EM User Interaction – Considerations for the Design of Mobile Phones

D. Manteuffel, D. Heberling, I. Wolff, IMST GmbH, D-47475 Kamp-Lintfort, Germany, manteuffel@imst.de

Abstract

This paper presents fundamental aspects on the electromagnetic (EM) User Interaction which have to be considered in the design and optimization of mobile phones are discussed. The study is based on numerical simulations of GSM900 and GSM1800 mobile phones. The absorption mechanism is analysed in more detail by generic models of modern cellular phones equipped with different types of antennas. The simulations are performed using EMPIRE^{TM} with a standardised numerical representation of the human head (SAM – Specific Anthropomorphic Mannequin).

1 Introduction

Mobile communication has become very familiar in our daily life. Today, nearly everybody uses mobile phones and thus led to a tremendous effort in the design of new mobile phones at the beginning of this new millennium. Because of the important impact of the aesthetical design of a mobile phone on its success on the market the device becomes smaller and smarter. On the other hand the EM interaction between the user and the small radiating devices become more important. The EM interaction between the mobile and the user can be treated by two different points of view:

On the one hand we can focus on the *impact of the mobile phone on the user*, which is often understood as the exposure of the user to the EM field of the radiating device. The absorption of electromagnetic energy in the human tissue (SAR – Specific Absorption Rate) generated by mobile phones has become a point of critical public discussions due to possible health risks. In late 2000, manufacturers within the MMF (Mobile Manufacturers Forum) decided to begin the reporting of SAR values on a global basis consistent with their commitment to consumers to provide all relevant and useful information on their phones. Therefore SAR becomes an important performance parameter for the marketing of mobile phones and underlines the interest in optimizing the interaction between the mobile and the user by both, consumers and mobile phone manufacturers.

On the other hand, from a more technical point of view, we can focus on the *impact of the user on the mobile*. With this regard, the tissue of the user represents a large dielectric and lossy material distribution in the near field of a radiator. It is obvious that therefore all antenna parameters such as impedance, radiation characteristic and radiation efficiency will be affected by the properties of the tissue. Moreover, the effect can differ with respect to the individual habits of the user to place his hand around the mobile or to attach the mobile to the head. With this regard, optimized user interaction becomes a technical performance parameter of mobile phones.

Although the principle effects have been carried out in several scientific publications based on both experimental and numerical data [1, 2], parametric studies that deal with different configurations of the mobile or use different types of antenna modules are very rare [3].

In this paper both aspects of the interaction between the user and a mobile phone described above are analysed by means of numerical simulations based on the FDTD (Finite Difference Time Domain) method. The aim of the investigation, dealing with a parametric approach for different typical mobile phone configurations, is to provide guidelines for the design of mobile phones with optimized user interaction.

2 Methods

2. 1 FDTD Method

In this investigation the commercially available electromagnetic field simulator EMPIRE™ is used for the numerical investigation of the antenna parameters of the mobile including the influence of the human head. EMPIRE™ applies the Finite Difference Time Domain (FDTD) method in order to solve Maxwell's equation for a given initial boundary problem [4].

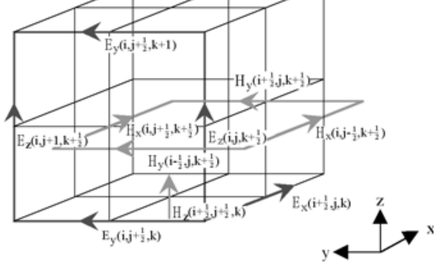

Fig. 1: Arrangement of electric and magnetic field components in a Yee-cell.

Figure 1 shows the arrangement of electric and magnetic field components in a so called Yee-cell. Please note that the field components are not defined at the common point in centre of the cell, but are arranged in a way that enables a simplified calculation of the curls in Faradays and Amperes law.

2. 1 Numerical Dosimetric Assessment

The biologically relevant parameter describing the effects of electromagnetic fields in the frequency range of interest (300 MHz – 3 GHz) is the specific absorption rate SAR (dimension: power/mass). The SAR may be spatially averaged over the total mass of an exposed body or its parts. The SAR is calculated from the r.m.s. electric field strength E inside the human body, the conductivity σ and the mass density ρ of the biological tissue:

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

A limitation of the specific absorption rate in terms of basic restrictions prevents an excessive heating of the human body by electromagnetic energy. In Europe the relevant SAR limit in the human head while using a mobile phone is set to 2 W/kg averaged over 10 g of tissue. Meanwhile a standard for compliance testing of mobile phones in terms of *SAR* has been established in Europe (EN 50361) [5].

Figure 2 shows the homogeneous SAM phantom for mobile phone compliance testing according to EN 50361 [5].

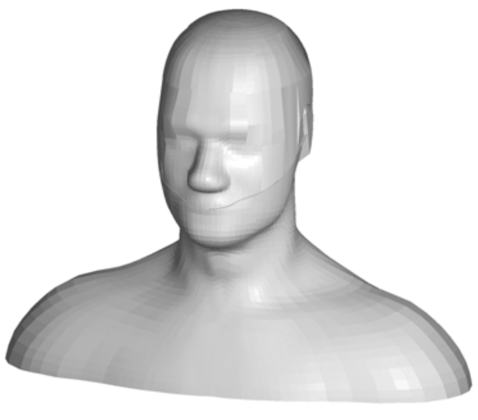

Fig. 2: SAM phantom.

3 Mobile Phone – User Interaction

There is an extensive discussion on the user effect of mobile phones especially with respect to *SAR*. Within this discussion generalized statements on different types of antennas or mobile phone configurations often are given without adequate scientific proof. As an example, one can often read that mobile phones using a flip which has to be lifted while using the mobile phone, reduces the amount of energy penetrating the users head, because the head is shielded towards the antenna by this flip. Another example states that mobile phones equipped with integrated antennas produce less SAR in the users head, because the antenna is mounted on the backside of the mobile and the PCB (Printed Circuit Board) shields the users head from radiation. It is the aim of the following investigations to discuss these statements on a scientific basis and to develop fundamental background to understand better the interaction between mobile phone and user.

3.1 Antennas in Mobile Phones

It has been derived in [6] for the simplified case of a dipole in front of a flat phantom, that the SAR induced in the flat phantom is proportional to the square of the current on the dipole in a first approximation. With this regard, it has been shown in [7] that the distribution of the surface current density on a mobile phone is related to the SAR distribution on a flat phantom when the mobile is positioned in front of the flat phantom.

Taking a closer look at a canonical model of a mobile phone the generalized current distribution can be divided into three portions (Figure 3):

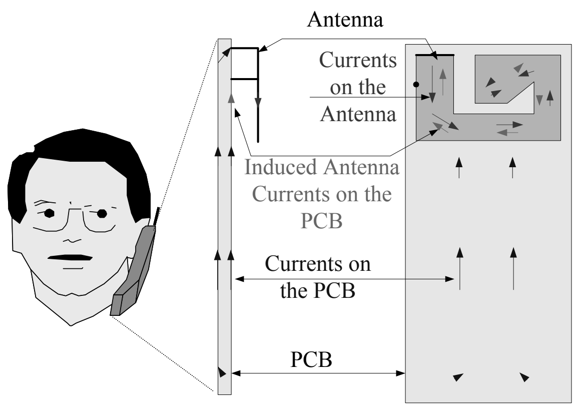

Fig. 3: Generalized current density distribution on a mobile phone.

As a first portion we can identify the current distribution on the antenna module itself. For a $\lambda/4$ antenna with shorting pin at one end of the patch, the current distribution follows a $\lambda/4$ distribution all along the patch. For this $\lambda/4$ antenna module is positioned on the PCB (Printed Circuit Board) of the mobile, a current distribution similar to the one on the antenna module, but opposite in phase is induced on the antenna side of PCB right under the antenna module. The field generated by this second portion of the current distribution interferes with the field generated by the current distribution on the antenna module and is partly cancelled. The third portion is excited on the PCB, too. Because the PCB of modern mobile phones is not large compared to the wavelength, it cannot be considered as a simple ground plane for the $\lambda/4$ antenna module. Due to the specific dimensions of the

PCB, the antenna module excites a current distribution on the PCB which is related to the boundary conditions of this conductive plate. For frequencies within the GSM900 band this may be around the $\lambda/2$ resonance of the PCB; for frequencies within the GSM1800 band this may be around the λ resonance respectively. In [3] this phenomenon has been investigated in more detail deriving an equivalent circuit of the mobile which contains one resonator replacing the antenna module and another resonator replacing the PCB.

3.2 User Interaction

In terms of SAR it is now interesting to see how the resulting current distribution containing the three portions described above couple to the tissue of the users head. In order to see the correlation of the current distribution on the mobile with the SAR in the tissue, the numerical model of the mobile is placed in front of a flat phantom to avoid any influence due to the anatomical shape of a real head. The distance between the PCB and the flat phantom is 5 mm. For the third portion of the current distribution (described above) is related to the PCB, eight different models of a mobile which vary in length of the PCB are used. Each mobile is equipped with an integrated C-Patch antenna.

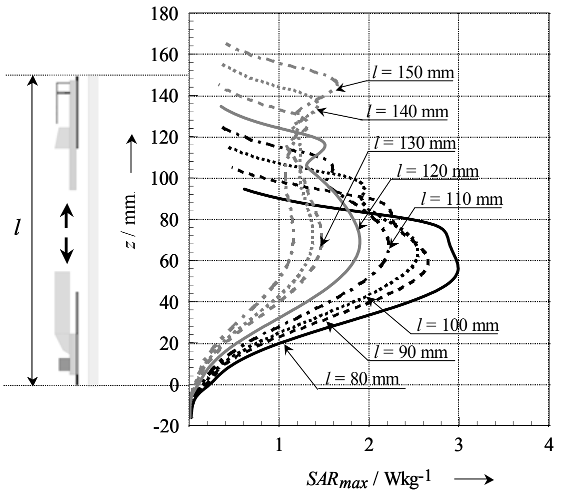

Fig. 4: SAR_{max} on the surface of a flat phantom for different models of a mobile phone: C-Patch antenna; $f = 925$ MHz; $P_{in} = 33$ dBm.

Figure 4 shows the maximum local SAR along the axis of the mobile on the surface of the flat phantom for 8 different models of a mobile phone equipped with an integrated antenna operating at 925 MHz. The input power at the antenna feeding point is $P_{in} = 33$ dBm. The simulation model of the mobile phone does not account for any losses. It can be observed that the SAR distribution on the surface of the flat phantom contains two local maxima for each model investigated. With respect to the generalized current distribution described above, it can be noticed that the maximum relative to the mid height of the mobile is related to the current distribution on the PCB. The other maximum relative to the top of the phone is related to the current distribution near the antenna feeding point. For all mobile phones smaller than 130 mm the maximum due to the current distribution on the PCB contains the highest SAR value. Additionally, using this length of the PCB ($l = 130$ mm) both maxima are nearly equal and the total maximum SAR is smallest. It is interesting to mention that a conductive plate of 40 mm × 130 mm is in resonance at the observed frequency.

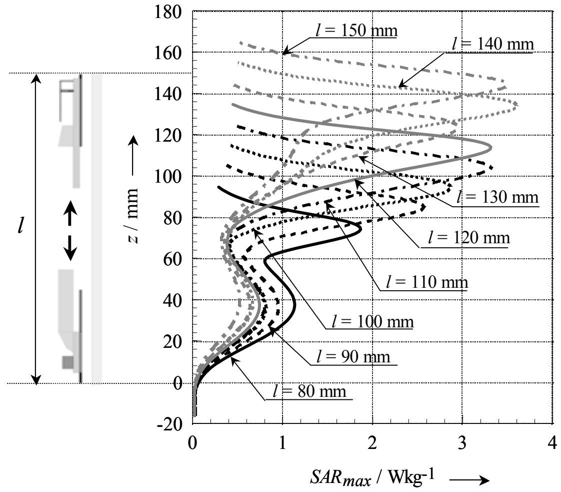

Fig. 5: SAR_{max} on the surface of a flat phantom for different models of a mobile phone: C-Patch antenna; $f = 1800$ MHz; $P_{in} = 30$ dBm.

Figure 5 shows the same kind of investigation for an antenna module operating at $f = 1800$ MHz. The input power at the antenna feeding point is $P_{in} = 30$ dBm. Similar to the investigation for the GSM900 frequency range two local maxima can be observed for the SAR distribution of each mobile. The maximum due to the current distribution at the antenna feeding point contains the highest SAR value in any case investigated at this frequency.

In a next step the coupling of the current distribution on the mobile with the SAR distribution in the tissue is investigated using a numerical representation of the SAM phantom for an integrated C-Patch antenna and an external helical antenna respectively. With respect to the results obtained above, the same canonical model of a mobile phone is used to analyze both antenna types.

Due to the plastic casing of the mobile phone and the plastic shell of the phantom the minimum distance between the PCB and the tissue of the phantom is 8 mm. The model of the mobile phone does not account for any losses. The mobile phone is positioned at the phantom according to the European Specification EN 50361 [5] in the *cheek* and the *tilted* position.

Figure 6 and Figure 7 show the maximum SAR in the phantom along the axis of the mobile averaged over a 10 g cube of tissue for an antenna module operating at $f = 925$ MHz and $f = 1800$ MHz respectively.

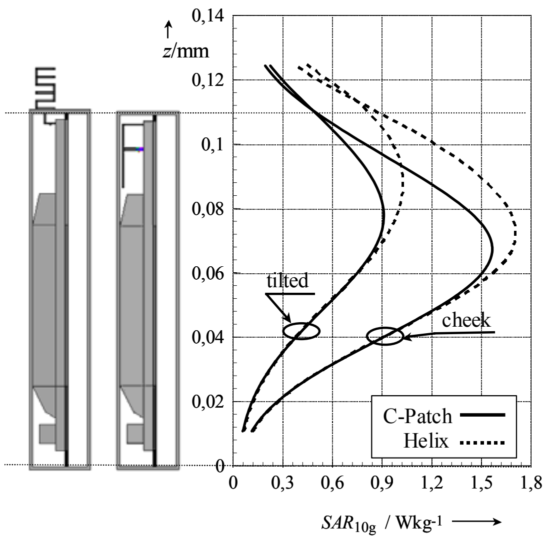

Fig. 6: SAR_{10g} in the SAM phantom for an external helical antenna and an integrated C-Patch antenna on the same mobile phone: f = 925 MHz; P_{in} = 33 dBm.

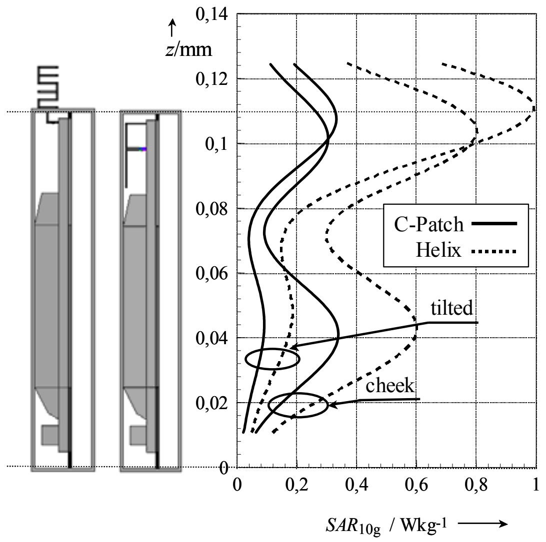

Fig. 7: SAR_{10g} in the SAM phantom for an external helical antenna and an integrated C-Patch antenna on the same mobile phone: f = 1800 MHz; P_{in} = 30 dBm.

It can be observed from Figure 6 that there is no significant advantage in terms of SAR using an integrated C-Patch antenna compared to an external helical antenna on the same mobile in the GSM900 frequency range. For both antennas the maximum SAR_{10g} in the phantom is related to the current distribution on the PCB of the mobile and thus appears in *cheek* position when the mid part of the mobile comes near the tissue at the cheek of the user. Regarding the GSM1800 frequency range a different conclusion can be found analysing the results displayed in Figure 7. For the helical antenna the maximum SAR_{10g} is related to the current distribution on the antenna module at the top of the phone and thus appears in *tilted* position in the ear region of the phantom. In this case an advantage in terms of SAR for the integrated antenna is significant.

4 Conclusion

It has been shown by numerical simulations that the *SAR* in the users head is not only related to the antenna concept used in the mobile, but also to the mobile configuration. Especially for GSM900 this is the most significant parameter. Therefore, in this frequency range it is not sufficient to focus on the antenna module to optimize of the user interaction. A promising approach that is based on the current distribution on the mobile is presented in [8].

5 References

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