COMPUTATION OF SPECIFIC ABSORPTION RATE IN THE HUMAN BODY DUE TO BASE-STATION ANTENNAS USING A HYBRID FORMULATION

M.A. Mangoud [(1)], R.A. Abd-Alhameed[(2)] and P.S. Excell[(2)]
[(1)] Arab Academy for Science and Technology, P.O.Box 1029, Alexandria, Egypt.
Mangoud@ieee.org
[(2)] University of Bradford, Bradford BD7 1DP, UK
r.a.a.abd@brad.ac.uk, p.s.excell@brad.ac.uk

ABSTRACT

The procedures that are required to ensure that a mobile communications base station antenna will meet safety standards are investigated in this paper. Compared with the traditional power density method, a procedure based on more rigorous physics was devised, requiring computation or measurement of the SAR within the biological tissue. A hybrid MoM/FDTD numerical method is then used as a powerful and flexible tool for real base station safety distance evaluation. It is shown that the power allowed by the more precise SAR method is, in many cases, between two and five times greater than that allowed by standards implementing the PFD method.

INTRODUCTION

The traditional method for assessment of the compliance of fixed radio transmitters with safety guidelines is to calculate the radiated power flux density (W/m^2) at the minimum distance of approach by personnel and to compare this with the maximum values that are specified in many safety guideline documents [1,2]. The calculation may be undertaken using simple far-field relationships or a more accurate computational-electromagnetics method that can take account of directions other than the main beam and distances in the near field.

This procedure is not viable for hand-held transmitters which couple to the biological tissue in the very near field and for this situation a procedure based on more rigorous physics is used, requiring computation or measurement of the specific absorption rate (SAR) within the biological tissue. The physics is more rigorous because the SAR is quantified in Watts per kilogram, thus being directly related to the rate of deposition of the heat energy in the tissue. This approach requires detailed computational models if it is to be assessed predictively, but such techniques have now become well established.

It is thus very desirable that the techniques developed for predictive compliance-assessment based on SAR be extended to cover transmitters further from the human head than is typically the case for mobile telephone handsets. Unfortunately, if the most popular existing field computation method for this purpose (the finite difference time domain or FDTD method) is used, the size of the computational problems rapidly become excessive. An alternative is to use the Method of Moments (MoM), this will model the field from the antenna at arbitrary distances with high accuracy, but it is incapable of representing the detailed structure of the human head.

PROPOSED SOLUTION

A solution to this problem is to use a computer program that is a hybrid of FDTD and MoM such that the more appropriate of these two methods can be applied to the different parts of the problem. Combining two methods that are so different in their fundamental principles is not a trivial matter, but it has recently been achieved for the case of the mobile telephone adjacent to a human head [3-7]. In modelling a mobile telephone, the MoM region is kept as small as possible, just sufficient to contain the phone itself and simulate its complex (usually helical) antenna. This region is placed as a sub-domain within the FDTD region and surrounded by a pair of bounding surfaces (a Huygens surface and an Equivalence-principle surface) which are used to re-launch the inward and outward travelling fields between the two domains. For studies of the effect of base stations on the body, the size of the Moment-Method region would be too large for it to be treated as a sub-domain, and hence a modified formulation has been devised, essentially treating the FDTD region as the sub-domain.

In order to maximize the usefulness of the method, it employs the frequency domain version of MoM and hence simple Fourier transforms (including phase information) have to be applied between each iterative step, in which interim field data is transferred between MoM and FDTD. The induced currents for the source region are first obtained, excluding the effect of the scatterer in the FDTD region, using the frequency domain version of MoM. The fields due to these currents are obtained on the closed surface (Huygens surface) that separates the source from the scatterer. Oscillating with respect to a reference phase of the source, these fields or their equivalent surface currents are converted to time-domain excitation incident fields or current sources using an inverse discrete Fourier transform. The FDTD algorithm is now executed with these time-domain sources to obtain the induced currents on the scatterer. The back-scattered fields on the source side of the Huygens surface are considered to be the excitation sources for the source region. These fields or their equivalent current sources are transferred to the frequency domain using a discrete Fourier transform, in which the phase difference relative to the reference phase of the source is taken into account. The MoM is then used in reverse to evaluate the induced currents on the source region due to both the source excitation region and the induced equivalent current sources from the FDTD method. The method is repeated until a steady state solution is obtained.

THEORETICAL FORMULATION

Consider Fig. 1: this shows two regions, one representing the source region A and the other the scatterer B. The source region is bounded by the closed Huygens surface S_c. The method starts by computing the fields due to the real currents of the source region A (previously evaluated using the internal excitation in the source region) on the surface S_c, excluding the scatterer region B. These fields are computed using the MoM wire current calculation, using Galerkin's solution with curved segments and triangular basis functions on the wire surface.

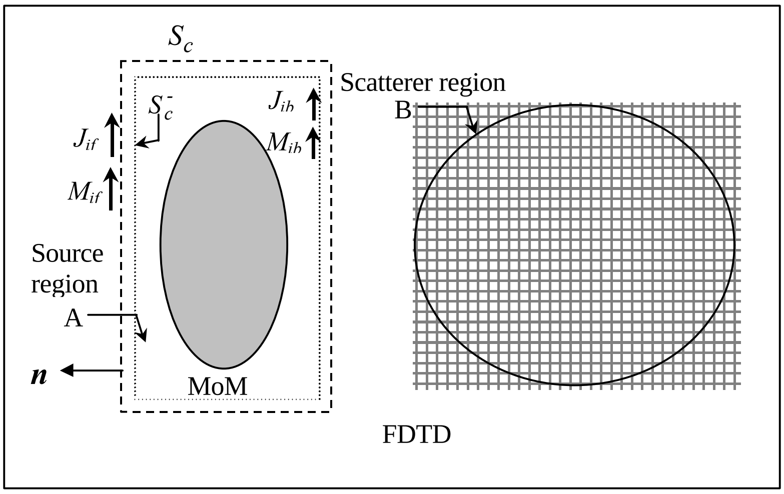


Fig.1 Hybrid MoM/FDTD configuration for the single source and scatterer geometries

The equivalent surface currents on the surface S_c that represent the outward travelling fields from the source to the scatterer, due to the fields of the source region A, can be written as:

$$\boldsymbol{J}_{if} = \boldsymbol{n} \times \boldsymbol{H}_{if}, \boldsymbol{M}_{if} = \boldsymbol{E}_{if} \times \boldsymbol{n}$$

where $\boldsymbol{n}$ is the unit vector normal to the surface and directed outwards from the source region. $\boldsymbol{H}_{if}$ and $\boldsymbol{E}_{if}$ are the forward scattered fields from the source region A on the equivalent surface S_c. $\boldsymbol{J}_{if}$ and $\boldsymbol{M}_{if}$ are the equivalent electric and magnetic source currents on the surface S_c. Thus these currents are treated as the source in the FDTD domain, propagating fields to the scatterer by using the $\boldsymbol{E}$ and $\boldsymbol{H}$ time domain equations. The FDTD updating equations for the field components for the previous two Maxwell equations are expanded with a three-dimensional modified total/scattered FDTD formulation for the special components on the Huygens surface, while the rest of the problem space field components follow the normal updating equations. The back-scattered fields were computed by FDTD at S_c^- (the closed surface interior to the surface S_c and bounding the region A). This closed surface is in the scattered field region, so that the calculated surface currents are due the scattered field only. The equivalent surface currents due to these fields, representing an additional source to the MoM domain (region A), are given by: $\boldsymbol{J}_{ib} = \boldsymbol{H}_{ib} \times \boldsymbol{n}$ and $\boldsymbol{M}_{ib} = \boldsymbol{n} \times \boldsymbol{E}_{ib}$, where $\boldsymbol{H}_{ib}$ and $\boldsymbol{E}_{ib}$ are the back-scattered fields computed at S_c^-. Note that $\boldsymbol{n}$ is directed outwards from the source region. $\boldsymbol{J}_{ib}$ and $\boldsymbol{M}_{ib}$ are the electric and magnetic equivalent surface currents at S_c^-. Now, the voltage back scattered (the excitation for the MoM) on the source region can be evaluated using the following equations, defined by reciprocity theorem:

$$V_b = \int_{S_c^-} (\boldsymbol{J}_{ib}.\boldsymbol{E}_{ms} - \boldsymbol{M}_{ib}.\boldsymbol{H}_{ms})ds_c^-$$

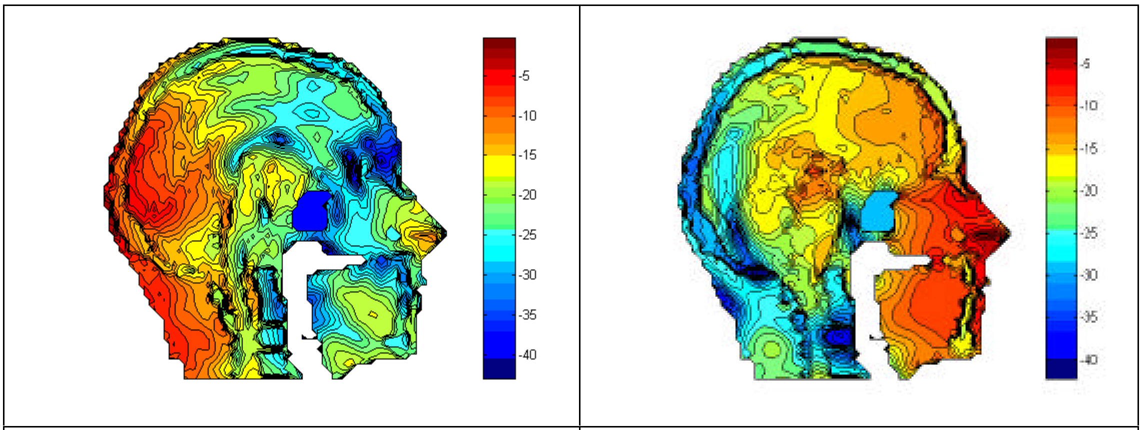
The vectors ***r*** and ***r*¢**apply to the source and observation points respectively and S_a is the conducting surface area of the structure within region *A*. $\boldsymbol{J}_{ms}$ is the electric test function used on the wire. $\boldsymbol{E}_{ms}$ and $\boldsymbol{H}_{ms}$ are the electric and magnetic fields respectively for the test function $\boldsymbol{J}_{ms}$. Since the excitation voltages are known, the MoM can be executed to compute the new currents and the procedure can be repeated until the steady state solution is reached.

EXAMPLE APPLICATION FOR A TYPICAL BASE STATION

This hybrid MoM/FDTD method can be efficiently applied to model the base station to human interaction situation, to ensure that a mobile communications base station antenna will meet safety standards. As a test example, the base station is represented by a well-characterised simple antenna (a dipoles) operated at 1800 MHz. Different calculations, applying several power flux density methods were also done and then compared with the specific absorption rate (SAR) method for computation of the maximum allowable power that may be radiated by a simulated base station antenna. For the SAR method, several simulation runs were undertaken at 1800 MHz, with the antenna at different distances from the head and the head oriented facing towards, and away from, the antenna. Six simulation runs were undertaken at 1800 MHz, with the antenna at three different distances from the head (0.5, 1, 2 wavelengths) and the head oriented facing towards, and away from, the antenna. The SAR values are shown in Table 1 and the SAR distributions in Fig 2 (for front and back cases). The results in Table 1 show that the SAR, for 1W radiated, is well within the ICNIRP guidelines for the particular case presented here, but more importantly they show that, for the cases where averaging is over 10g, the SAR with the antenna in front of the head is higher than when it is at the rear. The graphs in Fig. 2 appear to show that this is because of local field concentration in the nose. On the other hand, for 'whole-body' averaging (only possible over the whole head in this case, but indicative of the whole-body case), the situation with the antenna at the rear is slightly more onerous.

Table 1 SAR and Power Results for Half-Wavelength Dipole Radiating 1W at 1800 MHz.

f=1800 MHz	Distance from head surface in wavelengths	Absorbed power in head, W	SAR averaged over whole head, W/kg	SAR (peak), W/kg	Max. SAR (10g ave.), W/kg
Antenna in front of the head	0.5	0.0768	0.025927	6.6276	0.7684
	1	0.0373	0.012592	2.0006	0.2424
	2	0.0145	0.004895	0.5659	0.0697
Antenna at the back of the head	0.5	0.0888	0.029978	1.5281	0.3510
	1	0.0429	0.014483	0.4868	0.1061
	2	0.0164	0.005537	0.1312	0.0358



(a) D=-0.5 λ | (b) D= 0.5 λ

Fig. 2 Peak SAR distribution (dBW/kg) in the head for 1800MHz dipole 0.5λ (a) behind and (b) in front of human head

Maximum Permissible Radiated Powers Dictated by the SAR Method

By dividing the values of maximum SAR in Table 1 by the limiting values specified in the safety guidelines the maximum power that may be radiated by the dipole may be calculated. The implications of SAR and PFD-based assessment can be succinctly compared, at the limits of the distance range studied, in Table 2. The key results for the maximum power that can be transmitted while satisfying safety guidelines are included. It is evident that the power flux density (PFD) criteria, being based on approximations, contain conservative estimates that restrict the maximum allowable powers, in most cases, to a lower level than those permitted by the SAR method. In almost all cases, the SAR method permits the radiation of more power than is allowed by the PFD method. The most significant cases are seen when the ICNIRP guidelines are compared: the power allowed by the SAR method is between two and five times greater than that allowed by the PFD method. Since the SAR method is based on more precise science, it should be taken as the more accurate guide. The method shows that the hybrid MoM/FDTD method is a powerful and flexible tool for safety distance evaluation for real base stations.

Table 2 Maximum Permitted Powers at 1800 MHz

Authority	Method	Max. power at 0.08m (W)	Max. power at 0.32m (W)
NRPB	PFD	5.54	78.2
	SAR	13.0 (10g)	72.2 (WB)
ICNIRP (public)	PFD	0.521	7.35
	SAR	2.60 (10g)	14.4 (WB)

Note: The SAR-based power is whichever is given by the lower of the two averaging methods, as indicated in brackets. WB = Whole body averaging, 10 g = 10 g averaging.

Conclusion

It has been shown that the power flux density (PFD) criteria, being based on approximations, contain conservative estimates that restrict the maximum allowable powers. In most cases, the SAR method permits the radiation of more power than is allowed by the PFD method. The most significant cases are seen when the ICNIRP guidelines are compared: the power allowed by the SAR method is between two and five times greater than that allowed by the PFD method. Since the SAR method is based on more precise science, it should be taken as the more accurate guide. The novelty of the SAR-based procedure suggests further avenues for investigation, which would enhance its credibility and understanding of its implications. Investigation of smaller distances would shed further light on the transition between dominance of the 10g and whole-body averaging procedures. However, it is also possible that this transition would occur further away if the antenna studied were to be a realistic base-station array.

References

1. National Radiological Protection Board, “Board Statement on Restrictions on Human Exposure to Static and Time Varying Electromagnetic Fields and Radiation,” Documents of the NRPB, Vol.4, No.5, 1993.
2. ICNIRP (International Commission on Non-Ionising Radiation Protection) ”Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields (up to 300GHz)”, Health Physics, Vol. 74, No. 4, pp 494-522, 1998.
3. EU Standards, Measurements and Testing Programme, Contract No. SMT4-CT97-2173 ‘Electromagnetic Dosimetry for Mobile Communication Equipment’ (Short title: ‘CEPHOS – Cellular Phone Standards’), Final Report 1999.
4. P. Olley and P. S. Excell, “Classification of a High-Resolution Voxel Image of a Human Head”, International Workshop on Voxel Phantom Development, National Radiological Protection Board, Chilton, pp16-23, 1995.
5. M. A. Mangoud, R. A. Abd-Alhameed, P.S. Excell**,** Investigations of polarisation purity and SAR for personal satellite communications antennas using a hybrid computational method **,** Electronics Letters, Vol. 37, No. 21, pp 1272-1274, 2001
6. Mangoud, M.A., Abd-Alhameed, R.A. and Excell, P.S.: 'Simulation of human interaction with mobile telephones using hybrid techniques over coupled domains', IEEE Trans. on Microwave Theory and Techniques, Vol. 48, No. 11, pp. 2014-2021, 2000.
7. Abd-Alhameed, R.A., Excell, P.S., & Vaul, J.A.: ‘Conduction current crossing domain boundaries in a heterogeneous hybrid computational electromagnetics formulation’, Electronics Letters, Vol. 35, No. 21, (Oct. 1999), pp. 1786-1788.