HI-Shaped Antenna for Non-Invasive Diabetes Measurement and Monitor Fluctuating Diabetes

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ABSTRACT

The HI antenna senses the human pancreas dielectric radiation for diabetic measurement. Existing passive sensor antennas sense the dielectric radiation from the pancreas region at frequencies of 402.5 MHz and 2.4 GHz for a relative permittivity of 61.2155 and 57.201, respectively. The proposed antenna senses the dielectric properties of diabetic-affected pancreas, such as low- and high-fat diabetic pancreas, in the frequency range between 1.5 GHz and 3 GHz. The relative permittivity of the diabetic pancreas is in the range of 48.235 to 65.508. The proposed antenna can sense the diabetic range between 70 mg/dl and 475 mg/dl based on a change in dB level, whereas the existing diabetic sensing antenna measures the diabetic level based on resonance frequency. The resonance-frequency-based diabetic measurement shows inaccurate results. The HI antenna senses pancreas radiation effectively because of the shape and size of its slot, which covers the pancreas region of the human body without generating noise due to the crumbling effect during pancreas dielectric radiation acquisition. The proposed HI-shaped antenna is mounted in different parts of the human body, such as the hand, finger, stomach, and pancreas, for measuring fluctuating diabetes. Based on the experimental results of the proposed HI-shaped antenna, the pancreas is in an optimal location among the various parts of the body. The proposed HI-shaped antenna-based dielectric signal statical values were correlated with diabetic laboratory values for prediction of the diabetic value. The proposed antenna measures the fluctuation in diabetes with 85% accuracy.

Keywords: Antenna sensor, HI-Shaped antenna, Fluctuating diabetes, Signal statical parameters

1. INTRODUCTION

Diabetes rates in humans have increased due to lifestyle disorders. According to statistics, there are 500 million diabetics in the world. In India, 77 million people have a diabetic disorder. Diabetic disorder arises due to excess production of insulin by the liver or less use of insulin in the body, which results in high and low blood sugar levels in diabetics. [1]. Diabetes is measured through an invasive method using blood samples. Commercially available non-invasive methods of measuring diabetes are Glucosense, TensorTip Glucometer, Contact Lens, iQuickIt Saliva Analyzer, GlucoTrack, Noviosense, and Gluco-Wise, as shown in Figs. 1 [2]-[7]. Non-invasive devices use any one of the methods, such as optical, radiofrequency, electromagnetic, microwave, and electrochemical, for diabetic value measurement. However, non-invasive measurement of blood glucose from the above devices has mounting problems and a crumbling effect, making it impossible to monitor diabetic values continuously.

The measurement of blood glucose value (BGV) is essential for diabetic management. In this section, blood glucose measurement methods are analyzed for their advantages and disadvantages. BGV is monitored through invasive methods such as continuous blood glucose monitoring (CGM) and self-monitoring of blood glucose (SMBG). The CGM method performs the BGV measurement every 7 to 14 days, whereas the SMBG is measured three times per day. Twenty-nine insulin-intervention patients with type 1 diabetes were studied and analyzed for fluctuations in BGV through SMBG and CGM. Both methods of calculating correlations were evaluated with mean and standard deviation values, average daily risk range, Morbus value, and high-blood-glucose index, and the result shows no correlation

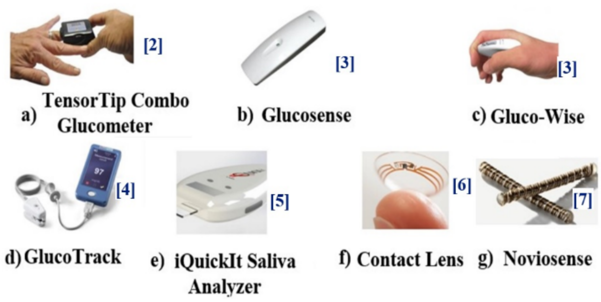

Fig. 1: Commercially available non-invasive diabetes measurement devices.

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between SMBG and CGM measuring diabetic value [8].

A needle-based glucose monitoring and closed-loop glycemic control system was developed and tested in the endocrine pancreas phantom. A based method calculated the infusion rates of insulin, glucagon, or both, and infusion pumps in dogs for 7 days [9] and was approved by the Food and Drug Administration in 1999 under CGM. The SMBG system plays a vital role in the management of diabetes and reduces the risk of adverse drug effects from diabetes drugs. SMBG is performed through urine sugar screening tests with a reagent strip [10]. Continuous glucose monitoring systems (CGMS) consist of a glucose sensor, transmitter, and receiver that monitor and display the glucose level. The glucose sensor is punctured into the subcutaneous tissue of the skin. CGMS-based glucose levels show the variation during exercise, the postabsorptive state, and mental stress [11]. Nowadays, non-invasive CGMS is performed through different types of glucose sensors, such as electrochemical, optical, piezoelectric, and electromagnetic impedance [12]–[14]. Physicians prefer non-invasive CGMS methods for accurate diabetic value measurement. Patentees prefer sensors without pricking for diabetic value measurement. Whereas the invasive glucose sensors need to be frequently changed every 7 days for more accurate results, safety measures to prick and dispose of the invasive sensor are to be taken [15]–[17]. The commercially available non-invasive CGMS are (a) the TensorTip Glucometer (b) Glucosense (c) GlucoWise (d) GlucoTrack (e) the iQuickIt Saliva Analyzer (f) Contact Lens (g) Noviosence. Fig. 1 shows the commercially available non-invasive diabetes measurement devices.

The TensorTipTM glumeter works based on fingertip tissue photography and measures glucose value through the blood at the capillary level instead of the skin. The glucose sense device consists of silica glass and infrared light. The glucose value is measured through the changes in the reflected spectrum due to glucose concentration. GlucoWise measures diabetes from skin regions such as the thumb and the forefinger through radio wave technology. GlucoTrack measures glucose from the earlobe through electromagnetic, ultrasound, and thermal technology. iQuickIt's salivary analysis measures diabetes through the saliva. Smart contact lenses measure the glucose level, and continuously fixing them on the body is never possible using a static electrical charge for power. Non-invasive measures of glucose from eye tears [18].

The above commercial methods have certain drawbacks for continuous monitoring of glucose levels due to the continuous harmful radiation they expose the human body to. Moreover, some of the above devices are under clinical trials. The continuous monitoring of glucose levels through devices leads to discomfort and overheating during long-term measurements. The commercial devices are not completely non-invasive, such as contact lenses or implantable devices, which fall under the category of semi-invasive devices. In addition, device users are imposed with restrictions, such as that glucose levels through sweat, saliva, breath, and eye tears are never to be measured continuously [19], [20]. Light-based blood glucose measurement has limited penetration with tissue and noise in the reflected signal because of the water content of the blood and other non-glucose metabolites, such as noncellular metabolites from plasma and diagnosis. The optical or microwave radiation intensity depends on temperature and substance thickness. Moreover, strong absorption with water is difficult for precise glucose measurement. The laser light damages the cell during CGM measurement and is susceptible to noise interference, resulting in a low SNR. Lack of selectivity arises due to the dielectric constant in the blood components, and accuracy changes depending upon ambient temperature. Frequent picking on the skin surface leads to blood infection and various problems such as septicaemia and viremia. The Table 1 shows existing glucose sensing methods using different sizes and frequencies of antenna. Table-2 shows the literature survey of traditional diabetic value measurement using different types of sensors.

1.1 Interferences from literature antenna survey

The existing diabetic measuring antenna senses the dielectric radiation of glucoses from the carpus region with a different resonance frequency range of 8 GHz to 12 GHz. The higher radiation exposed to the carpus region of the antenna leads to a higher temperature over the carpus region. To avoid the above problem, the proposed antenna is designed for 1.5 GHz to 3 GHz and senses the human glucose variation through dB levels. In humans, glucose level is measured through a home diagnostic device that uses blood samples from the fingertip. Pricking of blood samples from the finger leads to infections and mental stress when frequent blood samples are drawn for regular monitoring of glucose levels. Blood infections and various problems such as septicaemia and viremia are avoided through the proposed HI-shaped antenna-based diabetic value measurements. In this paper, an antenna is used as a sensor for measuring fluctuating diabetes through a proposed novel design such as a HI-shaped patch antenna to generate multiple bands of frequencies for glucose level sensing with reduced return loss and maintain a VSWR less than 2. Microstrip patch antennas are used due to their low profile, light weight, ease of manufacture, and low cost. A single-resonant frequency antenna design is used for glucose level measurement.

1.2 Fluctuating diabetes

Fluctuating diabetic values or brittle diabetes are due to explained and unexplained reasons that lead to low and high diabetic values (Hyperglycemia to Hypoglycemia). Moreover, diabetic value never stays at a small variation in diabetic value in many diabetic patients. In a non-diabetic person, the fluctuation of the diabetic value is

Table 1: *Existing glucose sensing methods using different size and frequency of antenna.*

Ref/ Year	Antenna design and frequency	Sensing method	Dimensions (L×W) of the substrate	Glucose Sensing Location and sensing object size (L×W)
[21]/2022	Microstrip patch antenna & 1-5GHz	Return loss	35×35mm for 4GHz	Water with glucose
[22]/2021	Split ring patch & 1-6GHz	Reflection and transmission	59×20mm	Fingertip Size (22×11) mm
[23]/2021	Square split ring patch antenna & 25.55GHz	Electrical properties	20×15mm	Thumb Finger Size (65×35) mm
[24]/2021	Microstrip patch antenna 1.3GHz	Permittivity with glucose	68×40mm	Fingers Size (22×11)
[25]/2021	Split square ring antenna & 2.4GHz	Resonance frequency shifted	35×35mm	Water with glucose
[26]/2020	Microstrip patch antenna & 27.76GHz	Resonance frequency shifted	36×36mm	Water with glucose
[27]/2020	Complementary split ring resonator & 1-6GHz	Return Loss	66×20mm	Fingertip Size (22×11) mm
Proposed	HI antenna & 2GHz	Return loss	43×43mm	Pancreas Size (30mm-head, 25mm-neck 20mm-tail)

Table 2: *Literature survey of traditional diabetic values measurement using different type of sensor.*

Ref/ Year	Problem	Sensor/Method	Advantages	Disadvantage
[28]/2022	Blood glucose measurement	Microwave sensor /fingertip	No pain and high accurate	Continuous monitoring not possible
[29]/2022	Monitoring of diabetes	Glucose biosensor	Biosensor, is in a good accordance	No fluctuating diabetes measurement.
[30]/2022	Blood glucose measurement	Antenna as sensor /pancreas	Measurement of glucose level is accurate	No optimal sensor as antenna is suggested.
[31]/2021	Glucose level monitoring	Microwave/RF sensing of blood glucose levels	Glucose monitoring using change in dielectric properties	Internal changes factors affecting the effective permittivity.
[32]/2020	Continuous glucose monitoring	Tears, saliva, intracellular fluids, and urine	High sensitivity	Accuracy low due to the limited data.
[33]/2020	Measurement of glucose monitoring	Microwave sensor	Compact, painless, more accurate	Affect the sensor due to Change in environmental
[34]/2016	Continuous monitoring of glucose level	Microstrip two faced patch antenna	Ease to use, high sensitivity and high penetration	Atmospheric conditions affect the working
[35]/2015	Glucose monitoring	Cavitous sensors/ Salivary analysis	No Pain and high sensitivity	Can be a little uncomfortable to use.
[36]/2012	Blood glucose monitoring	metal-oxide semiconducting sensors, e-nose	Independent of environmental Conditions.	The setup is complex and can be performed in a laboratory with specific equipment

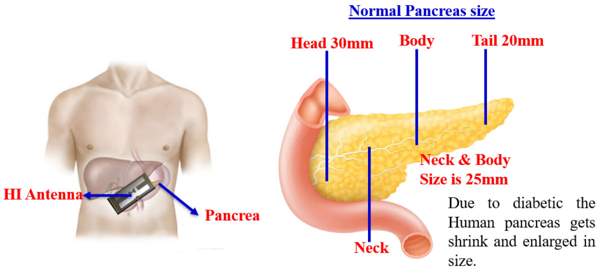


Fig. 2: Size of the pancreas and HI antenna covers the pancreas.

in the normal range. The factors for fluctuations are due to various factors such as quantity of food, type of food, gap between two meals, physical activity, and comorbidities such as chronic kidney disease and chronic liver disease infections. This fluctuation is called glycaemia variability. High glycaemic variability causes microvascular and macrovascular problems. Extreme fluctuation or a diabetic value causes emotional problems such as depression, feeling irritable, a lack of energy, and an uncontrollable temper.

1.3 Contributions

H patch and I slot used to cover the entire pancreas for maximum acquisition of dielectric radiations for diabetic measurement with more accuracy than the existing sensing regions such as the carpus region. Fig. 2 shows the size of the pancreas, and the HI antenna covers the pancreas. The performance of the proposed HI-shaped antenna-based diabetic measurement is performed during different activities, such as before and after food, whereas the existing method performed glucose measurement in glucose water and fingertip.

1. To design HI shaped microstrip antenna for measuring the fluctuating diabetes value from the pancreas in a non-invasive method and measure, fluctuating diabetes for avoiding adverse drug effects such as overdosing and lower drug usage.
2. To develop a home-based diagnostic system for self-assessments of diabetes values during different activities and food intake and to control anxiety and stress levels based on the current management of diabetes,
3. To prognosticate the diabetes level based on the correlation of the spectrum or signal value.

2. MATERIALS AND METHODS

As a sensor, the HI-shaped antenna turns the dielectric radiation from the pancreas into an electrical signal that can be used to measure the diabetic value.HI-shaped antenna sensor is placed over the different regions of the human body, such as the thumb, stomach, pancreas, and carpus region in the hand, for acquiring particular dielectric radiation signals of that region. Signal conditioning for the acquired signal is performed through USB DAQ hardware. The acquisition signals from different locations in the human body are analyzed to determine the optimum location in the human body for accurate measurement of diabetic values through a non-invasive method. The optimum location of a dielectric signal in the human body is evaluated through the variations in the VSWR, gain, reflection loss, and correlation between the diabetic value measured in the laboratory. HI-shaped antenna sensor is fixed on the pancreas for signal acquisition of dielectric radiation through USB DAQ, which has a sampling rate of 44.1 kHz and a Class D digital amplifier. HI- shaped antenna signal is acquired through the USB DAQ and Matlab Data Acquisition Toolbox. The proposed block diagram of an antenna as a sensor in diabetes measurement using a non-invasive method is shown in Fig.3 a).The graph in Fig. 3 b) shows the fluctuating diabetes sensing method.

No environmental factor affects the proposed sensor because of a protection patch over the sensor with a band. The repeatability of the sensor is tested by testing the same patient for glucose at different intervals. The HI-shaped antenna (antenna size 43mmx43mm) covers the pancreas (pancreas size to be up to 30mm for the head, 25mm for the neck and body, and 20mm for the tail) and measures the pancreas shrinkage and enlargement due to low and high diabetes.

3. ANTENNA DESIGN

The proposed HI-shaped antenna has a radiating edge and a sensing I-shaped slot. The H-shape in the antenna controls the resonances about a quarter of a wavelength away, achieving the required input inductive reactance and matching the capacitive impedance of the HI microstrip patch antenna. The H-shaped patch measures 8mm12mm and has an I-Slot in the center, as shown in Fig.4. An I-Slot enhances the bandwidth. The dielectric constant of 4.4 for FR4 is chosen as the dielectric factual. The value of the dielectric constant is selected to be high, as in Eq. (1). Fig. 4 a) shows the strategy of an HI-shaped antenna, and Fig. 4 b) shows the equivalent circuit of an HI antenna.

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0} \tag{1}$$

where ε_r is the relative permittivity and $\varepsilon_0 = 8.854 \times 10^{-12} F/m$.

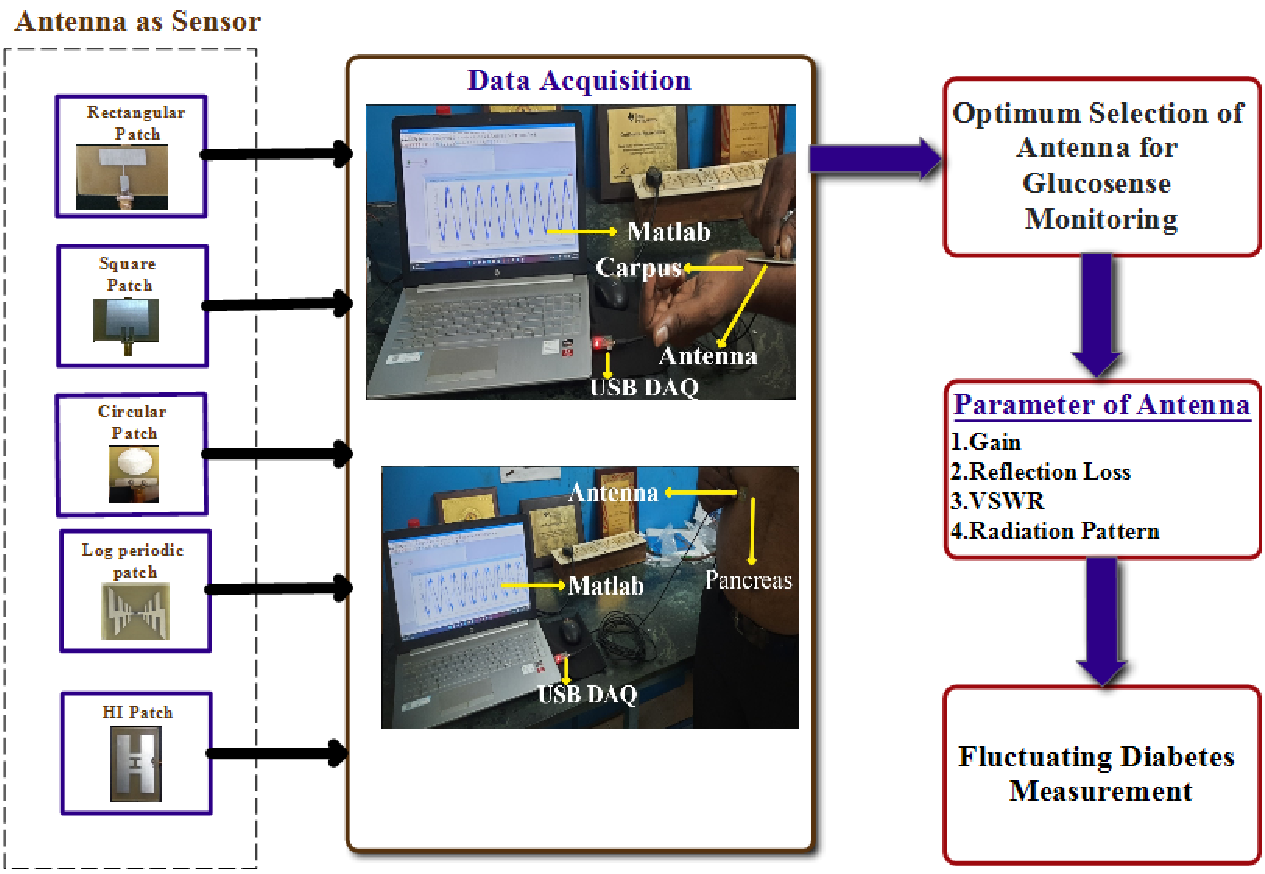
The best height selected for FR4 substrate is about 1.6 mm for designing patch antennas because it prevents the generation of surface waves, which results in loss. The operating frequency f_0 is given in Eq. (2).

$$f_o = \frac{c}{2L\sqrt{\varepsilon_r}}$$

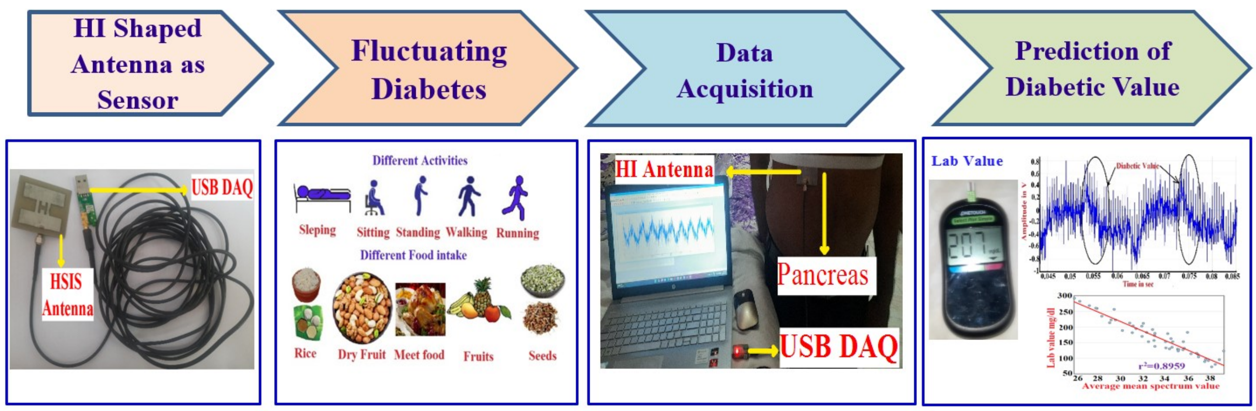
where c is velocity of light = $\frac{1}{\sqrt{\mu_o \varepsilon_o}} = 3 \times 10^8 m/\sec.$

$$f_o = \frac{1}{2L\sqrt{\varepsilon_o \varepsilon_r \mu_o}} \tag{2}$$

where $\varepsilon_r = 4.4 L = 38mm.$.

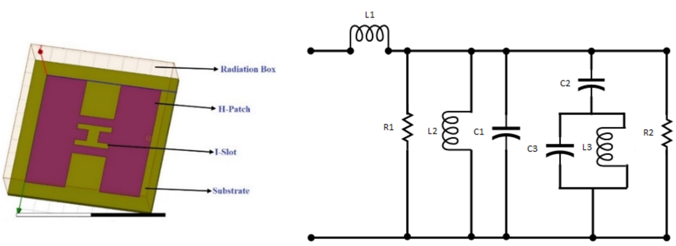


(a)



(b)

***Fig. 3**: (a) Proposed block diagram of antenna as sensor in diabetes measurement in non-invasive method and (b) Fluctuating diabetes sensing method.*



a) b)

***Fig. 4**: a) Strategy of HI-shaped antenna b) Equivalent circuit of HI antenna .*

***Table 3**: Proposed HI-antenna design parameters compared with microstrip antenna design.*

SL. No	Parameters	Rectangular Patch	Square Patch	Circular Patch	Log periodic patch	HI Antenna
1	Frequency of design	5.2 GHz	6 GHz	5.2 GHz	5 GHz	2.0 GHz [37]
2	Substrate thickness	1.6 mm	1.8 mm	1.6 mm	1.8 mm	1.6 mm
3	Temperature coefficient of dielectric	4.4	4.4	4.4	4.4	4.4
4	Dimensions (L×W) of the Patch	32mm×36mm	34mm×34mm	35mm×35mm r=15mm	35mm×35mm	38mm×38mm
5	Dimensions (L×W) of the Substrate	53mm×59mm	42mm×42mm	58mm×58mm	36mm×36mm	43mm×43mm
6	Coaxial drill	1.8mm	1.5mm	1.5mm	1.5mm	1.2mm
7	Advantage and disadvantage	Multi frequency band & Narrow bandwidth	Eliminate the feed radiation & Narrow band with	Multi frequency band & Narrow bandwidth	Radiation pattern is unidirectional and bidirectional & Low Polarization ratio	Wide bandwidth, support higher data transmission
8	Performance of Antenna as a sensor	Gain 4.22dB Antenna/ signal less correlation with lab value	Gain 3.24dB Antenna/signal very low correlation with lab value	Gain 4.62dB Antenna/ signal less correlation with lab value	Gain 6.2dB Low accuracy Antenna/signal not accurate with lab value	Gain 7.2dB High accuracy Antenna Signal correlated with lab value

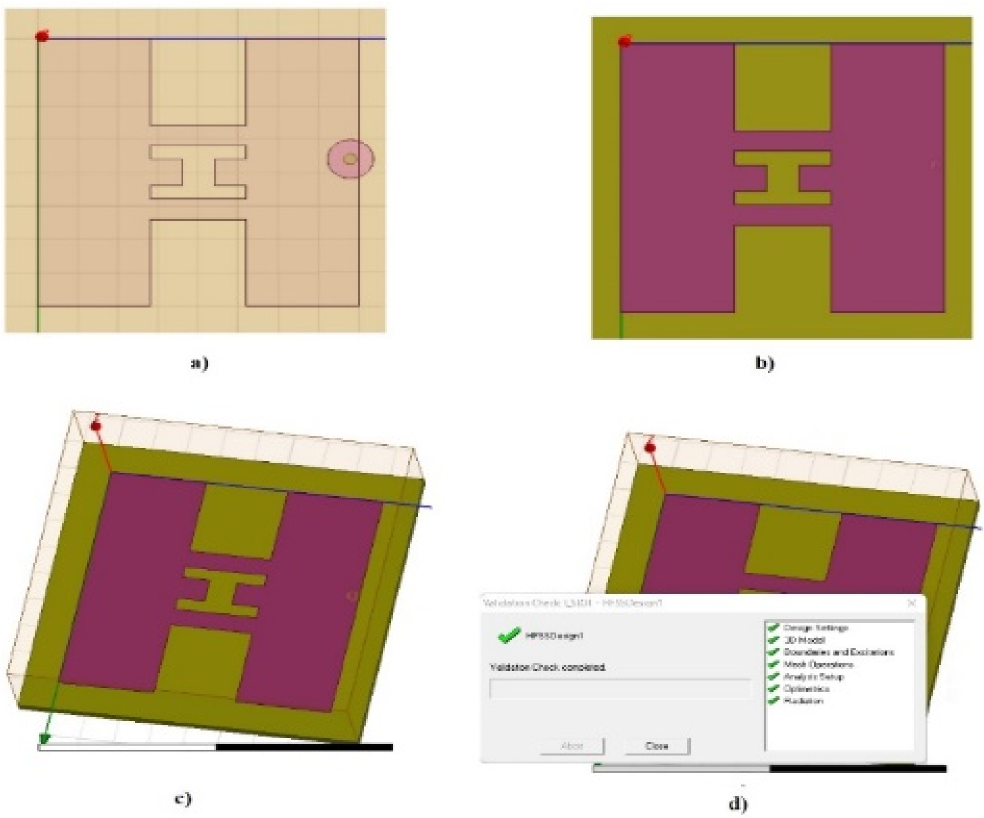


***Fig. 5**: a) Design of radiation patch b) Design of HI-Shaped c) Design of radiation box and d) Validation check.*

To obtain the frequency of operation of an HI patch antenna accurately, dimensions need to be considered. The expression for the frequency of operation of a patch antenna considering "L" (length) and "W" (width) is given in Eqs. (6) and (8). The resonant frequency is as in Eq. (3).

$$f_{r,nm} = \frac{c}{2\sqrt{\varepsilon_{r,eff}}}\sqrt{\left(\frac{n}{L+2\Delta L}\right)^2 + \left(\frac{m}{W+2\Delta W}\right)^2} \quad (3)$$

For a dominant (with n = 1, m = 0), the frequency of the operation expression reduces, as in Eq. (4).

$$f_{r,nm} = \frac{c}{2\left(L+2\Delta L\right)\sqrt{\varepsilon_{r,eff}}} \quad (4)$$

The width "W" of the patch "I" is an important parameter that controls the input impedance of an antenna. For a typical square-shaped antenna ($L = W$), the input impedance is typically 300Ω. An increase in width leads to a decrease in input impedance. Besides determining the input impedance, the width of a patch antenna affects the radiation pattern. The rectangular microstrip patch antenna has an effective dielectric constant of as in Eq. (5).

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r+1}{2}\left(1+12\frac{h}{W}\right)^{-1/2} \quad (5)$$

where ε_r is the dielectric constant of the substrate. A wide resonant frequency patch is used for determining resonance frequency, and the length is increased or decreased in order to get the desired resonance frequency.

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{eff}\mu_0\varepsilon_0}} - 2\Delta L \quad (6)$$

In the presence of a fringing field, antenna size increases by ΔL and is determined in Eq. (7).

$$\Delta L = 0.412h\frac{\left(\frac{W}{h}+0.264\right)\left(\varepsilon_{eff}+0.3\right)}{\left(\varepsilon_{eff}-0.258\right)\left(\frac{W}{h}+0.8\right)} \quad (7)$$

where h is height, W is width of the substrate, and ε_{eff} is effective of the patch.

The effective length and width of the patch are determined by Eq. (8).

$$L_{eff} = L + 2\Delta L \;\&\; W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (8)$$

The length and width of the substrate are the same as the ground. The base dimensions are determined by the length and width of the patch. The length and width of the base ground plane are determined as l_g= 6h+ L, W_g= 6h+W. The microstrip line feed has a disadvantage: an increase in substrate thickness creates surface waves and spurious radiations that result in bandwidth limitation. Hence, to overcome the above disadvantages, the coaxial feeding technique is preferred. The coaxial feed is called the probe feed. Table 3 shows the proposed HI-antenna design parameters compared with the exciting microstrip antenna design used as a sensor.

Existing passive sensor antennas sense the dielectric radiation from the pancreas region at a frequency of 402.5 MHz and 2.4 GHz for a relative permittivity of 61.2155 and 57.201, respectively. The proposed antenna senses the dielectric properties of diabetic-affected pancreas, such as low- and high-fat diabetic pancreas, in the frequency range between 1.5 GHz and 3 GHz. The higher frequency of the antenna is selected for the higher diabetic value (more than 600 mg/dl). The proposed HI-shaped antenna performs better than other microstrip antennas due to its high gain and antenna signal correlation between lab values.

The HI-shaped antenna substrate is made of FR4 (flame-retardant) material with a thickness of 1.6 mm and a constant dielectric constant of 4.4. The substrate is placed on the axis after selecting the box and entering the desired values for length and width (43 mm and 43 mm, respectively). The ground, which has a 2D planar structure, forms the bottom layer of the microstrip patch antenna. It is used to protect the patch from reflection. The dimensions of the ground are the same as the substrate. The ground is placed in the axis by selecting the rectangle symbol and entering the values of the length and width as per the proposed design. The length of the ground is equal to 43mm, and the width of the ground is equal to 43mm. The square patch is used for linear polarization and low cross-polarization. The diameter of the drill is 1.2mm. Figure 5 a) depicts the design of a radiation patch, b) the design of an I-Slot, c) the design of a radiation box, and d) the validation check".A H-shaped patch antenna has high gain, reduces VSWR, and an I-slot is set at the center of the antenna to obtain multiple bands of frequencies with optimized return loss. The radiation box, which is an air box or vacuum box in the antenna, provides an environment for testing the microstrip patch antenna.

4. RESULT AND DISCUSSION

4.1 Return Loss and VSWR

Return loss is the loss of power in the signal as in Eq. (9), which gets reflected due to the discontinuity present in the transmission line and is expressed in decibels (dB). Figure 6 a) depicts the return loss, while Figure 6 b) depicts the VSWR plot.

$$R_L = 10\log_{10}\frac{P_i}{P_r} \quad (9)$$

Fig. 6(a) shows the return loss for different blood glucose values. The resonant frequency has been selected for glucose concentrations of about 2.00 GHz. The return loss of different glucose concentrations is about -28.57 dB, -31.68 dB, -36.39 dB, -34.64 dB, and -40.19 dB, with

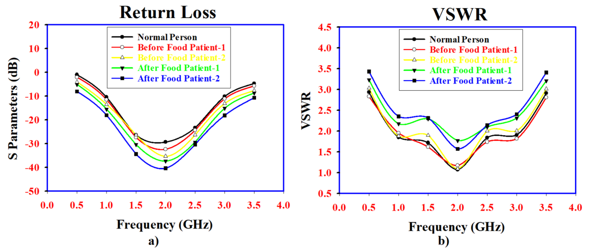


***Fig. 6**: a) Return loss of human with diabetic value after and before food intake and b) VSWR of human with diabetic value after and before food intake.*

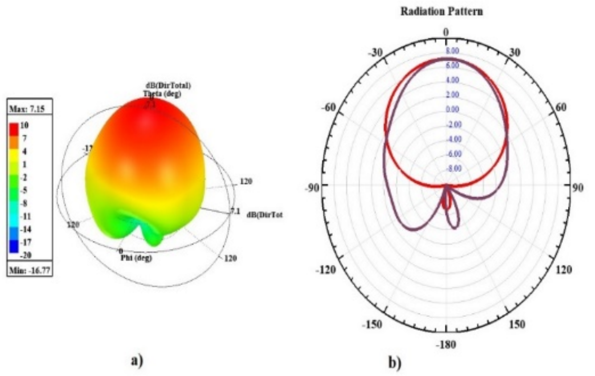


***Fig. 7**: a) Gain of microstrip antenna on patches b) Radiation pattern.*

the laboratory values of 70 mg/dl, 69 mg/dl, 113 mg/dl, 210 mg/dl, and 320 mg/dl, respectively. Fig. 6 b) shows the VSWR for different glucose concentrations. VSWR values have different glucose concentrations, such as 1.11, 1.19, 1.87, 1.19, and 1.57 for the respective laboratory values.

4.2 Gain and Radiation Pattern

Gain of HI antenna increases power, varies between 7dB-8dB. HI shaped antenna as better radiation pattern, with minimizing the side lobes and back lobes. Fig. 7 a) shows the Gain of microstrip antenna on patches and Fig.7 b) Radiation pattern.

Fig. 8 shows the current distribution of HI antennas at a) 2.5 GHz, b) 3.5 GHz, c) 4.5 GHz, and d) 5.5 GHz. HI region with high magnitudes around the dielectric junctions and interstices. Therefore, the region has been identified as the sensing region, which obtains strong interactions with the near field to which the glucose samples are attached. Therefore, inducing significant variations in the intrinsic properties of the sensor in response to subtle variations in the electromagnetic properties read to affect glucose value measurement.

4.3 Fabrication Results

Fig.9 in the HI shaped abricated antenna. The fabricated HI antenna return losses are -16.25 dB, -16.91 dB, -22.09 dB, -12.57 dB, and -25.30 dB with the operating frequencies of 1.90 GHz, 3.53 GHz, 4.46 GHz, 5.25 GHz, and 5.47 GHz, respectively. The VSWR values for a fabricated HI antenna are 1.76, 1.62, 1.16, 1.62, and 1.11 for the respective frequencies. Fig. 10(a) shows the return loss in the network analyzer for a fabricated HI antenna. Fig. 10 b) VSWR in a network analyzer for a fabricated HI antenna Table 4 shows the results of the fabricated HI-shaped antenna.

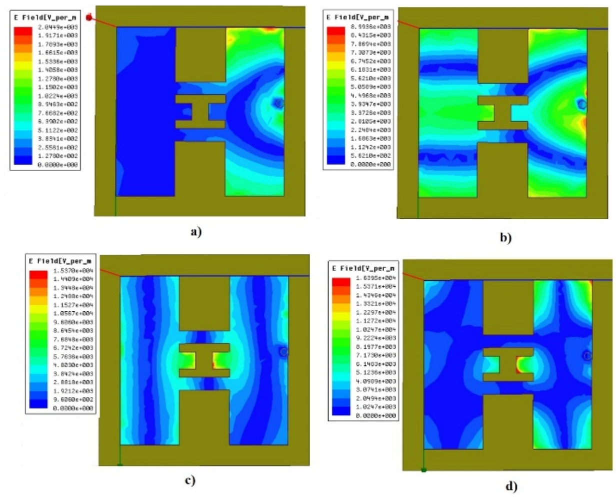


***Fig. 8**: Current distribution HI antenna at a) 2.5 GHz b) 3.5 GHz c) 4.5 GHz and d) 5.5 GHz.*

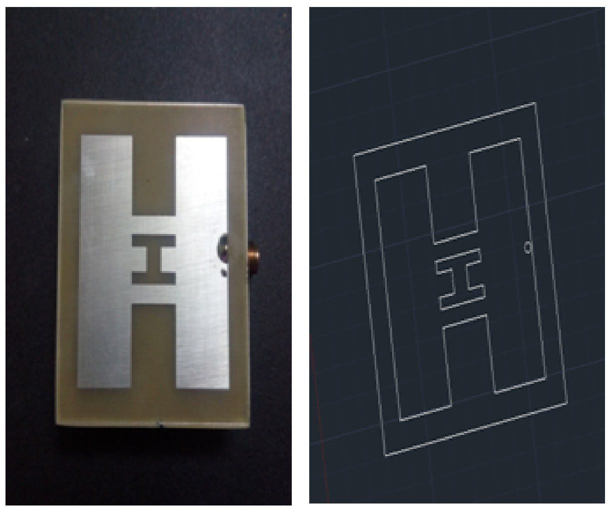
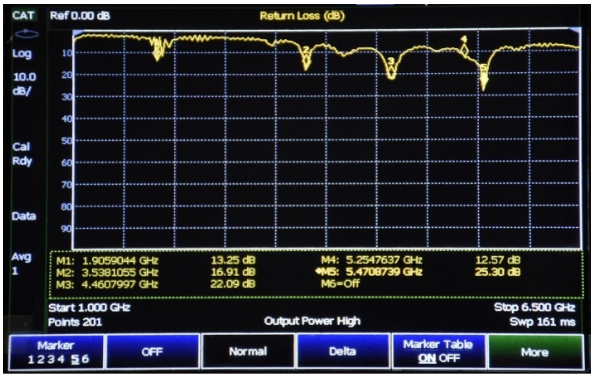


***Fig. 9**: Fabricated antenna and DXF Format.*

***Table 4**: Results of fabricated HI shaped antenna.*

SL. No	Frequency (GHz)	Return Loss(dB)	VSWR
1	1.90	-16.25	1.76
2	3.53	-16.91	1.62
3	4.46	-22.06	1.16
4	5.25	-12.57	1.62
5	5.47	-25.30	1.11



(a)

(b)

***Fig. 10**: (a) Return loss in network analyser (b) VSWR in network analyser.*

4.4 Antenna as sensor

HI-Antenna, as a sensor, converts an electromagnetic pancreatic dielectric radiation signal into an electrical signal for diabetic value measurement. The HI-Antenna sensor is fixed on various parts of the human body, such as the thumb, stomach, pancreas, and carpus region of the hand, for signal acquisition. Table 5 shows measurements from a location or the human body and their dielectric radiation. Fig. 11 shows the signal acquisition from the carpus region of the hand. A USB DAQ card has two channels with a 44.1 kHz sampling rate and a Class D digital amplifier. The HI antenna signal is acquired through the USB DAQ and MATLAB Data Acquisition Toolbox. From Table 5, the acquisition of and their spectrum show that in the pancreas, region-based spectrum shows more low and high frequency components and matches to the blood sample on the antenna spectrum as in the 8th row of Table 5.

The measured signal is shown in Table 5. Changes in blood glucose levels alter the dielectric properties of the tissue in human body and such changes seen in radiation emitted from human body. Human body generates electromagnetic fields. Radiation from the human body forms a field around the body, and vibration arises. Frequency vibration is proportional to human body electromagnetic field generation of the human body. Bioelectromagnetic fields interactions between living organism and termed as electronic phenomena. biophysical and

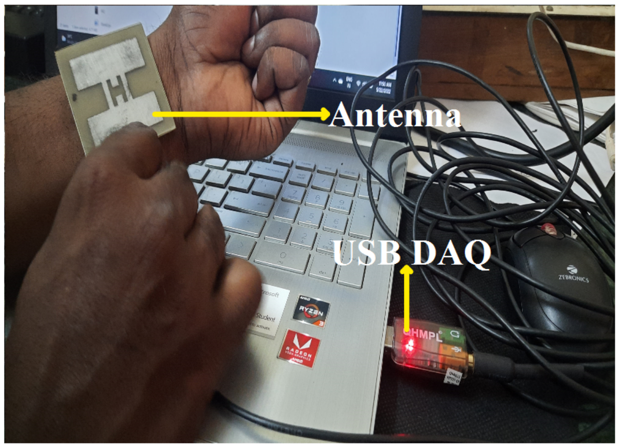


***Fig. 11**: Signal Acquisition from carpus.*

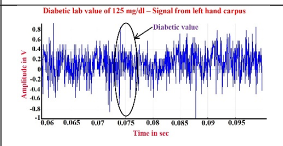
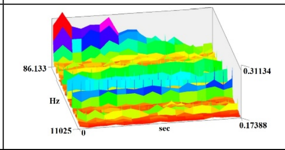
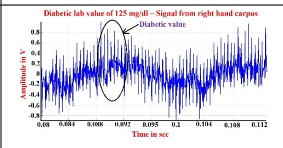
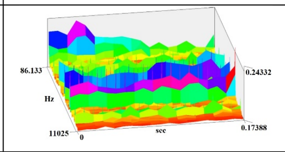
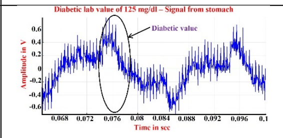
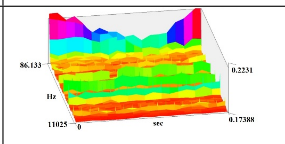
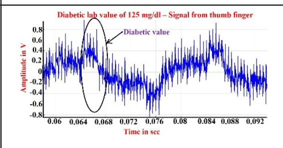
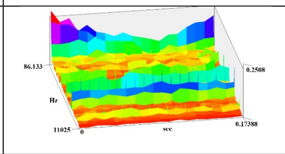
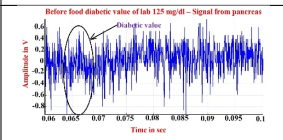
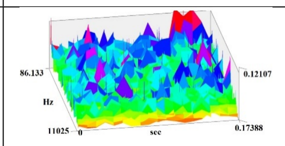
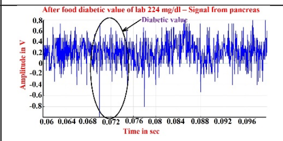
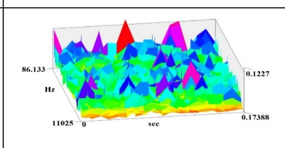
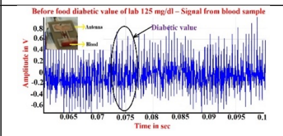
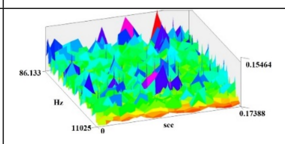
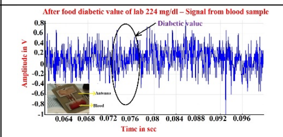
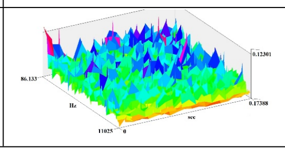
chemical processes, such as endogenous electromagnetic fields, are associated with living organisms' physiological and pathophysiological behaviors. Radiation waves of the human body are measured through non-invasive methods [38, 39]. In anatomy, each part of the body has different level of ration wave generation based on the physiological and pathophysiological parameters. In this paper, HI antenna measures the radiations from the human blood for glucose level measurement. Table 5 shows the radiation signal from the human body and different patient glucose levels with a spectrogram signal for the frequency change according to blood glucose levels.

Patients fasted for 8 to 10 hours and the signal was recorded, then one hour later the food intake signal was recorded.The experiment was performed at Jebi Medical Center (EC/2852/2022, dated March 14, 2012), Tamil Nadu, India. The HI-shaped antenna is fixed on the pancreas head surface of the human body and accumulates a signal for 10 seconds before measuring the diabetic value. Express pancreas signal better than other features in time-domain or frequency-domain alone, combining the merits of both domains and showing the relationship of time, frequency, and amplitude directly.

4.5 Predication of diabetic and validation with laboratory value

Machine learning is used in various applications such as SDN [40], EEG [41], and Bus Bar [42]. Linear regression is used to predict an individual's diabetic score using the average peak value of the signal, which is the dependent value, and the laboratory score obtained from the blood sample, which is the independent value. The root mean square error is small for the pancreatic region, and the correlation is shown in Fig. 12(a) before dietary regression modeling and in Fig. 12(b) after dietary regression modeling. The regression equation of the HI-shaped antenna before and after food intake is shown in Eq. (11). Table 6 shows the laboratory and average mean spectral value for fluctuating diabetic measurements.

***Table 5**: Radiation signal from human body and different patient glucose level.*

SL. No	Particular	Signal	Spectrogram signal	Remarks
1	Left Hand carpus			Less peaks
2	Right Hand carpus			Less peaks
3	Stomach			Less peaks
4	Thumb finger			Less peaks
5	Before food Lab value -125 mg/dl (Pancreas)			Makes more peaks low and high frequency components
6	After food Lab value -224 mg/dl (Pancreas)			Makes more peaks low and high frequency components
7	Blood Sample value before glucose level (125 mg/dl)			Makes more peaks low and high frequency components
8	Blood Sample value after glucose (224 mg/dl)			Pancreas in optimized location for measuring diabetic value

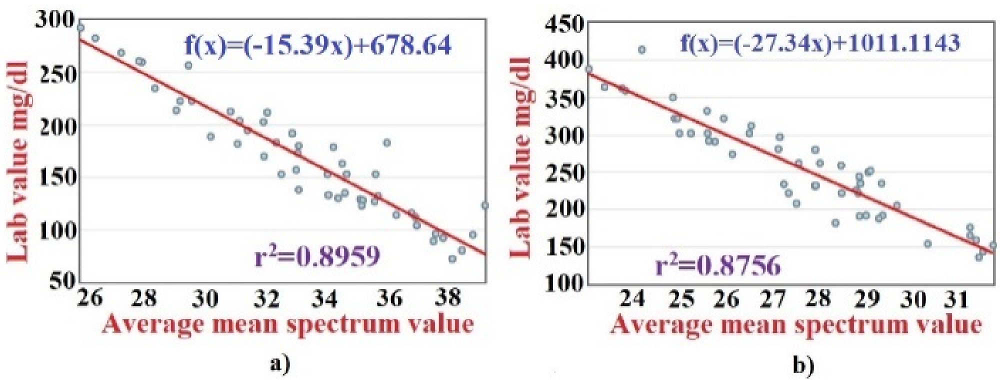


***Fig. 12**: a) Before dietary regression modelling and b) After dietary regression modelling.*

Table 6: *Laboratory and average mean spectrum value for fluctuating diabetic measurement.*

Diabetic test	Patients ID/ Gender/ age	Lab value mg/dl	Average mean spectrum value	Different Activities & Food Intake
Before dietary	P1/M/35	72	38.04	Running
	P2/M/47	170	31.85	Walking
	P3/M/63	116	36.7	Squat
	P4/F/42	269	27.16	Cycling
	P4/F/55	129	35.01	Lunge
	P5/M/31	173	32.96	Breathing
	P6/M/71	153	34.57	Squat
	P7/F/69	204	31.05	Walking
	P8/M/47	114	36.2	Running
	P9/F/38	128	35.1	Cycling
	P10/F/29	72	38.04	Lunge
After dietary	P1/M/35	322	25.95	Rice
	P2/M/47	262	27.58	Dry fruit
	P3/M/63	154	30.38	Seeds food
	P4/F/42	332	25.59	Meet food
	P4/F/55	192	29.4	Fruits
	P5/M/31	222	28.51	Glucose mixed in water
	P6/M/71	297	27.17	Starchy food
	P7/F/69	280	27.94	Rice
	P8/M/47	259	28.5	Fruits
	P9/F/38	226	28.83	Protein food
	P10/F/29	322	25.95	Meet food

$$\left.\begin{array}{l}\left.\begin{array}{l}Before\ Food\\ Diabetic\ value\end{array}\right\} \rightarrow\ f(x) = -15.39x + 678.64\\ \quad r^2 = 0.8959\\ \left.\begin{array}{l}After\ food\\ Diabetic\ value\end{array}\right\} \rightarrow\ f(x) = -27.34x + 1011.11\\ \quad r^2 = 0.8756\end{array}\right\} \tag{10}$$

The diabetes value is measured with a regression equation. Table 7 shows the diabetic value measured from laboratory values and the regression model, and the diabetic value with the proposed method has high accuracy.

5. CONCLUSION

HI-shaped antenna monitors the fluctuating levels of diabetes in the human body in the pancreas region. The dielectric radiation signals acquired from the pancreas lead to effective monitoring of fluctuating diabetic values from different regions of the blood such as the hand, finger, stomach, and pancreas. The pancreas shows better correlation with the laboratory-based diabetic value measurement. The non-invasive method of diabetic value measurement never measures fluctuating diabetes due to improper mounting of the sensor over the body, which is solved through the proposed HI antenna. The proposed HI-shaped antenna is mounted on the pancreas for measuring fluctuating diabetic values without pricking the human body. Among the different parts of the body, the optimized location is the pancreas, which measures diabetic value through a proposed HI-shaped antenna and values through the spectrum of the pancreas and a blood sample on the antenna. Moreover, different types of antennas, such as rectangular patches, square patches, circular patches, log periodic patch antennas, and HI-shaped antennas, are compared with the proposed HI-shaped antenna for diabetic value measurement, and pancreas dielectric signal static values are correlated with diabetic values from the laboratory. The proposed HI-slot antenna measures the fluctuation in diabetes with 85% accuracy compared with dielectric values from laboratories.

Table 7: *Predication of diabetic value.*

Diabetic Test	Patients ID/ Gender/ age	Lab value mg/dl (A)	Avg. mean spectr. value (x)	$f(x)$ HI Antenna Signal (B)	Acc. % (B/A x100)
Before dietary	P1/M/68	132	35.60	130.76	99.06
	P2/F/47	293	25.83	281.12	95.94
	P3/F/56	212	31.96	186.78	88.10
	P4/M/34	95	38.72	82.74	87.09
	P5/M/46	257	29.37	226.64	88.19
	P6/F/62	192	32.78	174.16	90.71
	P7/M/38	163	34.42	148.92	91.36
	P8/F/59	153	35.52	131.99	86.27
	P9/M/72	203	31.83	188.78	92.99
	P10/M/44	179	34.13	153.38	85.69
After dietary	P1/M/68	302	26.51	286.33	94.81
	P2/F/47	281	27.14	269.11	95.77
	P3/F/56	312	26.55	285.24	91.42
	P4/M/34	235	28.92	220.44	93.80
	P5/M/46	262	28.04	244.50	93.32
	P6/F/62	244	28.89	221.26	90.68
	P7/M/38	165	31.30	155.37	94.17
	P8/F/59	350	24.85	331.72	94.78
	P9/M/72	414	24.18	350.03	84.55
	P10/M/44	388	23.03	381.47	98.32

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