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Electromagnetic non-invasive glucometry: achievements and prospects

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Electromagnetic non-invasive glucometry: achievements and prospects

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Abstract. This work is devoted to the study of technologies for creating a method for non-invasive measurement of glucose in human blood. A brief overview is given on some of the existing technologies and developments in the field of the radio range for electromagnetic radiation and for recording small changes in the dielectric properties of biological environment. It also presents a new technology for non-contact measurement of blood glucose concentration in phantom blood using magnetic field sensors.

1. Introduction
For several decades to this day, humanity has been developing drugs to fight diseases. One of the most common diseases is diabetes, but there is still no cure for it [1]. Some diabetics do not consider diabetes as a disease, but as a way of life. A person with such a lifestyle needs to follow the diet, exercise and control the level of glucose in the blood [1].

Today, blood glucose is measured using invasive glucometry methods [1–3]. For measuring the glucose level, it is necessary to draw blood and measure the sugar concentration in any laboratory method. This is the essence of contact glucometry. Taking blood is not the most pleasant and safe procedure. Diabetics have to do this procedure dozens of times every day.

The most common glucose monitoring device is a household invasive blood glucose meter with disposable test strips. It's operation principle is based on measuring the change in current resulting from a chemical reaction of the blood with an enzyme (glucose oxidase) applied to the test strip. The measured change in current is proportional to the glucose concentration in the blood sample [4]. This variant of glucose measurement involves direct contact of the enzyme with the blood.

To address the problem with blood sampling, non-invasive (non-contact) or minimally invasive methods of glucose control are being developed. Non-contact methods include: technologies based on the effects of polarization rotation, surface plasmon resonance, technologies using IR spectroscopy, Raman spectroscopy, photoacoustic spectroscopy, and others. Unfortunately, the use of these methods, for one reason or another, does not satisfy the required measurement accuracy, have a high cost and are inconvenient in domestic use [2, 3–8].

In addition to optical methods, it should also be noted about promising technologies using THz and radio frequency range of electromagnetic radiation. Let's consider them in more detail.

2. Overview of microwave technologies
The authors of [5] presented a study using a phantom of a biological environment with different glucose concentrations. The work consisted of measuring the dielectric constant of the medium and the conductivity by the open-ended high-temperature dielectric probe of vector network analyzer. The

biological material's phantom consisted of distilled water, gelatin, oil, food coloring, sodium chloride, and detergent. Depending on the ratio of materials, phantoms of wet skin, fat, blood and muscle were obtained.

The measurements of the dielectric constant were compared with the literature and since satisfactory results were obtained, the authors measured the dielectric properties of blood phantoms, with different concentrations of glucose. According to the results of measurements, it was revealed that there is a difference between the concentrations, but it is rather small [5].

In [6], a biological environment (finger) was simulated using the CST Microwave Studio software package and its interaction with the radiation of a cylindrical resonator-antenna in the range of several GHz units. The simulated finger phantom obeyed the Cole-Cole one-field model for creating dielectric media. The estimation of the phantom's interaction with the antenna radiation was carried out by measuring the parameter S11 at resonant frequencies. As a result of modeling, the authors revealed a shift in the resonance minimum of the S11 parameter depending on the glucose concentration in the model (Figure 1). With increasing concentration, the resonance shifted from a frequency of 4.725 GHz (0 mg / dL) to 4.77 GHz (1600 mg / dL).

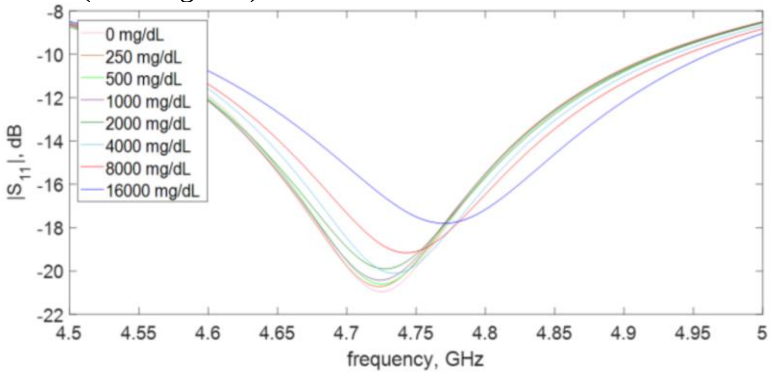


Figure 1. Resonance curves of reflection coefficient from different glucose concentrations.

The paper [7] presents a technology for measuring glucose concentration using two microstrip antennas operating at a frequency of 60 GHz. And that technology is real about is to measure the transmission coefficient S21 of the radiating system through the biomaterial with different concentrations of glucose.

Measurements of the transmitted coefficient were carried out with phantoms of the biomaterial as well as with humans.

A glucose solution in water was used as a phantom of biological material. Having received satisfactory results of measurements with phantoms, the authors of the work started measurements on humans. According to the research results, the authors [7] found a correlation between the transfer coefficient and glucose concentrations (Figure 2).

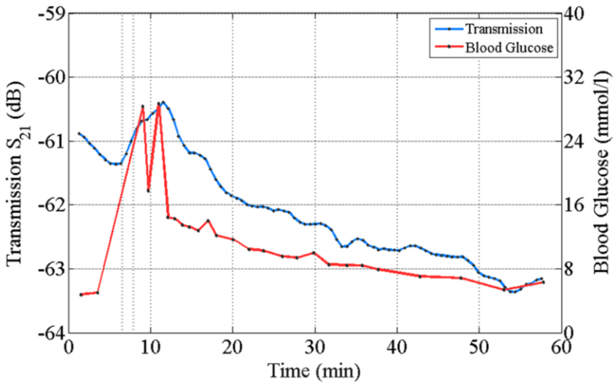


Figure 2. The dependence of the transfer coefficient and blood glucose level on time.

In conclusion to a small review, we can conclude that none of the authors denies the possibility of registering small changes in glucose concentration in the biological environment. As it turns out, the main problem with these measurements is accuracy and repeatability. Due to the requirements for blood glucose monitoring systems [8], satisfactory results have not been achieved so far.

3. Using a magnetic field

The magnetic field is currently used in various fields and methods ranging from navigation systems, tomography, geological prospecting, and ending with glucometry [9–14]. One of the reasons for the widespread use of magnetic fields is the simplicity and low cost of materials and methods.

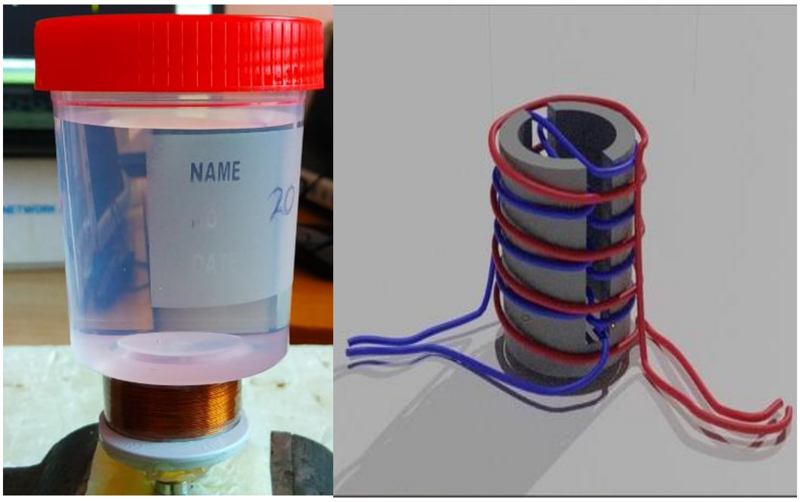
In this work, for use in non-invasive glucometry, an electromagnetic sensor is used, based on a differential circuit for connecting inductors. The possibility of using differential coils for measuring glucose concentration is presented in [10].

4. Description of the experiment

The differential circuit consists of two coils, one of which consists of a pair of out-of-phase radiating inductors (this is the first port). The second coil is wound around the first (this is the second port) and acts as a receiving coil.

As the medium used saline diluted to different concentrations of glucose (blood phantom). Phantoms were created with a volume of 100 ml each, with glucose concentrations of 0, 5, 10, 15 and 20 mmol/L. The solutions were placed in plastic containers and applied to the sensor (Figure 3).

Both ports are connected to Planar S5048 vector network analyzer and measured transmission coefficient S21 in the range from 20 kHz to 4.8 GHz in increments of 300 kHz sampling frequency.



a b

Figure 3. Differential measurement scheme: a) the measurement process; b) a simplified structure of winding coils.

5. Data processing and results

The transmission coefficient was measured as: $S_{21} = |S_{21}|\exp(i\varphi)$.

The results of all measurements of S21 phantoms with different glucose concentrations were first of all cleared from the influence of fluctuations (unevenness) in the frequency of the transfer function of the measuring system by subtracting the S21 values measured in the absence of a blood phantom. The data thus obtained were further normalized to values for pure saline, that is, at zero glucose concentration. The resulting frequency dependences were analyzed for associations with glucose concentration.

According to the results of the analysis, the measured frequency range revealed areas of monotonicity, where the transfer coefficient of different solutions is clearly different. The most clearly marked area is shown in Figure 4.

In Figure 4, the ordinate axis represents relative changes in differential coil system transmission coefficient n as a function of frequency, and sensing the concentration of glucose in phantom. Setpoints glucose concentration are shown by dots.

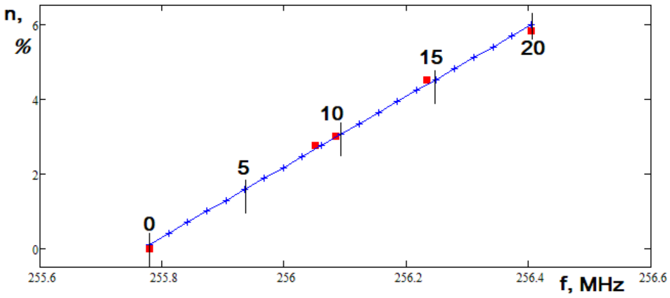


Figure 4. Changing the transmission coefficient of the differential coil system.

6. Conclusion

The section of the linear dependence of the transfer coefficient of the system of differential coils on the concentration of glucose in the blood phantom was experimentally discovered. It shows the prospect of continuing glucose studies using an alternating magnetic field. It is known that a change in the magnetic field causes the appearance of an induced electric current, which depends on the concentration of free charge carriers in the blood phantom. This concentration is related to glucose concentration.

Measurements of this kind use slowly changing quasi-static near-field fields, which are much weaker attenuated in absorbing media. The continuation of the planned studies should give the key to the creation of a non-invasive method for monitoring blood sugar and further for the treatment of diabetes.

Acknowledgments

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