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Testing of chlorine dosage in drinking water using microstrip patch sensor

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ABSTRACT

A new method using microstrip patch sensor is designed, simulated, and measured to detect the dosage of added chlorine to the drinking water using the relation between permittivity and matching impedance. The simulation is done using computer simulation technology-microwave studio software. The proposed sensor is designed on a single FR-4 layer with a low profile, 0.499 GHz bandwidth, center frequency of 2.94 GHz, gain of 6.55 dBi, and a good front to back ratio of 17.84 dB. In this work, the antenna design is started from a conventional patch antenna equation. Then, an optimization process is performed to achieve good parameter values for obtaining the desired objective. The objective is to utilize the microwave frequency to measure the chlorine dosage in water. The measurement results proved that the matching impedance can be used to find out the dosage of chlorine in drinkable water. The proposed method overcomes the open-ended coaxial probe method in terms of experimental time and contactless testing and shows high matching with the latter actual data. Moreover, the proposed method overcomes the conventional methods in terms of continuity and large scale of testing, non-contacting with the samples of water, and no additive chemical materials, which make the water samples not drinkable.

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1. INTRODUCTION

Drinking water is the most important source of life, at the same time, freshwater represents 2.5% of the whole water around the world [1]-[4]. The disinfection procedure of water is one of the most important issues for human life. Therefore, scientists studied and found a lot of methods to disinfect water from germs and bacteria. Some of these methods used chlorine [5], [6], iodine [7], [8] and fluoride [9], [10]. In some countries, other chemical materials are used [11], [12]. Each method has its advantages and disadvantages.

The major issue is that how to measure the concentration of the chemical material which was added to the water for disinfection. Especially, these materials have critical dosages depending on the material itself. The chemicals used for this purpose might be changed into a poisonous material in case of exceeding the allowable limits recommended in drinking water as per mg/L or even μg/L. Therefore, dealing with these additive chemical materials should be hardly restricted under supervision by professional staffs with accurate testing equipment.

For chlorination disinfectants, one of the widely testing methods is based on sampling water to measure the relative permittivity ($\mathcal{E}r$) of potable water using a vector network analyzer, laptop, and a special probe immersed into the testing sample to read the permittivity, which is changed in accordance of added chemicals.

These methods called open-ended coaxial probe method [13], [14]. Another method depends on color testing equipment (comparator) by adding a special tablet or liquid to the water sample. The color of the sample will be changed, which indicates that the dosage of chlorine has been added [1].

Compared to the other halogens, chlorine is considered as the preferable and more safe chemical material to disinfect the drinking water due to the wide range of permissible adding dosage per mg/L. Due to its pungent odor, its dosage starts from 0.5−1 mg/L as a drinking dosage and from 1.5−3 mg/L as a dosage for swimming pools [15], [16]. So, the maximum test ratio is 5mg/L for special cases. Moreover, the chlorine level is considered a poisonous material if it exceeds 8 mg/L [17], [18].

All the well-known measuring methods of chlorine concentration depend on separated water samples [19]. So, the testing samples are limited numbers per day, time-consuming, and they are not considered as a real-time method. These three major disadvantages make the conventional testing methods are dangerous especially the water treatment plant which is working continuously and non-stop. If there is any unexpected error in the chlorinator instrument used for adding chlorine, this will be considered as a disaster issue due to the uncertainty of detection for a dosage passed to the consumer. This means a huge amount of water passed to water network consumers with over/lower dosages of chlorine material. Especially, the chlorinators are working automatically.

The microwave frequency can be employed to detect the changes in media throw the technique of using microwave sensor [20]-[23]. These microwave sensors can be worked in contactless method through sending and receiving wireless frequency to the material under test (MUT). The results depend on analysing the receiving signals reflected from the MUT. For each tiny changing in the permittivity of the media, the microwave sensor can detect these changing throw different parameters, such as matching impedance, center frequency, and gain.

In this work, the desired application requires a sensor that can differentiate very close levels of permittivity of different water samples, which are varied from (80−20) according to chlorine dosage added to the distilled water. Therefore, a microstrip patch sensor (MPS) is designed, simulated using computer simulation technology-microwave studio (CST-MW) and measured. The proposed design is designed and optimized to differentiate among multi-close levels of permittivity Ɛ varied due to the adding of different dosages of chlorine to the water. The permittivity is obtained from the real measurement in [24]. According to the relation between $\mathcal{E}r$ and matching impedance S_{11} [13], the proposed MPS can indicate the chlorine level with three major advantages. These advantages are working in contactless water samples, real-time measuring, and can be run continuously. The proposed design has a great match with the results given by [24]. Moreover, it overcomes the conventional measuring methods in terms of continuity in reading, high accuracy, and no need to destruct the water samples of the test. Furthermore, there is no need to take a specific size of water to test. Due to flow water testing and the real-time measurement, the important issue is the tube which is filled with water under test. The MPS results are compared with the measurement results obtained in [24] in 25°.

2. SENSOR DESIGN

The sensor is designed with low profile to resonate at 2.94 GHz which is located at the same testing frequency range of [21]. It can differentiate among different levels concentrations of chlorine in drinking water; from the permissible concentration to starting of the toxic level. MPS has the same advantages and disadvantages as microstrip patch antenna (MPA) [25]. According to the desired application, the focus on the matching impedance (S_{11}) and the center frequency is more than other parameters of MPS [26].

The MPS is designed and simulated using CST-MW. Choosing the measuring frequency depends on the application. Accordingly, the designed MPS is optimized to gain the desired application requirement [27], [28]. The sensor has been printed on a single fire retardant (FR-4) layer of 1.53 mm thickness and $\mathcal{E}r$ of 4.3 + j 0.025. In the beginning, the design dimensions depend on the square patch antenna equations, which are well known. Then, using the optimization technique depending on application requirements [29], the final sensor shape is finalized. The dimensions and shape of the proposed MPS are illustrated in Figure 1. The substrate of FR-4 is chosen due to availability and inexpensive. From Figure 1, it can be seen that the sensor design contains two rectangular shapes of 32.4×16.8 $(H \times W)$ in mm. These two shapes support the propagation field to be directed to the Pyrex tube and reduce the FBR, while the circular shape used for increasing the bandwidth of the center frequency [30]. Finally, a long-slim rectangular shape in the direction of the feeder is utilized to increase the sensitivity along with the Pyrex tube. All the dimensions are optimized using CST-MW. The specification of the designed MPS is shown in Table 1. In the simulation, the perspective view of the MPS sensor is illustrated in Figure 2. In the parameter study, it is found that the optimum distance between the MSP and Pyrex tube is 5 cm.

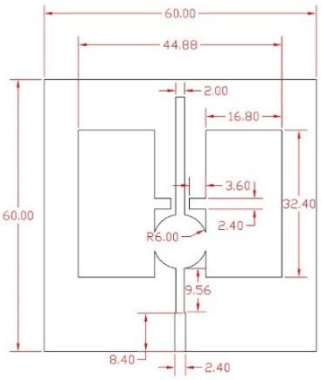


Figure 1. Proposed MPS dimensions

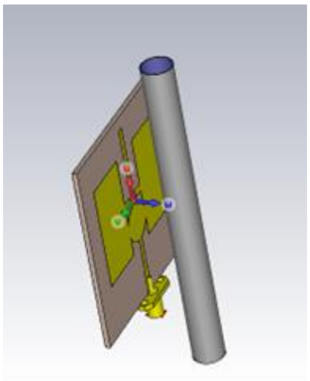


Figure 2. The perspective view of the simulated design

Table 1. The MPS parameters with Pyrex tube filled with distilled water

Parameter	Specification	Unit
Dimensions of MPS (without tube)	60×60×1.6 ($L \times W \times H$)	mm
Substrate	FR-4	–
Substrate thickness	1.53	mm
Substrate permittivity	4.3 + j 0.025	–
Tube	Pyrex	–
Tube diameter	20	mm
Tube thickness	0.5	mm
Pyrex permittivity	4.7 + j 0.00033	–
Distance between MPS and tube	10	mm
Resonance frequency	2.94	GHz
Bandwidth in (-10) dB	0.499	GHz
Directivity	6.55	dB
Gain	7.18	dBi
Front to back ratio	21.56	dB
Voltage standing wave ratio	1.098	–
Matching impedance	-26.59	dB
Linear efficiency	0.9353	–

The simulation started from the given data in [24]. These data are the real permittivity measured at a fixed temperature of 25°. Figure 3 shows the MPS response regarding the extracted data from an open-ended coaxial probe method.

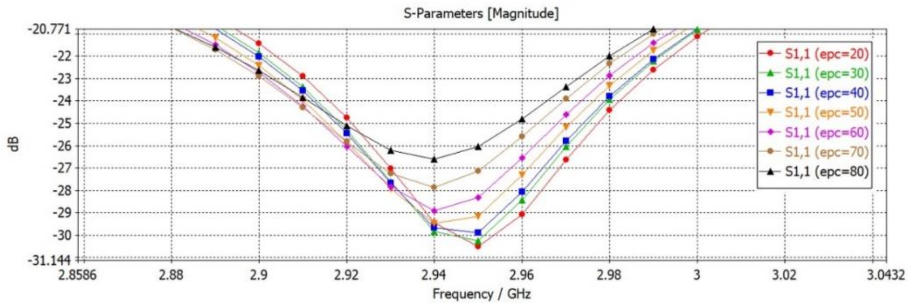


Figure 3. The S_{11} vs permittivity of different chlorine dosages ranged from (20–80)

3. MEASUREMENT

In the measurement, the proposed MPS is implemented using a single layer of FR-4 with a fully copper ground layer. It is connected to a vector network analyzer (VNA) via SMA of 50 Ω connector and a Pyrex tube is fixed in front of the MPS with a distance of 30 mm. The Pyrex tube connected to flow rate water source such as water disinfection plant or sub-station disinfection plant as illustrated in Figure 4. Figure 5(a) shows the patch of the fabricated proposed sensor and Figure 5(b) illustrates the ground layer of this sensor. The setup used for measuring the S_{11} is illustrated in Figure 6.

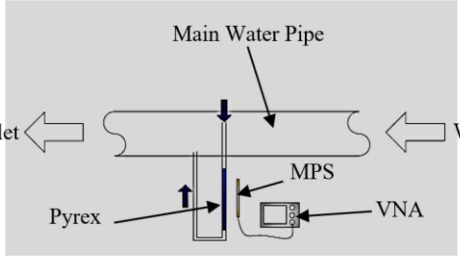
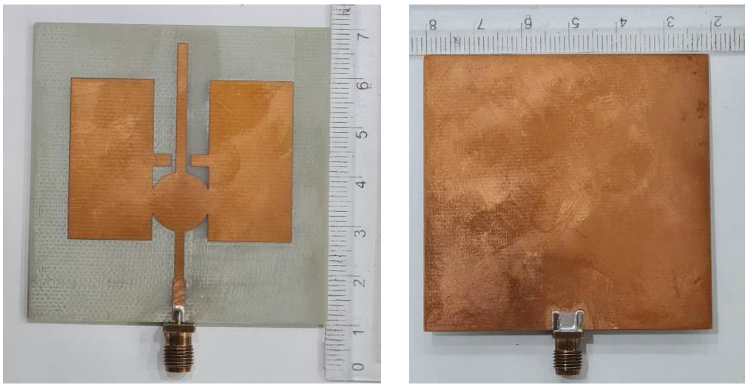


Figure 4. The connection between the MPS and disinfection plant



(a) (b)

Figure 5. Fabricated sensor: (a) sensor patch and (b) GND layer

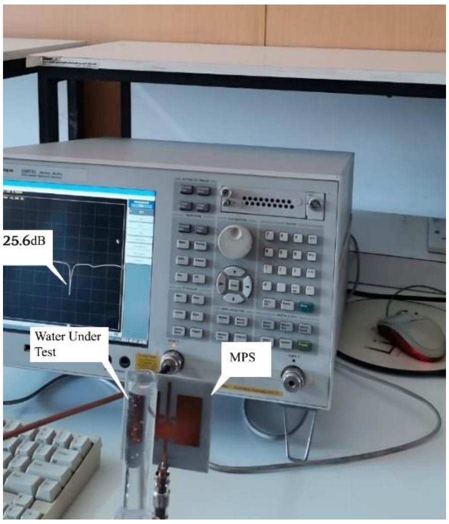


Figure 6. The measuring setup

4. COMPARISON AND DISCUSSION

In this paper, a comparison was done between simulation and measurement results. The idea is to prove that the proposed MSP can work properly to find out the dosage of chlorine added to the water. The method depends on the relation between S_{11} and permittivity [31]. The values of permittivity are measured in [24].

The results of measured S_{11} indicate that the S_{11} has a good response regarding the chlorine dosages added to water. This method depends on the S_{11} value which can be taken directly from VNA and no need for any kind of software. In Figure 7, a comparison of measured S_{11} between [24] and this work is shown. This comparison has proved that the efficiency of using the proposed MPS to find out the chlorine dosage in water. The practical values of this comparison are listed in Table 2.

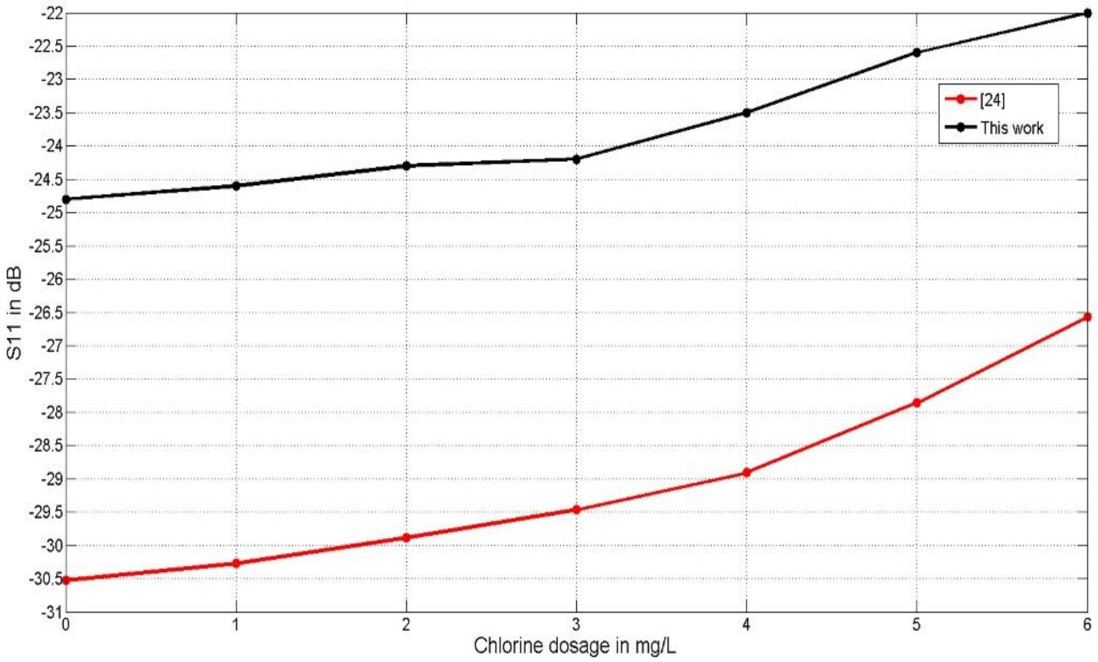


Figure 7. A comparison of measured S_{11} between this work [24]

It can be seen that the two curves in Figure 7 are similar in shapes, due to the relation between permittivity and S_{11}. This similarity gives a significant outcome because of the use of S_{11}, which can substitute the values of permittivity for measuring chlorine concentration of drinking water. Finally, by using lookup table, the values of chlorine dosages can be obtained.

Table 2. A comparison between practical results of the proposed method [24]

Chlorine dosage	S_{11} in [24] (dB)	S_{11} in the proposed MPS (dB)
0	-30.52	-24.8
1	-30.27	-24.6
2	-29.88	-24.3
3	-29.46	-24.2
4	-29.9	-23.5
5	-27.86	-22.6
6	-26.56	-22.0

The proposed MPS overcomes the conventional methods of measuring chlorine in drinking water by three main points. First, it can measure the dosage of chlorine in drinking water continuously (24 hour/daily). Second, the proposed MPS uses a non-contact method with water. Therefore, there is no effect on the water sample. Third, chlorine is a chemical material which may affect the testing of the open-ended coaxial probe. Consequently, it can affect the accuracy of the results. However, in this proposed method, due to the non-contact test, no effects are occurred on the measurement's setup and reading's accuracy.

5. CONCLUSION

Due to the desired application, the proposed antenna with its parameters achieved the main requirements to find out the chlorine dosage in water with a contactless method. The concept is that the permittivity of water is changed whenever chlorine is added to the water. According to the relation between the permittivity and S_{11}, the choline dosage in water is detected. The importance of this method is the continuity of measurements for 24 hours daily, with no need to drop out the water sample due to non-additive chemical material and contactless method. Moreover, it is considered a portable system of measurement. The measurement results indicate good reliability and it is compared with the data extracted from the open-ended coaxial probe technique. The outcome results show good agreement with the latter method. This work indicates that the S_{11} is a good parameter that can be used to measure the chlorine dosage in drinkable water.

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