Numerical Assessment of Specific Absorption Rate in the Human Body Caused by NFC Devices

S. Cecil, G. Schmid, K. Lamedschwandner
EMC&Optics
Seibersdorf Laboratories
2444 Seibersdorf, Austria
stefan.cecil@seibersdorf-laboratories.at

J. Morak[1], G. Schreier[1], A.Oberleitner[2], M. Bammer[2]
[1]Information Management and eHealth
[2]Biomedical Systems
Austrian Institute of Technology AIT
juergen.morak.fl@ait.ac.at andreas.oberleitner@ait.ac.at

Abstract*— The Near field communication technology (NFC) is applied for transferring data over short distances by maintaining an inductive coupling of the transmitter and the receiver at 13.56MHz. The relatively high magnetic field strength in the immediate surrounding of NFC devices give rise to the question about the local personal exposure of the user holding such a device in the hand or close to the body. In the present paper personal exposure in terms of the maximum 10g-averaged specific absorption rate (SAR) while using NFC was estimated for different scenarios using MRI-based anatomically correct body models. The simulations were performed with the method of Finite Differences in Time Domain (FDTD). The numerical models of the considered NFC devices were validated by SAR measurements using a simplified homogeneous body phantom and acceptable agreement between measurements and simulations was achieved. Several exposure scenarios with a cell phone comprising NFC functionality and a stationary NFC reader were investigated considering two different body models (male 34 years, male 14 years). The results showed maximum 10g-averaged SAR-values more than two orders of magnitude below the basic restriction recommended by the International Commission for Non Ionizing Radiation Protection (ICNIRP). The absolute maximum value of the maximum 10g-averaged SAR found in the considered scenarios was 11.18 mW/kg. Therefore, it can be concluded that personal exposure due to NFC devices typically cause SAR levels far below the basic restrictions of safety guidelines.

Keywords: Near field communication (NFC), Specific absorption rate (SAR), FDTD simulation

I. INTRODUCTION

Near Field Communication (NFC) can be expected to become one of the most utilized wireless standards for personal short range communications during the next years. For example, NFC is seen as the most promising technology for future mobile electronic payment and many other applications, as for example in the fields of retail support, health care, ambient assisted living and entertainment. In order to enable the end user to utilize NFC, the most efficient way will be to integrate the NFC technology into cell phones, similarly as it was done with the Bluetooth® technology in recent years. Actually there are a few NFC-compliant cell phone models on the market already, but the number of available NFC cell phone models can be expected to incline steeply in near future.

Along with the widespread use of a wireless technology, the issue of personal exposure against the electromagnetic fields emitted by this technology needs to be taken into account, and compliance with exposure limits is required to be demonstrated. A compliance determination for NFC could not be found in the literature. Investigations comparable with the numerous studies related to the compliance of mobile phones published in the past (e.g., [1],[2]) are still missing for NFC devices.

Based on their working principle of inductive coupling between transmitter and receiver, NFC devices produce relatively strong magnetic fields at a frequency of 13.56 MHz in their immediate surrounding. These strong and localized radio frequency (RF) magnetic fields cause the induction of RF currents inside body parts close to the NFC device (e.g., the hand holding the device during data transfer), which in turn leads to dissipation of electric power inside the tissue. In the working frequency range of NFC the relevant metric for localized exposure recommended by the International Commission of Non-Ionizing Radiation Protection (ICNIRP) is the Specific Absorption Rate (SAR) and the corresponding basic restrictions for the general public are defined as 2 W/kg for head and trunk and 4 W/kg for limbs, respectively. It is important to note that the given SAR values are understood as averaged over 10g of contiguous tissue and over any 6 minute time interval [3]. The rational behind the fact that local SAR limits are defined as average values over a certain tissue mass (10g according to [3]) is based on thermo-physiological considerations, because the elevation of tissue temperature due to RF exposure is currently seen as the biologically relevant interaction mechanism for frequencies > 10 MHz. Briefly speaking, due to efficient thermal equibrillation processes inside the tissue it is not possible to maintain significant temperature gradients inside a contiguous tissue volume of less or equal to 10g, even in case of a high SAR gradients.

In order to obtain estimates for the extent of personal exposure due to usage of NFC devices in practice, SAR measurements in simplified body phantoms with real devices as well as numerical computations using anatomically correct body models were carried out.

978-0-7695-3998-0/10 $26.00 © 2010 IEEE
DOI 10.1109/NFC.2010.14

II. METHODS

Two different NFC devices were considered. First, the Nokia 6212c cell phone with integrated NFC interface and second, the stationary NFC smart card reader device ACR 122 (Advanced Card Systems Ltd., Hong Kong). With these devices SAR measurements under worst case conditions using a simplified homogeneous body phantom were carried out and numerical computations for different NFC usage scenarios using anatomically correct body models were performed.

A. SAR Measurements

Standardized SAR measurement procedures have been established for compliance testing of mobile phones and similar equipment in the frequency range 300 MHz – 3 GHz used in close proximity to the ear during the last decade (IEC 62209-1, [4]). Recently, these procedures have been extended to more general wireless communication equipment operated close to the body in the frequency range 30 MHz – 6 GHz (IEC 62209-2, [5]). The principle of these SAR measurement procedures can be described in brief as follows: The device under test (DUT) is positioned below a simplified body phantom while keeping a typical or worst case distance between the DUT and the phantom. The phantom consists of a tub made of low loss material filled with tissue simulating liquid (TSL). The SAR-measurement setup is pictured in Figure 1. While the DUT is operated at its maximum output power the SAR induced by the DUT inside the TSL can be measured using special isotropic miniature probes. In order to obtain the spatial distribution of the SAR inside the TSL the probes are mounted to an automated probe positioning unit (e.g., a robot) which enables a spatial SAR scan inside the TSL. From the results of the SAR scan inside the TSL the maximum 10g-averaged SAR can be computed and compared with the basic restrictions. The whole procedure of the SAR measurements according to IEC 62209-1 and 62209-2 is intentionally designed in a way that the measurements lead to a conservative estimate of the maximum 10g-averaged SAR under real conditions, i.e., in the real (anatomically complex) body.

According to IEC 62209-2, for general devices not specifically operated close to the ear the shape of the body phantom is a simple tub with a flat bottom (thickness 2 mm) homogeneously filled with the TSL. In general, the dielectric properties of the TSL to be used are frequency dependent and the probe calibration factors strongly depend on the TSL's dielectric properties and frequency.

For the SAR measurements with the NFC devices (13.56 MHz) considered here, a TSL as specified in IEC 62209-2 for 30 MHz was used. This was considered acceptable because the dielectric properties of TSLs specified in IEC 62209-2 show relatively low frequency dependence in the frequency range 30 -100 MHz. An extrapolation of the TSL's dielectric properties down to 13.56 MHz shows less than 5% deviation from the values at 30 MHz.

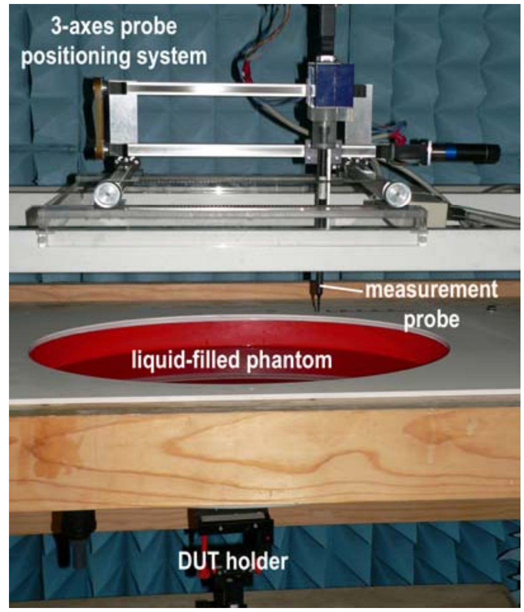

Fig. 1. SAR-measurement setup for determination of SAR in the tissue liquid phantom (TSL). The device under test (DUT) is positioned in touch with the phantom by the DUT holder

Finally, the specific calibration factors of our probe (ET3DV5, SPEAG, Zurich, Switzerland) for the used TSL (ε_r=55, σ=0.75 S/m) at 13.56 MHz were numerically obtained with the help of the probe's vendor and the total extended uncertainty (k=2) of the SAR measurement could be obtained to be less than ± 30%, as required by IEC 62209-2 [5] which has to be applied for SAR measurements of wireless equipment operated close to the body.

For the SAR measurements with the two considered NFC devices the worst case, i.e., the case of the devices touching the phantom bottom were considered. In case of the NFC cell phone both the situation with the front side as well as with the back side touching the phantom shell were investigated whereas in case of the NFC reader device, the DUT was touching the phantom shell with the top surface of the case.

B. Numerical Simulations

The numerical simulations were done with the 3D full wave simulation platform SEMCAD X (Schmid & Partner Engineering AG (SPEAG), Switzerland, www.semcad.com), based on the Finite Difference Time Domain (FDTD) method. The FDTD method, first proposed by Yee in 1966 [6], is a direct solution of Maxwell's curl equations in the time domain. The electric and magnetic field components are allocated in space on a staggered mesh of a Cartesian coordinate system (computational grid). The E- and H-field components are updated in a leap-frog scheme using the finite-difference form of the curl which surrounds the component.

For simulations of the electromagnetic fields in the human body an adequate model is needed. In our investigations two body models, based on MRI images of volunteers, were used.

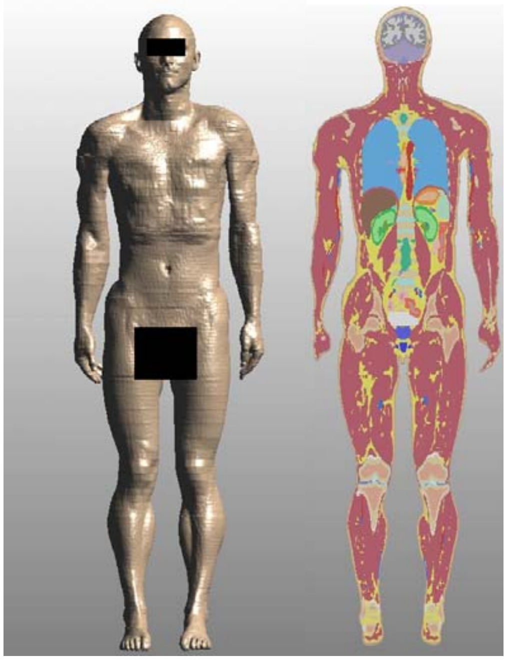

Fig. 2. Human body model "Duke" from the Virtual Family.

- Male body model "Duke" from the virtual family [7] (34 years adult with a weight of 70 kg and a height of 174 cm
- Male body model "Louis" [7] with posing function (14 years adolescent with 50 kg and 165 cm.)

The posing function of Louis is an algorithm allowing anatomically correct rotation of several body parts around the joints. With this function all thinkable human postures can be realized for the simulations.

Both heterogeneous models consist of approximately 85 different tissues. For the simulations all tissues were characterized by their corresponding dielectric properties at 13.56 MHz [8]. The spatial resolution of the computational grid in the investigated region of the body models was at least 1mm or better.

There were two different models of NFC devices applied in the simulations:

- Cell phone with NFC interface (NFC mobile)
- Stationary NFC device (NFC reader)

The NFC mobile has an integrated transmit and receive coil with some windings guided along the outer boundaries of the mobile's printed circuit board. For the simulations this antenna was simplified and represented by a single winding carrying a current that led to the same total magnetic field distribution as it was measured close to the real NFC mobile. The numerical model of the NFC mobile with the integrated antenna coil is depicted in Figure 3.

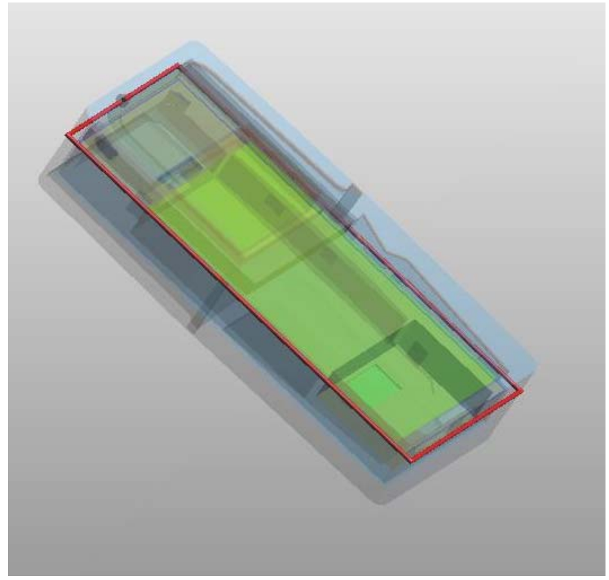

Fig. 3. Simulation model of the NFC mobile. The red highlighted wire is the NFC-coil integrated in the housing of the mobile

Similarly a simplified numerical model of the NFC reader was used for the simulations (see Figure 4).

III. Verification of the simulations

In order to validate the numerical models of the NFC devices and to determine the required feeding current of the numerical models to represent the real devices correctly, the SAR measurement scenarios were also investigated numerically (Figure 4). Based on the shape of the spatial SAR distribution inside the TSL the numerical models could be validated. As an example, Figure 5 shows the local SAR values along a straight line inside the TSL for both the SAR measurement and the numerical model of the NFC reader. As it can be seen from the figure, the numerical model well represents the real device (deviations less than approx. 10%). The required feeding current of the numerical models was obtained by comparison of the distribution of the local SAR values measured with the real devices and corresponding simulations with arbitrary but well defined feeding current.

This comparison resulted in feeding currents of 0.71 Ampere for the reader and 0.44 Ampere for the mobile.

With the obtained values of the feeding current the maximum 10g-averaged SAR of measurement and simulation can be compared (see Table I). The differences of the 10g-maximum-SAR values of measurement and simulation are in the expected range.

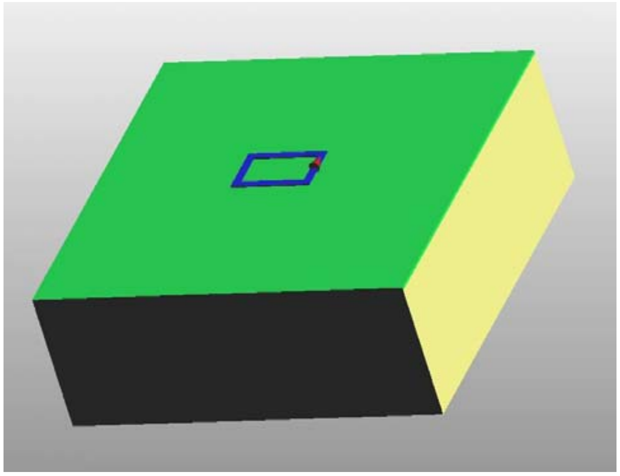

Fig. 4. Simulation model of the SAR measurement scenario with the NFC reader (without housing)

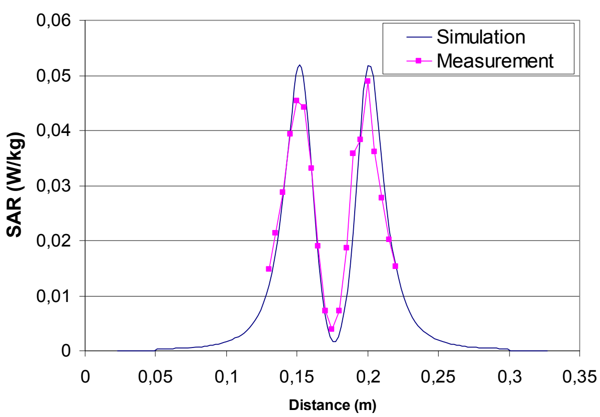

Fig. 5. Comparison of measurement and simulation results for verification

TABLE I
MAXIMUM 10G-AVERAGED SAR

	Measurement	Simulation
NFC mobile	2.5 mW/kg	2.7 mW/kg
NFC reader	41 mW/kg	33 mW/kg

Maximum 10g-averaged SAR caused by NFC mobile and NFC reader in the tissue simulating liquid (TSL) evaluated by measurement and numerical simulation

IV. INVESTOGATED SCENARIOS

To obtain evidence of the SAR distribution and the maximum localized SAR level caused by NFC devices in the human body in different situations four scenarios were simulated:

- NFC mobile in the hand of the model “Louis” while connecting to the NFC reader (Figure 6)

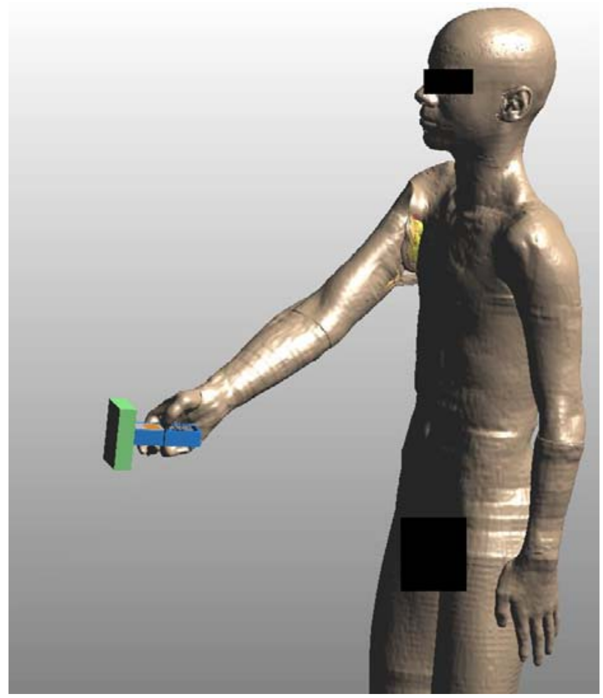

Fig. 6. Model “Louis” posed according to the scenario with NFC mobile in the hand connecting to the NFC reader.

- Activated NFC mobile on the ear of “Louis”. This scenario represents the situation when using the mobile phone while the NFC functionality is still active.
- NFC reader on the chest of “Duke” (Figure 7). Distance between antenna coil and body surface approximately 20 mm.
- NFC reader on the hip of “Duke” Distance between antenna coil and body surface approximately 5 mm.

The last two scenarios mentioned above might be seen as unrealistic, but they should represent worst case situations when unintentionally coming close to a NFC device.

V. RESULTS

From the performed simulations the SAR information was extracted. Figures 8 and 9 show the SAR distribution inside the exposed tissues for the scenario with the NFC reader in front of the chest and the situation with the NFC mobile in the user’s hand while connecting to stationary NFC device, respectively. For the comparison with the basic restrictions the maximum 10g- averaged SAR was extracted and is shown in Table 2 for all considered scenarios.

It has to be noted that all the SAR information given here correspond to a continuous field generation of the considered devices, i.e., a duty cycle of 1 was assumed. In reality the resulting (6 minute) time average of the SAR will therefore be typically significantly lower.

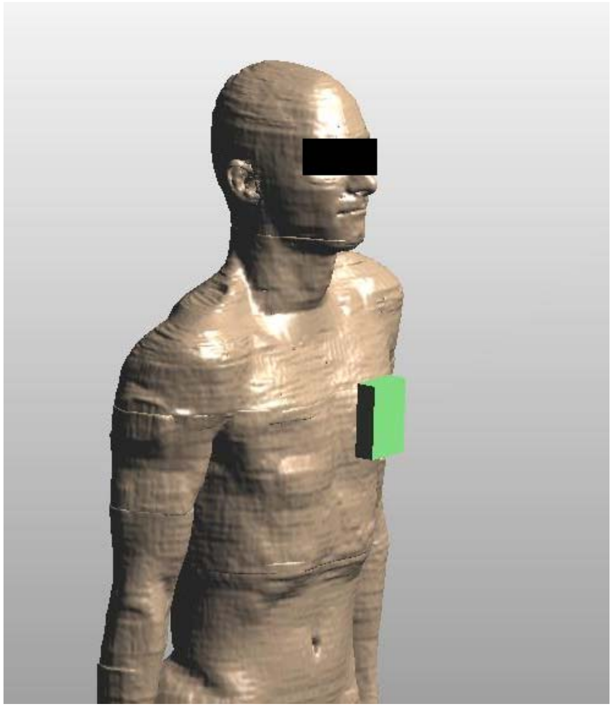

Fig. 7. Human model “Duke” with model of NFC reader on the chest

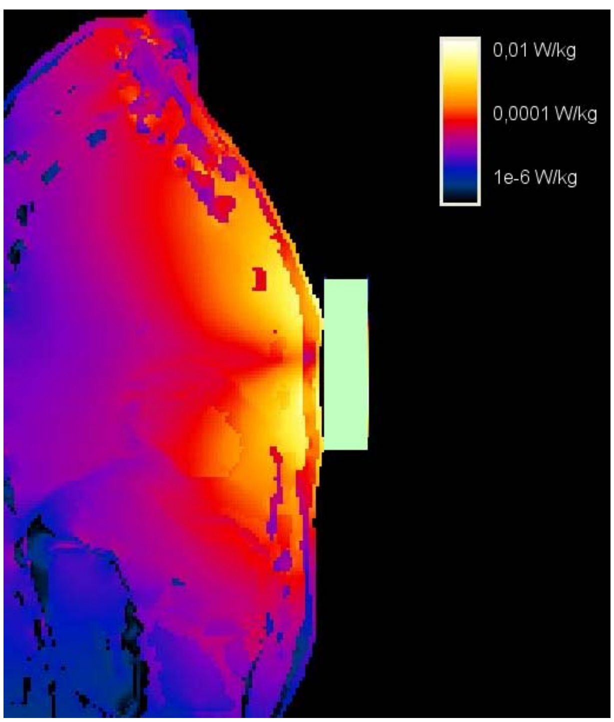

Fig. 8. SAR distribution in a cross section of the human model “Duke” with model of NFC reader on the chest

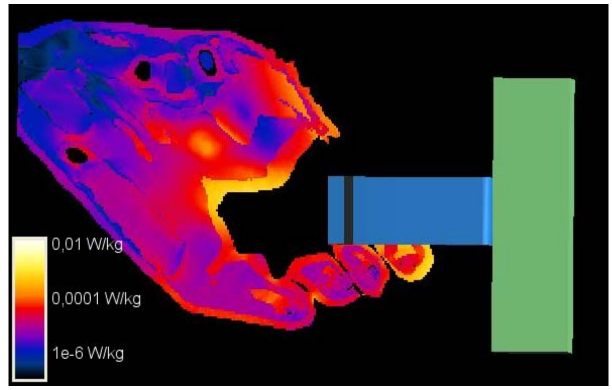

Fig. 9. SAR distribution in a cross section through the hand of model “Louis” caused by NFC mobile and reader

TABLE II
SIMULATED SAR IN SCENARIOS

Scenario	**10g-averaged SAR**
NFC mobile in hand near reader	6.52 mW/kg
NFC mobile on ear	0.26 mW/kg
NFC reader on chest	1.52 mW/kg
NFC reader on hip	11.18 mW/kg

Maximum 10g-averaged SAR caused by NFC mobile and NFC reader evaluated by numerical simulation

The NFC-reader positioned on chest and hip gives much higher SAR in the hip scenario. This difference is reasonable because of the higher distance of the reader´s current path from the body surface in the chest scenario (5 mm near hip compared to 20 mm near chest).

Table 3 summarizes the maximum 10g-averaged SAR values obtained during the SAR measurements with the real devices. A comparison of the SAR values in Tables II and III confirms the conservativity of the SAR measurement.

TABLE III
SAR MEASURED IN TISSUE SIMULATING LIQUID

NFC mobile with front side touching the phantom	2.5 mW/kg
NFC mobile with back side touching the phantom	0.65 mW/kg
NFC reader with top side touching the phantom	24.7 mW/kg

Maximum 10g-averaged SAR caused by NFC mobile (Nokia 6212c) and NFC reader (ACR 122) evaluated SAR measurements

VI. CONCLUSIONS

All obtained experimental and numerical results clearly showed that the maximum 10g-averaged SAR values caused by the considered NFC devices and exposure scenarios (including realistic worst case situations) were approximately at least 2 orders of magnitude below the basic restrictions according to the ICNIRP guidelines. Therefore, it can be concluded, that personal exposure by NFC devices can typically be neglected.

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