UNCERTAINTIES OF SAR-PROBE CALIBRATION AND OF SAR
MEASUREMENT FOR COMPLIANCE TESTS OF CELLULAR
PHONES
Soichi Watanabe†, Yukihiro Miyota‡, Masashi Takabe†, Hiroyuki Asou†,
Yoshihito Ishii†, Kenichi Satoh†, Kaori Fukunaga†, Akira Suzuki†, Tsutomu Sugiyama†,
Iwao Nishiyama†, Takashi Shinozuka†, and Yukio Yamanaka†
†National Institute of Information and Communications Technology
and ‡NTT Advanced Technology Corporation
∗E-mail: wata@crl.go.jp

Abstract: In standard procedures for compliance tests of cellular phones, it is required to evaluate the uncertainties of specific absorption rate (SAR) measurement. Some of the most important uncertainty factors were investigated in this study. Several types of SAR probes were calibrated. Uncertainties of the calibration factors due to deviations in the electrical properties of phantom liquid were then evaluated. Frequency characteristics of the calibration factors were also investigated. Furthermore, some uncertainties of SAR measurement with actual cellular phones, i.e., the effects of the position of the devices under test and of the operating frequency, were investigated. Evaluated uncertainties were subsequently compared with typical values described in standard documents.

Keywords: SAR, cellular phone, uncertainty, calibration, and compliance test

1 Introduction

Compliance of cellular phones with local specific absorption rate (SAR) limits has been mandated in many countries. Procedures for the compliance test have also been standardized internationally [1–3].

The standard procedures [1–3] recommend that SAR measurement systems for the compliance test should consist of a human head phantom, a SAR-probe, a scanning system, and a post-processing PC, as shown in Fig. 1. The standard procedures also require to evaluate uncertainties of SAR measurement.

Many uncertainty factors exist in the SAR measurement systems. Errors due to SAR-probe calibration are especially significant because they directly affect the measured SAR values. Conventional SAR probes consist of three orthogonal small dipoles with a diode that outputs DC voltage relating to electric-field (E-field) strength parallel to each dipole. The purpose of calibration of the SAR probes is therefore to calibrate the output voltage of each sensor measuring the known E-field.

In this study, several SAR-probes were first calibrated using waveguide calibration systems recommended in the standard procedures [1–3]. The calibration factors of the different probes were then compared. Next, uncertainties of the calibration factors due to deviations in the dielectric properties of the phantom liquid were evaluated. Frequency characteristics of the calibration factors were also investigated.

Furthermore, uncertainties of SAR measurements for actual cellular phones due to the position of the devices under test and the frequency characteristics of the SAR measurements were investigated. Although the electrical properties of the phantom liquid were known to be one of the most important uncertainty factors, this issue was investigated in prior research [4].

Finally, estimated values of these uncertainties were summarized and compared with typical values described in the standard procedures [1].

2 SAR-Probe Calibration

2.1 SAR-probe calibration system

To calibrate SAR probes, a well-known E-field (standard field) must be attained in the phantom liquid, and the phantom liquid should have the same dielectric properties as that used in the SAR measurement. Waveguide systems are recommended in the standard procedures [1–3] and were used in this study.

The SAR-probe calibration system consists of open-ended waveguides and a probe-scanning machine, as shown in Fig. 1. The waveguide is partitioned with a
Table 1: Calibration factors ($\gamma_i$) of SAR probes.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>900 MHz</th>
<th>1450 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probe</td>
<td>$\gamma_x$</td>
<td>$\gamma_y$</td>
</tr>
<tr>
<td>ET3DV5(1)</td>
<td>8.6</td>
<td>8.8</td>
</tr>
<tr>
<td>ET3DV5(2)</td>
<td>6.8</td>
<td>8.8</td>
</tr>
<tr>
<td>ET3DV6(1)</td>
<td>13.</td>
<td>11.</td>
</tr>
<tr>
<td>ET3DV6(2)</td>
<td>12.</td>
<td>12.</td>
</tr>
<tr>
<td>ET3DV6(3)</td>
<td>12.</td>
<td>12.</td>
</tr>
<tr>
<td>SEPT(1)</td>
<td>42.</td>
<td>36.</td>
</tr>
<tr>
<td>SEPT(2)</td>
<td>46.</td>
<td>36.</td>
</tr>
</tbody>
</table>

The calibration factors of the three-type probes were quite different. This was due to the different characteristics of the probe components, e.g., diodes and high-resistive lead lines.

Some of the probes had even values ($\leq 0.2$ [dB]) for the calibration factors between the three sensors, while the calibration factors of the other probes showed significantly large deviation ($\geq 1$ [dB]). This deviation may reflect the nonsymmetrical geometry of the sensors.

The calibration factors at 1450 MHz were about 10 % lower than those at 900 MHz, which was a consistent trend for all the probes.

2.3 Effects of electrical properties

We investigated the effects of the electrical properties of the phantom liquid on the calibration factors of the

The electrical properties of the phantom liquid were measured with an open-ended probe measurement system (85070, Agilent Technologies). The measured values of the electrical properties were maintained within ± 1.0 % from the target values, while the standard procedures allow larger tolerance (± 5 %).

2.2 Calibration factors of several SAR-probes

Three SAR probes, ET3DV5, ET3DV6 (SPEAG), and SEPT (Antennessa), were calibrated, and the evaluated calibration factors are listed in Table 1.

The calibration factors of the three-type probes were quite different. This was due to the different characteristics of the probe components, e.g., diodes and high-resistive lead lines.

Some of the probes had even values ($\leq 0.2$ [dB]) for the calibration factors between the three sensors, while the calibration factors of the other probes showed significantly large deviation ($\geq 1$ [dB]). This deviation may reflect the nonsymmetrical geometry of the sensors.

The calibration factors at 1450 MHz were about 10 % lower than those at 900 MHz, which was a consistent trend for all the probes.

2.4 Frequency characteristics

Frequency characteristics of the calibration factors of the ET3DV6 probe were also investigated. The calibration factors were evaluated at various frequencies, i.e., ± -10, -7.5, -5, -2.5, 0, 2.5, 5, 7.5, and 10 % from the original calibration frequency (900 MHz or 1450 MHz). The electrical properties of the phantom liquid were adjusted to the target values at each frequency, which was determined by interpolation between the reference values [1–3].

The deviation in the calibration factors averaged for the three sensors are in Fig. 2. The deviation is within ± 0.2 [dB] between -10 and +7.5 % of the center frequency. The rapid increase in deviation at the +10 %-shifted frequency might be due to a mismatch of the $\lambda/4$ slab.

A similar trend, except for the rapid increase, was also obtained at 1450 MHz, which is not shown here.
3 Uncertainties of SAR Measurement

3.1 Position of cellular phones

We investigated the dependence of the maximum local SARs, averaged over any 10-gram region of the head phantom, on the position of cellular phones under test. Four cellular phones were tested, including three communication systems (800-MHz PDC, 1.5-GHz PDC, and 2-GHz W-CDMA) and two handset types (straight and clamshell).

Each cellular phone was set at the standard position, defined as the "cheek position" [1–3]. The phone was then slightly moved to the direction along the Front-Neck (FN) or Back-Mouth (BM) line, as shown in Fig. 3. The angle of the phone to the head phantom was also slightly changed, as Fig. 3 shows.

The deviations in the maximum local SARs with the shift along the FN and BM lines are shown in Figs. 4 and 5. The deviation was smaller along the FN line than along the BM line. This is because the curvature along the FN line was larger than that along the BM line. Consequently, shifting the cellular phones along the FN line resulted in less change in the distance between the cellular phones and the surface of the head phantom.

The deviation in the maximum local SARs with the angle of the cellular phones to the head phantom is in Fig. 6. The angle deviation, except for "phone (d)," is comparable to those with the shift along the FN and BM lines. The deviation of "phone (d)," on the other hand, is significantly larger than those of the other phones. The reason is that the slight change in the angle causes a significant change in the distance between the cellular phones and the surface of the head phantom because the maximum local SAR of "phone (d)" appears around the lower part of the phone, i.e., near the mouth.
3.2 Frequency dependence

The maximum local SARs averaged over any 10-gram region were measured between the lowest and highest frequencies to be operated in actual services. The Four cellular phones as tested in section 3.1 were also used here.

The deviations in the maximum local SARs are shown in Fig. 7. It is shown that the deviations are within ±1 [dB] between the lowest and highest frequencies to be operated with the exception of “phone (d)”. The rapid deviation of “phone (d)” may be due to a change in the output power with the operating frequency because “phone (d)” is the very first model of the IMT-2000 system (2-GHz W-CDMA).

4 Discussion and Conclusion

Various SAR probes were calibrated with the waveguide systems. Some of the SAR probes had significantly large variation (over 1 dB) in the calibration factors between the three sensors. It was also shown that the dependences of the calibration factors on the electrical properties and on frequency are relatively small (less than 0.2 dB typically).

In the standard procedure [1], the typical uncertainty of the SAR-probe calibration is estimated to be 4.8 % (0.2 dB). Our results suggest that the uncertainty of the SAR-probe calibration could be higher than the typical value in the worst cases. Further investigations are therefore necessary to establish the SAR-probe uncertainty.

In this study, it was shown that the deviation in the maximum local SARs due to the slight shift of the position and of the angle of the phones under test could be over 1 dB. This value is significantly larger than the typical value, 6 % or 0.25 dB, described in the standard procedures as “Test Sample Positioning”. Because the typical value has been evaluated using statistical procedures as a TYPE-A uncertainty (with at least six devices tested), it is necessary to increase the number of tested devices.

It was furthermore shown that the maximum local SARs can vary by more than 1 dB within the operating frequency bands. This result supports the recommendation described in the standard procedures; the lowest and highest frequencies as well as the center frequency should also be tested when measuring SARs.

There are many uncertainty factors in SAR measurement and the effect of these are very complex. However, our results suggest that the dependence of the uncertainty factors can be categorized with some key characteristics, e.g. the position of the maximum local SAR and the operating frequency bands.

Although it is not easy to establish the uncertainty of SAR measurement, radio-frequency safety authorities urgently require it. International cooperation is therefore effective, and constructing such frameworks should be encouraged.

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References


