Effect Of Metals On The Reflection Coefficent For Non-Invasive Glucose Sensing In The Millimeter Waveband

Ömer Faruk GÖKTAŞ[11], İlyas ÇANKAYA[2], Esra ŞENGÜN ERMEYDAN[3]

[1,2,3] Department of Electrical Electronic Engineering, Faculty of Engineering and Natural Sciences, Ankara Yıldırım Beyazıt University, Ankara, Turkiye

[1] ORCID No: https://orcid.org/0000-0002-2021-4052
[2] ORCID No: https://orcid.org/0000-0002-6072-3097
[3] ORCID No: https://orcid.org/0000-0002-5953-4301

Keywords

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Abstract

Diabetes Mellitus is a chronic disease that affects more than 400 million people worldwide. Therefore, to minimize the side effects of the disease and to prevent hyperglycemia and hypoglycemia, it is important to determine and monitor the glucose level in blood. Invasive, minimal invasive and non-invasive methods are used to determine the glucose level in the blood. However, invasive and minimal invasive methods bring infectious and psychological risks and they are not cost-effective solutions. Besides, invasive methods cannot provide continuous monitoring of the blood glucose level and the risks for hyperglycemia and hypoglycemia during sleep cannot reduced. This situation has led researchers to determine the glucose level in the blood with a non-invasive method. In the search for non-invasive methods, the microwave and millimeter wave portion of the electromagnetic spectrum have significant potential. Complex permeability of blood for millimeter waveband is very sensitive to glucose concentration. In this study, materials such as brass, steel, aluminum and copper were used to re-reflect the signals applied to the glucose solution through the WR-28 adapter. It has been shown that with better reflection coefficient, glucose level can be distinguished more clearly and steel displays better reflection performance compared to other materials.

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1. INTRODUCTION

Non-invasive methods to measure blood glucose level are divided into four categories as electrochemical-based, optical based, electromechanical and electromagnetic-based methods (Sutradhar & Hazarika, 2022). Many studies have been conducted on various body fluids to determine glucose levels in tear fluid (Zhang et al., 2011), saliva (Malik et al., 2015), breath (Guo et al., 2012), and sweat (Gao et al., 2016) using electrochemical-based method. These studies showed a weak and lagging relationship between blood glucose levels and measured values. In electromagnetic-based methods, electromagnetic signals of different wavelengths are used and the relationship between the properties of the measured signal and the glucose level in the blood is

[1]Resp author; e-mail: ofgoktas@ybu.edu.tr

investigated after interaction with the human body. A very broad variety of studies focusing on electromagnetic wavelengths have been found in the literature such as radiowave/microwave/millimeter wave, bioimpedance spectrograpgy and raman spectroscopy (Xue et al., 2022). Microwave and millimeter wave radiation offer lower energy per photon and less scattering, meaning they can go deeper in the tissue to reach areas with sufficient blood concentration and provide a more accurate glucose tracking (Gonzales et al., 2019). Microwave and millimeter wave band methods three basic techniques to detect and define blood parameters: transmission, reflection and resonance perturbation. The forward-based transmission method examines the attenuation and phase change in the transmitted signal due to glucose level change by measuring the S21-transmission coefficient. Reflection-based technique, on the other hand, changes the amplitude and phase of the reflected signal due to the change in permeability in the blood when the glucose level changes, and the change in the glucose level is monitored by measuring the S_{11}-reflection coefficient. The resonance perturbation method works as a subset of the reflection and transmission methods targeting to measure changes in resonant frequency, quality factor and 3dB bandwidth and correlate them with variations in dielectric properties of the tested medium (Gonzales et al., 2019). In the first study conducted in the millimeter waveband, the researchers measured the complex permeability of the glucose solution and showed the variation of the transmission coefficient in the 35 - 38 GHz range (Nikawa & Someya, 2001). There are studies by measuring the transmission and reflection coefficient from a waveguide positioned on the tested tissue to the waveguide using an active transmission port (Siegel et al., n.d., 2014). There is a study examining the changes in glucose level by compressing animal tissue using a pair of patch antennas facing each other at 58 - 62 GHz (Cano-Garcia et al., 2018). In another study, a study based on measuring the transmission coefficient at 60 GHz using two microstrip patch antennas was carried out (Saha et al., 2017). In another study, Hu et al. proposed a non-invasive glucose concentration estimation system using transmission amplitude and phase data at glucose concentrations ranging from 0-300 mg/dL in the 60-80 GHz band (Hu et al., 2019).

Researchers stated that the reflection coefficient data is effective in distinguishing the glucose level in the blood (Cano-Garcia et al., 2016; Göktaş et al., 2022; Hofmann et al., 2012; Nikawa & Someya, 2001). Studies have been carried out to obtain a better S_{11}-reflection coefficient. In this study, materials such as brass, steel, aluminum and copper were used to re-reflect the signals applied to the glucose solution through the WR-28 adapter. When the results obtained were examined, it was observed that the measurements made using steel gave better results. In the following sections of the study, information is given about how the S_{11}-reflection coefficient parameter is measured and the experimental setup. Finally, the obtained results are mentioned and an idea is given about what the future studies could be.

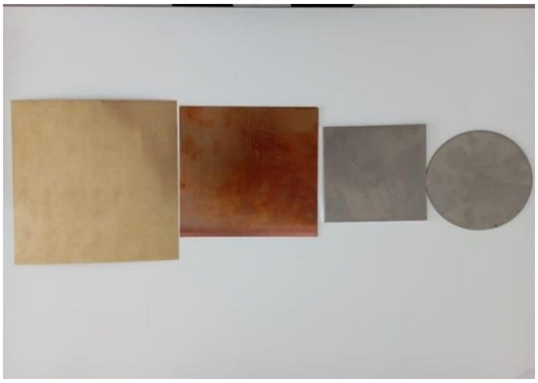
2. MATERIAL AND METHODS

Scattering parameters are the method that shows the circuit in a matrix structure without knowing which circuit elements the millimeter wave circuit consists of and its internal structure. In other words, it consists of the transition equations of a circuit defined as a black box.

Figure 1. Representative illustration of a 2 port circuit

In millimeter wave circuits, S parameters can be defined as the ratio of the voltage coming from any gate to the voltage reflected from the same gate. If V1+ is the sign applied to the system, some of this sign will be reflected as V1-, while some will exit the system as V2+. The reflection coefficient (S_{11}) is defined as the ratio of the amplitude of the reflected signal to the amplitude of the transmitted signal. To determine the S parameters, a fixed frequency wave is sent to each gate of the box and reflected and transmitted waves are measured at the other gates (Göktaş et al., 2022). In this way, in addition to the reflection coefficient parameter, the reverse voltage gain (S12), the forward voltage gain (S21) and the output gate voltage gain (S22) are calculated.

In this study, the effect of different materials on the reflection coefficient was investigated. Materials such as brass, steel, aluminum and copper (Figure 2.(a)) were used to re-reflect the signals applied to the glucose solution (Figure 2.(b)) via the WR-28 adapter.


(a)


(b)

Figure 2. Solutions and reflective metals (From left to right brass, copper, aluminum and steel)

In the study using a vector network analyzer, the WR-28 adapter was placed under the sample cup. Metals were placed on the upper part of the sample cup in order to re-reflect the incoming signal. The experimental setup is shown in Figure 3. The measurements were repeated 20 times and the average of these measurements was taken. Solution densities used in the study are in the range of 50 - 20000 mg/dl.

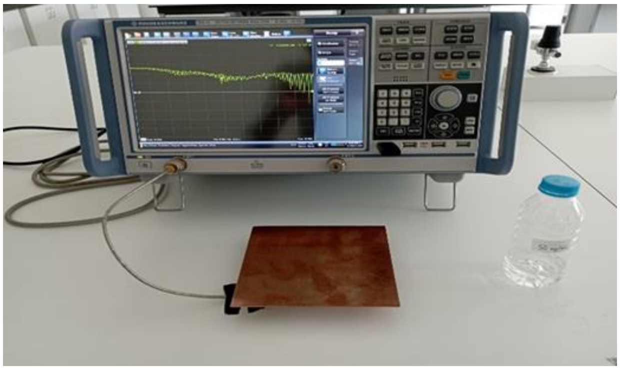


Figure 3. Experimental setup

3. RESULTS

Firstly, the effects of various metals on the reflection coefficient were examined and the results obtained are given in Figure 4 comparatively. Figure 4 shows the S11-reflection coefficient data obtained by placing the empty container and various materials on it. According to these data, the best results were obtained in steel, aluminum, brass and copper, respectively.

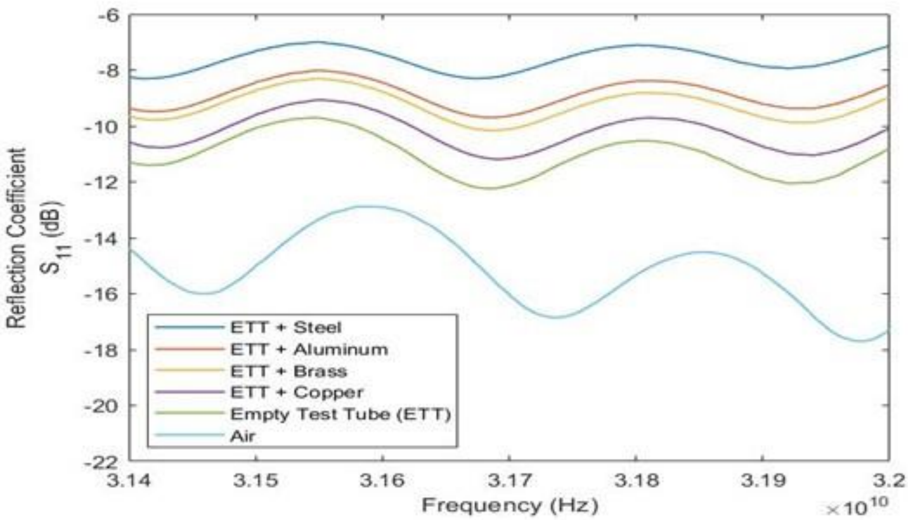


Figure 4. Reflection coefficient data obtained using empty container and reflective materials at 31 GHz.

Then, the graphical results of the measurements made using steel in solutions with different glucose densities are given in Figure 5. Since the operating range of the WR-28 adapter used in the measurement is between 28-40 GHz, the reflection coefficient data obtained at the center point between 31-34 GHz are presented. In the study, air and glucose solutions can be clearly distinguished. However, the difference in the change of glucose concentration in aqueous solutions is relatively small. These results show consistency when compared with other studies in the literature (Hofmann et al., 2012; Nikawa & Michiyama, 2007; Omer et al., 2018).

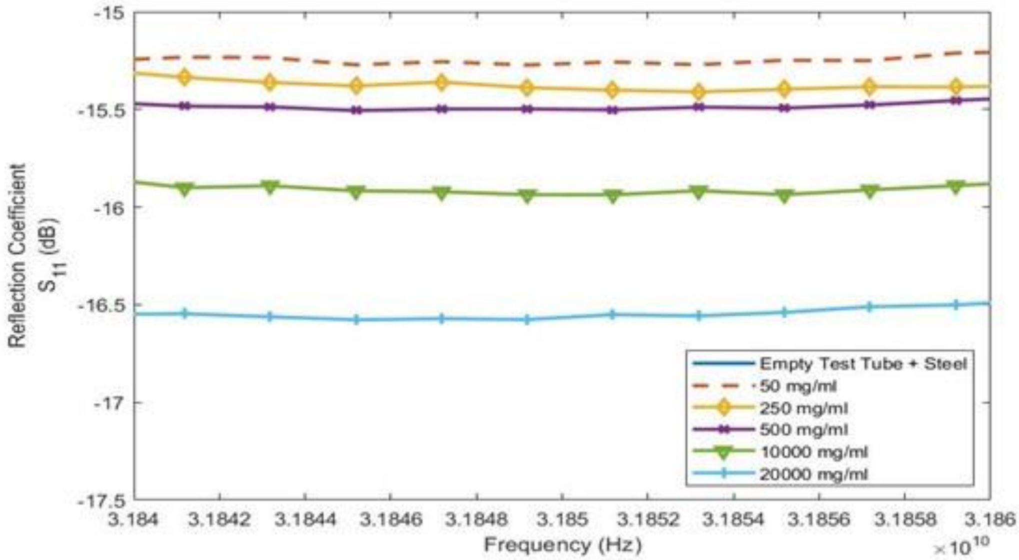


Figure 5. S_{11}-reflection coefficient data obtained using the WR-28 adapter and steel

4. CONCLUSION

This study showed that aqueous solutions with different glucose concentrations in the 30 – 35 GHz frequency range can be distinguished by non-invasive methods of glucose level measurement in the mm-wave band. Besides, the effects of various metals on the S_{11}-reflection coefficient were investigated. The addition of glucose to water changes the complex permeability of the water. This has enabled the reflection coefficient to be discriminating for solutions with different concentrations. Our basic approach is to find a ratio between the blood glucose level and the measured signal. However, the signal loss is quite high due to the scattering of the transmitted signal. At this stage of the study, the effect of metals on the reflection coefficient for different glucose concentrations at mm-wavelength was investigated. It has been shown that if the reflection coefficient is obtained better, the glucose level can be distinguished more clearly. It has also been shown that steel has better reflective performance than other materials. As a future work, these results will guide the material selection for the antenna to be designed so that the reflection coefficient can be obtained better.

Conflict of Interest

The authors declare that they have no conflict of interest.

Contribution of Authors

The authors involved in this study are Ömer Faruk GÖKTAŞ, İlyas ÇANKAYA and Esra ŞENGÜN ERMEYDAN; contributed to all aspects of the study. All authors contributed to the idea, design, inspection, resources, data collection, literature review, critical review and analysis and interpretation sections of the study.

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