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Dielectric Property Measurement of Biological Tissues at Millimeter-wave Frequencies: Uncertainty Analysis

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A continuous increase of wireless data traffic expects the research and development of high-speed wireless communication technologies operating at millimeter wave (MMW) frequencies. Knowledge of the dielectric properties of biological tissues is necessary to understand the interaction between electromagnetic waves and the human body. As an example, such properties have been used for safety assessments of electromagnetic wave exposure and in biomedical applications.

Accurate dielectric constants of biological tissues are necessary in research and development in bioelectromagnetics. We previously developed a measurement system with a coaxial sensor that can be used at frequencies ranging from 1 to 100 GHz for the measurement of biological tissues [1]. Thus, our interest is to clarify the accuracy of the system for biological tissue measurements. Although the measurement accuracy of the measurement system has been checked by comparing reference data with the reference data [2], there is a scarcity of available reference data, particularly over 5 GHz; thus, the conventional assessment procedure is inapplicable at such frequencies.

In this study, we aim to estimate the measurement uncertainty of dielectric property measurement using the coaxial sensor. The main issue is how to estimate uncertainty sources relevant to the measurement method; referred as the uncertainty of model approximation. Although the uncertainty of the model approximation was commonly estimated from the deviation between the measurement result and reference data, this approach is inapplicable at frequencies over 5 GHz. Therefore, we estimated the uncertainty by comparing the result with that using theoretically accurate method, i.e., the method based on the mathematical expression of the Maxwell's full wave formula. The uncertainty analysis was first conducted for reference liquid samples and then for brain tissue. For the uncertainty assessment for the brain tissues, we discussed contributions of each uncertainty source due to measurement system and that due to biological tissue.

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2. C. Gabriel and A. Peyman, "Dielectric measurement: error analysis and assessment of uncertainty," *Physics in Medicine and Biology*, **51**, October 2006, pp. 6033-6046, doi: 10.1088/0031-9155/51/23/006.