Faster Specific Absorption Rate Measurement Techniques

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Abstract— **This paper presents faster Specific Absorption Rate (SAR) measurement techniques based on a previously proposed estimation method. This estimation method theoretically estimates the SAR from a 2-D scanned electric field (E-field) by basically applying the equivalence theorem and the image theory. The method reduces the SAR measurement time without sacrificing accuracy. We present the applicability of this method and show that the estimated results are in good agreement with the original 3-D SAR distributions. In addition, the SAR measurements for a low-power transmitter and a multi-antenna transmitter employing the method are introduced as application examples.**
Key words: Faster SAR measurement, EO, Probe array, Multi-antenna, low power transmitter

I. INTRODUCTION

In recent years, the international Mobile Telecommunication 2000 (IMT-2000) cellular system including the Wideband Code Division Multiple Access (W-CDMA) and CDMA-2000 has become popular in Japan and worldwide. Wireless Local Area Networks (LANs) have also become commonplace. The International Telecommunication Union (ITU) adopted new primary allocations for mobile services and defines the term of IMT-Advanced as beyond IMT-2000 for the future system [1]. One of the current trends is to use a frequency range higher than that used in the current cellular system. Another situation is to employ a multi antenna transmitter such as in Multi-Input Multi-Output (MIMO) systems [2]. On the other hand, since the data transfer rate is increasing, various types of wireless device usage other than voice communications are evident practically everywhere, e.g., connected to Personal computer (PC) and using the video phones.

It is well known that Radio Frequency (RF) waves above 100 kHz produce heat in tissue and that a very high-level RF field may cause thermally related health effects. Based on established adverse health effects, safety guidelines were determined by organizations such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [3]. In these guidelines, the Specific Absorption Rate (SAR) is used as the primary dosimetric parameter for radio frequency energy absorbed by the human body. The SAR is given by

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

where σ is the electrical conductivity [S/m], ρ is the density of the tissue [kg/m^3], and E is the electric field [V/m] (r.m.s.). The spatial average SAR over a 10g mass (10g average SAR) is adopted in order to evaluate the near-field local exposure from radio devices based on the guidelines and the regulations, e.g., [3].

The SAR measurement procedures using an E-field probe comprising diode-loaded dipole sensors, with respect to a mobile phone for compliance testing, which is intended to be used at the side of the human head, were standardized by the International Electrotechnical Commission (IEC) [4] and other bodies. In order to respond to the above mentioned situations, the IEC is now developing another SAR measurement procedure for various types of wireless device usage such as mounting the device on the body, taking photos or videos, and sending E-mail [5] including frequency expansion up to 6 GHz. It is anticipated that the number of measurements to evaluate the SAR for such types of usage as well as the new technologies will increase and SAR measurements will become more and more time consuming. In this paper, ideas to reduce the time and number of SAR measurement are introduced.

II. SAR ESTIMATION METHOD

It is anticipated that the number of measurements required to evaluate the SAR for such types of usage described above will increase and SAR measurements will become more and more time consuming. Some studies were conducted on SAR estimation methods that significantly reduce the SAR measurement time [6]-[8]. We have also investigated a few techniques to reduce the SAR measurement time [9], [10]. A SAR measurement method that can estimate theoretically three dimensional (3-D) SAR distributions from 2-D measurement data [10] was proposed.

A. Basic Concept

Basically, the previously proposed estimation method employs the equivalence theorem and the image theory. Since there is no surrounding surface in a practical SAR measurement system (Fig. 1), in order to enable the use of them, three conditions are assumed: 1) Electromagnetic waves are only incident through the observation plane, which is located within the phantom. 2) No reflection occurs within the phantom. 3) Electric and magnetic fields on the observation

plane are assumed to be secondary sources. By applying these assumptions, the SAR distributions in depth can be estimated by measuring only the electric fields on a 2-D plane are measured. This means that only 2-D E-field data are required to evaluate the spatial average SAR. Therefore, it is expected that the SAR measurement time can be reduced without sacrificing accuracy.
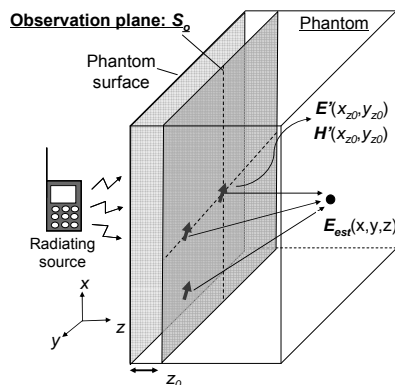

Fig. 1 Concept of proposed estimation method

B. Estimation Results

In order to simplify the calculations and measurements, a flat phantom and a dipole antenna as shown in Fig. 2 are used in this study. The frequencies are 300 MHz, 900 MHz, 1950 MHz, 2450 MHz, and 3500 MHz. In order to measure simultaneously the amplitude and phase of the E-field, a one-axis EO probe [11] is employed in the experiments. The 3-D SAR distribution is estimated based on the measured E-fields on the observation plane (S_0). It is noted that the E-fields from simulated results by the FDTD method was used at 300 MHz. The estimated SAR distributions in the phantom depth (z-axis) are plotted in Fig. 3. All SAR values are normalized to the maximum calculated SAR value by the FDTD method at the phantom surface at each frequency. Figure 3 shows that the estimated SAR distributions agree very well with the calculated results. Moreover, the 10g average SAR is calculated from the estimated 3-D SAR distribution and an approximate difference of less than 1.0% is observed compared to the original SAR value.
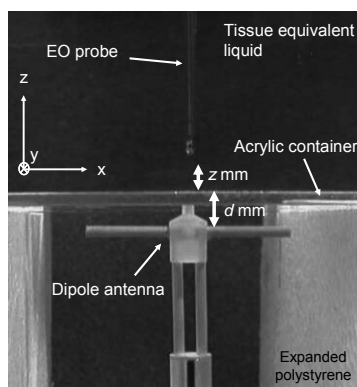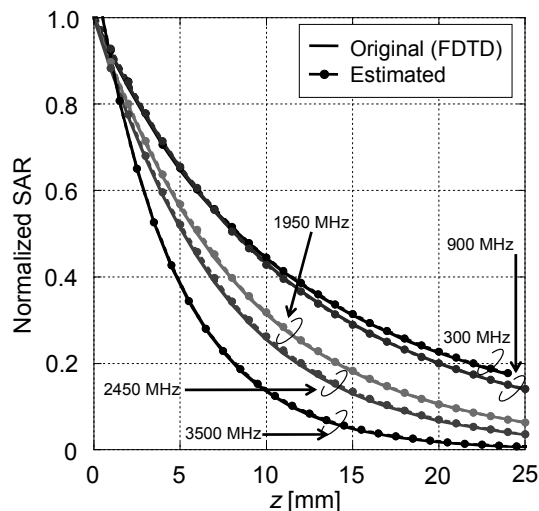

Fig. 2 Experimental configuration

Fig. 3 Estimated SAR distributions along z-axis

C. Application to Low Power Transmitter

The SAR measurement of a radio device that can simultaneously transmit using multi-frequencies may be necessary even if the maximum radiated power of one radio system does not exceed 20 mW [12]. Numerical analysis shows that the SAR for the measurement area closest to the phantom surface generated by the reference dipole almost exceeds the probe sensitivity of 0.01 W/kg at 5.2 GHz for the output power of not less than 1 mW, for example. Due to the steep decay in the phantom depth, however, differences in the 10g average SAR generated by the reference dipole and that by a PIFA (Planar Inverted-F Antenna) at 5.2 GHz are -5.2% and -80% at 1 mW, respectively. Since the proposed method only requires 2-D E-fields, it is expected that measurement accuracy can be improved. Figure 4 shows results for 10g average SAR with varying output power of a dipole antenna at 5.2 GHz. The investigation results show that the proposed procedure can improve the measurement accuracy corresponding to the antenna output power of 4 dB [13].
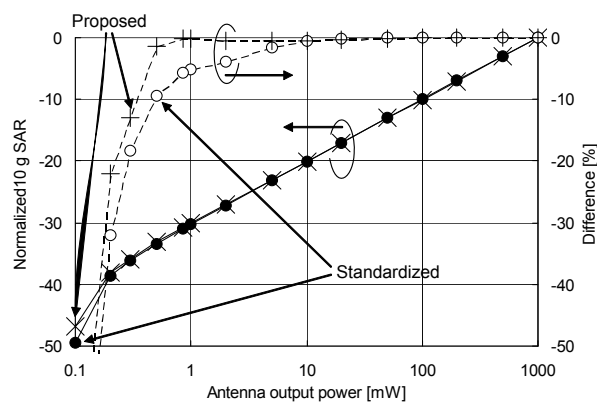

Fig. 4 Radiation power vs. averaged SAR at 5.2 GHz

III. FASTER SAR MEASUREMENT TECHNIQUES

A. Multi-Probe Array

As mentioned above, we can shorten the measurement time if the estimation method is used. However, applying only this method to an actual SAR measurement is not sufficient since the measurement of the 2-D E-field using one E-field probe is also time consuming.

Regarding this point, using a number of probes is another way to decrease the measurement time. Using a probe array of conventional E-field probes was proposed in [14]. It was shown that the spatial averaged SAR over a 10g mass can be obtained with a difference of less than 10% when the inter-probe distance is greater than 20 mm using a flat phantom. Regarding this point, the EO probe may be employed in a probe array with a lower interference level since it does not include metal elements and the probe tip is very small.

Another problem when constructing an arrayed probe system is the alignment of the multiple probes. It is difficult and complicated to construct a 3-D probe array system. Furthermore, constructing a 3-D array requires many probes and incurs a high cost. Therefore, it is not realistic to apply multiple probes to 3-D scanning SAR measurement. However, if the proposed estimation methods are employed, only a 2-D probe array is required in order to obtain a 3-D SAR distribution.

Consequently, although it is possible to accelerate the SAR measurement by using only the SAR estimation method, the proposed estimation method behaves extremely well in a multiple probe system in particular. This technique has the potential to measure the 3-D SAR distribution in several tens of seconds or a few minutes. Figure 5 shows the prototype of the EO probe array as an example.
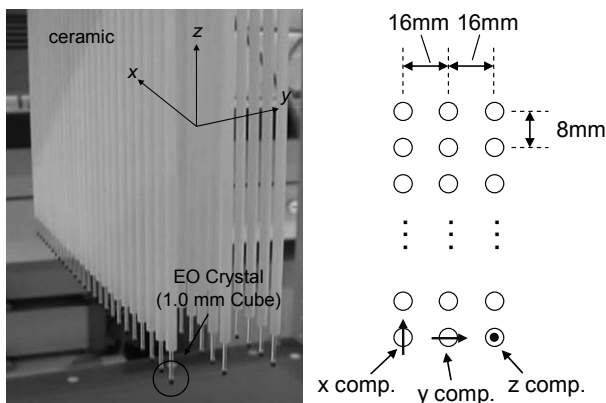
B. Multi-antenna SAR Measurement

It may be difficult for a multi-antenna transmitter to measure the SAR and determine the highest SAR if the current SAR measurement procedure is applied. This is because the amplitude and the phase of the input signal of each antenna are not fixed. This means that there is an enormous number of combinations between the amplitude and the phase to determine the highest SAR in the measurement. If the proposed method can be used, only the number of SAR measurements equal to the number of antennas would be required. In this case, the electric field distribution of each antenna, when an antenna is active and the others are non-active, is measured in 2-D and all of the distributions are combined. Finally, the three-dimensional SAR distributions used as arbitrary weighting coefficients of the antennas are numerically obtained prior to the determination of the 10g average SAR.

Figure 6 shows the results from the proposed method, where the 10g average SAR is related to the output power and the phase difference of the two reference dipoles. The 10g average SAR is obtained while $P_{out1}+P_{out2}$ = Constant, $1 \leq P_{out1}/P_{out2} \leq 3$, and the phase difference is 0 to 180°. In this case, the maximum 10g average SAR is obtained when $P_{out1}/P_{out2} = 3$ and the phase difference is 180°. Under the same conditions for the antenna output power and the phase difference of the two reference dipoles, the difference in 10g average SAR obtained from the three-dimensional electric field distributions using the proposed method to that from the original distribution is -2.4 %. Therefore, the routine of seeking the maximum average SAR works very well.
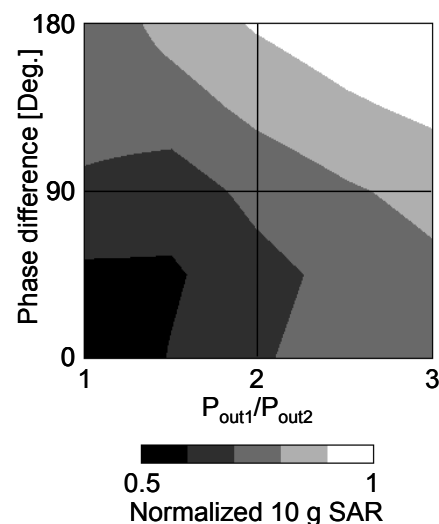

Fig. 5 Multi-probe array configuration

Fig. 6 10g average SAR related to output power and phase difference of the two reference dipoles

IV. CONCLUSION

This paper presented faster SAR measurement techniques based on our previously proposed estimation method, which theoretically estimates the SAR from a 2-D scanned E-field by applying the equivalence theorem and the image theory. The method reduces the SAR measurement time without sacrificing accuracy. We presented the applicability of this method and showed that the estimated results are in good agreement with the original 3-D SAR distributions. This method is also effective in evaluating a low power transmitter at a higher frequency that has a steep decay in the phantom depth. The results show the lowest output power is decreased to 4 dB.

In addition, a multi-probe array and evaluation method for a multi-antenna transmitter, which can reduce the scanning time and the number of measurements, were introduced. The evaluation method can significantly reduce the number of measurements for a multi-antenna transmitter such as MIMO.

REFERENCES

[1] A. Hashimoto, H. Yoshino, and H. Atarashi, "Roadmap of IMT-Advanced Development," IEEE Microwave magazine, pp. 80 – 88, August. 2008.
[2] 3GPP TR25.876, "Multi-input multi-output in UTRA," ver.7.0.0.
[3] ICNIRP, "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)," Health Physics., vol. 74, no. 4, pp. 494 – 522, Apr. 1998.
[4] IEC 62209-1, "Procedure to determine the specific absorption rate (SAR) for hand-held devices used in close proximity to the ear (frequency range of 300 MHz to 3 GHz)," Feb. 2005.
[5] IEC PT62209, "Procedure to determine the specific absorption rate (SAR) for mobile wireless devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz)," in draft.
[6] O. Merckel, J.-Ch. Bolomey, and G. Fleury, "Parametric model approach for rapid SAR measurements," IMTC2004, Instrumentation and Meas. Tech. Conf., pp. 178 – 183, Como, Italy, May 2004.
[7] M. Y. Kanda, M. G. Douglas, E. D. Mendivil, M. Ballen, A. V. Gessner, and C.K. Chou, "Faster determination of mass-averaged SAR from 2-D area scans," IEEE Trans. Microwave Theory and Tech., vol. 52, no. 8, pp. 2013-2020, Aug. 2004.
[8] A. Cozza, O. Merckel, and J.-Ch. Bolomey, "A new probe-array approach for fast SAR measurements," International Workshop on Antenna Technology 2007 (iWAT07), Cambridge, March 2007.
[9] T. Onishi, K. Kiminami and S. Uebayashi, "Estimation method based on the surface scanned EM field data with respect to SAR measurement," in XXVIIIth URSI GA, New Delhi, India, Oct. 2005.
[10] K. Kiminami, T. Iyama, T. Onishi, and S. Uebayashi, "Novel specific absorption rate (SAR) estimation method based on two-dimensional scanned electric fields," IEEE Trans. Electromagn. Compat., vol. 50, no. 4, pp. 828 - 836, Nov. 2008.
[11] T. Onishi, H. Togo, N. Shimizu, K. Kiminami, S. Uebayashi, and T. Nagatsuma, "SAR measurement employing electro-optic (EO) probe without using metal," Bioelectromagnetic Society Annual Meeting, Dublin, P-C-21, June 2005.
[12] T. Onishi, K. Kiminami, and T. Iyama, "Exclusion procedure with respect to SAR measurement for simultaneous multi-band transmission assessment," BEMS 30th Annual Meeting, P-26, June 2008.
[13] T. Iyama and T. Onishi, "SAR measurement procedure for simultaneous multi-band transmission assessment and SAR evaluation method for low power transmitter," IEICE Technical Report, EMCJ2008-58, Sept. 2008 (in Japanese).
[14] T. Iyama, T. Onishi, Y. Tarusawa, S. Uebayashi, and T. Nojima, "Novel Specific Absorption Rate (SAR) measurement method using a flat solid phantom," IEEE Trans. Electromagn. Compat., vol. 50, no. 1, pp. 43 – 51, Feb. 2008.