Design of Implantable MSA for Glucose Monitoring

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Abstract. The emerging techniques in the sensor field include an antenna as a bio-sensor. A simple Planar Inverted F antenna (PIFA) as an implantable glucose sensor to detect variation in glucose level is presented in this paper. The work includes design of PIF antenna using HFSS software and in vitro testing as a sensor with various glucose level in synthetic blood. The antenna is designed to resonate at frequency 530 MHz for demonstration purpose. The shift in the resonant frequency of 3.54 kHz per 1 mg/dl is observed with respect to change in glucose level concentration.

Keywords: ***PIFA, Implantable Antenna, Glucose Sensor, Synthetic blood, In-Vitro testing .***

1 Introduction

The latest figure from IDF reveal that currently, 366 million people have diabetes, 4.6 million deaths are due to diabetes and US $ 465 billion is spent on care, and every 7th second someone somewhere dies from these diseases [1]. Continuous glucose monitoring plays an important role in the therapy of these diseases. Now a day's various electrochemical, optical, piezoelectric, thermal or mechanical biosensors are used. These biosensors rely on interstitial fluids within the dermis to measure interstitial glucose level (IG) and can function only for 10 to 30 days after implantation in the body. They may degrade or fail and may damage surrounding tissues [2]. To increase the functional time of implant sensor, the proper biocompatible design should take into consideration.

The basic concept of antenna is, its resonant frequency depends on a dielectric constant of the substrate and surrounding material. Using the same concept, some antennas has been designed to sense various environmental parameters like moisture, gas, temperature, pressure etc. To measure moisture, a special material (PEDOT:PSS) was used with antenna, that absorbs water molecules. Change in input impedence and resonant frequency was noted with respect to moisture[3]. Physical dimension and dielectric constant of substrate are temperature dependent parameters. A microstrip patch antenna was designed to sense temperature variation[4], which shows resonant frequency shift was directly proportional to surrounding temperature. A strain and crack sensing systems were designed[5,6] to detect change in mechanical tensile strain in form of resonant frequency shift.

The proposed design is also based on the same concept. As the glucose level in the blood varies, dielectric property of the same also changes. Antenna, as a sensor, will be placed in human body under the skin and fat layer above muscle where the density of blood vessel is large.

When the change in blood glucose level, dielectric property of surrounding tissue will also change and hence antenna parameters. This change can be calibrated to detect the change in glucose concentration in blood. This antenna will be in vivo type, once implanted in the body, it will function for a long time. So patient will get relief from high-cost traditional ways of glucose monitoring. As it is an implantable sensor, it must operate in MICS band (402-405MHz) and also shall have the small size for above resonant frequency. With this constraint, we investigate PIFA structure.

2 Proposed Antenna Design

A small size antenna design within MICS band will not possible with conventional antenna design process[7,8]. If an additional element like short-circuit patch is introduced in the main geometry of structure will help to reduce size. This technique is called as PIFA. These structures have several advantages like a simple structure, small size, multiband frequency operations etc [9-14]. A simple square shape patch was selected due to its

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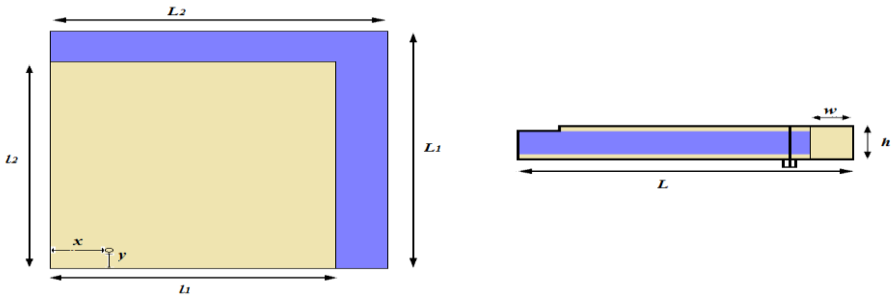
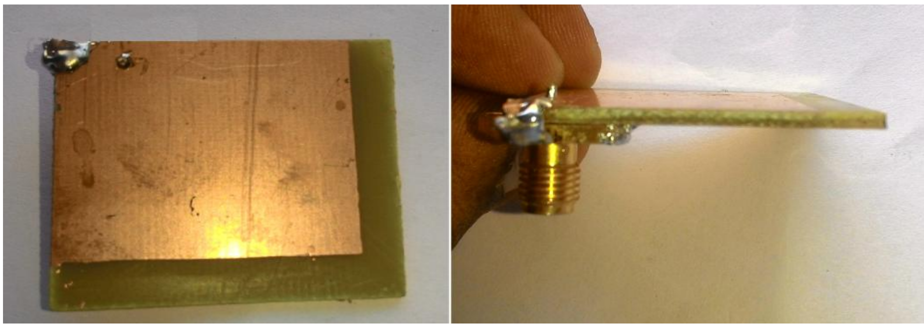
compactness and ease of fabrication. A Proposed antenna is designed and simulated using HFSS. As we are demonstrating antenna as a glucose sensor and PIFA as a size reduction technique, we took dimensions as 3.5 × 3.5 × 1.6 mm^3 which resonate at 526.5 MHz. Structure is shown in Fig. 1.



(a) (b)

Fig. 1. a) Top View b) Side View of the proposed Antenna.



(a) (b)

Fig. 2. Fabricated PIFA design a) Top view, b) side view, showing shortning vertical plne.

This antenna is fabricated on FR-4 Epoxy substrate with ε =4.4 and loss tangent (tanδ) 0.02, with dimensions L_1=35mm, L_2=35mm, l_1=29.6mm,l_2=30.5 mm, h=1.6 mm, x=2.5mm, y=6.5mm patch and ground is shorted with vertical plane of size w= 4mm as shown in Fig. 2. It can be further optimized to MICS band by using a silicon substrate of dielectric constant 12.

3 Experimental Verification

Fabricated antenna sensor is tested using Copper Mountan Technologies, PLANAR TR1300/1 VNA. Fig. 3 shows experimental setup, which represents as an antenna is placed in the human body, near to high-density blood vessels. Synthetic blood fluid was prepared by dissolving the appropriate quantities of 9 separate chemicals in distilled water [2]. Four different samples of 50 ml each were made with different glucose levels for different diabetic conditions as shown in the Table 1. Antenna was waterproofed with tape before immersing into SBF sample. S_{11} was observed one by one for all these samples.

Table 1. Glucose concentration for various diabetic conditions in SBF.

Sample No	Diabetic Condition	Glucose concentration (mg/dl)	Glucose in 50 ml SBF (grms)
1	Hypoglycemia	0	0
2	Normal	120	0.021
3	Hyperglycemia	270	0.039
4	Hyperglycemia	530	0.082

4 Results and Discussions

The proposed design was first simulated in Ansys HFSS and experimented with VNA in air. The simulated and experimental result of S_{11} are shown in fig. 4. In air, simulated values for gain and directivity was -16 dB and -12.1 dB. When antenna was placed in SBF sample, values of gain and directivity changes to -16.1 dB and -14 dB respectively.

In other case, the antenna is placed in synthetic blood fluid. Results were taken without glucose and then glucose concentration was increased step by step. Frequency shift was observed with respect to the change in glucose level. Observed readings with various glucose concentration are shown in Fig. 5.

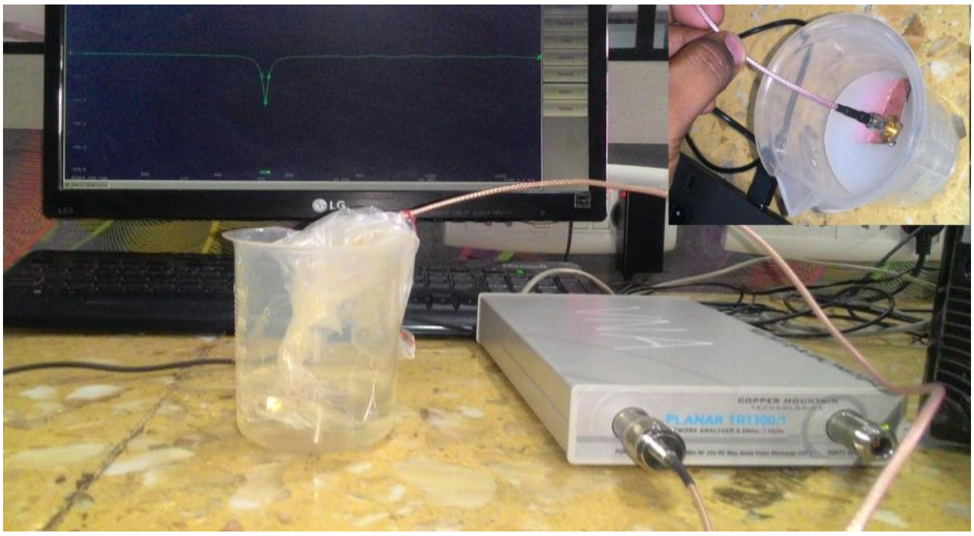


Fig. 3. Experimental Setup with SBF samples having different glucose level.

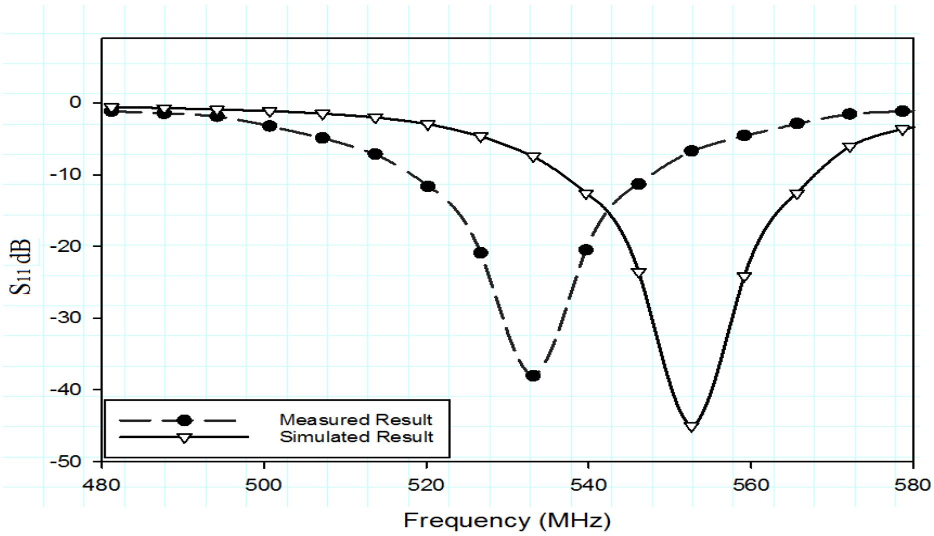


Fig. 4. Return Loss (S_{11}) in air.

Variations in center frequency and return loss (S_{11}) with various glucose level concentration is shown in Table 2. With increase in glucose concentration, return loss decreases and frequency shift (Δf) increases.

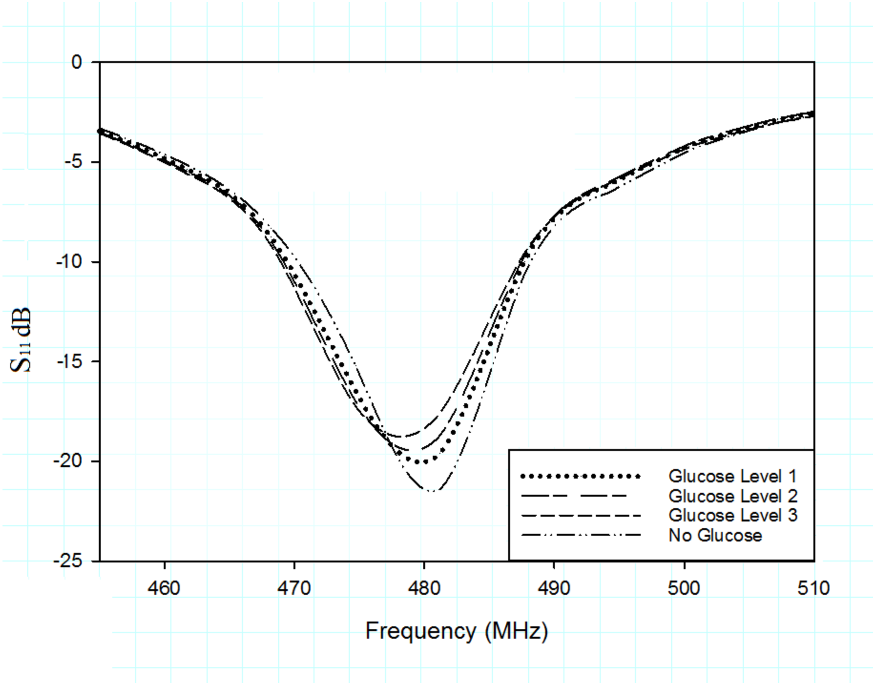


Fig. 5. Return Loss (S_{11}), when antenna placed in SBF samples.

Table 2. Variation in center frequency and return loss due to glucose concentration.

Sample	Center Frequency (in MHz)	Δf (MHz)	S_{11}(dB)	Glucose (grms)
Air	526.651	-	-38.602	-
Sample 1	480	46.651	-21.50	0
Sample 2	479.8	0.2	-20.5	120
Sample 3	479.3	0.5	-19.4929	270
Sample 4	478.128	1.172	-18.7071	530

5 Conclusion

In this paper, Planar Inverted F antenna, as a glucose sensor is realized. An antenna sensor is tested for 3 diabetic conditions, i.e. Hypoglycemia, normal and hyperglycemia. The frequency shift of 3.532075 kHz was observed as 1 mg/dl glucose concentration.

It is verified that antenna can be used as a glucose sensor. For designing an implantable antenna, size can be reduced using PIFA structure to operate in MICS band. This will be possible by using high dielectric constant material like silicon (ε_r =12). The preposed antenna is a good replacement for conventional glucose sensor with advantages like low cost, high reliability and maximum operating time.

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