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Study and Detection of Chlorine Concentration in Water using Microstrip Patch Antenna

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Abstract: This study explores the application of microstrip patch antennas for real-time monitoring of chlorine levels in water treatment. Traditional methods, time-consuming and requiring expertise, are addressed by the proposed technique. Utilizing HFSS software, the microstrip patch antenna dimensions were optimized for chlorine sensitivity. Simulations revealed a linear correlation between antenna behavior (S parameters) and changing chlorine concentrations. The consistent and proportional shift in S parameters with increasing chlorine dosage establishes the antenna's sensitivity to water composition changes. This linear relationship ensures a reliable correlation between the antenna's response and tested chlorine levels. The study concludes that HFSS-assisted simulations enable quantitative evaluation of chlorine dosage in water treatment systems. This underscores the antenna's accuracy in measuring chlorine levels, emphasizing its potential for precise real-time monitoring in water treatment applications.

Keywords: *Dielectric, HFSS, Microstrip patch antenna, S-parameter, Linear correlation*

1. Introduction

Water which only makes up 2.5% of the world's water supply [1]–[3], is crucial to the ecological and societal sustainability of our planet [4]. Scientific research into a variety of approaches, including the use of chlorine [5], [6], iodine [7], [8], and fluoride [9], [10], has been sparked by the relevance of water disinfection, a crucial step to eradicate hazardous germs and bacteria. This complex environment is further complicated by the varied utilization of alternative chemical materials in various areas [11], with each strategy presenting a complex interplay of benefits and drawbacks.

The key to solving the problem is to carefully evaluate the quantities of chemical additives used in the treatment of water [12]. These substances' critical dosage requirements are a focus point, and exceeding allowable limits can transform these initially useful molecules into harmful ones. The control of these chemical additives requires the application of tight regulations, the watchful eye of qualified supervision, and the use of precise testing tools. Chlorine stands out among the myriad disinfectants because of its wide allowable dosage range per mg/L [13]. Chlorine has a unique smell that makes it easy to recognize and also enables dose commencement at low concentrations of 0.5–1 mg/L for drinking water [14] and somewhat higher concentrations of 1.5–3 mg/L for swimming pools [15], [16]. For specific circumstances, a limit test ratio of 5 mg/L has been established, with levels exceeding 8 mg/L being considered poisonous [17]. Separated water samples are the mainstay of traditional chlorine content measurement techniques [18]. These techniques, however, have many drawbacks, including testing frequency restrictions, time-consuming procedures, and a fundamental lack of real-time capabilities. Such flaws provide significant dangers, especially in continually running water treatment facilities [19]. Unexpected malfunctions in chlorinator equipment could have severe results and raise doubts about how much chlorine is being delivered to customers.

With regard to these difficulties, the investigation of microwave frequencies for spotting changes in aqueous media is a paradigm-shifting strategy. In this, sensors are used in a contactless manner with wireless frequency transfer. In order to distinguish close permittivity levels in water samples, this study introduces the microstrip patch sensor (MPS), a precisely built entity simulated utilizing CST-MW. With its advantages in contactless sampling, real-time measurement, and continuous operation, the MPS ushers in a paradigm change. It not only outperforms conventional techniques in terms of reading accuracy, consistency, and the avoidance of sample damage, but it also surprisingly agrees with the findings from [20].

This game-changing invention has significant ramifications for improving water safety, especially in crucial applications like water treatment facilities and public water delivery networks. The MPS is a tribute to the never-ending search for innovations that rethink how

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we approach safeguarding the safety and purity of our water supplies [21], [22], ensuring the legacy of water treatment innovation remains. The presence of dangerous substances is inextricably linked to the quality of drinking water, with purity, odorlessness, and taste neutrality as its primary characteristics. Disinfection is the most crucial step in the process of treating drinking water since it uses chemicals to either kill or inactivate pathogen-causing organisms. The most common method used to purify water is chlorination, which uses chlorine and can be applied at different phases of the water treatment process. Chlorination is still the method of disinfection that people prefer around the world despite its downsides. In addition to its primary function in pathogen prevention, chlorination has a number of advantages, including as a decrease in unpleasant tastes, the eradication of slime bacteria, and the removal of chemical compounds with bad tastes that can impair disinfection.

Chlorination is praised for its ease of use, dependability, effectiveness, cost, and, most importantly, safety in preventing microbiological contamination of drinking water supplies. The simplicity of measuring chlorine, both in lab and outdoor situations, is a definite benefit. When chlorine is administered correctly, it leaves a residual disinfectant that helps keep water distribution systems from becoming recontaminated. Chlorine testing is a laborious, expensive, and time-consuming operation, thus it presents certain difficulties. On-site testing is essential due to the instability of free chlorine in water, particularly in warmer areas. Chlorine concentrations can drop quickly, highlighting the necessity for on-the-spot examination right away to prevent errors brought on by transferring samples back to the lab for subsequent analysis [23].

The need for improvements in monitoring chlorinated drinking water samples without sacrificing analytical performance is currently increasing. This requirement emphasizes the continued search for advancements in water testing techniques, notably those connected to chlorination, to maintain the security and caliber of drinking water sources. In the quest for real-time [24]., continuous water quality monitoring, the fusion of cutting-edge technologies, such as microwave sensors and microstrip patch sensors, presents a potential frontier and offers solutions to the problems presented by conventional testing methods.

The convergence of these several strategies offers a future where the security of our drinking water [25] is guaranteed by cutting-edge technologies and a dedication to innovation, despite the fact that water quality remains a global concern. Every new discovery and technical development creates new opportunities for guaranteeing that every drop of water that enters our taps is as pure as possible, making the journey toward water safety dynamic. The provision of clean, safe drinking water for populations around the world is the unifying objective of the dual views of old methods and developing technologies in this on-going story of scientific advancement.

2. Method

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

Parameters	Specification	Unit
Dimension of the Antenna	60x60x1.6	mm
Substrate	FR-4	-
Substrate Thickness	1.6	mm
Substrate Permittivity	4.4	-
Dimension of the Patch	29.2x37.4	mm
Tube	Pyrex	-
Tube radius	10	mm
Tube thickness	0.5	mm
Pyrex permittivity	4.7+j0.00033	-
Distance between Antenna and Tube	15	mm
Resonance Frequency	2.4	GHz

2.1. Initial Design and Optimization:

Standard equations are used to determine the square patch antenna's size in the early phases of design. Next, the sensor form is refined using a particular optimization technique that is customized for the application. This goal-driven, iterative process makes sure that the final design is based on tried-and-true ideas and carefully adjusted for best performance, all while meeting the needs of the application.

2.2. Detailed Antenna Design Process:

The 2.4GHz microstrip patch antenna has exact dimensions of 37.4 x 29.2 mm and is designed with great care. Situated on a 60 x 60 x 1.4 mm FR-4 substrate, the design choice is bolstered by an extensive comprehension of antenna theory and particular application requirements. This thorough method seeks to maximize the sensor's ability to identify variations in the composition of water [26].

2.3. Design Dimension Establishment and Optimization:

Initially, design dimensions are found using well-known square patch antenna computations. After that, the final sensor shape is refined and strengthened using an optimization procedure pertinent to the needs of the application. Iterative adjustments are made to the design parameters, taking into account target resonance frequency, sensitivity to medium fluctuations, and overall performance goals [27]. The final sensor configuration is crafted for optimal performance based on well-established antenna principles thanks to this purpose-driven, iterative approach.

2.4. Microstrip Patch Sensor (MPS) Configuration

To implement the proposed Microstrip Patch Sensor (MPS), a single FR-4 substrate sheet with a complete copper ground layer is used. In order to achieve the desired performance characteristics and ensure efficient signal transmission and reception, this arrangement is considered The suggested Microstrip Patch Sensor (MPS) is actualized during the measurement process by using a single sheet of FR-4 substrate with a full copper ground layer. In order to get the appropriate performance characteristics, this configuration is essential. By ensuring effective signal transmission and reception. A Pyrex tube is placed in front of the MPS with care, maintaining a fixed spacing of 15 mm to simulate real-world conditions.

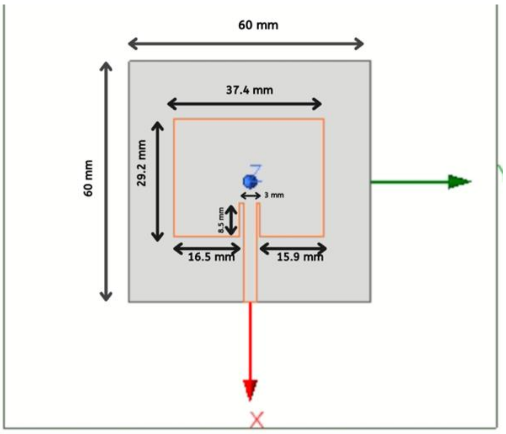

Fig 1. Representation of MPS.

Figure 1 shows precise visuals of the constructed suggested sensor which highlights the sensor patch [28], and provides a detailed picture of the ground layer. The single-layer FR-4 composition and crucial function of the copper ground layer are highlighted in these photos, which highlight the precise fabrication of the sensor [29]. Figure 1 illustrates the measurement setup and shows the carefully planned placement of the parts. Notably, the integration into a water supply with a flow rate and connection to a Pyrex tube mimic actual conditions found in water treatment facilities. The MPS is suited for applications where continuous and real-time chlorine concentration monitoring is required thanks to this setup, which guarantees that the MPS operates within a practical context. Its capacity to adapt to real-world situations is highlighted by the MPS' flawless integration into this sophisticated setup, confirming its potential for use in water treatment procedures.

The study's conclusions are more credible and practical as a result of the thorough construction and measurement setup, which give a thorough grasp of the experimental methods used.

necessary. Furthermore, a Pyrex tube is meticulously positioned in front of the MPS with a fixed spacing of 15 mm to replicate actual conditions when the measurement is being done

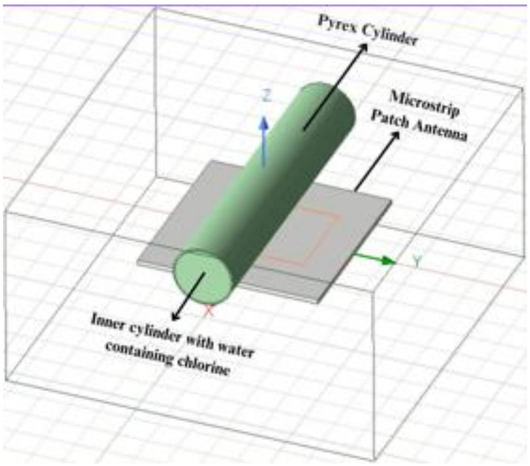

Fig 2. Representation of MPS with Tube.

Figure 2 shows an example of a conduit made of Pyrex that is connected to a water source with a high flow rate, such as a water treatment facility or a sub-station treatment facility. Integration of the microstrip patch antenna with a test tube shaped like a cylinder is a crucial step in the design phase of our project [30]. An exterior cylinder made of Pyrex material with a diameter of 10 mm and an inner cylinder with a diameter of 9.5 mm were created separately. The material used to build the inner cylinder has permittivity values that match the chlorine concentrations found in the cited research. For concentrations of 0 mg/L, 0.5 mg/L, 2 mg/L, 5 mg/L, and 6 mg/L, the permittivity values are systematically changed [31].

The response of the antenna to various chlorine concentrations can be seen visually thanks to the creation of a specific plot for each concentration. This thorough strategy uses a careful selection of permittivity values to ensure a detailed investigation of the antenna's sensitivity to various chlorine concentrations [32]. Another realistic portrayal of the environmental conditions found in practical applications is made possible by the use of Pyrex material in the outer cylinder.

The robustness of the study is a result of the experimental design's careful consideration of changing chlorine concentrations and the accompanying permittivity values [33]. The resulting graphs provide information about the antenna's performance under various circumstances, laying the groundwork for a more in-depth analysis and discussion of the research's findings.

3. Results and Discussion

3.1. Integration of Microwave Frequency and Microstrip Patch Sensor (MPS)

The proposed solution integrates microwave frequency with a finely tuned Microstrip Patch Sensor (MPS) for real-time, contactless monitoring of chlorine concentration. The precision of this approach has been validated through earlier research.

3.2. Non-Contact Testing for Enhanced Accuracy and Robustness

To maintain accuracy and enhance robustness, non-contact testing is employed. The contactless microstrip patch sensor is well-suited for automated water treatment, ensuring reliable performance in various environmental situations.

3.3. Investigation of S Parameter and Linear Association

A comprehensive investigation of the S parameter is conducted, considering permittivity values for different chlorine concentrations. The constant linear link between these factors is precisely mapped using HFSS software, contributing to a quantitative understanding of chlorine concentration indication.

Concentration of Chlorine(mg/L)	Permittivity	S-Parameter (dB)	VSWR
0	79.36	-20.93	1.387
0.5	71.70	-21.53	1.905
2	61.35	-23.24	1.241
5	56.90	-31.42	0.440
6	50.41	-25.97	0.685

Table 2. Permittivity vs S-Parameters (S_{11}) vs VSWR

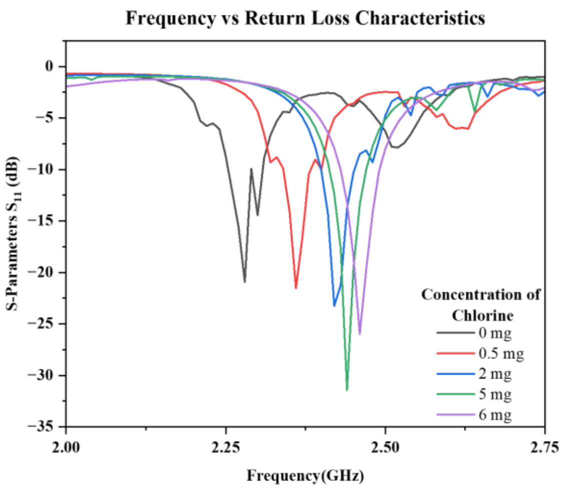

Fig 3. A comparison of measured S_{11} and Frequency.

3.4. Linear Trend Analysis, Methodology Testing, and Correlation Evaluation

The analysis reveals a linear trend in Figure 3, showcasing the antenna's reactivity to variations in chlorine levels. The consistent linear relationship emphasizes the reliability and accuracy of the S parameter for quantitative indication. Results from this investigation establish a robust basis for in-the-moment monitoring in water treatment processes, ultimately improving water quality and safety.

3.5. Stability Observations and Foundation for Further Analysis

Stability is observed in the performance of the microstrip patch antenna across various chlorine concentrations. The systematic approach to data collection enhances result validity, laying a strong foundation for additional analysis and future improvements in the suggested methodology.

VSWR:

The VSWR, or Voltage Standing Wave Ratio, measures how efficiently radio frequency power is transmitted from the source to the antenna. A lower VSWR indicates better power transfer efficiency, with a value of 1 indicating perfect impedance matching and no reflections. In RF systems, a VSWR value of less than 2 is typically desired, as it ensures that at least 90% of the power is delivered to the antenna, with minimal power being reflected back towards the source. This project achieved a VSWR below

2 at the target frequency of 2.4GHz, demonstrating efficient power transfer and good impedance matching, which are crucial for effective communication and minimal energy waste in water quality monitoring applications.

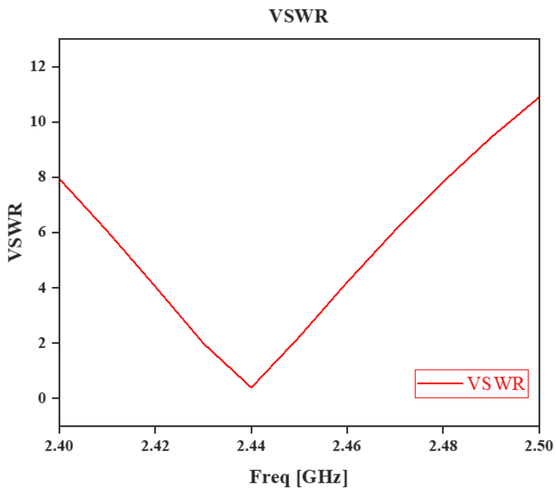

Fig 4. A measure of VSWR at 5mg concentration.

The following results are obtained for 5 mg concentration of Chlorine. The focus on a 5mg chlorine concentration for analyzing radiation pattern, E-plane, and H-plane characteristics stems from the observation of the maximum S11 parameter at this level. This concentration choice underscores the importance of precision in monitoring water quality, particularly in treatment scenarios where accurate chlorine level detection is essential for health and safety. By evaluating the antenna's response at this specific concentration, we gain insights into its practical efficacy and potential for implementation in real-world water treatment systems.

2D Gain plot and 3D Radiation pattern analysis

The investigation of the E-plane and H-plane at the 5mg concentration highlights the antenna's effectiveness in signal transmission across different planes. The 2D gain plot (Figure 5) illustrates the antenna's directional signal radiation along a horizontal axis, optimizing performance for targeted coverage. Conversely, the H-plane plot reveals vertical signal propagation, ensuring comprehensive communication capabilities. These findings illustrate the antenna's adaptability and effectiveness in diverse operational contexts, confirming its superiority in achieving balanced and efficient signal distribution for both horizontal and vertical communications.

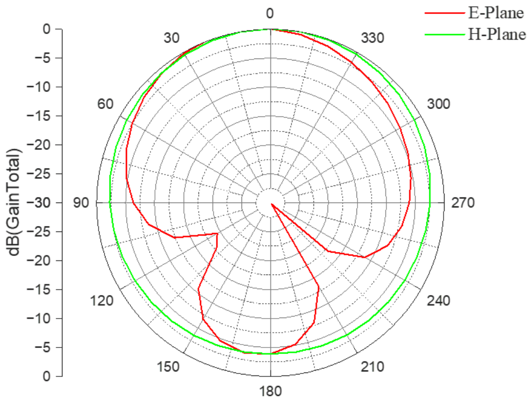

Fig 5. 2D Gain plot.

The 3D radiation pattern analysis, depicted in Figure 6, conducted at the 5mg chlorine concentration, visually represents the antenna's energy dispersion capabilities. It emphasizes the focused emission of power toward the intended direction, signifying the antenna's efficiency in targeted signal distribution. The observed pattern features a pronounced sphere-like major lobe, validating the antenna's capability to concentrate energy effectively. This combined analysis at the 5mg concentration illustrates the antenna's robustness in delivering efficient signal transmission both horizontally and vertically, enhancing its applicability across diverse scenarios.

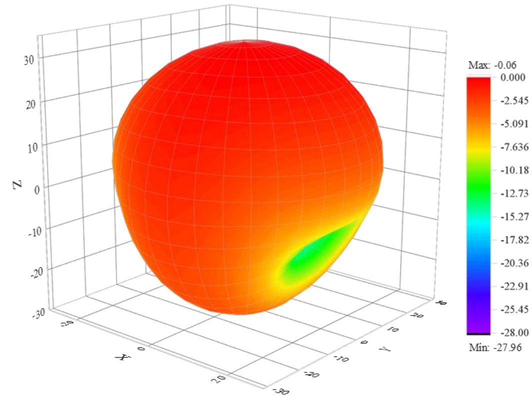

Fig 6. 3D Radiation pattern.

Conclusion

The proposed antenna has successfully met the fundamental requirements for calculating the dosage of chlorine in water using an avant-garde contactless technique. It was painstakingly built to adapt to the specific demands of its intended application. The sensor's fundamental mechanism involves controlling the increase in water permittivity brought on by chlorine addition. The sensor is skilled at detecting minute fluctuations in chlorine dosage in water samples by taking advantage of the complex relationship between permittivity and S_{11}. The sensor's extraordinary portability is noteworthy since it offers a convenient and adjustable measurement solution for a variety of circumstances.

A thorough comparison of the measurement results with those from the conventional open-ended coaxial probe approach demonstrates the measurement results' exceptional reliability. This rigorous evaluation highlights the proposed sensor's constant and reliable performance. The good agreement between the suggested sensor and the current method confirms that is an effective parameter for measuring the amount of chlorine in drinkable water.

The uniqueness of this research rests not only in the effective use of but also in the sensor's inherent portability, which represents a break from traditional, frequently laborious measurement techniques. The sensor is appropriate for real-time and continuous monitoring in a variety of water treatment applications due to its portability, which provides another level of adaptability. Additionally, the sensor's capacity to deliver precise readings without coming into touch with the water sample helps to minimize any interruptions to the testing environment, improving the system's overall robustness.

In essence, this study offers the field priceless new knowledge and makes a strong argument for as a potential metric for measuring chlorine concentrations. The results highlight the significance of accurate and transportable measuring options for maintaining water safety and quality. If this proposed sensor is successful, it will be a major step in overcoming the limitations of current approaches, opening the door to improved monitoring in water treatment facilities and ensuring that consumers receive safe drinking water.

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