Expression for Human Whole-Body Averaged SAR of Adults for Single Plane Wave Exposure

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***Abstract*—A simple expression to determine the human whole-body averaged SAR (SAR_{wb}) is proposed in the GHz region. Only the incident power density and the human mass are needed to apply the formula. The formula is applied to two 3-D full heterogeneous phantoms (the adult man *Duke* and the obese man *Fats*) and is validated at 3 GHz. The performance of the formula depends on the human mass and the azimuthal angle as well. Relative deviation between the formula based values and numerical values range from 32 % (Duke) to 11 % (Fats).**

I. Introduction

Due to the increasing deployment of the wireless equipments, it is important to investigate the possible health effects to the electromagnetic fields (EMF). Several works such as [1] determined the whole-body SAR (SAR_{wb}) based on plane wave(s) exposure. There have been other approaches to determine the human SAR_{wb}. Despite the large number of parameters involved in the SAR_{wb} assessment and their complexities, [2] proposed a formula on the basis of the analogy of the human body and a half dipole antenna to determine the SAR_{wb} for a plane wave exposure at the resonance frequency (order of 60-120 MHz).
The formula in [2] accounts for the tissues inhomogeneity and the proportion of fat in the human model as well. Because of the relative small penetration depth in the GHz region, the human absorption is mainly influenced by the body surface area (BSA), rather than the tissues properties. Therefore, a body surface area based formula to determine the SAR_{wb} in the GHz region, i.e., at 3 GHz, is proposed in this paper. The objective is to determine via a simple expression the human SAR_{wb} due to the Line Of Sight (LOS) exposure with only the weight and the power density as inputs. Both vertical and horizontal polarization are investigated, and all azimuthal angles as well. Moreover, the proposed formula is validated through numerical simulations with two realistic 3D heterogeneous phantoms at 3 GHz.

II. Methods

Prolate spheroids models usually approximate the human body to investigate the human exposure in the MHz region. An ellipsoid model however, describes more faithfully the human body characteristics in terms of body surface area [3]. Homogeneous ellipsoidal models of human bodies are used to determine the main parameters involved in the SAR_{wb} prediction-equation. The weight (resp. height) of each ellipsoid coincides with the weight (resp. height) of the corresponding human model. The details of Duke and Fats can be found in [4].
The SAR_{wb} can be expressed as:

$$SAR_{wb} = \frac{P_{abs}}{W} \tag{1a}$$
$$= \frac{ACS \times I}{W} \tag{1b}$$

where P_{abs}, W, I, and ACS are the absorbed power by the human (Watt), the person's weight (kg), the incident power density (Watt/m^2), and the person's absorption cross section (m^2), respectively. The ACS results from the interaction between a surface and a plane wave. It is therefore defined as the projected surface (on a plane) scaled by a factor, which is the percentage of the power absorbed by the surface. Similarly, the human ACS in diffuse fields can be defined as the projection of the human body surface on a plane scaled with the average fraction of power absorbed being absorbed.

$$ACS_{dmc} = \eta \times BSA_{pr} \tag{2}$$

where ACS_{dmc}, η and BSA_{pr} are the diffuse absorption cross section (m^2), the average fraction of the incident power being absorbed, and the area of the projected body surface area (m^2). The ACS_{dmc} [5] is determined in diffuse fields, i.e., several plane waves incident with a random polarization. The ACS from a single plane wave exposure (ACS_{los}) can be related to the ACS_{dmc} as follows:

$$ACS_{los} = k(\varphi, \psi) \times ACS_{dmc} \qquad \text{with } 0 < k < 1 \tag{3}$$

where φ and ψ designate the azimuthal and the polarization angle.

The human BSA is obviously very complex, depending mainly on the height and the weight. The human BSA can be determined with the weight as the only input [6].

$$BSA = 0.1173 \times W^{0.6466}, \quad \text{if W} \geq 10 \text{ kg} \tag{4a}$$
$$= 0.1037 \times W^{0.6724}, \quad \text{if W} < 10 \text{ kg} \tag{4b}$$

It is noteworthy to mention that the BSA determine with (4) is not a projected surface. The relation is therefore corrected with a factor (f) obtained from numerical simulations. We assume that the ellipsoid models coincide - in a morphological term - with the 3D heterogeneous models. The simulation

settings are described in [7].
Accounting the equations defined above, the SAR due to a single plane wave is:

$$SAR_{los}(\varphi,\psi) = k(\varphi,\psi)\times\eta\times f\times 0.1173\times W^{-0.3534}\times I_{los},$$
$$= 0.15\times k(\varphi,\psi)\times\eta\times W^{-0.3534}\times I_{los} \quad (5)$$

III. Results

The parameter η has been investigated and an average value of 0.53 is obtained at 3 GHz. The averaged k parameter as a function of the azimuth is shown in Fig. 1. It is important to mention that k is independent on the phantoms since the maximum standard deviation is only about 2 %. The k parameter curve shows that the absorbed surface depends on the incident wave azimuth. This is logical since the cross section of a human varies with the azimuth, i.e., larger cross sections occur for the frontal than for the side view. It is also noticed from Fig. 1 that the absorbed surface is higher for a horizontal polarized wave than for a vertical polarized wave in the GHz region. This phenomenon has also been pointed out in [8].

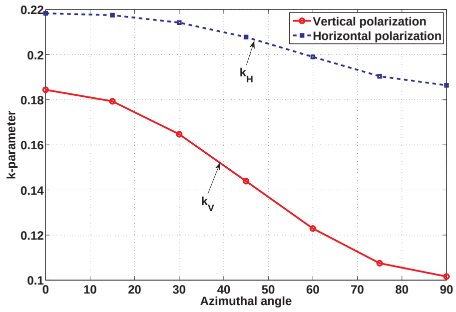


Fig. 1. Ratio k between the ACS from the LOS and DMC illumination (averaged over the phantoms). The maximum standard deviation is about 2 %.

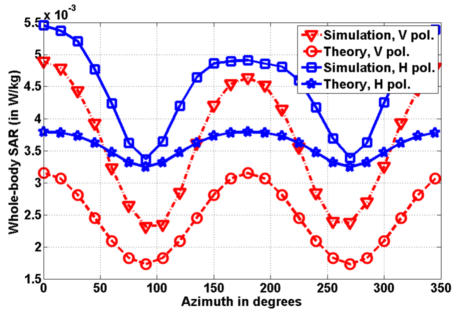
For a certain incident angle and polarization, the SAR_{wb} due to a plane wave is given as a function of the human weight and the incident power density:

$$SAR_{wb,los}(\varphi,\psi) = 0.08\times k(\varphi,\psi)\times W^{-0.3534}\times I_{los} \quad (6)$$

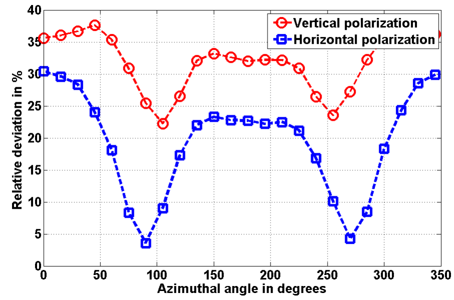
Fig. 2 shows the results for the 3D heterogeneous phantom Duke. It shows that the formula gives a better approximation of the SAR_{wb} when the wave is incident on Duke's sides, i.e., φ=± 90°. This trend is observed for Fats as well, showing thereby that the ellipsoid approximates better the human surface from the side view than from the frontal view. Satisfactory results are however obtained even from the frontal illumination.
An average standard deviation for a vertical (resp. horizontal) polarized plane wave of 32 % (resp. 20 %), and 15 % (resp. 11 %) is obtained for Duke and Fats, respectively. In general, it is observed that the formula gives a better estimation of the SAR when the adult mass increases.

IV. Conclusion

A simple formula to estimate the whole-body SAR induced by a single plane wave is proposed for adults. The proposed formula is compared to the numerical simulation with 3D heterogeneous phantoms (Duke and Fats) to verify its accuracy. Future research should address the formula to estimate the human whole-body SAR due to a diffuse illumination.



(a) SAR_{wb} values for Duke: Formula vs simulations



(b) Relative standard deviation. σ_V^{avg}=32%, σ_H^{avg}=20%.

Fig. 2. SAR_{wb} values and the related standard deviation for Duke.

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