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Analysis of Blood Glucose using Impedance Technique

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Abstract: This paper proposes a non invasive measurement technique to estimate the level of glucose by impedance measurement. This work presents a study of the varying concentrations of glucose using RF Impedance Spectroscopy (RIS). A cell was designed to create body environmental conditions having glucose concentration comparable to body glucose of a healthy person. The changes in the measured absorption properties due to the presence of glucose in water were examined between 1000 MHz and 4000 MHz. Results show wherever there is a change in blood glucose level, there will also be a change in the body impedance. The authors propose a quick, portable and low-cost device which could be used to monitor the level of glucose, cholesterol and other important body parameters. The device is based on the measurement of 'modulus of impedance' at molecular resonant frequency wherein absorption coefficient varies with blood glucose concentration.

Keywords: Glucose, Impedance Measurement, RF Spectroscopy, Network Analyzer, Four-probe Technique.

I. INTRODUCTION

Abnormalities in carbohydrates such as glucose and cholesterol are the important causes of diseases in the present era. The process when Glucose is oxidized in the body is called metabolism, which produces carbon dioxide, water, and some nitrogen compounds and in the process provides energy which can be used by the cells. The energy yield is about 686 kilocalories (2870 kilojoules) per mole.

Glucose is a primary source of energy for the brain, and hence its availability influences psychological processes. When glucose is low, psychological processes requiring mental effort (e.g., self-control, effortful decision-making) are impaired. [1][2][3][4] When fasting glucose blood sugar level is high, it can be a sign of prediabetes or diabetes mellitus.

RIS is a non-invasive and label-free method to analyze single cell according to their dielectric properties as a function of frequency. [5] RF impedance measurements have been used to study the electrical properties of biological tissue. In this technique, the electrical impedance of any part of the body is measured by either constant current method or a bridge method wherein, variations in the impedance are recorded as a function of the frequency. Pulsatile blood volume increase in the body segment, caused by systemic blood circulation, causes proportional decrease in the electrical impedance. The variation in the electrical impedance thus yields adequate information about the blood circulation.

An alternating current is used for bioelectrical impedance analysis (BIA) because it penetrates the body at low levels of voltage and current. In a complex electrical structure such as the human body, the part of the fluid volume or Total Body Water (TBW) measured by bioelectrical impedance is also a function of the frequency. At low frequencies below 5 kHz, the bioelectrical current travels primarily through extracellular fluids, but as the frequency increases, the current starts to penetrate body tissues, creating reactance, and the measure of this current flow starts to represent more of TBW measurement. At high frequencies (above 100 kHz), the current is assumed to penetrate all conductive body tissues (or all of the TBW in the conductor) and supposedly overcomes the capacitance properties of the body, reducing reactance to zero.

A typical Impedance Plethysmograph system is comprised of a sine-wave generator followed by voltage to current converter. This current is passed through the body segment of interest with the help of two surface electrodes known as current electrodes. Voltage signal developed along the current path is sensed with the help of another pair of electrodes known as voltage electrodes. The amplitude of the signal thus sensed is directly proportional to the electrical impedance of the body segment. Thus, amplification and detection of this signal yields instantaneous electrical impedance (Z) of the body segment. [6]

Impedance values measured at a spectrum of frequencies or at several discrete frequencies or some combination of frequencies may help to explain interindividual variations in body composition more precisely than an impedance measurement at a single frequency. Innovative uses of all data in an impedance spectrum should be considered through multivariate and curve-fitting statistical applications to estimate body composition.

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Factors that affect body fluid or electrical activity potentially affect measures of impedance. These correlations represent an association of multifrequency impedance with the physiological status of the body. Several of the blood variables represent electrolytes or ion levels in the body. Impedance measures the electrical conductivity of the body, so correlations with these types of variables is expected.

The voltage or impedance measurement does not provide any direct information as to how much current travels through intracellular versus extracellular volumes, in blood versus muscle, or in fat versus fat-free tissues. Current paths in the body used by impedance will generally differ from person to person because of differences in body size, shape, electrolytes, fluid distribution, or other aspects of the body's composition. These characteristics vary within an individual, and almost any change in body size, shape, or composition will have at least a small effect on impedance. Relationships between impedance and other variables such as TBW, FFM, or body fat have been established as statistical associations with impedance for a particular population rather than on a biophysical basis. These relationships are not absolute because the current diffuses throughout the conducting volume and makes use of any and all conductive paths that are available at the time of measurement. [7]

Present–day application areas are in impedance cardiography, pulmonary impedance, brain impedance and impedance imaging.

II. MATERIALS AND METHODS

A. Preparation of samples

The Glucose in the normal human blood ranges from 70-110mg/dL. Here the experiment is conducted with average glucose concentration of 90mg/dL. Double distilled water is used to prepare glucose-solution samples with glucose concentrations spanning from half to normal concentration and also double and triple concentration, (i.e. 45 mg/dL, 90 mg/dL, 180 mg/dL and 270 mg/dL). Each sample consists of 20 ml of water, and glucose is added to water to reach the indicated concentrations. Experiments were performed in 2 modes at a particular time (fast sweep and slow sweep). The experiment was repeated after 2 hours and 24 hours in order to nullify the environmental effect. The differences were compared to the first measures and were found to be within the precision of the meter.

B. Impedance measurement

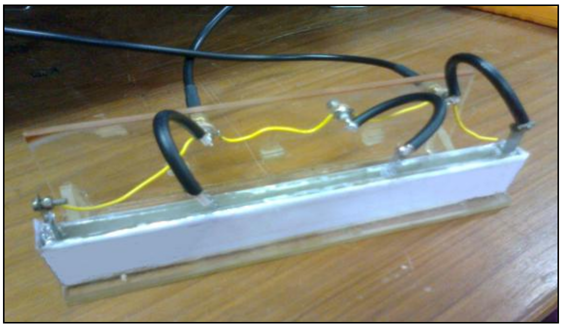

Fig. 1: Four probe impedance measurement cell

The measurement cell shown in Fig. 1 was designed based on the 4 probe method having dimensions, 9” x 1.5” x 1.5”. Signal is injected at electrode 1 and the transmitted signal through the liquid column is observed at electrodes 2 & 3 as shown in the schematic in Fig. 2. The difference of the signal at 2 & 3 gives the absorption in the region of 2 & 3 liquid column.

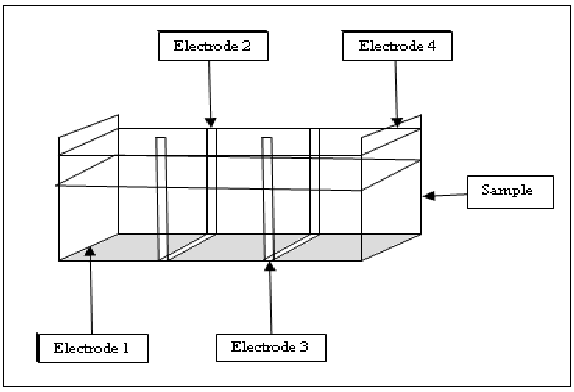

Fig.2: Schematic of the measurement cell

The 2 inner electrodes (Electrode 2 and Electrode 3) are made of stainless steel (SS) plates which are kept at a distance of 3 inches. SS sheet is used to avoid the localized pitting corrosion leading to the creation of small holes on the electrode surface. Initially the experiments were performed and there was a loading effect. This drawback was overcome by reducing the cross section area by introducing a number of plates thereby increasing the impedance accordingly. RF cables along with SMA connectors conforming to RG-58/U were used to connect the cell to a plastic container in order to reduce the mechanical disturbances and reflection losses. The entire cell was placed in a heavy metal box with an iron lid, in order to reduce the electrical disturbances. The metal box and the lid were individually grounded.

The impedance measurement was performed using a signal hound tracking generator USB-TG44A (Fig. 3) and a signal hound spectrum analyzer USB-SA44A (Fig. 4). The Signal Hound Tracking Generator ranges between 10 Hz to 4.4 GHz and works with the USB-SA44A, facilitating scalar network analyzer measurements.

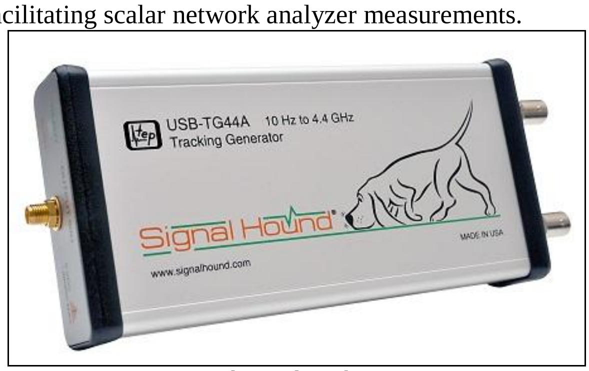

Fig. 3: Signal Hound Tracking Generator

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Fig. 4: Signal Hound Spectrum Analyzer

The Signal Hound Tracking Generator has 19 selectable step sizes from 10 Hz to 10 MHz and 16 step sizes from 100 Hz to 10 MHz above 4 GHz. The amplitude ranges from -30 to -12 dBm. (-30 to -10 dBm typical) with a step size of 1 dB.

The above Network Analyzer is capable of making a wide range of measurements. The internal I/Q demodulator captures upto 2 Megabytes of information each second, with a hardware-limited bandwidth of 250 KHz. The trace is actually a combination of several sweeps, mathematically combined to reject image and spurious responses.

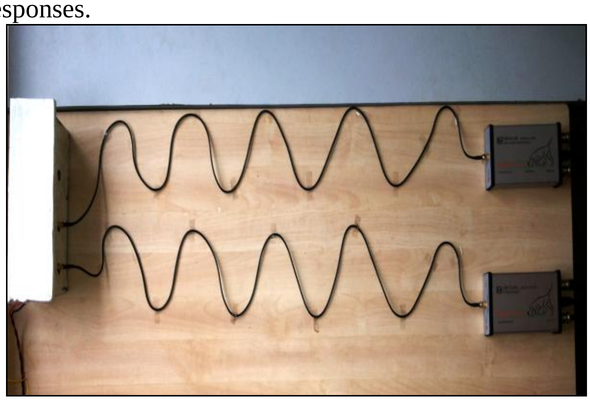

Fig. 5: Experimental Set-up

The Experimental set-up is shown in Fig. 5. The samples were analyzed in the 10MHz-4GHz range. The experiment was conducted in the basement laboratory wherein the signals of local mobile cell towers were found to be minimum, as the frequencies of these towers were found to be within the range of the experimental span.

The multi-frequency bio-electrical impedance spectrum can be modeled through multivariate and curve-fitting statistical applications to develop summary parameters to estimate body composition like glucose and cholesterol.

III. RESULTS

By using the above setup, the graphs were recorded as shown in Fig. 6 to Fig. 11. It may be noted here that even though the experiment was conducted from 10MHz to 4GHz continuously, the responses were found only in certain regions and only those are shown in Fig. 6 to Fig. 11.

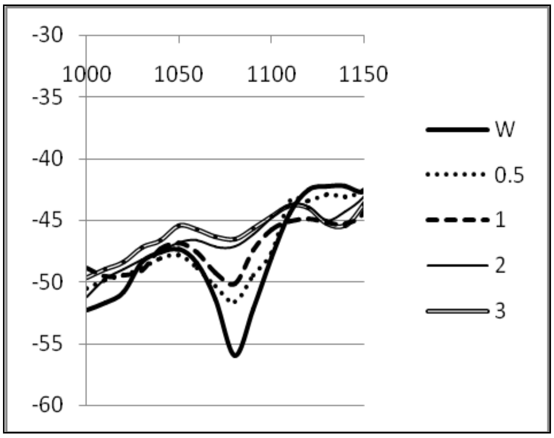

Fig. 6: Graph of 1000MHz to 1150MHz

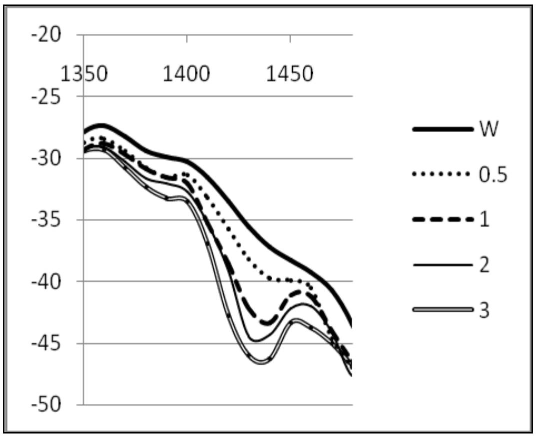

Fig. 7: Graph of 1400MHz to 1500MHz

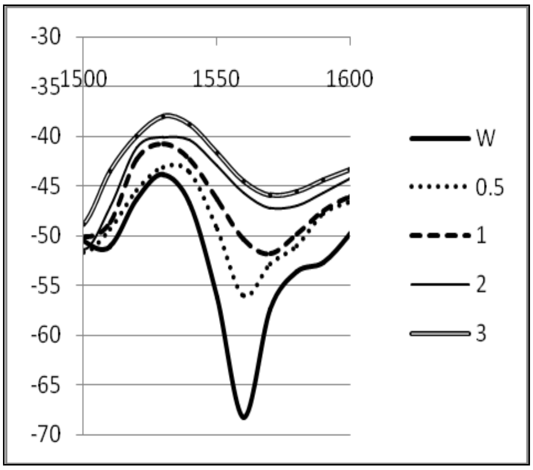

Fig. 8: Graph of 1500MHz to 1600MHz

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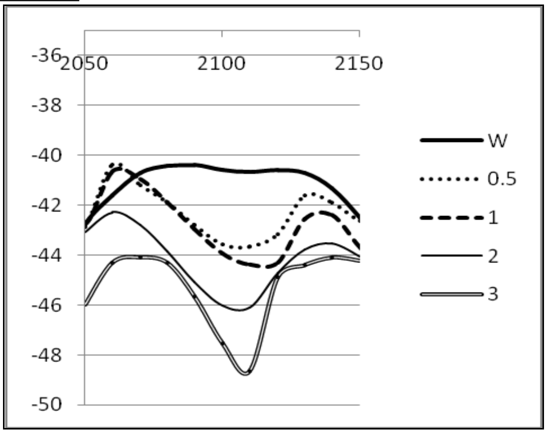

Fig. 9: Graph of 2050MHz to 2150MHz

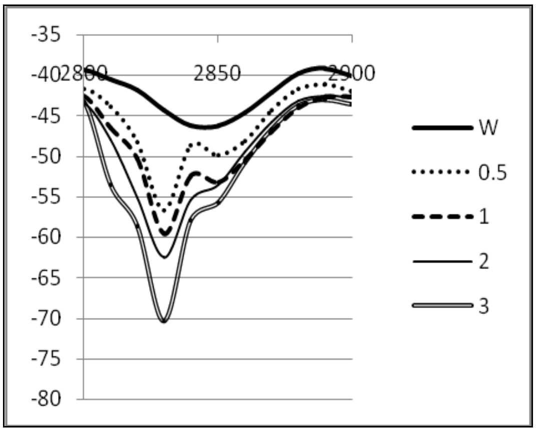

Fig. 10: Graph of 2800MHz to 2900MHz

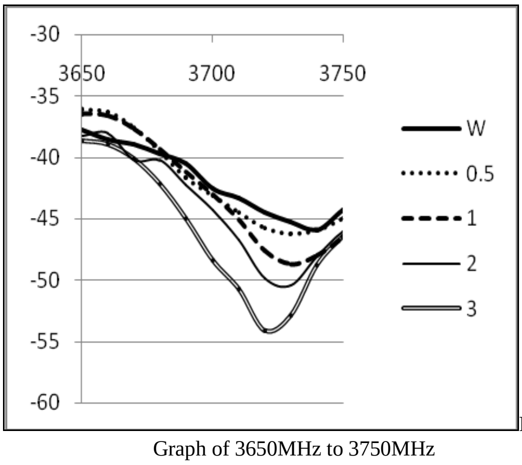

Fig. 11: Graph of 3650MHz to 3750MHz

It can be observed from the graph shown in Fig. 6 ranging from 1000MHz to 1150MHz that as the concentration of glucose increases, the absorption at 1080MHz decreases. Further in Fig. 7 at 1430MHz absorption increases as the concentration of glucose increases.

In Fig. 8 ranging from 1500MHz to 1600MHz there is a peak at 1530MHz i.e. the absorption decreases as the concentration of glucose increases and a trough at 1560MHz i.e. as the concentration of glucose increases, the absorption of glucose decreases. It can be observed from the graph shown in Fig. 9 that the absorption increases at 2100MHz as the concentration of glucose increases.

Fig. 10 ranging from 2800MHz to 2900MHz shows that the absorption increases at 2840MHz as the concentration of glucose increases. At 3730MHz, in Fig. 11, it can be observed from the graph that as the concentration of glucose increases, the absorption increases.

The changes within the physiological range of glucose (less than a few hundred mg/dl) were small and appeared to be within the measurement error.

IV. CONCLUSION

The manuscript reports a variation of impedance values in samples of glucose at different concentrations, ranging from 45mg/dL to 270 mg/dL. It is found that variations in glucose concentration directly affect the impedance modulus of the sample. In fact, even if the impedance variations were often small (around 3-4 dBs per mg/dL), they were clearly measurable. These findings will be the basis for possible development of a new approach, based on impedance technology, for the noninvasive monitoring of glycaemia.

There is no W.H.O. approved device available at present for use in clinical practice. A possible explanation might be the combination between the specific features of each method and the specific characteristics of diabetic patients, which make them respond differently to physical and chemical methods when compared to their healthy counterparts. The study conducted in this manuscript is towards possible development of a standalone user friendly gadget to monitor personal health parameters.

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BIOGRAPHIES

Ingrid Anne P. Nazareth born in Sharjah, U.A.E. is currently a Ph.D. Scholar in the Department of Electronics, Goa University, Goa (India). She completed her Masters in Electronics having secured the 1st place and is an awardee of the 'IV SERC School in Physics Gold Medal'. She was appointed a project fellow in the project "Design of Hyperspectral Smart Sensors using soft-core processors and IP cores". She was also a visiting faculty at the Goa University. Her research interest is in the field of Biomedical Electronics. She has attended a number of National Symposiums and Conferences where she has presented her research work.

Sulaxana R. Vernekar is currently pursuing her Ph.D in Electronics at Goa University. She is Assistant Professor in the Department of Computer Science at GGPR College of Commerce, Ponda - Goa and has 17 years of teaching experience. She has participated in number of symposium / workshops and presented her research work. Her areas of interest are agricultural electronics, micro electronics and digital signal processing.

Dr. Rajendra S. Gad completed Ph.D. Electronics and is an Associate Professor in the Department of Electronics, Goa University, Goa, India. He has worked on the Indian Council of Medical Research and University Grant Commission, New Delhi, funded research project in the area of noninvasive glucometer. Also closely associated with the Million Book Project of Carnegie Mellon University, USA and related digital repository projects of Indian Navy. Associated with ALTERA Inc. USA under the MOU with ALTERA University program. Attended summer training at CEDT IISc, Bangalore for two months from April 27, 1998. Attended SERC School on Bio-photonics, CAT Indore: February 06, 2006 -February 24, 2006; supported by DST, New Delhi. Dr. Gad is Sponsored and Administered "Leading Engineer of the World 2008" & 2000 Outstanding Intellectuals of the 21st century 2009/2010, by International Biographical Center, Cambridge, England. Dr. Gad, was a winner in Mentor Graphics Design contest 'Design and verification of LC3 processor' for year 2010 in India. He is also a recipient of the Indian National Science Academy Fellowship for the year 2012-13.

Prof. Gourish M. Naik obtained his Ph.D from Indian Institute of Science, Bangalore (1987) and served the institute as research associate in the areas of Optoelectronics and Communication till 1993. For the last 15 years, he is associated with Goa University Electronics Program. He is the founding head of University Instrumentation Center and established Fiber optic LAN & Wireless Communication Network at Goa University. He is also coordinator of DEITI (an educational broadcast studio supported by Indian Space Research). His other commitments are regulating digitization Center at Goa University to support the various Digital repository projects like DIGITAP (Digital Repository for Fighter Aircrafts Documentation) of Indian Navy, Million Book project of Ministry of Information Technology and Antarctica Study Center (NCAOR). He has to his credit around 50 odd research papers published in National and International Journals and has presented research works at various National and International Forums. He has delivered several key note addresses and invited talks at various institutes and also authored a book on Embedded Systems published by Springer (Holland). He is a member of Goa State Rural Development Authority and also advisor for Directorate of Education. He is also the chairman of Goa University Technical Advisory Committee. Presently he is head of Electronics and Instrumentation division at Goa University.