5-2 Studies on Evaluation Methods of Compliance to Radio Radiation Protection Guidelines

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Portable wireless terminals such as cellular phones are required to demonstrate their compliance to radio radiation protection guidelines in terms of local specific absorption rate (SAR). In this report, we show studies on SAR measurement methods used for compliance tests of cellular phones and on calibration methods of small isotropic E-field probes which used for the SAR measurement. These studies demonstrated that the international standard of the SAR measurement can appropriately be applicable to Japanese people and improved the repeatability and reliability of the compliance tests in Japan.

Keywords
Radio radiation protection guidelines, Local SAR, Cellular phone, Head phantom, SAR calibration, Uncertainty

1 Introduction

The radio radiation protection guidelines were issued to prevent adverse health effects associated with an excessive increase in the temperature of the human body due to high-frequency electromagnetic field exposure[1]. These guidelines were revised in 1997, and new partial-body absorption guidelines targeting wireless devices used in close proximity to the body, such as cellular phones, were appended[2]. The additional guidelines stipulate that local SAR, averaged over 10 grams of a given body tissue (excluding the extremities), may not exceed 2 W/kg.

In 2000, a methodology was established for demonstrating compliance with local SAR guidelines for portable wireless terminals, such as cellular phones, used near the temple region[3], and as of June 2002, it has become compulsory to conduct a local SAR-guidelines compliance test on portable wireless terminals such as cellular phones. Moreover, with the establishment of an international standard for SAR measurement in the human head[4], revisions have been made to the standard measurement method used in Japan[5]. Figure 1 shows the basic concept of the standardized SAR measurement method. A shell consisting of lossless dielectric material simulating the shape of the human head is filled with liquid having dielectric properties similar to those of head tissues. The local maximum SAR within the head is measured by scanning with a small isotropic electric-field probe.

At NICT, research efforts have continued toward the establishment of a measurement method that will ensure successful standardization both within Japan and internationally, along with efforts to develop a calibration method for the SAR measurement systems. This paper introduces an outline of such

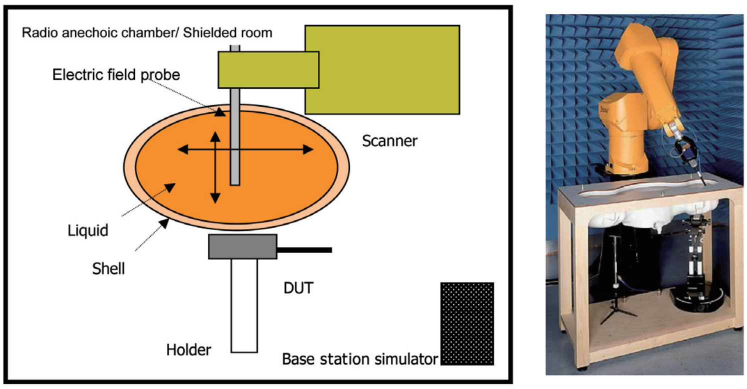

Fig.1 *Basic concept of standard SAR measurement method*

research and development.

2 Standard SAR measurement method

2.1 Studies on phantom head shape

A model having dielectric properties similar to those of the human body is substituted for an actual human body when making SAR measurements for exposure to radiofrequency radiation. This substitute model is often referred to as a "phantom". The phantoms used in the compliance test on cellular phones, etc., for the partial-body absorption guidelines all have the same shape throughout the world. This standard head phantom has the dimensions of a 90 th percentile Caucasian male and is referred to as the "specific anthropomorphic mannequin" (or SAM; Fig. 2). The SAM model is also used as the standard head model in Japan, although the model is significantly larger than the average head of a Japanese adult. Thus, we investigated the validity of use of the SAM model[6].

Investigations were also made on the effect of the shape of the pinna located nearest to the antenna-feed point of a cellular phone on SAR distribution. Based on the results, we determined that the pinna shape has a significant effect on SAR distribution for the head,

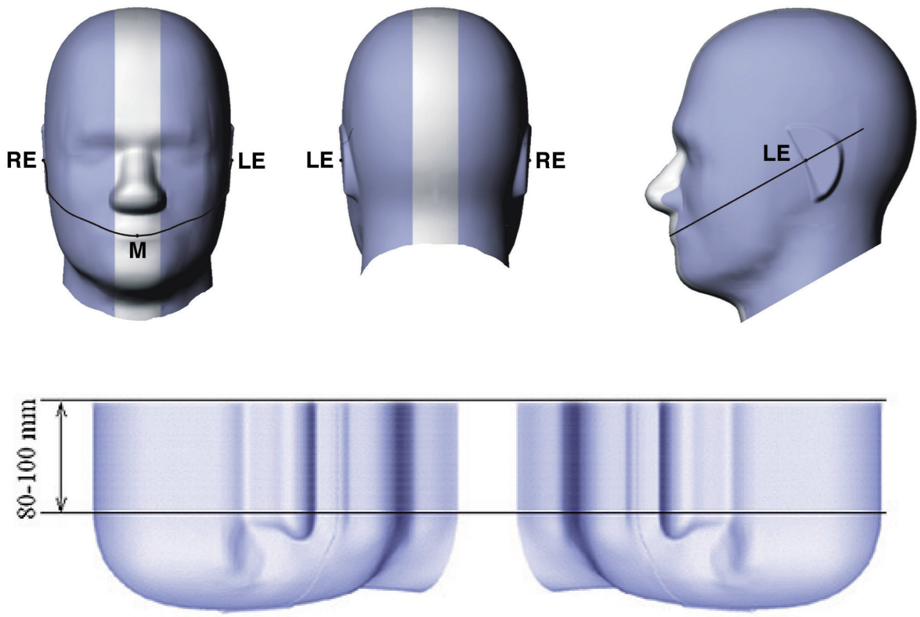

Fig.2 *International standard head model (SAM)*

although not as significant as the effect of differences in orientation of the cellular phone[7]. The results of this study have been cited in the IEEE standard[8]. However, both the IEEE and The International Electrotechnical Commission (IEC) recommend the use of a thin, lossless dielectric spacer as the pinna, taking into consideration the additional complexity to measurement procedures of filling the pinna with lossy dielectric material, and also due to the possible underestimation of head SAR due to increased distance between the head and antenna as a result of the presence of the pinna.

In these studies, head phantoms (with and without pinna) having the dimensions of the average Japanese male head were developed and used along with a head phantom having the dimensions of a 90th percentile Caucasian male (Fig. 3).

These studies have verified the applicability of the international standard head phantom (SAM) to compliance tests carried out for Japanese adults. Current studies are underway to determine the optimal phantom shape for evaluating the effect of portable wireless terminals used in positions other than near the head.

2.2 Studies on the phantom liquid

The head phantom is filled with liquid having dielectric constants equivalent to those of human head tissues. The dielectric constants of the liquid are adjusted so that the head phantom will return SAR values larger than those of an actual human head, which consists of several types of tissues with varying electrical properties[9]. Table 1 presents the target values for the dielectric constants of the phantom liquid.

Although research and development is underway to produce phantom liquids having the constants shown in Table 1, it is difficult to prepare a liquid that simultaneously satisfies the target values for relative permittivity and conductivity for the frequency of interest. In particular, the preparation of phantom liquids having the target dielectric constants for frequencies above 1 GHz required the use of alcohols that are hazardous to the environment. To avoid the use of such alcohols, NICT has collaborated with the National Physical Laboratory (NPL) of the United Kingdom and Bristol University to develop liquid compositions featuring smaller environmental loads[10].

When phantom liquids are used over an extended period of time, their composition changes due to the evaporation of water, resulting in altered dielectric constants. Furthermore, changes in liquids' temperatures also can affect dielectric constants. To examine such effects, NICT investigated temperature dependence and charted variations in dielectric constants with a change in the composition of a phantom liquid[11].

Generally, the dielectric constants of the phantom liquid have been measured using commercial open-ended coaxial probes. However, the uncertainty and the traceability of the measuring system are not yet clearly determined. Therefore, NICT has implemented the dielectric-constant measurement system developed by the NPL of the UK in order to con-

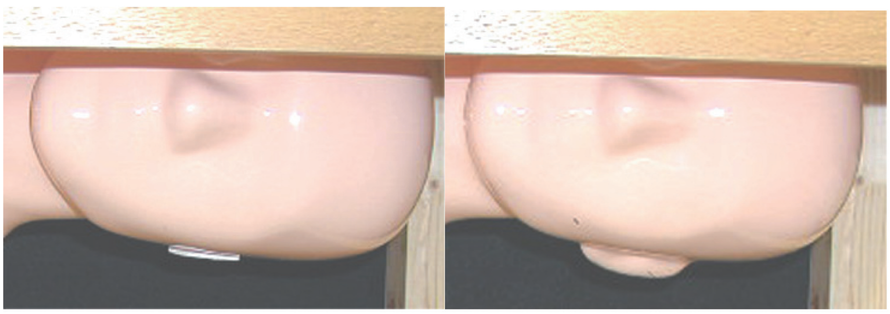

Fig.3 *Head phantoms (with or without pinna)*

Table 1 *Existing traceback methods*

Frequency (MHz)	Relative permittivity	Conductivity (S/m)	Frequency (MHz)	Relative permittivity	Conductivity (S/m)
30	55.00	0.75	2000	40.00	1.40
150	52.30	0.76	2450	39.20	1.80
300	45.30	0.87	3000	38.50	2.40
450	43.50	0.87	4000	38.00	3.50
835	41.50	0.90	5000	36.20	4.40
900	41.50	0.97	5200	36.00	4.70
1450	40.50	1.20	5400	35.80	4.90
1800	40.00	1.40	6000	35.30	5.30

duct a comparative study between various such systems. Further, in an effort to establish standard samples for validation testing of the measurement system, round-robin dielectric-constant measurements for various liquid samples are being performed by multiple research institutes in Japan and abroad.

Through these research activities, it should become possible to establish a method for preparing and maintaining phantom liquids easily and to keep the dielectric constants of the liquid at target values, and to contribute to improved reproducibility of measurement during compliance tests. Current efforts are being devoted to the development of a higher-performance phantom liquid that will realize the target dielectric constants for multiple frequencies with a single composition, or with improved temperature dependence, for example.

2.3 Studies on the evaluation of Type-A uncertainties

The international standard for SAR measurement established in 2005 requires a detailed evaluation of uncertainties. The standard emphasizes in particular that multiple measurements are required in order to perform statistical evaluation of the error associated with the placement by the operator of the cellular phone under test in the designated position immediately beneath the head phantom, and on the various effects of the low-loss dielectric holder retaining the cellular phone. Such uncertainties are referred to as Type-A uncertainties. A collaborative effort has now been undertaken by NICT, the Telecom Engineering Center, and NTT Docomo to evaluate Type-A uncertainties for cellular phones in Japan[12].

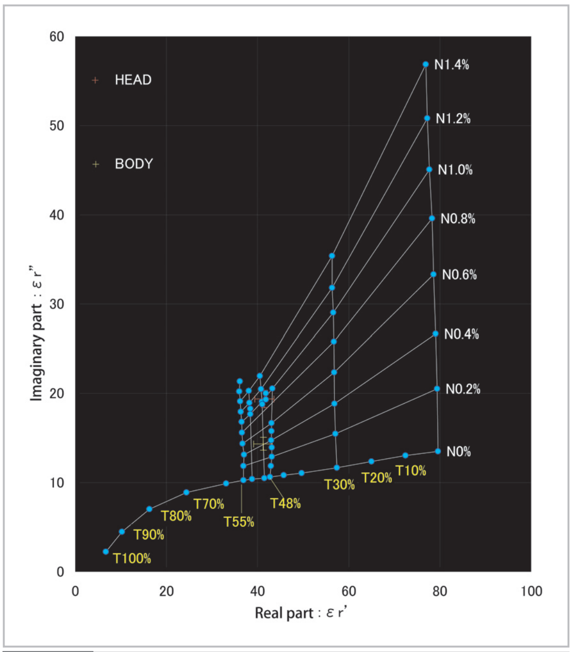

Fig.4 *Example of a compositional ratio matrix of phantom liquids*

3 SAR calibration method

3.1 Construction of a waveguide SAR calibration system and evaluation of uncertainty

The small isotropic electric-field probe (referred to below as the “SAR probe”) outputs, via high-resistance lines, DC signals produced by diode detection of the voltage received by small dipoles oriented in an orthogonal tri-axial array, as shown in Fig. 5. Because the output DC signals are produced by diode detection, they are proportional to the RMS value of the intensity of the received electric field. Furthermore, since there is little coupling between the high-resistance line and the high-frequency electromagnetic field, disturbances in the electromagnetic field distribution near the probe are minimized during the measurement of electric-field intensity.

When performing measurements using the SAR probe, it is necessary to determine the sensitivity (calibration factor), which relates the measured electric-field intensity to the out-

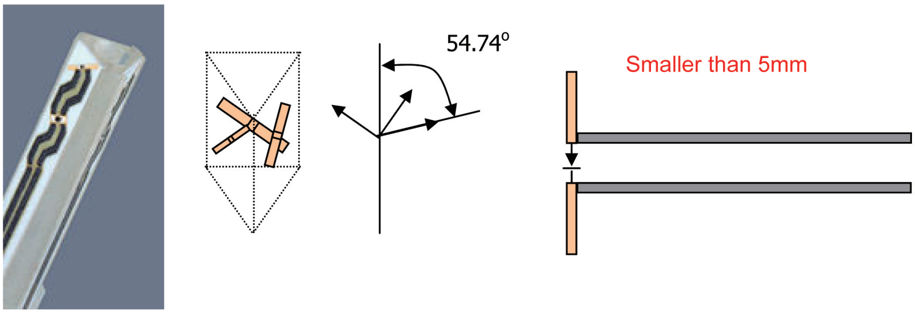

Fig.5 *Basic concept of the small isotropic electric-field probe used for SAR distribution measurement*

put DC voltage. Normally, the calibration of antennas is performed in radio anechoic chambers or at outdoor sites. In the case of SAR measurements, however, the calibrations must be made with the probe immersed in the phantom liquid used in actual SAR measurements, since the SAR probe calibration factor is dependent on the electrical characteristics around the probe.

Several SAR probe calibration methods have been proposed to date, and NICT has selected for implementation the waveguide SAR calibration system recommended under the international standard of measurement (Fig. 6). In this system, the waveguide is placed upright and positioned above a container filled with phantom liquid atop a quarter-wave (λ/4) dielectric plate matched to the phantom liquid. In this case, the electric-field intensity distribution generated within the liquid can be calculated theoretically based on the electric power input to the waveguide. Thus, SAR probe calibration can be performed by inserting the target SAR probe into the liquid and measuring the output voltage, and then comparing the measured value to the theoretically calculated electric field.

Additionally, a number of factors inherent in an SAR probe calibration system using a waveguide give rise to uncertainties. NICT is thus presently conducting joint research with the NPL of the UK and the Radio Research Laboratory (RRL) of Korea to evaluate uncertainties in the SAR probe calibration system. Through such research efforts, we hope to improve the precision and reliability of SAR probe calibration in Japan.

3.2 Studies on expanding the frequency band of the SAR calibration system

The IEC is currently preparing for revision of the SAR measurement method. One of the items slated for revision is the expansion of

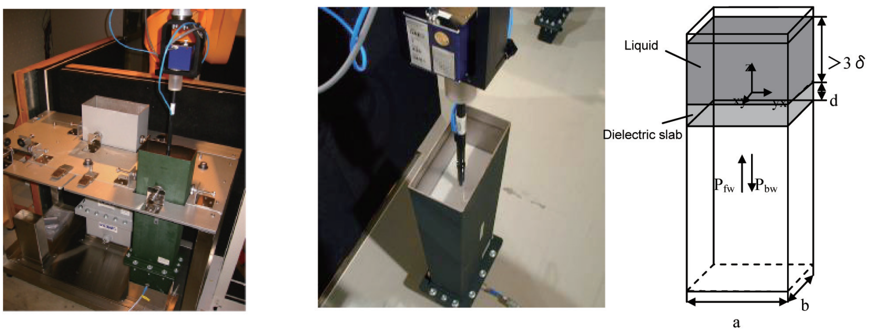

Fig.6 *SAR probe calibration system at NICT*

the target frequency band from the current 300-MHz to 3-GHz range to the 30 MHz to 6 GHz range, in order to target the new bandwidths allocated to next-generation cellular phones and commercial wireless terminals. In particular, since the waveguide for the frequency band above 3 GHz is extremely small, the effect of the SAR probe cannot be considered negligible. NICT is thus collaborating with Niigata University to establish a SAR-probe calibration method based on new principles (Fig. 7)[13]. Furthermore, since the waveguide for the frequency band below 800 MHz is extremely large, it is difficult to apply the conventional SAR probe calibration method to this frequency range. Thus, we are conducting

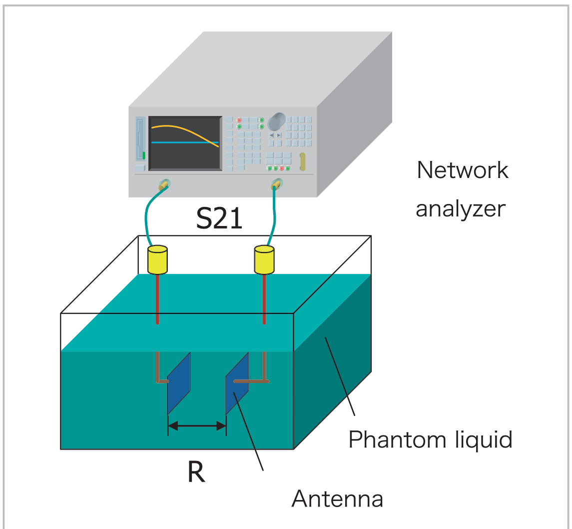

Fig.7 *Basic concept of the gain calibration method for a small antenna immersed in liquid used for SAR probe calibration*

research on a calibration method based on a comparison of SAR values obtained from temperature measurements (Fig. 8)[14].

4 Concluding remarks

This paper discussed various research efforts associated with test methods for demonstrating compliance with the partial-body absorption guidelines, which targets in particular cellular phones under the radio radiation protection guidelines. In the near future's ubiquitous network society, various portable wireless terminals will most likely be worn and used on various parts of the body. In order to use such devices safely and comfortably, it is imperative that the SAR measurement method be expanded to incorporate the various applicable situations, in addition to other improvements. At NICT, various research efforts are underway to evaluate uncertainties in the SAR measurement method and to establish a dedicated means of calibration. We are actively conducting joint research with both domestic and foreign research institutions, with a view to maintaining our influence on international standardization efforts, to helping establish the SAR measurement method, and to ensuring smooth introduction of the method in Japan.

Although not dealt with in this paper, NICT is also carrying out studies on verification methods for compliance with the protection guidelines for induced body current in the

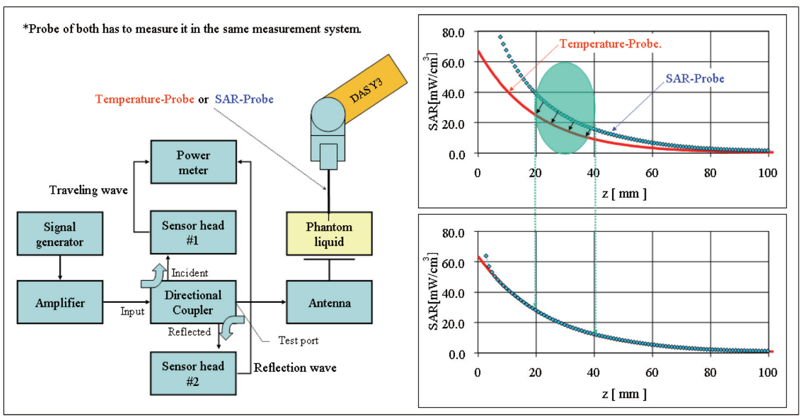

Fig.8 *Example of a SAR probe calibration experiment using temperature measurement*

ankle by VHF band radiofrequency radiation [15] and studies on methods of measuring the intensity of the middle-frequency electromagnetic field generated by IH instruments and the like[16]. Through these research efforts, we hope to create an environment in which radio waves are used safely and with ease in a variety of situations based on proper application of the partial-body absorption guidelines.

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