Microwave Sensor for Liquid Mixture Identification based on Metamaterial based on Double Concentric Elliptical Complementary Split Ring Resonator

Halfaya Ahmed[1], Mohamed Lashab[1], Salah Salmi[2], Soufi Youcef[3],

[1] Larbi Ben M'hidi university, Oum el Bouaghi, laboratory (LENT), Algeria.
[2] Mentouri university, Constantine Algeria.
3Larbi Tebessi University, Tebessa, Algeria

Abstract—In this paper a Microstrip line coupled double concentric elliptical complementary split-ring **resonator** etched in the ground plane is used to create a sensor. The operating frequency of presented metamaterial sensor is from 1Ghz to 2 Ghz .The sensor is designed and simulated with the commercial software CST Studio Suite . The liquid sample's complicated dielectric permittivity affects the resonance frequency and bandwidth. We can build an empirical link between sensor resonance and sample permittivity using data collected from simulations. the resonance frequency is shifted from 1.50 down to1.49 Ghz. On the basis of variations in the resonance frequency and peak attenuation of the transmission response [l S21 l max] on resonance the sensor estimates the complex permittivity of a liquid. The proposed sensor is easily to fabricated and reusable resonator.

IndexTerms: sensor, microwave, split ring resonator, Q-factor, Metamaterials , permittivity, dielectric, liquid mixture, CST Microwave suite.

I. INTRODUCTION

New universally adaptable and reasonably priced sensor designs are highly sought after by modern industry. A wide range of monitoring and control systems should be compatible with these sensor approaches. Engineering's constant advancement and the growing demand for quick and efficient solutions. The treatment of the most diverse types of processes was made possible by the treatment of the most diverse types of processes. Sensors of various types are developed. In Biomedical [1,3], chemical [4,5] and other research fields have embraced low microwave sensors due to their high sensitivity and robustness, as well as their low cost. The concept of metamaterials has recently been used to create a new and alternative sensing platform [6]. They are artificially engineered materials based on sub-wavelength resonators that can manipulate electromagnetic waves, causing modifications to their properties that do not occur or may be difficult to obtain in nature [7,12].

Split-ring resonators (SRR) or complementary split-ring resonators (CSRR) are the main components of metamaterial microwave sensors, By simulating and analyzing the equivalent LC (inductance and capacitance), using the phenomenon of resonance , which are made using various techniques such as Antenna [13,14] ,measurement thickness of dielectrics [15], measurement of complex permittivity [11], for Strain Direction and Level Detection .Dielectric characterization [14]. They've also been used in microfluidic systems to characterize the liquid's dielectric properties [19,22] , to adjust the resonance frequency or transport the liquid or dissolved analyse into the sensor region, band stop filter [23],rotation sensor [24].

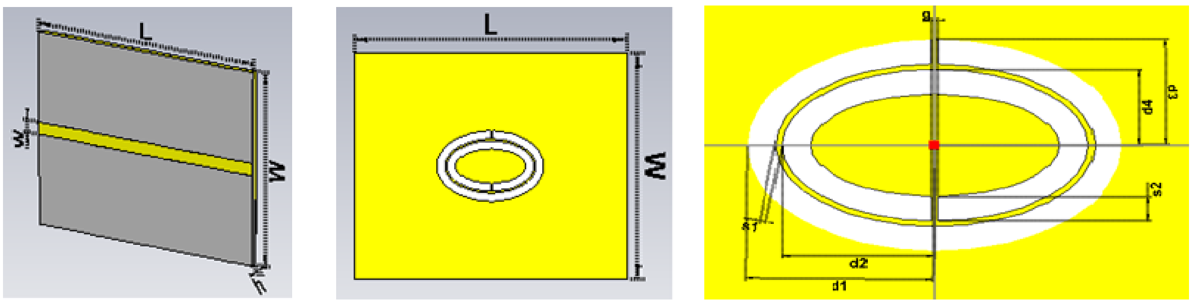
A double concentric elliptical complementary split-ring resonator (DECSRR) is used in this paper to generate a wider region of fringing electric field, thus increasing the effective interaction area with the sample. The proposed sensor calculates the complex permittivity of liquids based on variations in the resonance frequency and the transmission response's peak attenuation during resonance. The following part introduces the suggested microwave sensor design and explains the changes to the (DECSRR) fundamental structure using an analogous circuit model.

This paper is presented as follow, the first section is dealing with theoretical aspect of the Double Concentric Elliptical Complementary Split Ring Resonator (DCESR). The second section is concerned with discussion of the results and finally conclusion.

II. Sensor design And theoretical study:

II. 1.Proposed Design of the Sensor :

The proposed sensor consists on Microstripline coupled double concentric elliptical complementary ring-resonator (DECSRR) as shown in figure.1.



a) b) c)

Fig. 1. (a) 3D view of the sensor; (b) Ground plane with DECSRRs (c) DECSRRs with dimensions *L*= 30 mm, *W* = 25 mm, *h* = 0.787 mm, , *g* = 0.2 mm, *d1* = 5.9 mm, *d2* = 4.8 mm, *d3* = 1.95 mm, *D4* = 0.85 mm, *s1* = 0.2 mm, s2=0.9, *t* = 0.0175 mm, *w* = 1.6 mm.

The gadget was built on a Rogers RO3006 substrate with a relative permittivity of 6.5, and 0.0787 mm of thick. The ground plane and 50 Ω microstrip line copper metalization is 0.0175 mm .

II. 2 Theoretical study of the sensor:

The linked structure's equivalent lumped element circuit model is illustrated in Figure .2.(b); the equivalent circuit's resonance frequency may be determined using the following relationship[25] :

$$f_0 = \frac{1}{2\pi\sqrt{L_C(C+C_C)}} \quad (1)$$

Fig. 2. (a) ECSRRs , (b) equivalent circuit model, , with L and C for the unit lengh inductance and capacitance of the microstrip transmission line and (RLC)c for DECSRRs.

The CST Microwave Suite simulates the DECSRRs sensor, with L and C for the unit length inductance and capacitance of the microstrip transmission line and (RLC)c for DECSRRs.

III. Results discussion:

The Table I displays the reference values measured by Bao et al. in 1995 [26] [28] are used in this paper. As shown in Figure 3, the suggested sensor exhibits a resonance at 1.54 GHz with a notch depth of –31.96 dB. According to the following relationship [26], the quality factor of the suggested sensor is 44, which can be computed as follows:

$$Q = R\sqrt{\frac{C+C_C}{L_C}} \qquad (2)$$

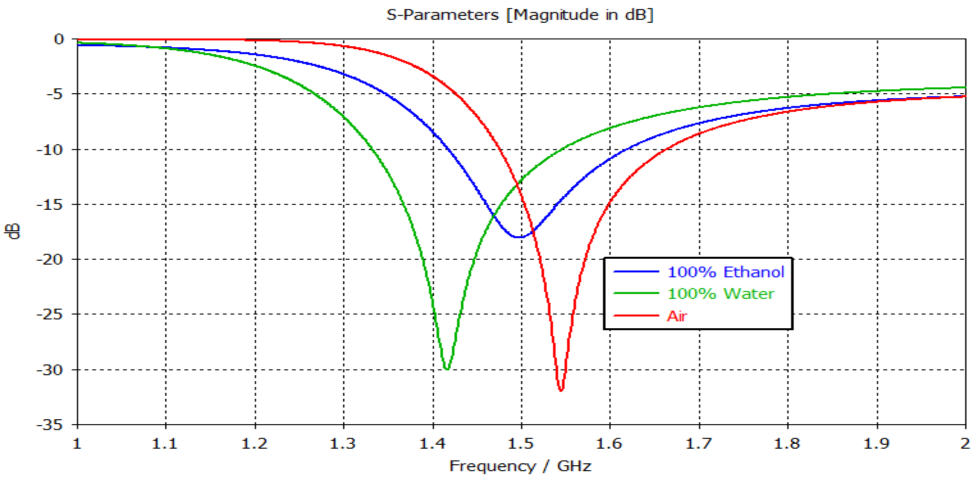


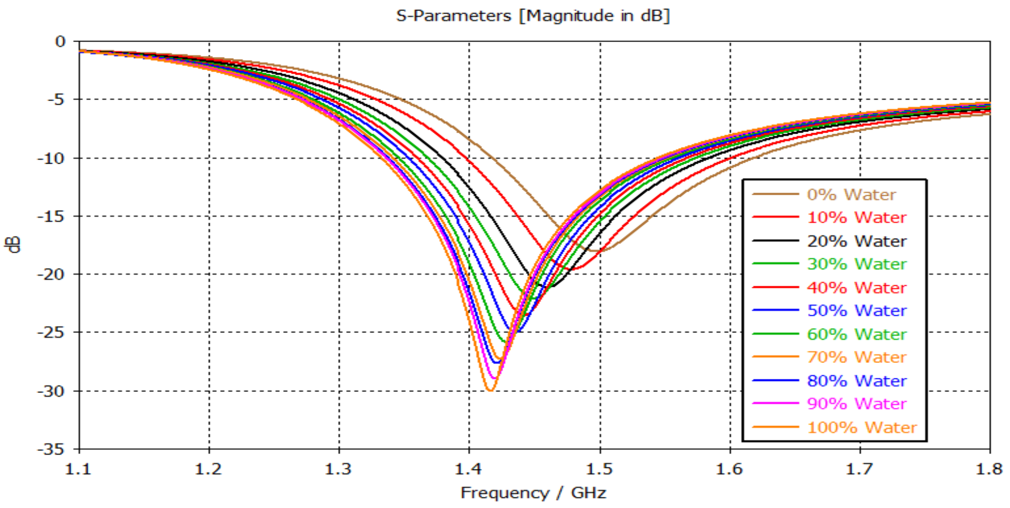
Fig.3, Simulation transmission response of the sensor in different conditions.

By adding liquid Ethanol on notice from Figure 3, that there is a displacement of the frequency of 0.05 GHz with respect to sensor loaded with air, the displacement is more interesting when the sensor is loaded with water, a difference if 0.15 GHz. The sensor has great sensitivity when the displacement is very wide, which means the error of measure is very low, this is the case in this sensor loaded with elliptical CSRRs

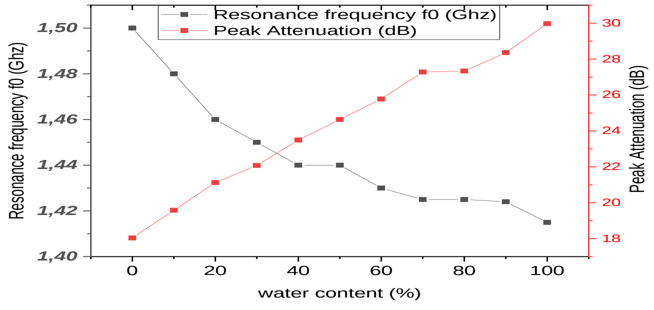
Table 1: References values of complex permittivity to binary mixtures water-ethanol [26] [28]

Water samples (%)	ϵ'	ϵ''	$\Delta\varepsilon'$	$\Delta\varepsilon''$
0	9	10	-38	-5
10	16.5	12.3	-30.5	-2.7
20	24	13.6	-23	-1.4
30	31.5	15.55	-15.5	0.55
40	39	15.6	-8	0.6
50	47	15	0	0
60	53	14.6	6	-0.4
70	61	12.8	14	-2.2
80	67	13.4	20	-1.6
90	72	10.6	25	-4.4
100	79.5	9	32.5	-6

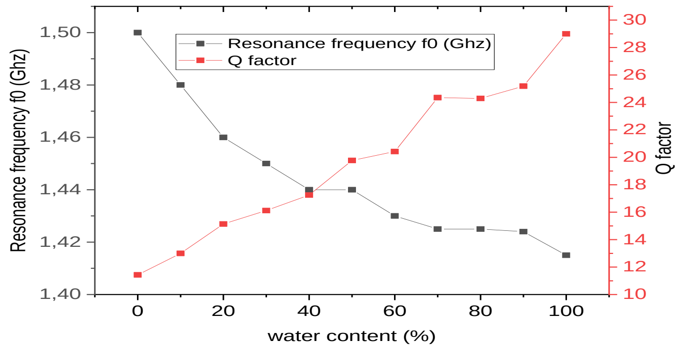
For the first set of simulations, the volume fraction of water is increased from 0% to 100% with a step size of 10%, the sensor's resonant frequency and peak attenuation are calculated and are captured . The results of the resonance frequency and maximum attenuation are shown in fig 4(b) . The resonance frequency has been altered from 1.5 GHz to 1.49 GHz As the water volume portion increases from 0% (100%Ethanol) to 100% fig 4 (a)The frequency shift that corresponds to this is around 100 Mhz.



(a)



(b)



(c)

Fig. 4. (a) The Simulation transmission response of the water-ethanol test samples of the sensor from 0% to 1000% with the step size of 10%.
(b) resonance frequency and peak attenuation at different steps ,
(c) resonant frequeny and Qfactor simulated for different water-ethanol volume fractions.

Fig.4 (c) illustrates the resonance frequency and Q factor at various volume fractions of the binary water–ethanol mixture. When the quantity of water in the mixture is increased, the resonant frequency decreases and the Q factor increases.

IV. Conclusion:

In this paper A sensor structure designed by Double Elliptical concentrated (DECSRRs) is used, theoretical study is presented and simulation is done on CST. Obtained results from simulation indicate that the sensor presents very interesting displacement when loaded with ethanol and more interesting displacement when loaded with water. Future work can be extended for CRLH metamatrial structure for the sake of very high sensitivity.

References:

[1] Long Li, Zhen Jia, Feifei Huo, and Weiqiang Han “A Novel Compact Multiband Antenna Employing Dual-Band CRLH-TL for Smart Mobile Phone Application,” *IEEE Antennas and Wireless Propagation Letters*, Vol. 12, 2013.

[2] Strangi, G., Sreekanth, K. V., & Elkabbash, M. (2017). “Hyperbolic Metamaterial-Based Ultrasensitive Plasmonic Biosensors for Early-Stage Cancer Detection,” *Next Generation Point-of-Care Biomedical Sensors Technologies for Cancer Diagnosis*, 155–172. doi:10.1007/978-981-10-4726-8_7

[3]Korostynska, O., Mason, A., & Al-Shamma’a, A. (2014). “Microwave sensors for the non-invasive monitoring of industrial and medical applications,” *Sensor Review*, 34(2), 182–191. doi:10.1108/sr-11-2012-72.

[4] Zhou H., Hu D., Yang C., Chen, C., Ji, J., Chen M., Chen Yu, Yang Y. ,Mu X. (2018). “Multi-Band Sensing for Dielectric Property of Chemicals Using Metamaterial Integrated Microfluidic Sensor,”. *Scientific Reports*, 8(1). doi:10.1038/s41598-018-32827-y.

[5] Kim, H. K., Yoo, M., & Lim, S. (2015). “Novel ethanol chemical sensor using microfluidic metamaterial,” *IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*. doi:10.1109/aps.2015.7305068, 2015.

[6] Tung, N. T., & Tanaka, T. (2018). “Characterizations of an infrared polarization-insensitive metamaterial perfect absorber and its potential in sensing applications,” *Photonics and Nanostructures - Fundamentals and* Applications, 28, 100–105. doi:10.1016/j.photonics.2017.12.004 , Oct 2008.

[7] V. Veselago, “The electrodynamics of substances with simultaneously negative values of ε and μ”. *Sov. Phys. Usp*. **10**(4), 509–514 (1968)

[8] J. Pendry, A. Holden, D. Robbins, W. Stewart, “Magnetism from conductors and enhanced Nonlinear phenomena,”. *IEEE Trans. Microw. Theory Tech*. **47**(11), 2075–2084 ,1999.

[9] Caloz, T. Itoh, “Application of the transmission line theory of left-handed (LH) materials to the realization of a microstrip LH line,” *Proceedings of the IEEE Antennas and Propagation, Vol. 52, No. 5, May 2004.*

[10] C. Caloz, T. Itoh, "Electromagnetic Metamaterials," (*Wiley, Hoboken*, 2006).
[11]. G. Eleftheriades, K. Balmain, "Negative-Refraction Metamaterials," (*Wiley, Hoboken*, 2005).
[12] Reddy, G. B., & Kumar, D. S. (2018). "Miniaturization of microstrip slot antenna using SRR and CSRR Loading,". *3rd International Conference on Microwave and Photonics* (ICMAP). 2018
[13] Öznazı, V., & Ertürk, V. B. (2008). A comparative investigation of SRR- and CSRR-based band-reject filters: Simulations, experiments, and discussions. Microwave and Optical Technology Letters, 50(2), 519–523.
[14] Rahman, M., Khan, W. T., & Imran, M. (2018). Penta-notched UWB antenna with sharp frequency edge selectivity using combination of SRR, CSRR, and DGS. AEU - International Journal of Electronics and Communications, 93, 116–122.
[15] Li, H., & Jiang, Z. (2019). A CSRR and SRR Based Ultrawideband MIMO Antenna with Band-Notched Characteristics. 2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting.
[16] Zhang, Q., Khan, S. N., & He, S. (2009). Realization of left handedness through CSRRs and SRRs in microstrip line. Microwave and Optical Technology Letters, 51(3), 757–760.
[17] Yoo, M., & Lim, S. (2013). "SRR- and CSRR-loaded ultra-wideband (UWB) antenna with tri-band notch capability," *Journal of Electromagnetic Waves and Applications*, 27(17), 2190–2197. doi:10.1080/09205071.2013.837013.
[18] Chuma, E. L., Iano, Y., Fontgalland, G., Roger, L. L. B., & Loschi, H. (2020). "PCB-integrated Non-destructive Microwave Sensor for Liquid Dielectric Spectroscopy Based on Planar Metamaterial 11211Resonator. Sensors and Actuators A: Physical, 112112. doi:10.1016/j.sna.2020.
[19] Chudpooti, N., Silavwe, E., Akkaraekthalin, P., Robertson, I. D., & Somjit, N. (2018). "Nano-Fluidic Millimeter-Wave Lab-on-a-Waveguide Sensor for Liquid-Mixture Characterization," *IEEE Sensors Journal*, 18(1), 157–164. doi:10.1109/jsen.2017.2772348 .
[20] Chuma, E. L., Iano, Y., Fontgalland, G., & Roger, L. L. B. (2018). "Microwave Sensor for Liquid Dielectric Characterization based on Metamaterial Complementary Split Ring Resonator," *IEEE Sensors Journal*, 1-1. doi:10.1109/jsen.2018.2872859.
[21] Hassan, A., Lee, K., Bae, J., & Lee, C. H. (2017). "An inkjet-printed microstrip patch sensor for liquid identification. Sensors and Actuators A," *Physical*, 268, 141–147. doi:10.1016/j.sna.2017.11.028
[22] Bonache, J., Gil, M., Gil, I., Garcia-Garcia, J., & Martin, F. (2006). "On the electrical characteristics of complementary metamaterial resonators," *IEEE Microwave and Wireless Components Letters*, 16(10), 543–545. doi:10.1109/lmwc.2006.882400 .
[23] Haq, T., Ruan, C., Zhang, X., Kosar, A., & Ullah, S. (2019). "Low cost and compact wideband microwave notch filter based on miniaturized complementary metaresonator," *Applied Physics A*, 125(9). doi:10.1007/s00339-019-2923-z.
[24] Baena, J. D., Bonache, J., Martin, F., Sillero, R. M., Falcone, F., Lopetegi, T., Sorolla, M.(2005). "Equivalent-circuit models for split-ring resonators and complementary split-ring resonators coupled to planar transmission lines," *IEEE Transactions on Microwave Theory and Techniques*, 53(4), 1451– 1461. doi:10.1109/tmtt.2005.845211.
[25] Withayachumnankul, W., Jaruwongrungsee, K., Tuantranont, A., Fumeaux, C., & Abbott, D. (2013). "Metamaterial-based microfluidic sensor for dielectric characterization," *Sensors and Actuators A: Physical*, 189, 233–237. doi:10.1016/j.sna.2012.10.027.
[26] Zhou, K.; Zhou, C.-X.;Wu,W. "Resonance Characteristics of Substrate-Integrated Rectangular Cavity and Their Applications to Dual-Band andWide-Stopband Bandpass Filters Design," *IEEE Trans. Microwave*. *Theory Tech*. **2017**, 65, 1511–1524.
[27] Bao, J., Swicord, M. L., & Davis, C. C. (1996). "Microwave dielectric characterization of binary mixtures of water, methanol, and ethanol," *The Journal of Chemical Physics*, 104(12), 4441–4450. doi:10.1063/1.471197.