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Analysis of SAR coefficient in the base station antenna field

Abstract. *The paper presents the analysis of the Specific Absorption Rate (SAR) coefficient for human body subjected to the electromagnetic field of the base station field. The biological model is prolate spheroid and the illumination is a uniform plane wave. The human body has been modeled using an isotropic lossy dielectric prolate spheroid. The calculations were done by semi-analytical method for different field parameters and body parameters. The aim of this study is to analyze the influence of different parameters on whole body SAR. The computations were made for gsm frequencies.*

Streszczenie. *W pracy przedstawiono analizę współczynnika SAR dla człowieka w polu dalekim stacji bazowych telefonii komórkowej. Przyjeto sferoidalny model ciała człowieka. Obliczenia przeprowadzono metodą opartą na analitycznym rozwiązaniu zagadnienia brzegowego dla różnych parametrów anten i parametrów ciała.(**Analiza współczynnika SAR w polu anteny stacji bazowej)**.*

Keywords: electromagnetic field, SAR, base station, spheroidal model
Słowa kluczowe: elektromagnetyczne, SAR, antena bazowa, model sferoidalny

Introduction

Nowadays, man is exposed to the fields emitted by widely used devices including base station atenna (BSA) of mobile telephony system. The development of mobile communication has resulted in large number of base stations located close to populated areas. Hence, an increasing public concern about the biological effects of electromagnetic fields on the human body and about the possible health hazard coming from these wireless communication sources has been observed.

The electromagnetic field affects the living organisms found in this field. The dose of absorbed radiation may generate long-term effects in the facility, e.g. heating. One of the parameters describing energy processes in biological tissue under the influence of the applied electromagnetic field and allowing to assess the effect of electromagnetic radiation on humans is the SAR (Specific Absorption Rate) absorption coefficient. This factor illustrates the processes that occur in the biological tissue under the influence of the field and is a measure of absorbed energy. Currently, SAR, along with the intensity of the electromagnetic field or power density, has become the basic size used to assess the exposure of humans associated with exposure to electromagnetic radiation. Safety in the field is important for the whole society, hence SAR is subject to standardization [1].

With the proliferation of mobile phones, the intensity of microwave fields in the environment has changed. The system is composed of base stations and two-way moblie devices that use signals with frequencies around 900 MHz, 1800 MHz, 2100 MHz or higher. Base stations have appeared around our homes to ensure communication between phone users and the network operator. All this resulted in a significant increase in the exposure of the population to the action of the electromagnetic field, and consequently fears of specialists and the public about whether or not mobile phone systems pose a threat to our health. The number of base stations is growing steadily and in proportion to the growing number of users and new services offered by operators. There is no convincing scientific evidence so far that such weak fields could affect biological structures, let alone cause any health consequences. However, the presence of antennas is still anxiety for people living around, and it is the need to demonstrate their safety.

When electromagnetic waves produced by BSA pass through human body, a part of the power is absorbed by the tissue. The commonly adopted measure for the absorbed energy in biological tissues is the SAR. The SAR is the coefficient which determines the thermal effect on the biological tissue subjected to the electromagnetic field. Protection from potential dangers is based on established safety guidelines, which propose maximum values for the SAR in order to limit the potentially hazardous overexposure. The safety guidelines for limiting exposure to electromagnetic fields have been published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Most countries introduce SAR limits in order to exclude or minimize the possible health effect. Analysis of electromagnetic field distribution and estimation of SAR are the base to risk assessment of exposure to BSA electromagnetic field.

The SAR takes into account the incient electromagnetic field parameters and also parameters of the body subjected to electromagnetic field. Value of SAR depends on incident field parameters such as intensity, frequency and polarization [1]. The absorption of electromagnetic field depends also on parameters of object such as size, shape and orientation [2]. SAR is higher when the body is more perpendicular than parallel to an incident field. It is also higher when the cross section of the body perpendicular to the incident magnetic field is larger. SAR for a given human body shape may be different for another one. The level of gsm energy absorbed in a child's body compared to those in an adult body is different due to their different electrical parameters and smaller body size.

The paper presents the analysis of the SAR coefficient for a spheroidal human model and various conditions of exposure to the field of distant antennas of base stations with the frequency 900 – 1800 MHz. The calculations were carried out for various antennas and electrical parameters of extortion, as well as the geometry and physical properties of the biological object.

The distribution of SAR can be achieved by computational technique or by experiment made on phantom [4]. Both are approximate solutions as they introduce assumptions. The analyzed object is complex in its nature. This paper presents the analysis of the whole-body averaged SAR inside a prolate spheroidal model of human body exposed to far-field electromagnetic fields. The geometry of the object is rather simple and distant from reality, but allows to estimate risk of exposure to electromagnetic field. The aim of the paper is analysis of SAR in the field of BSA for different human model with parameters of body coresponding to dimension and age human and for different parameters of BSA.

Base station antenna field

The base station contains all the elements necessary for transmission and reception of signals. There are a few sector antennas in one station. The sector antennas are the sources of electromagnetic field around the stations. The main function of these antennas is to send signals to moblie phones and receive signals from mobile phones. These antennas are located on antenna mast or on the roofs of buildings. Because mobile phones and their base stations are two-way radios, they produce radiation in order to communicate, exposing people near them to electromagnetic field giving concerns about mobile phone radiation and health. Mobile telephones are relatively low power so the radiation exposures from them are generally low. For protection from potential hazard national regulations restrict limits for electromagnetic field.

There are several parameters for characterization and analysis of the antenna performance namely radiation pattern, directivity, gains, polarization and bandwidth. One of the important parameters is the directivity D, which describes a transmitting antenna which allows most of the transmitted power to be sent in the wanted direction. More usefull parameters is antenna gain G. The gain G of an antenna is defined as the ratio of the power density in the direction of maximum radiation to that which will be observed at the same distance over an isotopic antenna while radiating the same total power [5], and typically it is expressed in the unit of dB. The power of the transmitters is in the range of 10-40 W for each channel and sector. The antennas used in the GSM system have a gain of about 14-20 dB.

Specific Absorption Rate

One of the parameters allowing to assess human exposure to the effects of electromagnetic radiation is SAR. This coefficient is a measure of absorbed energy. Currently, the SAR is one of the basic size used to assess human exposure associated with exposure to electromagnetic radiation. It determines the energy absorbed by unit of tissue mass in one second. Unit of SAR is W/kg. The SAR is defined as the time derivative of the energy entering the object with respect to mass:

(1) $$SAR = \frac{1}{dt}\left(\frac{dW}{dm}\right) = \frac{1}{dt}\left(\frac{dW}{\rho\, dV}\right)$$

where: W - energy absorbed in the object, m - mass, ρ - density of material (tissue) [kg / m^3], V - volume.

The practical measurement or determination of SAR values based on (2) is a complex issue. In SAR research and its distributions in a biological object, both analytical and experimental methods are used [1]. In both cases, the process is long-lasting and expensive for phantom research. It is necessary to know the electrical parameters of the phantom fluid, and obtaining them requires specialized equipment. The analytical and numerical methods are used to calculate the SAR coefficient [8].

In the radio and microwave frequencies, the SAR value calculated locally depends on the square of the effective value of the electric field E in the selected area of the human body:

(2) $$SAR(x, y, z) = \sigma \frac{E^2}{\rho}$$

where: ρ - generalized tissue conductivity [S/m], E - electric field.

The average value of the absorption coefficient in the whole or a selected area of the body describes the total dose of power absorbed by the body absorbing electromagnetic radiation with respect to the total mass of this body M.

(3) $$SAR_{WB} = \frac{\iiint_V P_V\, dV}{M}$$

SAR in living organisms depends on the parameters of the field such as frequency, intensity, polarization. SAR depens also on geometric and electrical parameters of the biological object. The biological material is dielectric, so in the case of variable fields the conductivity is three-part: one component representing the forward current, independent of the frequency and two components representing the offset current and the polarization phenomenon, linearly dependent on the frequency.

From theoretical studies and experimental models it appears that for an average person an electromagnetic field with a SAR value of 4 W/kg can cause an increase in body temperature by not more than 0.1-0.3 ° C on average. It is a small increase and does not pose a threat to health, however, a thermoregulation mechanism is already initiated. In addition, it is an average increase in body temperature, while the so-called hot spots where the temperature increase can be higher. Therefore, a safety margin was introduced, reducing the SAR value for the field affecting employees by 10 times, to a level of 0.4 W/kg. In the case of a field operating in general population, an additional safety factor was introduced, reducing the SAR value to 0.08 W / kg [5]. Since the limitation of the whole-body averaged SAR value does not provide sufficient protection against local energy absorption that could lead to local overheating, a limitation of the highest SAR values allowed locally has been introduced (for 1 g SAR tissue is 1.6 W / kg, and for 10g tissue 2 W / kg).

Model of the human body

The human body model in the shape of a spheroid, being an isotropic non-ideal dielectric with conductivity γ, magnetic permeability equal to vacuum permeability μ_0 and complex permittivity ε were assumed for calculations. Calculations were carried out in the far field with extortion in the form of a flat wave. The electromagnetic field of a distant cellular base station incident on a test object in the form of a plane wave can have different types of polarization. The main ones are: polarization E - (vector E vertical), polarization H - (vector E levels), polarization 45^0 - when the vectors E and H are at an angle of 45 degrees to the vertical and horizontal. To perform computer simulation in biological tissues, a method based on the analytical solution of the boundary problem simulating a man (spheroid) and an external electromagnetic field (electrical component) was used [3]. The method gives acquire knowledge about the SAR relationship in a relatively short time. Its correctness has been verified experimentally [4]. The method of determining the SAR coefficient in a spheroid shaped biological object is described in [3, 4]. The dimensions of the spheroid depend on the height and weight of the human. The long axis of the spheroid corresponds to the height, and the short axis corresponds to the weight. A constant average body density was assumed. For adults, the average weight corresponding to the height according to the Encyclopedia of Health [7] was taken as the calculation. The average density of human body tissues was assumed1000 kg/m3. The calculations were made for the body parameters of children up to 8 years of age, because above this age tissue parameters are as for adults. Body height and weight data needed for calculations were read from centile grids [7]. Then, these data were averaged. The data contained in Tab.1 were used for the calculations:

Table 1. The parameters of the models

Model	Adults		Model	Children	
	Height [m]	Weight [kg]		Height [m]	Weight [kg]
1A	1.50	50	1C	0.82	12
2A	1.60	58	2C	1.01	17
3A	1.70	64	3C	1.15	20
4A	1.80	73	4C	1.25	25
5A	1.90	82			

Results

Simulations were performed for 900 and 1800 MHz frequencies at H polarization. The SAR value was calculated for the data contained in Tab.1 for different distances from the radiation source. The results of calculations carried out for the 900 MHz frequency with the power supplied to the 300W antenna and the antenna gain of 15.5dB in the function of the distance from the antenna for children of different height and weight are shown in Fig. 1, and for adults in Fig. 2.

The graphs show that the value of the coefficient SAR decreases quite quickly and reaches the recommended value of 0.08 W/kg already below 20m. One can see differences in the amount of energy absorbed for children and adults. At the same distance, the SAR reaches higher values for children. The difference in the values of this coefficient between an adult and a child is small and disappears at a distance of about 20m. Figure 3 shows the average SAR values obtained for children and adults in comparison. The SAR values obtained from the calculations, which were carried out for the 1800 MHz frequency, and the antenna gain of 15.5dB are shown in Figure 4 for children and Figure 5 for adults. The analysis of the graphs allows to conclude that this case is very similar to the previous one and in the case of a child, the SAR ratio reaches the recommended value (0.08 W/kg) above 20m of distance from the antenna (Fig. 4). In the case of an adult, this distance is reduced to 10 m. The difference between average SAR values for children and adults is negligible (Fig. 6).

In all cases presented, it can be seen that the SAR decreases very rapidly as the distance from the antenna increases. In most of the presented cases, it decreases from about 0.1 W/kg to the recommended level even at a distance of about 20 meters. After exceeding this distance, SAR is reduced to very low values. It is also worth noting that the size of SAR, even in close distances from the antenna, decreases very quickly. Below the recommended value, it does not decrease so quickly, but it is so small that it has no impact on the human environment. It reaches zero at a distance of about 1500 m from the station.

In order to examine the influence of antenna parameters on the value of the SAR coefficient, calculations were made for various antenna parameters for one object. The determined values of the SAR at certain distances from the source at different frequency, power supplied to the antenna and antenna gain are shown in Fig.7. The SAR value increases as the antenna frequency increases (Fig.7). Thus, the distance of safe staying in the antenna field is extended. Raising the frequency by network operators has therefore also negative effects, although the positive ones are much higher.

The increase in frequency is caused by more and more subscribers and active phones as well as new possibilities.

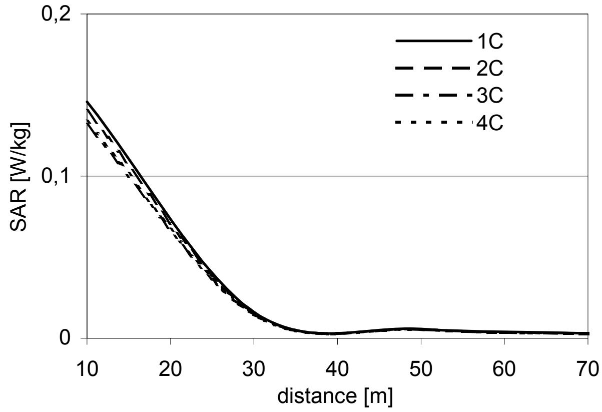

Fig.1. The SAR coefficient for children as a function of the distance from the source (for the antenna 900 MHz, gain 15.5dB)

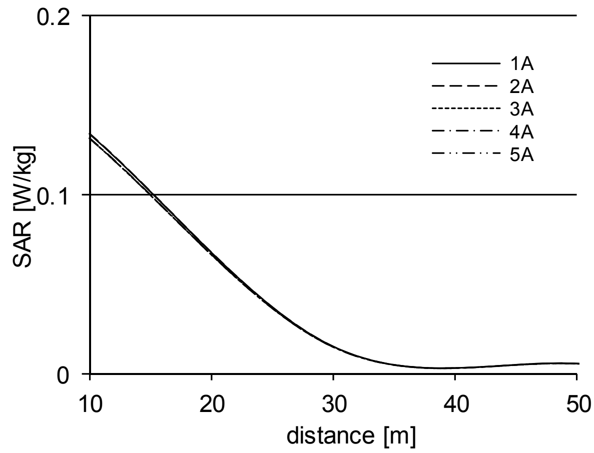

Fig.2. The SAR coefficient for adults (for 900 MHz frequency and the antenna gain 15.5dB)

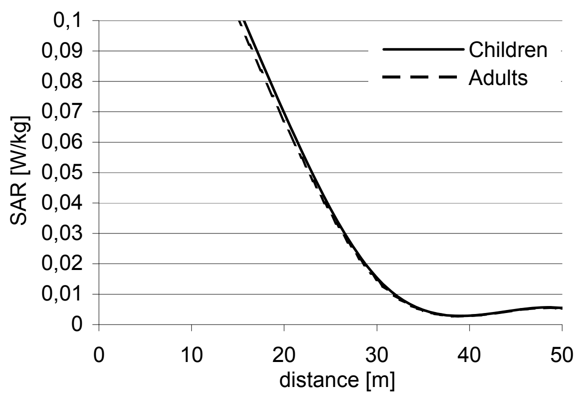

Fig.3. The comparison of SAR distribution for children and adults (900MHz)

The power supplied to the antenna also affects the SAR value. The value of the power supplied to the antenna is the maximum value at which the device can operate, in fact this value is on the order of 20 - 40W. The result is that the actual SAR value is much lower, and therefore completely safe for human health. Antenna gain also affects the amount of energy absorbed by the body. Analyzing the calculations, it can be noticed that the 18.1 dB gain doubles the value of the coefficient compared to the antennas with a profit of 15.5 dB. Antenna gain similarly to field polarization and power supplied to the antenna depends on antenna design parameters.

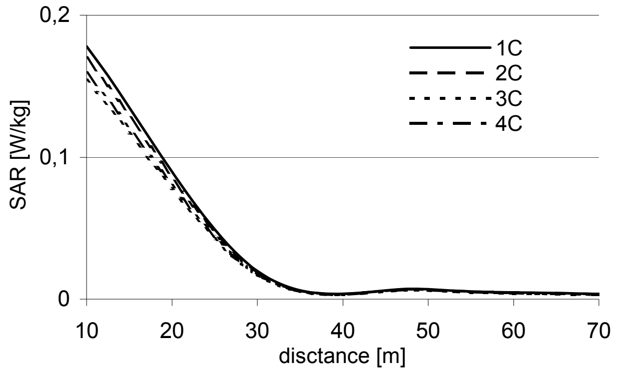

Fig.4. The SAR coefficient for children (for 1800 MHz frequency and the antenna gain 15.5dB)

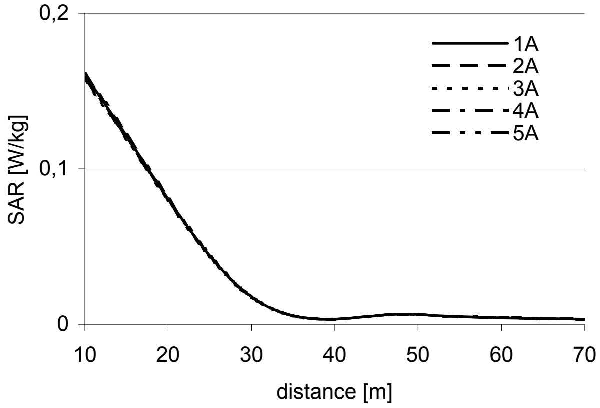

Fig.5. The SAR coefficient for adults (for 1800 MHz frequency and the antenna gain 15.5dB)

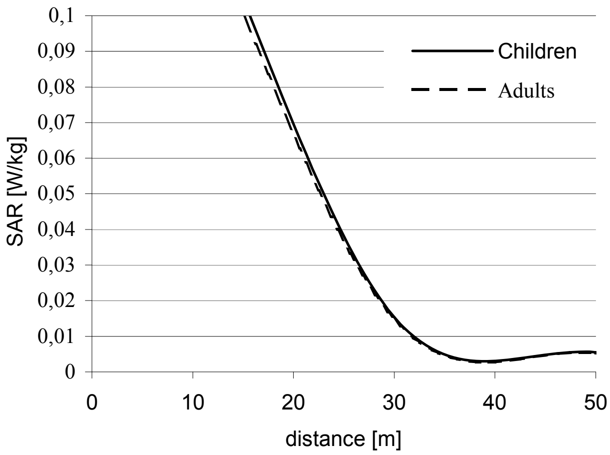

Fig.6. The SAR value depends on the age of the person

Conclusion

In this study, estimation formula for SAR of human bodies have been developed. The formula was be used for adults and children standing in the field of BSA antennas. The resulting SAR values are significantly lower than the limit values given in the current directive. The calculations of the SAR coefficient in the human body model in the field were made for the frequencies used by mobile operators. The SAR factor in the body depends on the antenna parameters such as frequency, power and antenna gain the calculations show that the increase of these parameters causes an increase in energy absorbed by the body. SAR is

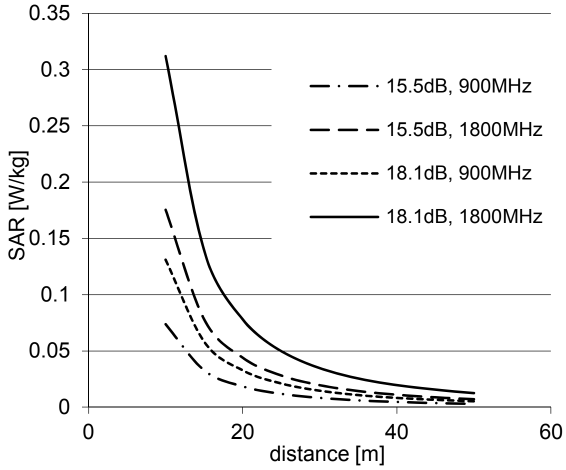

Fig.7. Influence of antenna parameters on SAR

different for children and adults. It is also caused by other tissue parameters of children and adults outside the body dimensions.

The calculations were carried out for the model of the human body, which is a simplified model. The actual human body is a complicated heterogeneous structure. It should also be added that the calculations were made for the maximum input power. In real base stations, this power is lower (between 20 and 40W). The result is lower values of the SAR coefficient. The distances at which this coefficient reaches the recommended value are in fact much shorter, which is connected with the total safety of staying close to the base stations. Research on the influence of the electromagnetic field from mobile telephone systems is still intensively conducted. The results of these experiments continuously verify the problem of the SAR.

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