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# Comparisons of SAR Values Measured between Fast and Full Measurement Procedures for Cellular Phones

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## Abstract

The procedure for measuring the 10g averaged specific absorption rate (SAR) next to an ear is specified in the IEC standard document (IEC 62209-1). It generally consists of two parts: an initial area scan and a following zoom scan. However, the measurement based on IEC62209-1 takes considerably long time to determine the peak spatial average SAR. Therefore, IEC 62209-1 also provides the procedure for a fast SAR measurement instead of the full/ordinary SAR measurement as described above. In this study, to verify the validity of the procedure for the fast SAR measurement, we measured the peak spatial average SAR of some cellular phones by both the fast and full SAR measurement procedures. Then we compared peak SAR values between the fast and full SAR measurement procedures. Our results show that the fast-procedure SAR values almost matched with the full-procedure SAR values within the range of the uncertainty assumed for the SAR measurements. In addition, the measurement time of the fast SAR measurement procedure was evaluated and found to be reduced by around 30% compared with the measurement time for the full SAR measurement procedure.

## 1. Introduction

With the progress in communication technology in recent years, various kinds of wireless communication devices have become widespread. In particular, cellular phones have become requisite tools in our daily life. In these circumstance, it has been necessary to evaluate the exposure of the human body to electromagnetic waves from wireless communication devices. Therefore, the manufacturers of such devices can demonstrate their compliance with international safety guidelines for assessing the safety of human exposure to electromagnetic waves [1]. The safety guidelines at the frequencies used for current cellular phones are regulated by using the value of the specific absorption rate (SAR), which is given as

$$\mathrm{SAR} = \frac{\sigma E^2}{\rho} \quad [\mathrm{W/kg}], \qquad (1)$$

where, $\sigma$, $E$, and $\rho$ denote the electric conductivity (S/m), electric field (V/m), and density (kg/m$^3$) of the human body, respectively. The IEC standard document (IEC 62209-1) specifies the protocols and measurement procedures for the measurement of the peak spatial average SAR next to ear using a tissue-equivalent liquid phantom model [2]. The protocol consists of two parts: an initial area scan and a following zoom scan. We call this ordinary procedure the full SAR measurement. In the full SAR measurement, SAR values should be measured for all available measurement settings, which is the combination of the frequencies and device positions. For instance, considering the SAR measurement of a long term evolution (LTE) device, there are many combinations of measurement settings including frequency bands, modulation schemes, and number of resource blocks. Hence, the number of measurements is much larger in LTE cellular phones than in 3G cellular phones.

For the above reason, it takes a considerably long time to measure the peak spatial average SAR of currently used cellular phones, especially LTE cellular phone. Therefore, IEC 62209-1 also provides an alternative procedure for a fast SAR measurement [2]. This procedure has an advantage of reducing measurement time of SAR values. To the best of our knowledge, the results of the full SAR measurement procedure have been reported [3][4].On the other hand, a few results of the fast SAR measurement procedure have been published. Thus, in this work, we aim to verify the validity of the fast SAR measurement procedure. For this purpose, we measure the SAR of two currently marketed cellular phones, Device #1 and #2, by the fast SAR measurement and compare the SAR values obtained by the fast and full SAR measurements. Finally, we estimate the time reduction resulting from the use of the fast SAR measurement.

## 2. Measurement procedures of fast and full SAR measurements

Fig. 1 shows the flow chart for each measurement procedure [2]. As mention in section 1, the full SAR measurement procedure consists of two parts: an initial area scan and following zoom scan. In the area scan

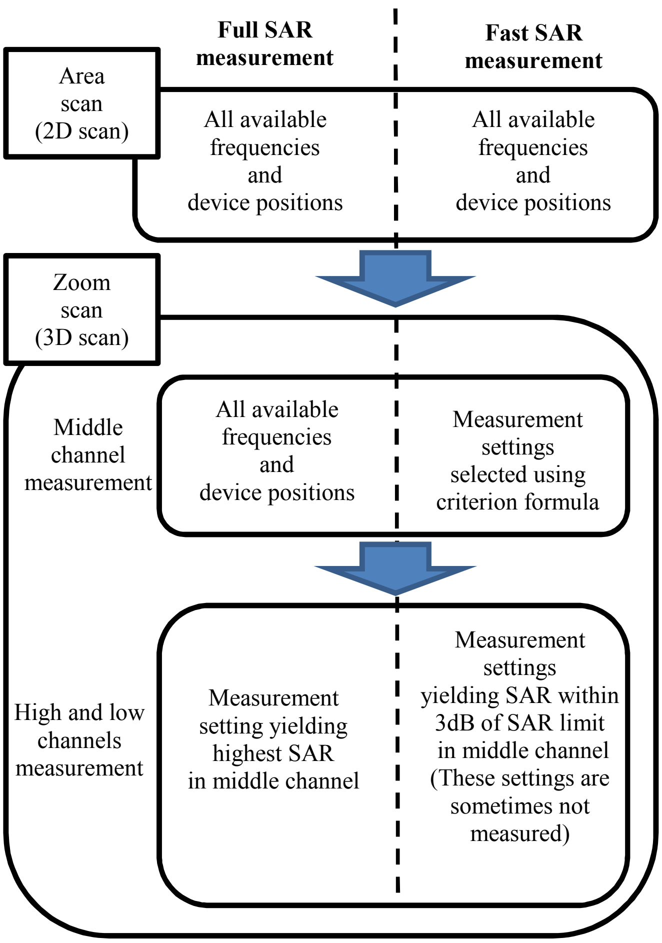


Fig. 1 Flow chart for fast and full SAR measurement procedures [2]

protocol, the electric field distribution near the inner surface of the container imitating the human head filled with the liquid phantom is measured by two-dimensional scanning with an electric-field probe. In the zoom scan protocol, the electric field is measured three-dimensionally around the peak electric field point obtained by the area scan protocol. Next, SAR value in each measurement point is calculated with Eq. (1). Finally, to obtain the peak spatial average SAR, the SAR value in each point is averaged over cubic area which is equivalent to 1 g or 10 g volume.

In the fast SAR measurement, SARs are measured under various conditions of communication modes (which were combinations of the frequency band and the modulation scheme) ($i$ group) and device positions (the $j$ group). Fast SAR measurement procedure also consists of area scan and zoom scan. However, as can be seen from Fig. 1, the number of measurement differ between fast and full SAR measurement. In the zoom scan of the fast SAR measurement, 1) firstly, the measurement setting yielding the highest SAR value in each communication mode $SAR_{\mathrm{max,area},i}$ measures SAR value $SAR_{\mathrm{max,zoom}\,i}$. After that, 2) the highest SAR value $SAR_{\mathrm{highest}}$ is found among measured SAR value in step 1). Next, 3) in the communication mode getting $SAR_{\mathrm{highest}}$, we choose and measure the SAR value in the measurement settings satisfied with the criterion formula as below:

$$SAR_{\mathrm{area}\,i,j} \geq SAR_{\mathrm{max,area}\,i} \times \left(B_{\mathrm{area}\,i} - \sqrt{B_{\mathrm{area}\,i}^2 - 1}\right) \quad (2)$$

$$B_{\mathrm{area}\,i} = \frac{1}{1 - (1.64 U_{\mathrm{area}\,i})^2} \quad (3)$$

Where, $SAR_{\mathrm{area}\,i,j}$ and $U_{\mathrm{area},i}$ are the estimated SAR from area scan result in $i$-th communication mode and $j$-th device position and the measurement uncertainty of area scan for the fast SAR measurement in $i$-th communication mode, respectively. As step 4), The other criterion function denoted as below is applied to decide to measure the SAR value in the communication modes except that having the highest SAR value.

$$SAR_{\mathrm{max,zoom}\,i} \geq SAR_{\mathrm{highest}} \times \left(B_i - \sqrt{B_i^2 - 1}\right) \quad (4)$$

$$B_i = \frac{1}{1 - \left(1.64\sqrt{U_{\mathrm{area}\,i}^2 + U_{\mathrm{zoom}\,i}^2}\right)} \quad (5)$$

Where $U_{\mathrm{zoom}\,i}$ denotes the measurement uncertainty of zoom scan. If $SAR_{\mathrm{max,zoom}\,i}$ satisfies the formula (4), return the step 3).

Therefore, the fast SAR measurement procedure can reduce the measurement time as compared with ordinally measurement procedure.

## 3. Comparison of Measurement Results

We measured the 10g averaged SAR of two available cellular phones held next to the ear, by the fast SAR measurement procedure. In addition, the results of the fast SAR measurement were compared with the values obtained by the full SAR measurement. Both fast and full SAR measurements were performed using a SAR assessment system DASY 52 with an E-field probe EX3DV4 (Schmid & Partner Engineering AG). The SAM phantom for the human head model was filled with tissue-equivalent liquid which dielectric properties were adjusted to the corresponding reference values listed in IEC 62209-1. The cellular phones were set to four device positions: left/right cheek and left/right tilt positions. As the communication modes, W-CDMA and LTE were selected. For the frequency bands and modulation schemes, we selected some of the available frequencies and modulation schemes in each cellular phone.

Table I shows results for the peak spatial average SAR of Device #1 obtained with both fast and full measurement settings in the middle channel. The blank cells in this table indicate a skipped measurement setting because it is not

TABLE I. Results of fast and full SAR measurements for Device #1

| Measured SAR [W/kg] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Device positions $j$ | Communication modes $i$ | | | | | | | | | | | |
| | 1: W-CDMA BAND1 (1950 MHz) | | 2: W-CDMA BAND6 (835 MHz) | | 3: LTE BAND1 (1950 MHz) QPSK | | 4: LTE BAND1 (1950 MHz) 16QAM | | 5: LTE BAND19 (835 MHz) QPSK | | 6: LTE BAND19 (835 MHz) 16QAM | |
| | Full | Fast | Full | Fast | Full | Fast | Full | Fast | Full | Fast | Full | Fast |
| 1: Right cheek | 0.287 | | 0.207 | 0.226 | 0.245 | | 0.182 | | 0.243 | 0.242 | 0.154 | 0.156 |
| 2: Right tilt | 0.166 | | 0.121 | | 0.156 | | 0.105 | | 0.086 | | 0.050 | |
| 3: Left cheek | 0.394 | 0.459 | 0.128 | | 0.288 | 0.332 | 0.291 | 0.254 | 0.180 | | 0.180 | |
| 4: Left tilt | 0.134 | | 0.127 | | 0.111 | | 0.089 | | 0.137 | | 0.137 | |

necessary to measure SAR for that setting in the fast SAR measurement procedure as described in Section 2. As can be seen from this table, the fast SAR measurement procedure can measure only measurement settings which yield the highest SAR value in each communication mode of the full SAR measurement results. In Table I, the combinations of the modulation scheme and device position yielding the highest SAR value was identical between two measurement procedures. In this case, the measurement setting getting the highest value was W-CDMA BAND1 Left cheek ($i$=1, $j$=3).

It is also noted that, in the full SAR measurement procedure, the peak spatial average SAR in the high and ow channels under the measurement setting resulting in the highest SAR value in the middle channel should be measured as described in Fig. 1. The measurement results are shown in Table II. From this table, we found the highest SAR of 0.394 W/kg in the middle and high channels. On the other hand, in the fast SAR measurement procedure, the SARs in the high and low channels are sometimes not measured. In the fast SAR measurement procedure, the high and low channels are measured when the SAR value in the middle channel is within 3 dB of the SAR limit, which is 2 W/kg as 10 g averaged SAR. All the measurement results in Table I were lower than 1 W/kg (which is within 3 dB of the SAR limit). Consequently, the high and low channels were never measured in this measurement. As a result, we obtained the highest SAR of 0.459 W/kg by the fast SAR measurement. By comparison of the highest SARs obtained by fast and full SAR measurement procedures, the difference between the SAR values obtained by the two procedures was 0.065 W/kg, which is a 16.5% difference relative to the full SAR measurement result (0.394 W/kg). We estimated the uncertainty of the measurement system to be about 11 %. Thus, this difference is within the range of the expanded uncertainty 22 %.

TABLE II. Results of full SAR measurements in all channels ($i$=1, $j$=3) for Device #1

| | SAR [W/kg] |
|---|---|
| Low | 0.366 |
| Middle | 0.394 |
| High | 0.394 |

Table III shows measurement results for Device #2. Fast SAR measurement has a reduced number of measurement settings, the same as in the results for Device #1. However, as can be seen from Table III the measurement settings yielding the highest SAR value do not match between the fast and full SAR measurement results in opposition to the result of Table I. The fast SAR measurement results indicate W-CDMA BAND6 Right cheek ($i$=2, $j$=1) to be the measurement setting giving the highest SAR value. On the other hand, the result of full SAR measurement denotes W-CDMA BAND1 Left cheek ($i$=1, $j$=3) to be the highest SAR measurement setting. Regarding the highest SAR value, the SARs in the two procedures are almost the same, 0.290 and 0.289 W/kg, respectively. Additionally, under the measurement settings $i$=2, $j$=1 or $i$=1, $j$=3, the difference between the SARs of two procedures is around 0.02 W/kg, which is within the range of uncertainty which is around 11 %. For these reasons, the incorrect selection of the peak SAR value is not significant. If the fast SAR measurement procedure is used in a realistic measurement environment, such differences in the measurement results discussed above would be observed. Moreover, considering the measurement uncertainty, the fast SAR measurement procedure is useful for reducing the measurement time.

In addition, we also evaluate the efficiency of measurement time reduction. We calculate the time reduction rate $R$ as

$$R = 100 \times \left(1 - \frac{T_{\text{fast}}}{T_{\text{full}}}\right), \quad (5)$$

TABLE III. Results of fast and full SAR measurements for Device #2

| Measured SAR [W/kg] | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Device positions $j$ | Communication modes $i$ | | | | | | | | | | | |
| | 1: W-CDMA BAND1 (1950 MHz) | | 2: W-CDMA BAND6 (835 MHz) | | 3: LTE BAND1 (1950 MHz) QPSK | | 4: LTE BAND1 (1950 MHz) 16QAM | | 5: LTE BAND19 (835 MHz) QPSK | | 6: LTE BAND19 (835 MHz) 16QAM | |
| | Full | Fast | Full | Fast | Full | Fast | Full | Fast | Full | Fast | Full | Fast |
| 1: Right cheek | 0.151 | | 0.270 | 0.289 | 0.092 | | 0.097 | | 0.270 | 0.266 | 0.229 | 0.222 |
| 2: Right tilt | 0.061 | | 0.113 | | 0.049 | | 0.037 | | 0.098 | | 0.079 | |
| 3: Left cheek | 0.290 | 0.265 | 0.238 | 0.257 | 0.230 | 0.176 | 0.186 | 0.141 | 0.189 | 0.217 | 0.183 | 0.183 |
| 4: Left tilt | 0.070 | | 0.126 | | 0.055 | | 0.042 | | 0.076 | | 0.075 | |

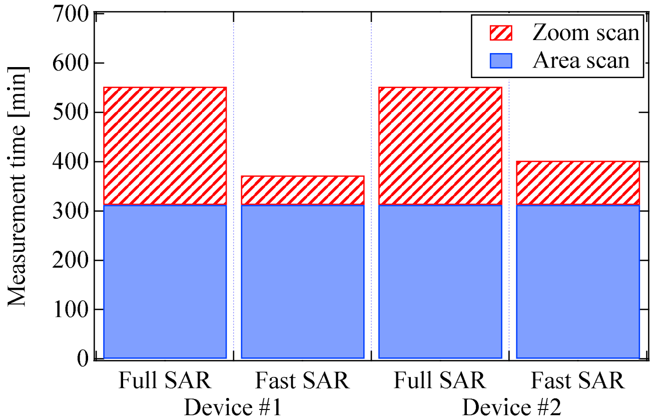


Fig. 2 Measurement times of fast and full SAR measurements

where $T_{full}$ and $T_{fast}$ denote the measurement times of the full and fast SAR measurement procedures, respectively. Fig. 2 shows each measurement time of the fast and full SAR measurement procedure for Devices #1 and #2. As can be seen from this figure, it takes same time to measure in area scan protocol between fast and full SAR measurement. The difference is observed only in zoom scan protocol. From this figure, the time reduction rates for each device are calculated as 32.6% and 27.2%, respectively. These results show that the fast SAR measurement procedure is useful for reducing the SAR measurement time.

## 4. Conclusion

We measured the peak spatial average SAR of two cellular phones placed next to the ear by the fast SAR measurement procedure. By comparison of the results of the fast and full SAR measurements, the results for one of the phones was found to show the incorrect selection of the measurement setting yielding the highest SAR value. However, we found that the difference between the highest SAR values obtained by each procedure was within the range of the uncertainty for the measurement 22 %. From this result, the incorrect selection of the peak SAR is not significant. In addition, we calculated the time reduction upon using the fast SAR measurement and we obtained reductions of 32.6 % and 27.2 % for those phones. These results confirmed the effectiveness of the fast SAR measurement procedure. In this study, evaluated measurement time does not include the time of setting device position, recharging a battery, etc. Considering the realistic measurement environment, these times are not ignored. So, the future work is to evaluate the time reduction including the measurement time excepted area scan and zoom scan, which are device position setting, battery charge, etc.

## 5. Acknowledgements


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## 6. References


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