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Microwave Sensor for Water Quality Testing

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Peer Review Information	Abstract
<p>Submission: 21 Oct 2025</p> <p>Revision: 18 Nov 2025</p> <p>Acceptance: 05 Dec 2025</p> <p>Keywords</p> <p>Complementary split-ring resonators (CSRR), Frequency(GHz), Vector Network Analyzer, Microwave Sensor</p>	<p>Water quality monitoring is vital to environmental sustainability, public health and industrial applications. Testing water quality requires laboratory analysis, which is both expensive and time-consuming. A cost-effective, real-time microwave sensing system for water quality assessment is presented in this study. We make use of various microwave resonators to measure water pollutants such as nitrates, phosphates and heavy metal substances, as well as pH levels. The suggested sensor array is capable of functioning at frequencies up to 1GHz to 10 GHz. The use of a GHz bandwidth allows for improved detection accuracy through broadband dielectric spectroscopy. Experimental evidence indicates that microwave sensing can detect and discriminate against a wide range of water contaminants with high sensitivity. This effort helps to develop compact, reusable and adaptable solutions for monitoring water quality.</p>

Introduction

Water contamination has ended up a worldwide concern due to industrialization, urbanization, and climate change. Contaminants such as overwhelming metals, nitrates, and broken up solids corrupt water quality, posturing dangers to human wellbeing and oceanic environments. These toxins begin from different sources, counting mechanical squander, rural runoff, and household sewage, driving to extreme natural and wellbeing results. The expanding demand for clean water has made proficient checking and appraisal of water quality a squeezing issue. Routine water quality appraisal strategies depend on chemical testing, spectroscopy, and electrochemical sensors, which regularly require costly gear and talented staff. These strategies regularly include

complex test collection and research facility examination, driving to delays in getting results. Moreover, the long taken a toll of keeping up these testing offices makes them illogical for broad sending, particularly in inaccessible and creating districts. Besides, customary strategies give as it were point-based information, making it difficult to track real-time varieties in water quality over huge zones.

Microwave detecting has developed as a promising elective for water quality appraisal. Not at all like customary strategies, microwave sensors misuse the dielectric properties of water and its contaminants to identify changes in conductivity, pH, and broken up substances in genuine time. Microwave detecting offers a few points of interest, counting fast estimation, non-invasive testing, and compatibility with remote information securing

frameworks, empowering inaccessible observing capabilities. This method encourages ceaseless observing of water quality, giving basic experiences into contamination patterns and empowering opportune mediation measures.

In this think about, we plan and assess a microwave sensor cluster for recognizing water contaminants, illustrating its adequacy in giving precise and cost- efficient water quality evaluation. By joining broadband dielectric spectroscopy, our sensor framework improves discovery exactness, making it a practical arrangement for large-scale water quality checking. This inquire about points to contribute to the advancement of next-generation water detecting innovations, guaranteeing economical and solid get to clean water.

Literature Survey

In (2023) Rusul Khalid Abdulsattar proposed this study introduces a compact microwave sensor enhanced with optical activation for detecting water contamination in crude oil in real time. The design features a microstrip resonator coupled with Moore fractal structures, where LDRs and microwave chip capacitors boost sensitivity. When exposed to light, changes in LDR impedance influence the sensor’s insertion loss, reflecting the level of water content. Testing showed the Q-factor decreased from 70 (pure oil) to 20 (fully contaminated), with measurement error below 0.024%. The sensor stands out for its simplicity, portability, and improved sensitivity compared to existing solutions.

Goldman et al. (2008) highlight the importance of dispersed sensor systems (WSNs) in assessing natural parameters and using them to determine water quality as one of their primary methods. Their research is in agreement with this.' Wavelet-mediated examination is the preferred method for early spill detection in water conveyance frameworks (WDS), as suggested by Whittle et al. (2013). This paper discusses this topic. The use of independent real-time sensors that prompt users to provide feedback on basic water pointers, as noted by Dong et al. (2016) suggests that water quality can be improved.

In 1998, Ivanov et al. conducted experiments on microwave interferon to verify the accuracy of sensors utilized in water quality testing. The results were impressive. Also, the EPA is in the process of creating administrative plans, such as the National Essential Drinking Water Controls (2019), that will establish binding standards for

contaminants, including the amount of overwhelming metals and microorganism counts. The measurement of the pH, broken up oxygen, and turbidity of water by NYCRR (2018) is

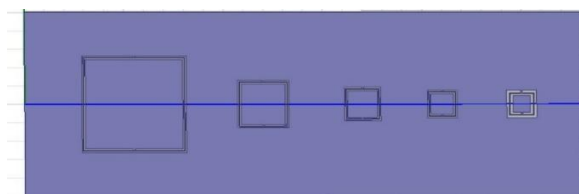


Fig 1: Microwave Sensor Array

dependent on neighbourhood regulations. Open water frameworks that meet safety and health requirements are recommended by the regulations, in addition to assessing lead and copper levels. The use of headways is essential for both sensor systems and administrative systems to ensure thorough checks of water quality, convenient problem-finding, and compliance with security standards in adverse conditions.

Proposed Methodology

3.1. System Design

The proposed microwave sensor cluster comprises of five complementary split-ring resonators (CSRR) working inside the recurrence run of 1 GHz to 10 GHz.

Table 1: Dimensions of designed CSRRs

	W(mm)	L(mm)	a(mm)	b(mm)
Sensor1	0.27	10.5	0.16	0.16
Sensor2	0.27	5.15	0.16	0.16
Sensor3	0.27	3.65	0.16	0.16
Sensor4	0.27	3	0.16	0.16
Sensor5	0.54	3	0.16	0.16

3.2 Experimental Setup

To test the microwave sensor cluster, water is used with varying levels of impurities, including counting nitrates, phosphates and other metals as well as pH varieties and changes in conductivity. The setup includes: VNA is utilized to fine-tune the response of the sensor. An opaque plexi-glass container with an adjustable test output. Testing with high-quality water to establish pattern readings.

3.3 Result and Analysis

Resonant frequency of CSRR can be approximated using parameters by analyzing changes in dielectric properties. The framework is planned to be cost-

effective, reusable, and adaptable for real-time water quality observing.

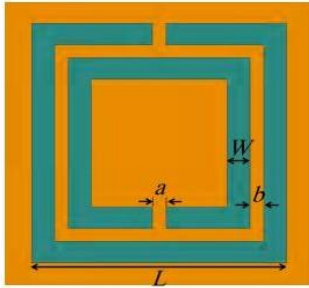


Fig 2. Parametric model of each CSRR

$$fc = \frac{1}{2\pi\sqrt{C_{eff} L_{eff}}} \quad \text{---(1)}$$

Where, L_{eff} - effective inductance of CSRR

C_{eff} - effective capacitance of CSRR

The microwave sensor is designed to detect following concentrations: The conclusions will be reached based on test information:

Nitrate Location: The velocity must be roughly

1.36. GHz, the detection of nitrate amounts as high as 30 mg/L demonstrated an easily detectable dielectric change.

Phosphate Discovery: For phosphate of 20 mg/L, there is expected reduction of about 2 dB in flag quality within the sensor cluster, confirming the system's affectability.

Metal Discovery: lead and other metal impurities can be detected

PH Level Observing: PH values of 4, 7, and 10 can be detected by observing the frequency shift.

Conductivity Estimation:

Changes in conductivity can be seen through adequacy varieties within the sensor reaction, with NaCl solution.

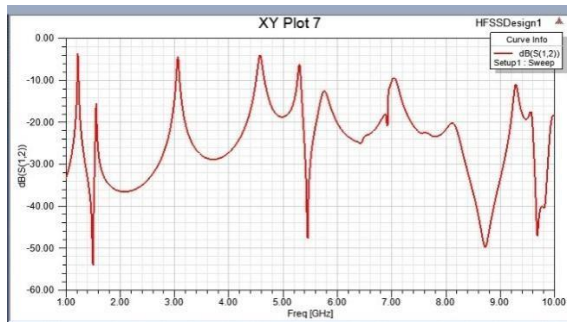


Fig 3. Simulation result

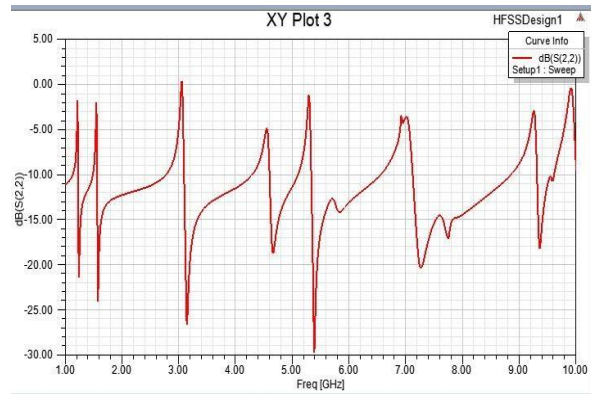


Fig 4. Frequency (GHz)

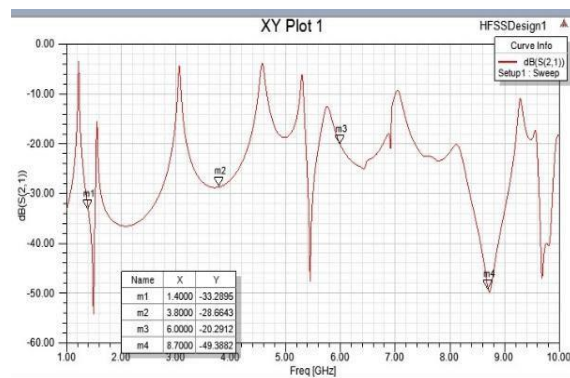


Fig 5. Frequency Vs S_{22}

Conclusion

Microwave sensor provides an effective and precise means of monitoring water quality in real time. Microwave sensor array based on complementary split ring resonators (CSRR) operating across wide frequency range of 1GHz to 10GHz. The cluster was able to detect various contaminants including nitrate, phosphate, heavy metals, changes in PH, conductivity, dissolved oxygen and demonstrated its potential for widespread use in natural checking and mechanical water management. Incitement will concentrate on enhancing sensor affectability, connecting with remote communication to safeguard inaccessible information, and improving machine learning computations for mechanized contaminant placement.

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