CSRR-Based Microwave Sensor for Measurement of Blood Creatinine Concentrations Levels

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Introduction: Current treatment of non-communicable diseases (NCDs) present dire problems for healthcare practitioners, as evident for chronic kidney disease (CKD) [1]. The advent of non-invasive sensors and the applicability for microwave engineering provide can ensure efficiency and effective NCD patient management. The authors in [2] highlighted the propensity of a non-invasive microwave plane sensor, in the form of a complementary split ring resonator (CSRR), to be sensitive to changes in the relative permittivity to a material acting as a perturbation to an applied electric field. Given that relative permittivities (ε_r) of blood analytes, such as glucose, show strong correlation to changes in analyte concentration [3], a simulation of the CSRR sensor in [2] sensitivity to extracellular blood permittivity was investigated as a design candidate for a CKD non-invasive sensor.

Computational Methods: A 3D model of the CSRR-based sensor [2] and the human epidermis (blood) was built in the COMSOL Multiphysics® software, with dimensions and material properties highlighted in Table 1 and Figure 1. The RF module was employed to parametrize changes in ε_r (1 to 100) over frequency using the following Maxwell equation:

$$\nabla \times \mu^{-1}(\nabla \times \vec{E}) - \omega^2 \varepsilon_0 \mu_0 \left(\varepsilon_r - \frac{j\sigma}{\omega \varepsilon_0} \right) \vec{E}$$

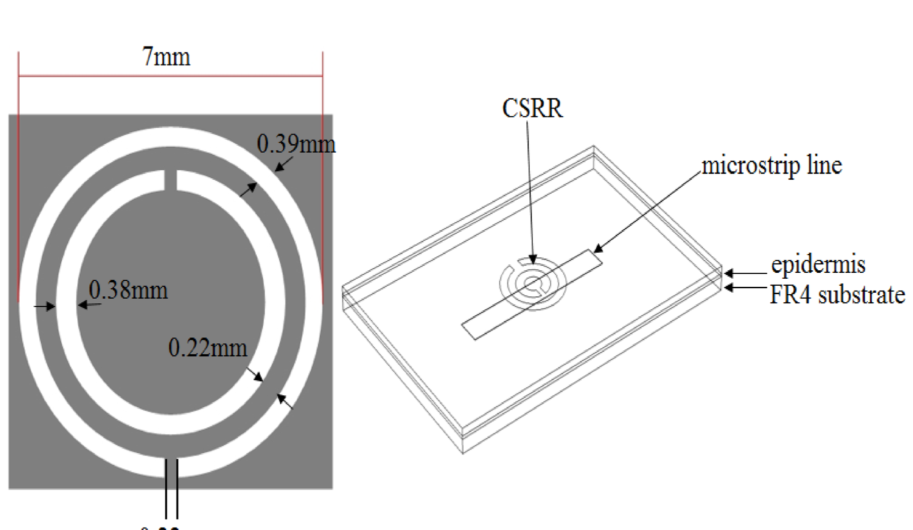

Figure 1. COMSOL model and CSRR design

Component	Shape & Dimensions	Electrical Parameters
Air (perfectly matched layer)	Sphere: radius = 110 mm	σ = 0 S/m ε_r = 1 μ = 1
Substrate (FR4)	Primitive Block: width = 40 mm depth = 26 mm height = 0.8 mm	σ = 0.004 S/m ε_r = 4.5 μ = 1
Epidermis (Blood)	Primitive Block: width = 40 mm depth = 26 mm height = 1 mm	σ = 0.8 S/m ε_r = 1- 100 μ = 1

Table 1. Geometry and material characteristics for simulation mode

Results: The simulation returned S_{11} versus frequency plots for reflection phenomena occurring at the excitation port of the sensor. The results in Figures 2 and 3 show a shift in resonance (2.65 GHz) from the unloaded condition (air) to when a block, modelled as the human epidermis (blood), is factored as a perturbation to the electric field applied at the excitation port of the sensor, over the frequency range of 1 to 10 GHz.

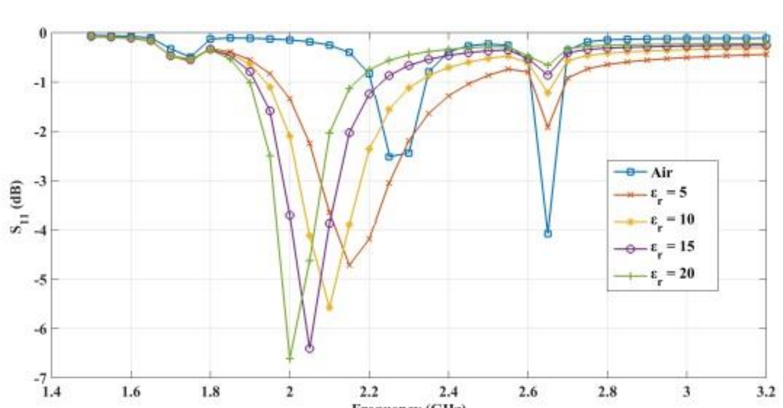

Figure 2. Resonance shift for $\varepsilon_r \in (5,20)$

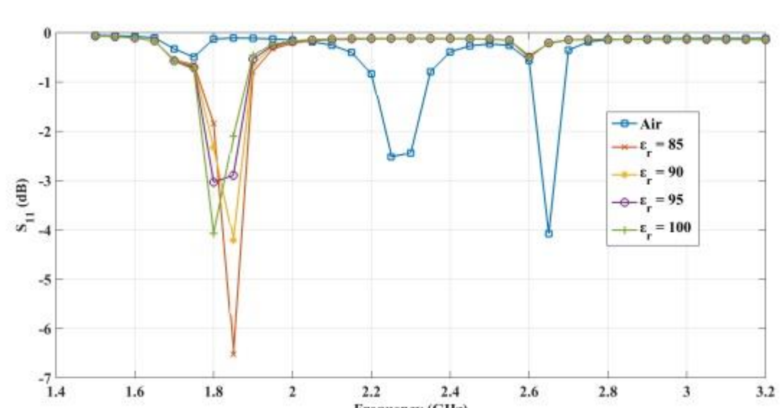

Figure 3. Resonance shift for $\varepsilon_r \in (5,20)$

At resonance, S_{11} progressively becomes less negative as less reflection of the microwaves occurs at the sensor with increases in εr of the loaded epidermis (blood). This correlation, Figure 4, (R^2 = 0.8984) highlight the applicability for CSRR sensor for non-invasive blood analyte monitoring.

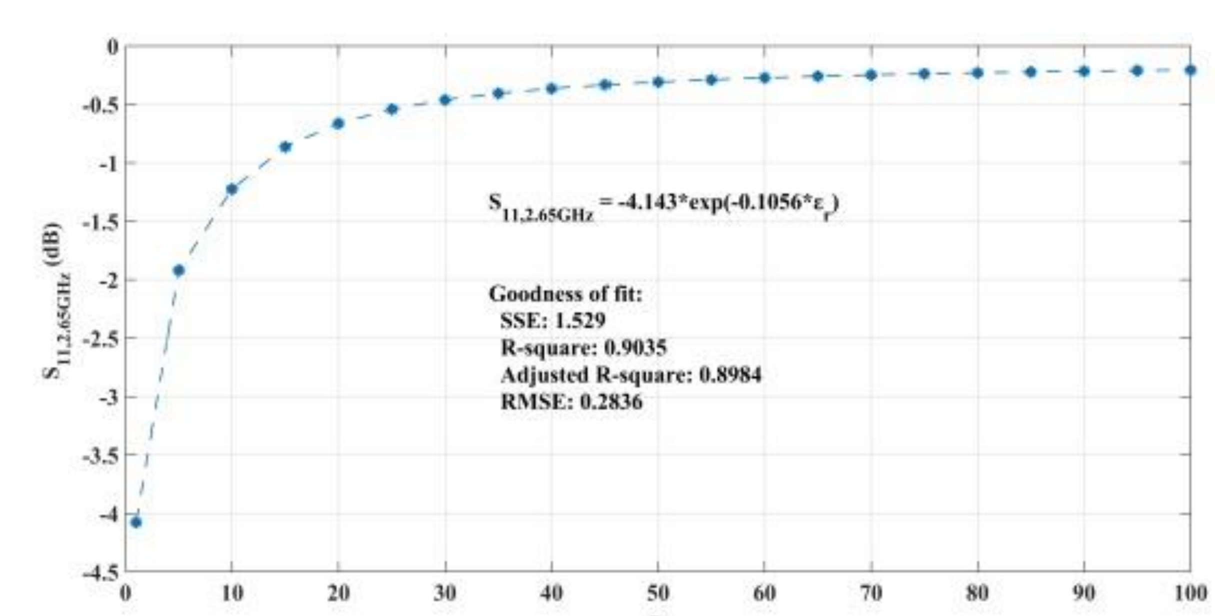

Figure 4. $S_{11,\ 2.65\ GHz}$ vs. ε_r

Conclusions: The simulation model shows that CSRR sensors, at least for the form factor investigated, are sensitive to changes in ε_r. As such, these results render the development of a prototype non-invasive device, to detect changes in blood ε_r, as the next step.

References:

1. Alwan, A., Global status report on noncommunicable diseases 2010, World Health Organization, (2011)
2. Ansari, M.A.H., Jha, A.K. and Akhtar, M.J., Design and Application of the CSRR-Based Planar Sensor for Noninvasive Measurement of Complex Permittivity, Sensors Journal, IEEE, 15(12), pp.7181-7189, (2015)
3. N.-Y. Kim, K. K. Adhikari, R. Dhakal, Z. Chuluunbaatar, C. Wang, and E.-S. Kimr, Rapid, Sensitive, and Reusable Detection of Glucose by a Robust Radiofrequency Integrated Passive Device Biosensor Chip, Sci. Rep. Scientific Reports, 5, 7807(2015)