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In Vitro Testing of Implantable Antenna For Glucose Sensing

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Abstract – *This article focuses on the design and testing of a compact implantable antenna sensor for continuous glucose monitoring. The main attraction of this article is the verification of an antenna as a glucose sensor. For this particular application, the antenna sensor operating at the WMTS band is demonstrated. This structure is simulated in the Ansys HFSS tool and tested with the blood phantom model with different glucose concentrations. The antenna was fabricated using an easily available low-cost FR-4 substrate with compact dimensions of 25×25×1.6 mm^3. The proposed structure demonstrates excellent radiation properties at the resonating frequency of 1.4 GHz with excellent -10 dB bandwidth of 115 MHz. Also, it gives the gain of -12.5 dB. As a sensor, this design shows a sensitivity of 13.1 KHz per mg/dl glucose.*

Keywords — *PIFA, Implantable antennas, Glucose sensor, MICS, WMTS.*

I. INTRODUCTION

The most recent figures from the IDF reveal that at present, 366 million individuals have diabetes, 4.6 million passing because of diabetes, and the US $ 465 billion is spent on care, and each seventh second, somebody somehow passes away from these disorders [1]. Contentious glucose observing assumes a significant job in the treatment of these illnesses. Presently, different electrochemical, thermal, optical, piezoelectric, or mechanical biosensors are utilized. These biosensors depend on interstitial liquids. Inside the dermis to gauge interstitial glucose level (IG) and can work just for 10 to 30 days after implantation in the body. They may corrupt and may harm encompassing tissues [2]-[4]. To expand the practical time of implanted sensors, the correct bio-compatible plan should mull over.

Figure 1 explains the operation of a medical implant with sensing capability. Any implantable medical device (IMD) consists of a battery, microcontroller, sensor, and antenna. The sensor converts the desired physiological signal of the host and converts it into an electric signal. The output of the sensor is then processed by the microprocessor, and it is sent to the base station situated in the vicinity by radio link. Further, the signal is then sent to the remote monitor. In this process, it is observed that there is some variation in the frequency signal transmitted by IMD to the base station. The cause of these variations in frequency is some physiological parameters of the host body, such as temperature, glucose level, tissue density, implant position, and so on.

Though all these parameters of the host body affect the transmitting frequency, only the glucose level variation shows considerable variations in the transmitting frequency. Because glucose is the only component in the human blood that fluctuates largely compared with others like vitamins, minerals, hormones, oxygen, etc., using this phenomenon, the glucose variations are sensed without the dedicated sensor in the implant resulting in a compact, low-cost IMD.

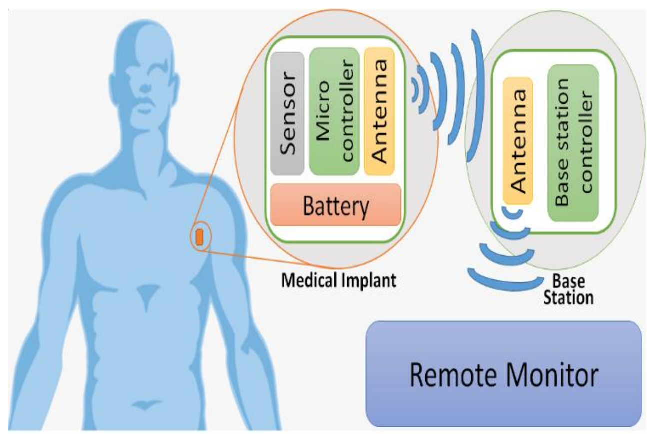

Fig. 1 Operation of an implantable biotelemetry sensing and monitoring system

In this work, the antenna is used for sensing as well as for communication purposes. The fundamental idea of this design is, the resonant frequency of an antenna sensor relies upon a dielectric constant of the substrate and encompassing material. Utilizing a similar idea, some antennas have been intended to detect different ecological parameters like moisture, gas, temperature, pressure, and so on [5]-[13]. To quantify moisture, a unique material was utilized with an antenna that ingests water particles. Change in input impedance and resonant frequency was noted concerning moisture. Physical measurement and dielectric steady of the substrate are subordinate temperature parameters. A microstrip antenna was intended to detect temperature variation, which shows the resonant frequency was straightforwardly relative to encompassing temperature. A strain and crack detecting framework were designed to distinguish the change in mechanical elastic strain in the type of resonant frequency variation. All reported examples are listed in Table I

TABLE I

Comparison of Various Antenna Sensor Systems.

Ref No	Year	Antenna type	Operating Frequency	Application
5	2011	Dipole	915 MHz	Gas
6	2012	Folded planar	880 MHz	Humidity
7	2012	Microstrip	1.6 GHz	Biochemical Mixture
8	2013	Microstrip	10 GHz	Glucose
9	2014	Helix	2-3.4 GHz	Drug Dose
10	2015	Microstrip	5-6 GHz	Temperature
11	2015	Microstrip	5.4 GHz	Strain
12	2016	Microstrip	5.8 & 2.9 GHz	Strain & Crack
13	2016	Microstrip	530 MHz	Glucose

The proposed plan is additionally founded on a similar idea. As the glucose level in the blood differs, the dielectric property of the equivalent likewise changes. An antenna, a sensor, will be implanted in the human body under the skin and the fat layer, above muscle where the density of the vein is relatively large.

At the point when the change in blood glucose level, the dielectric property of encompassing tissue will likewise change and henceforth resonant frequency of an antenna. This change can be aligned to identify the variation in glucose fixation in blood. This antenna structure will be in vivo type; when embedded in the body, it will work for a long period. So patients will get help from significant expense customary methods for glucose checking. As it is an implantable sensor, it must work in the MICS (402-405MHz) or the WMTS (608-614 MHz and 1395-1400MHz) [14] band and furthermore will have the little size for the above frequency band. The size of a standard antenna is conversely relative to its operating frequency. Therefore it is very difficult to design a small size antenna in the said frequency band.

Various miniaturized antenna designs have been reported in the literature. Traditional miniaturization techniques include slots making on patch [15]-[17], using multi-layer antenna design [18], [19], and meandering strip-line on patch [20]-[25]. In this paper, the examination of simple meandered PIFA [26]-[30] structures for size reduction is done.

II. ANTENNA DESIGN AND GEOMETRY

Fig.2 explains the proposed meandered W-Shaped PIFA with the dimensions for Implant application. This antenna is fabricated on FR-4 epoxy substrate with the dielectric constant (ε) 4.4 and loss tangent (tan δ) 0.02. The structure is fabricated on the substrate having ground plane of 25×25mm2, patch with the dimension L= W =25 mm, W1 = 20 mm, l1 = 8 mm, l2 = 6 mm, l3 = 4mm, l4 = 6 mm and l5= 2 mm. The shorting plane has dimensions, h=1.6 mm and x = 4.3 mm. The Feed point is positioned at x=5.5 mm and y=2 mm. The W-shaped meandering results in the increased electrical length of the radiating patch. This radiating patch is shorted with the ground by a vertical shorting plate to form PIFA. The design is simulated in Ansys HFSS with the two-layer phantom model representing human muscle and skin. Fig. 3 shows feed point position, shorting plane position, and simulation structure in HFSS and fabricated prototype. Whereas in Fig. 4, the fabricated structure is shown

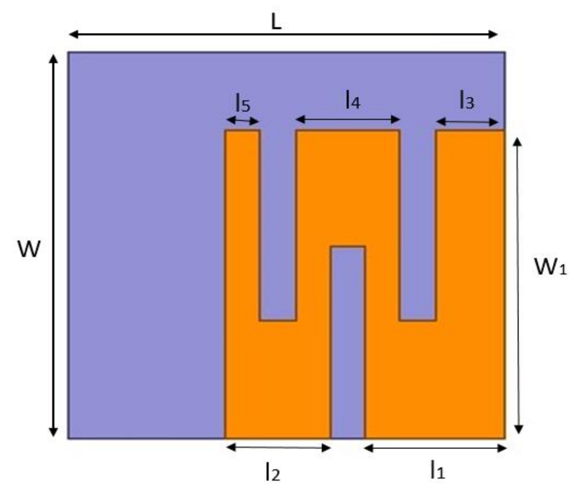

Fig. 2 Radiating Patch of the proposed antenna.

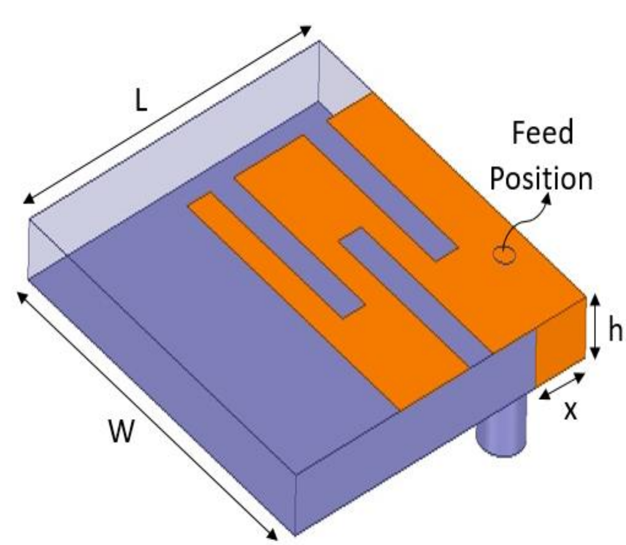

Fig. 3 Fabrication prototype in HFSS.

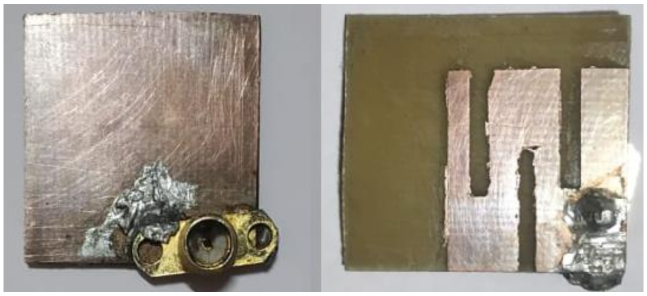

Fig. 4 Fabricated Antenna structure on FR-4 substrate.

III. SIMULATION AND RESULTS

The proposed antenna design is simulated in the Ansys HFSS software tool. This design is simulated in the human muscle phantom model having dielectric constant 43 (ε) and loss tangent of 1.55 (tan δ). The observed antenna parameters show that the designed antenna is working properly in the desired WMTS frequency band.

The simulated return loss characteristics of the proposed antenna are shown in Fig.5. The resonance frequency of 1.4 GHz is obtained. Also, 115 MHz -10dB bandwidth is achieved, which covers the entire WMTS frequency band.

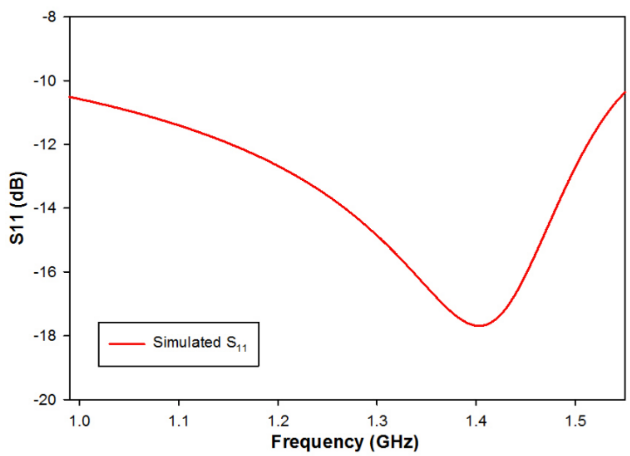

Fig. 5 Simulated reflection coefficient (S_{11}) of the proposed antenna.

The E-field and H-field distribution is shown in Fig. 6 and Fig. 7. From these plots, it is observed that the electric field strength is more at the farthest end of the patch from the feed point, and it is minimum at the shorting plane. H- field strength is maximum at the shorting plane and minimum at the farthest end of the patch.

The surface current distribution is presented in Fig. 8. It shows that the current density is maximum at the shorting plane and center of the radiating patch. It is a minimum at mid-length of the patch.

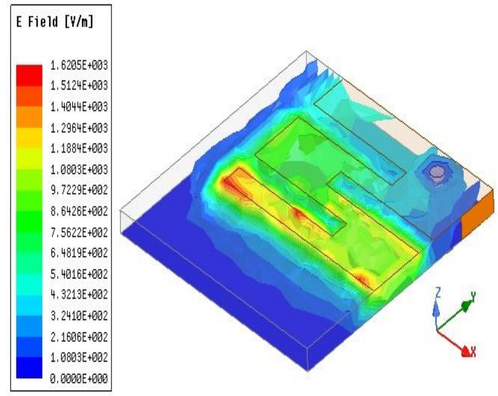

Fig. 6 Electric field (E Field) distribution on the structure.

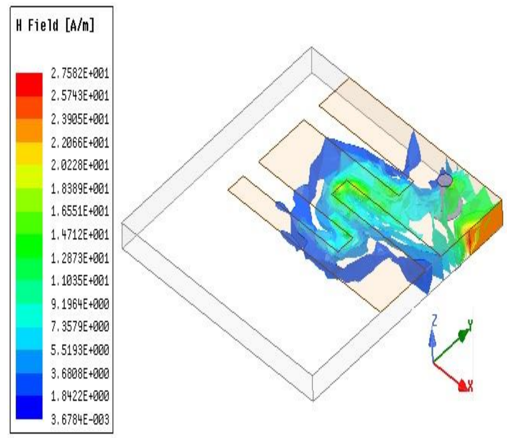

Fig. 7 Magnetic field (H Field) distribution on the structure.

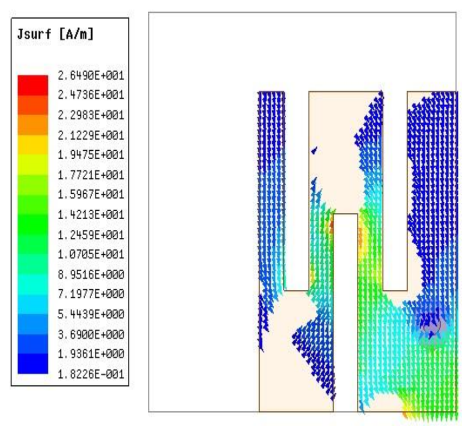

Fig. 8 Surface current distribution (j Surf) on the radiating patch.

The radiation pattern of the proposed antenna is simulated. As shown in Fig. 9. It has an omnidirectional pattern, with a maximum gain of -12.5 dB.

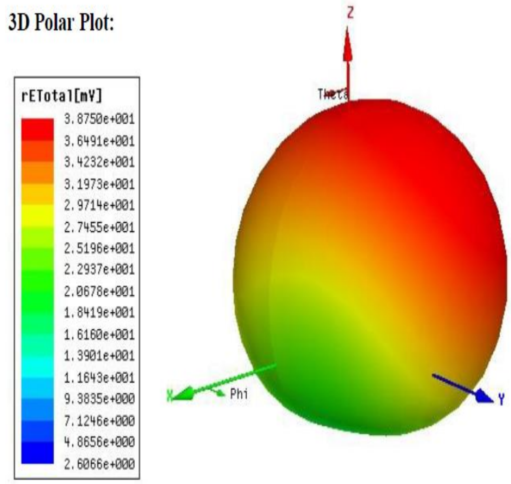

Fig. 9 Far-field Radiation Pattern.

IV. EXPERIMENTAL SETUP

The proposed antenna is tested on Copper Mountain Technologies, PLANAR TR1300/1 VNA. S_{11} of the antenna is measured in the air first, and then the antenna is placed in a blood phantom for further experiment representing human tissue. The experimental setup is shown in fig. 10. S_{11} is measured for different blood phantoms having different glucose levels. This procedure is repeated for 4 different SBF samples.

Fig. 10. Experimental Setup to test the designed antenna in blood phantom model.

V. MEASUREMENT & DISCUSSION

The designed antenna operates in its specific band. When the antenna is placed in SBF, resonant frequency shifted downwards.

The result from Table II shows the correlation between the glucose levels and the resonant frequency shift. An antenna design provides an impressive shift in resonant frequency according to glucose levels, as observed in Fig. 11. The result suggested that antennas have a capability for sensing glucose levels in the blood.

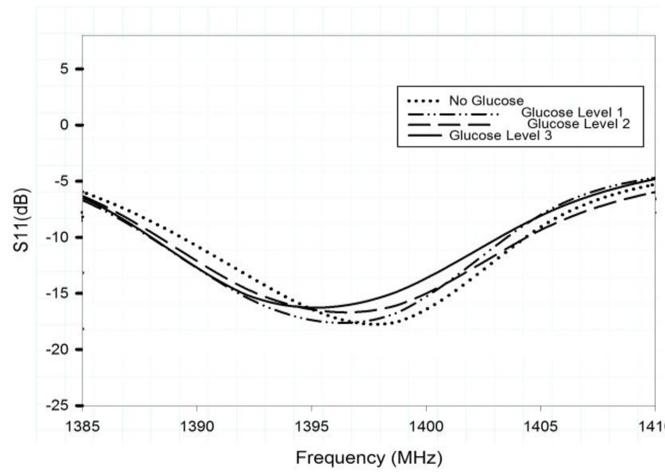

Fig. 11 Measured S_{11} when the antenna is placed in blood phantom.

TABLE II

Relation between glucose level and resonant frequency shift

Sample	*WMTS Band*			*Glucose (milligrams)*
	f_0 (MHz)	*Δf (MHz)*	*S_{11} (dB)*	
Air	1474.3	--	-31.2	-
1	1398.69	75.61	-17.4	0
2	1397.77	0.92	-16.5	120
3	1395.58	2.19	-15.7	270
4	1392.54	2.54	-14.3	530

VI. CONCLUSIONS

This paper represents an antenna as a glucose sensor. The antenna designed for the WMTS band is simulated and tested for glucose variation in SBF. A frequency shift of 13.1 KHz per mg/dl is observed for various SBF samples. The results prove that the above antenna design can be used as a glucose sensor. It also demonstrates good radiation characteristics. The design is simple, low cost, and reliable and could be a good replacement for conventional glucose sensors.

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