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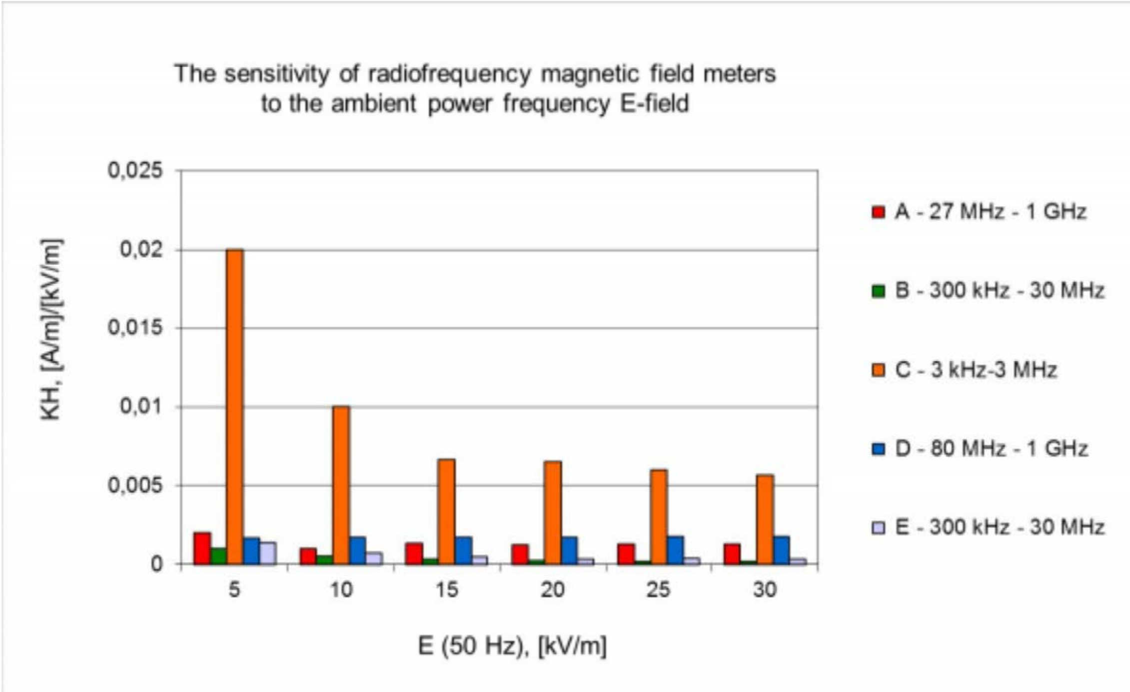

Figure 2. The sensitivity of measurement devices of radiofrequency magnetic fields to the 50 Hz frequency ambient electric field

PB-72 [11:00]
On the worst-case whole-body SAR assessment due to far-field exposure

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In this study we report a deterministic approach to evaluate the worst-case whole-body SAR due to far-field exposure. The approach is validated against a statistical approach (Monte Carlo) and the Self-Adaptive Differential Evolution optimization method, for two human numerical models and two frequencies under illumination from twelve plane-waves. It appears that the statistical approach performs worse than the other two methods, because it predicts lower values for the SAR.

Long Abstract

INTRODUCTION

Most of the numerical investigations on the dosimetric assessment of exposure in the far field of electromagnetic sources have been performed using a single plane wave exposure [1], [2]. However, in a realistic environment humans are exposed to multiple waves arriving from various directions and with amplitude and phase distributions depending on the type of environment (e.g., outdoor, indoor). Several recent papers have reported on this situation, using either case models of heterogeneous exposure [3] or statistical approaches [4], [5] to investigate the relation between the whole body specific absorption rate (SAR_{wb}) and the incident electromagnetic field in realistic environments with multipath propagation. It was found that single plane wave exposure does not represent the worst-case. Since in dosimetry we are interested in a conservative approach, in the present study we propose a methodology to calculate the maximum whole body SAR from multiple plane wave exposures, using deterministic and non-deterministic methods and comparing between them.

MATERIALS AND METHODS

Specific absorption rate under multiple plane-wave exposure

Specific absorption rate (SAR) can be related to the electric field at a point by:

$$SAR = \frac{\sigma \left| E \right|^2}{2\rho} \quad (1)$$

where σ is conductivity of the tissue (S/m), ρ is mass density of the tissue (kg/m^3) and E is the amplitude of a (harmonic) electric field in tissue (V/m). If we assume that the electric field E is generated by N independent sources, each one of them having a complex amplitude c_i, we obtain [6]

$$SAR = \frac{\sigma \left| \sum_i c_i \overrightarrow{E_i} \right|^2}{2\rho} \quad (2)$$

The above equation can be written as:

$$SAR = \frac{\sigma}{2\rho} \sum_i \sum_j c_i c_j \overrightarrow{E_i} \overrightarrow{E_j^*} \quad (3)$$

To calculate the whole-body SAR (averaged SAR over a volume), equation (3) can be written as:

$$SAR_{wb} = \sum_i \sum_j c_i c_j M_{ij} \quad (4)$$

where

$$M_{ij} = \frac{\int_{wb} \frac{\sigma}{2\rho} \overrightarrow{E_i} \overrightarrow{E_j^*} \varrho dV}{\int_{wb} \varrho dV} \quad (5)$$

contains the interaction between the electric fields generated by the independent sources.

Deterministic approach

Matrix M is hermitian, thus diagonalizable by the unitary transformation $\mathbf{M_{wb}=UDU^+}$, where U is the unitary matrix and D is a diagonal matrix; its elements are equal to the eigenvalues of M. As a result, the SAR_{wb} is maximized for the maximum value of D, which is the maximum eigenvalue of M.

Monte Carlo approach

It is possible to generate an arbitrary number of incident plane waves with different amplitude and phase, by randomly generating vectors c_i. Then, combining these vectors in equation (4) with matrix M, it is possible to retrieve the SAR_{wb} distribution and its maximum value. In this study we used uniform amplitude and phase probability distributions.

Differential evolution approach

Differential evolution (DE) is a metaheuristics method that tries to maximize a multidimensional real-valued function by iteratively trying to improve a candidate solution with regard to a given measure of quality. It makes few or no assumptions about the problem being optimized and can search a very large space of candidate solutions [7]. A self-adaptive version of the method (SADE) has already been successfully applied to antenna and microwave design problems [8].

Numerical models and technique

The exposure assessment was performed for one adult (Duke) and one child (Thelonious) anatomical model from the Virtual Family [9]. For each of the two numerical models, the following simulation setup was applied: Six different plane waves with incident directions of the corresponding major sides (front, back, top, bottom, right and left) and for two orthogonal polarizations of the electric field per incident direction were used to calculate the M matrix. The calculations of the electric field inside the models were performed for two frequencies (866 and 2450 MHz) using SEMCAD-X (SPEAG, Zurich, Switzerland). Then, the fields were extracted in MATLAB, where the appropriate functions were implemented to calculate the M matrix and the corresponding SAR_{wb} with the three approaches. All the values of SAR_{wb} were normalized to the same total incident field power density corresponding to 1V/m.

RESULTS

Table 1 presents the derived results for the maximum SAR_{wb} using the aforementioned methods and assuming exposure to twelve plane waves. It is clear that SADE, which is a non-deterministic method, achieves the same maximum like the eigenvector approach, which is deterministic and should be able to predict the global maximum. The SADE was run several times and the reported value in table 1 is the average for each case. The Monte Carlo method, on the other hand, cannot predict exactly the worst-case SAR_{wb} value but it can give a value which is up to 0.5 dB lower, when 100'000 arbitrary vectors are used for the calculation. Figures 1 and 2 depict the amplitude and phase distributions, respectively, for the plane waves that result in the values of Table 1 for each method and for the case of the male adult model (Duke) at 866 MHz.

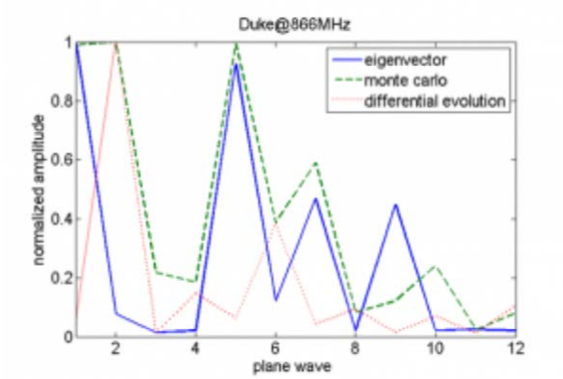

FIGURE 1: AMPLITUDE DISTRIBUTION OF THE PLANE WAVES EIGENVECTORS FOR EACH METHOD OF TABLE 1

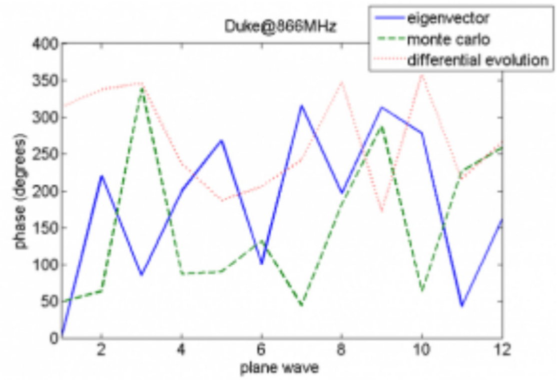

FIGURE 2: PHASE DISTRIBUTION OF THE PLANE WAVES EIGENVECTORS FOR EACH METHOD OF TABLE 1

The most time consuming steps of the above approach are two: The calculation of the plane wave exposures and the calculation of matrix M. Once these steps are performed for any anatomical numerical model, then the maximum SAR$_{wb}$ is readily available with the eigenvector approach and can be verified with the SADE approach. Then, using arbitrary vectors of amplitude and phase distributions that depend on a specific environment, it is easy to generate a statistical model with the Monte Carlo approach, like the one introduced in [4]. It should be pointed out that the results presented here do not necessarily represent the worst-case SAR$_{wb}$ for any exposure situation. This can be achieved only if more than twelve plane waves are used, i.e., by employing intermediate angles for the azimuth and elevation of the plane waves in the calculations.

Method	SAR$_{wb}$ (W/kg)			
	Duke		Thelonious	
	866MHz	2450MHz	866MHz	2450MHz
Eigenvector	9.43E-6	8.28E-6	1.76E-5	1.54E-5
Monte Carlo	8.73E-6	7.33E-6	1.60E-5	1.43E-5
Self-Adaptive Differential Evolution	9.43E-6	8.28E-6	1.76E-5	1.54E-5

TABLE 1: DERIVED RESULTS FOR SARWB WITH THE DIFFERENT METHODS

CONCLUSIONS

In this study we reported a deterministic method to evaluate the worst-case whole-body SAR due to a given multiple plane wave exposure. The method was verified by a metaheuristics optimization method and was compared with a statistical method (Monte Carlo). It can be readily applied to any human numerical model and for any frequency of exposure.

ACKNOWLEDGMENTS

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PB-74 [11:00]
Frequency Selective Spot Measurements in Greek Indoor Environments

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Public concern has recently shifted from base stations radiation to devices operating in wireless networks and short range communications systems ubiquitous by now in indoor environments. In this study, frequency selective measurements were performed in 42 rooms, both at urban and suburban locations in Thessaloniki, Greece, to assess exposure. The results show that power density at places with indoor sources is twice as high compared to places where no WiFi or DECT transmitters are present.

Long Abstract

INTRODUCTION

Several studies and measurement campaigns have been conducted during the last decade in order to assess exposure to electromagnetic radiation in the environment. However, early research was mainly focused on outdoor locations and public places. Due to the rapid penetration of telecommunication applications in everyday life, the background radiation within indoor places has changed both qualitatively, new RF sources have been added, and quantitatively, the cumulative exposure has risen.

Although it has been shown in several studies [1]-[3] (Foster 2007, Schmid et al. 2007, Joseph et al. 2012) that exposure caused from WiFi sources is many times below the ICNIRP exposure guidelines [4], in some studies [5]-[6] (Frei et al. 2009, Markakis and Samaras 2013) it is reported that the contribution from different RF sources in indoor environments differs from that in outdoor environments. Additionally, apart from WiFi devices other technologies, such as DECT or baby surveillance devices, are added to the background radiation indoors. In this study we performed frequency selective measurements to assess the contribution to exposure from various electromagnetic sources present in typical Greek indoor environments.

MATERIALS AND METHODS

Measurement locations

The measurements were performed at homes, offices and schools both in urban and suburban areas of Thessaloniki, Greece. In particular, 28 rooms (living rooms and bedrooms) in home environments, 6 rooms in office environments and 8 classrooms in schools were studied. On the whole 32 measurements were performed in an urban environment (20 of them in densely populated areas) whereas 10 measurements were performed in the suburbs.

Methodology and equipment

The equipment used in the measurement campaign was a broadband electric field probe (NBM-550, Narda Safety Test Solutions, Pfullingen, Germany) and a selective radiation meter (SRM-3000, Narda Safety Test Solutions, Pfullingen, Germany).

Initially each room was swept with the broadband meter in order to identify the location of highest exposure and afterwards frequency selective measurements were conducted at 11 locations inside each room. A similar methodology was first introduced by Bürgi et al [7] in another measurement campaign that took place in Switzerland. According to this approach, seven measurements points per room – three at the center of the room at different heights and four at the vertices of the rectangle which are 1m away from the center of the room – provide stable estimates of the average exposure. In addition, three measurements were performed in front of the room windows and one measurement at the location of maximum exposure.

The frequency range covered the majority of telecommunication applications from 88MHz to 2.4GHz. There is no active application, such as WiMax, in Greece at frequencies above 2.4GHz. In contrast to [7] DECT, WiFi and mobile uplink frequencies were included in our analysis.

RESULTS

Data analysis

Measurement places were divided to those with indoor sources (WiFi or DECT) inside the room (23 rooms) and to those where only outdoor sources existed (19 rooms). The total power flux density was calculated averaging the values from the ten measurement points (center and window) inside each room. Furthermore, the flux density was calculated taking into account only the locations near the window (three measurements) or the locations in the center of the room (seven measurements). In figures 1 and 2 the variation of power density is presented. The red line marks the median value, the box edges represent the 25th and 75th percentiles and the outer bars extend to the most extreme data points not considered outliers.

The median value of total power density in the presence of indoor sources is 5.3×10^{-4} W/m^2, whereas this value reduces to about half when the total power density results from outdoor sources only. Moreover, in the case of outdoor sources only,