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

Z. Ramsaroop[1], S. Rocke[1], N. Gayapersad[1], J. Persad[1]

[1]Department of Electrical and Computer Engineering, The University of the West Indies, St. Augustine Campus, Trinidad and Tobago

Abstract

Non-communicable diseases (NCDs) have globally become a prevalent problem, accounting for more than 60% of the mortality worldwide. NCDs impose socioeconomic consequences to low-income countries as 80% of NCD deaths occur in such countries [1, 2]. The World Health Organization has necessitated that cost-effective preventive measures, which have an immediate impact on the burden at population level, are required in low to middle-income countries [3]. Non-invasive technology offers a low cost and less painful alternative for effective management of NCDs [4]. This technology, in the form of wearable sensors, confers advantages in the healthcare management of NCDs due to the ability to continuously monitor the patient's health. This introduces a paradigm shift in diagnostics as practitioners can better and progressively diagnose a patient.

In chronic kidney disease, an NCD, blood creatinine levels increase due to impaired filtration and distal tubule secretion of creatinine. However, creatinine clearance measurement is both cumbersome and error-prone. Indirect estimation of the estimated glomerular filtration rate (eGFR), the typical measure of renal function, from the serum creatinine concentration [5], has resulted in imprecise estimation of creatinine excretion and hence impairs chronic kidney disease management [6, 7]. This motivates the need to develop a sensor for non-invasive and continuous monitoring of blood creatinine concentrations as a preventive measure to mitigating the occurrence of end stage renal failure to a patient.

Microwave non-invasive planar sensor based on a circular complementary split ring resonator (CSRR) has been found to be sensitive for the permittivity measurement of a specimen kept in contact with the sensor at resonant frequency [8]. A 3D model of this sensor was recreated in the COMSOL Multiphysics® software using the RF Module. The human skin was incorporated into the geometry, with the relevant material properties, as the specimen in contact with a circular CSRR. The material properties, relative permittivity, relative permeability and conductivity were set to the values in the frequency range (1-10 GHz) for wave excitation at the lumped port on a microstrip copper line below the plane of the CSRR. This frequency range is representative of the acceptable range for medical applications [9] and provides the penetration depth into the skin tissue for detecting blood permittivity changes. Changes in blood analyte concentrations within the skin provide a platform for detecting changes in the dielectric properties of blood due to the effect of an applied electric field [10]. The COMSOL® software is used to simulate changes

in dielectric properties of blood via a parametric study of blood permittivity for a relative permittivity range of 1 to 100. The preliminary results (Figures 1 and 2) have showed a shift in the resonant frequency and depth change due to changes in the relative permittivity of the skin in contact with the sensor. These results implicate the potential of using microwave sensors for management of NCDs as the resonant frequency shift can be taken as a measure of the blood analyte concentrations, such as creatinine, due to relative permittivity changes.

Reference

[1] B. Nojilana et al., Persistent burden from non-communicable diseases in South Africa needs strong action. South African Medical Journal, 106(5), pp.436-437, 2016.

[2] D.K. Sanghera, Emerging Epidemic of Non-Communicable Diseases (NCDs) in South Asia: Opportunities for Prevention. J Diabetes Metab,7(647), p.2, 2016.

[3] A. Alwan, Global status report on noncommunicable diseases 2010. World Health Organization, 2011.

[4] A. J. Bandodkar and J. Wang, Non-invasive wearable electrochemical sensors: a review. Trends in biotechnology, 32(7), pp.363-371, 2014.

[5] A.S. Levey, et al., Using standardized serum creatinine values in the modification of diet in renal disease study equation for estimating glomerular filtration rate. Annals of internal medicine, 145(4), pp.247-254, 2006.

[6] S. S. Waikar et al., Creatinine as the gold standard for kidney injury biomarker studies?. Nephrology Dialysis Transplantation, 24(11), pp.3263-3265, 2009.

[7] A.S. Levey et al., Serum creatinine and renal function. Annual review of medicine, 39(1), pp.465-490, 1998.

[8] M. A. H. Ansari et al., Design and Application of the CSRR-Based Planar Sensor for Noninvasive Measurement of Complex Permittivity. Sensors Journal, IEEE, 15(12), pp.7181-7189, 2015.

[9] IEC.60601-2-6..1984.. Medical Electrical Equipment. Part 2: Particular Requirements for the Safety of Microwave Therapy Equipment..Geneva,.Switzerland:.Safety, 1984.

[10] S. Chakraborty et al., Investigating the quasi-oscillatory behaviour of electrical parameters with the concentration of D-glucose in its aqueous solution at room temperature by employing impedance spectroscopy technique. Journal of Electrical Bioimpedance, 6(1), pp.10-17, 2015.

Figures used in the abstract

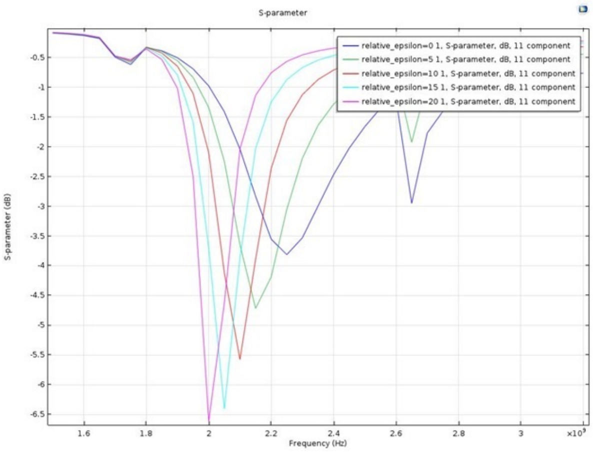

Figure 1: Circular CSRR resonance shift due to relative permittivity changes (0 to 20) in skin in contact with CSRR sensor

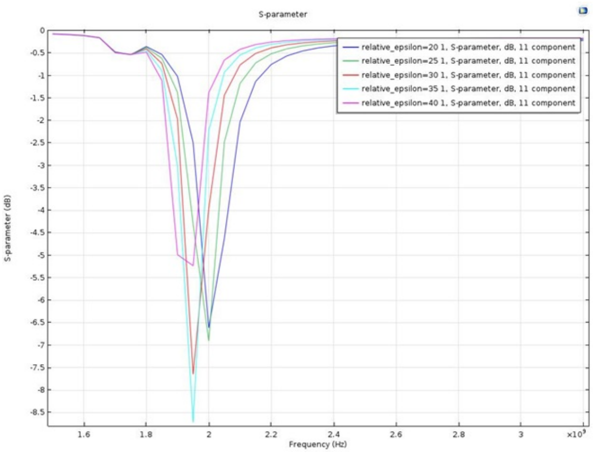

Figure 2: Circular CSRR resonance shift due to relative permittivity changes (20 to 40) in skin in contact with CSRR sensor