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Design and testing of circular metamaterial-based salinity sensors

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ABSTRACT

The salinity sensor is a salt level detection tool designed based on the electrical properties of water. The salinity sensor consists of two electrodes that are dipped in water where the sensor is given a potential difference so that electrons flow in the sensor-building circuit. The electrode is connected to a variable resistor which forms a voltage divider circuit connection. This research aims to design a metamaterial (MTM) sensor to detect salt levels in the 100 – 900 MHz range and investigate the performance of MTM sensors for detecting salt levels. The working MTM sensor design has been successfully designed and tested, where the MTM sensor is also able to differentiate frequency values from samples with different salt levels.

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1. INTRODUCTION

Water is a basic need for human life. Water is used for drinking, cooking, bathing, washing, cleaning equipment, watering plants, and for other purposes. Bingkuang Lake is an area close to the river, namely the Kampar River, where most of the people depend on the existence of this river. This community dependence makes the river a source of clean water, a source of income and livelihood for the community. This area is far from coastal settlements and the sea, but monitoring of water conditions still needs to be carried out to ensure that the water source is safe for consumption and can be used for community needs [1-3]. Salinity measurements can be carried out using various methods and equipment, one of the tools that can be used is a salinity sensor [4, 5].

The salinity sensor is a salt level detection tool designed based on the electrical properties of water. The salinity sensor consists of two electrodes that are dipped in water [6, 7]. The sensor is given a potential difference so that there is a flow of electrons in the sensor-building circuit. The electrode is connected to a variable resistor which forms a voltage divider circuit [8-10].

In general, salinity sensors are not widely available, and apart from being relatively expensive and unaffordable, the salinity sensors that are presented are mostly only total dissolved solid (TDS) sensors which are less specific for use [11, 12]. Therefore, it is necessary to carry out research as an alternative so that it can be used as a reference. In this research, the sensor was designed specifically for salinity so that it becomes a sensor that is planned to be affordable in the future. The research stage, it is certainly still relatively expensive, in this research the sensor that was designed used a PCB printing method, where this time the method used was easy and cheap to reference [13-15]. The PCB printing method is carried out by making a prototype of a metamaterial (MTM) sensor component to detect the salinity of a solution. The sensor was tested using NaCl dissolved in 7 ml and distilled water. MTM has been researched for development as biosensors since the demonstration of their manufacture and characteristics was successfully proven by Smith et al. (2001) [16].

MTM has negative refractive index properties which give rise to new techniques in the development of diagnostic devices. This negative refractive index is caused by the negative phase two in the left-handed material often called negative index material [17, 18]. One interesting application of MTM to study is as a salinity sensor. MTM is a unique optoelectronic design with electromagnetic properties that are not found naturally, one of which is a negative refractive index [19].

Research that has been carried out regarding monitoring water conditions based on the existing internet of things is research conducted by Hakiki et al. (2022). This research only uses a TDS sensor, an Arduino microcontroller as an analog to the digital data processor, an SX1276 Transceiver module as a data sender and receiver, and an ESP32 NodeMCU whose results can only be monitored using an Oled display and the Blynk application where the research is still ongoing. not yet affordable and the tools used are relatively expensive and quite difficult to find on the internet [20]. In this research, the design and manufacture of a water monitoring system with water quality sensors was carried out. The tool made is an electronic system equipped with a microcontroller, water quality sensor, and display. This tool can be used with high data accuracy, data consistency, and durability for measuring water quality.

2. RESEARCH METHODS

2.1. Study of Literature

A literature study was carried out to determine salt levels by investigating the performance of MTM sensors by searching and collecting information from various reference sources such as journals, books, and other sources.

2.2. Sensor Design

The design and size used for the TDS sensor can be seen in Figure 1 and Table 1. After being designed, this sensor is printed using the PCB printing method with a gap width of 1 – 5 mm, where this sensor consists of copper metal inclusions (X) 12 mm above the substrate. FR4 epoxy with a substrate thickness (t_s) of 2 mm, and a substrate length and width (L_1 and L_2) of 170 mm. The metal inclusion structure consists of 2 loops/rings or circular rings with an inner ring radius (R_2) of 36 mm, an outer ring radius (R_1) of 55 mm with a ring or strip thickness of 0.01 mm, ring width (g_1) of 7 mm, length and width strip connecting the ring to the connector (g_2) 20 mm. which follows the principle of the MTM split ring resonator.

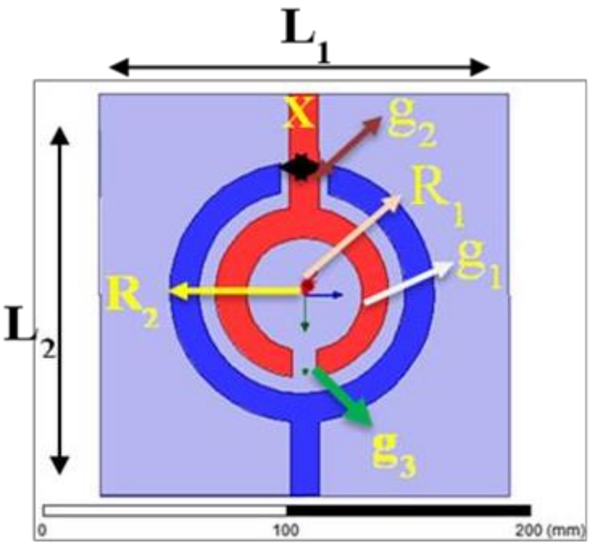

Figure 1. Sensor design.

Table 1. Design size.

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
L_1	170	g_1	7	R_1	55
L_2	170	g_2	20	R_2	36
X	2	g_3	10	t_s	2

2.3. Sample Variations

This research used a sensor that was tested with two variations using NaCl dissolved in 200 ml with Aquades in the range of 1 – 7 grams, the concentration range of which can be seen in Table 2.

Table 2. Concentration of NaCl salt with salt.

Sample code	Mass of NaCl (grams)	Volume of distilled water (mm)
A	1	200
B	2	200
C	3	200
D	4	200
E	5	200

2.4. Test and Calibration Scheme

The form of this research testing scheme is shown in Figure 2. The sensor is connected to a vector network analyzer (VNA) which has been connected to a PC (laptop). Then the circuit/s and frequency measurements were carried out. Increasing salt concentration will affect the shift in frequency and parameters. For the sensor to work accurately, NanoVNA needs to calibrate the measurement values first. The steps to calibrate are first to press the on button to activate NanoVNA, then press on the screen select in the calibration menu, and select the open, Lord, short, and save menu. This calibration uses a laboratory standard salt solution with a temperature measured at room temperature, using a standard Salinity Sensor and TDS meter.

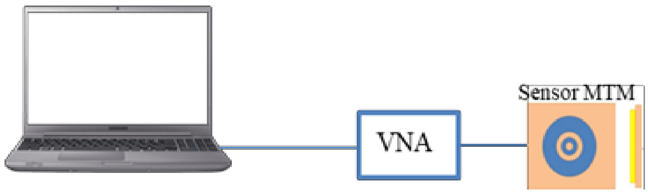

Figure 2. Test scheme.

2.5. Field Testing

Field testing was carried out by taking water samples from one location on the river with three drilled wells from the houses of residents around the village in Danau Bingkuang village. Water samples taken from the river flow are divided into three points across the river cross-section each in three depth layers, namely the surface, middle, and riverbed layers, and then analyzed using a salinity sensor by reading the output results after calibration. This measurement was in the Integrated Physics Laboratory, FMIPA, Muhammadiyah University of Riau. Samples taken are stored in a 1.5-liter bottle and the coordinates are recorded by GPS to be recorded in a logbook.

3. RESULTS AND DISCUSSIONS

3.1. Sensor Design

The MTM sensor design for measuring salt levels in water is designed in HFSS software using the PCB printing method as shown in Figure 3. The design that has been designed and printed is connected using a 4-inch PVC pipe which is then filled with 200 ml aquades solution with samples. Data collection process is carried out using NanoVNA and a laptop as shown in Table 3.

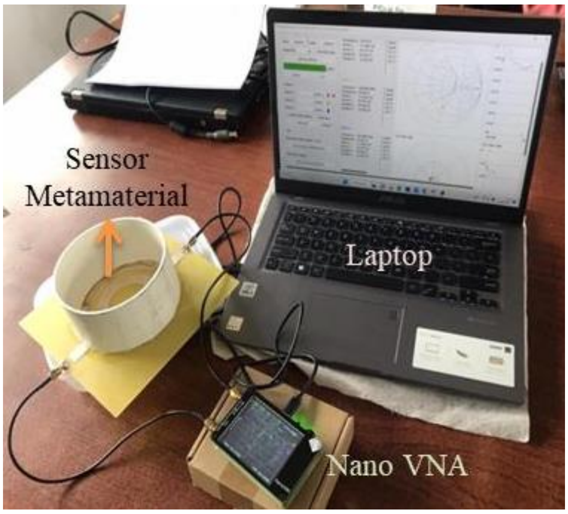

Figure 3. Data collection process.

Table 3. MTM sensor performance results.

Sample	Frequency (MHz)	S11 (dB)	S21 (dB)
Aquades	196.019	-9.748	-5.013
NaCl 1 gram + aquades 200 ml	304.872	-12.503	-18.89
Well water	199.188	-9.815	-4.377
Kampar River water	208.853	-12.24	-4.206
Siak River water	285.541	-11.394	-11.616

3.2. Linearity

The test experiments carried out are shown in Figure 3. The results obtained can be seen in Table 3. It was found that a shift occurred with different references for each different sample. Continued with Figure 4. The linear regression results for five different concentrations obtained very good linearity, with a correlation coefficient R^2 of 0.9978. This means that the designed MTM sensor can detect salt concentrations in different water solutions. However, it needs to be followed up with improvements and needs to be verified with other test equipment such as a salinometer, TDS, and other salt content detection measuring instruments.

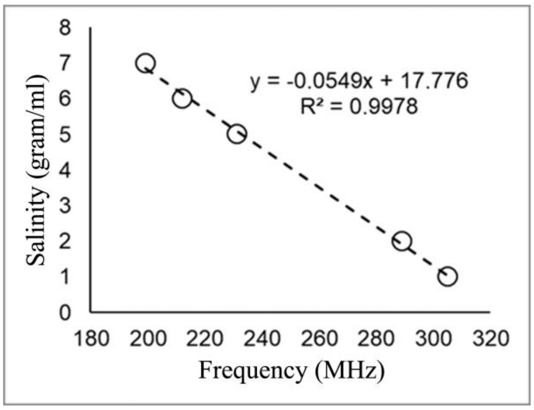

Figure 4. Frequency plot and round markers of temporary measurement data dashboard (linear regression curve).

Previous research was carried out by Marzuki and Yunianto (2013) on making a simple fiber sensor for measuring the refractive index of sugar solutions and salt solutions. The research results showed that the concentration of sugar and salt was linearly related to the refractive index value, the degree of correlation R^2 = 0.95006 and R^2 = 0.99856 [21]. Research conducted by Siltri et al. (2016) regarding the manufacture of salinity and water turbidity measuring instruments using electrode and

LDR sensors resulted in two parts of the research, the first was performance specifications, this system used copper electrodes as salinity sensors and LDR as turbidity sensors. It consists of two plastic boxes namely a circuit box and a sample box. The second is a design specification which consists of several data such as the accuracy and accuracy of salinity measurements which have an accuracy of 95.71% with a precision of 97.22%, turbidity measurements have an accuracy of 96.25% and a precision of 97.69% [22]. Next, research was conducted by Kirana and Suryono (2016) regarding the design of a system for monitoring water salinity levels using wireless sensor systems. so that the equation value for salinity is obtained, the equation value is $y = 0.049\ x - 35.306$. This equation is entered into the microcontroller program. The calibration results obtained a correlation coefficient on the salinity sensor of $R = 0.993$ with an error of 0.025 ppt [23]. Furthermore, research on the concentration design of NaCl solutions using multi-mode fiber optics with a w-system model was carried out by Wibowo and Rubiyanto (2012) where in the characterization the BF5R-D1-N detector was used which contained a light-emitting diode as a light source with a wavelength of 660 nm and a phototransistor as a detector to receive the light. By analyzing the absorption values at ultraviolet and visible light wavelengths, the refractive index of the NaCl solution, and the power losses experienced by this sensor due to microbending, bending, and scattering. It was found that the amount of power loss experienced by the sensor was proportional to the amount of NaCl concentration given. Providing distance between the legs provides a difference in sensitivity in the measurement and the maximum sensitivity value is at a distance of 2.5 cm. This sensor working system is also capable of calculating the concentration of NaCl solution with a range of 0.0 – 5.0 M and an accuracy of up to 0.025 M [24]. Research conducted by Nadi et al. (2019) on the design of a multi-sensor-based water quality detection system for PH, dissolved oxygen, temperature, and conductivity where the water quality monitoring tool has sensors that detect parameters such as temperature, pH, dissolved oxygen, and conductivity in water [25].

4. CONCLUSION

The working MTM sensor design has been successfully designed and tested, where the MTM sensor is also able to differentiate frequency values from samples with different salt levels. The linearity results from the MTM sensor show a very good value with a linear regression correlation of 0.9978.

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