NON-INVASIVE MEASUREMENT OF BLOOD SUGAR LEVEL BY MILLIMETER WAVES

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***Abstract* — Measurement of blood sugar level by non-invasive method is highly required. Nevertheless, practical non-invasive technique has not been reported. In this paper, to measure blood sugar level using millimeter wave non-invasively, complex permittivity of glucose mixed sodium chloride solution is measured and obtained the change of transmission coefficient in millimeter wave region. An applicator system to measure blood sugar level *in vivo* is designed and optimized by simulation using Transmission Line Modeling (TLM) method.**

I. INTRODUCTION

Recently, the number of patients of diabetics becomes increased. It is estimated about 2,200,000 in Japan. The diabetes itself does not feel sickness by itself. Therefore it is considered that the real number of patients will be more than above. In Ministry of Health, Labour and Welfare research 1996, the number of suspicious for diabetics is 690 million and the number of undeniable for possibility of diabetics is 680 million [1].

The measurement of blood sugar level is indispensable to control the diabetes. To measure the blood sugar level, the current technique available is only invasive method which to collect blood from the patient. It is demanded to develop techniques to measure the blood sugar levels non-invasively [2].

In this study, a new technique to measure blood sugar level, which to use millimeter waves, is proposed. The transmission coefficient of glucose solution in millimeter waves is measured. Discussion is made for the possibility of the non-invasive measurement of the blood sugar level by measuring transmission coefficient of the part of human body non-invasively.

II. MEASUREMENT OF COMPLEX PERMITTIVITY OF GLUCOSE SOLUTION

To confirm the possibility of measurement of blood sugar level *in vivo*, glucose solution including 0.9 weight % (w.t.%) sodium chloride was applied as blood equivalent fluid as *in vitro* experiment. At first, complex permittivity and conductivity were measured by reflection method in 35-38 GHz using the system shown in Fig. 1. The open coaxial probe was used for the measurement and the error of the measured complex permittivity is less than ±5%. The results are shown in Figs. 2. (a) and (b). The change of complex permittivity for 1% concentration change of glucose in the frequency range of 35-38GHz is 0.16-j0.31.

It is known in the frequency range below 10 GHz, the conduction loss from ionized sodium chloride becomes high, thus the change of the complex permittivity from glucose contents is hidden by the saline loss. On the other hand, the frequency range above 30 GHz, dielectric loss becomes dominant. In this frequency range, the complex permittivity heavily depends on the concentration of glucose solution even if saline is including.

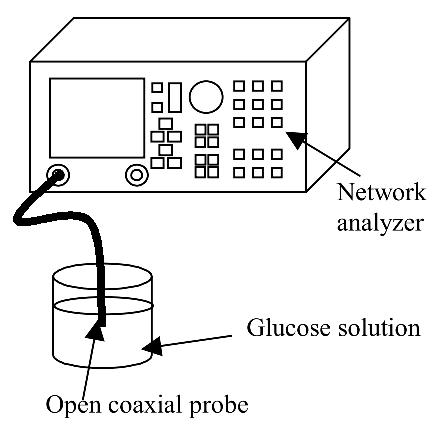
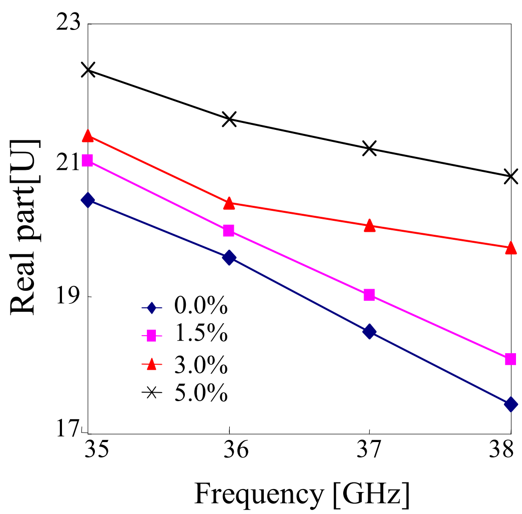
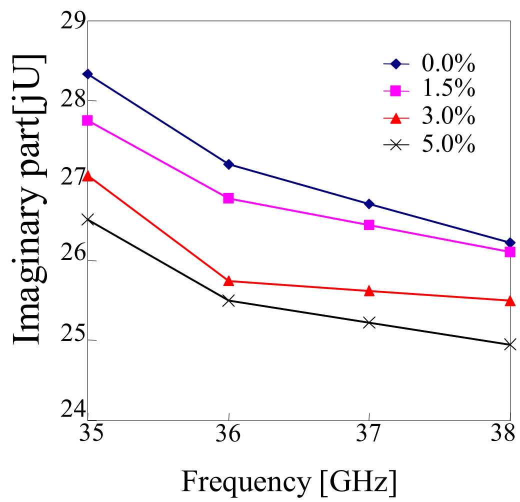


Fig. 1. Experimental setup.



(a) Real part



(b) Imaginary part

Fig.2. Change of relative complex permittivity versus glucose concentration in 35-38GHz.

III. Estimation of Transmission Coefficient Change

It is necessary to measure very small change of complex permittivity, because usual change of glucose contents in blood is very small. To obtain very small change of transmission coefficient for soft material as human tissue, subtracted transmission coefficient is measured to reduce the disturbance occurred from individual differences.

Two lossy layer, which is similar except for the thickness, is considered as Figs 3 (a) and (b). From the plane wave approximation, subtracted transmission coefficient for the Fig. 3 (a) and (b) is

$$E = \frac{\frac{E_1'}{E_1}}{\frac{E_2'}{E_2}} = e^{-jkL} \qquad (1)$$

where, L is defined as

$$L = L_1 - L_2 \qquad (2)$$

The transmission coefficient k is

$$k = \beta - j\alpha \qquad (3)$$

where α is the attenuation constant and β is the phase constant and can be represented as

$$\alpha = \sqrt{\frac{1}{2}\omega^2\mu_0\left(\sqrt{\varepsilon'^2+\varepsilon''^2}-\varepsilon'\right)} \qquad (4)$$

$$\beta = \sqrt{\frac{1}{2}\omega^2\mu_0\left(\sqrt{\varepsilon'^2+\varepsilon''^2}+\varepsilon'\right)} \qquad (5)$$

where ε ' is permittivity, and ε " is loss factor. When equation (3) is substituted to equation (1),

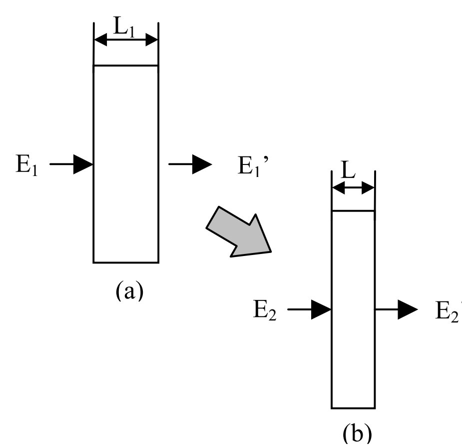


Fig. 3. Measurement of subtracted transmission coefficient.

$$E = e^{-j(\beta - j\alpha)L} = e^{-\alpha L} e^{-j\beta L} \qquad (6)$$

therefore, subtracted loss of material which the thickness is L can be obtained as

$$E = e^{-\alpha L} \qquad (7)$$

In real measurement, thin part of the body, *i.e.* finger or ear, can be used to measure transmission coefficient to obtain blood sugar level. For the *in vitro* study, thin acrylic resin container is used for the measurement (see Fig. 4).

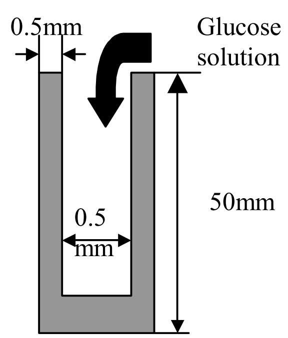


Fig. 4. Thin acrylic resin container.

To reduce the reflection between applicator and sample boundary, taper shaped Teflon is applied as dielectric guide. The shape of Teflon is shown in Fig. 5. The one side of the Teflon guide is inserted in the waveguide.

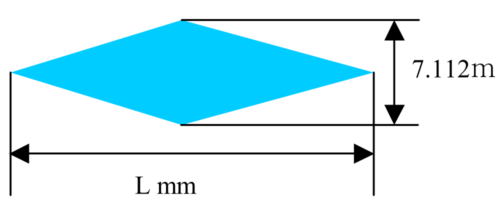


Fig. 5. Dielectric guide using Teflon.

IV. Simulation Using TLM Mehod

Transmission coefficient is simulated using TLM method. Simulation model is shown in Fig. 6. As shown in Fig. 6, excitation source, Teflon part, acrylic resin holder and glucose sample are set in the dielectric rod applicator. Simulated transmission coefficient versus glucose concentration where dielectric length L is set as 26.0 mm is shown in Fig. 7. In Fig. 7, the total transmission coefficient from the source to the receiving terminal is indicated. In Fig. 7, the thickness of the layer of glucose solution is 0.5 mm. From Fig. 7, it is found when the glucose concentration increases in the saline solution, the loss becomes decreased in the frequency range from 35 to 38 GHz. The rate of decrease is 0.3 dB/w.t.% of glucose consentration.

To obtain accurate transmission coefficient of the soft material, measuring setup is designed as shown in Fig. 8. As shown in Fig. 8, the subtracted transmission coefficient is obtained as changing the thickness of the material by rotating the vernier of the micrometer. The results is shown in Fig. 9. From the results, it is found that sensitivity increased to 0.4 dB/w.t. % of glucose consent-

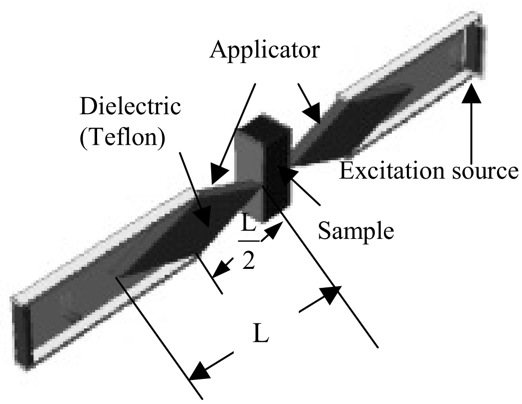


Fig.6. Simulated model.

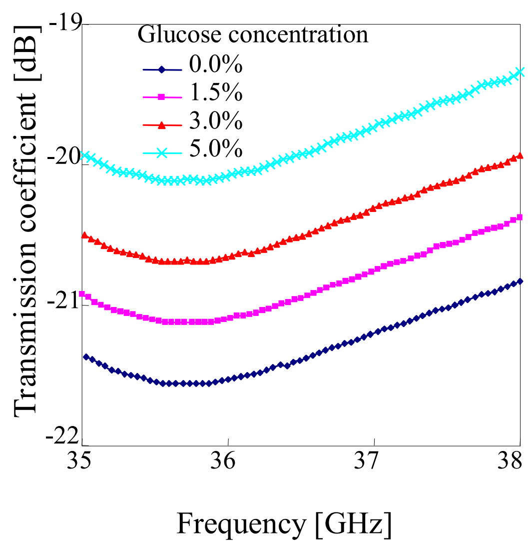


Fig. 7. Frequency characteristic of transmission coefficient.

ration and can obtain stable results. The thickness is changed from 1.0 mm to 0.5 mm, the simulated results agree well to the theoretical value.

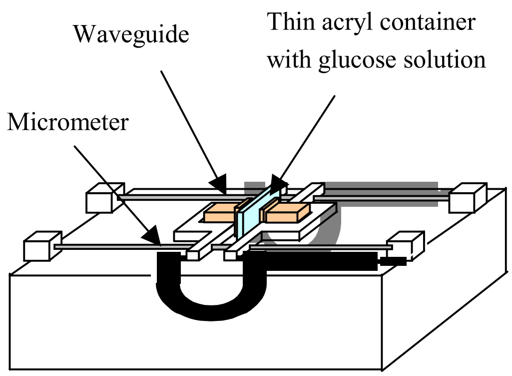


Fig. 8. Measuring setup to obtain subtracted transmission coefficient.

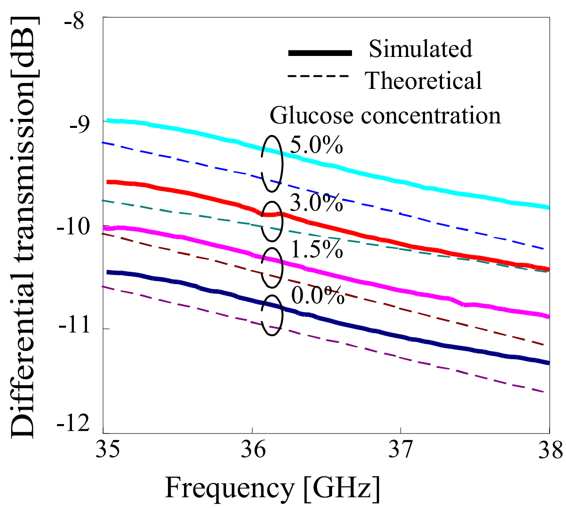


Fig. 9. Frequency characteristic of subtracted transmission coefficient.

V. Conclusions

In this study, complex permittivity of glucose solution mixed with saline solution was measured and the change of transmission coefficient can be obtained as changing the concentration of glucose solution in millimeter wave region from 35 to 38 GHz.

By obtaining subtracted transmission coefficient, it can be measured that the sensitivity can be increased as 0.4 dB/w.t.% for the change of glucose concentration.

The results show the possibility of non-invasive measurement of blood sugar level by millimeter waves.

References

[1] T, Yokoyama, "Diabetes Prevention and Treatment", pp. 18-19, TAKAHASHI SHOTEN, 1999.

[2] D. Someya, Y. Nikawa, and M. Yamamoto, "Measurement of Blood Sugar Level Using Millimeter Waves", Korea-Japan Microwave Workshop (KJMW2000) Proceeding, pp.32-35, 2000.