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Blood-Sugar Monitoring by Reflection of Millimeter Wave

Yoshio Nakawa and Jutuyuki Misukawa
Graduate School of Engineering, Kansai University
4-28-1 Setagaya, Setagaya-ku, Tokyo, 154-8515 Japan

Abstract — Diabetes mellitus has now emerged as a serious public health problem in Asia. To control blood glucose level, blood-sugar monitoring technique is necessary. Nevertheless, non-invasive blood-sugar measuring technique has not been in practical use. Complex permittivity of blood is very sensitive to the glucose concentration in microwaves. In this paper, a new technique is proposed to obtain blood glucose level using a resonant applicator non-invasively. It is found from in vivo measurement of reflection coefficient using the resonant applicator, blood glucose level can be obtained by measuring the value of reflection coefficient at the resonant frequency.

Index Terms — Medical diagnosis, reflection coefficient, blood-sugar, in vivo measurement.

I. INTRODUCTION

In recent years, diabetes mellitus has now emerged as a serious public health problem in Asia. By estimated 330 million persons in the Southeast Asia region are affected at present. It is expected that by the year 2025 there will be nearly 60 million diabetics in this region. According to these estimations, by the year 2025, there will be an added 170% increase in the number of diabetics in developing countries, while the increase in developed countries will be about 120%.[1]. To study the diabetes, it is vital to measure the blood glucose level. The available techniques of the measurement are very invasive method which is to collect the blood sample from patient. It is not a high standard for them. Today, the techniques of non-invasive measurement are already developed[1-3].

The complex permittivity of blood is very sensitive to the glucose concentration in microwaves. Nevertheless, high loss of human tissue sometimes makes the change of glucose undetectable. Usually, it is assumed that the complex permittivity of blood is constant. The change of the complex permittivity of human model can be obtained and the change of the blood glucose level[3].

In this paper, to apply measurement to obtain blood glucose level, reflection coefficient of the human tissue are simulated, and the improvement of sensitivity is evaluated for the measurement of reflection coefficient. The technique is tested in vivo and the result can be applied to measure blood glucose non-invasively.

II. MEASUREMENT OF REFLECTION COEFFICIENT

A. Resonant Non-Invasive Probe

The reflection coefficient is obtained by using an open coaxial probe. The complex permittivity is calculated by measured reflection coefficient. The experimental setup is shown in Figs. 1 (a) and (b). A Vector Network Analyzer (Agilent 8753C) was used to measure the reflection coefficient from the open coaxial probe at room temperature. The total error of the measurement is ±5% or less.

Fig. 2 (a) and (b) shows the Cole-Cole plot of pure water and glucose solution with 5.0% glucose concentration using an open coaxial probe. In Fig. 2 (a), the temperature of the medium is varied and the complex permittivity was obtained with the WDL (decrease constant) and increasing the amount of glucose especially in the lower frequency. Figs. 3 (a) and (b) show the result of the complex permittivity versus frequency of the glucose solution which mixed with 5.0% weight percent sodium chloride. The results are shown with glucose concentration as a parameter. The results show the frequency increase, the relative permittivity, and the electric loss decrease. From Fig. 3 (a) and (b) it is found that the weight percent change of glucose concentration, the value periodically changes 0.250 - 1.125 when glucose concentration changes 0.5 weight percent. At the same time, the electrical loss will change 50%. Therefore, by measuring the microwave reflection coefficient, it is possible to measure the change of the blood glucose level. Nevertheless, high sensitivity measurement technique is necessary.

III. MEASUREMENT OF REFLECTION COEFFICIENT

The reason why the sensitivity is needed is put between the waveguide and the reference. The setup is shown in Fig. 1 (a). In Fig. 1 (b), metal fiber with the diameter of 0.005 mm.
the length of 4.8 mm is applied. PTFE with the thickness of 0.56 mm is attached on the aperture of waveguide.

Fig. 1. Experimental setup to measure complex permittivity of glucose solution.

(a) Cole-Cole plot of pure water.

(b) Cole-Cole plot of glucose contents water with 5.0% concentration.

Fig. 2. Cole-Cole plot of medium.

(a) Real part

(b) Imaginary part

Fig. 3. The frequency characteristic of complex permittivity of glucose solution.

Fig. 4. Diagnosis of blood sugar level by microwave reflection coefficient.
mm. The metal thickness is 40 μm. Here, a = 22.4 mm, b = 22.4 mm, c = 2.78 mm, d = 2.78 mm and e = 1.36 mm.

Fig. 5. Frequency characteristic of reflection coefficient (amplitude).

The simulated result of the reflection coefficient for amplitude and phase are shown in Figs. 5 (a) and (b). In the simulation, frequencies up to 60 GHz were performed. The results show that the 0.1 weight percent change of glucose concentration, the resonant frequency of the reflection change 25 MHz. If the frequency is fixed at 56.64 GHz, the reflection increases 1.6 dB for every 0.1 weight percent increase of glucose concentration. Also, from Fig. 5 (b), the change of glucose concentration can be affected the phase change of reflection coefficient. The method presented here is highly sensitive to obtain the change of glucose level for the blood flowing under the nail.

IV. MEASUREMENT OF REFLECTION COEFFICIENT USING METAL PATCH

To develop more practical applicator for the measurement, circular patch applicator is developed. The patch is fed by waveguide. Fig. 6 shows the general view of the patch applicator. The patch is on the epoxy resin substrate with 0.91

The applicator setup is shown in Fig. 7. The applicator, directly attached to the fingertip, is set with waveguide. The simulation was performed using TLM method to obtain reflection coefficient.
V. EXPERIMENTAL RESULTS

The change of reflection coefficient was measured as changing glucose contents in resonant frequency. The result is shown in Fig. 8. It is found that the resonant frequency becomes lower when the glucose contents become higher. These characteristics are corresponding to the characteristics of the glucose solution (See Fig. 3).

The change of reflection coefficient was measured in vivo for volunteer subject as changing glucose contents in reflection coefficient. The result is shown in Fig. 9. The result shows that the change of resonant frequency is almost as linear to the change of blood glucose level and the ratio is 0.011 [dB/(mg/dl)].

VI. CONCLUSIONS

Microwave has a great potential to apply to the field of medicine. Simulated and experimental evaluations measuring reflection coefficient in microwaves show the possibility of the non-invasive measurement of blood glucose level. From the in vivo measurement, the sensitivity of the reflection coefficient as a function of the blood glucose ratio was 0.011 [dB/(mg/dl)]. This value can be enough detectable using such as vector network analyzer.

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