity measurement. PNA in conjunction with dielectric slim probe are used to measure the dielectric constant, ε' and loss factor, ε'' of saline water with different molarity (salinity). Reflection measurements using loop antenna were also conducted for reflection coefficient. Then, the measured reflection coefficient is presented as magnitude and phase. It can be observed that both dielectric constant and loss factor decrease when frequency increases. The measured reflection coefficient in terms of magnitude and phase decrease when frequency increases. The effect of molarity on the dielectric properties is major factor lead to the variation of magnitude and phase of reflection coefficient. However, the phase has no significant response towards the variation of salinity. Suffice to say, the dielectric and reflection measurement present considerably good of performance in assessing the salinity in water

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