Measuring Glucose Content in Aqueous Solutions by means of Split Ring Resonator (SRR) Loaded Transmission Lines

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Abstract – **It is shown in this paper that a pair of uncoupled microstrip lines each one loaded with a split ring resonator (SRR) in a symmetric configuration is useful to measure the solute content in very diluted solutions. The principle of operation of this microwave sensor is symmetry disruption, achieved by loading one of the SRRs with the solvent (reference liquid) and the other one with the solution (liquid under test –LUT). To this end, the structure is equipped with a pair of fluidic channels. The output variable of this sensor is the cross-mode insertion loss (in linear form), very sensitive to small perturbations between the reference liquid and the liquid under test. The structure, applied to the measurement of glucose concentration in deionized (DI) water, is able to resolve glucose concentrations of 2.5g/L and the maximum sensitivity is 0.0036 (g/L)$^{-1}$.**

I. INTRODUCTION

Metamaterial-inspired resonant elements, such as the split ring resonator (SRR) and other related resonators, are electrically small resonators formerly used for the implementation of bulk metamaterials, planar metamaterials and metamaterial transmission lines [1]. Such metamaterial-inspired resonators are very sensitive to the surrounding medium and are therefore useful for the implementation of sensing elements able to monitor the properties of such medium. Particularly, metamaterial resonators are of interest for the measurement of the complex dielectric constant of solids [2]-[5] and liquids [6]-[8]. Most implementations are based on the variation of the notch frequency and depth experienced by a transmission line loaded with these resonators [2]-[4],[6], caused by the material under test (or liquid under test –LUT), when it is put in close proximity, or in contact, with the sensing resonator. In other implementations, symmetry disruption is the sensing principle [5],[8]. In this case, major robustness against cross sensitivities caused by environmental factors (temperature, humidity, etc.) is achieved, as long as symmetry is invariant under changes in ambient factors (which may take place at a scale much larger than resonator's dimensions).

Among the microwave sensors based on symmetry disruption, coupling modulation sensors [9] and frequency splitting sensors [5],[8] have been reported. In the first category, symmetry disruption leads to a variation of the electromagnetic coupling between a transmission line and the resonant element, which in turn modulates the transmission coefficient. Hence, the variable of interest can be measured from the maximum excursion experienced by the transmission coefficient (notch magnitude [9]), or from the amplitude variation of an injected harmonic signal at the output port [10]. Although coupling modulation sensors can be applied to dielectric characterization, they have been mainly oriented to the measurement of spatial variables or velocities [10], since line-to-resonator coupling is very dependent on the relative orientation/position between these elements. In frequency splitting sensors, a transmission line structure is symmetrically loaded with a pair of resonant elements, thus generating a notch [5],[8]. The operating principle in this case is the frequency splitting that appears when the resonators are asymmetrically loaded. These sensors have been applied to the dielectric characterization of liquids [5],[8], but their resolution is limited. To be able to resolve very small perturbations, an approach based on the measurement of the cross-mode insertion loss of a pair of symmetric uncoupled lines each one loaded with a resonant element (an open complementary split ring resonator) was first presented in [11]. In this paper we report a sensing structure based on a pair of microstrip lines loaded with SRRs, which is applied to the measurement of glucose concentration in diluted aqueous solutions.

II. The Sensing Structure

The proposed sensing structure is composed by the pair of SRR-loaded lines (etched on a commercial microwave substrate), plus the fluidic channels and the necessary mechanical accessories for liquid injection. The layout of the pair of SRR loaded lines and the photograph of the fabricated sensor are depicted in Fig. 1, where the relevant dimensions are indicated, as well as the regions where a dry film is deposited in order to avoid substrate absorption. The considered substrate is the FR4 with dielectric constant, loss tangent, and thickness of ε_r = 4.4, tanδ = 0.02 and h = 1.6 mm respectively. Concerning the fluidic and mechanical parts of the sensor, the fluidic channel has been implemented by means of polydimethylsiloxane (PDMS), and channel dimensions are: height h_{ch} = 1.5 mm, width w_{ch} = 4.6 mm, and length l_{ch} = 26 mm (Fig.1 c). The mechanical parts are based on a polyether ether ketone (PEEK) structure, which has been designed to accommodate the fluidic connectors for liquid injection in a controllable way through a syringe.

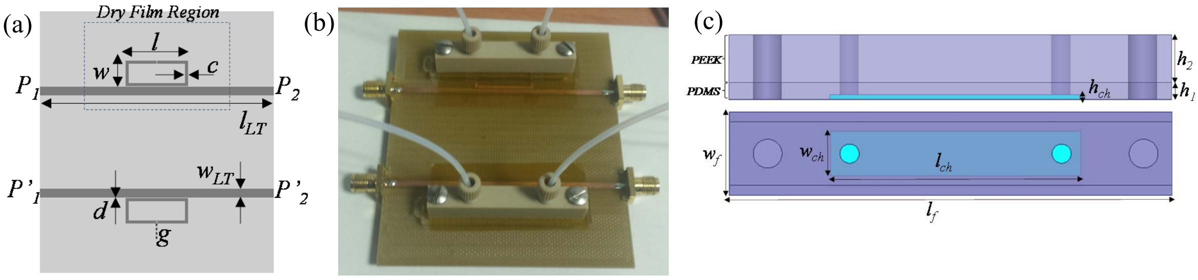

Fig. 1. Layout of the sensor metallic pattern (a), photograph of the fabricated device (b) and lateral and top views of the mechanical and fluidic parts (c). Dimensions are (in mm): w = 8.17, l = 20, c = 1, d = 0.2, g = 0.2, l_{LT} = 75, w_{LT} = 2.98, h_1 = 3.5, h_2 = 9, w_f = 11 and l_f = 50.

Sensing is based on cross-mode conversion, generated by an asymmetric dielectric load of the SRR pair. Thus, if the liquids in each channel are identical, symmetry in the structure is preserved, and the cross-mode transmission coefficient, S_{21}^{DC} , is ideally null. Conversely, if the liquids are different (i.e., they exhibit different dielectric constant), differential-mode to common-mode conversion (and vice versa) arises, and S_{21}^{DC} takes a finite (complex) value. The main advantage of this sensing method, based on the measurement of the cross-mode insertion loss, is resolution and sensitivity. The reason is that S_{21}^{DC} is very sensitive to small perturbations in the symmetry of the structure. Therefore, it is expected that the proposed structure can be applied to the measurement of solute concentration in diluted solutions. For that purpose, the solvent (the reference liquid) is injected to the reference channel, whereas the other channel is filled with the LUT.

III. Validation and Application to Glucose Concentration Measurement in DI Water

We have measured the cross-mode insertion loss in the structure of Fig. 1 by filling the LUT channel with different solutions of glucose in DI water. In all the cases, the reference channel is filled with pure DI water (the solvent). The results are depicted in Fig. 2(a), where it can be seen that glucose concentrations of at least 2.5 g/L can be resolved. Fig. 2(b) depicts the glucose concentration as a function of the cross-mode insertion loss (in linear form). From these data, we have obtained the following calibration curve,

$$Glu[g/L] = -33271300 \cdot |S_{21}^{DC}|^4 + 4012400 \cdot |S_{21}^{DC}|^3 - 113821.54 \cdot |S_{21}^{DC}|^2 + 941.83|S_{21}^{DC}| \qquad (1)$$

which exhibits a correlation coefficient of R = 0.9989. The maximum sensitivity is found to be 0.0036 $(g/L)^{-1}$.

We have repeated the measurement of the cross-mode insertion loss for different values of the glucose content, and it has been found that the results are repetitive. Once the calibration curve has been obtained, it can be used to determine the glucose content form the measurement of the maximum value of the cross-mode insertion loss.

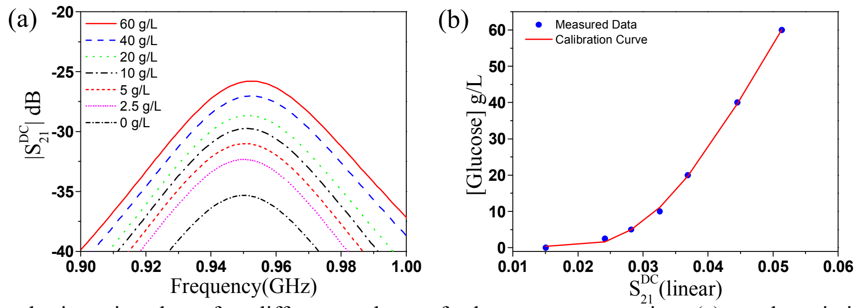

Fig. 2. Cross-mode insertion loss for different values of glucose concentration (a), and variation of the glucose concentration with the maximum value of S_{21}^{DC} (b). The calibration curve is depicted in (b).

IV. Conclusion

In conclusion, a sensing structure for monitoring the glucose concentration in diluted aqueous solutions has been reported. The structure uses a pair of uncoupled lines loaded with SRRs and fluidic channels on top of them. Since the cross-mode insertion loss is very sensitive to structure asymmetries, it has been used as output variable in the proposed sensor. The achieved resolution and sensitivity are 2.5 g/L and 0.0036 $(g/L)^{-1}$.

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