Blood-Sugar Monitoring by Reflection of Millimeter Wave

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Blood-Sugar Monitoring by Reflection of Millimeter Wave

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***Abstract* — Diabetes mellitus has now emerged as a serious public health problem in Asia. To control blood glucose level, blood-sugar monitoring is necessary. Nevertheless non-invasive blood-sugar monitoring 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. An estimated 30 million persons in the South-East Asia region are affected at present. It is estimated that by the year 2025 there will be nearly 80 million diabetics in the region. According to these estimates, by the year 2025, there will be an almost 170% increase in the number of diabetics in developing countries, while the increase in developed countries will be about 42%[1]. To control the diabetes, it is vital to measure the blood glucose level. The available technique of the measurement is now only invasive method, which is to collect the blood sample from patients. It is not a light burden for them. It is why the techniques of non-invasive measurement are strongly demanded[2], [3].

The complex permittivity of blood is very sensitive to the glucose concentration in microwaves. Nevertheless, high loss of human tissues sometimes hide the change of complex permittivity, if we measure the permittivity from outside, non-invasively. The change of the reflection coefficient of human model can be obtained the change of the blood glucose level[4], [5].

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

II. MEASUREMENT OF COMPLEX PERMITTIVITY OF GLUCOSE

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 Fig. 1. Vector Network Analyzer (Anritsu 37397C) was used to measure the reflection coefficient from the open coaxial probe at the room temperature. The total error of the measurement is ±5% or less.

Fig. 2 (a) and (b) show the Cole-Cole plot of pure water and glucose containing water with 5.0 % glucose concentration using open coaxial probe. In Figs 2, the temperature of the medium is changed and the complex permittivity was obtained with the 8 °C of temperature range. It is found that the relative dielectric constant decrease with increasing the temperature in the lower frequency. Also, from the results shown in Figs. 2, it can be found that the relative dielectric constant increase with increasing the contents 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 is mixed with the 0.9 weight percent sodium chloride. The results are shown with the glucose concentration as a parameter. The results show that the frequency increases, the relative permittivity and the dielectric loss decrease. From Figs.3 (a) and (b), it is found that 1.0 weight percent change of glucose concentration, the complex permittivity changes 0.386 - j0.325 in average. When glucose concentration changes 1.0 weight percent, the relative dielectric constant will change 2.0% and dielectric loss will change -1.2%. Therefore, by measuring the microwave reflection coefficient, it might be possible to measure the change of the blood glucose level. Nevertheless high sensitivity measurement technique is necessary.

III. MEASUREMENT OF REFLECTION COEFFICIENT USING RESONANT METAL FIBER

In order to increase the sensitivity, a metal fiber is put between the waveguide and the fingertip. The setup is shown in Fig. 4. In Fig.4, metal fiber with the diameter of 0.05 mm, the length of 4.8 mm is applied. PTFE with the thickness of 0.56 mm is attached on the aperture of waveguide.

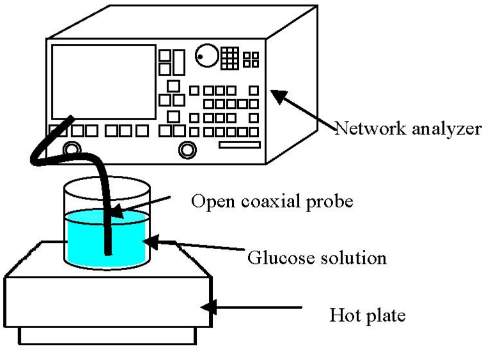
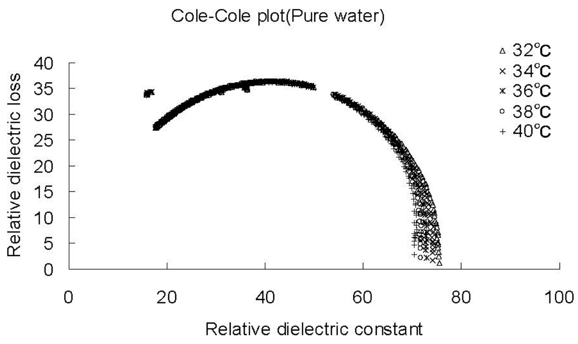
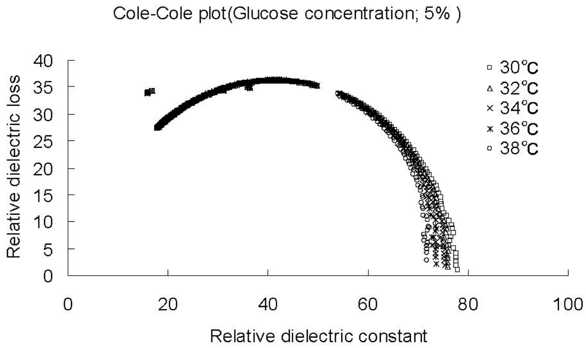


Fig. 1. Experimental setup to measure complex permittivity of glucose solution.

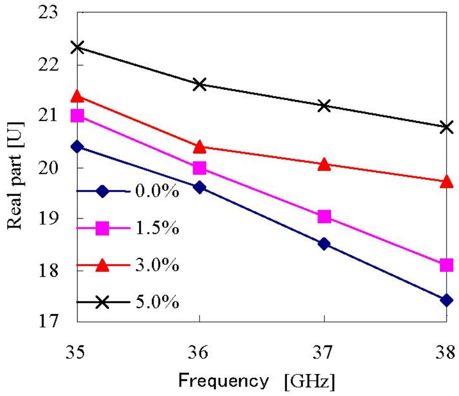


(a) Cole-Cole plot of pure water.

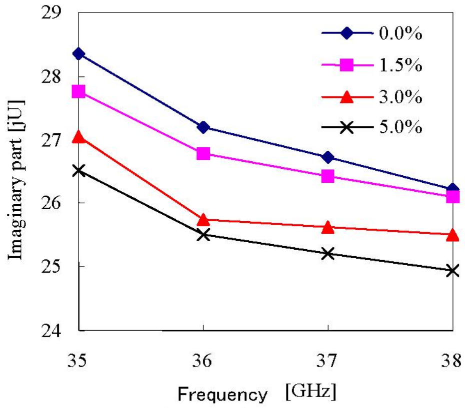


(b) Cole-Cole plot of glucose contents water with 5.0% concentration.

Fig. 2. Cole-Cole plot of medium.



(a)Real part



(b)Imaginary part

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

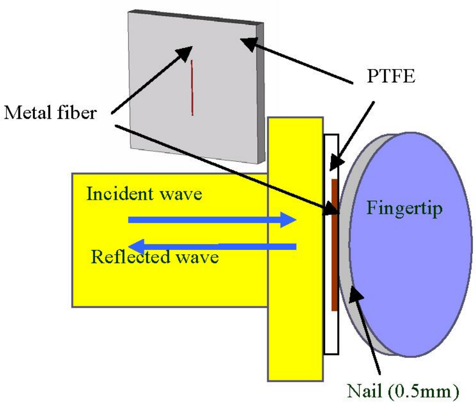
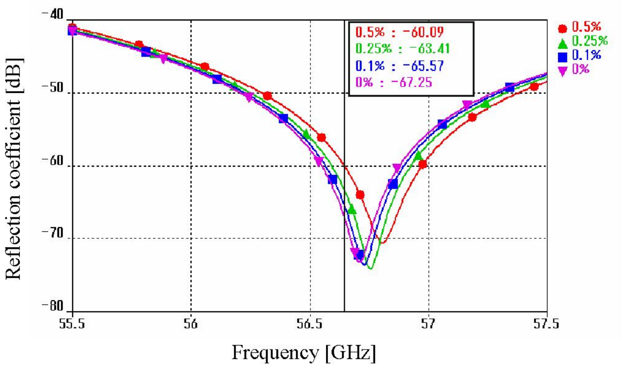
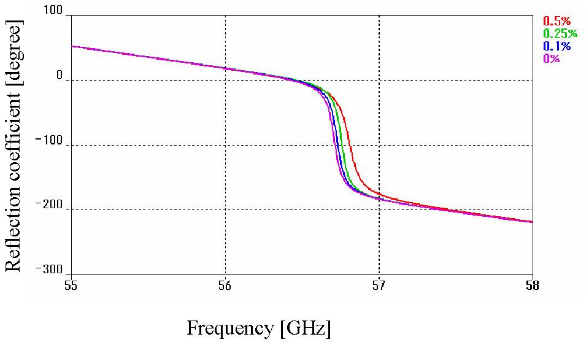


Fig. 4. Diagnosis of blood sugar level by microwave reflection coefficient.



(a) Amplitude



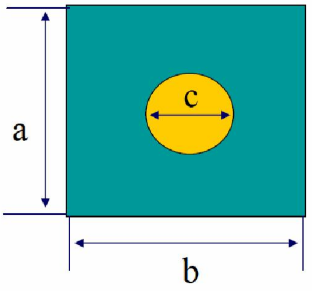
(a) Phase

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

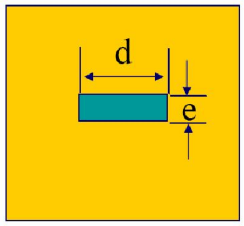
The simulated result of the reflection coefficient for amplitude and phase are shown in Figs. 5 (a) and (b). In the simulation, frequencies up to 60 GHz were performed. The results show that the 0.1 weight percent change of glucose concentration, the resonant frequency of the reflection change 25 MHz. 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 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.



(a) Schematic of patch.



(b) Patch feeder in waveguide side.

Fig. 6. General view of patch applicator.

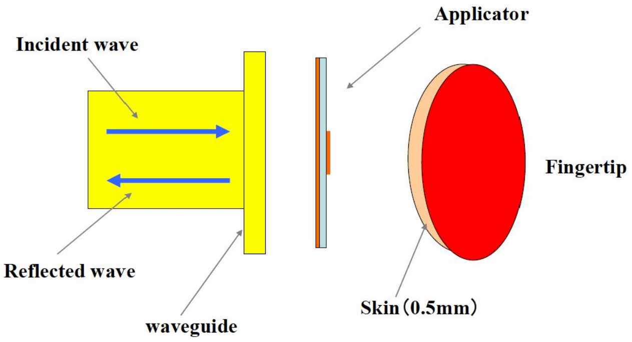


Fig. 7. Setup of the applicator.

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.

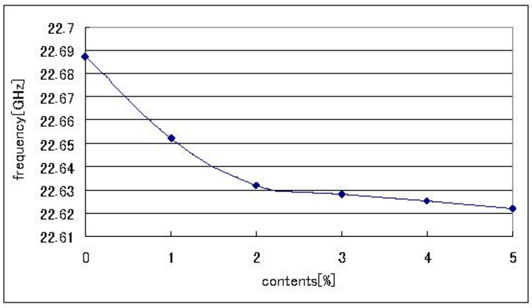


Fig. 8. Simulated reflection coefficient *vs.* glucose contents.

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)].

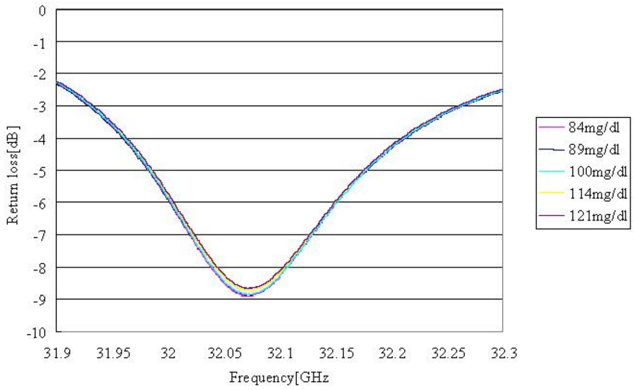


Fig. 9. *In vivo* experimental results of return loss *vs.* frequency as a parameter of glucose level.

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.

ACKNOWLEDGEMENTS

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