THE RELATION BETWEEN SAR AND THE ELECTROMAGNETIC FIELD DISTRIBUTION FOR HETEROGENEOUS EXPOSURE CONDITIONS

Georg Neubauer(1), Stefan Cecil(1), Patrick Preiner(1), Niki Mitrevski (1),Günter Vermeeren (2), Wout Joseph (2), Luc Martens (2), Sven Kuehn(3), Niels Kuster (3)

(1) ARC Seibersdorf research, A-2444 Seibersdorf, Austria, Email: georg.neubauer@arcs.ac.at
(2) Ghent University, Department of Information Technology, Belgium, Email: luc.martens@intec.UGent.be
(3) Foundation for Research on Information Technologies in Society, Switzerland, Email: kuster@itis.ethz.ch

ABSTRACT

In the frame of this part of the EUREKA project BASEXPO the relation between the specific absorption rate and the electric field strength is investigated for real life exposure conditions arising next to common RF sources, e.g. mobile communication base stations. The first results show that the deviation of the whole body specific absorption rate for heterogeneous exposure conditions from the plane wave conditions is in most cases below 50 %.

1. INTRODUCTION

Most of the international guidelines, standards and other related documents dedicated to protect the population against adverse health effects arising from the exposure against electromagnetic fields are based on a concept including two types of limits: basic restrictions and reference levels. Basic restrictions are based on established health effects, in the RF range the specific absorption rate (SAR) is the most relevant basic restriction [1,2,3,4]. Reference levels are mainly provided for practical exposure assessment purposes. Some reference levels are derived from basic restrictions using measurements and both analytical and numerical approaches, e.g. electric and magnetic field strength levels are derived from the specific absorption rate. However, these relations were mainly established based on plane wave exposure conditions and simple phantoms dedicated to mimic the human body. It has to be taken into account that the exposure conditions in the vicinity of fixed installed RF transmitters, e.g. mobile phone base stations, are usually heterogeneous for real life conditions due to multipath propagation, shadowing effects, impact of the environment and under certain circumstances due to the interaction between the human body and the antenna system. The existing scientific body of information on this topic is limited, mainly focuses on reactive near field exposure conditions and is not adequate to draw final conclusions [5-12, 16]. The aim of this project is therefore the provision of measurement and calculation data to establish a correlation between basic restrictions, incident electromagnetic fields and optimized free space measurement technologies. This correlation is obtained by the simulation of a human body model in homogeneous as well as in scattered field zones. The correlation is based on knowledge gained about incident fields as well as common measurement methods to meet reference levels. Numerically obtained information on the transition of the incident field strength to the induced field strength is validated experimentally.

To perform systematic simulations of body induced SAR distributions in human phantoms typical exposure conditions arising in the vicinity of fixed installed RF transmitters have to be investigated. One major problem of such scenarios is the fact that the sources are often located far away from the exposed person and the propagation paths from such sources arrive due to multipath propagation from different directions leading to heterogeneous field distributions. Optical tools are well suited to assess the field distributions for such scenarios taking into account the impact of objects, e.g. buildings and ground. However, optical numerical tools are not suitable for the determination of SAR distribution in phantoms while some numerical tools based on discrete solutions of Maxwell's equations, e.g. the method of the Finite Differences in Time Domain (FDTD) are suitable to determine SAR distributions in human bodies exposed to electromagnetic waves. Due to limitations in available working memory and processing time of existing computer systems there are limitations of the size of the calculation space, i.e. the examined volume. It is therefore usually not possible to simulate areas including electromagnetic sources being far away from the exposed phantom with suitable spatial resolution, e.g. a person being 20 m or more away from a base station.

The problem to be solved is therefore to combine the advantages of optical tools and suitable numerical tools solving Maxwell's equations, e.g. FDTD tools. One possibility is to use so called hybrid solutions [13-15], one of them was developed in the frame of this project and will be presented in the next chapter.

Proc. 'EuCAP 2006', Nice, France
6–10 November 2006 (ESA SP-626, October 2006)

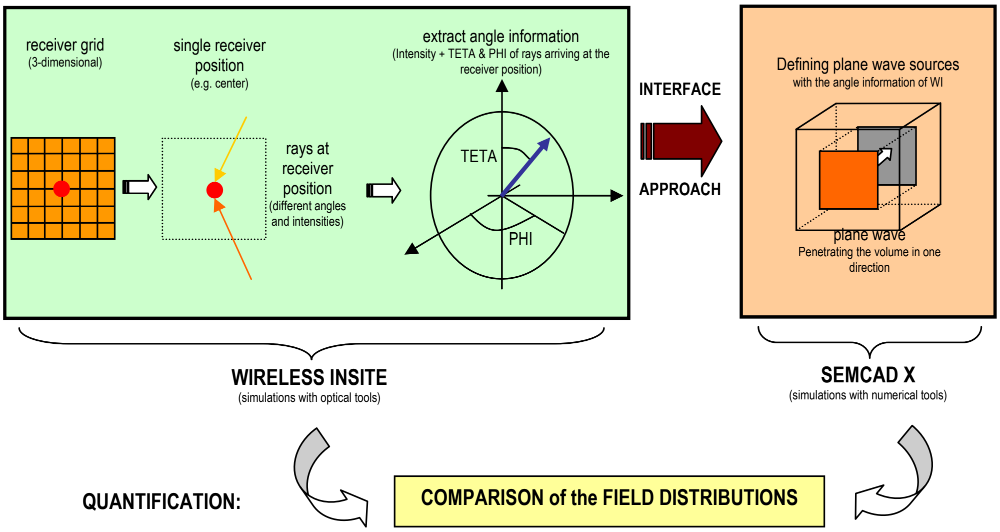

Figure 1. Principal Approach generating information of rays arriving at a receiver Position (Wireless Insite) and reproducing the field distribution by setting up plane waves with the information (SEMCAD)

Wireless Insite **SEMCAD**

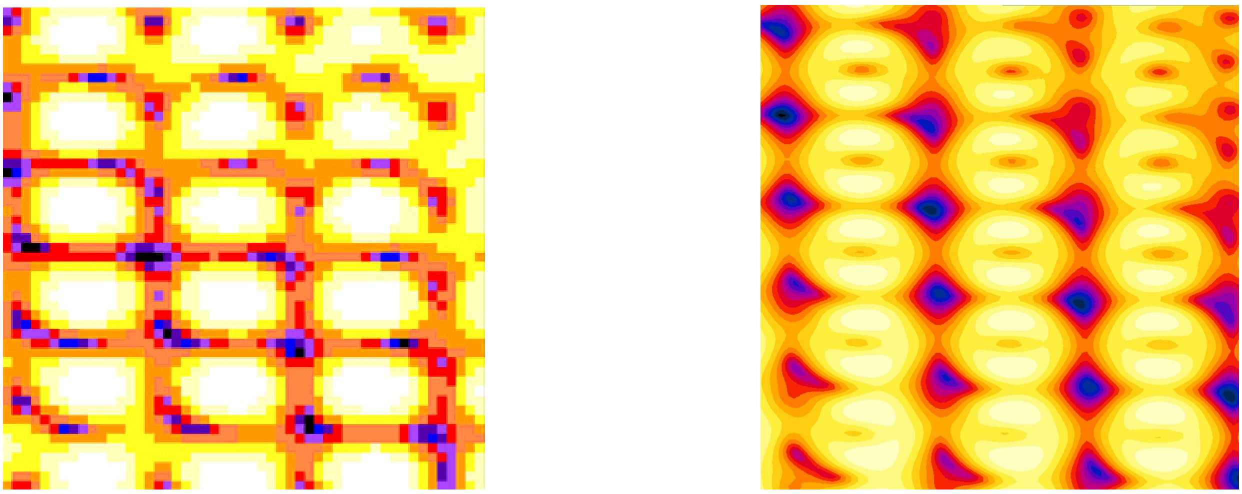

Figure 2. Comparison of the calculated fields in Wireless Insite and the by plane waves recreated field distribution in SEMCAD

2. METHODS

2.1 Numerical Approach

In the frame of this project the main focus is set on a qualitative description of the incoming waves into the calculation room used within a numerical tool solving Maxwell's equations to obtain SAR distributions in a phantom. The results obtained with the optical tool Wireless Insite from Remcom are therefore used to define the exposure conditions used for SAR determination with the FDTD-tool *SEMCAD* (*SEMCAD* of Schmid & Partner AG; based on solving the Maxwell equations).

The principle approach is to gain information on incoming electromagnetic waves by evaluating the received rays on a single position with the help of an optical based tool (Remcom's *Wireless Insite*). This approach can be applied, when the single position in the investigated volume approximately receives the same rays like all other positions in the volume. With the help of this information the field distribution is recreated within SEMCAD. There all rays are recreated by plane waves, because in large distance to the transmitter (compared to the wavelength) all incoming waves can be approximated by plane waves. Figure 1 shows the principle of the developed method and Figure 2 the quantitative comparisons of the field distributions generated with *Wireless Insite* and *SEMCAD*, which demonstrated the suitability of this approach (qualitative comparisons not shown).

In the investigated scenario described in Section 2.2 a receiver grid is calculated with the help of *Wireless Insite* and the information on a single position in the center of the grid is used for further calculations with *SEMCAD*. The relevant information are the angles of the received rays (TETA and PHI) describing the orientation of the ray in area receiver position, the intensity of each ray and the propagation time. This body of information is used to define the incoming plane waves in the FDTD platform (*SEMCAD)*. These plane waves are than super positioned to investigate the heterogeneous exposure of the human body model (Visible Human Project).

Both whole SAR and local body SAR are determined. The whole body SAR is normalized to the electric field strength averaged over the volume of the phantom. For each position the whole body SAR is compared to the plane wave exposure case (frontal exposure, vertical polarisation).

2.2 Examined Scenario

A typical urban scenario was chosen to investigate multipath exposure conditions (see Figure 3). The scenario consists of four buildings with flat roofs located at a street crossing. Each building has the same dimensions, i.e. a side length of 40 m and a height of 20 m. The material properties of the buildings correspond to those of concrete at the examined frequencies. The transmitting antenna is located at two typical positions on one building: at the edge of the building 3 m above the rooftop and at the centre of one wall 10 m above ground. An ideal dipole with a radiated power of 2 W is used as source. Investigations are performed at 946, 1840 and 2140 MHz to cover the downlink bands of GSM 900 & 1800 and UMTS, respectively. 21 locations representing the position of an exposed person are examined. The reference position is located 1 m above ground in case of positions located on the street, 10 m above ground for the positions at the walls representing a person standing on a balcony and 1 m above the rooftop in case of persons standing on the roof.

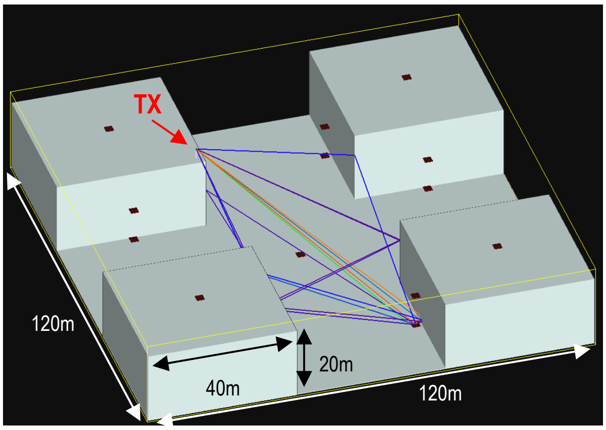

Figure 3. Investigated scenario including 21 receiver positions (black points) and one of the two transmitter locations (red sphere)

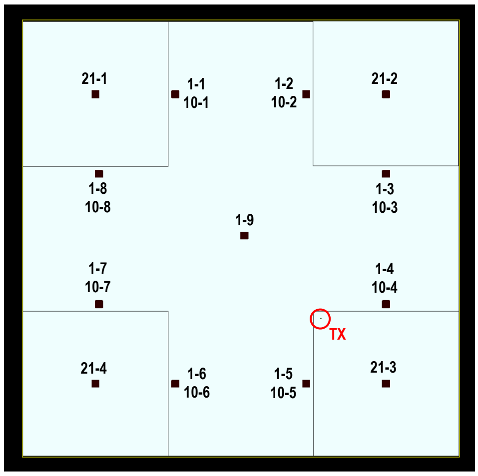

Figure 4. Nomenclature of the receiver positions. The first number indicates the height (1m, 10m or 21m) and the second the index

The examined scenarios include both Line of Sight (LOS) and Non Line of Sight (NLOS) conditions. Between seven and ten rays propagating from different directions are taken into account. As shown in Figure 1 the different rays are described by the two angles theta and phi, their power and the respective propagation time.

3. RESULTS

Results of the exposure conditions at 946 MHz are given in Table 1. The position in the investigated scenario (according to Figure 4, where the first number indicates the height and the second the index) is given in the first column. In the second column the whole body specific absorption rate at the respective position normalized to the averaged electric field strength at the position of the phantom is specified. It has to be mentioned that the field strength is exactly averaged over the voxels that would compose the phantom in absence of the phantom, therefore the averaged electric field strength corresponds exactly to the whole body SAR. Column 3 gives the deviation of the whole body SAR at a given position from the whole body SAR for frontal plane wave exposure, vertical polarisation.

The results demonstrate that in 18 out of 21 cases the whole body SAR differs less than 30 % from the plane wave exposure case. However, the largest deviation from the plane wave case found is 63.85 %. The position P 21-4 is one of the positions located in a height of 21 m above ground, corresponding to a rooftop scenario. The reference level at 946 MHz is 42.29 V/m for the general population, a person exposed to an averaged field level would therefore have a whole body SAR of 0.041 W/kg. This would still be about 50 % below the basic restriction of the whole body SAR of 0.08 W/kg for the general population.

Position	WB-SAR [(µW/kg)/(V^2/m^2)]	Dev. To Plane Wave [%]
Plane Wave	13.99	0
P 1-1	16.75	19.75
P 1-2	9.17	-34.40
P 1-3	10.50	-24.95
P 1-4	14.31	2.31
P 1-5	11.97	-14.45
P 1-6	14.61	4.46
P 1-7	13.27	-5.14
P 1-8	14.52	3.80
P 1-9	9.83	-29.69
P 10-1	12.58	-10.02
P 10-2	8.92	-36.20
P 10-3	10.25	-26.73
P 10-4	14.69	5.05
P 10-5	13.07	-6.58
P 10-6	13.12	-6.16
P 10-7	14.44	3.28
P 10-8	15.16	8.40
P 21-1	14.90	6.53
P 21-2	15.26	9.12
P 21-3	10.88	-22.20
P 21-4	22.92	63.85

Table 1. Whole body SAR normalized to the averaged incoming electric field strength – comparison with plane wave case for all scenarios at 946 MHz

The same scenarios were also investigated for 1840 and 2140 MHz (results not shown). The highest whole body SAR found for these frequencies is about 56 % above the plane wave case.

4. DISCUSSION

This method is an approach and represents a simple way of linking an optical based tool with a numerical tool solving the Maxwell Equations, as only the information of one receiver position (derived with *Wireless Insite*) is taken to recreate a small region with the help of *SEMCAD*. Compared to hybrid tools which are mathematically based methods for linking an optical tool with a numerical tool the described method is based on the main directions of incoming rays on a certain position.

It has to be pointed out that this methodology is not dedicated to transfer the information on incoming waves from the optical platform to the FDTD platform in a precise way. The purpose of this methodology is to transfer major exposure descriptors for representative exposure conditions in a qualitative way. Preliminary investigations have shown that this requirement can be achieved.

Looking at results obtained so far, the deviation from the plane wave exposure are in most cases moderate. Additional investigations focussing on the effect of polarisation, shadowing effects, impact of the phantom are ongoing in the frame of this project and need to be taken into account before any conclusions can be drawn. In addition the numerical results will be validated by measurements.

5. REFERENCES

[1] ICNIRP *Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)*, Health Physics 74 (4), pp. 494 – 522, 1998

[2] Council Recommendation 1999/519/EC of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz), Official Journal L 197 of 30 July 1999

[3] Directive 2004/40/EC of the European Parliament and of the Council of 29. April 2004 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields), Official Journal of the EC L184/1-L184/9, 24.5.2004

[4] IEEE Standard for Safety Levels with respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz, IEEE Std C95.1-2005, the Institute of Electrical and Electronic Engineerings, Inc. 3 Park Avenue, New York, NY 10016-5997, USA

[5] Hansen, V., Bitz, A., Streckert, J., El Ouardi, A., *A numerical approach for efficient calculation of human exposure in front of base station antennas*, XXVIIIth General Assembly of International Union of Radio Science, October 23 – 29, 2005, Abstract Book Poster Presentation, p 159

[6] Bitz, A., El Ouardi, A., Streckert, J., Hansen, V. *Efficient calculation of human exposure in front of base station antennas*, Presentation at the BioEM

2005, June 20.-24., 2005, Dublin, Ireland, Abstract Book pp. 31-32.

[7] Cooper, J., Marx, B., Buhl, j., Hombach, V. *Determination of Safety Distance Limits for a Human Near a Cellular Base Station Antenna*, Bioelectromagnetics 23 429-443, 1997

[8] Dimbylow, P.J. *FDTD calculations of the whole boy averaged SAR in an anatomically realistic voxel model of the human body from 1 MHz to 1 GHz*, Phys. Med. Biol. 42, pp 479 – 490, 1997

[9] Dimbylow, P.J, *Fine resolutions calculations of SAR in the human body for frequencies up to 3 GHz*, Phys. Med. Biol. 47, pp 2835 -2846, 2002

[10] Dale, Ch., Wiart, J., Wong, M.-F., *EMF Exposure Regarding Base Station*, Sixteenth International Wroclaw Symposium and Exhibition on Electromagnetic Compatibility, June 25-28, 2002, Proceedings pp 343-346

[11] Bernardi, P., Cavagnaro, M., Pisa, S., Piuzzi, *Human Exposure to Radio Base Station Antennas in Urban Environment*, IEEE transactions on microwave theory and techniques, Vol. 48, No. 11, 2000

[12] Bernardi, P., Cavagnaro, M., Ciccetti, R., Pisa, S., Piuzzi, E., Testa, O. *A UTD / FDTD investigation on Procedures to assess Compliance of Cellular Base Station Antennas with Human Exposure limits in a Realistic Urban Environment*, IEEE Transactions on Microwave Theory and Techniques, Vol. 51, No. 12, December 2003

[13] Martin, A., Rubio, A., Villar, R., Martinez-Burdala, M. *Combination of FDTD and time domain equivalent currents method for safety assessment in human exposure to base station antennas*, XXVIIIth General Assembly of International Union of Radio Science, October 23 – 29, 2005, Abstract Book Poster Presentation

[14] Mangoud, Mohab A., Abd-Alhameed, Raed A., Excell, Peter S. *Simulation of Human Interaction with Mobile Telephones Using Hybrid Techniques Over Coupled Domains*, IEEE Transactions on Microwave Theory and Techniques, Vol. 48, No. 11, December 2000

[15] Cerri, G., Chirandini, S., Russo, P., and Schiavoni, A, *Electromagnetic Coupling Between Arbitrarily Bent Wires and Scatterei Analysed by a Hybrid MoMTD/FDTD Approach* IEE Proc.-Microw. Antennas Propag., Vol. 147 No. 4, August 2000

[16] Meyer, F.J.C., Davidson, D.B., Jakobus, U, Stuchly, M.A. *Human exposure assessment in the near field of GSM base station antennas using a hybrid finite element/method of moments technique*, IEEE Transactions on Biomedical Engineering, Vol 50, No.2, 2003


EuCAP 2006
esa
SP-626
Proceedings
Copyright: © 2006 European Space Agency
ISBN 92-9092-937-5 ISSN 1609-042X

EUCAP CHAIRS

J. Mosig (General Chair), EPFL, CH
P. Ingvarson (Vice Chair), Saab Ericsson Space, S
B. Arbesser-Rastburg (Vice Chair), ESA-ESTEC, NL
A. Roederer (Honorary Chair), ESA-ESTEC, NL
P. Brachat (Local Chair), France Telecom R&D, F
C. Pichot (Local Chair), Univ. de Nice, F

Publication	Proceedings of the European Conference on Antennas and Propagation 'EuCap 2006', Nice, France (ESA SP-626, October 2006)
Editors	H. Lacoste & L. Ouwehand
Published by:	ESA Publications Division ESTEC Postbus 299 2200 AG Noordwijk The Netherlands
Printed in:	The Netherlands
Price:	60 Euros
ISBN No:	92-9092-9375
ISSN No:	1609-042X
Copyright:	© 2006 European Space Agency

SP-626
October 2006

Proceedings of

The European Conference on Antennas and Propagation: EuCAP 2006

6-10 November 2006
Nice, France

European Space Agency
Agence spatiale européenne