# Measurement of the dielectric properties of the skin at frequencies from 0.5 GHz to 1 THz using several measurement systems

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***Abstract*—The dielectric properties of skin layers, which are the epidermis, dermis, and subcutaneous fat, were measured using several measurement systems. Measurements were conducted *in vitro* from 0.5 GHz to 1 THz. Measurement results indicated good agreement between each measurement system at a tissue temperature of approximately 35 °C.**

## I. INTRODUCTION

KNOWLEDGE of the dielectric properties of biological tissues is necessary for understanding the interaction between electromagnetic fields and the human body. Dielectric properties reported by Gabriel [1] have contributed to the safety assessment of electromagnetic field exposure and research and development for medical applications. However, the measurement conducted by Gabriel was at frequencies of up to 20 GHz because of the limitations of the measurement system [1]. With the advancement of technologies that use millimeter-wave (MMW) and terahertz (THz) waves, it is essential to understand the dielectric properties of biological tissues in the MMW and THz frequency range.

The skin plays an important role in clarifying the interaction between electromagnetic waves and a biological body. The dielectric properties of the skin have been measured by several researchers [2][3]. Almost all the measurements were performed *in vivo* using a nondestructive probe. The results of these measurements represent the ideal condition of biological tissues, because they include the effects of basal metabolism and blood flow, which are neglected in excited tissue in *in vitro* measurements. However, the depth of the measured tissues is a practical concern in *in vivo* measurements.

We focus on the dielectric characteristics of the skin layers, which are the epidermis, dermis, and subcutaneous fat in this study. Measurement was conducted *in vitro* from 0.5 GHz to 1 THz using several measurement systems.

## II. METHOD

In this study, enucleated porcine skin was fractionated into the epidermis, dermis, and subcutaneous fat. Measurements were performed up to 48 h after the animal was euthanized.

Three types of measurement system were applied to the measurement of dielectric properties at body temperature (approximately 35 °C).

One is the free-space method with spot-focus-type lens antennas [4], which was employed for the measurement of the epidermis and dermis from 50 to 110 GHz. A pair of lens antennas (KLA-002, Kanto Electronic Application and Development Inc.) was connected to a vector network analyzer (E8361A, Agilent Technologies) via an MMW frequency extender (N5260A, Agilent Technologies). The dielectric properties of the tissues were derived from transmission coefficient measurements [5]. A localized air conditioner (PAU-AZ1800SE, Apiste) was used to control the temperature of the biological tissues.

The second is the coaxial probe method, which was employed for the measurement of the epidermis, dermis, and subcutaneous fat. This method is nondestructive and effective for the dielectric property measurement of biological tissues. Two types of coaxial probe were used from 500 MHz to 50 GHz (Performance Probe 85070E, Agilent Technologies) and up to 110 GHz [6]. Each dielectric probe was connected to a vector network analyzer (E8364C and E8361, Agilent Technologies). A water bath unit (MATS-OTOR-MJ, Tokai Hit) and a thermal plate (MATSOTSF-LO, Tokai Hit) were used to control the temperature of the biological tissues to 35 °C

The third is a THz time domain spectroscopy (THz-TDS) measurement system (TAS7500TS, Advantest), which was used for the measurement of the dermis and subcutaneous fat from 50 GHz to 1 THz. The temperature of the tissues was maintained at 35 °C using thermal plates (MATS-OTSF-LO and TP-OTA14X, Tokai Hit).

## III. RESULTS

Measurement results are shown in Fig. 1. The vertical and horizontal axes in the figure show the dielectric properties, which are the relative permittivity and loss factor, and the frequency, respectively. The figure also shows reference values obtained by Gabriel [1] and Pickwell et al. [7] at body temperature.

Firstly, we compare the measurement results obtained with several measurement systems. The dielectric properties of both the epidermis and dermis obtained by the coaxial probe method agree with a 10% deviation from those obtained by the free space method at 50 GHz. The differences in the measurement results for the dermis between the free-space method and THz-TDS are 6% and 10% at 100 GHz for the relative permittivity and loss factor, respectively. The differences in the measurement results for the subcutaneous fat between the coaxial probe method and THz-TDS are 6% and 13% at 55 GHz for the relative permittivity and loss factor, respectively.

Next, we compare our measurement results of the epidermis and subcutaneous fat with the reference values. The dielectric properties of the epidermis reported by Pickwell et al. [7] deviate by approximately 30% and 5% from our measurement results at 100 GHz for the relative permittivity and loss factor, respectively.

On the other hand, a clear difference was observed for the subcutaneous fat between our measurement results and the data reported by Gabriel [1]; the dielectric properties obtained in this study were much higher than those reported by Gabriel [1]. The reason for the difference in fat tissues is discussed as follows. The dielectric characteristics of biological tissues were simply explained in terms of dipolar relaxation. $\gamma$-Dispersion, which is the dipolar relaxation due to the polarization of water molecules [8][9], is dominant in the MMW band. This implies that the water content of the tissue is one of the important parameters for determining its dielectric properties, especially at MMW frequencies. A previous study showed that the water content of adipose tissue widely differs with the type of sample [10]. Therefore, it is assumed that the difference in dielectric properties between the subcutaneous fat in this study and the fat in the study by Gabriel [1] was observed because of the difference in the water content of the fat sample. This suggests the variation of the dielectric properties of adipose tissue with the water content, and also indicates the importance of obtaining measurement data of adipose tissue from certain body parts.

## IV. Summary

The dielectric properties of skin tissues, which are the epidermis, dermis, and subcutaneous fat, were measured using three types of measurement system. Our measurements cover dielectric data of skin tissues at frequencies from 500 MHz to 1 THz. In this study, enucleated porcine skin was used for the measurement at body temperature. Measurement results obtained with several measurement systems indicated fair agreement with each other. Furthermore, measurement results of the epidermis and subcutaneous fat by an *in vitro* experiment were compared with those of reference values. The measurement results of the dermis were in reasonable agreement with those obtained by an *in vivo* experiment. In contrast, a clear difference was observed between the results of subcutaneous fat obtained in this study and those of the fat obtained by Gabriel. We suggested that the difference was observed because of the difference in the water content of the fat sample.

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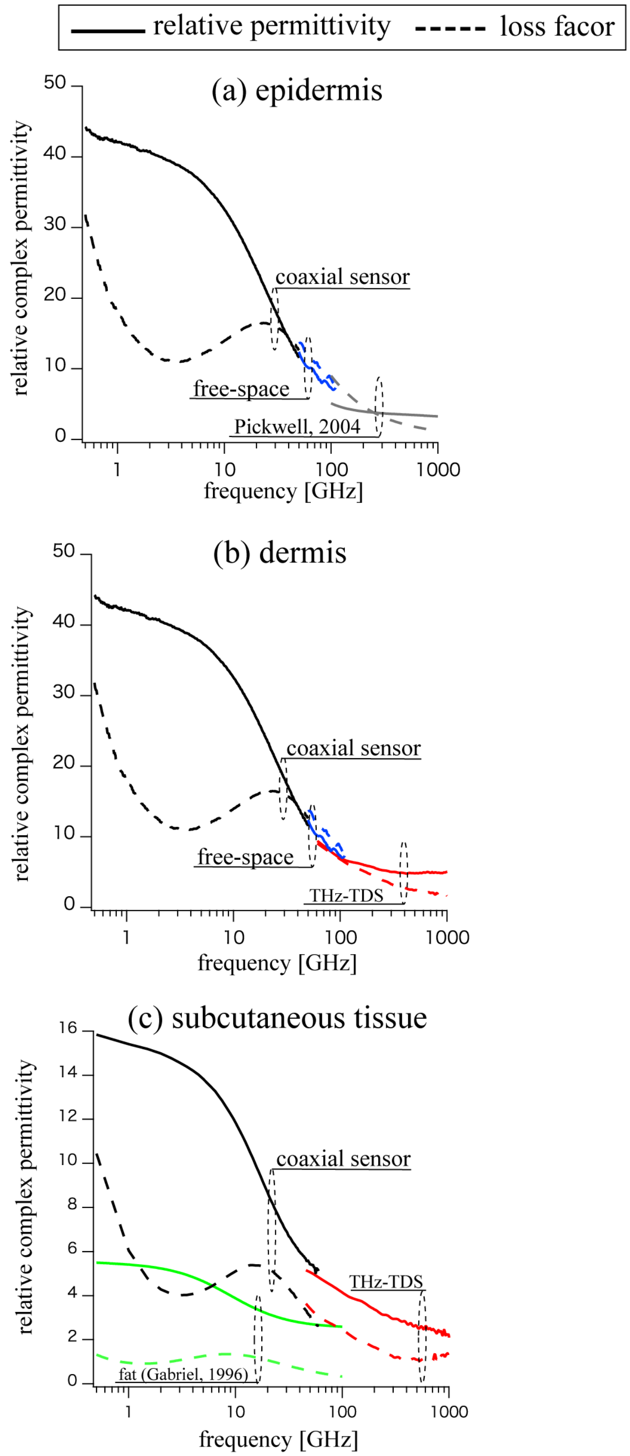


**Fig. 1.** Frequency dependence of measured dielectric properties from 0.5 GHz to 1 THz. The solid and dotted lines in the figure indicate the relative permittivity and loss factor, respectively. Our measurement was conducted at a tissue temperature of approximately 35 $^{o}$C.