Non-Invasive Blood Glucose Measurement Depending on the Blood Dielectric Properties by using One Ultra-Wideband Transceiver

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Abstract - *This paper has been introduced to define an ultra-wideband device used for measuring the glucose concentration in the blood non-invasively. The glucose concentration has been found relatively changing within the blood dielectric properties, according to the percentage of glucose that contain. Where a decrease in the blood dielectric properties (permittivity) has been observed when the glucose percentage was increased (inverse relationship). This decrease was appeared clearly when the frequency range is increased and remain almost constant when it passes the 5GHz. Although, other factors may have an affect on the dielectric properties like; temperature, gender, clotting rate, and blood density. This method can be applied accurately by using one ultra-wideband transceiver that attached to the superficial blood vessel, then compares between the send and the received signals which have been detected by the same transceiver to calculate the reflection coefficient.*

Key Words: **Ultra-wideband transceiver, blood glucose concentration, blood dielectric properties, UWB Glucometer.**

1. INTRODUCTION

An ultra-wideband (UWB) electromagnetic wave with a frequency ranges from 3.1 to 10.6 GHz is an emerging technology with a very wide range of applications, especially in medical scopes. With a safe power spectrum (-41.3dBm/MHz) according to American Federal Communications Commission (FCC) [1] and International Commission on Non-Ionizing Radiation Protection (ICNIRP) safety guidelines [2]. It is a non-ionizing wave and doesn't have any biological side effects on the human tissue (only thermal effect). These features encourage the researchers to propose a number of papers in this scope. Most of these papers would focus either on the differences in the dielectric properties of human tissue like breast cancer detection[3], or on the organ movement detection like heart rate and respiratory detection[4]. The main problems faced by such researches are the absorption and attenuation of the signal by the skin and the vicinity layers, while the returning signal from the deep layers is very weak. As well as, the inability to distinguish between the tissues that have convergent dielectric properties. These problems will introduce new challenges to be solved by researchers.

In this paper, we will deal with blood dielectric properties which have been treated extensively in many researches. There are many laboratory techniques that can be used to measure the dielectric properties. The Ultra-wideband technique is on of them that is very effective, simple, low cost, and non-invasive, that make UWB preferred in use.

For patients with diabetes is very important to know the blood glucose percentage periodically and without pain. As well as, it is important to obtain this percentage accurately and easily. There are many techniques have been used to measure the blood glucose concentration based on optical, chemical, electrical or hybrid technique. Also, these techniques would have come with an invasive or non-invasive manner and with different levels of accuracy. The proposed technique is based on the detection of a change in the blood dielectric properties which is related to the change in the blood glucose concentration, with investment in the ultra-wideband technology. Many researches are suggested in these disciplines like; a) Non-invasive a UWB system for reliable glucose concentration level measurement in human blood depending on artificial intelligence[5], that no blood sample has been taken. By using two UWB microstrip antenna with signal acquisition and data processing, where the system work with an artificial neural network manner. The system sends the UWB wave in the central frequency of 4.7 GHz from one side and received it from the other side then applying artificial neural network on the received signal. The drawback of this system is producing inaccurate readings and the system needs too long training time. b) Blood plasma glucose dielectric properties study[6], which shows that the correlation between glucose concentration and dielectric properties of blood (permittivity and conductivity), that a single-pole Cole-Cole model has been used for finding the permittivity and conductivity as a function of glucose concentration. Also, a microstrip patch antenna has been used. c) Near-infrared spectroscopy has been used to monitor blood glucose concentration non-invasively[7], based on the scattering property of glucose molecules and enhanced algorithm. d) The optical rotation effect of glucose has been used to design a non-invasive blood glucose detection device. This device based on Faraday magneto-optical effect and depending on the Programmable System-on-Chip to control the system. Where the Faraday coil will response to the increase in the current produced from photodetector excited by polarized light, that decreases the coil rotation angle. The glucose concentration will be proportional with the Faraday coil angle change and can be invested from it, this device can detect the glucose concentration variance from 75-500 mg/100ml [8].

2. ULTRA-WIDEBAND GLUCOMETER

The proposed device will be depending on the reflected waves from the blood for measuring the glucose concentration. Where a Vivaldi UWB antenna has been attached to the superficial blood vessels to detect the reflection coefficient. The reflection coefficient(Γ) can be obtained from the comparison between the amplitude of transmitted and received(reflected) waves[9]:

$$E_r = \Gamma . E_i \quad (1)$$

where E_i is the incident wave, $and\ E_r$ is the reflected wave. Also, the reflection coefficient has proportional relationship with the blood permittivity(Ɛr) as illustrated below:

$$\Gamma = \frac{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}} \quad (2)$$

Finally, the blood glucose concentration has been measured with high percentage of accuracy, which is related to the changes in the blood permittivity (dielectric properties).

3. DIELECTRIC PROPERTIES

The dielectric properties are the fundamental parameters that affect the propagation of the electric field. It is a measure of how the electric field behaves or interacts with materials, which can be used (for example) to understand how easily an electric field will polarize a given dielectric material. Dielectric constant and loss tangent are both numerical values which can be defined permittivity of a dielectric material. While the conductivity is the extent that it allows an electric current to flow through it. Where it is used for the rate or degree that electromagnetic wave, electricity, heat, or sound travels through a certain medium.

3.1. Dielectric properties measurement techniques:

- Transmission /Reflection technique[10].
- Open ended coaxial probe technique.
- Free space technique.
- Resonant technique.

3.2. Dielectric properties of blood effected by:

- Blood temperature[11].
- Applied electromagnetic wave frequency[12].
- Human gender[13].
- Blood group type (A, B, AB and O)[14].
- Clotting rate[13].
- Blood composition[15].
- Blood hematocrit level[15].
- Hemoglobin percentage [16].

3.3. Blood dielectric properties measurement using open ended coaxial probe experiment

The dielectric properties will be different from one material to another. It will enable us to recognize the substances by recognizing its dielectric properties. In these experiments, the glucose concentration of blood will be increased individually in relation to the increase of the dielectric properties. It is a microwave measurement method. The experiments will be done in frequency center of 5GHz and in 37°c temperature on many blood samples with various concentrations. The main parts of the experiment are following and as shown in Figure 1:

- Dielectric probe (open ended coaxial probe model: 85070E performance probe).
- RF vector network analyzer (compatible with the above probe model: E5063A ENA series).
- Water bath.
- Thermostat.
- Adjustable probe stand.

- PC computer (laptop).
- Glucometer.
- Alcohol wipes and glass sample containers.

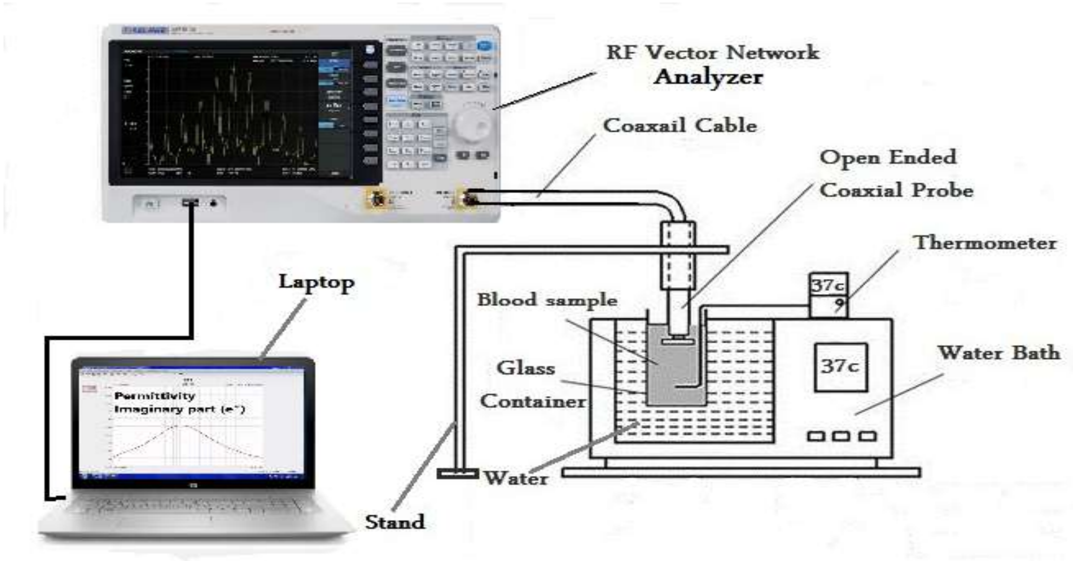

Figure 1: Blood dielectric properties measurement system

3.4. Dielectric properties measurement experiment principle of work:

The vector network analyzer is an RF test instrument able to measure the response of a network as a vector or real and imaginary parameters and in the frequency range from 100kHz to 8.5GHz, it is very suitable to work with single frequency measurement and can be connected with PC computer. Also, the coaxial probe is an RF transducer that is used to measure the dielectric properties of materials. The permittivity can be measured by dipping the coaxial probe end in the liquid that the electromagnetic field wave penetrates the liquid and the reflected signal is measured. Then permittivity of liquid can be obtained. The water bath and thermostat are used to maintain the blood samples at a certain temperature (37^{o}c). Depending on the reflection coefficient and time of arrival of propagation wave the material permittivity equation will be as follow[17]:

$$\varepsilon = \frac{2\Gamma \sin\left[2s + \frac{2\pi(t_2 - t_1)}{\lambda}\right]}{s\left[1 + \Gamma^2 + 2\Gamma \cos\left[2s + \frac{2\pi(t_2 - t_1)}{\lambda}\right]\right]} \qquad (3)$$

where Γ is the reflection coefficient, s is standing wave ratio and λ is the wavelength.

3.5. Dielectric properties measurement experiment procedure:

I. Start Agilent technologies software from network analyzer device or from connected computer.
II. Calibrate the device which is achieved by select the desired frequency and use standard tests[18]:
   - Open circuit calibration.
   - Short circuit calibration.
   - Water calibration.
III. Start measurements and clean the probe by alcohol wipes after each test.
IV. Organize the results on excel sheet.

4. EXPIRMENT RESULTS

The experiments have been applied by adding glucose water intravenous nutrient with different concentrations to detect its effects on the dielectric properties (especially on the permittivity), where we will use the glucose concentrations from 50mg/dL to 16000mg/dL, and the results are shown in **Error! Reference source not found.**. Note that all experiments are practiced in frequency of 5GHz at temperature 37^{o}c and with fresh blood as well as, the donor blood group is O positive.

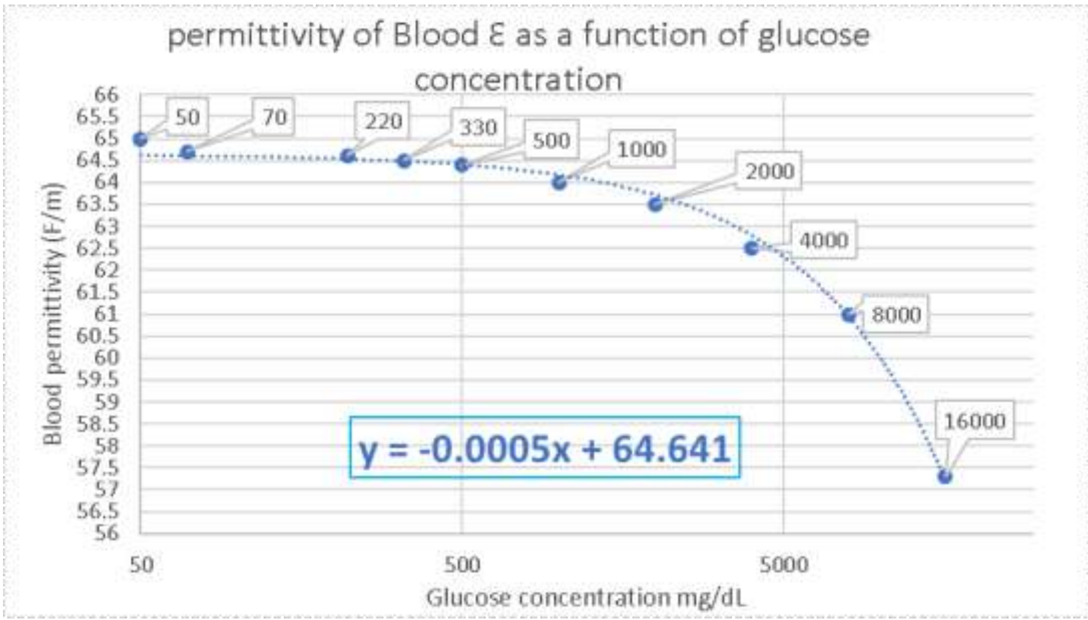

Figure 2: blood permittivity as a function of glucose concentration

According to the above results which illustrated in the Figure 2, we can note that the blood permittivity will be decreased gradually when the glucose concentration in the blood was increased, and vice versa. Also, the curve equation mentioned in the same figure (Figure 3) can be served for finding the glucose concentration in the blood.

5. CONCLUSIONS

The blood dielectric properties can help us to find the glucose concentration non-invasively by using one ultra-wideband transceiver(antenna) depending on the comparison between the sent and reflected waves. The UWB antenna will be attached to the superficial blood vessel to avoid the noise and power attenuation from another human tissue to increase the accuracy of readings(where the using of two antennas to send and receive the waves from the other side of hand, will result in the wave is being passed through many layers, that the power of signal will be absorbed will cause inaccurate measurement). Taking into the account, that the other parameters can have affects on the dielectric properties, which are mentioned above in the section 3.2). The permittivity has clear reverse proportional relationship with blood glucose concentration that can be used to determine the glucose concentration in blood high accuracy in comparison with the previous studies that are illustrated in Figure . Also, the Table 1 will mention a summary of relationships that serve our conclusions:

Table 1: A summary of relationships

Relationship	Notes
Glucose concentration α $\frac{1}{\varepsilon}$	
Glucose concentration α $\Gamma_{1/2}$	By consider the blood is 2nd medium
Glucose concentration α $T_{1/2}$	By consider the blood is 2nd medium
Anti-coagulant material α Ɛ	
Anti-coagulant material α $\frac{1}{\Gamma_{1/2}}$	By consider the blood is 2nd medium
Anti-coagulant material α $\frac{1}{T_{1/2}}$	By consider the blood is 2nd medium
Blood temperature α Ɛ	
Hemoglobin percentage α Ɛ	

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