Measuring Blood Glucose Levels with Microwave Sensor

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ABSTRACT

In this paper an effort is made to documentation of the design of microwave sensor which can be used for non – invasive blood glucose monitoring . It is very simple and cost effective self monitoring continuous blood2 glucose monitoring system .The software used for microwave sensor was Sonnet Lite Project Editor V-13.55® which was freely available on the internet. Two oscillators were used 500-2000 Mhz frequency due to design limitation of sensor. Simulation result shows where there was a change in blood glucose level there will also change in the body impedance. With using multimeter value could easily be measure. Purposed hardware and result also shown in this paper.

Keywords

Microwave sensor, Diabetes, Non-invasive, Impedance, Glucose measurement.

1. INTRODUCTION

Diabetes is spreading its tentacles deep into the human genetic code. As the number of diabetics is increasing every day and a lack of any kind of vaccination and cure to prevent and cure protect this disease need to develop a real-time continues blood glucose sensor increases. Today a glucose monitors are a very big market and non-invasive glucose sensors are projected to drive the future glucose sensor market.

The SMBG equipment available in the market mostly depends on finger pricking for blood samples. An enhancement to the SMBG techniques i.e. Non-Invasive SMBG would allow comparatively easy and a more continues information about the changes in blood glucose of diabetic subjects.

Since 1950's, microwave instruments have been used increasingly in a wide range of sensing applications. Their capability to non-destructively determine parameters inside a volume makes them ideal for measuring where contact to the sample is cannot be made. This property of microwave sensor makes it ideal for non-invasive measurement of physiological parameters of the human body. One such parameter and the objective of this research is blood glucose concentration, which diabetics must closely monitor

2. Permittivity and S-Parameters

Charged particles are present in all materials; these when come in contact with electric or magnetic fields, produce secondary fields.

When the electric field passing through the dielectric medium its transmission is governed by a phenomenon called permittivity (ϵ). The relative permittivity (ϵ_r) of a material is also called the dielectric constant and is “an experimentally measurable parameter. The relative permittivity of a material is a ratio of its permittivity to the permittivity of free space (equation 1)

$$\epsilon_r = \frac{\epsilon}{\epsilon_0} \quad (1)$$

An equation (1.3) for complex permittivity has to be used when an electric field is applied across a conducting medium

$$\epsilon = \epsilon' - j\epsilon'' \quad (1.1)$$

to measure the |S 21|. But first let's take a brief introduction about S parameters.

Figure 1: Two Port Network

$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix} \quad (1.3)$$

The $|S_{11}|$ parameter represents the input port voltage reflection coefficient,

$$S_{11} = \left. \frac{V_1^-}{V_1^+} \right|_{V_2^+=0} \quad (1.4)$$

The $|S_{12}|$ parameter is the reverse voltage gain,

$$S_{12} = \left. \frac{V_1^-}{V_2^+} \right|_{V_1^+=0} \quad (1.5)$$

The $|S_{21}|$ parameter is the forward voltage gain,

$$S_{21} = \left. \frac{V_2^-}{V_1^+} \right|_{V_2^+=0} \quad (1.6)$$

The $|S_{22}|$ parameter is the output port voltage reflection coefficient.

$$S_{22} = \left. \frac{V_2^-}{V_2^+} \right|_{V_1^+=0} \quad (1.7)$$

3. Related Literature

There has been little work done in the area of blood glucose and permittivity correlations. Because of this there is minimal research, but the research that has been done suggests that a correlation exists between blood glucose and permittivity. The following studies used microwave measurement techniques other than a resonant sensor to measure the permittivity and relate it to blood glucose concentration.

Ismail conducted a study in which they used a wave guide to measure the permittivity of blood samples in Plexiglas vials. The authors measured the $|S_{11}|$ and $|S_{21}|$ parameters of the vials containing blood and used one of their previous methods for determining the permittivity. They concluded that the measured and calculated values for the human blood were in agreement.

Park measured the correlation between blood glucose and permittivity using an impedance analyzer. A new needle-type sample cell was pinned on the tail of a hamster and the permittivity was measured. Comparisons were done using a commercial glucose meter typically used by diabetes patients. The authors provide graphs, shown in Figure, that show a

non-linear relationship between glucose and permittivity. In conclusion, the authors state that the “blood glucose of a hamster and the dielectric constant values of a hamster’s tail were the same as time goes on. Indirectly this indicates that the value of the relative permittivity is correlated with the value of blood glucose.”

(a)

(b)

Figure 2: (a). Time dependence of ϵ' at 10 kHz in a hamster tail.

(b)Time dependence of blood glucose in a hamster using a glucose meter

$$\hat{\epsilon}(\omega) = \epsilon_{\infty} + \sum_n^2 \frac{\Delta\epsilon}{1 + j\omega\tau}$$

4 .HARDWARE DESIGN

4.1 Design of Microwave sensor

Figure 3: Block diagram of Microwave Sensor

Two VCOs were used in step index mode because, no single VCO with such large frequency output range could be designed with known technologies. The two VCOs hence used are RFMD's UMS-1000-A-16-G and UMS-2000-A-16-G. The Logarithmic Power Detector (LPD) used in designing the above shown schematics is Linear Technologies' LT5538F. LT5538F is a The LT@5538 is a 40MHz to 3800MHz monolithic logarithmic RF power detector, capable of measuring RF signals over a wide dynamic range, from – 75dBm to 10dBm

4.2 Design of load Tissues

Before designing the sensor it was compulsory to design a load where the sensors would be tested, hence a load tissue was designed using Sonnet Lite the second order Debye equation and the parameters is shown .

Figure 4: Design of Load tissues

A model of the layers of body was created so that he simulation of the sensor would provide results consistent with those that would be found when used in conjunction with real s of human tissue. The model, shown the fig consist of a layer of cover film , a 0.015 mm layer of dry skin, a 0.3 mm layer of wet skin, a 0.2 mm layer of fat, a 0.5 mm of blood and 2mm layer of muscle

Table 1

Parameters used in Debye equation for modeling Tissues

Type of Tissue	ϵ_{∞}	$\Delta\epsilon$	τ_1 (ps)	$\Delta\epsilon_2$	τ_2 (ns)	$\Delta\epsilon_3$	τ_3 (μ s)
Blood	4.0	56	8.38	5200	132.63	0.0	0.00
Fat	2.5	9	7.96	35	15.92	3.3 x 10 ⁴	159.15
Muscle	4.0	50	7.23	7000	353.68	1.2 x 10 ⁶	318.31
Skin (Wet)	4.0	32	7.23	1100	32.48	0.0	0.00
Skin (Dry)	4.0	39	7.96	280	79.58	3.0 x 10 ⁴	1.59

4.3 Circular Spiral

As shown in figure 5 the circular Spiral was designed in the Sonnet editor. A circular spiral was chosen because an ideal circular spiral would have infinite vertices as compared to thirty two vertices of the eight sided spiral and sixteen vertices of rectangular spiral. Also it has been observed that increasing the discontinuity in the resonator makes the resonator more sensitive to changes in dielectric constant in the ambience.

Figure 5:.Bottom and top view of the circular Spiral Resonating patch Resonator sensor

Figure 6 : Attributes of the Circular Spiral Resonating Patch Resonator sensor

The resonator hence designed was simulated on the load as described in figure for changing values of dielectric constant of blood, i.e. for varying levels of glucose the result of this simulation are shown in form of a graph in fig 6.

Figure 7: Response of the Circular Spiral Patch For blood

As evident from the response of the simulation the circular spiral resonating patch resonator would be best as compared to the other two designs as changes in the $|S_{21}|$ parameters vary completely with frequency shifts at all maxima and minima. This Resonator sensor was hence prototyped.

4.4 Interfacing Connector

To interface the sensor RJ 45 Cable was used as it is available readily in the market and is very easy to use. The details of the connection of the RJ 45 are shown in Figure 8

Figure 8: RJ 45 different power supply at different pins

Table 2
Voltage ratings for the inputs and output

TERMINAL NAME	MIN	TYPICAL	MAX
VCO1_ENABLE		12V	
VCO1_TUNE	0.5 V		11 V
GROUND1		0 V	
VCO2_ENABLE		12V	
VCO2_TUNE	1 V		14 V
GROUND2		0 V	
VCC		5 V	
VOUT	0.3 V		0 V

Figure 9: The testing Circuit Schematic

To test the sensor a testing circuit was designed as shown in Figure 8.1. As the sensor uses RJ45 cable to interface with anything therefore we use a RJ45 female connector at testing board to connect to the sensor. At pin no 1 and 3 a 12 volt supply is connected via two way switch. This alternately enables VCO1 and VCO2. Pin no 2 and 5 are connected to a 15 volt supply via variable resistor. A voltmeter connected parallel to pin no 2 and ground gives readings for the voltage being scanned. Pin no 4 and 6 are directly connected to ground and the output is received from pin no 8. A voltmeter is connected between the output and ground to give |S21| parameters of the resonator.

output voltage at pin no 8 the following formula is used:

$$|S21| = -(V_{out} - 1.7 V) \times 50dBm/V$$

$$BG = \{[-(V_{out}-1.7) \times 50] + 32.85\} / 0.1093$$

BG-----Estimated blood glucose concentration

Vout-----output voltage at pin no 8 of the sensor

Table 3

Results of Experiment

Time	Glucose meter Reading mg/dl	Sensor V _{out} Volts	S21 dBm Calculated	Sensor output approximate Mg/dl
10:00	91	1.24	-23	90
10:05	91	1.24	-23	90
10:10	94	1.26	-22	99
10:15	99	1.26	-22	99
10:20	106	1.28	-21	108
10:25	113	1.28	-21	108
10:30	124	1.32	-19	127
10:35	129	1.32	-19	127
10:40	135	1.34	-18	136
10:45	141	1.36	-17	145
10:50	138	1.36	-17	145
10:55	132	1.34	-18	136
11:00	128	1.32	-19	127
11:05	123	1.32	-19	127
11:10	119	1.3	-20	118
11:15	114	1.28	-21	108
11:20	108	1.28	-21	108
11:25	105	1.28	-21	108

Figure 10: Comparison between the output of glucometer and the sensor developed

As the output for both the blood sugars is similar but not same a regression was done calculating the R square value of correlation function and was found to be 0.9639 and correlation plot of regression is shown in the figure 6.7. But the standard deviation of the error in results was found to be 3mg/dl which is a high and the rate of error as far as commercial production of such a sensor is concerned; but satisfactory for first prototype of a sensor. The results were comparable with that of the commercial Glucometer and the standard deviation error of ± 3 mg/dl and R-square 0.9639 were calculated.

5. CONCLUSION

Permittivity which is measured using this sensor not only on blood glucose but several other factors like Body Temperature, Blood Pressure, Heart rate etc. To develop a commercially available sensor from such a sensor a lot of experimentation and calibration algorithm through research is required.

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