Compact Resonators for Permittivity Reconstruction of Biological Tissues

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Abstract

In this paper, a patch resonator is proposed for non-invasive measurement of dielectric properties of biological tissues. Resonator is operating at 2.4 GHz when placed on tissue. The patch resonator is simulated in HFSS with four layered tissue mimicking material (skin, fat, blood, muscle) placed on top. The electrical properties of blood layer is decreased and the change in S parameters is tracked. Effective dielectric properties of the tissue is reconstructed from simulated S parameter response of the resonator.

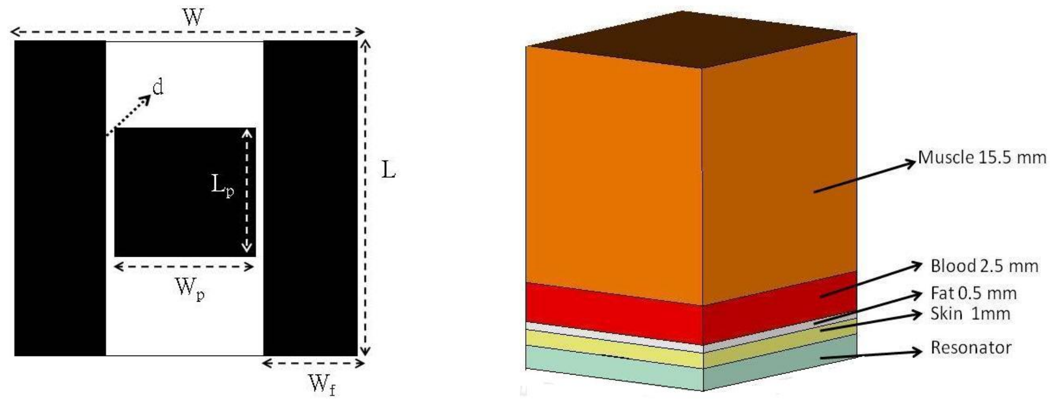
1 Introduction

Accurate measurement of dielectric properties of materials is vital due to the potential applications in material science, bio-electromagnetics, and basic understanding of wave propagation in a dielectric media. Dielectric property measurement of biological tissues at microwave frequencies is a cumbersome task since the biological tissues are water based materials and the highly conductive medium of the tissue presents hostile environment to the electromagnetic wave. In the last decade, dielectric properties of biological tissues, malignant tissues, and body liquids have been successfully measured with using different techniques [1-3]. Conventional measurement techniques include coax probes, waveguide methods, and cavity resonators. Although coaxial probes provides broadband results, the test fixture is bulky and the probes are costly. Moreover, the of the coax probe is small thus it may cause mechanical inaccuracies. Cavity resonators provides precise measurements, however, cavity resonators are suitable for measurements with liquids in small amount.

In this study, we are focusing on the changes in electrical properties of body liquids and tissues due to the disease related alterations such as diabetes. It has been reported that the dielectric properties of blood and subcutaneous tissue changes with alterations in blood glucose levels [4,5]. However, previous studies are performed with excised blood plasma which may lead to alterations in electrical properties.Therefore, there is a need to characterize the in-vivo alterations in dielectric properties caused by blood glucose change. Our goal is to utilize a compact, non-invasive test fixture for measurement of effective change in dielectric properties of blood and subcutaneous tissue due to alterations in blood glucose. To do so, a patch resonator designed and simulated in Ansoft high frequency structural simulator (HFSS) with four layered tissue (skin, fat, blood, and muscle) mimicking material. Dimensions of the patch resonator and the simulation results is given. Dielectric properties of blood layer is decreased and the response of patch resonator tracked at 2.4 GHz.

2 Patch Resonator

A pact resonator is designed and simulated in HFSS. Dimensions of the resonator shown in fig. 1a is given in Table 1. Taconic Rf-30 (tm) $\varepsilon_r = 3$, $tan(\delta) = 0.0014$ is used as a substrate with 1.6 mm thickness and resonator has a full ground plane. Note that the resonator has two ports and feeded with capacitive coupling. Simulation results for air media is given in fig. 2a and in fig. 2b S11 and S21 respectively. The structure is resonating at 8.7 Ghz in air media. The resonance will be shifted to a lower frequency when placed on tissue. Simulation results with four layered tissue shown in fig. 1b will be given. Dielectric properties of blood layer will be decreased based on the previous publications and well known debye equation. For different glucose levels the change in sensor response will be tracked and the effective permittivity of the four layered tissue will be reconstructed from the S parameter response of the resonator.

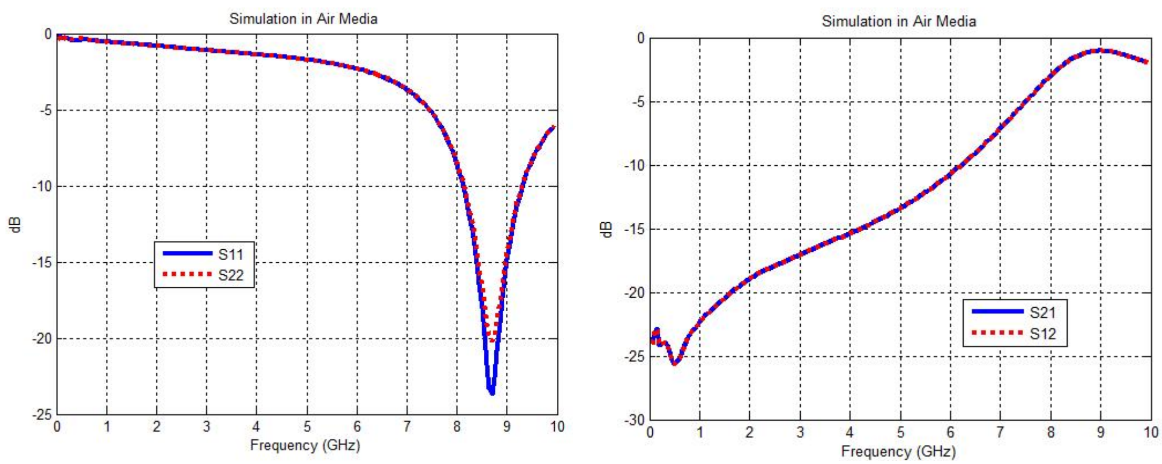


(a) (b)

Figure 1: (a) Patch Resonator, (b) four layered (skin, fat, blood, muscle) tissue.

Table 1: Dimensions of the Patch Resonator

$Variable$	$Length(mm)$
L, W	15
L_p, W_p	6.7
W_f	4.05
d	0.1

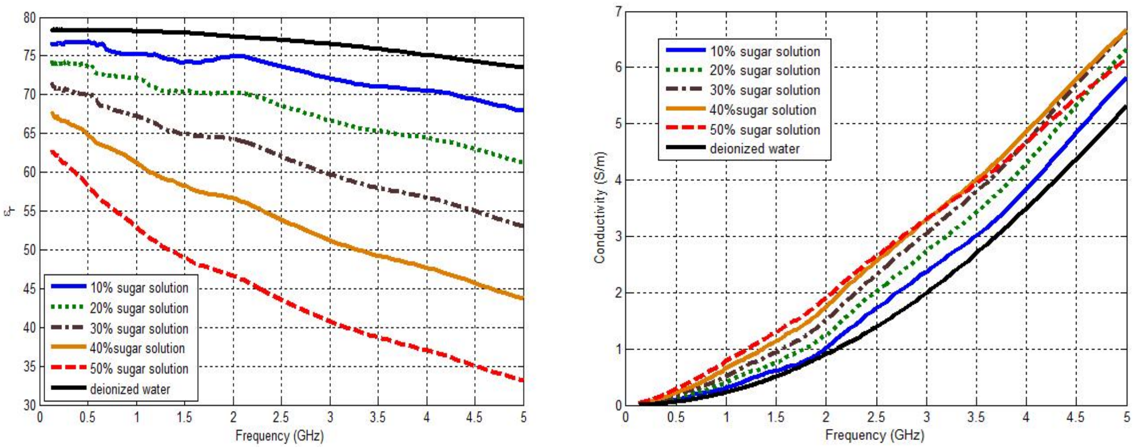


(a) (b)

Figure 2: (a) Simulated S11 and S22 response in air media, (b) simulated S21 and S12 response in air media.

3 Testing of the Resonator

The resonator will be tested with sugar-water phantoms prepared by mixing de-ionized water and sucrose.5 different solutions is prepared containing 10, 20, 30, 40, and 50 percent by weight sugar. Dielectric properties of phantoms is measured with MCL coaxial probe up to 5 GHz [6]. The solutions will be placed on resonator and the resonator response will be measured. Through S parameter measurements dielectric properties of the solutions will be retrieved. The retrieved dielectric properties will be compared with measured dielectric properties with MCL probe for validation. Measured permittivity and conductivity of the solutions are given in fig. 3a, and 3b respectively. The permittivity of the solution decreases as the sugar contend increased and conductivity increases. In previous studies the dielectric properties of blood is measured up to 20 GHz and it has been reported that the permittivity and conductivity of the blood plasma is decreasing with the increase in blood glucose levels. In this study, we are investigating the sensitivity of sensor response to the changes in permittivity since the conductivity of blood plasma is less responsive to the alterations in glucose levels.



(a) (b)

Figure 3: (a) Relative dielectric constant measurements of sugar-water solutions, (b) conductivity measurements of sugar-water solutions.

4 Conclusion and Future Work

A compact patch resonator operating at 2.4 GHz is designed and simulated with four layered tissue mimicking material. Effective dielectric properties of the tissue placed top of the resonator will be retrieved from the simulated S parameter response. The resonator will be fabricated and the measurements will be performed with blood simulating liquid phantoms prepared by mixing sugar and deionized water. Phantoms will be used to test the sensitivity of the resonator to the change in electrical properties. The permittivity of the solutions will be retrieved and through the sensor response and the retrieved results will be compared with the MCL coaxial probe measurements.

5 References

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