Influence of the incident angle of single plane-waves on the organ specific SAR at 950 MHz

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INTRODUCTION
The organ or tissue specific averaged SAR (SAR_{osa}) is important for epidemiological research, as it provides information about the localization of the absorption of electromagnetic fields (EMFs). This quantity is assessed near base station antennas [1] and under the influence of mobile phones [2, 3]. A method for assessing the organ specific averaged SAR_{osa} for realistic environments, is introduced in [4]. Such a realistic far-field electromagnetic environment is determined by statistical input parameters, including the azimuth and elevation incident angles [5], describing the probability for a certain exposure scenario to occur. In order to investigate the environmental differences in SAR_{osa} values, a study of the influence of the incident angle of single plane-waves is necessary. The goal of this paper is to investigate which incident field angles have the largest influence on SAR_{osa} in real environments.

MATERIALS AND METHODS
To investigate the influence of plane-wave incident angles on the SAR_{osa}, we select the GSM downlink frequency of 950 MHz. The phantom under consideration in this study is the virtual family boy (vfb) [6]. The dielectric properties of the phantom’s tissues are obtained from the Gabriel database [7]. The SAR_{osa} in this realistic phantom is determined using finite-difference time-domain (FDTD) simulations using SEMCAD-X. FDTD simulations are carried out every 10° for the azimuthal angle $\varphi$ and every 5° for the elevation angle $\theta$. Both transverse electric (TE) and transverse magnetic (TM) polarization are considered. Figure 1 shows the used reference system in relation to the vfb. The phantom’s transverse axis is parallel to the Z-axis and the vfb is looking in the positive x direction.
RESULTS

Figure 2 shows the SAR_{osa} for the vfb’s liver as a function of [θ,φ] for TE polarization. The total incident field strength is equal to the ICNIRP reference level for the EMF at this frequency: 42.38 V/m [8]. As can be seen from Figure 1, the liver shows the expected dependence of the SAR_{osa} on both θ and φ. The liver is located at the right side of the phantom, causing a higher SAR_{osa} for φ ∈ [180°, 30°]. Incident plane-waves with an elevation angle around θ = 90° will have the shortest propagation distance in tissue before reaching the liver and thus have the highest SAR_{osa}. The mean SAR_{osa} (with standard deviation) is 0.017±0.0068 W/kg, with a maximum value of 0.033 W/kg and a minimal value of 0.0063 W/kg, shown in Table 1. The minimal, mean, and maximal value correspond to the 13 %, 70 % and 99 % quantiles in the indoor Pico-cell environment [4] respectively. A worst-case estimation of the SAR_{osa} for the liver at 950 MHz can thus be made using the maximum single-plane wave value at the appropriate incident angles.
Figure 2: $SAR_{osa}$ for the vfb’s liver as a function of the elevation and azimuthal angle for TE polarized incident plane-waves causing $E_{rms} = 42.38 \text{V/m}$, averaged over free-space, for the GSM downlink frequency of 950 MHz. The blue circle indicates the maximum value.

Table 1 lists the angular mean $SAR_{osa}$ for some selected organs and tissues of the vfb. The standard deviation, minimum, and maximum values and their corresponding incident angles are also listed in Table 1. The cerebrospinal fluid accounts for the highest $SAR_{osa}$ due to its high conductivity, while the liver and heart muscle have lower values, due to their location inside the abdominal and thoracic cavity. The elevation angles presented in Table 1, used in the reference system shown in Figure 1, show that the brain regions have maximal values for plane-waves with a low elevation angle, while incident plane-waves from below the phantom account for lower $SAR_{osa}$ values. In general the position of the organ in the phantom will strongly influence the location of the angular minima and maxima.

<table>
<thead>
<tr>
<th>Name</th>
<th>$SAR_{osa,\text{mean}} \ [\text{W/kg}]$</th>
<th>$SAR_{osa,\text{min}} \ [\text{W/kg}]$</th>
<th>$(\theta,\varphi)_{\text{min}} \ [^\circ]$</th>
<th>$SAR_{osa,\text{max}} \ [\text{W/kg}]$</th>
<th>$(\theta,\varphi)_{\text{max}} \ [^\circ]$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TE</td>
<td>TM</td>
<td>TE</td>
<td>TM</td>
<td>TE</td>
</tr>
<tr>
<td>Liver</td>
<td>0.017±0.007</td>
<td>0.011±0.005</td>
<td>0.0063</td>
<td>0.0018</td>
<td>0.033</td>
</tr>
<tr>
<td>Brain Grey Matter</td>
<td>0.042±0.014</td>
<td>0.040±0.013</td>
<td>0.013</td>
<td>0.017</td>
<td>0.057</td>
</tr>
<tr>
<td>Brain White Matter</td>
<td>0.030±0.010</td>
<td>0.027±0.009</td>
<td>0.010</td>
<td>0.012</td>
<td>0.040</td>
</tr>
<tr>
<td>Hearth Muscle</td>
<td>0.017±0.084</td>
<td>0.015±0.010</td>
<td>0.003</td>
<td>0.002</td>
<td>0.040</td>
</tr>
<tr>
<td>Cerebrospinal fluid</td>
<td>0.091±0.030</td>
<td>0.094±0.028</td>
<td>0.025</td>
<td>0.034</td>
<td>0.131</td>
</tr>
</tbody>
</table>

Table 1: Mean, minimal and maximal $SAR_{osa}$ for some of the vfb’s organs for single incident plane waves with
Table 1 shows that there exists a polarization dependence of the mean, minimal, and maximal values, which is smaller than the dependence on the incident angle of the plane-wave. For the individual angular pairs the influence of the polarization will be more important. The ratio of SAR\textsubscript{osa} values for 2 different sets of incident angles can lead up to a factor of 20 (Heart-muscle).

**CONCLUSIONS**

The influence of plane-wave incident angles on the SAR\textsubscript{osa}, using FDTD simulations is investigated. There exists a strong dependence of the SAR\textsubscript{osa} on the pair of incident angles. Differences in SAR\textsubscript{osa} values up to a factor of 20 have been observed. A smaller influence due to the polarization is also observed.

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**REFERENCES**


