SAR Estimation with Corrections for the Effects of the Magnetic Field Reflected off a Human-Model Surface

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1. Introduction

The possible biological hazards of human exposure to electromagnetic radiation from radio-frequency transceivers, such as hand-held portable phones, is a matter of increasing public concern. Safety guidelines have been established with recommended limits on specific absorption rates (SARs).

Among the various previously reported experimental approaches to SAR estimation that use phantom models, the work of Kuster et al. is notable in that it provides the possibility for an SAR estimation technique that can be applied directly to human subjects [1]-[4]. Kuster et al. have verified that SAR on the surface of a human phantom model is proportional to the square of the incident magnetic field at the surface, and they have given a formula for estimating SAR on this basis. Since an incident magnetic field can itself be estimated on the basis of antenna current, it would seem possible, then, to estimate SAR on the basis of the levels of current measured with a magnetic-field (H-field) probe located near an antenna. In order to apply an H-field probe (H-probe) to actual SAR estimation, however, it is necessary to correct for the effects of the magnetic field that is reflected off the phantom surface.

In this paper, we propose a method for using a double-loop probe to correct for the effects of the reflected magnetic field. In our experiments, a human head-sized phantom model was experimentally exposed to the near-field of a half wavelength dipole antenna. By comparing our results with those obtained using an electric-field (E-field) probe method, we were able to confirm the validity of our method of correction.

2. SAR estimation model

Figure 1 shows an SAR estimation model when the electromagnetic waves from a half wavelength dipole antenna are perpendicularly incident to a phantom. The phantom is an infinite plane with permittivity ε, permeability $\mu = \mu_0$, conductivity σ, and mass density ρ. The distance between the dipole antenna and the phantom surface is d. Using the incident magnetic field at the surface (H_i), calculated on the basis of antenna current at feed point (I), we can express spatial-peak SAR at the phantom surface as [3]:

$$SAR=\frac{\sigma}{\rho}\frac{\omega\ \mu_0}{\sqrt{\varepsilon^2\omega^2+\sigma^2}}(1+\alpha\Gamma)^2\ H_i^2 \qquad (1),$$

where
$$H_i=\frac{I}{2\pi d} \qquad (2).$$

Here, Γ represents a magnetic reflection coefficient, α represents a correction coefficient, $\omega = 2\pi f$ (f : frequency), and $\mu_0 = 4\pi \times 10^{-7}$.

Antenna current may be calculated on the basis of the magnetic field produced by the antenna. The magnetic field receiving probe used here was a shielded loop probe, 1cm in diameter [5]. It was placed near the feed point, with the loop plane parallel to the flat surface of the phantom. The distance t between the feed point and the loop center was 4cm. With this probe arrangement, magnetic field H_f from the antenna, expressed as a vector originating at the center-point of the H-probe, has only an X-axis component. Consequently, antenna current can be calculated from the measured value of H_f as $I = 2\pi t \times H_f$.

The phantom model used in our experiments was a cylinder cut as shown in Fig. 4. The flat surface of the phantom was irradiated with electromagnetic waves from a half wavelength dipole antenna with a balun at 900MHz. At this frequency, relative permittivity was $\varepsilon_r = 43.1$, conductivity was $\sigma = 0.91$[S/m], and mass density was $\rho = 2.5$[g/m ^{3}].

3. SAR estimation

Figure 2 shows SAR values at the phantom surface, as obtained both by the H-field probe method and by the E-field probe (E-probe) method. Each value was normalized by the max value of SAR as obtained by the E-field probe method. With the E-field probe method, the SAR was calculated, on the basis of measurements of electric field E at the phantom surface, as SAR = $\sigma E^2/\rho$. Values obtained by the two methods tend to agree well at greater distances, but at shorter distances (i.e. when d is less than 4 cm), values obtained by the H-field probe method are smaller and form a differently shaped curve. This disparity arises because of the effects of the magnetic field reflected off the phantom surface, i.e. effects of the reflection are included in antenna current measurements.

Figure 3 illustrates relevant magnetic field vectors for the probe in two different alignments: parallel to the phantom surface (dotted line) and perpendicular to it (solid line). Reflected magnetic field H_r may be expressed as a vector originating at the center-point of the H-probe. In the parallel alignment, as noted earlier, antenna current may be obtained on basis of H_f. In this case, however, the probe also receives H_{rx}, the X-axis direction component of the reflected magnetic field. Consequently, the total magnetic field component in the X-axis direction (H_v) may be expressed as $H_v = H_f - H_{rx}$. Calculation of antenna current on the basis of this H_v value, in which the value of H_{rx} is included, results in our underestimating the actual value of antenna current here, and it produces the SAR values shown as triangles in Fig. 2.

In order to measure the reflected magnetic field component, we turned the probe 90 degrees, so that its loop plane was perpendicular to the phantom surface. In this probe arrangement, the only component of the reflected magnetic field that will be measured is H_{ry}, the Y-axis direction component, from which we are able to calculate H_{rx}, as $H_{rx} = H_{ry} \times t / 2d$. Consequently, H_f can be calculated as the sum of H_{rx} and H_v ($H_f = H_v + H_{rx}$).

4. SAR estimation using an orthogonally designed double-loop probe

We used an orthogonally designed probe composed of two loops (loops 1 and 2) in an attempt to eliminate the effects of the reflected magnetic field (see Fig. 4). These loops were placed, respectively, parallel and perpendicular to the phantom surface. This allowed us to measure both the X-axis components and the Y-axis component shown in Fig. 3, and then to estimate an accurate value for H_f (= $H_v + H_{rx}$). The O symbols in Fig. 5 indicate SAR values derived from H_f values corrected in this way. As may be seen in this figure, the curve produced on the basis of these corrected values shows significantly improved agreement with the curve produced on the basis of values obtained from an E-field probe; this indicates the validity of the method we have adopted to correct for the effects of the reflected magnetic field.

5. Conclusion

We have developed a method for using an orthogonally designed double-loop H-probe in the estimation of SAR for a human phantom model. In our experiments, we were able to estimate SAR on the basis of calculations which successfully corrected for the effects of the magnetic field that was reflected off the phantom model. Further, we were able to confirm the validity of this method of correction by comparing our results with those obtained using an E-field probe method.

[REFERENCES]

[1] M.A. Stuchly, A. Kraszewski, and S.S. Stuchly, "Exposure of human models in the near and far field — a comparison," IEEE Trans., vol. BME-32, no. 8, pp. 609-616, Aug. 1985.

[2] A.W. Guy and C.K. Chou, "Specific absorption rates of energy in man models exposed to cellular UHF mobile-antenna fields," IEEE Trans., vol. MTT-34, no. 6, pp. 671-680, June 1986.

[3] N. Kuster and Q. Balzano, "Energy absorption mechanism by biological bodies in the near field of dipole antennas above 300MHz," IEEE Trans., vol. VT-41, no. 1, pp. 17-23, Feb. 1992.

[4] O. Fujiwara and M. Nomura, "Correlation between spatial distributions of surface-SAR and magnetic near-field in realistic head model for microwave exposure," IEICE Trans., vol. E76-B, no. 7, pp. 765-767, Jul. 1993.

[5] J.D. Dyson, "Measurement of near fields of antennas and scatterers," IEEE Trans. vol. AP-21, no. 4, pp. 446-460, 1973.

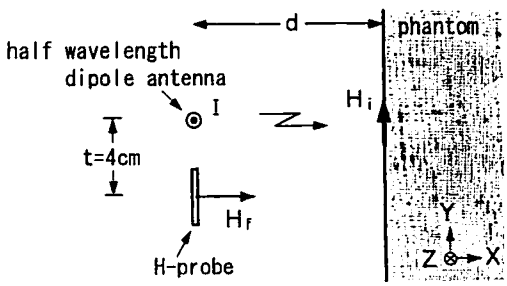

Fig. 1 SAR estimation model (H-probe was arranged for measuring X-axis direction component of the magnetic field (Hf) from the antenna).

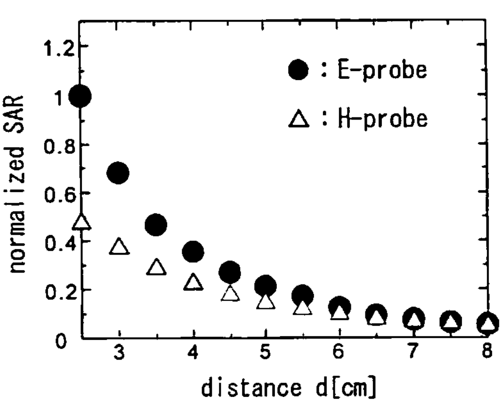

Fig. 2 Comparison of SAR values.

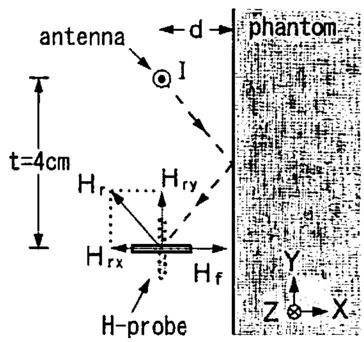

Fig. 3 H-probe arrangement for measuring both X-axis and Y-axis components of magnetic fields, direct and reflected.

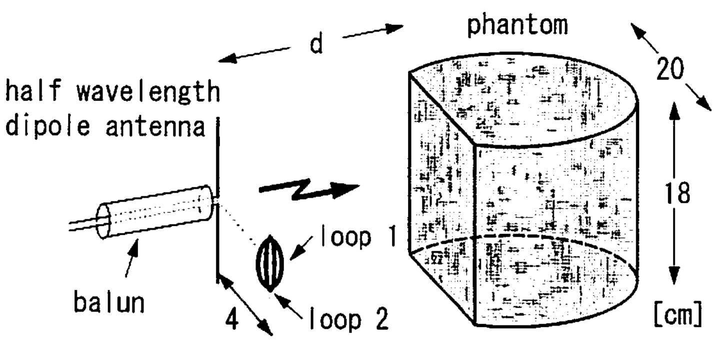

Fig. 4 Experimental setup with orthogonally designed double-loop probe.

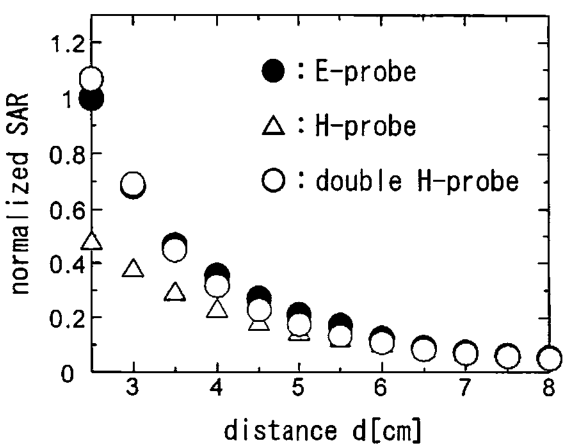

Fig. 5 Comparison of SAR values.