Planer Microwave Liquid Sensor Based on Meta-material Complementary Split Ring Resonator

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Abstract. This paper introduces a microwave sensor utilizing metamaterials designed for liquid characterization. It is a complementary split ring resonator (CSRR). The liquid samples are placed inside a glass tube. The interaction of electromagnetic between the resonator and the liquid to be tested modifies the resonance frequency, which changes for each complex permittivity of different samples. The proposed sensor is optimized to have consistent quality factor and a high sensitivity using the HFSS software. The measurement results are used for the validation of these results.

Keywords: Metamaterial , Complementary Split Ring Resonator Microwave, Liquid Sensor ,.

1 Introduction

The measurement of electromagnetic properties allows the determination of chemical or biological characteristics [1]. The use of microwave-based sensors eases this task. This is due to their low cost [2], reliable and robust design [3], ease of integration, and manufacturing [4], [5]. These sensors have become essential due to their widespread application in various fields including healthcare [6], biomedicine [4], agriculture [7], environmental monitoring, food industry, and more.

The advancement of met materials has greatly enhanced the appeal of these sensors. The design of artificial materials (MTMs), i.e., MTMs, is known for their periodic structure. This periodicity enables accurate permittivity measurements through planar technology employing negative permeability [8], [9]. The properties of metamaterials are influenced by the design shape and orientation [10].

Biomedical detection and chemical categorization depend on the sensors executed using MTM technology [11], i.e., the SRR or the complementary molten ring resonator (CSRR) [11]-[14]. One of the configurations mentioned above involves creating an electric field within the

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structure, adjacent to a dielectric material [15]. This configuration directly relates the resonance frequency of the sensor to the measurements the quality factor Q being detected.

This study explores optimization steps for designing a new sensor based on CMMs, simulated using HFSS software. In a second step, a validation of these results by measurement results for the characterization of transmission parameter S21. The proposed CSRR sensor whose tube positioning is horizontal to the sensor plane surface provides the possibility of changing the direction and diameter of the test tube. The presence of the sample in the tube placed above the sensor causes a strong electromagnetic interaction between the CSRR resonator and the liquid under test, which modifies the resonance frequency and the quality factor Q of the CSRR sensor. An empirical relationship between the resonance frequency and the Q-factor with the complex permittivity of the different liquid samples has been estimated. A simulation setup for different concentrations of the water-ethanol mixture by HFSS software was utilized in order to testing the projected sensor and validation by measurement results.

2 Geometric Sensor Design

The proposed sensing is illustrated in Fig 1. The sensor is made of copper, which is designed on the Rogers RO3035 substrate with a thickness of 0.75 mm, a dielectric constant of ε = 3.5, and dielectric losses of about tan δ = 0.0015. It is crucial to have a microwave liquid sensor characterization. The geometry is illustrated in Fig.1a, 1b and 1c which shows the side view proposed structure, top view and bottom view respectively. The specific geometric characteristics of our proposed sensor are detailed as follows W=28mm, L=20mm, Hs=0.75mm. W1=6.2mm, W2=3.6mm, W4=1.6mm. L1= 9.2mm. L2=8.54, L3=6.2mm. L4=1.6mm. ,L5=2.26, L6=0.94mm, d1=6.2mm, d2=5.02mm, d3=3.84, d5.2.26mm. d6=1.67mm, a1, a2 and a3=0.3mm.

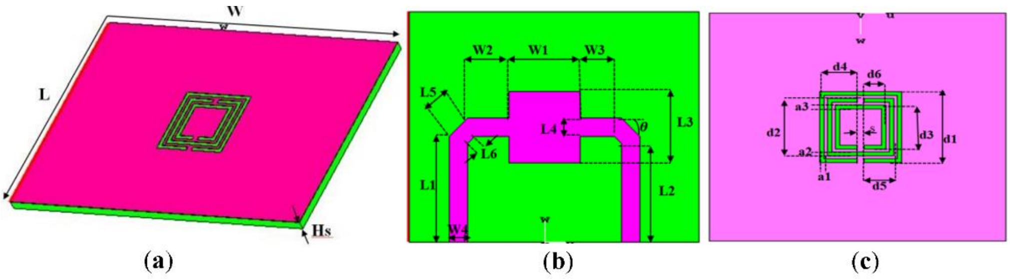

Fig. 1. Dimensional diagram of the proposed sensor structure: (a) side view; (b) top view and (c) bottom view.

3 Our proposed sensor

The structure proposed is shown in fig 2. It is a horizontal test tube placed parallel concerning the plane of our microwave sensor, composed of two copper layers of 35 µm thicknesses each. Figure 1.c shows the lower (ground) layer, which consists of a CSRR, while Figure 1.b shows the upper copper layer of the micro strip transmission line, the perspective view in Fig 1.a. The capillary tube is 75 mm in length, with outer and inner radii of 0.75 mm and 0.5 mm, respectively, and has 5.5 glass relative permittivity.

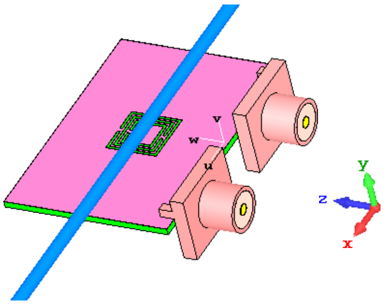

Fig. 2. 3D view of the proposed sensor.

4 Results and discussions:

Figure 3 displays a prototype of the suggested microwave sensor created using planar printed resonator technology, designed for characterizing water-ethanol mixtures.

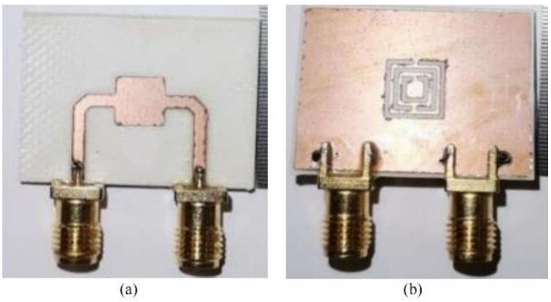

Fig. 3. Fabricated prototype of the proposed sensor: (a) Top view of the 2-port patch; (b) Bottom view.

The microwave sensor's performance was evaluated with two different tube orientations (tube along x-axis and z-axis) (Figure 4a and 4b).

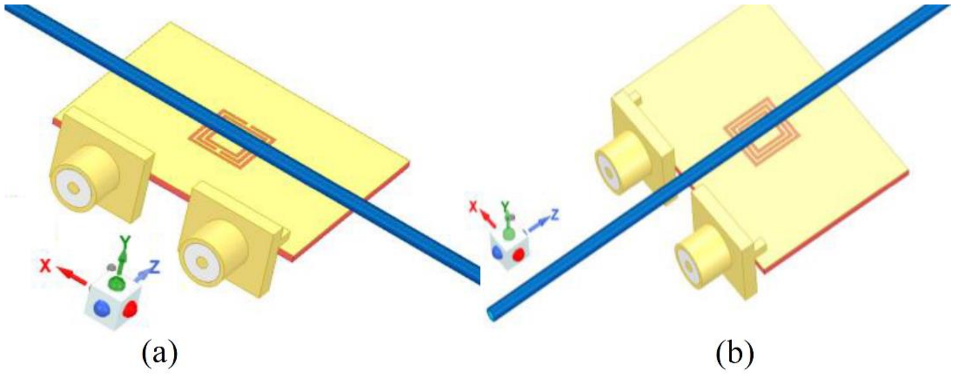

Fig. 4. 3D view of the proposed sensor: (a) first orientation (ox) and (b) second orientation tube (oz).

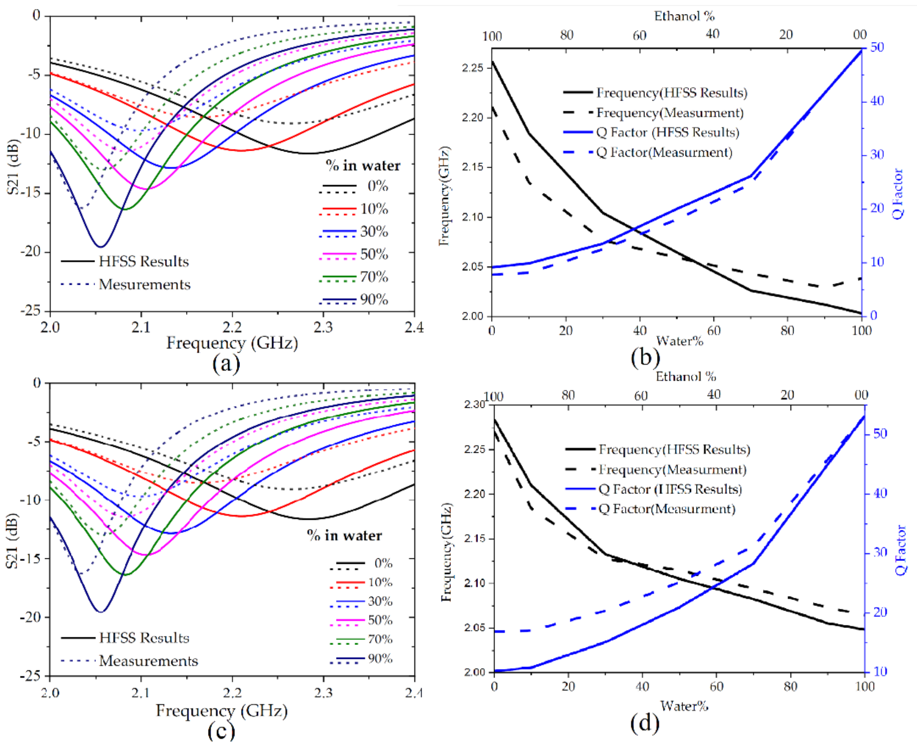

Fig. 5. Simulated and measured S21, Q-Factor and resonant frequency: (a) and (b) first orientation (ox) , (c) and (d) second orientation tube (oz).

Figure 5 depicts the computedand measured outcomes of the fabricated and designed sensor across various concentrations of water-ethanol mixture using a tube with radius r=5mm. Comparison between HFSS simulated S21 parameter and measurements for the two different orientations of the test tube —along ox (Fig 5. (a, b)) and oz (Fig 5. (c, d))— shows excellent agreement.

However, the x-oriented configuration yields superior results, prompting its adoption for upcoming measured and computed procedures.

The sensitivity S is calculated as: S = $\Delta Fr/\Delta\varepsilon r$ [14], ΔFr and $\Delta\varepsilon r$ represent the changes in relative dielectric constant and resonant frequency respectively, as water-ethanol concentrations vary ($\Delta fr = fr_{\_0\%} - fr_{\_100\%}$)and ($\Delta\varepsilon_r = \varepsilon_{r\_100\%} - \varepsilon_{r\_0\%}$) [9]. The Q, is defined as $F_r/\Delta F$ at -3dB, [14].

Based on Table 1, significant performance enhancement is observed for r=5mm, particularly in the ox orientation with the comparsion to results reported for the y orientation in [12].

Table 1. The impact of the tube orientation on Sensitivity and Q-Factor.

Tube radius	Orientation of Tube	$\Delta F_{r0\%-100\%}$	Sensitivity S	Max Q-Factor
r=5	oz	236	3.44	53
r=5	ox	253.7	3.7	50

5 Conclusion:

The proposed microwave planar sensor based on metamaterial CSRR operates at an average frequency of 2.2 GHz for the characterization of the samples of the binary wa-ter-ethanol mixture positioned in the glass tube horizontally at the top of the sensor .The excitation of the sensor by the transmission line located in the lower part of the sensorinduces a strong interaction between the CSRR and the sample to be tested which causes a displacement of the resonant frequency for different fraction of the mixture. The two parameters namely Q and resonance frequency of the fractions of the mixture were achieved by simulating by HFSS and validation by measurement results.

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References

[1] L. La Spada et L. Vegni, « Electromagnetic Nanoparticles for Sensing and Medical Diag- nostic Applications », Materials, vol. 11, no 4, Art. no 4, avr. 2018, doi: 10.3390/ma11040603.

[2] A. E. Omer et al., « Low-cost portable microwave sensor for non-invasive monitoring of blood glucose level: novel design utilizing a four-cell CSRR hexagonal configuration », SciRep, vol. 10, no 1, p. 15200, sept. 2020, doi: 10.1038/s41598-020-72114-3.

[3] H. Yu et al., « Design and analysis of ultrafast and high-sensitivity microwave transductionhumidity sensor based on belt-shaped MoO3 nanomaterial », Sensors and Actuators B: Chemical, vol. 304, p. 127138, févr. 2020, doi: 10.1016/j.snb.2019.127138.

[4] N. Chudpooti et al., « In-Situ Self-Aligned NaCl-Solution Fluidic-Integrated Microwave Sensors for Industrial and Biomedical Applications », IEEE Access, vol. 8, p. 188897-188907, 2020, doi: 10.1109/ACCESS.2020.3031864.

[5] L. Jasińska et K. Malecha, « Microfluidic Modules Integrated with Microwave Compo- nents—Overview of Applications from the Perspective of Different Manufacturing Tech- nologies », Sensors, vol. 21, no 5, Art. no 5, janv. 2021, doi: 10.3390/s21051710.
[6] Z. Marinković, G. Gugliandolo, M. Latino, G. Campobello, G. Crupi, et N. Donato, « Characterization and Neural Modeling of a Microwave Gas Sensor for Oxygen Detection Aimed at Healthcare Applications », Sensors, vol. 20, no 24, Art. no 24, janv. 2020, doi: 10.3390/s20247150.
[7] H. Kim et al., « Global scale error assessments of soil moisture estimates from microwave-based active and passive satellites and land surface models over forest and mixed irri- gated/dryland agriculture regions », Remote Sensing of Environment, vol. 251, p. 112052, déc. 2020, doi: 10.1016/j.rse.2020.112052.
[8] C. Cao et al., « Homogenization of artificial media with a transmission line approach », Appl. Phys. A, vol. 126, no 3, p. 238, févr. 2020, doi: 10.1007/s00339-020-3420-0.
[9] M. Askari et al., « Additive manufacturing of metamaterials: A review », Additive Manu- facturing, vol. 36, p. 101562, déc. 2020, doi: 10.1016/j.addma.2020.101562.
[10] Y. I. Abdulkarim et al., « Design and study of a metamaterial based sensor for the applicationof liquid chemicals detection », Journal of Materials Research and Technology, vol. 9, no 5,p. 10291-10304, sept. 2020, doi: 10.1016/j.jmrt.2020.07.034.
[11] Y. Khanna et Y. K. Awasthi, « Dual-Band Microwave Sensor for Investigation of Liquid Impurity Concentration Using a Metamaterial Complementary Split-Ring Resonator », Jour-nal of Elec Materi, vol. 49, no 1, p. 385-394, janv. 2020, doi: 10.1007/s11664-019-07761- y.
[12] S. Mosbah, C. Zebiri, D. Sayad, I. Elfergani, M. L. Bouknia, S. Mekki, R. Zegadi, M. Palandoken, J. Rodrguiz, R. A. Abd-Alhameed, “Compact and Highly-Sensitive Bended Microwave Liquid Sensor Based on Metamaterial Complementary Split Ring Resonator”, Journal of Applied Scienses 2022, 12(4), 2144. DOI: 10.3390/app12042144.
[13] A. Salim et S. Lim, « Complementary Split-Ring Resonator-Loaded Microfluidic Ethanol Chemical Sensor », Sensors, vol. 16, no 11, Art. no 11, nov. 2016, doi: 10.3390/s16111802.
[14] S. Mekki, R. Zegadi, S. Mosbah, D. Sayad, I. Elfergani, M. L. Bouknia, J. Rodriguez, A. Desai, M. Palandoken and C. Zebiri, “Equivalent circuit of a planar microwave liquid sensor based on metamaterial complementary split ring resonator”, Frequenz, vol. 78, no. 1-2, 2024, pp. 37-45.
[15] A. Ebrahimi, W. Withayachumnankul, S. Al-Sarawi, et D. Abbott, « High-Sensitivity Met-amaterial-Inspired Sensor for Microfluidic Dielectric Characterization », IEEE Sensors Journal, vol. 14, no 5, p. 1345-1351, mai 2014, doi: 10.1109/JSEN.2013.2295312.