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A Comparative Study for Development of Microwave Glucose Sensors

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Abstract

This paper presents a comparative study in an attempt to identify the best frequency of operation for a potential microwave glucose sensor. Two patch antennas operating at 2.45 GHz and 5.8 GHz are designed to radiate towards high permittivity and high loss de-ionized water medium. Antennas are covered with superstrates to limit the contact with the liquid and mounted at the bottom of containers. From the measured S_{11} response of the antennas with changing glucose levels, it was concluded that the antenna operating at the higher frequency is more sensitive to the changes in the glucose levels.

1. Introduction

Proper management of chronic diseases can only be possible with life style adoptions and appropriate medical care enabled with the collected vital signs information [1]. One of the vital signs is blood glucose levels that should be regulated to prevent the complications of diabetes disease. Diabetes patients are monitoring the blood glucose levels with chemical means where a drop of blood needs to be withdrawn, usually from the fingertips of the patient. Current monitoring technique is unable to meet the need to collect the continuous blood glucose levels data for effective management of the disease. Another drawback of the current monitoring technique is the invasive nature of the application, discouraging the patient from collection of frequent measurements. Therefore, there is a need for a continuous and non-invasive technique to monitor the blood glucose levels.

Within the last decade, microwave sensing has been increasingly studied as a candidate technique for continuous and non-invasive blood glucose monitoring. A microwave cavity resonator is investigated in [2] detect the dependence of the Q factor and S_{21} magnitude to the variations in blood glucose concentrations. Other than cavity resonators, split ring resonators (SRR) have been investigated in the literature [3]. An open-ended microstrip spiral transmission line is proposed in [4]. Forward transfer function (S_{21}) variation resulting from the changes in the permittivity of the test material is measured with the spiral antenna over the frequency range from 100 MHz to 5 GHz. The spiral resonator is then used in another study to retrieve the relative permittivity of phantoms with varying sugar contents [5]. In [6], an ultra wide band monopole antenna is modified to operate at lower frequencies. The antenna is then simulated in HFSS, for three different glucose concentrations: hypoglycemia, normoglycemia, and hyperglycemia. In [7], a patch resonator operating at 2.46 GHz is proposed. Change in input impedance of the resonator was measured.

The literature suggests that the glucose dependent dielectric property changes alters the response of the microwave resonators. However, a significant permittivity change can only be possible with high levels of glucose [8]. Considering the realistic glucose changes in the human body, the realistic permittivity change is very limited. Thus, there is a need for a comprehensive study investigating the best possible sensor design and operation frequency to realize a microwave noninvasive glucose sensor.

In this study, to identify the best frequency of operation, two patch antennas designed to operate at two different ISM bands are investigated with glucose solutions. Section 2 gives the antenna designs, experimental set-up is given in Section 3, Section 4 shows the results, and finally Section 5 presents the conclusion.

2. Design of Antennas

Two patch antennas operating at 2.45 GHz and 5.8 GHz ISM bands are optimized to function in a high permittivity and high loss de-ionized water environment. Both of the antennas are fabricated on an FR4 substrate with the relative permittivity of 4.4 and dissipation factor of 0.021 at 10 GHz. Antennas are also covered with two FR4 superstrates. The superstrate prevents the direct contact between the radiating parts of the antennas and the liquids. Due to the high permittivity environment surrounding the antennas, two layers of FR4 is stacked together to form a thick layer of superstrate which decreased the effective permittivity of the microstrip antennas. Through this approach is adopted to ease the fabrication of antennas. It should be noted that, a superstrate can be useful to limit the specific absorption rate (SAR) for a practical application. The thickness of the FR4 material is standard (1.6 mm).

An iterative approach is used to design the antennas. First the required antenna dimensions are calculated to operate at the air medium, then the layers are added and the antenna is optimized with the trial-and-error method. Final simulation set-up is given in Fig. 1. The liquid box shown in the figure is de-ionized water with dielectric properties are εr = 79 and σ = 1.5 S/m at 2.45 GHz and εr = 73 and σ = 5 S/m at 5.48 GHz. The Dielectric properties are measured with agilent dielectric probe kit. Optimized width and length of the patch antenna operating at 2.45 GHz are 7.5 mm and 26 mm respectively. Optimized width and length of the length of the patch antenna operating at 5.48 GHz are 3 mm and 4 mm respectively.

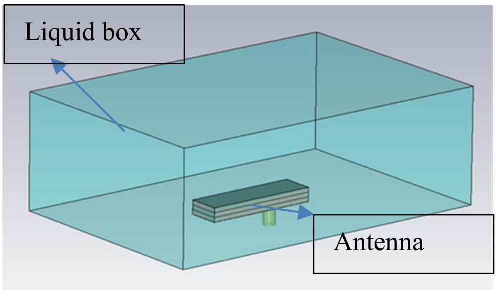


Figure 1. Final simulation set-up of the antenna operating at 2.45 GHz.

3. Experimental Set-up

Fabricated antennas are first covered with two layers of FR4 superstrate. The superstrate is attached to the antenna with a thin layer of epoxy. Fabricated antennas are shown in Fig. 2. The authors do not expect a significant change in the response of the antenna due to the epoxy layer. The antennas are then mounted at the bottom of containers, shown in Fig. 3.

Figure 2. Patch antenna covered with two layers of FR4 superstrate mounted at the bottom of a 3D printed ABS container.

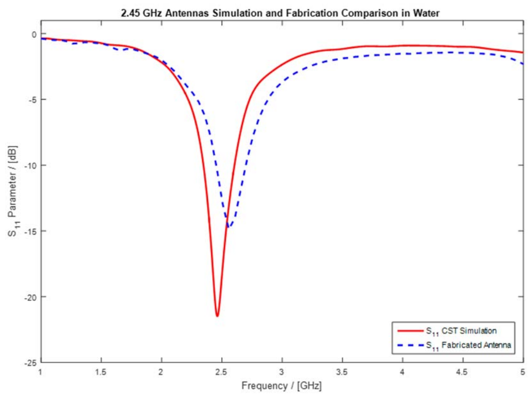
During the simulations, dimensions of the water surrounding the antenna is determined with trial and error method. Due to the customized dimensions, the containers are fabricated with 3D printing. The ABS material is used during the fabrication. It is estimated that the dielectric properties of the ABS material are close to dielectric properties of plastic. Dimensions of the containers for the antenna operating at 2.45 GHz and 5.8 GHz are 40 x 120 x 40 mm^3 and 30 x 40 x 20 mm^3, respectively.

Figure 3. Patch antenna covered with two layers of FR4 superstrate mounted at the bottom of a 3D printed ABS container.

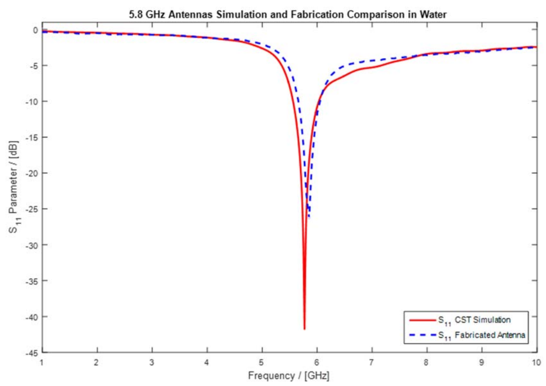
To validate the antenna performance, the measurements are first taken in air medium. Then, the containers are filled with de-ionized water and different glucose solutions. The glucose solutions are prepared by mixing a 5% dextrose solution with de-ionized water. The resulting mixtures contains glucose concentrations ranging fromm 200 mg/dl to 1500 mg/dl. Although the glucose levels of a healthy human changes in between 70 mg/dl to 180 mg/dl, the diabetes patients can experience glucose levels as high as 400 mg/dl on a daily basis without hospitalization. This wide range serves as a proof of concept to validate the performances of the patch antennas. It should be noted that this study also targets a potential microwave sensor that can be utilized as an alarm mechanism if the diabetes patient experiences a very high glucose level and needs assistance.

4. Results and Discussions

To validate the antenna performance, first the measurements with de-ionized water are taken. The measured results are shown in Fig. 4 (a) and Fig. 4 (b) for 2.45 GHz and 5.8 GHz, respectively.



(a)



(b)

Figure 4. (a) Simulated and measured S_{11} response of the 2.45 GHz patch antenna in de-ionized water; **(b)** Simulated and measured S_{11} response of the 5.8 GHz patch antenna in de-ionized water.

All measurements are performed with Agilent's PNA-X N5245A Network Analyzer. Measured and simulated response of both antennas agrees well.

S_{11} measurements are performed by changing the glucose solutions in the containers. Measured S_{11} response for 2.45 GHz antenna is shown in Fig. 5.

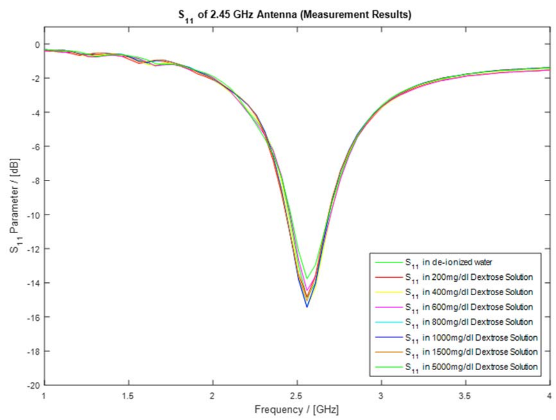


Figure 5. S_{11} response of the 2.45 GHz patch antenna with solutions having different glucose concentrations.

Table I. Measured S_{11} magnitude of .45 GHz and 5.8 GHz antennas with varying glucose levels.

Dextrose Levels (mg/dl)	S_{11} response at 2.45 GHz	S_{11}response at 5.8 GHz
0	-14,87	-26,32
200	-14,82	-30,19
400	-15,4	-38,85
600	-14,45	-38,52
800	-15,39	-28,77
1000	-15,44	-29,6
1500	-15,06	-28,92

The change in glucose levels does not affect the frequency of operation. However, the matching of the antenna is affected from the change in glucose levels. Table I. shows the changes in S_{11} magnitude of both the 2.45 GHz and 5.8 GHz antenna. Response of the 5.8 GHz antenna is found to be more sensitive to the changes in glucose levels.

Ultimately, the eventual goal of a microwave glucose sensor is to replace the current glucose monitoring systems. However, this results suggests that, unlike other anomalies, glucose levels considered high for human body in does not significantly change the permittivity of tissues. Despite the challenges of microwave glucose sensing presented due to low permittivity changes, promising results suggests that such method remains as an alternative candidate for continuous, non-invasive sensing.

5. Conclusions

Two patch antennas optimized to operate in a de-ionized water medium is fabricated and tested with glucose solutions. From the S_{11} measurements it can be seen that the frequency of the operation of both antennas remains the same. Which means that the permittivity of the deionized water is not changing enough to shift the frequency for both antennas. However, the glucose dependent change in dielectric properties are effecting the input impedance of both antennas. The patch antenna operating at 2.4 GHz is less responsive to those changes than the antenna operating at 5.8 GHz. This is expected since the antenna operating at higher frequency is expected to be more sensitive.

7. References

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