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Research Article

Detection of Human Blood Sugar using Time Domain Reflectometry (TDR) Technique

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ABSTRACT

Dielectric properties of liquids cover a vast area of interest for scientists from a variety of disciplines of science and technology including medical physics and bio sciences. Time Domain Reflectometer (TDR) based method for determination of human blood sugar levels is presented. This method of detection of blood sugar based on dielectric properties works well and needs further refinements by designing different sample cells with impedance matching and improved waveform analysis techniques. The TDR based blood analysis system is capable of finding out the blood sugar level of blood samples just using one drop of blood in minutes. The blood sugar level of the sample is found to affect the peak voltage values of the reflected waveform from the TDR setup. The system is tested for its reproducibility and accuracy by conducting series of experiments. The resulting waveforms are analyzed manually and using computer program, from graphs using the TDR data file. There is excellent agreement between values of blood sugar levels determined using TDR based instrument and standard conventional techniques, this validates the instrumental setup and the measuring technique. The relation between the peak voltage value and the blood sugar level of the sample is presented and details discussed.

Keywords: Blood Sugar detection, TDR, Microwave, dielectric properties, dielectric constant, Low Frequency TDR.

INTRODUCTION

The measurement of dielectric properties of blood is known to be of importance for diagnosis of diseases. The dielectric properties of diseased blood cells are different from those of healthy blood cells. Depending

on the presence of sugar or glucose in the blood, the dielectric properties of blood changes[1]. This could be used to identify blood containing excess glucose from normal blood. Microwave techniques can be used to estimate blood sugar level[2]. We have developed a Time Domain Reflectometer (which is similar to the one developed by Cole et.al. used for the measurement of dielectric relaxation properties of the solution over wide range of frequencies) for the estimation of dielectric properties of blood samples. A Low Frequency TDR[3-6] is designed and is used for determination of the dielectric constant of whole blood. The study on dielectric relaxation of liquids gives important information about molecular structure, molecular interaction between components of solution, dynamics and kinetics of the solution. Since, the molecular response is in microwave region, most of the measurements are carried out in microwave region to know the liquid properties. The dynamic-kinetic and kinetic properties of liquid are generally carried out in dilute solutions with non polar solvent using frequency domain technique. To study the dielectric properties of the solution of polar liquid in polar solvent the most reliable technique is Time Domain technique.

For converting into frequency domain, the reflected pulse without sample [R_1 (t)] and with sample [R_x (t)], are used and their sum and difference is calculated. Subtraction gives [p (t) = R_1(t) – R_X(t)] and addition gives [q(t)=R_1(t) + R_x(t)]. These time dependent p(t) and q(t) waveforms are converted in frequency domain using Fourier transforms. The frequency dependent data of p (ω) and q (ω) are used to compute reflection coefficient of the blood under study over the frequency range 10 MHz to 10 GHz using equation[7].

$$\rho^*(\omega)=[C\, j\, \omega\, d][p(\omega)/q(\omega)] \qquad (1)$$

Where C is velocity of light, ω is angular frequency, d is effective pin length and $j=\sqrt{-1}$.

.This reflection coefficient $\rho^*(\omega)$ gives the frequency dependent complex permittivity spectra $\varepsilon^*(\omega)$ over the corresponding frequency range. The Havriliak Negama equation[8] relates the static dielectric constant, average relaxation time, permittivity at infinite frequency, Cole-Cole and Davidson-Cole distribution parameters with complex permittivity spectra as

$$\varepsilon^*(\omega) = \varepsilon_\infty + (\varepsilon_o - \varepsilon_\infty)/[1+ (j\, \omega\, \tau)\, (1-\alpha)]\beta \qquad (2)$$

Where $\varepsilon^*(\omega)$ is complex permittivity, ε_o is static permittivity, ε_∞ is permittivity at infinite frequency, τ is relaxation time, α is Cole-Cole distribution parameter and β is Davidson-Cole distribution parameter.

Initial investigation using low frequency TDR techniques on blood samples give encouranging results. It is observed that there is relationship between some properties of the reflected waveform and the important properties of blood samples like blood sugar level and the blood group the sample belongs to.

Time domain dielectric spectroscopy has been used by others for various pathological tests[1, 9, 10]. Jean et.al[11]. and Gaur et.al[12] has reported the relationship between the blood sugar content and its dielectric properties.

This Time Domain Reflectometry (TDR) technique has been used in the present work to study few dielectric relaxation properties of blood which is a complex mixture of bimolecules. The analysis of reflected pulses is carried out to get reflection properties that are related to the presence of sugar in blood sample.

EXPERIMENTAL

The TDR based system designed for study of blood samples makes use of DS1000 oscilloscope with its standard plugins for TDR. The step pulse waveform used for the study was taken from the pulse generator and had a rise time of 5 ns and the amplitude of the pulse was 100 mV. The reflected waveform was

monitored using a time window of 60 ns, recording 600 points corresponding to a resolution of 0.1 ns ((100ps). The signal was connected to the sample cell with the help of a coaxial transmission line with characteristic impedance of 56 Ω and the coaxial cable had SMA connectors at the ends for matching of impedance on either sides. The reflected pulse without sample [$R_1(t)$] and with sample [$R_x(t)$] are digitized with 1024 points per waveform and stored in oscilloscope memory after averaging over 64 times. These reflected pulses (data) are transferred to PC and saved in a file with appropriate name for further processing. Computer programs are developed for analyzing the data from reflected pulse. The peak voltage value of the first peak of the waveform is affected by the change in the dielectric properties of the blood sample which in turn depend on the sugar contents in the blood. Blood contains Plasma, RBC, WBC etc and water as major constituents and thus the dielectric properties are governed by the composition of these components. We studied large number of blood samples with different values of blood sugar levels. The reflected waveforms were analyzed. The estimated values of blood sugar based on TDR waveform are in close agreement with the actual values obtained in pathological laboratory using standard conventional methods.

The TDR wave form data that is saved in the form of a text file in the computer can be used for further processing to find the peak voltage value. From a series of tests it is observed that there exists a relationship between the blood sugar level of a blood sample and the peak voltage of the reflected waveform. As is known that the blood consists of large bulky molecules and plasma, it also has sugar in the form of glucose. The amount of glucose present in the blood menifests itself in the form of difference in amount of reflection.

The TDR waveform data from the experiments can be analyzed by plotting a graph to determine the blood sugar level from the peak voltage value of the first pulse. The blood sugar level can be estimated from a single set of data of reflected waveform. Computer programmers are developed to read in the text files containing the TDR waveform data of the reflected pulse. This program then finds out the peak voltage value and from this the blood sugar level is calculated.

Blood samples were collected time to time and it was required that fresh samples are used. Therefore, the collected samples are used within six hours of collecting the sample. The samples collected were mixed with anticoagulant for storage till the experiment. Out of these 1000 samples, about 500 samples were normal blood samples and the rest were of diabetics and anemia. To study the dielectric properties, one drop of blood from the sample was used and placed in the sample cell. First the sample cell was well cleaned using distilled water and tissue paper. The cell was then dried using hot air blower to remove any traces of water after washing and cleaning.

The sample cell was connected to the experimental setup for recording the waveforms from TDR. Before every observation a waveform was recorded without blood in the sample cell as empty reading and the data was stored for further processing. With the help of a fresh syringe a drop of blood was carefully placed on the sample cell. With the sample in the sample cell, the waveform of TDR was recorded and the data was saved for further processing under appropriate file name to keep record of the observation for different samples. The same sample was re-analyzed by cleaning the cell and loading a fresh drop of blood from the sample using a fresh syringe.

The purpose of taking two readings for each sample was to ensure the reproducibility in the readings and reduce experimental error. The points from the TDR file can be plotted on graphs and peak values carefully determined from the graph. For ease of operation, computer programs are developed, These programs read the text file generated by the TDR based experimental setup, stores the data in an array and analyses it for occurrence of the first peak. We have used data files with 600 data points taken at an interval of 0.1 ns (i.e. 100 ps).

RESULT AND DISCUSSION

Initial testing used normal blood samples with known blood sugar levels. The experimental setup sends a fast voltage pulse of 100 mV with a rise time of 5 ns using a coaxial transmission line to the sample cell and the reflected waveform is saved in the form of a text file in the computer attached to the experimental setup. These TDR waveforms so recorded are used to plot the waveforms for further investigations or use in computer programs for finding out the peak voltage values for the estimation of blood sugar levels.

During the process of calibration and standardization it was observed that several blood samples with slight variation in blood level show identical peak values. This suggests that further improvement in accuracy and sensitivity could be achieved controlling other parameters and better design of the sample cell. We are working on that and trying to come up with better predictions of the blood sugar levels using TDR based instrumentation.

Figure-1 below shows a set of selected plots of TDR waveforms obtained from different blood samples having different blood sugar levels. The values of blood sugar levels for different curves are also shown in legends on the plots. It is seen that different peak voltages represent corresponding blood sugar levels and are shown in **Table – 1.**

The peak voltage values when compared with corresponding blood sugar level in **Table – 1** suggest a linear relationship between the two, i.e. Peak voltage and blood sugar level of the sample.

Fig. 2 is a plot of blood sugar level versus peak voltage, the points plotted represent actual data from the experiments and the line joining these points is the least square fit applied to these points. It is clearly seen that the fitted line shows very good correlation as the value of r^2 is close to unity indicating a good fit. The equation shown in the inset is the equation to the least square fit line to the data points. The plot and the fitting line describe the relationship between the blood sugar level and the peak voltage value.

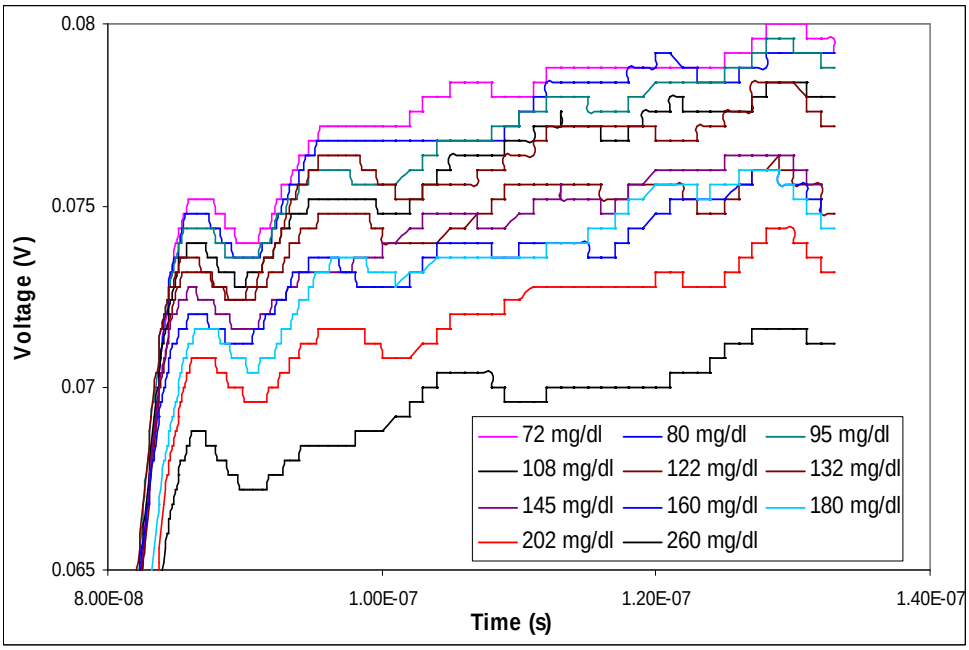

Fig.1: TDR waveform for blood samples with different blood sugar levels.

Table - 1: Corresponding blood sugar level

Sample No.	Peak Voltage (mV)	Actual Blood Sugar (mg/dl)		Sample No.	Peak Voltage (mV)	Actual Blood Sugar (mg/dl)
1	75.2	72.0		23	73.2	132.0
2	74.8	80.0		24	73.2	132.0
3	74.8	84.0		25	72.8	142.0
4	74.4	92.0		26	72.8	145.0
5	74.4	94.0		27	72.8	145.0
6	74.4	94.0		28	72.8	147.0
7	74.4	94.0		29	72.8	147.0
8	74.4	95.0		30	72.8	147.0
9	74.4	96.0		31	72.8	150.0
10	74.0	102.0		32	72.4	152.0
11	74.0	102.0		33	72.4	156.0
12	74.0	108.0		34	72.4	160.0
13	74.0	109.0		35	72.4	162.0
14	74.0	109.0		36	72.0	166.0
15	74.0	110.0		37	72.0	170.0
16	73.6	121.0		38	71.6	180.0
17	73.6	122.0		39	71.6	181.0
18	73.6	123.0		40	71.6	182.0
19	73.6	119.0		41	70.8	202.0
20	73.2	130.0		42	70.4	222.0
21	73.2	132.0		43	70.0	233.0
22	73.2	132.0		44	68.8	260.0

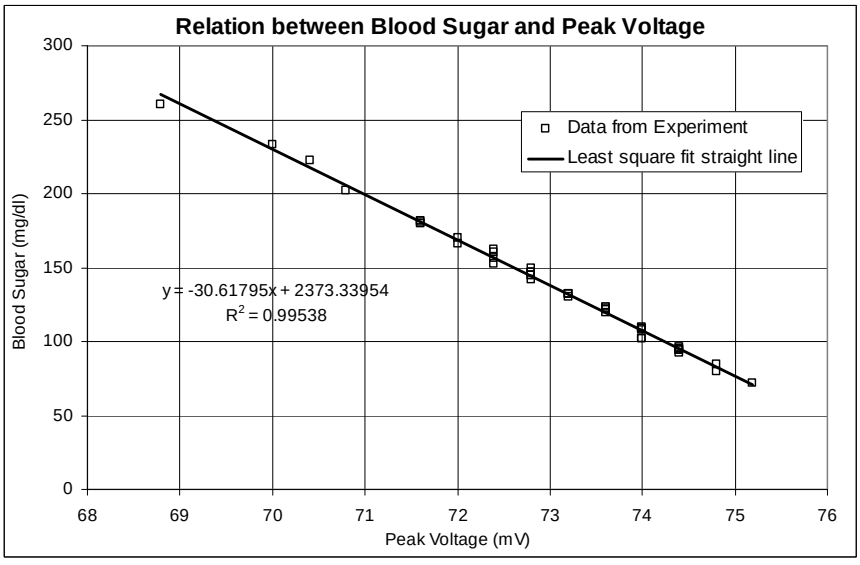

Fig. 2: Relation between blood sugar level and peak voltage for blood samples.

This plot serves the purpose of calibration plot for the blood sugar level measurements based on the peak voltage measurements. This plot can be used for the estimation of the blood sugar level of any sample by using the TDR experimental setup and measuring the peak voltage value. Once peak voltage value is measured, the same can be used to read corresponding sugar level from the graph or can be estimated from the best fit equation:

$$y = -30.61795 \cdot x + 2373.3395 \quad (3)$$

Where y is the blood sugar level of the sample in mg/dl and x is the peak voltage value of the first peak in mV obtained from the TDR data.

For the purpose of validation and evaluation of the performance of the blood sugar level estimation setup we used TDR waveforms for few samples and the values of peak voltages measured were determined. The computer program reads in the TDR data file and finds the peak voltage of the first peak and from this value of peak voltage, the blood sugar level is calculated using the above equation. The blood sugar levels estimated from the equation are compared with the actual blood sugar levels (obtained from pathological laboratories for the same samples) The results are found to be in good agreement and are compared in Table –2. This validates the performance, reproducibility and validity of the experimental setup used for blood sugar level measurement. There is slight difference between the actually measured values and values calculated from the equation. This is because of the limitation of sensitivity of the system, a more sensitive measurement is expected to provide more accurate results.

The blood sugar levels obtained using equation 3 for different samples in the range of 72 mg/dl to 260 mg/dl are shown in **Table- 2.**

Table -2: Comparisons of blood sugar levels calculated from the equation 3 and standard values from pathology laboratory.

Sr. No.	Blood Sugar mg/dl		Sr. No.	Blood Sugar mg/dl	
	Actual	Measured		Actual	Measured
1	72	70.87	11	132	132.11
2	80	83.12	12	132	132.11
3	84	83.12	13	145	144.35
4	94	95.36	14	150	148.45
5	95	95.36	15	166	168.85
6	96	95.36	16	180	181.09
7	108	107.61	17	202	205.59
8	109	107.61	18	222	217.84
9	121	119.86	19	233	230.08
10	130	132.11	20	260	266.82

It is observed that for the blood sugar level estimations using equation – 3 are in reasonably good agreement with the actual values for the blood samples obtained from pathological laboratory with standard methods in the range of 72 mg/dl to 260 mg/dl.

CONCLUSION

The blood sugar concentration determination method based on dielectric constant is one of the methods known to have potential of prediction of sugar levels. In this process, different steps are involved. The linear trend has been observed between dielectric constant and blood sugar level; however this linearity is

not same over the different regions of the plot. The present approach appreciably simplifies the process of estimation of blood sugar level using the TDR wave form and the peak voltage.

The blood sugar levels obtained from the first peak of the TDR wave form are found to be in good agreement with the actual values (measurement from pathological laboratory). There is slight difference in several cases studied that can be attributed to pathological laboratory measurements and mainly to the limitation of the peak value measurements in our TDR setup. Work on improving the measurement accuracy and improved design of sample cell is in progress. Further work along these lines is expected to substantially improve the technique.

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