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Definition of a parameter for a typical specific absorption rate under real boundary conditions of cellular phones in a GSM network

D. Gerhardt

E-Plus Mobilfunk GmbH & Co. KG, E-Plus-Platz, D-40468 Düsseldorf, Germany

Abstract. Using cellular phones the specific absorption rate (SAR) as a physical value must observe established and internationally defined levels to guarantee human protection. To assess human protection it is necessary to guarantee safety under worst-case conditions (especially maximum transmitting power) using cellular phones.

To evaluate the exposure to electromagnetic fields under normal terms of use of cellular phones the limitations of the specific absorption rate must be pointed out. In a mobile radio network normal terms of use of cellular phones, i.e. in interconnection with a fixed radio transmitter of a mobile radio network, power control of the cellular phone as well as the antenna diagram regarding a head phantom are also significant for the real exposure.

Based on the specific absorption rate, the antenna diagram regarding a head phantom and taking into consideration the power control a new parameter, the typical absorption rate (SAR_{typ}), is defined in this contribution. This parameter indicates the specific absorption rate under average normal conditions of use. Constant radio link attenuation between a cellular phone and a fixed radio transmitter for all mobile models tested was assumed in order to achieve constant field strength at the receiving antenna of the fixed radio transmitter as a result of power control. The typical specific absorption rate is a characteristic physical value of every mobile model.

The typical absorption rate was calculated for 16 different mobile models and compared with the absorption rate at maximum transmitting power. The results confirm the relevance of the definition of this parameter (SAR_{typ}) as opposed to the specific absorption rate as a competent and applicable method to establish the real mean exposure from a cellular phone in a mobile radio network. The typical absorption rate provides a parameter to assess electromagnetic fields of a cellular phone that is more relevant to the consumer.

Correspondence to: D. Gerhardt
(dietmar.gerhardt@eplus.de)

1 Introduction

Radio frequency electromagnetic fields are absorbed by the human body and lead to a temperature increase of biological tissue. This is characterised by the specific absorption rate SAR and is related to the electrical field strength E_{eff} in the biological tissue and its conductivity σ and density ρ:

$$SAR = \sigma \frac{E_{eff}^2}{\rho} \tag{1}$$

The specific absorption rate can be determined according to equation 1, among other things, over the measurement of the electrical field strength in a human body (or head) phantom, which is filled with a tissue-simulating liquid (DASY, 1995; Kuster, 1997; ES 59005, 1998; EN 50360, 2001; EN 50361, 2001).

For radio systems in operation the specific absorption rate may not exceed a fixed exposure limit, so that personal safety is ensured (ICNIRP, 1998; EC Recommendation, 1999). The exposure limit of the specific absorption rate for cellular phones is at a value of 2 W/kg averaged over 10 g of tissue mass. For cellular phones the specific absorption rate SAR is proportional to the transmitting power P:

$$SAR = K\ P \quad \text{with} \quad K: \quad \text{proportionality constant} \tag{2}$$

For the CE conformity tests the specific absorption rate is determined during maximum transmitting power (EN 50360, 2001; EN 50361, 2001). This does not correspond to a typical, average operating transmitting power during a phone call. The cellular phone works with the minimum technically necessary transmitting power that ensures an error free radio link to the fixed radio transmitter. The decisive parameter is the radio link attenuation, which essentially depends on the distance and on the angle between the antennas of the fixed radio transmitter and the cellular phone. The antenna gain of cellular phones in presence of a head phantom, measured after Schneider et al. (1998), indicates a pronounced variation depending on the azimuth angle φ and elevation angle ϑ (Fig. 1).

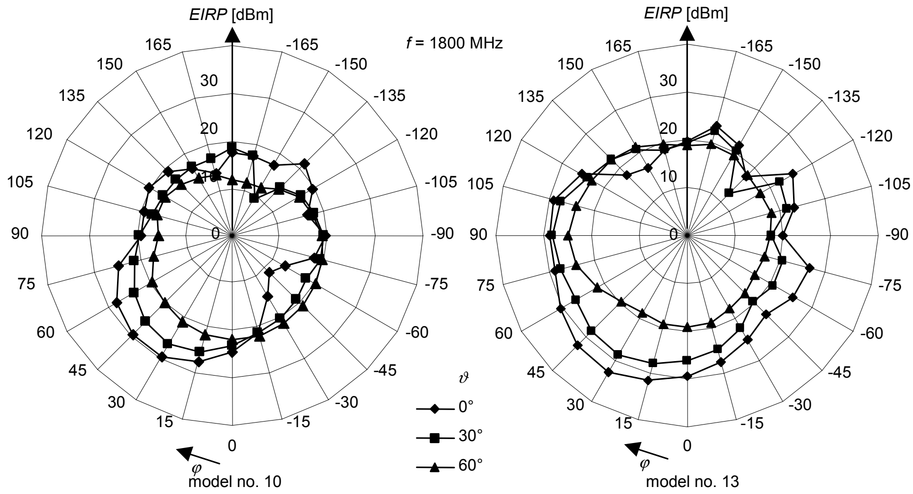

Fig. 1. Measured EIRP in dBm, examples for 2 mobile models.

If real exposure conditions are assessed with the typical use of a cellular phone, the specific absorption rate during maximum transmitting power of the cellular phone is not a meaningful value. This requires the definition of a so-called typical specific absorption rate (SAR_{typ}), which essentially considers both the antenna gain in presence of a head phantom and the power control.

2 Method

In order to derive the typical specific absorption rate the power of the cellular phone must be controlled, for each mobile model, such that with constant distance regarding radio link attenuation to the receiving antenna of the fixed radio transmitter the same field strength (or power density) is present. The distance r between cellular phone and fixed radio transmitter is large in relation to the wavelength of the electromagnetic field, so that far field conditions are present. The power density S is given by:

$$S = \frac{G(\varphi, \vartheta) P}{4\pi r^2} \tag{3}$$

The antenna gain G is angle dependent (φ: azimuth, ϑ: elevation) and takes into account the influence of a head phantom (see Figs. 1 and 2). A constant receiving power of the antenna of the fixed radio transmitter demands $4\pi r^2 S$ = const., so that the power control for the transmitting power P is dependent on the angle of the cellular phone according to Eq. (3):

$$P(\varphi, \vartheta) = \frac{4\pi r^2 S}{G(\varphi, \vartheta)} \tag{4}$$

The constant K can be determined from Eq. (2) with the measured specific absorption rate SAR_{max} during maximum transmitting power $P_{max} = 1\,\mathrm{W}$ ($f = 1.8\,\mathrm{GHz}$, GSM1800). The specific absorption rate from Eq. (4) and the equivalent isotropic radiating power $EIRP(\varphi, \vartheta) = G(\varphi, \vartheta) P_{max}$ is given by:

$$SAR(\varphi, \vartheta) = \frac{4\pi r^2 S}{EIRP(\varphi, \vartheta)} SAR_{max} \tag{5}$$

$EIRP$ can be determined by measurement and indicated as $EIRP_{\mathrm{dBm}}$. By using cellular phones for φ an evenly distributed probability is given, so that Eq. (5) is averaged over φ:

$$\overline{SAR}(\vartheta) = \frac{1}{N} \sum_{i=1}^{N} SAR(\varphi_i, \vartheta) \tag{6}$$

The typical power P_{typ} depends on the characteristics of the mobile radio network (Wiart et al., 2000; Vecchia et al., 2001) and from Eq. (3) the following condition results:

$$\frac{1}{N} \sum_{i=1}^{N} \frac{4\pi r^2 S}{G(\varphi_i, \vartheta)} \stackrel{!}{=} P_{typ} \tag{7}$$

From Eq. (7) the term $4\pi r^2 S$ can be determined as follows:

$$4\pi r^2 S = \overline{G}(\vartheta) P_{typ} \quad \text{with} \quad \overline{G}(\vartheta) := \frac{1}{\frac{1}{N} \sum_{i=1}^{N} \frac{1}{G(\varphi_i, \vartheta)}} \tag{8}$$

For the determination of $\overline{G}(\vartheta)$ a more realistic result can be obtained by averaging the function of $\overline{G}(\vartheta)$ also over a selection of mobile models. Since the antenna gain of the radio base station antenna depends on the elevation angle ϑ, Eq. (8) is evaluated explicitly for different values of $\vartheta = \{0°, 30°, 60°\}$ to make it possible to compare the mobile models under the same typical transmitting power. With this boundary condition averaging over ϑ is valid:

$$\overline{\overline{SAR}(\vartheta_j)} = \frac{1}{M} \sum_{j=1}^{M} \overline{SAR}(\vartheta_j) \tag{9}$$

Table 1. Measured and calculated radio properties for different mobile models

mobile model	SAR_{max} [W/kg]	SAR_{typ} [W/kg]	$EIRP$ [dBm]
no. 1	0.20	0.04	24.82
no. 2	0.14	0.03	22.84
no. 3	0.34	0.08	24.58
no. 4	0.41	0.07	23.95
no. 5	0.47	0.11	22.53
no. 6	0.32	0.10	20.83
no. 7	0.60	0.15	23.43
no. 8	0.57	0.16	22.97
no. 9	0.50	0.16	22.25
no. 10	0.39	0.18	21.02
no. 11	0.56	0.17	21.92
no. 12	0.75	0.18	23.38
no. 13	0.95	0.18	24.85
no. 14	0.74	0.22	23.30
no. 15	0.47	0.30	21.97
no.16	0.76	0.24	22.52

It is further noted that a call consist of talk time t_S and talk break t_{DTX} (DTX: discontinuous transmission), which has an influence on the power P_{typ}:

$$P_{typ} = P_S v + P_{DTX}(1 - v) \quad \text{with} \quad v = \frac{t_S}{t_{DTX}} \tag{10}$$

During the talk time t_S the cellular phone works with the transmitting power P_S and during the talk break t_{DTX} with the transmitting power P_{DTX}. For $v > 0.5$ and $P_S \gg P_{DTX}$, to a good approximation P_{typ} is given by:

$$P_{typ} \cong P_S v \tag{11}$$

From the above equations the typical specific absorption rate can be calculated as follows:

$$SAR_{typ} = \frac{v P_S SAR_{max}}{MN} \frac{1}{1\text{ mW}} \sum_{j=1}^{M} \overline{G}(\vartheta_j)$$

$$\sum_{i=1}^{N} 10^{-\frac{EIRP_{\text{dBm}}(\varphi_i,\vartheta_j)}{10\,\text{dBm}}}$$

$$\text{with} \quad \overline{G}(\vartheta_j) = \frac{1}{\sum\limits_{i=1}^{N} \frac{1}{G(\varphi_i,\vartheta_j)}} \tag{12}$$

3 Results

The typical specific absorption rate (v = 0.7; P_S = 0.4 W; f = 1800 MHz) was calculated for 16 different mobile models from Eq. (12). Table 1 shows the results in the comparison to the specific absorption rate at maximum transmitting power and the averaged EIRP.

Equation 12 shows the relation between SAR_{typ} and SAR_{max}. In addition, a crucial parameter is the angle dependent EIRP, so that no pronounced correlation between

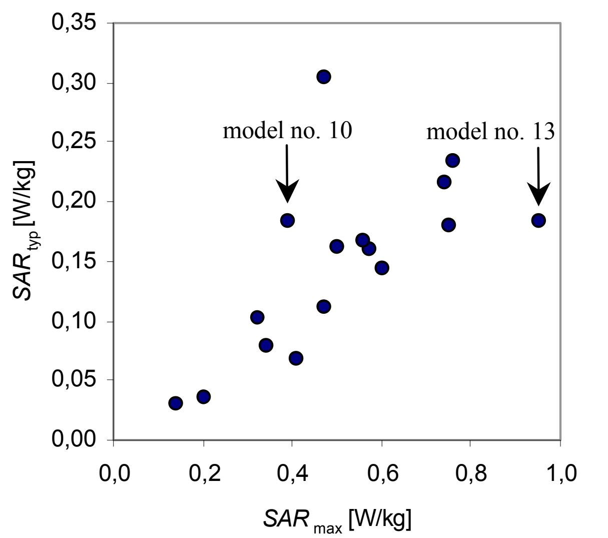

Fig. 2. SAR_{typ} and SAR_{max} of different mobile models from Table 1

SAR_{typ} and SAR_{max} exists (see Fig. 2). In Table 1 and Fig. 3 averaged over φ and ϑ $EIRP$ is shown and as can be seen, no pronounced correlation shows up between SAR_{typ} and $EIRP$. SAR_{typ} is thus an independent parameter for the characterisation of mobile models.

4 Discussions

A substantial result is to be recognised in Fig. 2. For some mobile models clear differences in the maximum specific absorption rate are visible, while the typical specific absorption rate changes by significantly less . There are mobile models, which show a far higher value for the maximum specific absorption rate but comparable (slightly lower) value for the

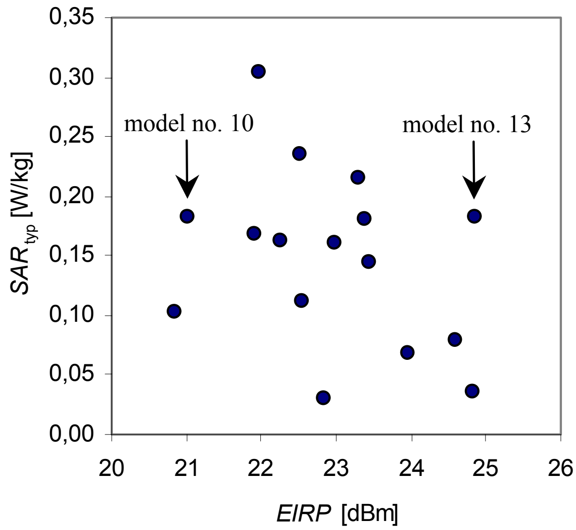

Fig. 3. SAR_{typ} and $EIRP$ of different mobile models from Table 1.

typical specific absorption rate (see Fig. 2 for mobile models 10 and 13 as an example).

An incorrect estimate of the real mean exposure would be produced if the mobile models were compared using only the specific absorption rate during maximum transmitting power. For the evaluation of real exposure conditions the typical specific absorption rate provides a suitable parameter for a reliable quantitative and qualitative comparison. The maximum specific absorption rate cannot supply this, since it was defined with a completely different objective in mind, namely safety aspects. It is also clear that the specific absorption rate for typical call conditions is lower, compared to the specific absorption rate during maximum transmitting power. The power control has a crucial influence in this regard.

Mobile models with a large EIRP value also exhibit good radio supply. This helps to provide a higher quality in the mobile radio network.

5 Conclusion

For the consumer it is important to have a criterion at hand by which the exposure conditions in a typical call situation can be judged. While the specific absorption rate supplies a statement about the safety of the cellular phone during maximum transmitting power, an estimate of real exposure conditions only becomes possible by the calculation of the typical specific absorption rate according to the presented model. For the estimate of good exposure and radio characteristics, this procedure offers clear advantages.

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