Measurement of Non-Invasive Blood Glucose Level by UWB Transceiver in Diabetic Patient Type-1-

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Abstract. Diabetes is a silent killer and a rapidly increasing global epidemic worldwide. The change in healthy diabetes diet and life-style is only therapy as no permanent treatment. The measuring of the amount of Blood Glucose Level (BGL) continuously is important for diabetes management. In general terms, two types of diabetes can be identified as Type-1- and Type-2-.
Type-1- is the most dangerous type and affects (5-10 percent) of the diabetic population; they have to inject or pump insulin themselves. The common method of measuring is glucometer which the sample of blood is taken by clipping patient’s finger and analysis this sample. This invasive method is painful and discomfort for the patient. This article presents a microwave sensor with frequency falls in the range of Ultra-wideband (UWB) spectrum to determine blood glucose level non-invasively (i.e., without giving any sample of blood). Ultra-wideband technology for the Wireless Body Area Network (WBAN) is an important technology due to its advantages in sensing and communication for biomedical applications. The proposed system consists of a piece of microwave resonator that can be placed on the arm of the patient. Then, the first frequency resonance of the sensor is modifying because of many changes are calculated in dielectric blood permittivity and frequency value transferred from the sensor. Relationship between the frequency response and the changing in blood permittivity is observed. This may result in a measurement phase in which the Blood Glucose Level present has a relation with the frequency response value of the sensor. This system showed a clear and accurate outcome. Besides, it is easy to use by patient himself in any time with multiple use without exchanging any part of it, and safe because no taking any drop of blood just put the sensor in touch with patient's skin without pains, and low cost compared with other methods that measure the glucose level.

Keywords: Ultra-wideband, microwave sensor, diabetic Type-1-, non-invasive, blood glucose, dielectric properties.

1. Introduction
Many commonly technologies used to measure the amount of glucose has been found, such as light scattering spectrometry, near-infrared and far-infrared spectrometry, laser Raman spectrometry and electrochemical analysis of glucose in saliva [1]. These methods sometimes have many limitations such as pains for patients, high complexity, long time for measured, high cost, low accuracy and effectiveness [2]. These limitations drive us into this work and seek to find a new technology that can escape the pains as well as reduce the complexity and expense. The needed technology was the Ultra-wideband (UWB) with its essential specifications.
1.1 Context Theoretic

Electromagnetic waves (EM) can be divided into: (radio waves, microwaves, terahertz (THz) waves, infrared (IR), ultraviolet (UV), X-rays, and gamma rays) which depend on their wavelengths or frequencies. Electromagnetic waves with higher frequencies produce higher photonic energy that can damage the tissues because of the ionizing radiation shown in Figure 1. On the other hand, non-ionizing radiation is seen as sufficient and safe for non-invasive biomedical imaging and sensing [3].

![Figure 1. The electromagnetic spectrum glucose level.](image)

The power-efficient transmission acts as a key role in new green communication [4]. The UWB has special characteristics that making it a very important technology with high data rate and short-range wireless communications [5]. Ultra-wideband has non-ionizing radiation and has no biological side-effects, and it has more ability to penetrate through the tissues of the human body. Ultra-wideband technology is a very necessary technology for WBAN because of many advantages such as very low radiated power (-41.3dBm/MHz) for the frequency range between (3.1 to 10.6GHz) according to Figure 2 of the American Federal Communications Commission (FCC) [6].

![Figure 2. Indoor power spectrum from the American Federal Communications Commission.](image)
These ranges are very critical for preventing interference with other wireless networks operating on the same spectrum, low power consumption, good coexistence with other wireless technologies, multipath and interference robustness [7]. Ultra-wideband uses: assisting people with disabilities (speech, blind, hands), medical check-up, physical therapy and clinical monitoring (blood pressure, heart rhythm, body temperature, blood glucose levels for Type-1 diabetic patients) [8].

Different types for measuring the amount of glucose in blood non-invasively devices have been depended on a full range of the electromagnetic spectrum, which includes: radio waves, microwaves (GHz to THz range), infrared and visible radiation [9]. In a radio and microwaves ranges, near field monitoring has been very widely used in the non-invasive characterization of dielectric properties (permittivity and conductivity) of materials. There are many studies displaying the complex of the dielectric constant that varies with the existence and changing of blood glucose concentration in the water/glucose system in the human body [10]. Since 1950's, a microwave instruments have been used increasingly in many applications because of their capability to non-destructively and determine parameters inside a volume. This feature of the microwave sensor makes it ideal for using in measuring the physiological parameters of the human body non-invasively. The important parameter is blood glucose concentration which diabetes Type-1- can closely monitor [11].

A reliable non-invasive blood glucose concentration continuously using UWB microwave technique with Artificial Intelligence (AI) which consisting for a pair of homemade Ultra-wideband micro strip bio-antenna one of them for transmitting Ultra-wideband pulse train with resonant frequency (4.7GHz) through one side of the hand and the second for receiving scattered signals from the other side then processed these waves using artificial neural network (ANN) module. The received signals are changed depending on the values of permittivity and conductivity, and we noticed that the value of permittivity and conductivity decrease when glucose concentration increase and the difference is increasing in the higher frequency range. So that the differences in blood dielectric properties are considering as functions of both frequency and glucose concentration. The advantages of this method are easy to use by the doctor in the hospital or end-users at home, safe, low cost and displaying consistent and reliable results [12].

A non-invasive method to appreciate the level of glucose in blood with using electromagnetic waves. This method is depended on an antenna with a resonant frequency, it can operate over (500MHz – 6GHz) and dielectric properties of body tissues that it will be shifted the frequency of resonance of the antenna. These shifting used to calculate permittivity, conductivity and glucose level of blood. Then, this technique can be designed as a wristwatch to hold it on the patient's arm. By using this method, we can create a database of the level of blood glucose for diabetes patients which having similar gender, age and they can measure their glucose level directly without making contact with blood. The important advantage of this method is an inexpensive technique [13].

A portable non-invasive method using Ultra-wideband microwave imaging and with Artificial Intelligence for predicting blood glucose level without prick the patient's finger and take a sample of his blood. This technique consists of a hardware module (Near Infrared Sensor which put on the finger, Ultra-wideband transceiver, battery, photodiode and LCD display) and a software module (Arduino microcontroller, two of small Ultra-wideband biomedical planar antennas). Then, the frequency is about (4.7GHz) and the best wavelength is (940nm). This system displays the glucose level depending on the amount of Body Mass Index (BMI) of the person by taking and entering his height and weight. Therefore, the result is an inaccuracy, but the cost is minimum [14]. To summarize, Table 1 was comparing different types of electromagnetic wave-based methods that showed below [15].
Table 1. Comparison of various electromagnetic wave-based methods

| Technology | Penetration | Target                | Sensitivity | Selectivity      | System size | Cost   |
|------------|-------------|-----------------------|-------------|------------------|-------------|--------|
| NIR        | > 1mm       | ISF, blood            | High        | Good             | Portable    | Low    |
| MIR        | Several µm  | ISF                   | High        | Good, better     | Large       | High   |
| Fluorescence | < 1mm    | Tear, ISF, blood      | High        | Excellent        | Portable    | Low    |
| Raman      | < 1mm       | ISF, tears            | Low         | Excellent        | Portable    | Medium |
| THz        | ~100 µm     | ISF                   | High        | Good             | Large       | High   |
| Microwave  | > 1mm       | Blood, ISF            | High        | Poor             | Portable, wearable | Very low |

A comparison of the results is listed in Table 2, where each parameter reflects specific technology already described [15].

Table 2. Performance comparison for different technologies

| Technology | Experiment | Number of points | Sensitivity | R²  | MAE  | LOD   |
|------------|------------|------------------|-------------|-----|------|-------|
| NIR        | In vivo    | 2737             | -           | -   | 0.65 mM | -     |
| MIR        | In vivo    | 14               | -           | -   | 0.67 mM | -     |
| Fluorescence | In vitro | 8                | 0.12 µM⁻¹  | 0.99 | -    | 2 µM  |
| Raman      | In vivo    | 34               | -           | 0.84 | 0.37 mM | -     |
| THz        | Ex vivo    | 20               | -           | 0.97 | 0.25 mM | -     |
| Microwave  | In vivo    | 89               | 0.0235 µM⁻¹ | -   | -    | 1.33 mM |

The proposed UWB technology that it becomes to be a new perspective for measuring the amount of glucose in the blood in diabetic patients Type-1-. This approach will attempt to address these several problems and will be discussed in other parts including an overview of Type-1- diabetes, forms of blood glucose calculation, biological hazards of glucose level calculation, Ultra-wideband glucometer, dielectrical properties.

1.2 Diabetes

Diabetes is a chronic disease that happens when insulin is not controlling the blood sugar levels in the body. According to the World Health Organization (WHO), hundred millions of people suffered from diabetes in both Type-1- or Type-2- on earth and diabetes considered the important reasons of death in many countries [16]. In both types, regular blood glucose level helps to prevent the risk of complications of diabetic hyperglycemia (when the level of blood glucose is > 200 mg/dL) or hypoglycemia (when the level of blood glucose is < 70mg/dL) [17,18], such as blindness, renal failure, heart disease and even death [19]. In 2014, 382 million of people having diabetes and the possibility that 592 million people may
suffer from diabetes in the year up to 2035 [20]. Type-1 diabetes, which is called (Juvenile diabetes) occurred in children and is the result of a decrease in insulin produced by beta-cells [21].

1.3. Types of measuring the concentration of glucose in the blood

Appreciation the amount of blood glucose techniques are usually classified into invasive, minimally invasive and non-invasive depending on the type of detection, as shown in Figure 3 [22].

![Blood Glucose Monitoring Technique Diagram](image)

**Figure 3.** An overview of blood glucose monitoring techniques.

Blood glucose measurement technologies are very important for people that have an unbalancing amount of blood glucose. In recent researches, Continuous Blood Glucose Monitor (CBGM) measures the amount of glucose in the fluid inside the body. Different devices collect information in different manners using tiny sensors. The monitor displays the glucose level, if the level of glucose drops to a dangerously low level or a high preset level, the monitor will sound an alarm. This device can improve to control the level of glucose in the blood in diabetic patients Type-1- and Type-2-, in Type-2- diabetes, this device need to link it to an insulin pump [23]. However, on the market, many types of blood glucose measurement are invasive such as glucometer which needs to clip the patient's finger to take blood as a sample. This method will cause pain for the patient and bad for children and inappropriate for measuring the level of blood glucose continuously especially in Type-1- diabetes which they need to measure the level of the blood glucose continuously in a day [24].

A remote sensing of a Wireless-Electrodeless Quartz Crystal Microbalance Dissipation (WE-QCMD) to measure a real-time glucose level and to monitor patient status through the implantation of polymer-coated quartz disks inserted under the skin and wireless control from outside the body. This technique is
operating at a constant frequency about (6MHz) in the ring-down mode. The advantages of this method are to offer good glucose sensitivity and very fast response time at (37 C) about (5 min) [25].

In the recent years, the most famous type is Abbott Free Style Libre [26], a mini-invasive blood glucose meter put on the patient's arm Type-1- diabetes, which can give the readings of glucose level during 24 hours as a continuous blood glucose measurement, and needs a micro-needle to prick the skin. This type of method measures the blood glucose amount in the interstitial fluid (ISF) under the skin, instead of measuring the glucose in the blood directly. This reading has a time lagging between the amount of glucose in the blood and the amount of glucose in the interstitial fluid [27].

Therefore, great efforts are putting to find non-invasive methods of blood glucose measurement that may use body fluids like interstitial fluid, tears, saliva, sweat and urine in addition to blood [28]. There are many non-invasive methods to account the glucose level in blood in diabetic patients Type-1- such as: light scattering spectrometry [29], near-infrared and far-infrared spectrometry [30], laser Raman spectrometry [31] and electrochemical analysis of glucose in saliva [32].

An ATR optical model with a silicon prism to produce terahertz waves (THz) of human skin. The frequency of THz is ranging between (0.3 to 3 THz) and can be emitted by a femtosecond laser and reflected waves was detected by very thick crystal [33]. Then, they explained the changing in the dielectric property (permittivity) in solution by a Debye model which contains the relaxation time and dielectric constant. THz is more sensitive to molecules, and it needs an excitation source, and it has poor penetration depth because of these reasons THz can reach interstitial fluid only [33].

Nowadays, high-performance monitoring systems with cost-effective, small size, high accuracy for diabetic Type-1- should be produced. Then, many researchers are designing and developing a Remote Patient Monitoring System (RPMS) to achieve the quality of a diabetic patient's life Type-1-, especially in rural places. This approach is not only to measure the physiological parameters but to wirelessly relay the data to healthcare centres in real-time [34]. Wearable Remote Patient Monitoring System is made up of several wearable sensors that calculate the following physiological parameters: blood glucose, blood pressure, body temperature, blood oxygen and pulse rate [35].

An alternate non-invasive method to measure Fasting Blood Glucose Levels (FBGL) depending on the change of electrochemical parameters of saliva instead of blood because saliva is a very simple bio-fluid and the salivary glucose raised during diabetes and only a few drops of saliva in the morning may be as similar as blood for calculating FBGL. The advantages of this technique are very fast, low cost, efficient method and without pain [36].

1.4. Biological Hazard of measuring glucose level

Generally, patients with diabetes performing Blood-Glucose Self-Monitoring (BGSM) can rely on the accuracy of the measuring tests. However, other factors can be categorized into design defects, environmental conditions such as (temperature, humidity, altitude, electromagnetic radiation), vital factors, including blood perfusion, hematocrit, oxygen pressure (pO2), bilirubin, uric acid and blood glucose interferences appeared. Incorrect calculation of blood glucose contributes, for example, to incorrect treatment errors to provide the insulin dose. Hence the limits in blood glucose tests should be acknowledged to all patients and diabetes teams [37].

1.5. UWB Glucometer

The proposal device may depend on the waves that reflected from the blood to measure the level of glucose. Where Ultra-wideband sensor attached to the skin to determine the coefficient of reflection from the blood vessel. The reflection coefficient (Γ) can be gotten from the comparison between the amplitude of transmitted and received (reflected) waves [38]:

\[ E_r = \Gamma \cdot E_i \]  

(1)

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

6
\[ \Gamma = \frac{\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}} \]  

Finally, the level of glucose in the blood has been obtained with high accuracy, which is depending on the change in the dielectric properties (blood permittivity).

### 1.6. Dielectric Properties

Dielectric properties are important parameters which influence the propagation of the electric field. It measures the behaviour or interaction of the electrical field with materials and can be used to understand easily how the electrical field can polarize a dielectric properties material. Loss tangent and dielectric constant are numerical values that a dielectric material (permittivity) can be described as. Although the conductivity is an indicator that enables the flow of electric current through it. Where electromagnetic wave, electricity, heat, or sound passes through a given medium where it is used for rate or degree. The techniques of measuring the dielectric properties are including:

- Techniques of Transmission / Reflection [39].
- The technique of Open-ended coaxial probe.
- The technique of Free space.
- The technique of Resonant.

And the blood dielectric properties affected by many parameters such as:

- Blood temperature.
- Human gender [40].
- Applied electromagnetic wave frequency [41].
- Type of blood group.
- Clotting rate.
- Blood composition [42].
- Hemoglobin percentage [43].
- Blood hematocrit level.

### 2. Methodology

The proposed ultra-wideband microwave sensor methodology is presented in Figure 4. The purpose system presented here is to obtain a non-invasive method to measure the amount of blood glucose by considering the deficiencies of previous studies. The framework of the proposed system includes of a microwave sensor (HB-100) with frequency about (10GHz), and this frequency is one of the ranges of Ultra-wideband frequencies, amplifier circuit shown in Figure 4, Arduino (Uno type), power supply (5V), LCD display and Bluetooth (HC-05).

![Figure 4](image-url)  

**Figure 4.** (A)The circuit of HB-100 Microwave sensor, and (B) The amplification circuit.
The proposed model is depended around a microcontroller (Arduino Uno) for full processing. In (30) cases of Type-1 diabetic patients, we analyze the microwave actions based on non-invasive measurements of blood glucose concentrations at a hospital. They noticed a correlation between a concentration in solutions and dielectric properties of reading and emulsions. High sensitivity was obtained by the proposed system and has a sensitive to errors. Microwaves are electromagnetic waves that having frequency range between (300MHz to 300 GHz) and its wavelength is between (1mm - 1m).

Microwaves are also used as their wavelengths can quickly reach the signal across all kinds of materials. The theoretical system consists of a transmitting (Tx) and receiving (Rx) sensors as shown in Figure 5 where Tx transmits UWB pulse through the hand then scattered signal was received by Rx from this hand.

![Theoretical system model](image)

**Figure 5.** Theoretical system model.

Because all the materials have an equal or greater dielectric constant than the free space. The dielectric constant is one factor that can be measured experimentally. We may indirectly determine certain properties of this material in relation to its molecular structures when we calculate the properties of the given material (dielectric). When the electrical network is connected to a transmission line characterised by a given impedance, which is named the characteristic impedance, they are measured the relationship between reflected and incident waves produced. Microwave sensors are ideal for determining blood properties because they work at high frequencies or short wavelengths and can move through the human body's fat layers of skin. Resonance techniques were used because of their capability to reliably produce a variable. As electrical fields interfere with the sensor which has dielectric properties, a resonator sensor begins to work. The coupled energy gives a maximum response to the sensor's resonance frequency, where this result relies on the relative permittivity of the material under analysis. Changes in material permittivity occurred in the frequency change that produces valleys or peaks within it. Since blood is characterised as a complex substance in which each certain component (cells, hormones, proteins and
glucose) is dissolved in water, then the frequency-related permittivity of blood is affected by other variables. Blood permittivity is determined by any part thereof. A microwave (UWB) sensor that has frequency response at multiple ranges will theoretically cross the response of one of the parameters even if the other parameters change. The dielectric properties of the different body layers (permittivity) may have seen variations as a function of the frequency shown in Figure 6.

![Figure 6](image-url)

**Figure 6.** The relative di-electrical constant of various biological tissues as a function of frequency.

Since dielectric permittivity is a function of frequency, and its equation shown below [44]:

\[
\varepsilon = \frac{2\Gamma \sin\left[2s + \frac{2\pi(\ell_2 - \ell_1)}{\lambda}\right]}{s\left(1+\Gamma^2+2\Gamma \cos\left[2s + \frac{2\pi(\ell_2 - \ell_1)}{\lambda}\right]\right)}
\]  

(3)

where \(\Gamma\) is the reflection coefficient, \(s\) is standing wave ratio, and \(\lambda\) is the wavelength.

Glucose sensor should be mounted on a region with the least amount of fat to optimize the waves that have been transmitted through the various layers. At a frequency of 1GHz, waves travelling through skin and layers are transmitted only (50 percent) of their intensity, but if the same waves travel through skin and muscle layers, (93 percent) of their energy can be transmitted. Therefore, if the sensor put on the muscle than on fat tissues, it must be reached with more blood. The sensitivity is getting better as we weighed a lot of blood, and the sensor needs to be able to detect changes in the dielectric (permittivity). For this experiment, the finger places on the surface of the sensor creating changes for their parameters, and hence the measuring technique uses a body part with relatively low-fat content and high blood content that enables us to perform a calculation with high energy transmission rates. Using this kind of sensors, diabetics could run several tests a day in a non-invasive manner that would provide good control of blood glucose levels and improve care and quality of life. Now we use a sensor which can be easily positioned on the surface of the body with skin contact as shown in Figure 7.
3. Results and Discussion

In Table 3 below, we noticed the relation between the glucose concentration measuring by either invasive or non-invasive methods with many variables including [age, sex, Body Mass Index (BMI), temperature, pressure, pulse rate and respiratory].

From the table, many results can be classified as below:

- The lowest age is 5 years measured blood glucose with a (2.6 Hz sensor) while the highest age is 35 years measured blood glucose with a (1.57 Hz sensor). The blood glucose level is also rising with increasing age.
- The lowest BMI is 15.9 measured blood glucose with a (1.57 Hz sensor), while the maximum Body Mass Index is 35.4 measured blood glucose with a (1.84 Hz sensor). For BMI value increasing, the sensor frequency shift is also increasing.
- The lowest temperature of 36 °C has measured blood glucose with a (2.73 Hz sensor), while the maximum temperature of 37.9 °C has measured blood glucose with a (1.57 Hz sensor). For the temperature value rising, the sensor frequency change is decreasing.
- The lowest pressure value is 100/50 mmHg measured blood glucose with a (1.99 Hz sensor), while the maximum pressure value is 160/100 mmHg measured blood glucose with a (0.54 Hz sensor). When the pressure value increases, the sensor frequency shift is decreasing.
- The lowest pulse rate value is 69 pulse/min measured blood glucose with a (1.5 Hz sensor), while the maximum pulse rate is 100 pulse/min measured blood glucose with a (1.99 Hz sensor). As the magnitude of the pulse rate increases, so does the frequency increasing too.
- The lowest respiratory value is 14 res/min blood glucose measured with (0.54 Hz sensor) while the highest respiratory value is 22 res/min blood glucose measured with (2.71 Hz sensor). When the respiratory value increases, so the frequency also increased.

Based on the above findings shown in Figure 8, we may infer that blood permittivity slowly decreases as we increase blood glucose concentration and the reverse is true where we can increase blood with dielectric properties by decreasing the concentration of glucose.
Table 3. The relation between sensor readings and vital signs.

| Cases | Age | Sex | BMI   | Temperature (°C) | Pressure (mmHg) | Pulse rate (pulse/min) | Respirator (res/min) | BG Level Glucose (gm/dL) | BG Level Sensor (Hz) |
|-------|-----|-----|-------|------------------|-----------------|------------------------|----------------------|------------------------|---------------------|
| 1     | 12  | F   | 27.2  | 36               | 110/70          | 90                     | 16                   | 140                    | 2.73                |
| 2     | 24  | M   | 18.5  | 36.7             | 120/70          | 83                     | 15                   | 180                    | 1.97                |
| 3     | 8   | F   | 25.6  | 37.1             | 100/60          | 95                     | 20                   | 142                    | 2.68                |
| 4     | 17  | M   | 23.3  | 36.5             | 120/80          | 78                     | 18                   | 190                    | 1.89                |
| 5     | 5   | M   | 28.3  | 36.8             | 100/60          | 93                     | 21                   | 135                    | 2.6                |
| 6     | 20  | F   | 17.5  | 37               | 120/70          | 80                     | 17                   | 200                    | 1.7                 |
| 7     | 35  | M   | 15.9  | 37.9             | 130/100         | 75                     | 15                   | 260                    | 1.57                |
| 8     | 14  | M   | 29.2  | 36.2             | 120/80          | 80                     | 16                   | 210                    | 1.82                |
| 9     | 30  | F   | 17.5  | 37.5             | 145/95          | 86                     | 14                   | 220                    | 1.79                |
| 10    | 22  | M   | 20.5  | 37.4             | 135/90          | 79                     | 18                   | 240                    | 1.59                |
| 11    | 29  | M   | 23.4  | 37.7             | 140/85          | 69                     | 15                   | 270                    | 1.5                 |
| 12    | 7   | M   | 26.7  | 36.9             | 100/50          | 100                    | 19                   | 160                    | 1.99                |
| 13    | 18  | F   | 22.5  | 37.1             | 130/80          | 84                     | 15                   | 190                    | 1.88                |
| 14    | 11  | M   | 26.5  | 36.1             | 110/70          | 96                     | 17                   | 175                    | 1.98                |
| 15    | 34  | F   | 18.2  | 37.8             | 155/100         | 83                     | 14                   | 280                    | 1.48                |
| 16    | 25  | M   | 19.5  | 37.9             | 150/95          | 76                     | 15                   | 290                    | 1.35                |
| 17    | 9   | M   | 25.5  | 36.4             | 100/80          | 92                     | 18                   | 134                    | 2.62                |
| 18    | 27  | F   | 22.9  | 37.9             | 135/95          | 80                     | 14                   | 195                    | 1.85                |
| 19    | 19  | F   | 20.5  | 37.5             | 130/90          | 82                     | 16                   | 230                    | 1.69                |
| 20    | 6   | M   | 27.5  | 36.8             | 95/70           | 95                     | 22                   | 140                    | 2.71                |
| 21    | 23  | F   | 30.5  | 37.4             | 130/85          | 100                    | 17                   | 238                    | 1.60                |
| 22    | 13  | M   | 25.4  | 36.9             | 120/80          | 97                     | 19                   | 185                    | 1.95                |
| 23    | 31  | F   | 32.8  | 37.8             | 145/100         | 80                     | 15                   | 280                    | 1.48                |
| 24    | 28  | M   | 24.6  | 37.6             | 150/90          | 70                     | 17                   | 300                    | 0.97                |
| 25    | 15  | M   | 26.8  | 36.2             | 110/75          | 75                     | 16                   | 230                    | 1.7                 |
| 26    | 21  | M   | 35.4  | 37.1             | 135/95          | 87                     | 15                   | 195                    | 1.84                |
| 27    | 35  | M   | 20.5  | 37.8             | 160/100         | 72                     | 14                   | 320                    | 0.54                |
| 28    | 26  | M   | 17.7  | 37.4             | 140/90          | 75                     | 16                   | 270                    | 1.5                 |
| 29    | 33  | M   | 30.9  | 37.7             | 140/90          | 71                     | 14                   | 290                    | 1.35                |
| 30    | 16  | M   | 23.3  | 36.8             | 120/80          | 72                     | 15                   | 260                    | 1.59                |

Figure 8. Blood permittivity as a function of glucose concentration.
4. Evaluation Criteria for Measuring the Level of Blood Glucose Non-invasively
This segment illustrates the reason why blood glucose monitoring is non-invasive in Type-1 diabetic patients. This has high demand as it is ideal for patients with diabetes which would require more regular and continuous blood monitoring without pain.

The motivation behind this segment derives from the popular interest in healthcare and wearable technology (IT) systems with distributed computing technologies. Pervasiveness and non-invasiveness are important primarily because the system also involves good people who would like to be monitored continuously for the sake of prevention and early detection.

UWB is a strong candidate for a link to Wireless Body Area Network (WBAN). Within the range (typically < 10 meters) of Wireless Body Area Network, the relevant wireless technology can provide short-range, low power, and highly secure wireless connexions for use in close proximity or internal of body.

5. Conclusion
In this study, a microwave resonator sensor was designed as a spiral microstrip line that has been simulated to display significant changes in the frequency response value that affect the permittivity value of the material chosen. The proposed method would have the ability to calculate physiological changes arising from variations in blood glucose levels when the material being measured interacts with a microwave resonator, and we can assess blood glucose concentration by Type-1 patient at any time and send this result to Bluetooth smartphone at any time.

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