INTRODUCTION

A multi-antenna transmitter, e.g. in Multi-Input Multi-Output (MIMO) systems, will be implemented in the user equipment (UE) of mobile communication systems in the near future [1]. Applying the standardized procedures [2][3] for obtaining the maximum average Specific Absorption Rate (SAR), which is an evaluation index for RF exposure to human, requires the measurement of the three-dimensional SAR distribution prior to determining the average SAR in each case if weighting coefficients are variable. Therefore, this process is expected to be time consuming. Procedures for estimating the SAR for a multi-antenna transmitter were proposed in [4] and [5], in which the maximum SAR at each point can be obtained. On the other hand, we proposed a measurement procedure that can obtain the SAR distributions for arbitrary weighing coefficients of antennas using a short measurement process [6]. This paper shows the numerical verification of our proposal using four dipole antennas and a flat phantom.

MATERIALS AND METHODS

The SAR distribution for arbitrary weighting coefficients for antennas can be calculated using the measured amplitude and phase of the two-dimensional electric field distribution generated by the radiation from each antenna, which is detected using a vector probe. Based on the SAR distribution, which can be obtained using the equivalent theorem and image theory [7], the average SAR can be calculated for arbitrary weighting coefficients, and the maximum average SAR can be obtained for a multi-antenna transmitter. The SAR at an arbitrary point in the phantom can be obtained according to the following equation,

\[
\text{SAR}(r) = \frac{\rho}{\sigma} \left| \sum_{i=1}^{n} w_i E_i(r) \right|^2
\]

where \(E\) [V/m], \(\rho\) [kg/m³], \(\sigma\) [S/m], \(n\),and \(w_i\) are the electric field in the human body, the density, the conductivity of human tissue, the number of antenna, and the complex weighting coefficients, respectively. Figure 1 shows a flowchart of the proposed procedure to determine the maximum average SAR for a multi-antenna transmitter. For a certain weighting coefficient, the average SAR can be obtained based on the corresponding three-dimensional SAR distribution.
Figure 2 shows a verification model comprising four dipole antennas at 1950 MHz and a flat phantom. Two-dimensional electromagnetic fields are calculated for $z = 4.5$ mm using the Finite-Difference Time-Domain (FDTD) method. Based on two-dimensional electric fields, the three-dimensional SAR distribution is estimated using the equivalent theorem and image theory [7] prior to obtaining the average SAR.

RESULTS AND DISCUSSION

The average SAR is estimated based on both the original three-dimensional SAR distribution (antennas #1 to #4 are simultaneously active) and that based on the combination of two-dimensional electric field distributions for $z = 4.5$ mm when either of the antenna is active. Figure 3 shows the SAR distributions for $z = 10$ mm along the $y$ axis when $P_{\text{out}1}$ to $P_{\text{out}4}$ are the same. Case I indicates the SAR distributions that are all in phase, and Case II indicates the SAR distributions when Ant. #1 and #3 are in phase and Ant. #2 and #4 are out of phase. The SAR distributions for the same conditions are in extremely good agreement. The differences in the 10 g SAR obtained in both ways described above in Cases I and II are +7.9% and +1.4%, respectively. It is confirmed that the proposed procedure works very well and that the measurement accuracy of the proposed procedure is sufficient from a practical point of view.

CONCLUSIONS

The SAR estimation method based on two-dimensional electric fields can be applied to determine the maximum average SAR for multi-antenna transmitters. It is expected that the measurement time can be drastically shortened.

REFERENCES

[2] 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.