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# Resonance properties of the biological objects in the RF field

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**Abstract.** Irradiation of people with electromagnetic fields emitted from miscellaneous devices working in the radio-frequency (RF) range may have influence, for example may affect brain processes. The question of health impact of RF electromagnetic fields on population is still not closed. This article is devoted to an investigation of resonance phenomena of RF field absorption in the models of whole human body and body parts (a head) of different size and shape. The values of specific absorption rate (SAR) are evaluated for models of the different shapes: spherical, cylindrical, realistic shape and for different size of the model, that represents the case of new-born, child and adult person. In the RF frequency region, absorption depends nonlinearly on frequency. Under certain conditions (E-polarization), absorption reaches maximum at frequency, that is called "resonance frequency". The whole body absorption and the resonance frequency depends on many further parameters, that are not comprehensively clarified. The simulation results showed the dependence of the whole-body average SAR and resonance frequency on the body dimensions, as well as the influence of the body shape.

## 1. Introduction

Nowadays, the presence of nearly ubiquitous radio-frequency and particularly microwave (MW) electromagnetic fields is given mainly by continuously increasing utilization of these fields in communication, industrial and domestic appliances. Too large absorption of RF field energy may cause an increase of temperature in tissues, e. g. inside the head and may affect processes in that tissues [1], [2]. Variety of neurological effects of RF fields has been observed [3], e. g. influence on processes, related to attention and manipulation of information in working memory [4], [5].

To protect tissues from possibly detrimental thermal effect, an amount of absorbed RF energy in tissues must be determined.

## 2. RF dosimetry

The rate of RF energy absorption in tissues is described by an important dosimetric quantity, the specific absorption rate (SAR). Value of SAR [W/kg] depends on material properties of tissue and induced internal electric field in the body according to the following relation [2]:

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

where  $E$  is the rms value of electric field intensity [V/m],  $\sigma$  is the tissue electrical conductivity [S/m] and parameter  $\rho$  is the mass density [kg/m<sup>3</sup>] of biological tissue.

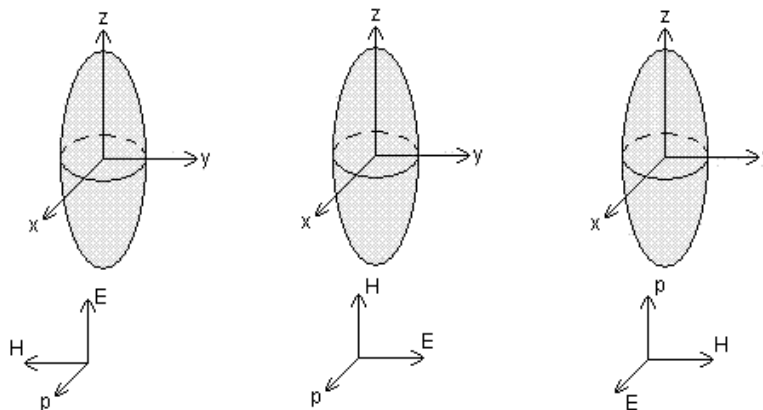
Even though the SAR is defined as the local (point) quantity, the average values of SAR are commonly used for practical purposes:

$$SAR_{avg} = \frac{1}{V} \int_V SAR dV \quad (2)$$

where  $V$  is the volume [ $m^3$ ] of biological tissue with the mass [kg] over which is SAR averaged:

- in the case of the whole-body (total) average SAR, the volume  $V$  is volume of whole-body;
- in the case of the head average SAR, the volume  $V$  is volume of head;
- in the case of the 10 g (or 1 g) SAR, the volume  $V$  is volume of 10 g (or 1 g respectively) of tissue.

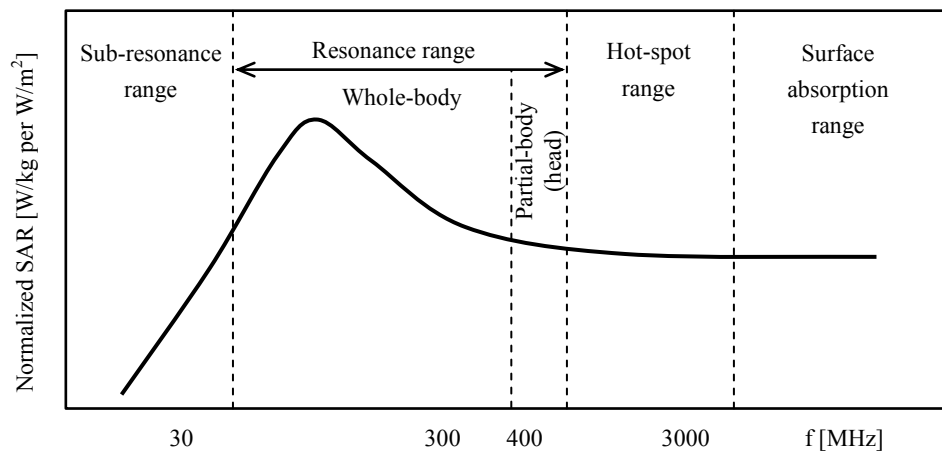
Absorption in the human body depends on many parameters of the field (frequency, orientation of field, etc.) and many parameters of irradiated body [2], [6]. For far-field exposure conditions (plane wave), absorption differentiates markedly for three main polarizations: E-, H- and P-polarization, when electric field vector  $\vec{E}$ , magnetic field vector  $\vec{H}$  and Poynting vector of wave propagation  $\vec{P}$  is parallel to longitudinal axis of the body (figure 1).



**Figure 1.** Polarization of plane wave with respect to orientation of longitudinal axis of rotational ellipsoid (z-axis) representing human body.

With regard to character of the field absorption in a human body, the RF range can be subdivided into the four regions [2], shown in figure 2 (for E-polarization):

- The sub-resonance range; frequencies less than 30 MHz. In this range, the whole-body average absorption increases rapidly with frequency.
- The resonance range, that is from 30 MHz to about 300 MHz for the whole-body absorption resonance, and to higher frequencies for partial body resonances.
- The "hot-spot" range, which is extending from about 400 MHz up to about 3 GHz. Localized energy absorption can occur in this range.
- The surface absorption range, for frequencies greater than about 3 GHz. The energy absorption and temperature elevation is localized at the surface of the body.



**Figure 2.** Normalized whole-body average SAR dependence on frequency in the case of E-field vector parallel to longitudinal axis of adult human body.

### 3. Model and simulation parameters

The electromagnetic field absorption in human body in RF frequency range depends on many parameters, like frequency, model shape and material parameters of tissues [2]. In this article, the spatial distributions of the specific absorption rate (SAR) are evaluated for the models of different shapes: spherical, cylindrical, realistic shape (Sam model of the head, Laura model) and for different heights of models, that represented the head or whole body of children and adult persons.

Simulations were performed in the time-domain by means of the Finite Integration Technique (FIT) in CST Microwave Studio program environment [7]. In the simulations, the models of the head and whole body were exposed to the plane wave (power density of  $1 \text{ W/m}^2$ ) representing far-field exposure conditions. The surrounding space around the models was vacuum and the boundary of computational space (open conditions) was in distance of at least 0.2 m from the model in all directions.

#### 3.1. The head models

The two polarizations were chosen: E-polarization (electric field vector  $\vec{E}$  parallel to longitudinal axis of the model) and P-polarization (the Poynting field vector  $\vec{P}$  parallel to longitudinal axis of the body). Since RF absorption depends nonlinearly on frequency, reaching usually the maximum for the E-polarization at so called "resonance frequency", the whole-body average SAR was evaluated in wide frequency range from 100 MHz to 1 000 MHz.

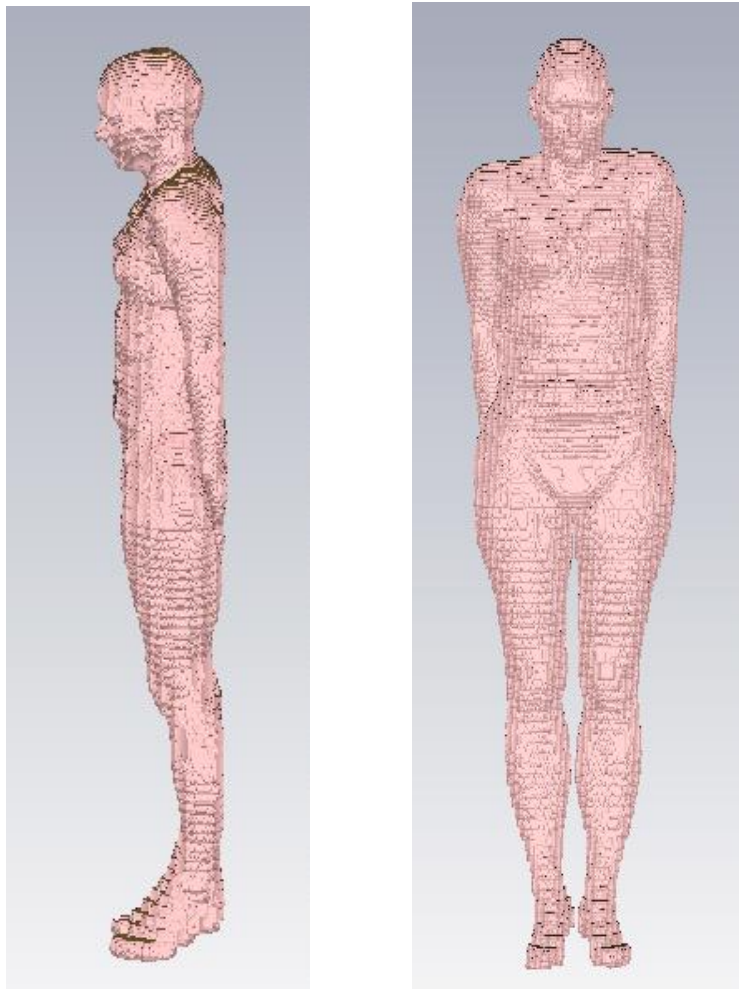
The homogeneous models consist only of materials with electrical parameters of brain grey matter (BGM) or brain white matter (BWM): the frequency dependent parameters (permittivity and electrical conductivity) were set according to [8], relative magnetic permeability  $\mu_r = 1$  and mass density of  $1030 \text{ kg/m}^3$ .

#### 3.2. The whole body models

For assessment of energy absorption in the human body we used several homogeneous model types: the ellipsoidal, cylindrical and anthropomorphic model of woman body (Laura model, see figure 3). Simulations were performed for different model dimensions: e. g. an ellipsoidal model had the constant height to width ratio of 3:1, i. e. the ellipsoids with height  $h = 0.5 \text{ m}$ ,  $0.6 \text{ m}$ ,  $0.9 \text{ m}$ ,  $1.2 \text{ m}$  and  $1.8 \text{ m}$  had width  $w = 0.17 \text{ m}$ ,  $0.2 \text{ m}$ ,  $0.3 \text{ m}$ ,  $0.4 \text{ m}$  and  $0.6 \text{ m}$ , respectively, that simulated the body of new-born, younger and older child and adult person. The height of Laura model was  $h = 1.8 \text{ m}$ .

As the body model material was chosen a muscle tissue material. Values of frequency dependent parameters (permittivity and electrical conductivity) were taken from [8], mass density of tissue material of  $1030 \text{ kg/m}^3$  was assumed and relative magnetic permeability was  $\mu_r = 1$ .

Models were exposed to the plane wave with power density of  $1 \text{ W/m}^2$  for E-polarization. Laura model was irradiated from side. Simulations have been performed at the frequencies from range of 20 MHz to 500 MHz in CST Microwave Studio program environment [7].

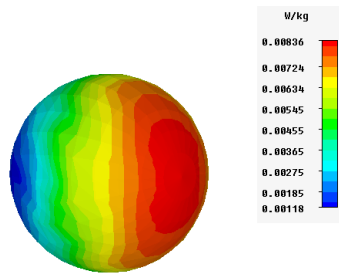


**Figure 3.** Realistic model of woman body (Laura model).

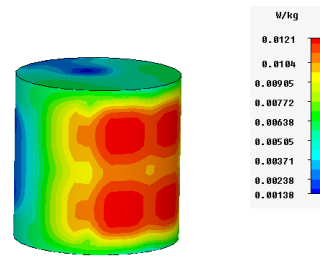
## 4. Simulation results

### 4.1. The head models

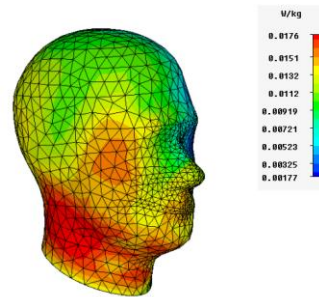
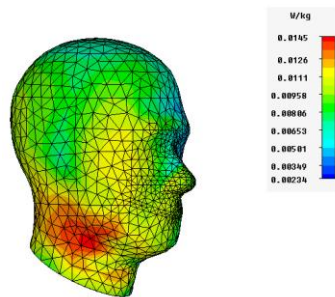
The simulated spatial distributions of SAR (10 g average) for spherical and cylindrical model of human head at selected frequencies are shown in figure 4 and figure 5. The simulated spatial distributions of SAR (10 g average) for the SAM model of human head at selected frequencies are presented in figure 6.



**Figure 4.** The distribution of SAR (10 g) in the spherical model of height  $h = 20$  cm at 450 MHz, resonance frequency.

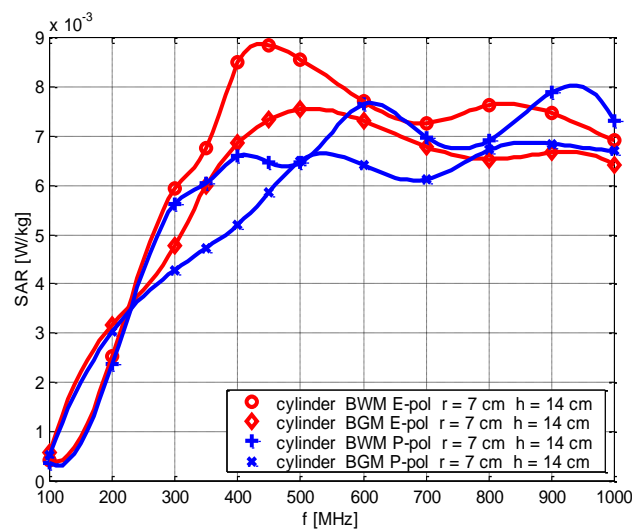


**Figure 5.** The distribution of SAR (10 g) in the cylindrical model of width and height of 20 cm at 350 MHz, resonance frequency.



**Figure 6.** The distribution of SAR (10 g) in the SAM model of height  $h = 20$  cm at 450 MHz and 700 MHz.

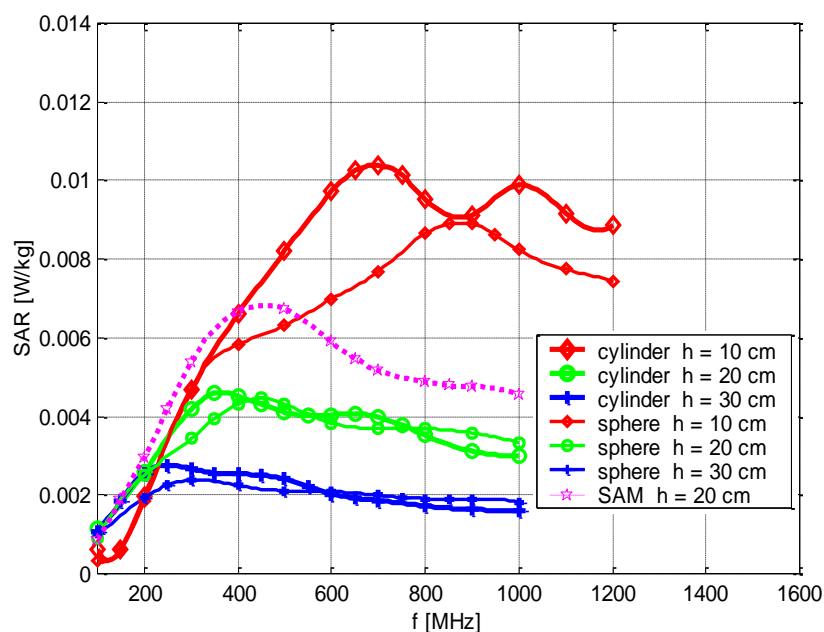
The frequency dependences of whole-body average (total) SAR for cylindrical model of human head simulated for two different materials and for two polarizations are shown in figure 7 (simulated values are indicated by markers).



**Figure 7.** Frequency dependence of whole-body average SAR for the cylindrical model of width and height of 14 cm for two different materials (BWM and BGM) and for two polarizations.

For realized simulation, absorption is higher for brain white matter (BWM) than for brain grey matter (BGM) material for the major part of RF frequency range. The resonance frequency (first clear maximum of absorption) is distinctive only for E-polarization, while for P-polarization the absorption is increasing wavy and the first local maximum is not the highest one.

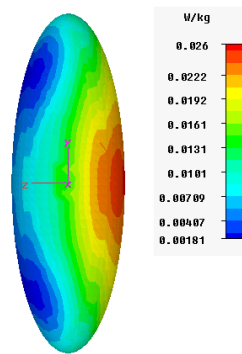
Summarized frequency dependences of whole-body average SAR (simulated values are indicated by markers) for different head models of various body dimensions are shown in figure 8. The simulation results show that the body resonance frequency depends on the model shape, as well as on the model height. The body resonance frequency and the whole-body average SAR at resonance frequency are approximately inversely proportional to the body height.



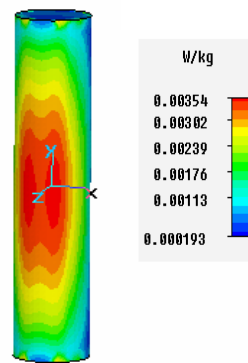
**Figure 8.** Frequency dependence of whole-body average (total) SAR for the spherical, cylindrical (diameters are equal to heights) and SAM model of BGM material for E-polarization for different model heights..

#### 4.2. The whole body models

The spatial distribution of SAR (10 g average) for ellipsoidal model (of height  $h = 0.5$  m, and length : width ratio of 3:1) and cylindrical model (of width 0.4 m and height 1.8 m) are shown in figure 9 and figure 10, respectively.

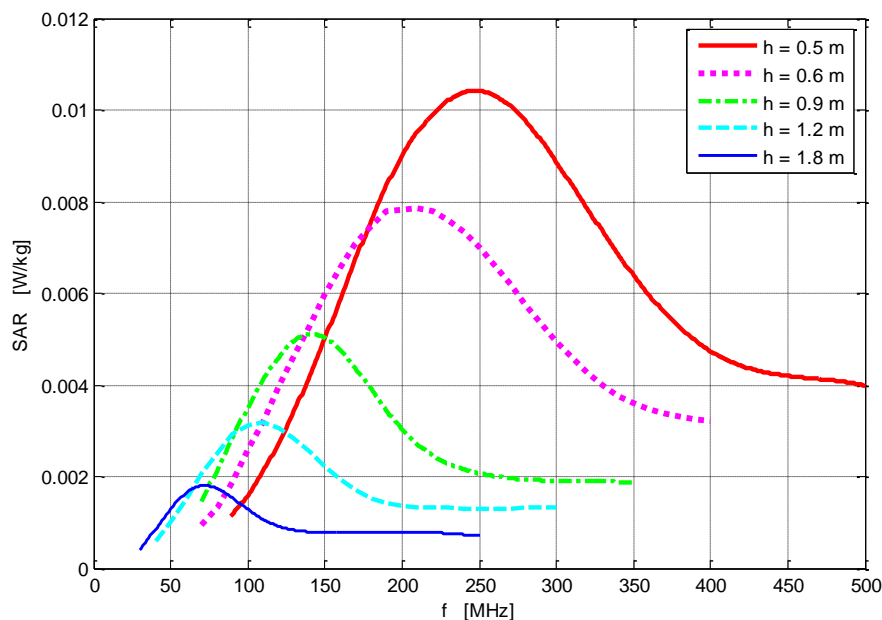


**Figure 9.** The distribution of SAR (10 g) in the ellipsoidal model for  $h = 0.5$  m and ratio 3:1 (length : width) at 247 MHz (resonance frequency).



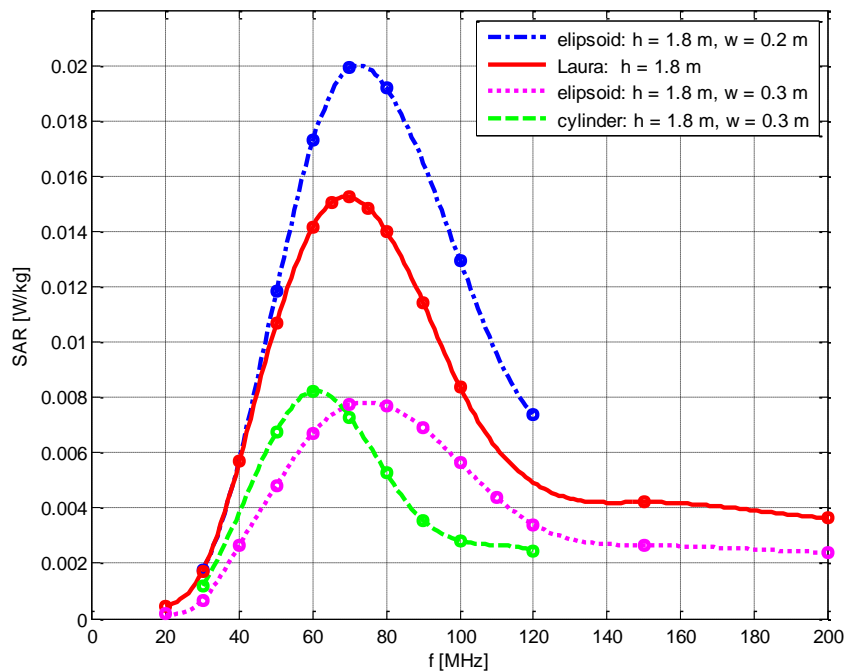
**Figure 10.** The distribution of SAR (10 g) in the cylindrical model of width  $w = 0.4$  m and height  $h = 1.8$  m at frequency 32 MHz.

Frequency dependences of the whole-body average SAR for ellipsoidal models of the constant height to width ratio of (3:1) with heights  $h = 0.5$  m, 0.6 m, 0.9 m, 1.2 m and 1.8 m are shown in figure 11. It is obvious, that the smaller is the model height, the higher is the resonance frequency, and the higher is the total SAR at resonance frequency. This means, that the resonance frequency of children body is higher than the resonance frequency of adult human bodies and also the total SAR at resonance frequency is higher for children than for adult people.



**Figure 11.** Frequency dependence of whole-body average (total) SAR in the ellipsoidal model of human body for different heights  $h$  (constant height to width ratio of 3:1).





**Figure 12.** Frequency dependence of whole-body average SAR for the human body models of height  $h = 1.8$  m: Laura model of woman body, ellipsoidal models of width  $w = 0.2$  m and width  $w = 0.3$  m and cylindrical model of width  $w = 0.3$  m.

In figure 12 are shown frequency dependences of the whole-body average SAR for four models of the same height of  $h = 1.8$  m: anthropomorphic woman model (Laura model), the ellipsoidal model of width  $w = 0.2$  m and width  $w = 0.3$  m, and cylindrical model of width  $w = 0.3$  m. The resonance frequencies for ellipsoidal model and Laura model are about 70 MHz (69 MHz for Laura model, 72 MHz and 74 MHz for ellipsoidal model of width  $w = 0.2$  m and  $w = 0.3$  m, respectively), and resonance frequency for cylindrical model is 61 MHz. The resonance frequencies are mainly determined by the height of models, the width and shape of model is of less importance.

The total SAR at resonance frequency of Laura model is higher than of ellipsoidal and cylindrical model of width  $w = 0.3$  m, but lower than resonance frequency of ellipsoidal model of width  $w = 0.2$  m. We suppose that this effect depends on width of model.

The values of resonance frequencies for different models resulted from simulations are summarized in figure 13, as well as the assumed relation according [9]. We can roughly say [10], that absorption reaches maximum (resonance frequency  $f_r$ ), when height of model is equal to half of wavelength ( $\lambda$ ):

$$f_{r0}(h) = \frac{c}{\lambda} = \frac{c}{2 \cdot h} \quad (3)$$

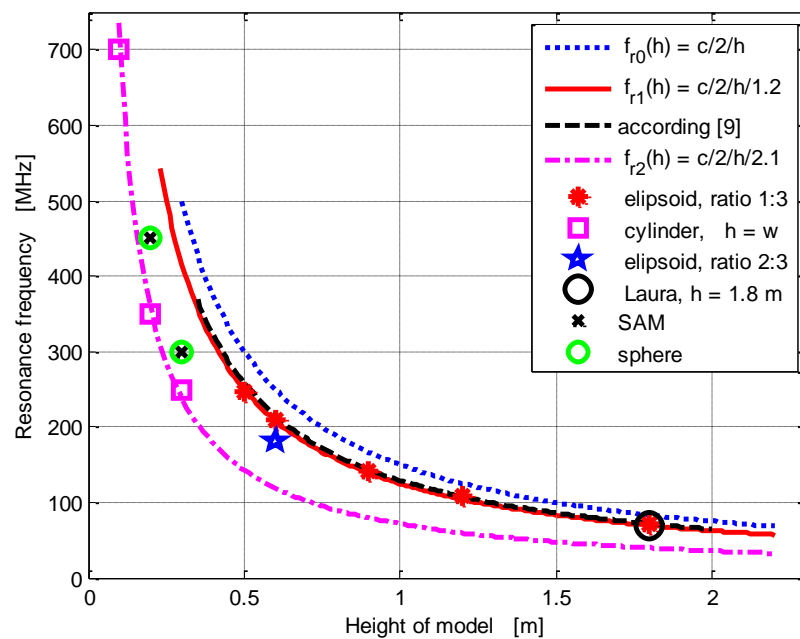
where  $\lambda$  is wavelength and  $c$  is speed of light.

The resonance frequency values for the ellipsoidal and cylindrical model (figure 13) are lower than that estimated according the relation (3). Therefore, we suggest that the more proper approximation of resonance frequency for these models would be according to corrected relation:

$$f_{r1}(h) = \frac{c}{2 \cdot h \cdot 1.2} \quad (4)$$

for the ellipsoidal model with constant height to width ratio of 3:1, or with the another correction constant of 2.1 for the cylindrical model ( $h = w$ ):

$$f_{r2} = \frac{c}{2 \cdot h \cdot 2.1} \quad (5)$$



**Figure 13.** Resonance frequency dependence on the height  $h$  for different models of head and human body: the ellipsoidal body model (with the constant 3:1 ratio of height to width), cylindrical model and Laura model and different models of human head: spherical model, cylindrical and SAM model.

## 5. Conclusion

The dependencies of whole-body average SAR and resonance frequency on parameters of human body model have been investigated in this article. According to the simulation results we can conclude, that in the resonance frequency range the whole-body average SAR depends strongly on the human body size: the smaller is the model height, the higher is the whole-body average SAR.

We observed, that the values of resonance frequency are similar for the selected types of body models (ellipsoidal and anthropomorphic) of the same height. The simulation results show that the resonance frequency depends mainly on the model height: the smaller is the model height, the higher is the resonance frequency. The influence of electrical tissue properties on the whole-body average SAR was less pronounced (lower absorption for brain grey matter than for brain white matter).

The results of simulations show that even though the body resonance frequency is determined primarily by the body height, other parameters of body shape (correction constants for two model shapes are proposed) must be also included for more precise assessment.

### Acknowledgments

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