EVALUATION OF RESONANCE PROPERTIES OF THE HUMAN BODY MODELS SITUATED IN THE RF FIELD

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Abstract. *The radio-frequency (RF) electromagnetic field absorption in the human body model is investigated in this article. Absorption of prolate model of the biological body exhibits resonance properties in the case of so called E polarization. This occurs in the arrangement when the longitudinal axis of the body is parallel with an electrical component of the electromagnetic field. Absorption properties of a homogeneous human model have been explored in the frequency range from 20 MHz to 500 MHz in the CST Microwave Studio programme environment. The simulation results of RF field absorption in the model of the human body are presented for ellipsoidal, cylindrical and anthropomorphic Laura model shapes, and for various heights and widths of the model body. The values of the resonance frequency and also whole-body absorption values at these frequencies are evaluated.*

Keywords

Absorption, CST MW studio, human body model, resonance properties, RF field, SAR.

1. Introduction

There has been continuously increasing industrial, domestic and other applications of RF electromagnetic fields in recent decades. Consequently, the question of biological and health effects of these fields on human beings requires examination. Since the thermal effects of RF fields are of considerable importance, an assessment of the field absorption inside the human body is the primary task [1], [2].

Even though, external RF fields are relatively easy to measure, the measurement of the internal field inside the human body is not possible in the majority of cases. Numerical computation [3] is considered most suitable for assessment of internal body fields.

2. Radio-Frequency Dosimetry

A specific absorption rate (SAR) is utilized as the basic measurement in RF field dosimetry, [1], [2], [3]. Before SAR can be quantified inside the exposed biological body, the internal electric field E must be computed. Consequently, SAR values can be evaluated from internal electric field E values:

$$SAR = \frac{\sigma E^2}{\rho}, \tag{1}$$

where: σ is tissue conductivity and ρ is the mass density of the biological tissue. Although SAR is a point variable, it is usually evaluated as an average value over 10 grams of tissue, or over the whole body as total SAR.

Absorption in the human body depends on many parameters of the field and many parameters within the irradiated body [2], [4]. For far-field exposure conditions (plane wave), absorption differs significantly for the three basic E-, H- and P- polarizations [5], when the electric, magnetic or Poynting vector is parallel to the longitudinal axis of the body. Here, an ellipsoidal representation of the human body is shown in Fig. 1.

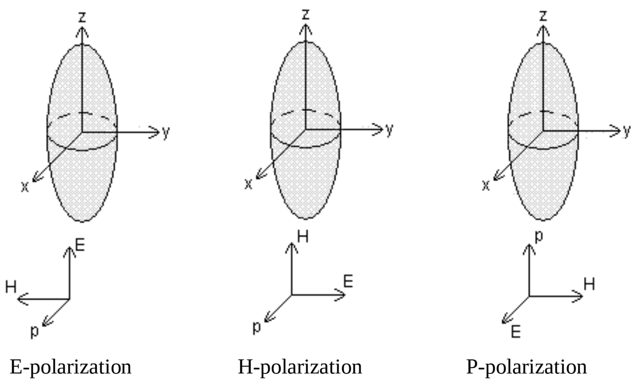

Fig. 1: Plane wave polarization dependent on the orientation of the longitudinal axis (z-axis) in an ellipsoidal model.

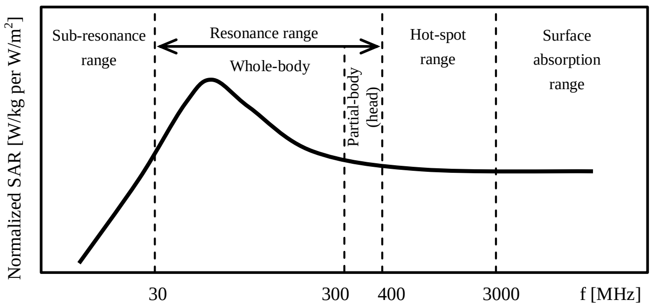

Fig. 2: Normalized whole-body average SAR dependence on the frequency in E-polarization.

With respect to the field absorption in a human body for E-polarization, the RF range can be subdivided into four regions [2], which are shown in Fig. 2:

- The sub-resonance range has frequencies less than 30 MHz. In this range, the whole-body average absorption increases rapidly with frequency.
- The resonance range for whole-body absorption resonance is from 30 MHz to approximately 300 MHz, and higher frequencies for partial body resonances, for example, in the head. In this range, the absorption reaches its maximum at resonance frequency.
- The "hot-spot" range extends from approximately 400 MHz to about 3 GHz, and localized energy absorption can occur in this range.
- The surface absorption range here has frequencies greater than approximately 3 GHz, so that energy absorption and temperature elevation is localized at the body surface.

3. Model Parameters

For assessment of energy absorption in the human body, we use several homogeneous model types: the simplified models of cylindrical and ellipsoidal shape and the anthropomorphic model of the female body (the Laura model in Fig. 3). In order to simulate new-born, younger and older children and adults' bodies, the cylindrical and ellipsoidal model maintains a constant height to width ratio of 3:1 while the body height is increasing. For example, models with height h = 0,5 m, 0,6 m, 1,2 m and 1,8 m have widths w = 0,17 m, 0,2 m, 0,4 m and 0,6 m, respectively. The height of the Laura model is 1,8 m.

These models consist of muscle tissue. Relative magnetic permeability of $\mu_r = 1$, and a mass density of 1030 kg·m^{-3} were assumed for this tissue. The frequency dependent parameter values of permittivity and electrical conductivity were adopted from reference number [6]. The computational space around the model was filled by vacuum.

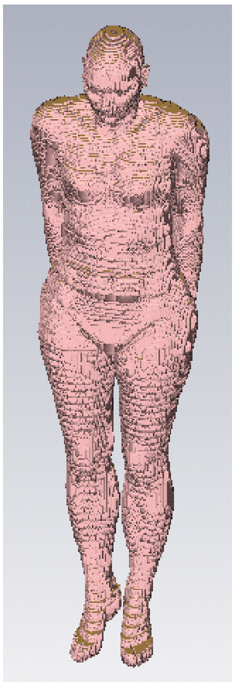

Fig. 3: The Laura model of a woman's body.

Models were exposed to the plane wave (representing far-field exposure conditions) with power density of 1 W·m^{-2}. Since prolate bodies exhibit pronounced resonance properties only for E-polarization, most of the simulations were performed for E-polarization. If not specified, E-polarization is applied. Laura model was irradiated laterally. Simulations were performed at frequencies from 20 MHz to 500 MHz in the CST Microwave Studio programme environment [7].

4. Simulation Results

An example of spatial distribution of SAR (10 g average) values for the ellipsoidal model with height h = 1,8 m at frequencies of 60 MHz and 250 MHz for H-polarization is shown in Fig. 4. Spatial distributions of SAR values for cylindrical models with height h = 0,6 m and h = 1,8 m for E-polarization are shown in Fig. 5 to Fig. 8.

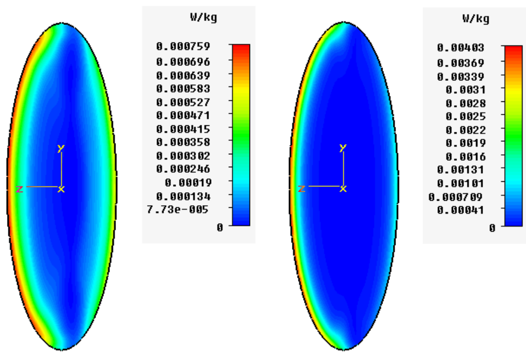

Fig. 4: Distribution of SAR (10 g) in the ellipsoidal model of h = 1,8 m and ratio 3:1 (height: width), at 60 MHz and 250 MHz, H-polarization.

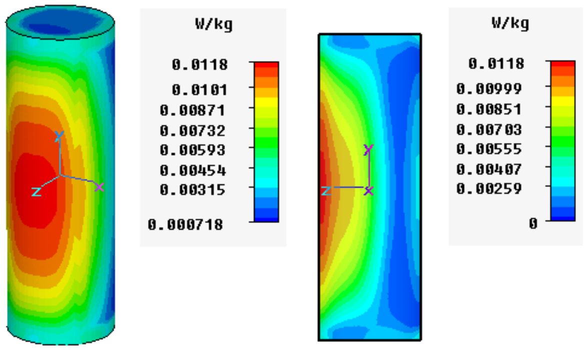

Fig. 5: Distribution of SAR (10 g) in the cylindrical model of h = 0,6 m and ratio 3:1 (height: width) at 100 MHz.

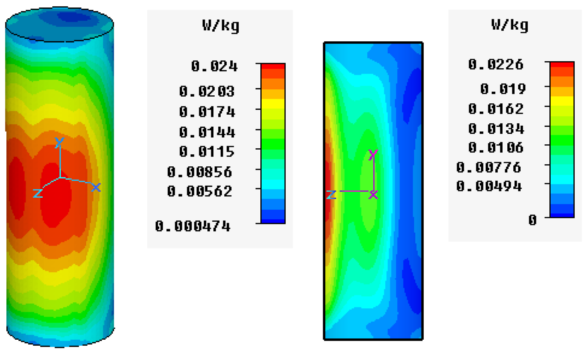

Fig. 6: Distribution of SAR (10 g) in the cylindrical model of h = 0,6 m and ratio 3:1 (height: width) at 200 MHz.

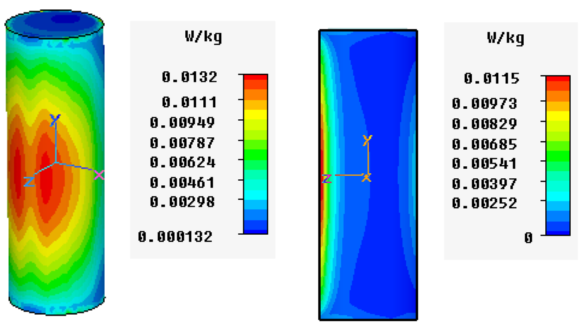

Fig. 7: Distribution of SAR (10 g) in the cylindrical model of h = 1,8 m and ratio 3:1 (height: width) at 60 MHz (near the resonance frequency).

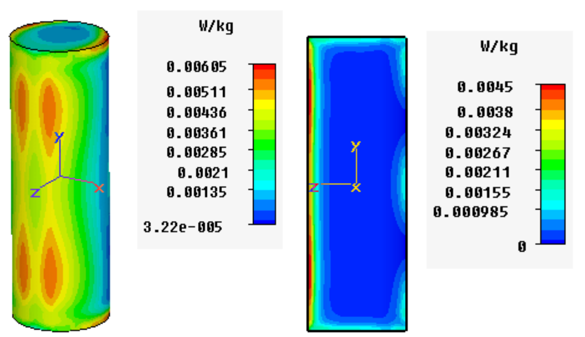

Fig. 8: Distribution of SAR (10 g) in the cylindrical model of h = 1,8 m and ratio 3:1 (height: width) at 200 MHz.

Frequency dependences of whole-body average SAR for the constant height to width ratio of 3:1 for ellipsoidal models with heights h = 0,5 m, 0,6 m, 1,2 m and 1,8 m are shown in Fig. 9. It is obvious that smaller model heights have higher resonance frequency, and a higher total SAR at the resonance frequency. Therefore, the body resonance frequency of children is higher than that for adults, and the total SAR at the resonance frequency is also higher in children.

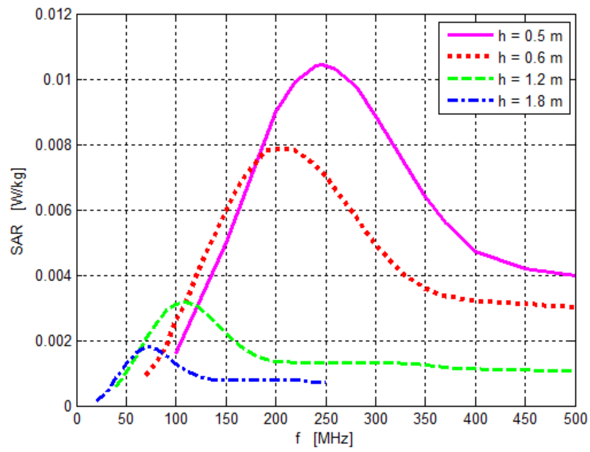

Fig. 9: Frequency dependence of whole-body average (total) SAR in the ellipsoidal model of the human body with different height h (constant height to width ratio of 3:1).

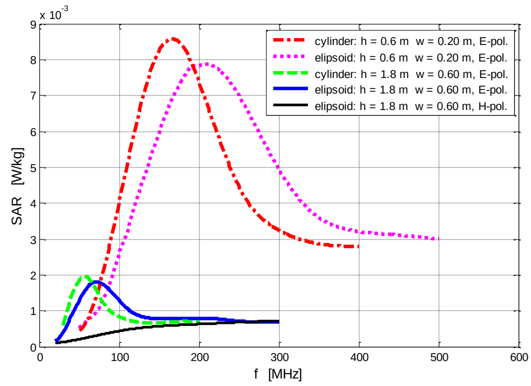

Fig. 10: Frequency dependence of whole-body average (total) SAR in the ellipsoidal and cylindrical model of the human body with different height h (constant height to width ratio of 3:1).

Frequency dependencies of whole-body average SAR for the cylindrical and ellipsoidal models of heights h = 0,6 m and 1,8 m with constant height to width ratio of 3:1 are shown in Fig. 10. There are depicted dependencies for E-polarization and for comparison also one example for H-polarization.

Contrary to E-polarization, the resulting whole-body average SAR is increasing monotonically with frequency for H-polarization.

As shown, the resonance frequency is somewhat smaller for the cylindrical model, while the total SAR at the resonance frequency is a little higher in the cylindrical model than in an ellipsoidal model with the same height.

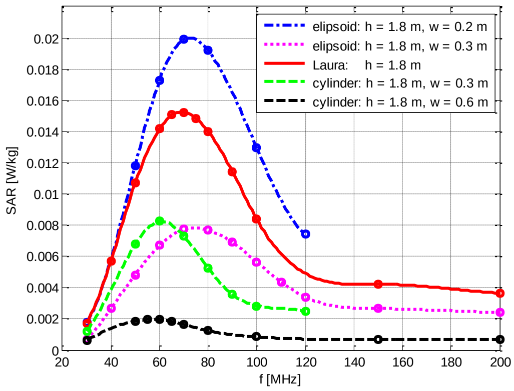

Fig. 11: Frequency dependence of whole-body average SAR in the ellipsoidal, cylindrical and Laura model of the female body with height *h* = 1,8 m and different model widths.

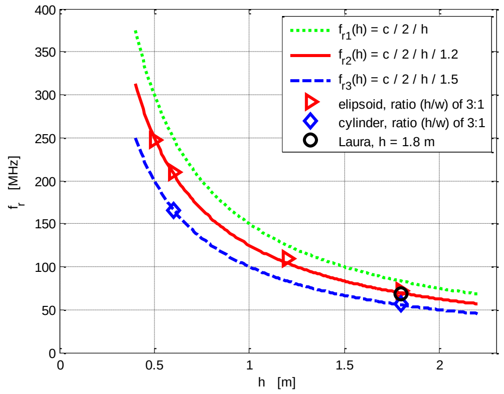

Fig. 12: Resonance frequency dependence on the height *h* of the ellipsoidal and cylindrical body model (with the constant 3:1 ratio of height to width) and the Laura model.

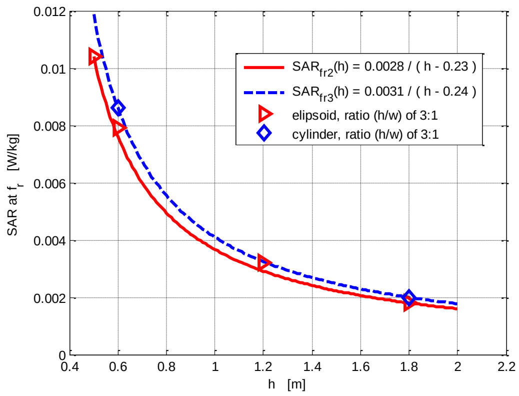

Fig. 13: Whole-body average SAR at the resonance frequency for the ellipsoidal body model and cylindrical model (with constant height to width ratio of 3:1).

Figure 11 depicts frequency dependencies of the whole-body average SAR for several models of the same height: the ellipsoidal model with height $h = 1,8$ m (and width $w = 0,2$ m or $w = 0,3$ m), the cylindrical model with height $h = 1,8$ m (and width $w = 0,3$ m or $w = 0,6$ m) and for the anthropomorphic female model of Laura with a height of $h = 1,8$ m. The resonance frequencies for all models are quite similar (it is slightly smaller for the cylindrical models), since it is mainly determined by equal model heights. Total SAR at the resonance frequency is higher for the Laura model than for an ellipsoidal model with 0,3 m width and lower than for the ellipsoidal model with 0,2 m width. We presume that this is a consequence of lateral irradiation of the Laura model, which is via the smaller side dimension.

The values for resonance frequencies for different models resulting from the simulations are in Fig. 12. From [8], it is considered that the absorption reaches a maximum (resonance frequency f_r) when the height of the model equals half the wavelength (λ):

$$f_{r1}(h) = \frac{c}{\lambda} = \frac{c}{2 \cdot h}, \tag{2}$$

where c is the speed of light.

The resonance frequency values for the ellipsoidal and cylindrical models (Fig. 12) are lower than estimated by the relationship in (2). Therefore, we suggest that a more accurate approximation of resonance frequency for these models is satisfied by the relationship:

$$f_{r2}(h) = \frac{c}{2 \cdot h \cdot 1,2}, \tag{3}$$

for ellipsoidal models of constant height to width ratio of 3:1.

Similarly, we can correct the relationship for cylinders with a constant height to width ratio of 3:1 by:

$$f_{r3}(h) = \frac{c}{2 \cdot h \cdot 1,5}. \tag{4}$$

Furthermore, we suggest, that the approximate relationship of the whole-body average SAR at the resonance frequency shown in Fig. 13 for the ellipsoidal model with a constant height to width ratio of 3:1 is:

$$SAR_{fr2}(h) = \frac{0,0028}{h - 0,23}. \tag{5}$$

In addition, the whole-body average SAR at the resonance frequency for the cylindrical model with a constant height to width ratio of 3:1 is in the form:

$$SAR_{fr3}(h) = \frac{0,0031}{h - 0,24}. \tag{6}$$

The whole-body average SAR at the resonance frequency of the cylindrical model is very close to that of the ellipsoidal model with a constant height to width ratio of 3:1.

5. Conclusion

The dependencies of resonance attributions involving the resonance frequency and the whole-body average SAR at the resonance frequency on parameters in a human model were investigated in this article. We observed that the values of resonance frequency are quite similar for the selected ellipsoidal, cylindrical and anthropomorphic body model types when identical height was involved. The results of simulations show that although the body resonance frequency is mainly dependent on the body height, body shape parameters must also be included for more precise estimation. The whole-body average SAR at the resonance frequency for models of the same height depends markedly on additional model parameters, and this especially refers to the width of the model.

Resonance properties are present at frequencies were wavelength is comparable with body height. For lower frequencies, penetration depth is quite large (tens of centimeters), so only small part of transmitted electromagnetic wave in the body is absorbed. For much higher frequencies than resonance frequency, the penetration depth is only few millimeters, so practically all transmitted wave is absorbed. Therefore, the whole-body average SAR is not further increasing.

Acknowledgements

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