Final Report on the project C2006-07: "Evaluation of the correlation between RF dosimeter reading and real human exposure"

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Executive Summary

The selection of an adequate exposure assessment approach is imperative for the quality of epidemiological studies. In the past it turned out that exposimeter are a reasonable approach to determine exposure profiles, however certain limitations have to be considered. Apart from the limited dynamic range it is important to take into account that these devices give only an approximation of the exposure. It was therefore decided to investigate the relation between the field strength measured close to the human body at the location of the exposimeter and the exposure, i.e. the field strength at the location of the human body without the human body being present.

Two different scenarios were investigated by numerical means using the visible human model as phantom. For FM, GSM and UMTS an urban outdoor scenario was examined having the transmitting antenna mounted on the roof of one of four buildings of a street crossing. For WLAN an indoor scenario with the antenna located below a desk was investigated. For GSM the average degree of underestimation by the exposimeter (relation of the averaged field levels at the location of the exposimeter to the field level averaged over the volume of the human body not being present) was 0.76, for UMTS 0.87 and for FM no underestimation was found, the ratio was 1. , in the case of WLAN the degree of underestimation was more pronounced, the ratio was 0.64.

To verify the outcome of the numerical simulations, measurements with exposimeters were performed in an anechoic chamber. In general, two volunteers carried the exposimeters at field levels well below the reference levels of the general public given in the ICNIRP guidelines of 1998, the exposimeter readings were compared to the exposure assessed by frequency selective measurements. The arithmetic mean of several samples measured by the exposimeter was taken. Most pronounced deviations were found in the UMTS and WLAN band, i.e. 0.33 and 0.29, respectively. For FM and the GSM band the deviations were lower: 0.69 and 0.65. Again, a general trend of underestimation of exposure was observed. The degree of underestimation becomes even more pronounced when looking at samples instead of arithmetic mean of samples: For GSM the normalised mean value was 0.44, for FM 0.55, for UMTS 0.14 and for WLAN 0.17. If all samples are taken together the degree of underestimation was 0.3. These results do not necessarily mean that an exposure assessment with exposimeters leads to an underestimation of the exposure. A multivariable regression model of the Antennessa measurements shows for instance if a person might be exposed dorsal to the incoming field having the exposimeter mounted on the back being exposed in the GSM 900 band at a distance of 3m from the transmitting antenna with reflectors in the room, then the exposimeter would overestimate the field by a factor of 1.43, i.e.143% of the real exposure. However, most combinations of the variables lead to an underestimation of the exposure when using the exposimeter.

Taken all results together the question arises what correction factor has to be applied when using the exposimeter. We suggest using the most conservative correction factors to avoid underestimation of the exposure. This implies that for GSM 900 downlink and FM signals a correction factor of 1.9 can be applied. For UMTS downlink signals a correction factor of 9 can be recommended, the data on WLAN are too limited to give recommendations. The real exposure is in most of the examined cases underestimated by exposimeters.

Some recommendations for the use of exposimeters can be given: the exposimeters have to be calibrated in regular intervals; realistic signals instead of CW signals shall be used for calibrations. A correction factor for the impact of the human body shall be applied. It is necessary to distinguish between periods when the exposimeter is carried on the body and periods when the exposimeter is placed nearby the body of the user.

Generalities

This Final Report is subdivided in four sections: the first section gives an overview on existing literature on RF exposimeters.

The second section deals with the validation of numerical approaches by measurements. In addition to the validation of the numerical approaches comparisons between field levels averaged over a volume corresponding to the human body and exposimeters readings of devices worn on the human body were performed under controlled conditions in an anechoic chamber. The investigations were performed at frequencies from the FM, GSM, UMTS and WLAN bands.

The third section presents the results of numerical simulations dedicated to investigate the correlation between dosimeter reading and human exposure again for the FM, GSM, UMTS and WLAN bands.

Finally the fourth section includes a discussion and analysis of the previous sections and uncertainty estimation for the use of the investigated exposimeters and recommendations for the use of such devices.

Contents

1. Introduction

A few approaches were made in the last years to develop ‘exposimeters’, devices suitable to record the individual RF exposure of the general population. Two different concepts for separation of the exposure contributions from technical relevant RF bands, e.g. GSM 900 and UMTS were brought up in Germany and France. The reliability of these devices was investigated in first pilot studies. It was demonstrated that the devices are suited for individual exposure assessment, however also some shortcomings were observed. Examples are false summation of signals within the same band, out of band responses and high calibration factors in a few frequency bands. No profound investigation on the relation between real exposure and exposimeter reading was found in literature. In addition to the investigations mentioned above some other studies investigated workers exposure or exposure level on outdoor ground level, but the concepts are not suitable to assess individual exposure of the general population. New concepts of textile antennas and arrays of body worn receivers were shown; such approaches might be promising for the future, but are so far not advanced enough to be used in epidemiological studies.

A representative outdoor scenario for the exposure within an urban area was selected and the relation between the field level assessed by the exposimeter and the “real” exposure was investigated by means of numerical simulations. Investigations are performed for an antenna mounted on a roof for FM, GSM 900 and UMTS. For WLAN an indoor scenario was investigated. To validate the results measurements in anechoic chamber were performed in addition. Volunteers exposed well below the limits of the ICNIRP guidelines for the general public of 1998 carried exposimeters on the back, hip and the upper arms. Exposimeter readings were compared with the field levels averaged over the volume of the human body.

Based on these results recommendations for the use of exposimeters were derived.

2. Overview on existing literature on RF exposimeters

The literature search for this project was done in the databases of the IEEE, WHO, and the proceedings of the BEMS 2004 and 2006, the BIOEM 2005 and URSI 2005 conferences as well as using internet search machines such as Google. The main key words we have been looking at were 'dosimeter', 'dosimetry', 'personal dosimetry' and 'dosimeter', 'exposimetry', 'exposimeter', 'personal exposure meter' and 'bodyworn measurement system'. Keywords like 'RF monitoring', 'RF measurement system', 'individual (RF) exposure' and 'exposure assessment' have also been used. Moreover the journal of Bioelectromagnetics was investigated and international experts have been contacted.

Neubauer et al 2006 identified the use of RF exposimeters as one of the best approaches to learn about the populations RF exposure, some examples of available systems are shown in Neubauer et al 2005. This chapter analyses mainly the results of scientific publications and presentations that became available since the finalisation of the analysis given in Neubauer et al 2005.

Designing reliable RF exposimeters is a very challenging task. One of the major problems is the fact that the body of the user is disturbing the reading of an exposimeter, one of the major questions is how to handle this problem. In that context Liesenkötter and Eder 2005 discussed the receiver characteristics of exposimeters. They question the approach to search for the maximum field strength without the presence of the human body, arguing that in case of the presence of the body, it will absorb the relevant components of the incoming radiation. Only bodies with dimensions being small compared to the incoming wave length will have SAR values that can be derived from the field strengths at the position of the human body not present. They conclude that exposure has to be assessed close to the surface of the human body using non – isotropic exposimeters because, according to the authors opinion, in case of the use of isotropic probes at least one of the antennas will systematically underestimate certain field components, i.e. the field components being parallel to the human body. They point to the need to investigate the dependency of the receiving properties of the exposimeter on the polarisation of the incoming field, i.e. the angle between the field vector and the antenna axes. According to the authors it is required to get reliable estimates of exposure (averaged field levels) that persons carrying exposimeters move sufficiently in the heterogeneous field.

Radon et al 2006 investigated the practical use of two frequency selectives exposimeters, namely a Maschek dosimeter prototype and the Antennessa DSP-090 system. They performed 24 hours exposure assessments with 42 children, 57 adolescents and 64 adults using the Maschek dosimeter prototype. In addition a validation study with 40 subjects was carried out comparing the self reported exposure to mobile phone frequencies to the exposimeter readings. Readings of the Maschek device and the Antennessa device were compared for 40 subjects. No association between self reported exposure and exposimeter readings was found. The measurements with the two exposimeters in parallel were performed using different sampling rates, i.e. measurements every second using the Maschek exposimeter and every 13 seconds in case of the Antennessa exposimeter. The Maschek exposimeter was placed on the participant's right upper arm for 24 hours, the antennessa exposimeter was placed at the waistband using the belt clip in case of adults and adolescents, in case of children it was placed in the backpacks of children. According to a personal communication with the first author the exposimeters were placed on the bedside table during sleeptime. For each subject and exposimeter the percentage of the 24 hour measurements above a level of 0.1 V/m was assessed. Spearman rank correlation was used to investigate comparability of the exposimeter readings. The correlation coefficient for the relative frequency of exposure above 0.1 V/m was 0.35 ($p = 0.03$). Many effects may contribute to the differences in the exposimeter readings, e.g. the different position of the exposimeters on the body of the subjects. In another German study the adequacy of the use of the Maschek exposimeters (ESM 140) was investigated (Spegel et al 2006). A cross sectional population based pilot

study on acute health effects was performed, 24 hours exposure profiles from each study participant were recorded. Measurements were performed in one second intervals. The study population consisted of 100 children and 150 adults in Munich. During daytime the exposimeter were worn on the right upper arm, at night they were positioned on the bedside table. Exposure was never above 0.9 V/m, exposure levels above 0.1 V/m were between 0.1 to 96.5 % of the 24 hour period, depending on the study participant. The median exposure time above 0.1 V/m was 4.1 % for all study participants. GSM 900 exposure was dominant compared to WLAN and GSM 1800 exposure. The authors state that there was a tendency towards a higher degree of participation of people having mobile phones and living near to base stations to participate in the study, the average exposure of the whole population could therefore be somewhat lower. Exposimeters were generally accepted by the study participants.
The ESM 140 exposimeter from Maschek is a device capable to measure signals in the GSM 900, GSM 1800, UMTS, DECT and WLAN frequency bands. The device does not distinguish between uplink and downlink signals. It has a weight of 70g and a dynamic range from 0.01 to 5 V/m. It is capable to operate for 6 days without interruption. Eight signal channels are always measured in parallel and the readings are stored in a memory with space for 130.000 records each (Maschek 2007).

The applicability of the French exposimeter manufactured by Antennessa was examined in several European countries, i.e. France, UK, Austria, Switzerland and Hungary.
Gati et al 2005 presented the exposimeter EME SPY 120 (the next generation of the Antennessa DSP 090 system). It is a frequency selective, isotropic personal exposimeter able to distinguish between the exposure contributions within 12 different bands given in Table 1- 1 according to the manufacturers specifications (see also Wiart et al 2005).

Frequency band	Axial isotropy
FM: 88 – 108 MHz	+/- 0.3 dB
TV 3: 174 - 223 MHz	+/- 2.5 dB
TETRA: 380 – 400 MHz	+/- 1.1 dB
TV 4 & 5: 470 - 830 MHz	+/- 1.1 dB
GSM Tx: 880 – 915 MHz	+/- 0.8 dB
GSM Rx: 925 – 960 MHz	+/- 1.0 dB
DCS Tx: 1710 – 1785 MHz	+/- 2.0 dB
DCS Rx: 1805 – 1180 MHz	+/- 1.6 dB
DECT: 1880 – 1900 MHz	+/- 1.3 dB
UMTS Tx: 1920 – 1980 MHz	+/- 1.4 dB
UMTS Rx: 2110 – 2170 MHz	+/- 1.8 dB
WIFI (WLAN): 2400 – 2500 MHz	+/- 3.2 dB

Table 1- 1: Specifications of the EME SPY 120 exposimeter according to the manufacturer's homepage (Antennessa 2007)

The system offers the opportunity to sample at rates from 4 up to 255 seconds, the battery used allows for continuous measurements of more then 7 days and approximately 7000 samples can be registered in one measurement period. The lower detection limit is 0.05 V/m, the dynamic range is 40 dB. Investigations performed by Wiart et al 2006 demonstrated that exposure was 70 % of the time below 0.05 V/m, events above 1 V/m are rare. Röösli et al 2008 proposed statistical methods to deal with personal exposure data with a large proportion of measurements below the detection limit.
An extensive report on the use of the exposimeter DSP 090 (predecessor of the EME SPY 120 exposimeter) was written by Mann et al 2005. The report describes laboratory testing and volunteer trials. The laboratory tests demonstrated that the performance of the exposimeter was mostly in line with the requirements for the reliable assessment of individual exposure. However, several limitations need to be taken into account. One of the finding was that the exposimeter does not properly sum multiple signals within the same band and there appears to be a battery charging reliability problem. It is also

mentioned that the lower detection limit of 0.05 V/m is a limiting factor for the establishment of an exposure gradient in the population under investigation, however the exposimeter is well suited to discriminate the exposure of people living next to base stations or television broadcast transmitters from those of people living elsewhere.
Response to modulated signals was investigated by the authors, an overview of the results is given in Table 1- 2 showing the largest deviations within the TV, DCS 1800 downlink and UMTS downlink bands.

Band	Response dB	Signal frequency and modulation
FM	- 1.8 ± 0.5	98 MHz FM ± 75 kHz deviation
TV3	- 0.4 ± 0.5	220 MHz pseudo DAB
TV4 & 5	+ 5.4 ± 0.4	591.25 MHz Analogue PAL TV
TV4 & 5	+1.2 ± 0,5	602 MHz pseudo DVB
GSMtx	+ 1.0 ± 1.0	895.5 MHz GSM uplink 1 slot active
GSMrx	- 0.7 ± 0.4	947.5 MHz GSM downlink 8 slots active
DCStx	+ 0.2 ± 0.6	1747.5 MHz GSM uplink 1 slot active
DCSrx	-3.0 ± 0.2	1842.5 MHz GSM downlink 8 slots active
UMTStx	+ 0.4 ± 0.1	1950 MHz 3G TDMA uplink
UMTSrx	-5.7 ± 0.9	2140 MHz TDMA downlink

Table 1- 2: Response of the exposimeter DSP 090 using modulated signals for calibration (Mann et al 2005)

Comparisons between frequency selective measurements using isotropic antennas, spectrum analysers and tripods with exposimeter measurements were performed for 80 exposure conditions by Mann et al 2005. Only in 15 cases field strengths were high enough to allow comparisons. Results demonstrated that the exposimeter seems to underestimate TV signals. Similar effects were observed in the GSM and DCS downlinkbands. The authors suppose that these effects arise due to wrong accumulation of several signals in the same band. Signals in different bands showed no significant difference between single band exposure with the exception of interactions between TV4&5 band and GSM downlink band. Several investigations on the electromagnetic immunity were performed. The exposimeter was immune against 50 Hz 5 kV/m electric fields and 100 µT magnetic fields. No response from TV receivers and PC monitors was found. An out of band response in the FM band was found arising from a 27.12 MHz field.

Lehmann et al 2006 investigated the performance of both the DSP120 and the ESM 140 in the GSM 900 and UMTS downlink bands under controlled conditions in an anechoic chamber and in a corridor next to the anechoic chamber to take into account heterogeneous exposure conditions. The read out of the exposimeters was compared to the field levels measured with a reference probe, i.e. an EMR 300 from Narda. The investigations were performed without the presence of a phantom or the human body, by using a cylindrical phantom filled with salt water and also with volunteers. It needs to be mentioned that the ESM 140 was mounted in a height of 140 cm above ground corresponding to a position on the upper arm whereas the DSP120 was mounted on a position on the hip in a height of 100 cm. For the measurements without phantom and volunteer the results demonstrate that the DSP120 performs isotropic measurements being well in line with the reading of the reference probe at GSM 900 frequencies. Exposure is underestimated by the DSP120 for UMTS signals. As expected the ESM140 shows a strong dependency on the orientation of the device towards the incoming field. This can be explained by the fact that the system uses only one dipole showing therefore anisotropic behaviour. Using the body phantom both devices tend to underestimate the field levels both in the GSM and UMTS band in most positions due to the influence of the human body. In the reflective environment measurements were performed both on the phantom and the volunteer's body. Important differences between the results obtained on the phantom and those obtained on the human were observed. The field levels measured on the human body were considerable smaller compared to those measured using the phantom. Averaged normalised values were reduced from 1.22 (phantom) to 0.71 (human) in case

of the DSP120 and from 0.71 to 0.64 in case of the ESM 140 at the examined frequency in the GSM band.
In addition, Lehmann and colleagues performed comparisons between model calculations using both the free field line of sight model and the empirical COST – Walfish – Ikegami (CWI) model. The test person equipped with the DSP120 had also a GPS receiver to make comparisons between calculations and measurements possible. It was shown that the COST – Walfish – Ikegami model shows lower field levels compared to the measured one's and that the free field line of sight model gives higher values. The authors conclude that this might be an indication that the free field line of sight model might be better suited to estimate exposure compared to the CWI model.

Isselmou et al 2006 presented a new approach to map RF exposure similar to numerical methods used for weather forecasting. In the first step the electromagnetic field distribution is estimated using numerical tools taking into account antenna positions and the impact of buildings. This gives a rough estimate of the field distributions. The next step is to combine these data with data obtained by measurements in the same area, e.g. obtained with an exposimeter (in this case not used close to the human body). The combination of these data is performed using the so called geostatistical method "kriging". Based on the mathematical combination of these two sets of data estimated exposure values can be determined for the whole area of investigation.

The applicability of the exposimeter DSP 090 for individual RF exposure assessment was also investigated by Thuroczy et al 2006. 21 participants were involved in the study taking place in the city of Budapest, exposure was recorded for 24 hours for each individual. The exposimeter was mounted on the body and/or carried in a bag. Duration of exposure, field intensity (maximum, arithmetic mean), standard deviation and time weighted average were determined. One third of the participants were exposed above the detection level of 0.05 V/m between 40 and 70 % of the assessment period, half of them spent less than 10 % of the assessment time above the threshold. Highest exposure was found while travelling, lowest exposure was found while sleeping in the bed.
Neubauer et al 2006b performed similar investigations in Vienna and its surroundings using the same type of exposimeter. The evaluations focused on mobile communications downlink signals. Highest exposure was found in the underground stations, mean values were somewhat higher for GSM 1800 stations compared to GSM 900 base stations (1.05 V/m versus 0.51 V/m). Mean exposure due to UMTS base stations was slightly above the lower detection limit. In several cases the upper detection limit was reached, additional measurements using broadband meters showed values slightly above 20 V/m, but it cannot be ruled out that uplink signals contributed to this overall exposure. Average exposure during underground rides, in cinema and shopping centres and during urban strolls (inner city) was between 0.18 and 0.34 V/m, depending on the scenario and the frequency range. Indoor exposure was in most cases lower than outdoor exposure and often below the detection level. An example is given in Figure 1- 1 for GSM 900 signals, the bars indicate the mean value of all scenario whereas the lines on the bars shows the scatter of the measurements for the specific scenarios.

In the Qualifex study in Switzerland the follow up device of the DSP 090 (EME SPY 120) was used to collect 198 weekly personal exposure measurements from 166 study participants (Frei et al 2007). These measurements will be combined with diary data to evaluate the most important exposure relevant behaviours. In a preliminary analyses from 109 study participants weekly mean exposure was between 0.08 and 0.58 V/m. Average exposure of the sample was 0.24 V/m. Largest exposure contributions were from mobile phone handsets, mobile phone base stations and DECT cordless phones (Röösli et al. 2008).

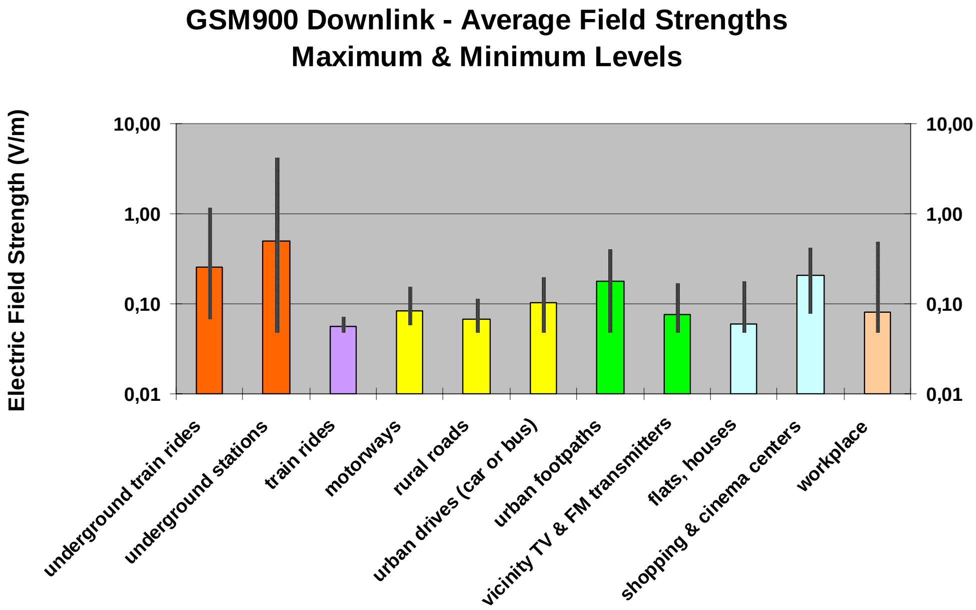

Figure 1- 1: Averaged GSM 900 downlink signals measured using exposimeters (Neubauer et al 2006b)

Additional investigations were performed by Knafl et al 2007. The authors performed investigations in an anechoic chamber demonstrating that the exposimeter ESM 140 from Maschek shows an important inherent anisotropy when not being carried on the human body. This result is not unexpected, because the exposimeter uses only one dipole. Moreover, if the dipole is orientated orthogonally to the incident field considerable underestimation of the real field levels might occur. In addition, the authors also observed problems with isolation and sensitivity when using the ESM 140 and also the EME SPY 120. The authors point out that the presence of the human body can induce important changes of the field distribution. Finally they recommend performing profound analysis of measurement data together with exposure simulations.

De Seze et al 2007 found that 95 % of all measured field levels were below the detection limit of 0.05 V/m when using the EME SPY 120 as exposimeter. Results were obtained in the frame of an ongoing French study. They discuss the shape of the distribution of the field levels. Based on preliminary data the authors conclude that the distribution can be approximated by a LogNormal distribution.

Occupational RF exposure was assessed by Cooper et al 2004 using personal monitors combined with data loggers. Data loggers were developed in the frame of the project, the exposimeter were RadMan devices (Wandel & Goltermann ESM 20). Both electric and magnetic field strengths were assessed for periods of about 170 minutes (first generation of data logger), the sampling rate was about 2.8 seconds for the first generation of data logger and 0.6 seconds for the second generation, 8 hours of storage time could be achieved. The device performs isotropically electric and magnetic field measurements in parallel, indicating the percentage of the reference level reached. The upper detection limit of the exposimeters corresponds to 126 % of the occupational reference level. The purpose of the study was to investigate the feasibility of an epidemiological study, not compliance assessment. Data loggers were built into a plastic case with dimensions of 3 x 8 x 16 cm, the weight was 265 gram. The logger was placed into the pocket of employees outer clothing, the connection between the exposimeter and the datalogger was established via a fibre optic cable. A push button on the data logger allowed marking events. Personal exposure was collected in a wide range of RF environments including broadcast sites operating in the VHF and UHF bands, telecommunication sites, AM transmitting stations, a radar facility and a satellite earth station. Data were obtained from workers performing a broad range of tasks dedicated to be representative for daily activities. The exposimeter was typically worn in the breast pocket or clipped to the subject's climbing harness. Activities were usually recorded in a diary. Results showed considerable differences in the exposure of the workers in the various environments. Good correlations between measured electric and magnetic fields were generally found. A total number of 147 persons recorded their exposure, however in 23 cases records were found to be incomplete. From the remaining 124 records 17 were obtained from workers being occupied outdoor on the ground, 31 from persons remaining indoor and 76 from workers operating on masts. The background exposure level was found to correspond to about 20 to 25 % of ICNIRP levels. High power transmitters were defined as sites having an output power above 1 kW per channel, medium power sites were transmitter with an output power between 10 W and 1 kW per channel and low power sites were installations with an output power below 10 W per channel. An example of an electric field strength recorded for an engineer operating on a high power VHF/UHF mast is shown in Figure 1- 2.

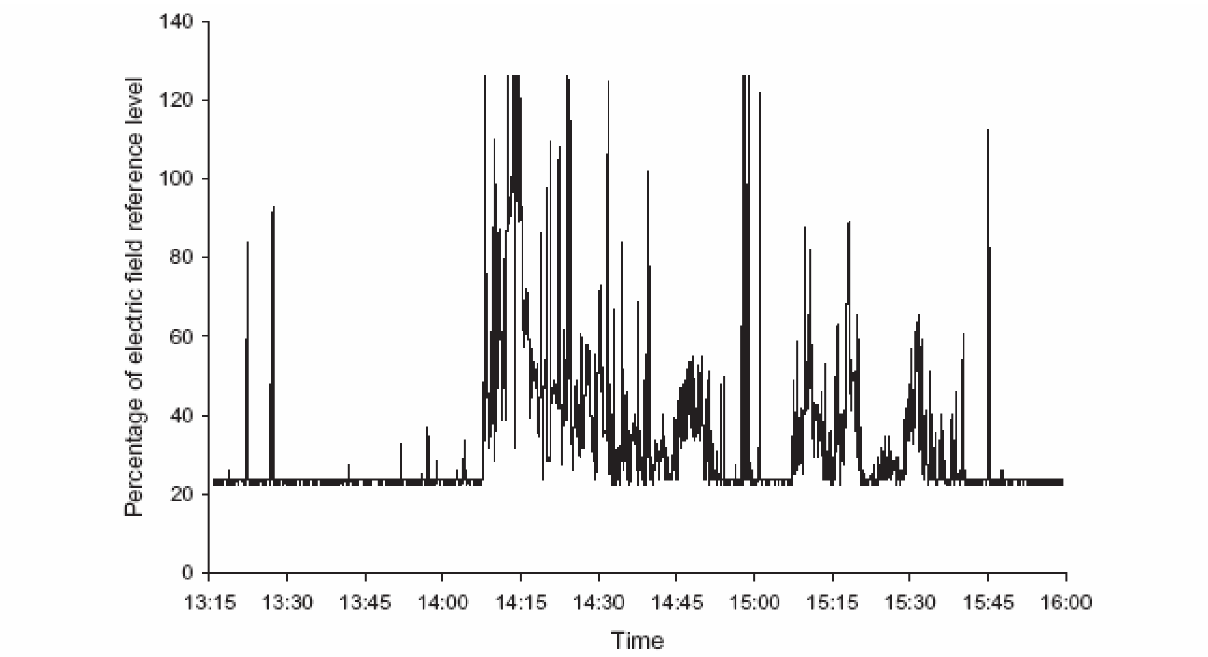

Figure 1- 2: Electric field strength recorded for an engineer operating on a mast supporting antennas for high-power VHF/UHF broadcast during his occupation (Cooper et al 2004)

Wide variations of both electric and magnetic field strengths were found, highest instantaneous exposure was usually recorded when subjects were in close proximity to antennas. Exposure at low power broadcast and telecommunication sites, at ground level at VHF/UHF sites and inside buildings did usually not exceed detection limits. The authors conclude that due to the good correlation between recorded electric and magnetic field levels it is probably not necessary to measure both quantities. Measures of average exposure such as arithmetic, geometric mean and rms correlated well with each other. The authors conclude that exposimeters are a convenient mean for exposure assessment and might be suited for future epidemiological studies. Limitations are the narrow dynamic range and the unreliability of the fibre optic connection between the data logger and the exposimeter.

Gajda et al 2004 presented a RF field mapping system for the measurement of cellular mobile phone and base station signals. The system can be mounted on cars and consists of two antennas suitable to measure the emissions in the frequency bands 824 to 894 MHz and 1850 to 1975 MHz. The signals of two receivers are multiplexed and transferred to a computer, the sum of the exposure is obtained for both bands. This data are combined with the information from a GPS receiver to allow allocating exposure data with information of the location. Traces of outdoor exposure can be assessed using cars, however the system is not suitable to assess individual exposure (see also Health Canada 2007).

Software modified GSM mobile phones (SMP) were used by Erdreich et al 2005 to investigate which factors have impact on the handset power control (PWC), a major factor relevant for exposure of individuals (see also Shum et al 2004 and Kelsh et al 2004). Data from SMPs used by individuals in an occupational population who are normally issued cell phones for work purposes and activity logbooks were used to search for the above mentioned factors. Data were gathered on call time, date, duration and power control by SMP's. Subjects used the SMPs for a period of five days. The used SMPs are able to store data for 3 hours of talk time collecting power output data every 2.5 seconds. Information on individual conditions as urban/suburban, indoor/outdoor, weather conditions and use of hand free kits were collected by the mean of a logbook. The most important predictors of power output were study area and movement. The output power was higher for indoor exposure and for rural exposure compared to urban conditions. SMP are not suitable to give information on global individual RF exposure, however the combined use of multi band exposimeters and SMPs might be an approach to investigate the contribution of the own mobile phone to the global exposure in the uplink bands including also the exposure contributions from the mobile phones of bystanders.

Klemm and Tröster 2006 presented UWB textile antennas designed for Wireless Body Area Network (WBAN) applications. Such antennas can be integrated into clothing due to small thickness (0.5 mm) and their flexibility. It has been demonstrated by the authors that such antennas are well suited for transmissions on the human body in the UWB frequency range. A combination of such antennas integrated in special clothing's might also offer the opportunity to simultaneously monitor exposure in other frequency ranges and might be a basis for future exposimetric concepts. To describe channel properties at indoor conditions Cotton and Scanlon 2006 used a bodyworn measurement system consisting of a fixed transmitter and an array of six bodyworn self-contained data logging 868 MHz receivers (see Fig. 1-3). Each of the receivers was included in a wearable array and included a helical antenna mounted on a 25.4 mm ground plane. Such systems might be used to monitor personal exposure continuously, a disadvantage of existing systems is the small bandwidth.

Figure 1- 3: Bodyworn receivers (Cotton and Scanlon 2006)

Iskra et 2007 investigated the opportunity to determine the whole body SAR by an array of both loop and dipole sensors on the trunk. The investigations were performed at 100 and 900 MHz by numerical simulations. They found that the output from the sensors must be corrected by a weighting function to convert the results to a whole body SAR estimate.

3. Validation of numerical approaches by measurements

3.1. Test Set Up

This section gives an overview on the measurement protocol of work package 2. The purpose of workpackage 2 is to validate numerical approaches shown in the next chapter by measurements. It was therefore decided to measure locally field distributions for the four investigated frequency bands (GSM, UMTS, WLAN and FM) under controlled conditions, i.e. in an anechoic chamber. Both homogeneous and heterogeneous field conditions were examined, reflectors are used to generate multipath propagation conditions. The measured field levels are used to validate numerical simulations. Finally, persons with exposimeters are placed in the anechoic chamber and the reading of the exposimeter on the body is compared to the calculated and measured field levels.

Two volunteers, differing significantly in morphology and anatomy were used for the investigations with humans for four different frequency bands. Additional investigations only at GSM have been done with nine other volunteers. The persons with mounted exposimeter were rotating in 30° steps around their sagittal body centre axis.

Measurements were performed using real GSM, UMTS, FM (UKW) and WLAN signals.

3.1.1. Used Personal RF Exposimeters (PEM)

In Table 3- 1 the used Personal RF Exposimeters are shortly described with their main characteristics.

	Maschek	Antennessa
Type	ESM 140	EME SPY 120
Serial Number	10146	DE_002_5105
Number of probe axis	1	3
Measurement Range	0.01 V/m – 5 V/m	0.05 V/m – 5 V/m
Resolution	10 mV/m	not specified
Recording period	min. 0.5 sec – max. 10 sec	min. 4 sec – max. 255 sec
Dimensions [mm]	106 x 47 x 28	193 x 95.6 x 69.4
Weight with batteries	76 g	450 g

Table 3- 1: Description of main characteristics

Table 3- 2 gives an overview of the working frequency bands and axial isotropy information for the 3 axis exposimeter.

	Maschek ESM 140	Antennessa EME SPY 120	
Frequency Band	Ability *	Frequency Range [MHz]	Axial Isotropy [dB]
FM (UKW)	No	88 – 108	± 0.3
TV 3	No	147 – 223	± 2.5
Tetra	No	380 – 400	± 1.1
TV 4&5	No	470 – 830	± 1.1
GSM Uplink	Yes	880 – 915	± 0.8
GSM Downlink	Yes	925 – 960	± 1.0
DCS Uplink	Yes	1710 – 1785	± 2.0
DCS Downlink	Yes	1805 – 1880	± 1.6
DECT	Yes	1880 – 1900	± 1.3
UMTS Uplink	Yes	1920 – 1980	± 1.4
UMTS Downlink	Yes	2110 – 2170	± 1.8
WIFI / WLAN	Yes	2400 – 2500	± 3.2

* Frequency Range is not specified by the manufacturer; no axial isotropy due to 1 axis measurement system

Table 3- 2: Frequency Band and axial istotropy information of the used PEMs

3.1.2. Investigated Frequency Bands (Used Frequencies for Test Set Up)

In Table 3- 3 the used test frequencies and the signal information are described.

Frequency Band	Test Frequency	Additional information	Remarks
FM	100 MHz	Frequency deviation = 20 kHz Signal frequency = 400 Hz, Sine wave	ESM 140 not specified for FM/UKW
GSM	946 MHz	Channel 55, only BCCH	Downlink
UMTS	2140 MHz	Channel 10700, only P-CPICH	Downlink
WLAN	2462 MHz	Channel 11, Standard IEEE 802.11g Modulation = DQPSK transmission technique = OFDM	WLAN was set to continuous signalling

Table 3- 3:Frequencies used for investigations

In Table 3- 4 the used settings for the spectrum analyser are given.

Frequency Band	Frequency start/stop	Spectrum Analyser settings
FM	97.5 – 102.5 MHz	RBW = 120 kHz, VBW = 300 kHz, Sweeptime = 8 ms, Detector = Peak
GSM	943.5 – 948.5 MHz	RBW = 300 kHz, VBW = 1 MHz, Sweeptime = 6 ms, Detector = Peak
UMTS	2100 – 2200 MHz	RBW = 5 MHz, VBW = 3 MHz, Sweeptime = 100 ms, Detector = RMS
WLAN	2437 – 2487 MHz	RBW = 300 kHz, VBW = 1 MHz, Sweeptime = 100 ms, Detector = RMS, Average = 50 times, Band Power Method

Table 3- 4: Spectrum analyser settings used

3.1.3. Set Up of the Exposimeters and the Field Strength Measurements

The field strengths measurements were performed using the Add3D method. Therefore a precision conical dipole antenna has been rotated in all 3 orthogonal directions to determine the electric field on each position. For one "body position" six single 3 axis measurements on different positions have been done to perform spatial averaging, see also Equation 3- 1 for the calculation of the spatial averaging method and Figure 3- 1 and Table 3- 5 for the set up.

$$E = \sqrt{\frac{\sum_{i=1}^{6} E_i^2}{6}}$$

Equation 3- 1: Calculation of spatial averaging

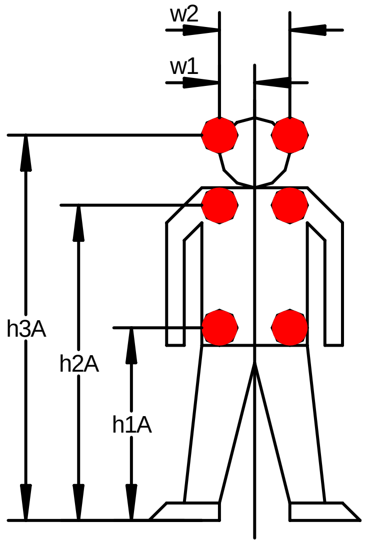

Figure 3- 1: Add3D positions for spatial averaging

	Add3D
Height h1A	110 cm
Height h2A	150 cm
Height h3A	170 cm
Width w1A	20 cm
Width w2A	40 cm

Table 3- 5: Height information for spatial averaging

The field strengths measurements and partially the PEM measurements have been done in three different distances to the transmit antenna:

- Position P1 = 2.0 m
- Position P2 = 2.5 m
- Position P3 = 3.0 m

The exposimeter measurements have been done in general with two volunteers, in case of the GSM 900 downlink band with eleven volunteers. Three different positions in the anechoic chamber were investigated (see Figure 3-2). The exposimeters were mounted at three different locations on the body, leading to different individual heights for each volunteer, as shown Table 3- 6.

	Position on body	Exposimeter used
Height h1	approx. height of hips	EME SPY 120 (Antennessa)
Height h2	approx. height of upper arm	ESM 140 (Maschek)
Height h3	approx. height of scapula (back)	EME SPY 120 (Antennessa)

Table 3- 6: Overview of the positions of the exposimeters

Height of hips, upper arm and scapula depends on the morphological parameters of each volunteer. In Table 3- 7 all the parameters of all volunteers are listed according to gender, age, weight, height, body mass index and the dimensions while wearing the exposimeter for the investigations (see Figure 3- 2 and Figure 3- 3 for details).

	Male / Female	Age	Weight	Height	h 1	h 2	h 3	l 1	l 2	BMI
		[years]	[kg]	[cm]	[cm]	[cm]	[cm]	[cm]	[cm]	
Volunteer A	F	16	46	160	75	109	121	25	23	17,97
Volunteer B	M	31	97	183	135	125	88	26	33	28,97
Volunteer C	F	27	49	158	80	109	-	24	24	19,63
Volunteer D	M	27	69	170	83	119	-	25	27	23,88
Volunteer E	F	30	63	164	81	111	-	24	24	23,42
Volunteer F	M	44	82	181	92	124	-	24	29	25,03
Volunteer G	M	21	82	186	89	126	-	27	27	23,7
Volunteer H	M	26	70	180	95	126	-	24	26	21,61
Volunteer I	F	23	51	167	90	120	-	24	20	18,29
Volunteer J	F	28	58	170	89	121	-	24	24	20,07
Volunteer K	M	54	79	187	70	135	-	26	27	22,59

Table 3- 7: Information on the volunteers and the position of the PEMs
(BMI = Body Mass Index)

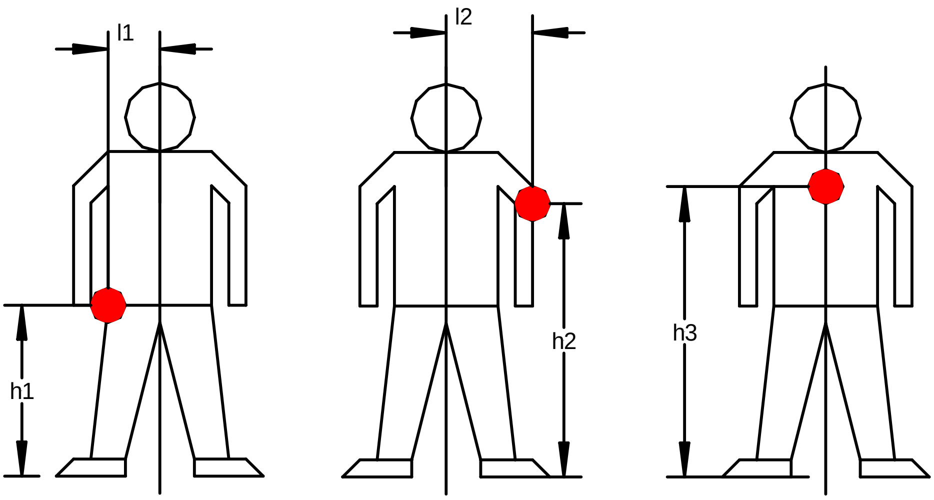

Figure 3- 2: Schematic view of the volunteers and the position of the PEMs

Figure 3- 3: Location of the Maschek and Antennessa exposimeters

In Table 3- 8 the overview of the measurements correlating to the volunteers is given.

Dosimeter	ESM 140						EME SPY 120					
Position	P1		P2		P3		P1		P2		P3	
Using Reflector	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes
Volunteer A	GSM	GSM UMTS	GSM	GSM UMTS	GSM UMTS	GSM UMTS	GSM	FM GSM UMTS	GSM	FM GSM UMTS	FM GSM UMTS	FM GSM UMTS
Volunteer B	GSM	GSM UMTS	GSM	GSM UMTS	GSM UMTS WLAN	GSM UMTS	GSM	FM GSM UMTS	GSM	FM GSM UMTS	FM GSM UMTS WLAN	FM GSM UMTS
Volunteer C	-	-	-	GSM	-	GSM	-	-	-	GSM	-	-
Volunteer D	-	-	-	GSM	-	GSM	-	-	-	GSM	-	-
Volunteer E	-	-	-	GSM	-	GSM	-	-	-	GSM	-	-
Volunteer F	-	-	-	GSM	-	GSM	-	-	-	GSM	-	-
Volunteer G	-	-	-	GSM	-	GSM	-	-	-	GSM	-	-
Volunteer H	-	-	-	GSM	-	GSM	-	-	-	GSM	-	-
Volunteer I	-	-	-	GSM	-	GSM	-	-	-	GSM	-	-
Volunteer J	-	-	-	GSM	-	GSM	-	-	-	GSM	-	-
Volunteer K	-	-	-	GSM	-	GSM	-	-	-	GSM	-	-

Table 3- 8: Information of the PEM measurements correlating to the volunteers

The measurements have been done in the anechoic chamber of the Austrian Research Centers GmbH – ARC in Seibersdorf, Austria. The facility is a fully anechoic chamber which is equipped with RF hybrid absorbers.

As explained in chapter 3.1 two different exposure conditions have been investigated. One approach was to investigate exposure with the direct signal propagating from the antenna without any reflections, the other approach was to investigate exposure due to the direct signal and reflected signals from additional reflectors.
For the multipath propagation conditions three different reflectors have been used (see dimensions in the schematic drawing). Figure 3- 4 shows the test set up inside the anechoic chamber with the mounted additional reflectors. The volunteers and the Add3D system were placed on the test floor, which was mounted above the floor absorbers. In Figure 3- 5 the three measurement positions on the test floor are shown.

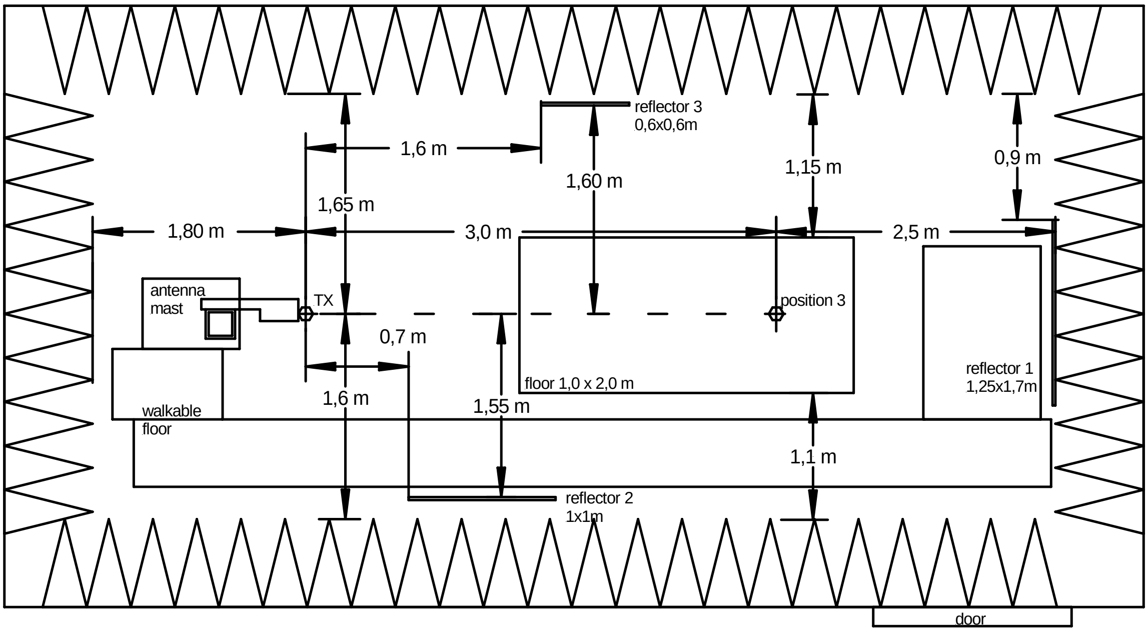

Figure 3- 4: Schematic drawing of the set up inside the anechoic chamber

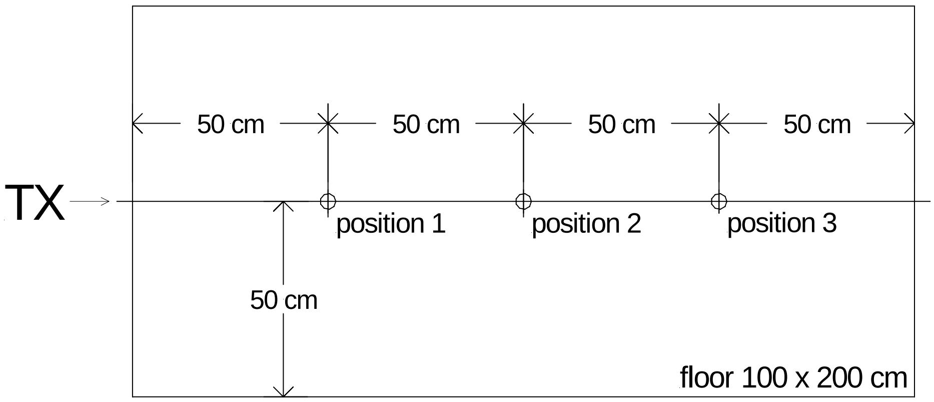

Figure 3- 5: Positions of the volunteers on the test floor

3.1.4. Simulation of Add3d-measurements in the anechoic chamber

In the 4 investigated frequency bands Add3d-measurements were performed to compare these results representing real exposure with the exposimeter measurements. Additional to this comparison numerical simulations of the investigated scenarios were done to verify the field distributions also by numerical means. Unlike to the measurements it is possible when performing simulation, to evaluate an averaged field value of the whole body volume by field levels obtained in a very fine resolution and to compare the result to those obtained by the add3D measurements.
The simulations were performed with the FDTD-Tool SEMCAD (FDTD= Finite Differences in Time Domain; see further details at www.semcad.com)
For the simulations the antennas, which were applied at the measurements had to be modelled. The models of the antennas for all frequency bands are shown in Figure 3- 6.

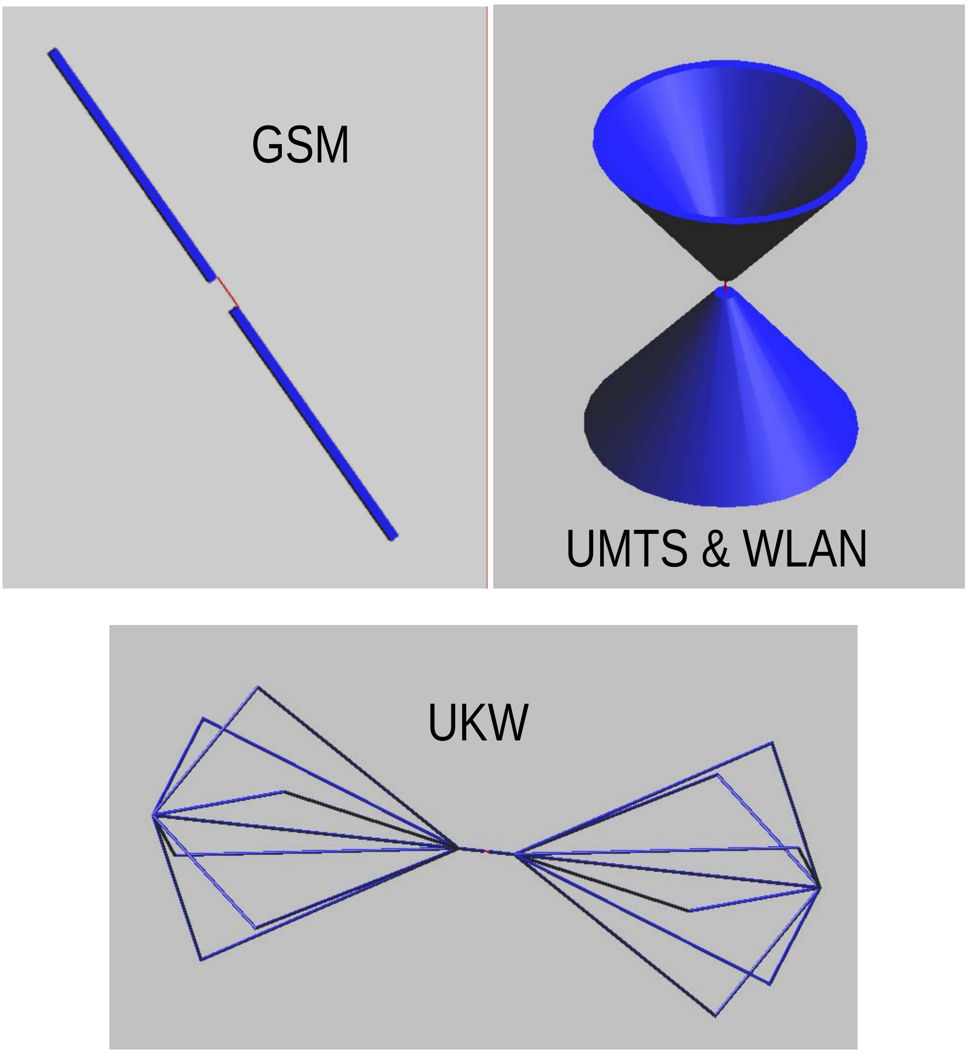

Figure 3- 6: Simulation model of the antennas obtained with SEMCAD

In the frame of the simulations the measurement scenario was modelled. The measurements were done in an anechoic chamber, so the boundaries of the simulation domain were set to “absorbing”. The metallic reflectors and the antennas for the corresponding frequency were placed in the calculation room. Around the three measurements positions the electric and magnetic field was recorded, the recorded region is shown in Figure 3- 7 with the green cuboids. There is no human body model applied in these simulations.
For each measurement position at each frequency the E-field of the whole volume was averaged (15,000 E-field values in 5mm steps over the body volume). Then the E-field at the 6 measurement positions (see Figure 3- 1 and Table 3- 5) was extracted and averaged with the same method than for the measurements (see chapter 3.1).
The simulation results of the E-field averaged over the whole body volume and averaged over the 6 measurement points are then compared to the measurement results in chapter 3.2.

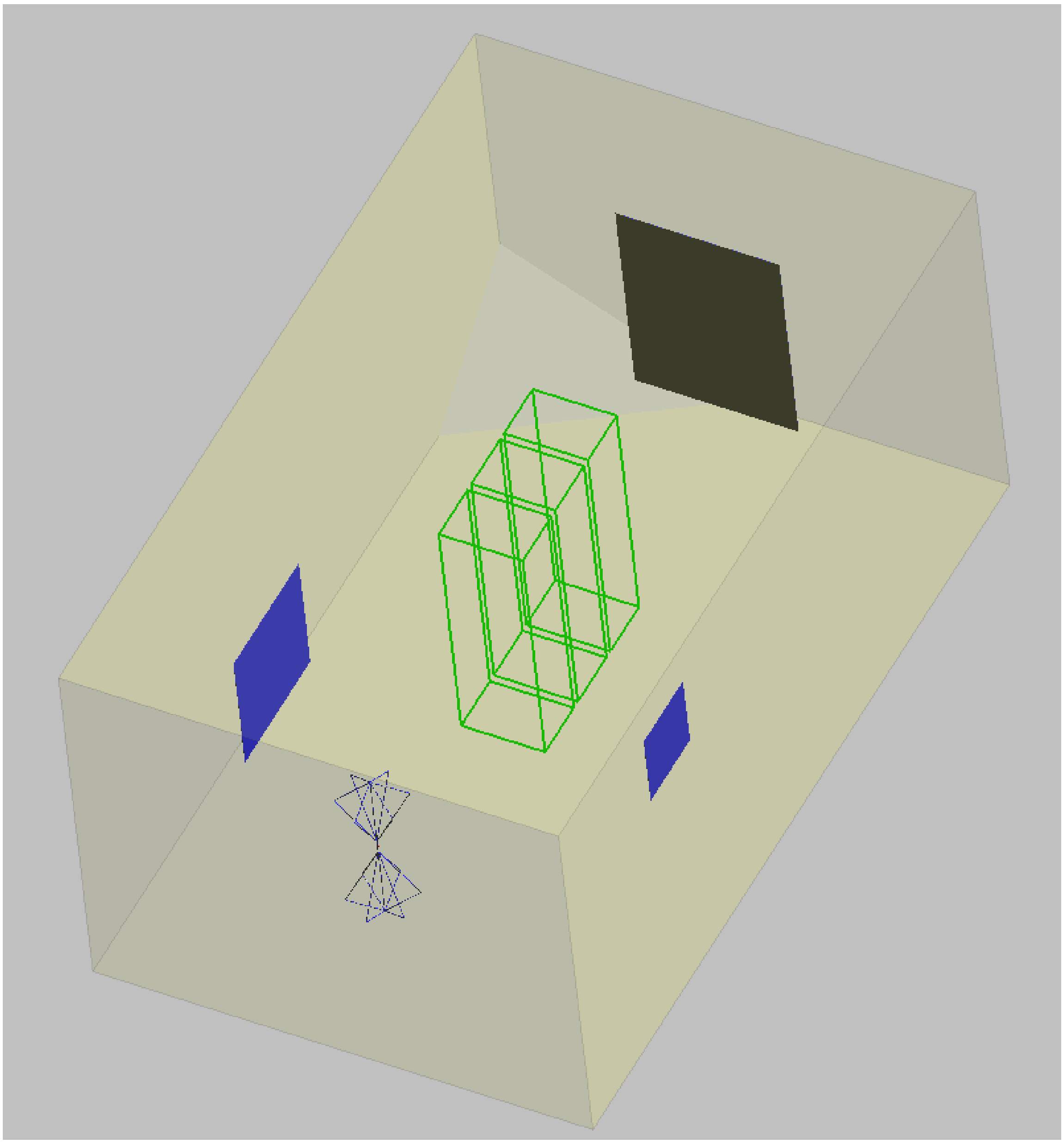

Figure 3- 7: Measurement scenario in the anechoic chamber with reflectors for FM exposure modelled with SEMCAD

3.2. Results

In the following figures of this chapter the test results from the exposimeter measurements, Add3D measurements and the calculated numerical simulations are shown.
All values shown have been normalised to an input power of the transmitting antenna of 1 W to make data comparable.
The exposimeter's results were not corrected by an additional calibration factor. The inherent manufacturer's calibration factors have been used.
As explained in chapter 3.1.3 the Antennessa exposimeter was worn at the hips and the back, and the Maschek exposimeter was weared on the upper arm. The next table gives an overview on the investigations performed in the frame of this part of the project.

Captions used in the diagrams of this chapter:

Black vertical line:	Shows the span of the exposimeter readings from the lowest reading to the highest reading, while the person was turning in 30° steps (angle) around his body centre axis.
expo mean:	The arithmetical mean value of the twelve readings obtained at the different orientations of the persons (rotation in 30° steps around the sagittal axis).
meas 6P:	Shows the reference value, which is taken from the Add3D measurement reading (averaged over 6 points).
sim 6P:	Indicates the simulation reference value from the simulated Add3D reading.
sim WP:	Gives the simulated whole body averaged electric field levels (5 mm resolution).

3.2.1. FM Results

	Position 3	
angle	hips	back
degree	V/m	V/m
0	0.72	0.93
30	0.80	0.88
60	1.42	0.77
90	1.39	1.33
120	1.52	2.11
150	1.81	2.28
180	1.97	2.57
210	1.52	1.85
240	1.22	1.25
270	1.07	1.02
300	0.85	0.71
330	0.77	0.77
meas 6P	2.13	2.13
sim 6P	1.61	1.61
sim WP	2.10	2.10
expo mean	1.25	1.37

Table 3- 9: FM, field strengths for person A, without reflector in the anechoic chamber, only position 3

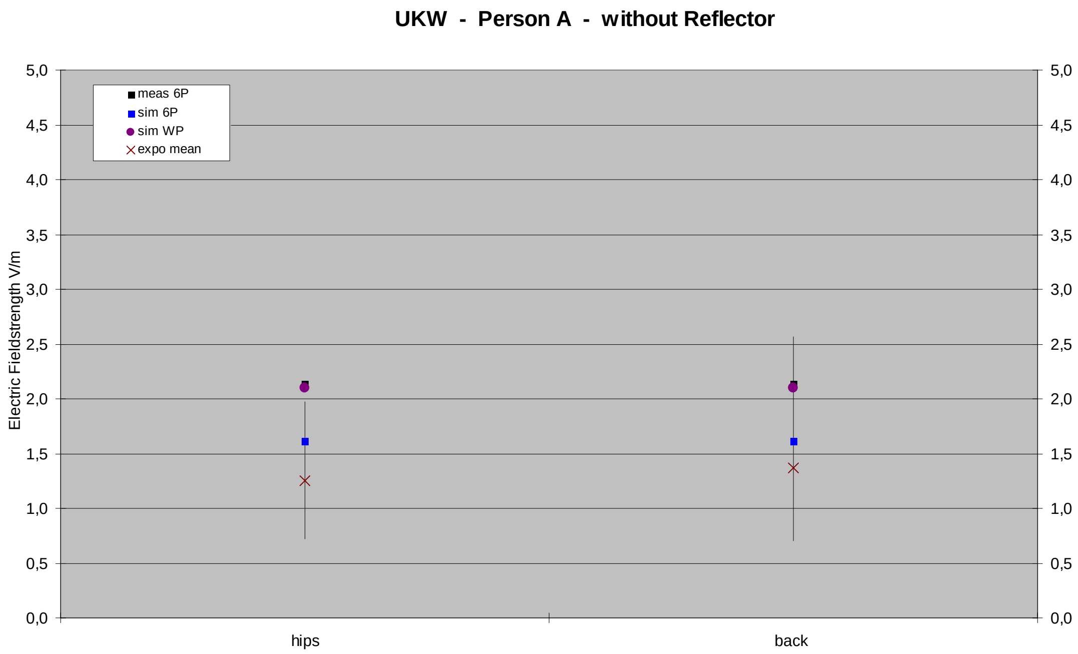

Figure 3- 8: FM, field strengths for person A, without reflectors in the anechoic chamber, only position 3

	Position 3		Position 2		Position 1	
angle	hips	back	hips	back	hips	back
degree	V/m	V/m	V/m	V/m	V/m	V/m
0	0.52	0.86	0.68	0.81	0.91	1.05
30	0.42	0.73	0.49	0.90	0.82	0.96
60	0.69	0.58	0.67	1.81	0.70	0.83
90	1.53	1.30	1.33	2.60	1.65	2.71
120	2.16	2.30	3.06	3.46	3.07	3.21
150	2.48	2.60	3.50	3.41	3.97	3.23
180	2.67	2.13	3.79	2.98	4.13	2.61
210	2.62	1.24	2.35	2.33	3.67	2.36
240	1.86	0.78	1.48	1.63	2.23	0.95
270	1.25	0.55	1.36	0.89	1.51	0.95
300	0.65	0.63	1.05	0.90	1.26	1.14
330	0.51	0.67	0.87	0.86	1.05	1.16
meas 6P	1.65	1.65	2.47	2.47	2.66	2.66
sim 6P	1.61	1.61	2.14	2.14	2.40	2.40
sim WP	1.57	1.57	2.08	2.08	2.43	2.43
expo mean	1.45	1.20	1.72	1.88	2.08	1.76

Table 3- 10: FM, field strengths for person A, with reflector in the anechoic chamber

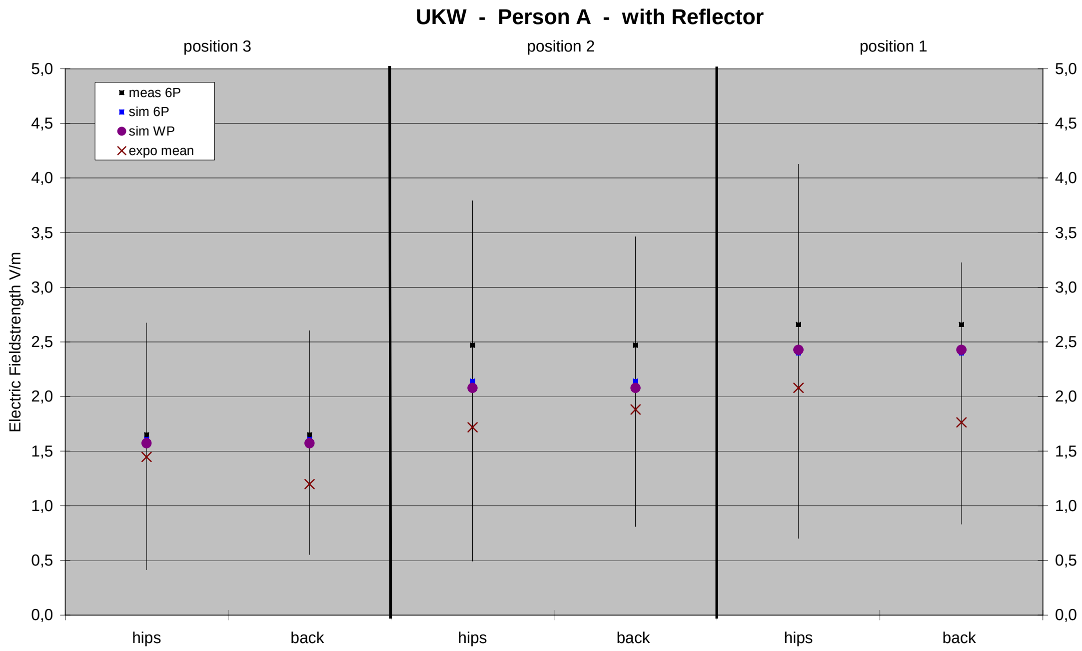

Figure 3- 9: FM, field strengths for person A, with reflector in the anechoic chamber

	Position 3	
angle	hips	back
degree	V/m	V/m
0	0.74	0.45
30	0.80	0.42
60	0.91	1.22
90	1.12	1.87
120	1.73	2.16
150	2.18	2.04
180	2.32	1.80
210	1.79	1.56
240	1.42	1.36
270	1.05	0.89
300	0.82	0.34
330	0.73	0.40
meas 6P	2.13	2.13
sim 6P	1.61	1.61
sim WP	2.10	2.10
expo mean	1.30	1.21

Table 3- 11: FM, field strengths for person B, without reflector in the anechoic chamber, only position 3

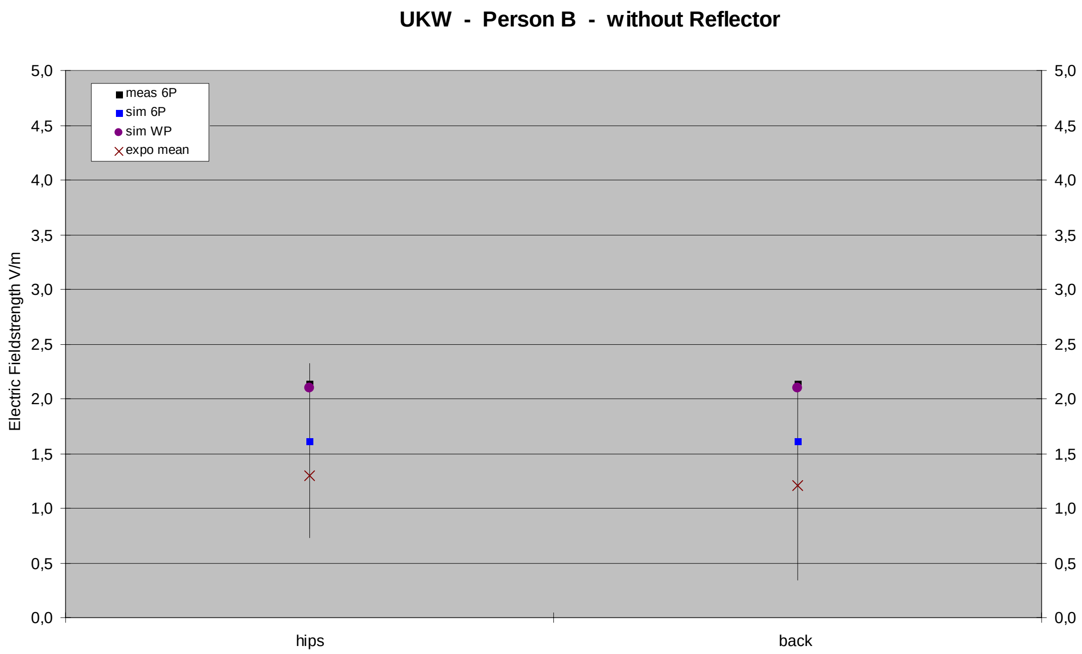

Figure 3- 10: FM, field strengths for person B, without reflectors in the anechoic chamber, only position 3

	Position 3		Position 2		Position 1	
angle	hips	back	hips	back	hips	back
degree	V/m	V/m	V/m	V/m	V/m	V/m
0	0.58	0.49	0.51	0.40	0.85	0.65
30	0.41	0.43	0.49	0.57	0.73	0.48
60	0.50	0.68	1.29	1.46	1.54	0.92
90	1.21	1.42	1.95	2.03	2.68	1.82
120	1.84	1.83	2.88	2.27	3.49	2.04
150	2.21	1.74	3.70	2.07	3.77	1.31
180	2.60	1.30	3.60	1.74	3.42	1.24
210	1.86	0.90	2.55	1.58	2.69	1.20
240	1.51	0.99	1.69	1.51	1.67	1.57
270	0.96	0.81	1.23	1.05	1.32	0.73
300	0.55	0.31	0.93	0.41	1.11	0.60
330	0.57	0.42	0.65	0.38	0.95	0.62
meas 6P	1.61	1.61	2.14	2.14	2.40	2.40
sim 6P	1.65	1.65	2.47	2.47	2.66	2.66
sim WP	1.57	1.57	2.08	2.08	2.43	2.43
expo mean	1.23	0.94	1.79	1.29	2.02	1.10

Table 3- 12: FM, field strengths for person B, with reflector in the anechoic chamber

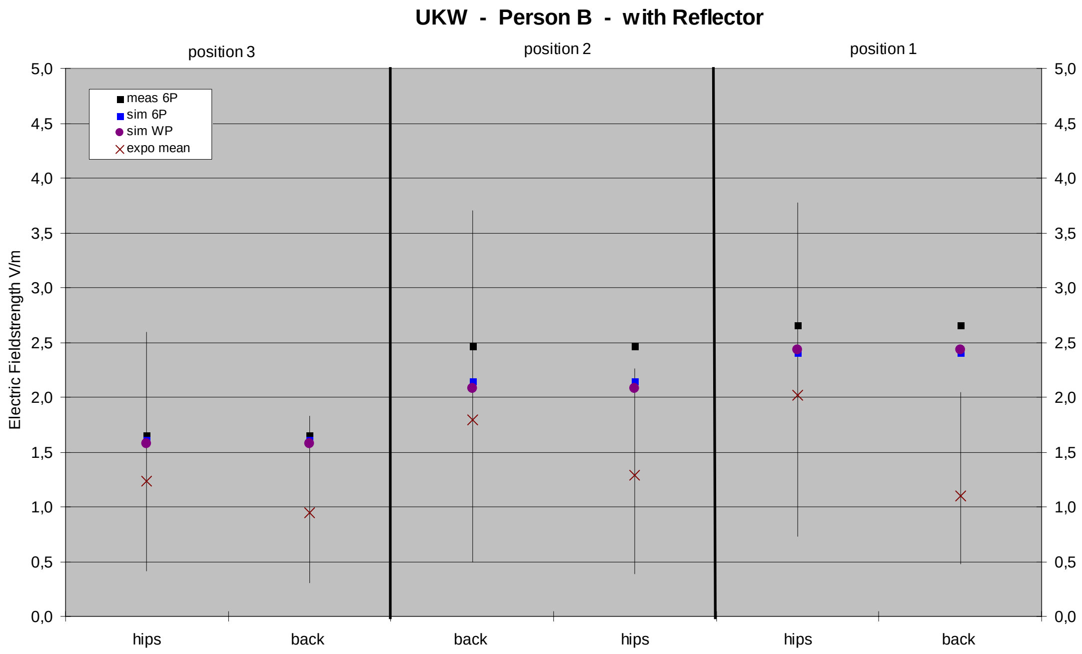

Figure 3- 11: FM, field strengths for person B, with reflector in the anechoic chamber

Summary FM:

Table 3- 13 shows the summary of all FM measurements.

Mean value, standard deviation, maximum and minimum are normalised to each measured Add3D value. Furthermore they have been calculated of all measured positions including both investigated conditions with and without mounted reflector inside the anechoic chamber for each part of the body. These values were split for person A and person B as well as for both together (person A+B).

N > ref (%) shows the number of the normalised measured points in percent which are greater than its Add3D value.

Normalised standard deviation, normalised maximum and normalised minimum are the given standard deviation, maximum and minimum normalised to the respective mean value.

	Person A		Person B		Person A +B	
	hips	back	hips	back	hips	back
Mean value	0.74	0.70	0.76	0.55	0.75	0.63
Standard dev.	0.44	0.38	0.44	0.30	0.44	0.35
Maximum	1.62	1.58	1.73	1.14	1.73	1.58
Minimum	0.20	0.38	0.23	0.16	0.20	0.16
N > ref (%)	25	25	31.25	8.33	28.13	13.54
Normalised standard dev.	0.60	0.54	0.58	0.54	0.59	0.55
Normalised maximum	2.20	2.26	2.26	2.05	2.31	2.52
Normalised minimum	0.27	0.54	0.30	0.29	0.27	0.26

Table 3- 13: Summary of the FM measurements results

Table 3- 14 shows the correlations between exposimeter readings and simulations (both averaged over 6 points and over all field values of the entire volume associated with the position of the human body) versus the Add3D measurements (averaged over 6 points).

	Correlation
sim 6P	0.69
sim WP	0.93
expo mean	0.67

Table 3- 14: Correlations for the FM measurements and simulations

3.2.2. GSM Results

	Position 3			Position 2			Position 1		
angle	hips	back	upper arm	hips	back	upper arm	hips	back	upper arm
degree	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m
0	0.42	0.78	0.41	0.41	0.84	0.49	0.57	1.23	0.61
30	0.42	1.16	0.10	0.45	1.32	0.07	0.57	2.22	0.12
60	0.90	1.40	0.24	1.13	1.86	0.45	1.40	2.35	0.45
90	1.28	1.02	0.79	1.39	1.72	0.97	1.86	2.15	1.12
120	1.80	1.93	1.30	2.16	2.31	1.56	2.58	3.03	2.02
150	1.73	2.51	1.22	1.99	3.04	1.61	2.88	3.89	1.99
180	1.93	2.57	1.57	2.29	3.18	2.10	2.77	3.79	2.66
210	1.98	2.63	1.63	2.26	2.95	1.95	2.85	3.29	2.41
240	1.87	1.87	1.48	2.19	1.90	1.72	2.64	1.95	2.33
270	1.66	1.13	1.32	1.89	1.53	1.37	2.32	1.71	1.81
300	1.21	1.50	0.66	1.30	1.94	0.81	1.49	2.24	0.81
330	0.51	1.18	0.53	0.62	1.39	0.59	0.57	1.70	0.68
meas 6P	1.89	1.89	1.89	2.14	2.14	2.14	2.93	2.93	2.93
sim 6P	2.29	2.29	2.29	2.73	2.73	2.73	3.28	3.28	3.28
sim WP	2.20	2.20	2.20	2.59	2.59	2.59	3.11	3.11	3.11
expo mean	1.31	1.64	0.94	1.51	2.00	1.14	1.87	2.46	1.42

Table 3- 15: GSM, field strengths for person A, without reflector in the anechoic chamber

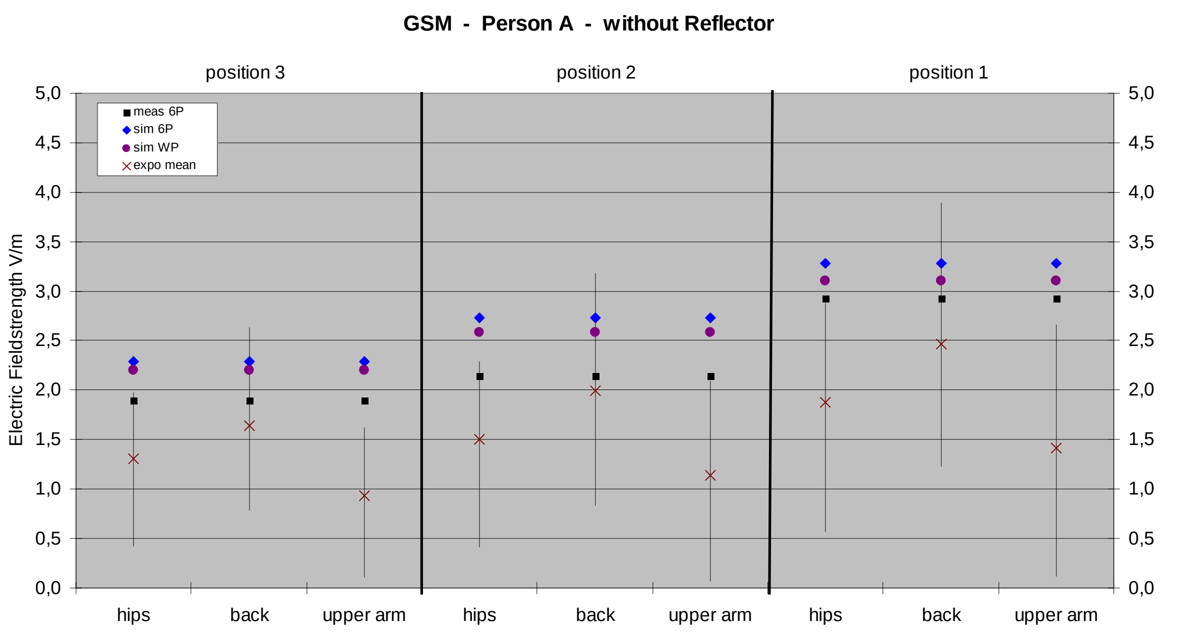

Figure 3- 12: GSM, field strengths for person A, without reflectors in the anechoic chamber

	Position 3			Position 2			Position 1		
angle	hips	back	upper arm	hips	back	upper arm	hips	back	upper arm
degree	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m
0	0.49	1.30	0.71	1.39	1.39	0.89	0.84	2.19	0.85
30	0.31	0.83	0.40	1.13	2.40	0.52	1.10	1.95	0.40
60	0.73	1.12	0.85	1.89	3.44	0.88	1.10	1.76	0.64
90	1.56	2.12	1.02	2.23	3.93	1.57	1.11	2.09	0.80
120	2.20	4.65	0.43	0.76	1.86	3.05	2.71	4.54	1.81
150	2.38	4.32	1.54	1.29	2.35	2.25	2.65	4.13	2.74
180	2.78	2.63	2.41	2.48	4.67	2.40	2.16	3.16	1.23
210	1.49	2.70	1.10	2.05	3.28	2.37	2.19	4.27	3.29
240	1.31	2.39	2.55	1.93	2.09	1.30	2.25	3.16	1.94
270	0.82	1.60	0.60	1.89	1.55	1.73	1.23	1.60	1.60
300	1.04	0.65	0.47	2.00	1.71	1.46	1.07	2.63	1.00
330	0.60	1.01	0.44	0.78	1.31	1.26	0.47	1.39	0.38
meas 6P	1.40	1.40	1.40	3.59	3.59	3.59	3.65	3.65	3.65
sim 6P	1.68	1.68	1.68	6.03	6.03	6.03	2.92	2.92	2.92
sim WP	2.75	2.75	2.75	3.58	3.58	3.58	3.72	3.72	3.72
expo mean	1.31	2.11	1.04	1.65	2.50	1.64	1.57	2.74	1.39

Table 3- 16: GSM, field strengths for person A, with reflector in the anechoic chamber

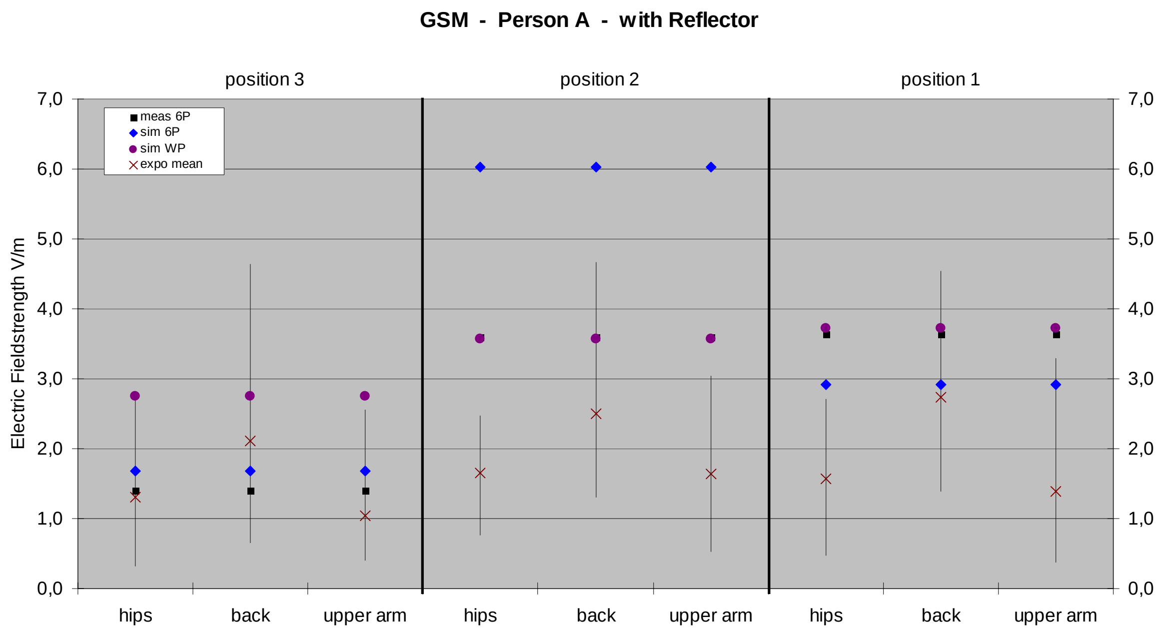

Figure 3- 13: GSM, field strengths for person A, with reflectors in the anechoic chamber

	Position 3			Position 2			Position 1		
angle	hips	back	upper arm	hips	back	upper arm	hips	back	upper arm
degree	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m
0	0.10	0.59	0.18	0.15	0.78	0.19	0.14	0.95	0.41
30	0.33	0.82	0.24	0.43	0.85	0.36	0.60	1.16	0.21
60	0.59	0.73	0.44	0.81	0.74	0.39	0.74	0.97	0.46
90	1.00	0.51	0.67	1.24	0.48	0.81	1.47	0.52	0.91
120	1.24	1.13	0.91	1.41	1.52	1.06	1.92	1.92	1.19
150	1.59	1.68	1.92	1.80	2.08	2.25	2.23	2.57	2.93
180	1.74	1.88	2.38	1.96	2.12	2.80	2.51	2.67	4.03
210	1.56	1.74	2.41	1.76	1.98	2.55	2.15	2.21	3.70
240	1.30	1.13	1.95	1.50	1.32	2.04	1.85	1.53	2.74
270	0.97	0.43	0.83	1.00	0.48	1.00	1.33	0.54	1.24
300	0.66	0.56	0.50	0.69	0.75	0.54	0.90	0.83	0.60
330	0.34	0.77	0.35	0.41	0.56	0.45	0.45	0.81	0.59
meas 6P	1.89	1.89	1.89	2.14	2.14	2.14	2.93	2.93	2.93
sim 6P	2.29	2.29	2.29	2.73	2.73	2.73	3.28	3.28	3.28
sim WP	2.20	2.20	2.20	2.59	2.59	2.59	3.11	3.11	3.11
expo mean	0.95	1.00	1.06	1.10	1.14	1.20	1.36	1.39	1.58

Table 3- 17: GSM, field strengths for person B, without reflector in the anechoic chamber

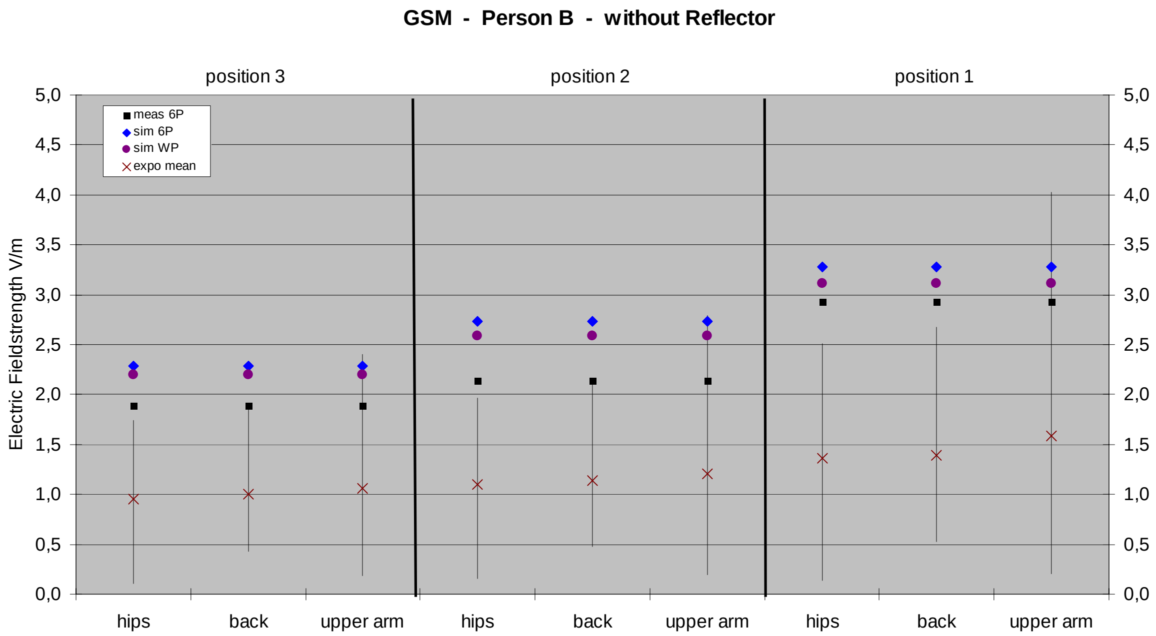

Figure 3- 14: GSM, field strengths for person B, without reflectors in the anechoic chamber

	position 3			position 2			position 1		
angle	hips	back	upper arm	hips	back	upper arm	hips	back	upper arm
degree	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m
0	0.84	0.78	0.57	0.86	1.76	0.62	0.54	1.21	0.36
30	0.81	0.74	0.48	1.75	1.58	0.70	0.99	0.94	0.52
60	0.39	0.33	0.34	2.26	1.04	0.81	0.51	1.10	0.98
90	1.12	0.52	0.74	2.67	1.51	0.96	1.27	0.79	1.25
120	2.19	2.16	0.94	0.84	1.16	3.27	2.84	2.14	0.90
150	2.34	2.53	3.11	2.31	1.74	2.42	1.86	2.06	4.15
180	1.41	1.95	3.31	2.92	3.01	2.66	2.53	2.19	2.56
210	2.22	1.68	2.49	1.61	1.83	3.17	2.82	2.39	4.15
240	1.61	1.87	2.99	2.27	1.39	1.02	2.35	1.70	2.71
270	0.61	0.47	0.29	1.91	0.92	1.10	1.23	0.78	0.67
300	0.58	0.55	0.46	1.54	0.74	0.51	0.98	1.19	0.68
330	0.48	0.59	0.37	0.92	1.27	0.41	0.44	0.97	0.42
meas 6P	1.40	1.40	1.40	3.59	3.59	3.59	3.65	3.65	3.65
sim 6P	1.68	1.68	1.68	6.03	6.03	6.03	2.92	2.92	2.92
sim WP	2.75	2.75	2.75	3.58	3.58	3.58	3.72	3.72	3.72
expo mean	1.22	1.18	1.34	1.82	1.49	1.47	1.53	1.46	1.61

Table 3- 18: GSM, field strengths for person B, with reflector in the anechoic chamber

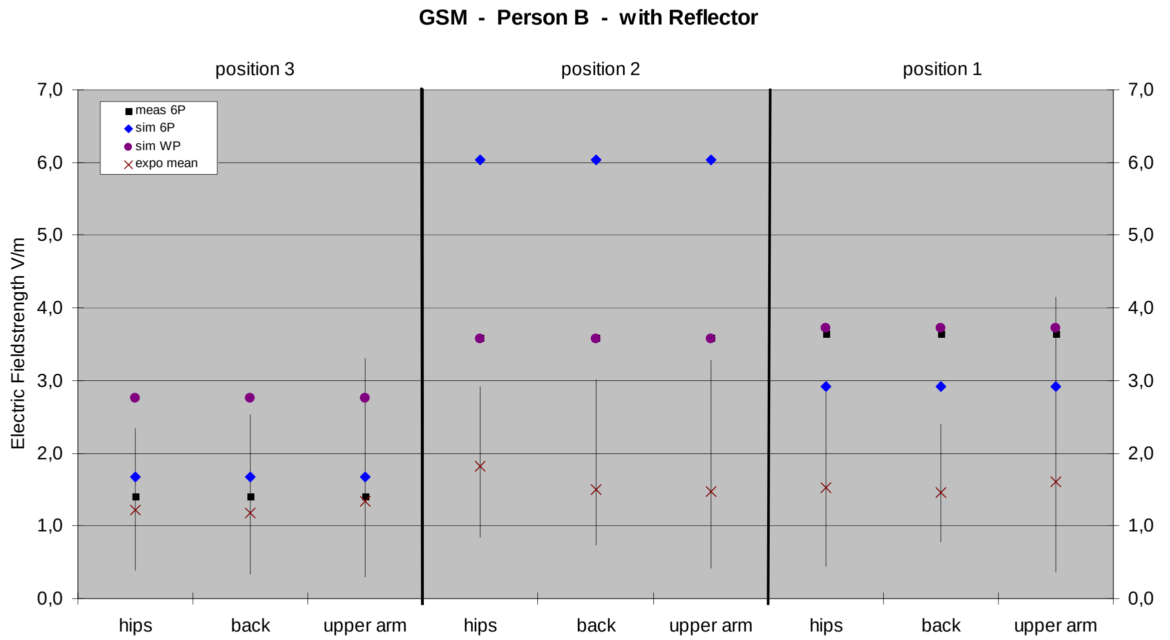

Figure 3- 15: GSM, field strengths for person B, with reflectors in the anechoic chamber

Summary GSM:

Table 3- 19 shows the summary of the GSM measurements for person A and person B.

Mean value, standard deviation, maximum and minimum are normalised to each measured Add3D value. Furthermore they have been calculated of all measured positions including both investigated conditions with and without mounted reflector inside the anechoic chamber for each part of the body. These values were split for person A and person B and are given as well for both persons together (person A+B).

N > ref (%) shows the number of the normalised measured points in percent which are greater than its Add3D value.

Normalised standard deviation, normalised maximum and normalised minimum are the given standard deviation, maximum and minimum normalised to the respective mean value.

	Person A			Person B			Person A +B		
	hips	back	upper arm	hips	back	upper arm	hips	back	upper arm
Mean value	0.64	0.93	0.52	0.55	0.53	0.58	0.59	0.73	0.55
Standard dev.	0.37	0.53	0.34	0.34	0.34	0.53	0.36	0.49	0.45
Maximum	1.98	3.31	1.82	1.67	1.80	2.36	1.98	3.31	2.36
Minimum	0.13	0.36	0.03	0.05	0.18	0.07	0.05	0.18	0.03
N > ref (%)	15.28	33.33	4.17	15.28	23.61	8.33	11.11	20.14	13.19
Normalised standard dev.	0.58	0.57	0.66	0.62	0.64	0.92	0.60	0.67	0.82
Normalised maximum	3.08	3.55	3.53	3.06	3.39	4.07	3.34	4.52	4.31
Normalised minimum	0.20	0.39	0.06	0.09	0.33	0.12	0.08	0.24	0.06

Table 3- 19: Summary GSM

Table 3- 20 shows the correlations between exposimeter readings and simulations (both averaged over 6 points and over all field values of the entire volume associated with the position of the human body) versus the results of the Add3D measurements (averaged over 6 points).

	Correlation
sim 6P	0.74
sim WP	0.88
expo mean	0.47

Table 3- 20: Correlations GSM

Summary GSM with 11 volunteers:

As described in chapter 3.1.3 (Table 3- 8) nine other volunteers with different age, height and weight have been wearing the exposimeters inside the anechoic chamber, additionally. Altogether with person A and B the results of the exposimter readings of 11 volunteers will be compared in this chapter.

The measurements were performed as described below:
Maschek exposimeter on position 2 and position 3; mounted on the left upper arm.
Antennessa exposimeter only on position 2; mounted on the right hip.
In all three scenarios the reflectors were mounted in the anechoic chamber.

In chapter 3.1.3 (Table 3- 7) the gender, height, weight, age and the different positions of the exposimeters on the volunteers are described.

angle	A	B	C	D	E	F	G	H	I	J	K
degree	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m
0	0.71	0.57	0.44	0.42	0.38	0.37	0.65	0.49	0.70	0.49	0.63
30	0.40	0.48	0.41	0.30	0.28	0.36	0.64	0.46	0.41	0.51	0.41
60	0.85	0.34	0.86	0.54	0.49	0.47	0.44	0.37	0.49	0.83	0.35
90	1.02	0.74	1.03	0.84	0.40	0.24	0.43	0.43	0.27	0.31	0.35
120	0.43	0.94	1.98	1.87	1.62	0.63	0.64	0.70	0.64	1.31	0.90
150	1.54	3.11	3.23	3.32	3.35	3.05	1.34	1.95	2.10	3.91	1.28
180	2.41	3.31	1.84	0.85	0.90	2.34	3.12	2.83	2.22	1.51	2.94
210	1.10	2.49	1.17	1.49	2.50	1.28	0.44	0.82	0.76	0.76	0.63
240	2.55	2.99	1.93	1.28	1.74	2.20	2.97	2.93	2.23	1.77	2.54
270	0.60	0.29	0.57	0.42	0.32	0.47	0.67	0.56	0.59	0.39	0.56
300	0.47	0.46	0.68	0.68	0.54	0.57	0.65	0.15	0.62	0.65	0.43
330	0.44	0.37	0.81	0.72	0.62	0.16	0.13	0.40	0.54	0.57	0.19

Table 3- 21: Field strengths for the Maschek exposimeter reading for each 30° angle and each volunteer on position 3 with mounted reflectors inside the anechoic chamber

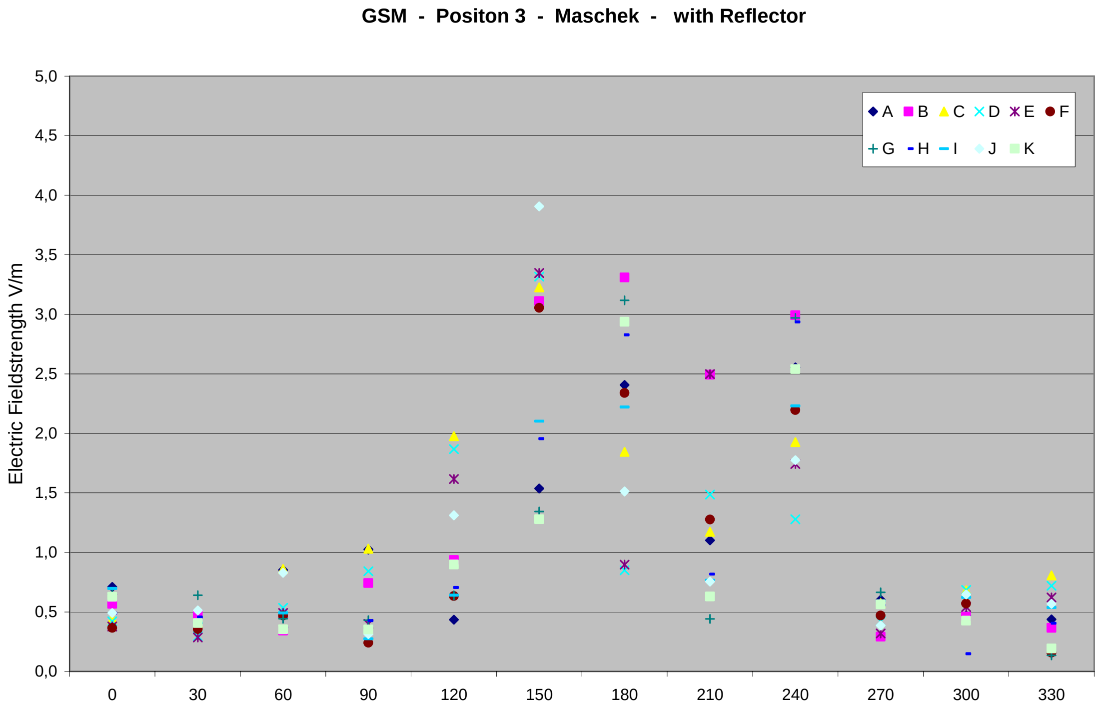

Figure 3- 16: Difference of exposimeter reading between all eleven volunteers for each 30° angle on position 3 with the Maschek exposimeter and mounted reflectors inside the anechoic chamber

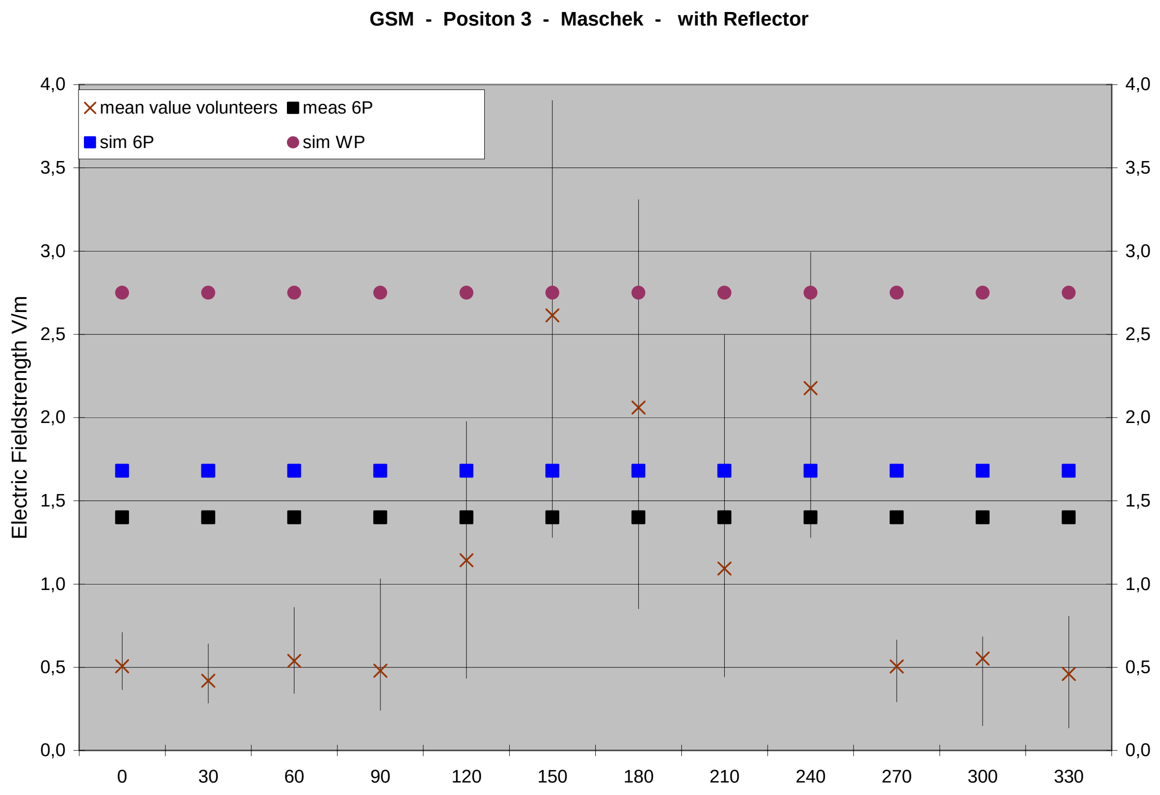

Figure 3- 17: Field strengths for the Maschek exposimeter for each 30° angle on position 3 with mounted reflectors inside the anechoic chamber

Angle	Mean value	Standard dev	Maximum	Minimum
0	0.379	0.090	0.507	0.261
30	0.302	0.072	0.458	0.204
60	0.392	0.144	0.614	0.245
90	0.395	0.214	0.737	0.172
120	0.757	0.389	1.412	0.310
150	1.829	0.668	2.790	0.913
180	1.575	0.605	2.364	0.608
210	0.872	0.499	1.783	0.315
240	1.632	0.406	2.137	0.913
270	0.353	0.089	0.475	0.208
300	0.383	0.113	0.489	0.106
330	0.321	0.162	0.576	0.096

Table 3- 22: Mean value, standard deviation, maximum and minimum exposimeter readings of all 11 persons for each orientation normalised to the Add3D reference value (meas 6P)

Volunteer	Mean value	Standard dev	Maximum	Minimum
A	0.746	0.536	1.824	0.289
B	0.958	0.881	2.364	0.208
C	0.890	0.601	2.304	0.292
D	0.757	0.609	2.369	0.212
E	0.782	0.711	2.390	0.204
F	0.722	0.698	2.181	0.112
G	0.722	0.707	2.226	0.096
H	0.719	0.704	2.096	0.106
I	0.689	0.534	1.593	0.196
J	0.774	0.716	2.790	0.224
K	0.667	0.639	2.097	0.137

Table 3- 23: Mean value, standard deviation, maximum and minimum exposimeter values of all 12 angles for each person normalised to the Add3D reference value (meas 6P)

angle	A	B	C	D	E	F	G	H	I	J	K
degree	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m
0	0.89	0.62	0.26	0.38	0.12	0.32	0.57	0.90	0.25	0.51	0.67
30	0.52	0.70	1.45	1.18	0.92	1.16	0.68	1.09	0.46	1.39	0.13
60	0.88	0.81	2.12	2.29	1.33	1.86	1.12	1.54	0.67	2.27	0.84
90	1.57	0.96	3.06	2.59	1.94	2.45	1.64	1.84	1.49	2.79	1.26
120	3.05	3.27	3.46	4.01	3.48	2.86	2.84	3.41	2.50	4.57	2.55
150	2.25	2.42	0.51	0.74	0.71	0.43	2.24	1.83	1.16	1.15	1.56
180	2.40	2.66	3.76	3.10	3.75	2.81	2.42	3.06	2.57	3.22	2.76
210	2.37	3.17	2.47	1.54	1.84	1.61	3.01	2.77	2.73	2.19	2.02
240	1.30	1.02	2.19	1.26	1.59	0.70	1.13	0.68	0.76	1.26	0.73
270	1.73	1.10	3.11	2.20	2.55	0.94	1.73	1.66	1.98	1.97	1.51
300	1.46	0.51	1.12	0.99	1.30	0.96	0.97	1.96	1.79	1.27	1.33
330	1.26	0.41	0.78	0.62	0.68	0.71	0.59	1.17	1.13	1.23	0.63

Table 3- 24: Field strengths for the Maschek exposimeter for each 30° angle and each volunteer on position 2 with mounted reflectors inside the anechoic chamber

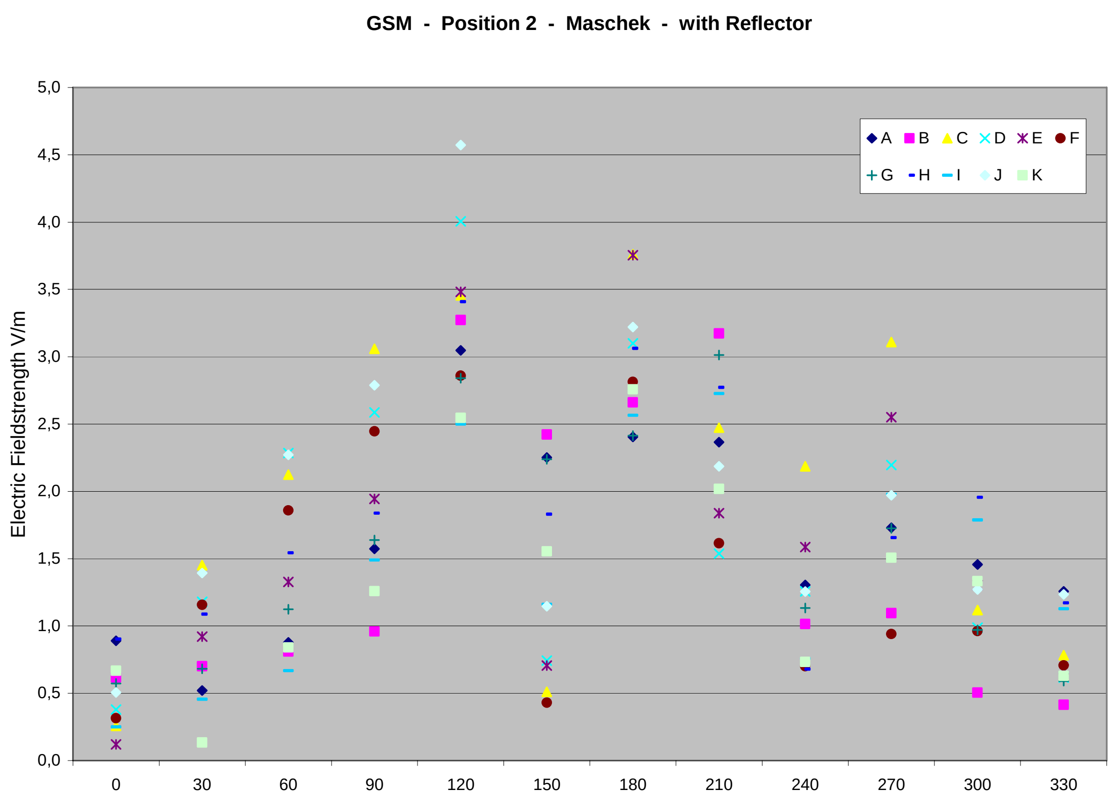

Figure 3- 18: Difference of exposimeter reading between all eleven volunteers for each 30° angle on position 2 with the Maschek exposimeter and mounted reflectors inside the anechoic chamber

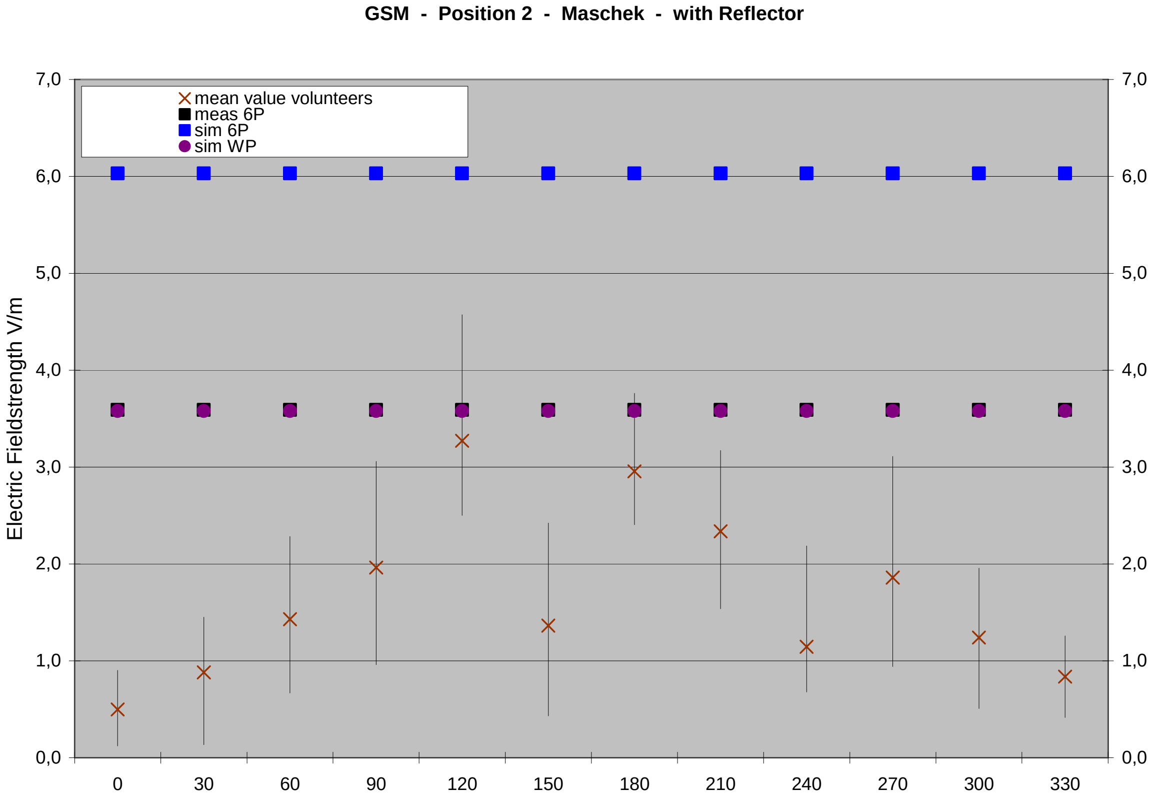

Figure 3- 19: Field strengths for the Maschek exposimeter for each 30° angle on position 2 with mounted reflectors inside the anechoic chamber

Angle	Mean value	Standard dev	Maximum	Minimum
0	0.139	0.072	0.251	0.033
30	0.245	0.116	0.404	0.037
60	0.398	0.173	0.637	0.186
90	0.547	0.187	0.852	0.267
120	0.911	0.173	1.274	0.696
150	0.380	0.205	0.675	0.120
180	0.823	0.133	1.048	0.670
210	0.651	0.154	0.884	0.428
240	0.319	0.127	0.609	0.189
270	0.518	0.172	0.866	0.262
300	0.346	0.113	0.545	0.141
330	0.233	0.084	0.350	0.115

Table 3- 25: Mean value, standard deviation, maximum and minimum exposimeter values of all 11 persons for each orientation normalised to the Add3D reference value (meas 6P)

Volunteer	Mean value	Standard dev	Maximum	Minimum
A	0.457	0.209	0.849	0.145
B	0.410	0.301	0.912	0.115
C	0.564	0.332	1.048	0.072
D	0.485	0.308	1.116	0.106
E	0.469	0.310	1.046	0.033
F	0.390	0.252	0.796	0.088
G	0.440	0.243	0.839	0.160
H	0.509	0.240	0.950	0.189
I	0.405	0.239	0.760	0.069
J	0.553	0.312	1.274	0.141
K	0.371	0.223	0.768	0.037

Table 3- 26: Mean value, standard deviation, maximum and minimum exposimeter values of all 12 angles for each person normalised to the Add3D reference value (meas 6P)

angle	A	B	C	D	E	F	G	H	I	J	K
degree	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m
0	1.39	0.86	1.56	1.20	0.86	1.05	0.61	1.34	2.15	1.26	1.12
30	1.13	1.75	1.29	1.25	1.25	1.41	0.77	1.41	1.52	0.89	1.60
60	1.89	2.26	2.20	2.06	0.96	2.28	2.09	2.16	3.21	2.24	2.64
90	2.23	2.67	1.68	2.90	1.99	2.68	2.92	2.23	2.90	1.88	2.70
120	0.76	0.84	1.63	2.75	2.35	1.41	1.15	1.13	1.34	1.16	0.67
150	1.29	2.31	1.56	1.01	1.00	1.54	2.16	3.45	1.58	1.89	3.41
180	2.48	2.92	2.71	3.46	2.03	3.57	4.14	3.03	3.78	3.33	4.48
210	2.05	1.61	2.64	2.83	2.80	1.87	1.91	2.17	2.85	2.64	2.37
240	1.93	2.27	2.64	1.57	2.07	1.85	2.00	2.80	2.68	2.99	2.53
270	1.89	1.91	2.33	1.80	1.90	2.22	2.43	2.42	2.53	3.11	2.46
300	2.00	1.54	1.94	1.88	1.81	1.69	1.58	1.45	2.30	1.94	1.98
330	0.78	0.92	1.78	1.39	0.71	1.16	1.73	1.53	1.70	1.52	1.22

Table 3- 27: Field strengths for the Antennessa exposimeter for each 30° angle and each volunteer on position 2 with mounted reflectors inside the anechoic chamber

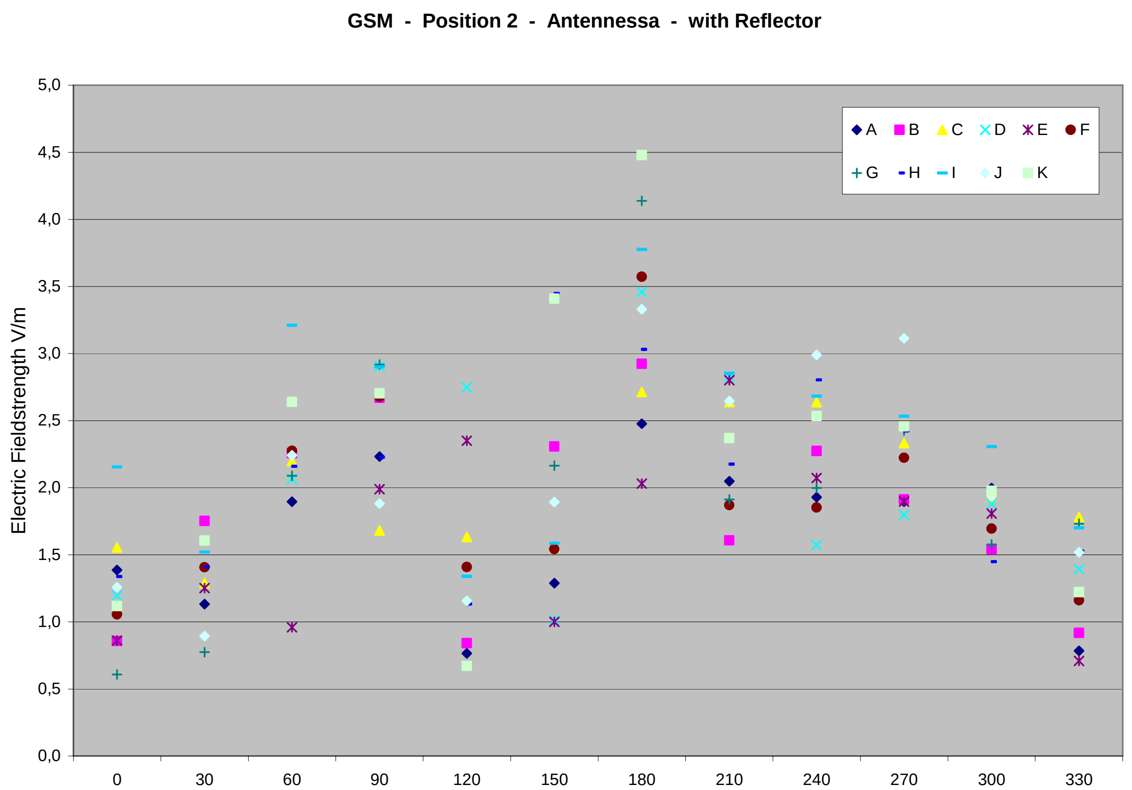

Figure 3- 20: Difference of exposimeter reading between all eleven volunteers for each 30° angle on position 2 with the Antennessa exposimeter and mounted reflectors inside the anechoic chamber

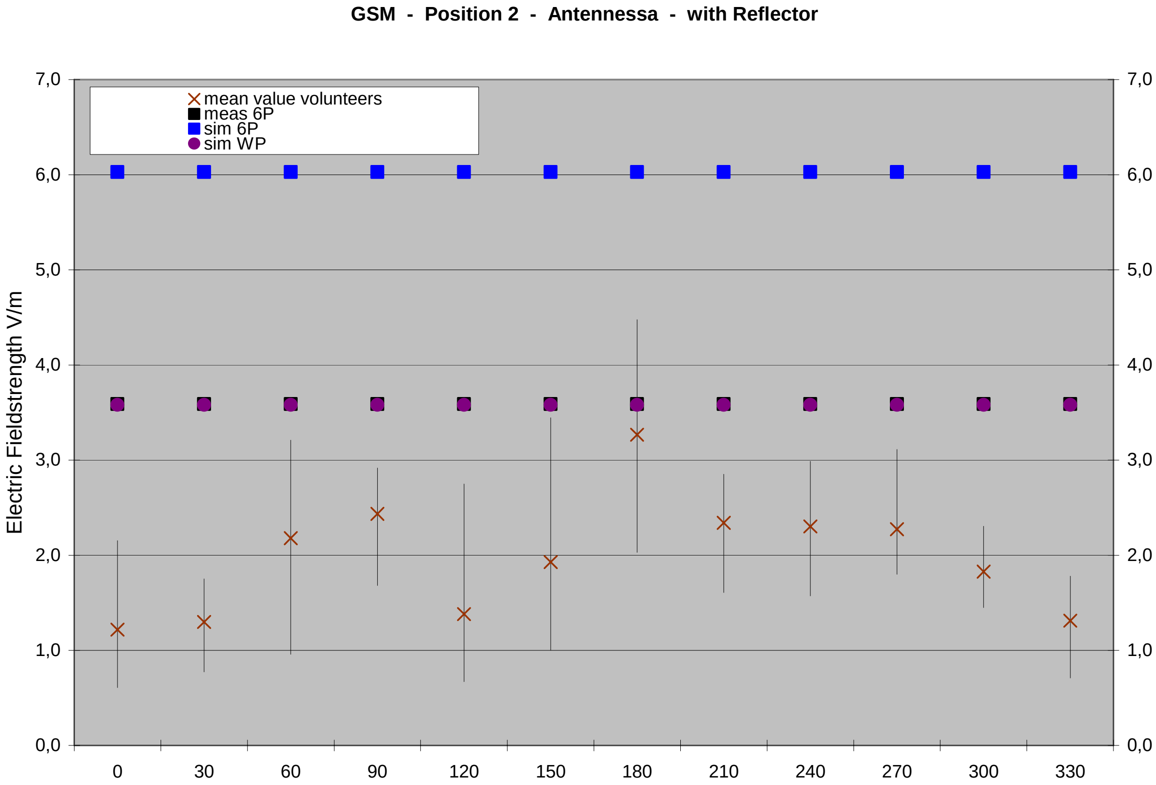

Figure 3- 21: Field strengths for the Antennessa exposimeter for each 30° angle on position 2 with mounted reflectors inside the anechoic chamber

Angle	Mean value	Standard dev	Maximum	Minimum
0	0.339	0.115	0.600	0.169
30	0.362	0.081	0.488	0.216
60	0.607	0.150	0.894	0.267
90	0.678	0.125	0.813	0.468
120	0.385	0.181	0.766	0.187
150	0.537	0.237	0.960	0.279
180	0.910	0.202	1.247	0.565
210	0.652	0.123	0.795	0.448
240	0.642	0.126	0.832	0.438
270	0.633	0.108	0.867	0.501
300	0.509	0.069	0.642	0.403
330	0.366	0.107	0.496	0.197

Table 3- 28: Mean value, standard deviation, maximum and minimum exposimeter values of all 11 persons for each orientation normalised to the Add3D reference value (meas 6P)

Volunteer	Mean value	Standard dev	Maximum	Minimum
A	0.460	0.157	0.690	0.213
B	0.507	0.195	0.814	0.234
C	0.556	0.137	0.756	0.359
D	0.560	0.222	0.964	0.282
E	0.458	0.186	0.780	0.197
F	0.528	0.198	0.995	0.294
G	0.545	0.266	1.153	0.169
H	0.583	0.207	0.960	0.315
I	0.663	0.209	1.052	0.373
J	0.577	0.224	0.928	0.249
K	0.631	0.292	1.247	0.187

Table 3- 29: Mean value, standard deviation, maximum and minimum exposimeter values of all 12 angles for each person normalised to the Add3D reference value (meas 6P)

Summary for GSM of all eleven volunteers:

Mean value, standard deviation, maximum and minimum are normalised to each measured Add3D value. The mean value is including the measured normalised exposimeter values of all eleven volunteers with all 30° angle.

N > ref (%) shows the number of the normalised measured points in percent which are greater than its Add3D value.

Normalised standard deviation, normalised maximum and normalised minimum are the given standard deviation, maximum and minimum normalised to the respective mean value.

	Position 3 Maschek	Position 2 Maschek	Position 2 Antennessa Hips
Mean value	1.07	1.65	1.98
Standard dev.	0.91	0.97	0.77
Maximum	0.13	0.12	0.61
Minimum	3.91	4.57	4.48
N > ref (%)	25.76	3.03	2.27
Normalised standard dev.	0.85	0.59	0.39
Normalised maximum	0.13	0.07	0.31
Normalised minimum	3.64	2.77	2.26

Table 3- 30: Summary for GSM exposimeter investigations of all eleven volunteers

3.2.3. UMTS Results

	Position 3		
angle	hips	back	upper arm
degree	V/m	V/m	V/m
0	0.11	0.09	0.03
30	0.12	0.04	0.10
60	0.16	0.18	0.23
90	0.32	0.23	0.46
120	0.64	0.71	0.82
150	0.81	0.72	1.28
180	1.04	1.08	1.56
210	0.80	0.92	1.43
240	0.50	0.40	1.05
270	0.35	0.28	0.70
300	0.18	0.16	0.33
330	0.11	0.06	0.11
meas 6P	1.37	1.37	1.37
sim 6P	2.09	2.09	2.09
sim WP	2.04	2.04	2.04
expo mean	0.43	0.41	0.67

Table 3- 31: UMTS, field strengths for person A, without reflector in the anechoic chamber

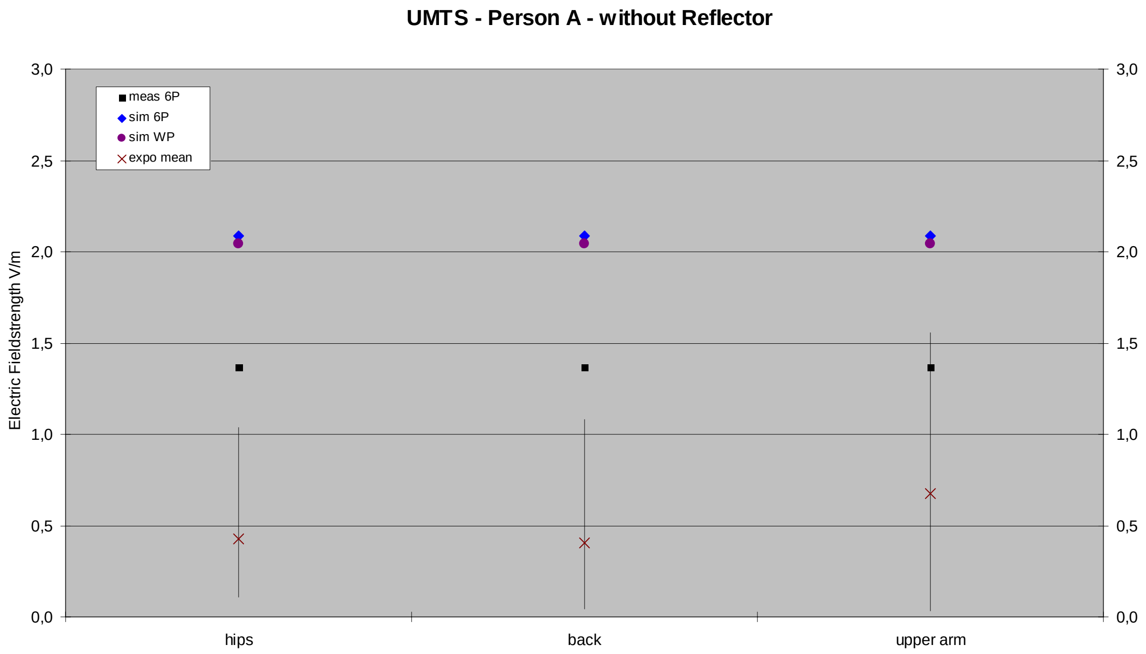

Figure 3- 22: UMTS, field strengths for person A, without reflectors in the anechoic chamber

	Position 3			Position 2			Position 1		
angle	hips	back	upper arm	hips	back	upper arm	hips	back	upper arm
degree	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m
0	0.23	0.19	0.35	0.29	0.22	0.43	0.39	0.29	0.39
30	0.32	0.21	0.34	0.39	0.23	0.48	0.57	0.22	0.67
60	0.31	0.19	0.50	0.61	0.51	0.44	0.78	0.34	0.48
90	0.66	0.45	0.61	0.45	0.46	0.87	0.88	0.82	0.53
120	1.05	0.91	0.65	1.33	0.51	1.21	0.84	0.84	1.97
150	0.52	0.65	1.91	1.16	1.40	2.59	0.92	1.78	2.08
180	1.47	1.58	2.15	1.04	1.60	2.28	1.71	1.47	2.19
210	0.54	0.86	2.43	1.08	1.57	2.49	1.30	1.16	2.65
240	0.83	0.57	1.37	0.83	0.68	1.47	0.74	1.10	1.62
270	0.82	0.94	1.00	0.48	0.55	1.18	0.29	0.50	1.48
300	0.32	0.46	0.65	0.39	0.30	0.35	0.35	0.36	0.46
330	0.24	0.24	0.47	0.21	0.23	0.47	0.43	0.37	0.15
meas 6P	2.94	2.94	2.94	2.90	2.90	2.90	2.28	2.28	2.28
sim 6P	3.46	3.46	3.46	2.73	2.73	2.73	2.67	2.67	2.67
sim WP	2.86	2.86	2.86	3.17	3.17	3.17	3.58	3.58	3.58
expo mean	0.61	0.60	1.04	0.69	0.69	1.19	0.77	0.77	1.22

Table 3- 32: UMTS, field strengths for person A, with reflector in the anechoic chamber

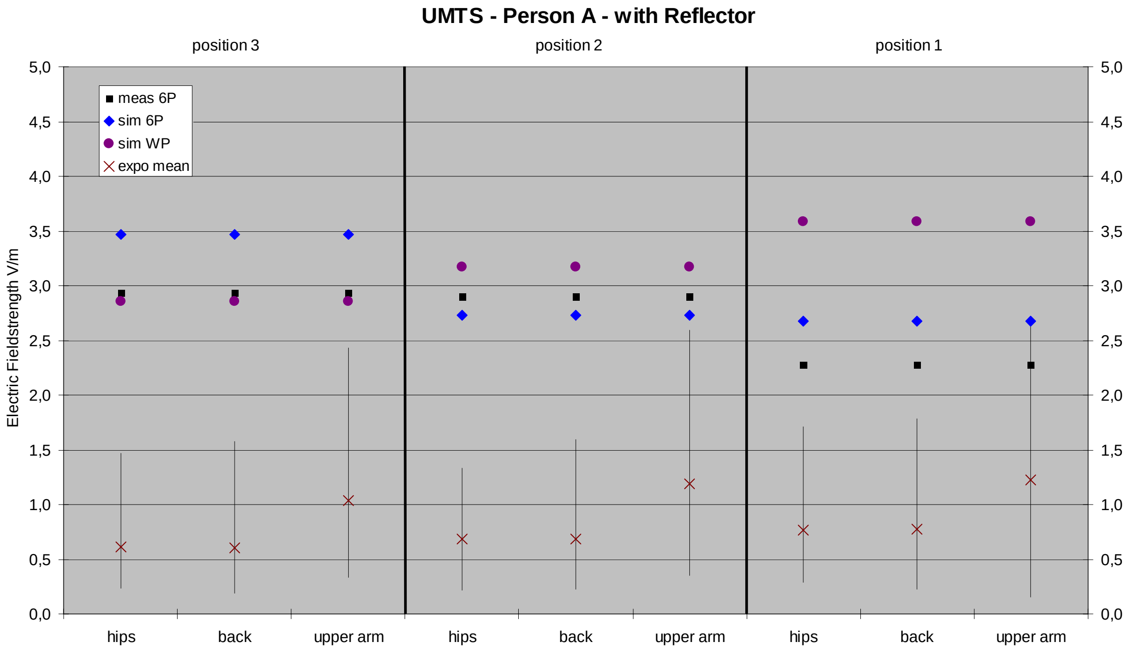

Figure 3- 23: UMTS, field strengths for person A, with reflectors in the anechoic chamber

	Position 3		
angle	hips	back	upper arm
degree	V/m	V/m	V/m
0	0.03	0.07	0.08
30	0.09	0.09	0.08
60	0.18	0.13	0.29
90	0.25	0.20	0.53
120	0.53	0.51	0.91
150	0.96	0.87	1.41
180	1.09	0.99	1.62
210	0.91	0.94	1.35
240	0.74	0.65	0.82
270	0.42	0.27	0.41
300	0.16	0.12	0.14
330	0.10	0.12	0.05
meas 6P	1.37	1.37	1.37
sim 6P	2.09	2.09	2.09
sim WP	2.04	2.04	2.04
expo mean	0.46	0.41	0.64

Table 3- 33: UMTS, field strengths for person B, without reflector in the anechoic chamber

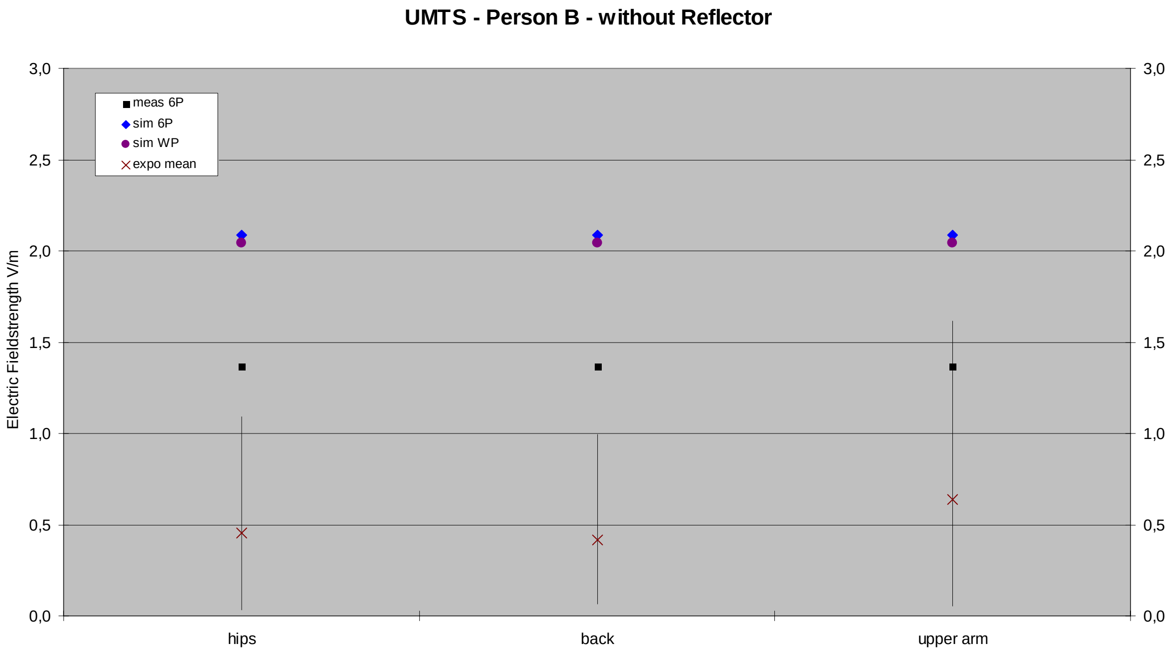

Figure 3- 24: UMTS, field strengths for person B, without reflectors in the anechoic chamber

	Position 3			Position 2			Position 1		
angle	hips	back	upper arm	hips	back	upper arm	hips	back	upper arm
degree	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m
0	0.28	0.29	0.41	0.41	0.31	0.41	0.27	0.30	0.33
30	0.28	0.26	0.30	0.34	0.35	0.36	0.31	0.25	0.50
60	0.27	0.25	0.47	0.42	0.49	0.84	0.49	0.21	0.39
90	0.61	0.27	0.94	0.97	0.52	1.55	0.34	0.59	1.37
120	0.48	1.07	0.41	0.69	1.07	0.97	0.88	0.55	1.01
150	1.29	1.13	2.08	1.79	1.62	1.80	0.96	1.01	2.79
180	0.62	1.54	2.80	1.54	0.80	1.68	1.04	1.89	3.07
210	1.39	0.99	2.45	1.15	1.29	1.40	1.44	1.73	2.39
240	1.38	1.03	1.27	1.04	0.82	1.40	1.55	0.78	1.32
270	0.28	0.21	0.78	0.56	0.20	0.46	0.66	0.35	0.80
300	0.41	0.21	0.51	0.33	0.21	0.66	0.71	0.18	0.53
330	0.44	0.22	0.65	0.53	0.22	0.55	0.42	0.23	0.22
meas 6P	2.94	2.94	2.94	2.90	2.90	2.90	2.28	2.28	2.28
sim 6P	3.46	3.46	3.46	2.73	2.73	2.73	2.67	2.67	2.67
sim WP	2.86	2.86	2.86	3.17	3.17	3.17	3.58	3.58	3.58
expo mean	0.64	0.62	1.09	0.81	0.66	1.01	0.76	0.67	1.23

Table 3- 34: UMTS, field strengths for person B, with reflector in the anechoic chamber

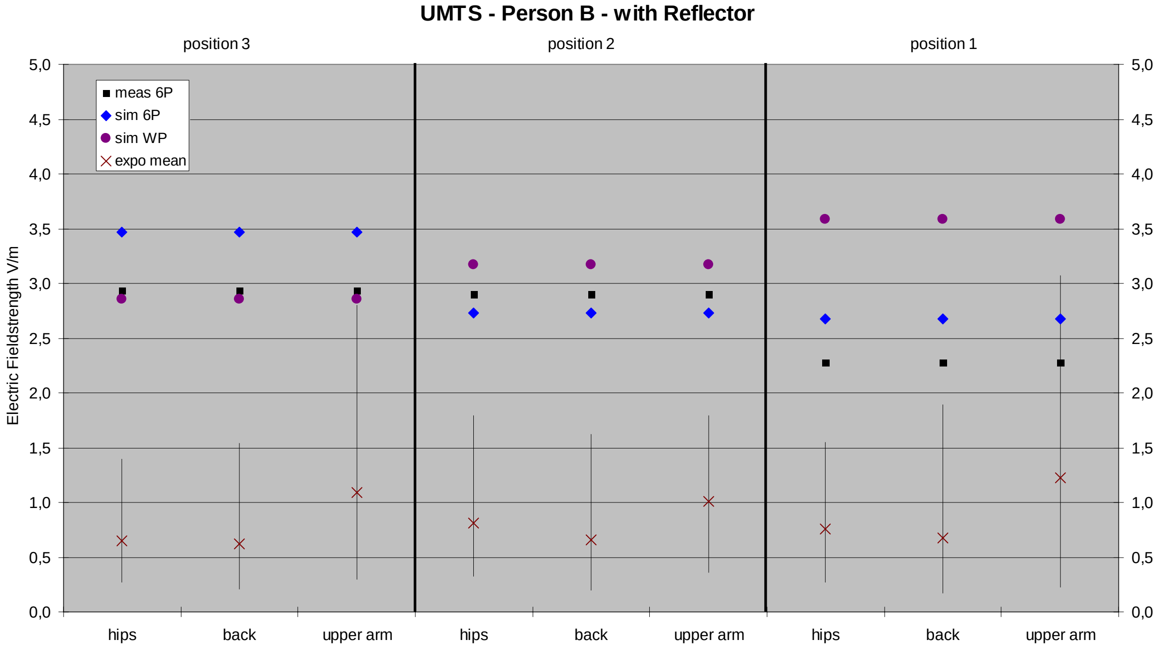

Figure 3- 25: UMTS, field strengths for person B, with reflectors in the anechoic chamber

Summary UMTS:

Table 3- 35 shows the summary of the UMTS measurements

Mean value, standard deviation, maximum and minimum are normalised to each measured Add3D value. Furthermore they have been calculated for all measured positions including both investigated conditions with and without mounted reflector inside the anechoic chamber for each part of the body. These values were split for person A and person B and are as well shown for both persons together (person A+B).

N > ref (%) shows the number of the normalised measured points in percent which are greater than its Add3D value.

Normalised standard deviation, normalised maximum and normalised minimum are the given standard deviation, maximum and minimum normalised to the respective mean value.

	Person A			Person B			Person A +B		
	hips	back	upper arm	hips	back	upper arm	hips	back	upper arm
Mean value	0.27	0.27	0.45	0.29	0.26	0.43	0.28	0.26	0.44
Standard dev.	0.18	0.21	0.33	0.20	0.22	0.35	0.19	0.21	0.34
Maximum	0.76	0.79	1.16	0.80	0.83	1.35	0.80	0.83	1.35
Minimum	0.07	0.03	0.03	0.07	0.03	0.03	0.02	0.03	0.03
N > ref (%)	0.00	0.00	6.25	0.00	0.00	10.42	0.00	0.00	8.33
Normalised standard dev.	0.65	0.77	0.75	0.69	0.83	0.80	0.67	0.80	0.77
Normalised maximum	2.78	2.94	2.60	2.75	3.20	3.13	2.83	3.14	3.07
Normalised minimum	0.27	0.12	0.06	0.25	0.12	0.06	0.08	0.12	0.06

Table 3- 35: Summary of the UMTS measurements

Table 3- 36 shows the correlations between exposimeter readings and simulations (both averaged over 6 points and over all field values of the entire volume associated with the position of the human body) versus the Add3D measurements (averaged over 6 points).

	Correlation
sim 6P	0.69
sim WP	0.93
expo mean	0.69

Table 3- 36: Correlation coefficients for UMTS

3.2.4. WLAN Results

	Position 3		
angle	hips	back	upper arm
degree	V/m	V/m	V/m
0	0.04	0.14	0.04
30	0.18	0.14	0.04
60	0.19	0.22	0.17
90	0.38	0.25	0.27
120	0.68	0.65	0.52
150	0.78	0.75	0.95
180	0.79	0.91	1.45
210	0.67	0.78	1.54
240	0.53	0.44	1.02
270	0.33	0.19	0.49
300	0.23	0.25	0.21
330	0.08	0.12	0.06
meas 6P	1.58	1.58	1.58
sim 6P	2.03	2.03	2.03
sim WP	1.99	1.99	1.99
expo mean	0.41	0.40	0.56

Table 3- 37: WLAN, test results for person B, without reflector in the anechoic chamber

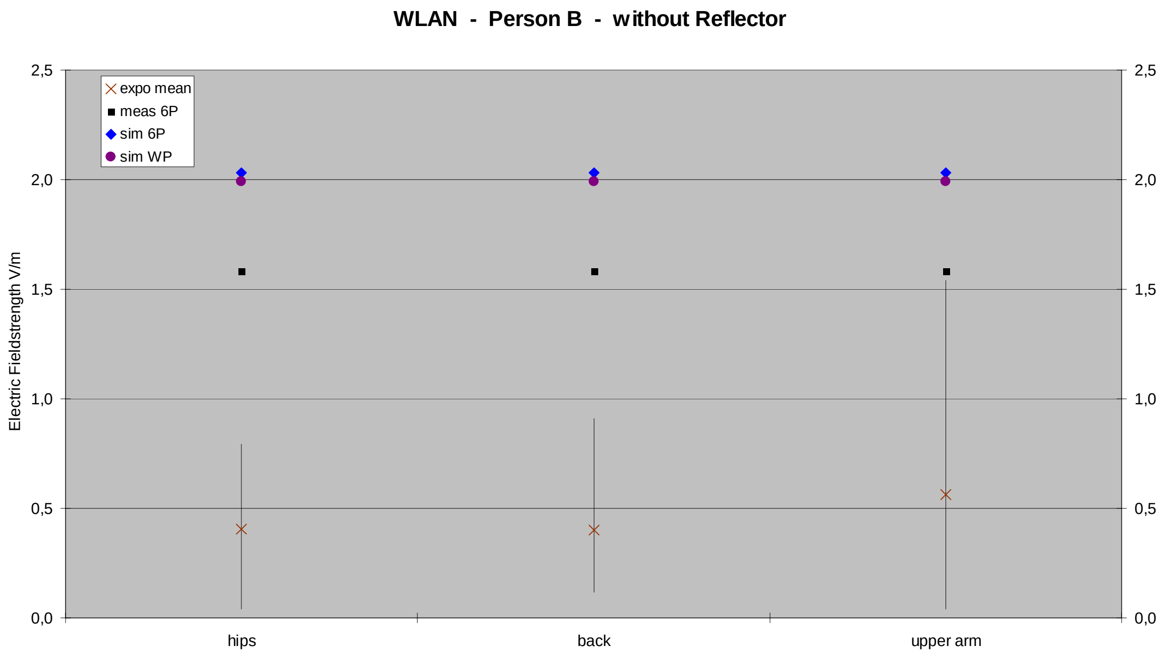

Figure 3- 26: WLAN, test results for person B, without reflectors in the anechoic chamber

3.3. Statistical Analysis of the Exposimeter Samples

The aim of this chapter is to show statistical data based on the analysis of the samples taken by the exposimeter. This is in contrast to the previous chapter, where the averages of several samples were taken as basis for the analysis. An example for this could be a number of 55 samples taken from the exposimeter at an orientation of 30°. In this chapter all samples are used for the analysis, in the previous chapter only the arithmetic mean was used for further investigations.

As already mentioned in previous chapters the aim of the project is to compare measurements from an exposimeter carried by a person with the true (measured) field value at the same place without the person being in the field.
Measurements were done in an anechoic chamber to guarantee controlled exposure conditions. With an excessive measurement campaign with 2 persons the following factors were evaluated:

- Angle: person turned around the axis in steps of 30°.
- Band (FM, GSM900, UMTS, WLAN)
- Reflector: yes/no
- Distance: 3, 2.5 or 2 m between person and transmitter
- Position were the device was carried: Antennessa: hip or back; Maschek: upper arm

For detailed descriptions please refer to chapter 3.1.

In a second measurement campaign measurements were repeated with additional 9 persons. With the Antennessa device these measurements were done only for GSM at the hip, at position 2 with reflector (see also Figure 3- 4 and Figure 3- 5). With the Maschek device measurements were done at position 2 and 3 (GSM, arm, with reflector).
Due to the faster sampling interval of 1 second more measurements per angle were obtained with Maschek than with Antennessa (sampling interval of 4 seconds). Table 3- 38 gives an overview of all samples taken in the frame of specific investigations.

	Identity											
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**Total**
	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
Angle												
0	1050	1134	135	55	55	55	55	135	134	135	135	3078
30	1050	1140	135	55	55	55	55	135	134	135	135	3084
60	1047	1137	135	55	54	55	55	135	134	135	135	3077
90	1044	1125	135	55	55	55	55	135	135	135	135	3064
120	1050	1140	135	55	55	55	55	135	135	135	135	3085
150	1050	1140	135	55	55	55	55	135	135	135	135	3085
180	1050	1140	135	55	55	55	55	135	135	135	135	3085
210	1050	1140	135	55	55	55	55	135	135	135	135	3085
240	1050	1140	135	55	55	55	55	135	135	135	135	3085
270	1050	1140	135	55	55	55	55	135	135	135	135	3085
300	1050	1140	135	55	55	55	55	135	135	135	135	3085
330	1050	1140	135	55	55	55	55	135	134	135	135	3084
Total	12591	13656	1620	660	659	660	660	1620	1616	1620	1620	36982
Band												
GSM	6831	6821	1620	660	659	660	660	1620	1616	1620	1620	24387
UKW	1440	1440	0	0	0	0	0	0	0	0	0	2880
UMTS	4320	4315	0	0	0	0	0	0	0	0	0	8635
WLAN	0	1080	0	0	0	0	0	0	0	0	0	1080
Total	12591	13656	1620	660	659	660	660	1620	1616	1620	1620	36982
Distance												
2m	3717	3708	0	0	0	0	0	0	0	0	0	7425
2,5m	3717	3711	900	420	420	420	420	900	900	900	900	13608
3m	5157	6237	720	240	239	240	240	720	716	720	720	15949
Total	12591	13656	1620	660	659	660	660	1620	1616	1620	1620	36982
Body												
back	2520	2695	0	0	0	0	0	0	0	0	0	5215
hip	2520	2700	180	180	180	180	180	180	180	180	180	6840
arm	7551	8261	1440	480	479	480	480	1440	1436	1440	1440	24927
Total	12591	13656	1620	660	659	660	660	1620	1616	1620	1620	36982
Reflector												
0	5031	6101	0	0	0	0	0	0	0	0	0	11132
1	7560	7555	1620	660	659	660	660	1620	1616	1620	1620	25850
Total	12591	13656	1620	660	659	660	660	1620	1616	1620	1620	36982

Table 3- 38: Overview on the number of samples taken to investigate the impact of the angle, band, distance, location of the exposimeter on the body and reflector on the exposimeter readings

The letter in the line identity gives the code of a specific person being exposed, e.g. code “h”. The lines with the angle give the information on the number of samples being taken in a certain orientation of a specific test subject, e.g. 1050 test samples were taken by person “a” at an angle of 30°, whereas only 135 samples were taken by person “k”. The large difference results from the fact that person “k” was only exposed due to the GSM 900 downlink frequency, whereas person “a” was exposed in all frequency bands and at all three positions. The approach for the attributes band, distance, location on the body and reflector is the same. “Band” gives information on the frequency band examined, e.g. GSM. The “distance” is defined from the transmitting antenna to the central axis of the exposed person, e.g. 2.5 m. “Body” indicates where the exposimeter was located on the body, e.g. the back. Finally “reflector” tells if reflectors were used for the specific part of the investigations to obtain rather homogeneous or heterogeneous exposure conditions, e.g. 0 stands for no reflectors used. In total 36.982 samples were taken by all persons together.

3.3.1. Aim of the data analysis

The aim of the data analysis can be summarised as described below:

1. To predict the average underestimation of the exposimeter measurements for different frequency bands, body position with and without reflectors.
2. To investigate the association between the exposimeter reading and body measures (e.g. BMI)

3.3.2. Methods

For our analyses we used the natural logarithm of the ratio between exposimeter measurements (in V/m) and true value (in V/m). All descriptive analyses (e.g. calculation of mean values) were performed on the log scale and the results were back-transformed. In addition, we performed multiple linear regression models to predict underestimation of the exposimeter for different frequency bands, body position with and without reflectors. Separate models were done for Antennessa and Maschek measurements. Dependent variable was the log-transformed ratio between exposimeter measurements (in V/m) and true value (in V/m). A sensitivity analysis showed that an analysis based on the ratios of the power flux density (W/m²) would yield similar results. Explanatory factors included in the model were: frequency band, distance, angle and reflector. In the Antennessa model also body position was included. Model coefficients were back-transformed. Due to the log transformation of the dependent variable the model is multiplicative. Thus, the back-transformed coefficients correspond to factors and the predicted mean values correspond to geometric means. Based on the regression model outputs predictions for the average underestimation were done for different frequency bands and body position with and without reflectors. Predictions were adjusted for ID, distance and angle.

It was hypothesized that the ratio between measured and true EMF is associated with body masses such as body mass index, (BMI) or broadness of the hip. These associations were investigated based on the measurements for GSM at a distance of 2.5m with reflector which were performed with a total of 11 individuals either at the hip (Antennessa) or at the upper arm (Maschek). For each individual, we calculated the mean value of the log-transformed ratios between measured and true EMF for the angle=0° and angle=180° separately as well as for all angles together. These log-transformed ratios were used as dependent variable in regression models. Explanatory factors were BMI, broadness of the hip and length. It was also tested whether there was indication of an interaction between BMI and gender.

3.3.3. Results

The ratio between the exposimeter readings and the reference values was examined. The reference values were averages of the field strengths measured at the six locations according to the method specified in chapter 3.1 (true measurements). Table 3- 40 gives an overview about the median, mean and standard deviation (SD) of the ratio between exposimeter measurements and the reference value. Note that the mean values correspond to geometric means because they were obtained from log-transformed ratios (back-transformed).

	N	Median	Mean	Sd
Angle				
0	2184	0.15	0.12	0.16
30	2190	0.13	0.12	0.16
60	2184	0.18	0.19	0.20
90	2169	0.35	0.31	0.28
120	2190	0.5	0.44	0.45
150	2190	0.69	0.68	0.49
180	2190	0.8	0.73	0.48
210	2190	0.78	0.68	0.40
240	2190	0.56	0.50	0.43
270	2190	0.33	0.29	0.22
300	2190	0.22	0.19	0.18
330	2190	0.18	0.14	0.15
Total	26247	0.34	0.30	0.41
Band				
GSM	13652	0.47	0.44	0.45
FM	2880	0.53	0.55	0.40
UMTS	8635	0.14	0.14	0.17
WLAN	1080	0.19	0.17	0.27
Total	26247	0.34	0.30	0.41
Distance				
2m	7425	0.33	0.31	0.34
2.5m	7428	0.34	0.31	0.35
3m	11394	0.35	0.28	0.49
Total	26247	0.34	0.30	0.41

Table 3- 39a: Number, median, geometric mean and standard deviation (sd) for the samples taken by the exposimeter depending on orientation of the probands (angle), band,distance of the volunteer to the transmitting antenna, location of the exposimeter on the body (e.g. back), reflector and identity (id)

Body				
Back	5215	0.39	0.34	0.45
Hip	5220	0.37	0.33	0.40
Upper arm	15812	0.3	0.28	0.40
Total	26247	0.34	0.30	0.41
Reflector				
0	11132	0.4	0.32	0.36
1	15115	0.31	0.29	0.45
Total	26247	0.34	0.30	0.41
Identity				
a	12591	0.39	0.32	0.40
b	13656	0.3	0.28	0.42
Total	26247	0.34	0.30	0.41

Table 3- 40b: Number, median, geometric mean and standard deviation (sd) for the samples taken by the exposimeter depending on orientation of the probands (angle), band,distance of the volunteer to the transmitting antenna, location of the exposimeter on the body (e.g. back), reflector and identity (id)

Exposure ratios				
Reflector=1	**Antennessa**		**Maschek**	
Band	back	hip	upper arm	Total
GSM	0.612	0.506	0.446	0.464
FM	0.505	0.622		0.56
UMTS	0.1	0.113	0.169	0.145
Total	0.314	0.38	0.352	0.352

Reflector=0				
Band	back	hip	upper arm	Total
GSM	0.608	0.473	0.394	0.432
FM	0.513	0.549		0.531
UMTS	0.102	0.118	0.151	0.136
WLAN	0.175	0.168	0.172	0.172
Total	0.381	0.344	0.299	0.32

Table 3- 41: Average ratio between exposimeter measurements and reference value for different combinations of explanatory variables based on the measured samples Mean values for all different angles, distances and individuals

Table 3- 41 gives an overview on the relation between exposimeter measurements and reference field strengths. It is interesting to notice that in all cases the exposimeter underestimate exposure. This effect is mostly pronounced in the UMTS band. No major differences between reflector and no reflector used, back and hip were found.
Table 3- 42 shows the coefficient from the multivariable regression model of the Antennessa measurements. Antennessa measurements are highly influenced by the angle of the body with respect to the source (reference angle 0°). Shielding the EMF source with the body results in four times lower measurements than without shielding. There are considerable differences between the individuals (reference individual a). Measurements of the person with most underestimation were on average 63%

lower than measurements of the person with least underestimation (0.663/1.056). There were also considerable differences between the frequency bands. Least underestimated is the GSM band and UKW. UMTS and WLAN are considerably more underestimated. Interestingly, underestimation at 2.5 m is larger than at 3 m. Lowest underestimation is found at 2 m distance. There is no significant difference between hip and back. With reflector true values are less underestimated than without.

Variable	Factor	lower 95%CI	upper 95%CI	p-value
Angle Ref: 180°	1 [Ref.]			
0°	0.245	0.236	0.255	0
30°	0.280	0.269	0.292	0
60°	0.384	0.369	0.400	0
90°	0.543	0.521	0.565	0
120°	0.724	0.696	0.754	0
150°	0.879	0.845	0.916	0
210°	0.841	0.808	0.876	0
240°	0.660	0.634	0.688	0
270°	0.421	0.404	0.438	0
300°	0.344	0.330	0.358	0
330°	0.266	0.256	0.277	0
Identity: Ref: a	1 [Ref.]			
id==b	0.797	0.783	0.811	0
id==c	0.909	0.847	0.977	0.0093
id==d	0.873	0.813	0.938	0.0002
id==e	0.663	0.617	0.712	0
id==f	0.832	0.775	0.894	0
id==g	0.816	0.760	0.877	0
id==h	0.923	0.859	0.992	0.0285
id==i	1.056	0.983	1.134	0.1350
id==j	0.906	0.843	0.973	0.0069
id==k	0.945	0.880	1.016	0.1241
Band: Ref: GSM	1 [Ref.]			
FM	0.993	0.971	1.016	0.5615
UMTS	0.192	0.188	0.197	0
WLAN	0.340	0.323	0.359	0
Distance: Ref: 2m	1 [Ref.]			
2.5m	0.982	0.958	1.005	0.125
3m	1.088	1.063	1.113	0
Body: Ref: back	1 [Ref.]			
hip	0.984	0.967	1.002	0.0774
Reflector	1.047	1.026	1.069	0
Constant	1.192	1.148	1.238	0

Table 3- 42: Multiple linear regression model of the Antennessa measurements[1]

[1] How to interpret the coefficient of the model? The factor const refers to the average underestimation if all other factors are set to the reference value (i.e. angle=180; id=a, band=GSM, position=2m, body=back and reflector=0). By multiplying the factors one can obtain the underestimation for each scenario. Example: I would like to know the underestimation for WLAN at angle=90 for id=a at the back at position 2.5 m distance with reflector: 0.543*1*0.340*0.982*1*1.192=21.6%

If an individual carries an exposimeter over a sufficient time period one can assume that distance and angle to the source are randomly varying. Thus, we predicted the average underestimation of the exposimeter over all angles and distances (Table 3- 43). In general model predictions are similar to the simple mean values (see Table 3- 41) for each scenario. However, the model predicts similar values for the back and the hip, whereas the simple mean values for those two sites were different.

Band	Relation of the exposimeter reafing to exposure Reflector (0 /1) and body location of exposimeter: 0		1	
	Back	Hip	Back	Hip
GSM	.525 [.508,.542]	.516 [.502,.530]	549 [.535,.565]	.528 [.518,.538]
FM	.555 [.533,.578]	.548 [.526,.567]	.546 [.528,.564]	.537 [.522,.553]
UMTS	.107 [.103,.112]	.106 [.102,.110]	.106 [.103,.110]	.104 [.101,.107]
WLAN	.190 [.180,.2014]	.187 [.177,.198]		

Table 3- 43: Average underestimation of the Antennessa measurements compared to the real exposure for different frequency bands, body position with and without reflectors (values in square brackets are 95% confidence intervals)

There is little difference between the predictions with and without reflectors and whether the exposimeter is carried on the hip or at the back. Thus, overall frequency band specific correction factors were calculated for the ratio between exposimeter measurements and true field in the absence of a body (Table 3- 44). On obtains a correction factor of 0.54 for UKW, 0.53 for GSM900, 0.11 for UMTS and 0.19 for WLAN.

Band	Relation	CI+	CI-
GSM	.529	[.518	.540]
FM	.544	[.527	.561]
UMTS	.105	[.102	.109]
WLAN	.189	[.179	.199]

Table 3- 44: Frequency band relation for Antennessa measurements compared to real exposure including 95% confidence intervals (square brackets)

Table 3- 45 shows the coefficient from the multivariable regression model of the Maschek exposimeter measurements. The general picture is the same as for the Antennessa measurements, however underestimation is larger on average (const=15%). The angle has a larger influence on the Maschek measurements than on the Antennessa measurements. The between subject variability is similar to that of the Antennessa (min/max=65%). UMTS underestimation is less pronounced than with Antennessa. Reflector and distance show somewhat more impact on the measurements.

Variable	Factor	lower 95%CI	upper 95%CI	p-value
Angle: Ref: 180	1 [Ref.]			
0	0.157	0.151	0.162	0
30	0.149	0.144	0.154	0
60	0.255	0.246	0.263	0
90	0.377	0.365	0.391	0
120	0.580	0.561	0.601	0
150	0.813	0.785	0.841	0
210	0.812	0.784	0.840	0
240	0.666	0.643	0.689	0
270	0.397	0.384	0.411	0
300	0.263	0.254	0.272	0
330	0.186	0.179	0.192	0
Identity: Ref: a	1 [Ref.]			
id==b	0.978	0.961	0.996	0.0159
id==c	1.320	1.275	1.367	0
id==d	1.126	1.067	1.188	0
id==e	0.963	0.913	1.016	0.1719
id==f	0.907	0.859	0.957	0.0004
id==g	1.017	0.964	1.073	0.5399
id==h	1.089	1.051	1.127	0
id==i	0.962	0.929	0.996	0.0307
id==j	1.207	1.166	1.250	0
id==k	0.864	0.834	0.895	0
Band: Ref: GSM	1 [Ref.]			
UMTS	0.385	0.378	0.393	0
WLAN	0.397	0.379	0.415	0
Distance: Ref: 2m	1 [Ref.]			
2.5m	0.955	0.935	0.976	0
3m	1.208	1.183	1.234	0
Reflector	1.111	1.090	1.132	0
Constant	0.951	0.921	0.982	0.002

Table 3- 45: Multiple linear regression model of the Maschek measurements

Table 3- 46 and Table 3- 47 show the correction factors for the Maschek exposimeter measurements with and without reflector as well as the average values.

Band	reflector 0	reflector 1
GSM	.398 [.389,.407]	.449 [.444,.454]
UMTS	.176 [.171,.182]	.170 [.166,.174]
WLAN	.182 [.174,.190]	

Table 3- 46: Average underestimation of the Maschek measurements for different frequency bands, body position with and without reflectors (values in square brackets are 95% confidence intervals)

Band	Relation	lb	ub
GSM	.435	[.429	.440]
UMTS	.172	[.168	.176]
WLAN	.182	[.174	.190]

Table 3- 47: Frequency band relation for Maschek measurements including 95% confidence intervals (square brackets).

3.3.4. Association between body mass and exposimeter measurements

Body measures had a significant effect on the measurements if the EMF source was shielded by the body; i.e. at small angles. Table 3- 48 shows the regression coefficients for different body measures and Antennessa measurements. Strongest association was found for BMI at angle=0°. Per unit increase in BMI, the measured EMF was reduced by a factor of 0.925 (95% confidence interval: 0.874-0.980). Each kilogram increase in bodyweight reduced measured EMF by a factor of 0.985 (95% CI: 0.973-0.996). There was no interaction between gender and BMI. Thus, one can conclude that the association between Antennessa measurements and BMI is the same for men and women, although the study sample is quite small to make final conclusion.

	coefficient	lower 95%CI	upper 95%CI	p-value
BMI	0.925	0.874	0.980	0.013
Weight	0.985	0.973	0.996	0.014
Height	0.982	0.961	1.002	0.075
Hips_l	0.801	0.668	0.960	0.022
Hips_h	0.994	0.980	1.009	0.421
Back_b	0.935	0.882	0.991	0.028
Male	0.713	0.459	1.108	0.116

Table 3- 48: Association between body measures and the ratio between Antennessa measurements and true EMF at angle=0° (gre=size) h=high; l=length

h...distance from ground to exposimeter
b...distance from central axis of body to exposimeter

For mean values over all angles (Table 3- 49) the BMI was not significantly associated with the ratio of Antennessa measurements to true values (p=0.31), although the trend was the same as for the angel=0°. Measurements at angle=180° were not associated with body measures (Figure 3-1). At angle=150° the strongest positive correlation between BMI and measurements were found, but still far from significant (p=0.57).

	coefficient	lower 95%CI	upper 95%CI	p-value
BMI	0.986	0.959	1.015	0.307
Weight	0.9989	0.993	1.005	0.698
Size	1.002	0.993	1.011	0.630
Hips_l	0.981	0.896	1.074	0.646
	pred_ant			
Hips_h	0.999	0.994	1.005	0.809
	pred_ant			
Back_b	0.990	0.963	1.018	0.446
	pred_ant			
Male	1.024	0.848	1.237	0.782

Table 3- 49: Association between body measures and the ratio between Antennessa measurements and true EMF for all angels° (gre=size) h=high; l=length

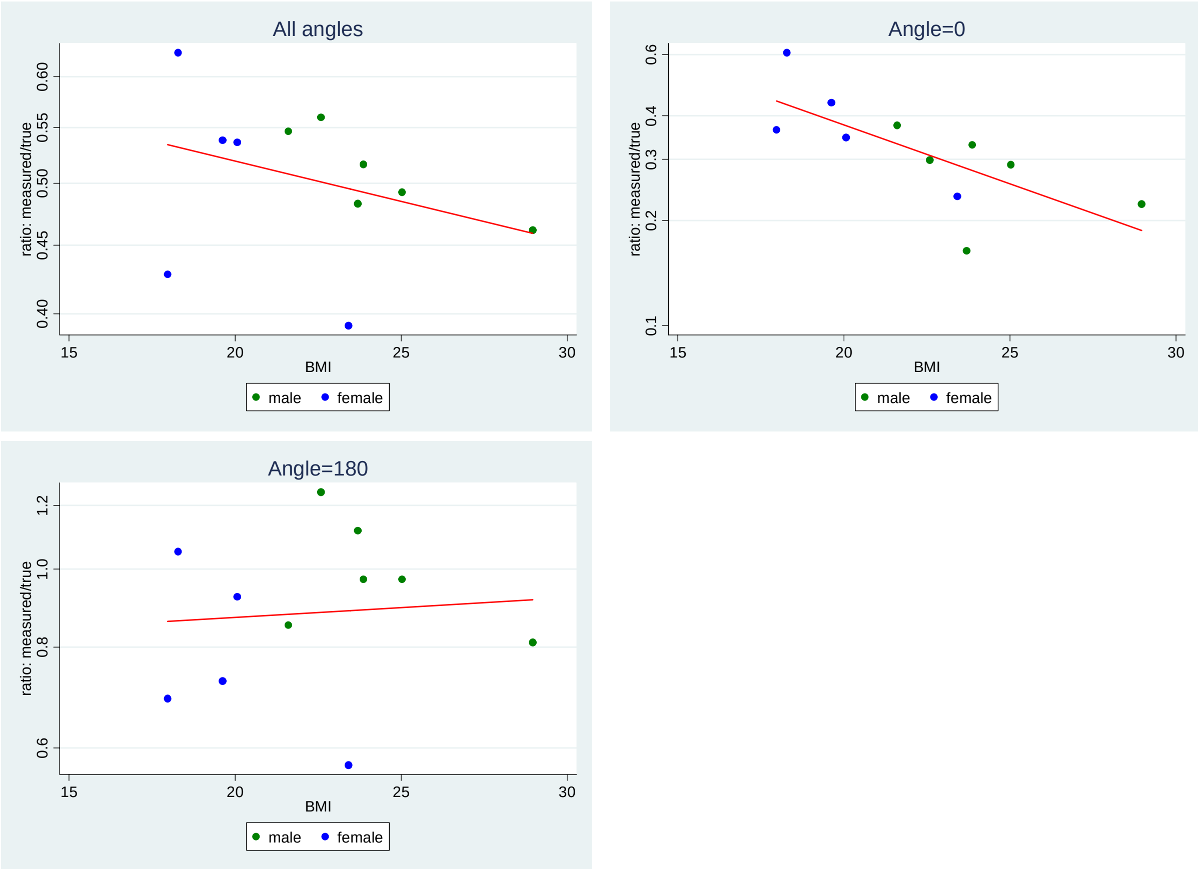

Figure 3- 27: Association between BMI and the ratio of the Antennessa measurements over true EMF for different angles (0°, 180°, average). Measurements at the hips: GSM, distance 2.5m with reflector

On average (all angels) we observed no significant associations of the Maschek measurements to any body measures were found although in tendency measured values were decreasing with increasing BMI (Figure 3- 28).

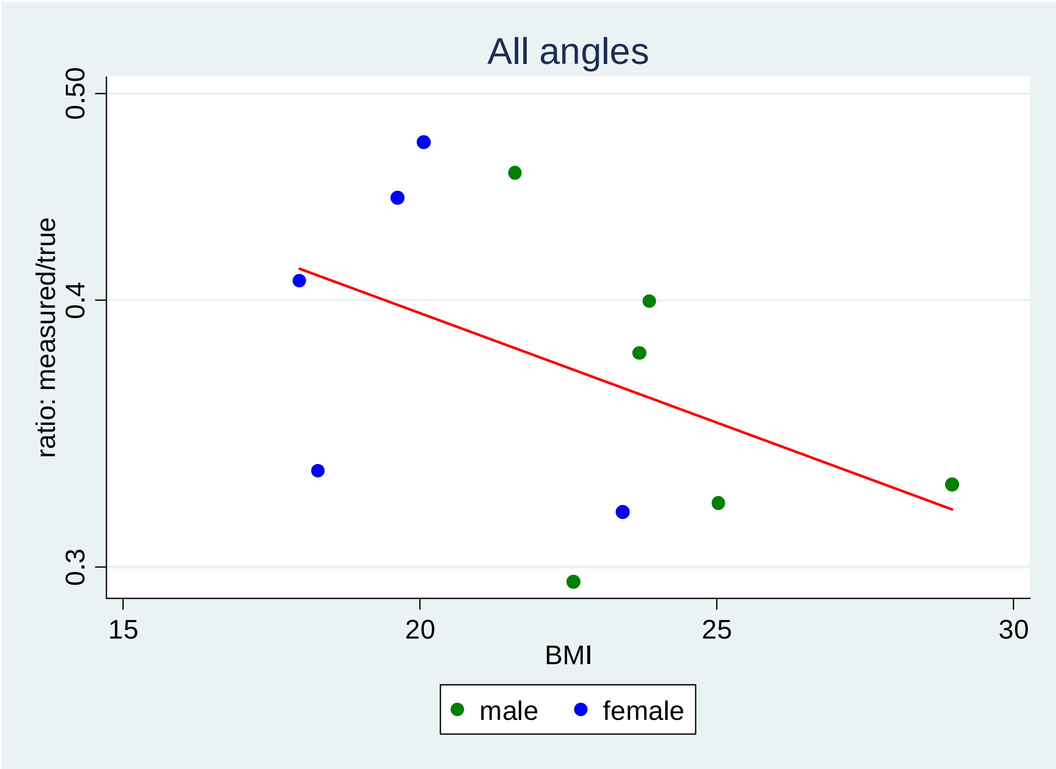

Figure 3- 28: Association between BMI and the ratio of the Maschek measurements over true EMF for all angles combined. Measurements: GSM at distance 2.5m with reflector

The lack of isotropy of the Maschek device makes it plausible that body mass may affect other angles than 0° more. From table can be concluded that measurements at angle 270°, 300° and 330° degrees were significantly associated with body mass index ($p<0.05$). The ratio decreased by factor of 0.91 (300°) or 0.92° (330°) per unit increase in the BMI. There were no significant positive correlations.

	coefficient	lower 95%CI	upper 95%CI	p-value
masch_0	1.002	0.884	1.136	0.968
masch_30	1.007	0.862	1.178	0.917
masch_60	0.993	0.896	1.100	0.881
masch_90	0.954	0.838	1.085	0.426
masch_120	1.009	0.973	1.0476	0.584
masch_150	1.011	0.891	1.147	0.849
masch_180	1.002	0.968	1.038	0.897
masch_210	1.000	0.944	1.058	0.988
masch_240	0.979	0.902	1.063	0.569
masch_270	0.939	0.884	0.998	0.044
masch_300	0.914	0.875	0.955	0.001
masch_330	0.915	0.881	0.951	0.0005
pred_masch	0.977	0.944	1.011	0.155

Table 3- 50: Association between BMI and the ratio of the Maschek measurements over true EMF for all angles

4. Investigations of the correlation between exposimeter reading and averaged field levels by numerical measurements

4.1. Description of the Investigated Scenarios

The numerical simulations of the human body for evaluating the correlation between exposimeter reading and averaged field levels were performed applying the FDTD-tool SEMCAD X (FDTD = Finite Differences in Time Domain[2]). In SEMCAD a model of the human body with defined exposimeter positions was calculated.
The applied body model consists of 113 different tissues. For the calculation the required dielectric properties have to be assigned to all tissues. The dielectric properties of the human tissues change depending on the frequency, so for each calculated frequency a separate assignment of the dielectric properties has to be done. The assigned tissue properties for all applied frequencies base on the data of C. Gabriel[3] and are free available online (http://niremf.ifac.cnr.it/tissprop/).
The spatial resolution of the human model was 2.5 mm at all investigated frequencies.

Figure 4- 1: Human body model for the calculations in SEMCAD. The model consists of 113 different tissues with the corresponding dielectric properties assigned.

[2] Basics for the FDTD-Method:
Allen Taflove and Susan C. Hagness. *Computational Electrodynamics: The Finite-Difference Time-Domain Method*. Artech House, 2000.

[3] Gabriel, C.; Gabriel, S. (1996): "Compilation of the Dielectric Properties of Body Tissues at RF and Microwave Frequencies"

The exposimeter measurements were mimicked in the simulations by evaluating the averaged electric field strength in the volume at the exposimeter position near the human body. Therefore different sensors[4] were defined at the different exposimeter positions using the SEMCAD platform. The volume of the sensors is approximately equivalent to the active antenna volume of the respective exposimeter. For the exposimeter of Antennessa a larger volume was chosen compared to the exposimeter of Maschek. The Maschek exposimeter was only positioned on the upper arms of the model, the Antennessa on 8 other positions on the body, located around the hips and on the back. All 10 exposimeter positions are shown in Figure 4- 2 with their denotation.

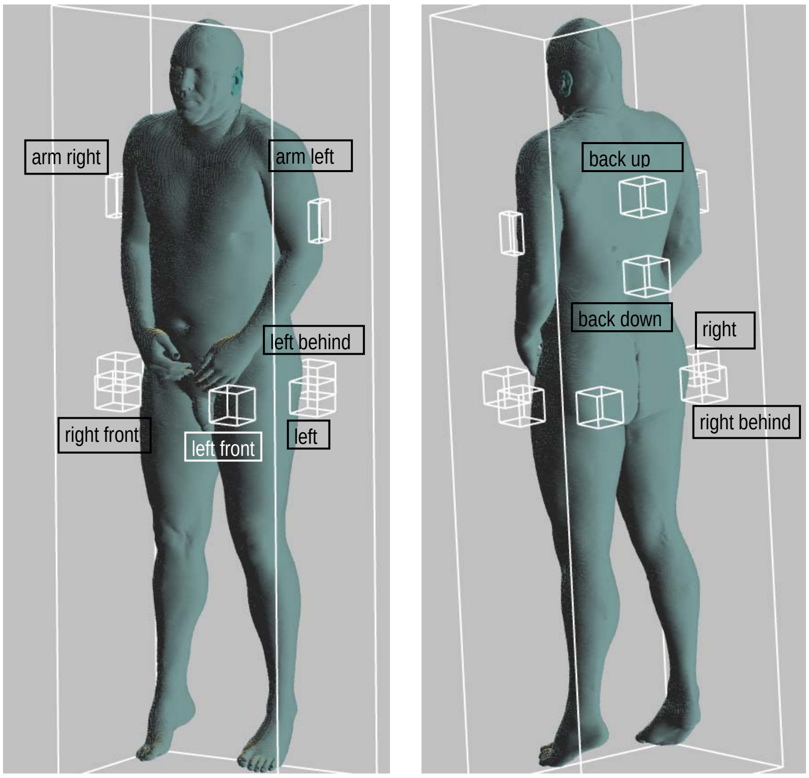

Figure 4- 2: Position and denotation of the exposimeter positions near the human body.

From the resulting E-field of the exposimeter sensors according to Figure 4- 2 the quadratic mean and the linear mean was calculated to get a corresponding “exposimeter measurement result” from the simulations.

At the frequencies of 100 MHz, 946 MHz and 2140 MHz the so called “4-Square Scenario” was applied, which was chosen to be representative for realistic exposure conditions for FM, GSM and UMTS. Four cuboids (40 m x 40 m) with a height of 20 m represent buildings with the enclosed street canyons.
The field on the exposimeter sensor positions is evaluated in two steps: The spacious field distribution of the whole 4 cuboids scenario is calculated using the ray-tracing-tool “Wireless Insite”. With the results of the Wireless Insite calculation the simulations with SEMCAD are set up, to calculate the local E-field on the sensor positions near the body (see Figure 4- 2). 21 different locations for the human model were chosen to deliver results which can be applied in SEMCAD to calculate the electric field strength at the location of the human body (not being present) and at the location of the antennas of the exposimeters

[4] A sensor is a defined volume, where the results of the calculation of E- and H-field is recorded separately.

close to the model of the human body (being present) to investigate the relation between whole body exposure and exposimeter reading (see also Preiner et al 2006). Both LOS (Line Of Sight) and NLOS (Non Line Of Sight) conditions were investigated in this basically simple scenario. Different heights of the receiver grids represent locations (positions of persons) on the ground (1 m) or on the balcony (10 m) or even on the rooftop (21 m – 1 m above the rooftop). Figure 4- 3 shows the examined scenario where the small black squares represent the receiver grids and therefore the position of the person under investigation. The dimensions of the scenario can be seen in Figure 4- 4.

There is only one transmitter in the simulation, which is located in a height of 23m on the rooftop (TX1). All transmitters at all frequencies have dipole characteristic (vertical standing) with a transmitting power of 1 W assigned to. Base stations mounted on rooftops are often located on the corner of building tops therefore this was considered as a typical scenario set up.

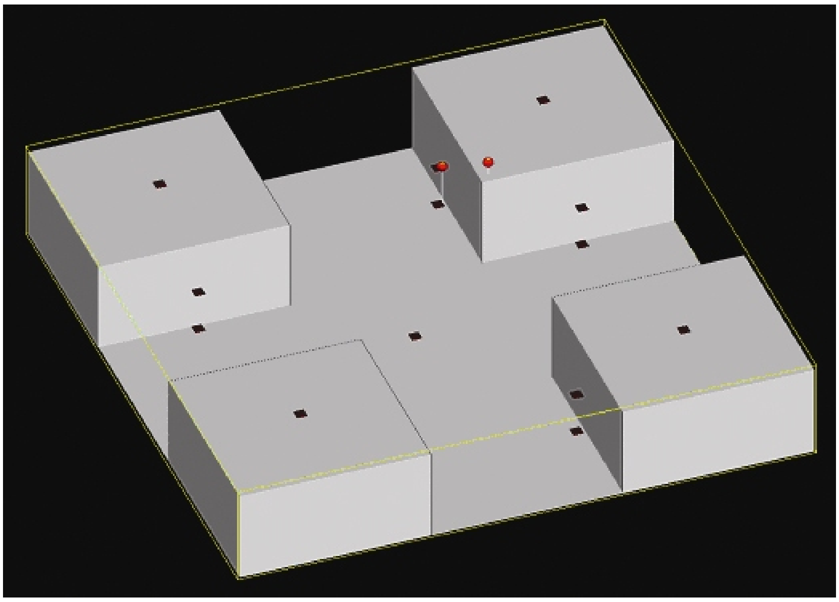

Figure 4- 3: Scenario with four cuboids (height 20 m) representing buildings with the enclosed street canyons. The antennas are positioned on top and on the side of one building (red spheroids). Locations under investigation corresponding to the location of an exposed person are marked with black squares.

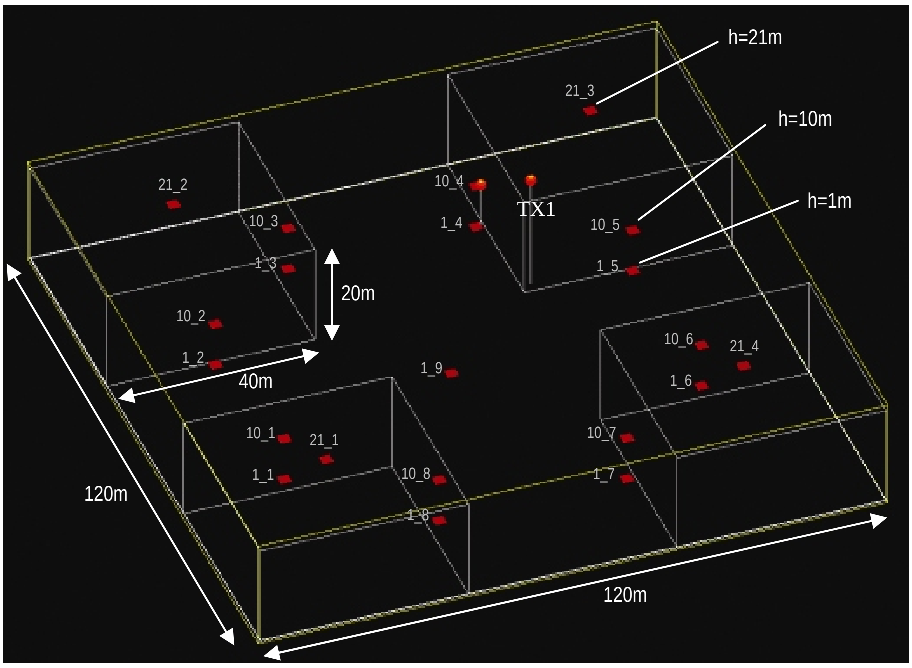

Figure 4- 4: Dimensions of the scenario with the receiver grids located in a height of 1 m, 10 m and 21 m indicated by the first number (*height_index*).

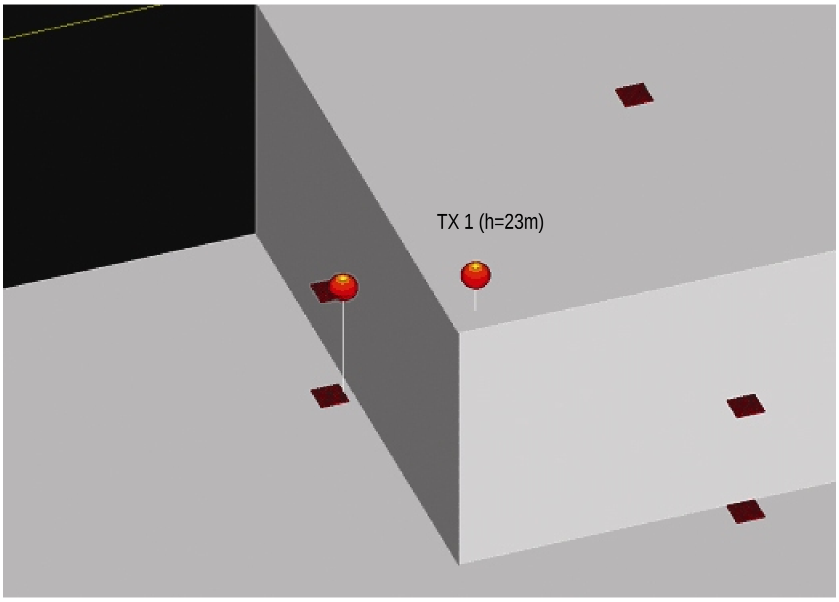

Figure 4- 5: Transmitting antennas: TX1 in a height of 23 m.

To generate information which is used later on for simulations using the *SEMCAD* platform, receiver grids with a dimension of 2 m x 2 m with a grid step of 10cm were chosen to provide the data needed. In sum 21 receiver grids were positioned in the whole scenario: 9 in a height of 1 m (two on two sides of each building and one in the middle of the ground), 8 in a height of 10 m (two on two sides of each building) and 4 on top of each building (in the centre of each building top), see Figure 4- 3 and Figure 4- 4. Figure 4- 6 and Figure 4- 7 are showing the propagation paths coming from the transmitter to one of the receiver grids (location of exposure), where Figure 4- 6 is a LOS (Line of Sight) and the Figure 4- 7 a NLOS (None Line of Sight) position. Due to reflections on the building fronts and on the ground, rays from several different directions are reaching the receiver grids with different intensity, direction and time of arrival. For the centre position of each receiver grid the information on the incoming rays (angles, intensity and time of arrival) were used as input information in SEMCAD for recreating the scenario by plane waves. Due to the fact that the time of arrival was considered, the phase shift between the incoming rays was taken into account.

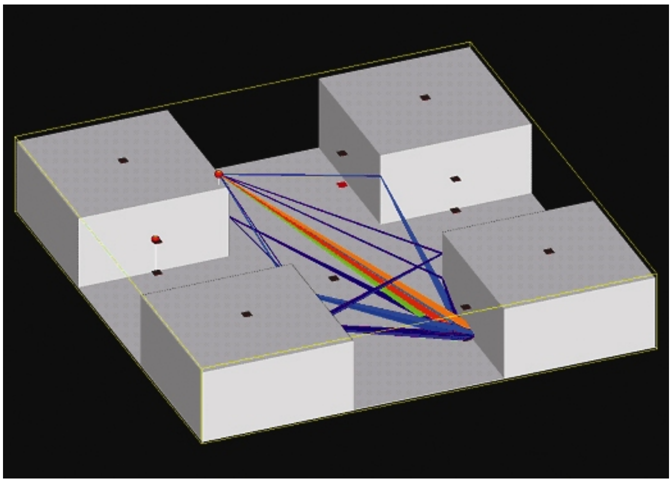

Figure 4- 6: Propagation paths at receiver grid 1_1 (Line Of Sight Conditions, LOS).

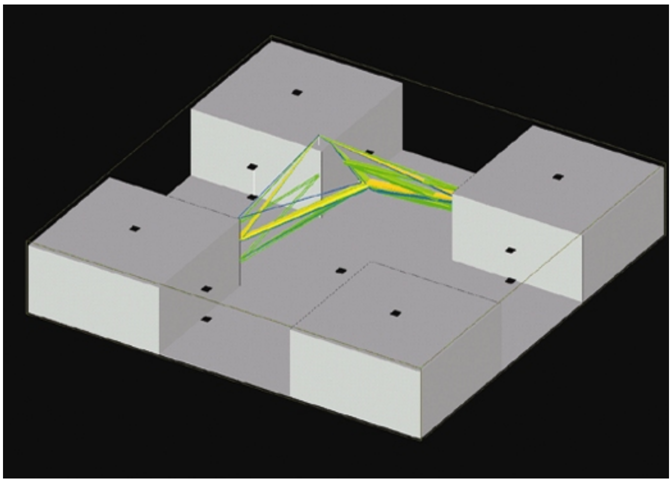

Figure 4- 7: Propagation paths of receiver grid 5_1 (Non Line Of Sight Conditions, NLOS).

The information obtained by the Wireless Insite simulations is used to expose the phantom with different incoming electromagnetic waves using the platform SEMCAD to derive the relation between exposimeter reading and real exposure for multipath, i.e. heterogeneous exposure conditions. The different incoming electromagnetic waves are modelled by “plane wave sources” in SEMCAD.

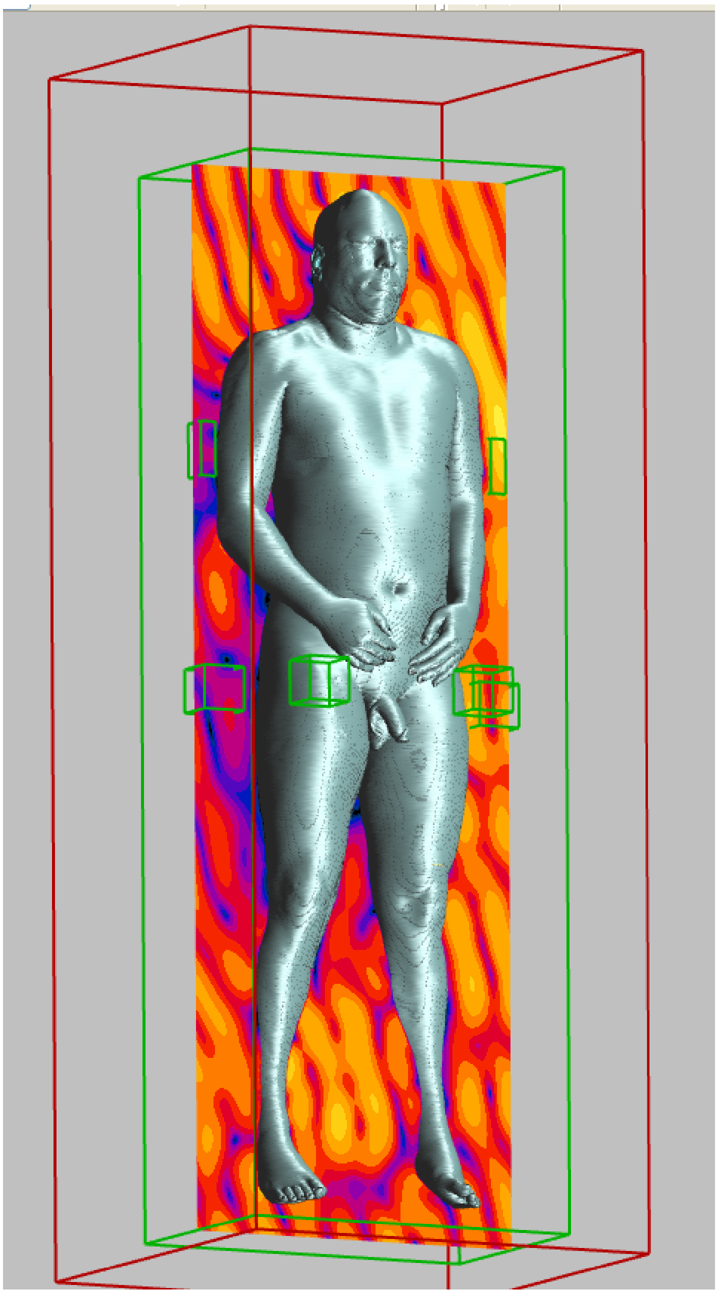

Figure 4- 8: E-field of SEMCAD simulation for the 4-Square Scenario. The red cuboid represents the 10 overlayed plane wave sources, which emulate the incoming propagation paths.

At the WLAN-frequency of 2,450 MHz another scenario was applied, because it is not typical to transmit WLAN from the rooftop. For WLAN it was considered as more typical to investigate an indoor scenario with one access point. In Figure 4- 9 the selected scenario for WLAN is shown. It mimics a small coffeehouse with a WLAN transmitter. The body model is positioned at 7 different places and the transmitter is positioned in 3 different places in the coffeehouse, this gives a total of 21 investigated scenarios. Two phantom positions are behind the bar, and 5 in front of the bar and between the tables and chairs. The transmitter is positioned one time under the bar and two times on the ceiling. The transmitter is always modelled as a vertical standing dipole (see Figure 4- 10) with a transmitting power of 1 W. This scenario is small enough to be calculated directly in SEMCAD, therefore Wireless Insite was not used for these scenarios. The analysis of the exposimeter data was done in the same way than at the other frequencies.

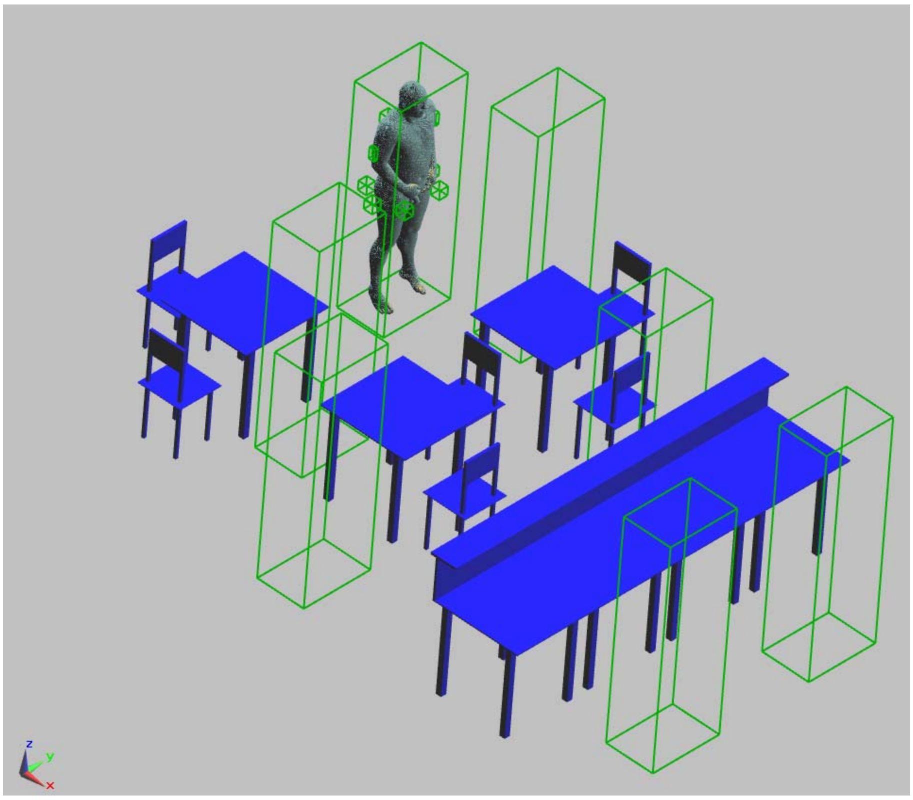

Figure 4- 9: “Coffeehouse” scenario simulated in SEMCAD. The sensors represent the 7 different simulated positions of the human model in the coffeehouse.

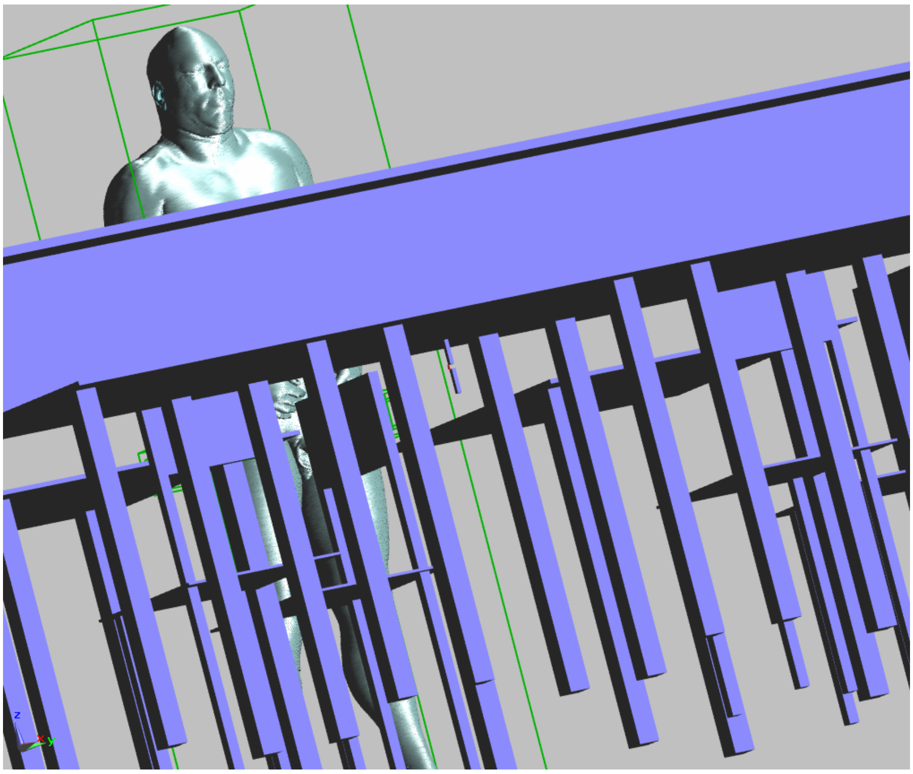

Figure 4- 10: Position of the WLAN antenna under the bar. The antenna is modelled as a vertical standing dipole.

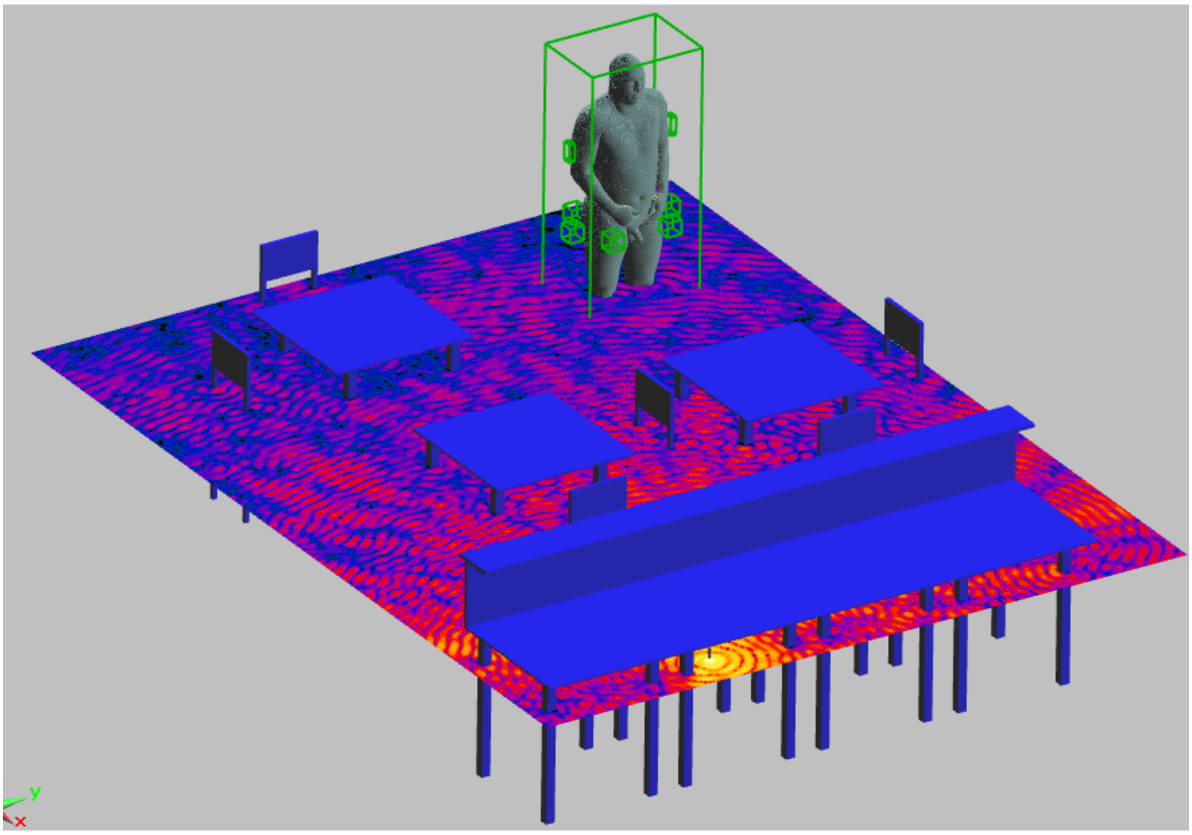

Figure 4- 11: E-field distribution in the small coffeehouse at the scenario with the antenna under the bar

4.2. Results

4.2.1. Results for 946 MHz (GSM)

In this chapter the results of the exposimeter simulations are shown for all examined frequencies. The GSM results at 946 MHz are shown in more detail (representative for all investigated frequencies), to show the handling of the data. For the other frequencies the final results are shown.

Linear averaged	Whole Body	arm left	arm right	left	left behind	left front	right	right behind	right front	back up	back down
946 MHz 1m_1	0,115	0,037	0,026	0,066	0,145	0,119	0,025	0,086	0,048	0,099	0,118
946 MHz 1m_2	0,146	0,119	0,033	0,194	0,164	0,162	0,026	0,070	0,052	0,080	0,088
946 MHz 1m_3	0,156	0,089	0,065	0,196	0,139	0,176	0,133	0,094	0,073	0,054	0,038
946 MHz 1m_4	0,102	0,124	0,092	0,120	0,069	0,173	0,082	0,064	0,159	0,059	0,037
946 MHz 1m_5	0,100	0,031	0,102	0,036	0,087	0,062	0,129	0,098	0,130	0,061	0,053
946 MHz 1m_6	0,146	0,119	0,033	0,194	0,164	0,162	0,026	0,070	0,052	0,080	0,088
946 MHz 1m_7	0,146	0,092	0,082	0,149	0,185	0,040	0,130	0,180	0,032	0,209	0,192
946 MHz 1m_8	0,111	0,078	0,064	0,111	0,080	0,055	0,114	0,104	0,045	0,165	0,183
946 MHz 1m_9	0,145	0,128	0,038	0,163	0,159	0,094	0,063	0,153	0,018	0,137	0,164
946 MHz 10m_1	0,129	0,073	0,021	0,091	0,146	0,158	0,021	0,089	0,068	0,091	0,114
946 MHz 10m_2	0,159	0,151	0,021	0,205	0,168	0,163	0,025	0,069	0,054	0,100	0,092
946 MHz 10m_3	0,180	0,176	0,085	0,279	0,172	0,282	0,108	0,110	0,170	0,102	0,068
946 MHz 10m_4	0,115	0,120	0,086	0,102	0,077	0,152	0,135	0,079	0,154	0,042	0,035
946 MHz 10m_5	0,108	0,053	0,093	0,070	0,082	0,105	0,072	0,089	0,134	0,049	0,040
946 MHz 10m_6	0,181	0,062	0,078	0,075	0,212	0,176	0,144	0,216	0,109	0,252	0,225
946 MHz 10m_7	0,162	0,092	0,081	0,159	0,209	0,047	0,152	0,206	0,038	0,218	0,179
946 MHz 10m_8	0,123	0,082	0,085	0,158	0,112	0,064	0,134	0,091	0,052	0,205	0,209
946 MHz 21m_1	0,096	0,052	0,018	0,124	0,118	0,065	0,043	0,119	0,016	0,070	0,095
946 MHz 21m_2	0,105	0,054	0,010	0,119	0,083	0,105	0,015	0,029	0,065	0,021	0,021
946 MHz 21m_3	0,299	0,085	0,236	0,109	0,043	0,365	0,487	0,230	0,432	0,091	0,073
946 MHz 21m_4	0,105	0,025	0,032	0,060	0,113	0,018	0,095	0,104	0,033	0,071	0,077

Table 4- 1: Simulation results of all scenarios and all dosimeters at GSM frequency of 946 MHz and 1 W transmitted power. All results are given in [V/m]. The E-fields in the exposimeter volume and the fields in the whole body volume are linearly averaged.

Quadratic averaged	Whole Body	arm left	arm right	left	left behind	left front	right	right behind	right front	back up	back down
946 MHz 1m_1	0,121	0,038	0,026	0,069	0,147	0,121	0,026	0,088	0,050	0,103	0,120
946 MHz 1m_2	0,146	0,120	0,034	0,194	0,167	0,163	0,026	0,074	0,054	0,084	0,092
946 MHz 1m_3	0,162	0,091	0,067	0,198	0,142	0,178	0,133	0,099	0,076	0,056	0,040
946 MHz 1m_4	0,111	0,126	0,093	0,123	0,070	0,174	0,086	0,067	0,160	0,060	0,038
946 MHz 1m_5	0,108	0,032	0,103	0,040	0,089	0,063	0,129	0,101	0,133	0,066	0,057
946 MHz 1m_6	0,146	0,120	0,034	0,194	0,167	0,163	0,026	0,074	0,054	0,084	0,092
946 MHz 1m_7	0,147	0,093	0,083	0,151	0,186	0,041	0,132	0,181	0,032	0,212	0,194
946 MHz 1m_8	0,118	0,080	0,065	0,113	0,083	0,056	0,115	0,108	0,045	0,168	0,187
946 MHz 1m_9	0,145	0,128	0,038	0,165	0,161	0,096	0,065	0,157	0,018	0,139	0,167
946 MHz 10m_1	0,136	0,075	0,022	0,098	0,147	0,160	0,024	0,092	0,070	0,092	0,117
946 MHz 10m_2	0,160	0,153	0,022	0,206	0,170	0,164	0,025	0,071	0,056	0,105	0,096
946 MHz 10m_3	0,190	0,179	0,086	0,280	0,176	0,284	0,108	0,115	0,177	0,105	0,070
946 MHz 10m_4	0,126	0,121	0,089	0,105	0,079	0,155	0,136	0,080	0,158	0,046	0,039
946 MHz 10m_5	0,117	0,054	0,093	0,075	0,083	0,106	0,076	0,092	0,135	0,052	0,043
946 MHz 10m_6	0,193	0,070	0,081	0,082	0,215	0,177	0,149	0,217	0,112	0,258	0,226
946 MHz 10m_7	0,164	0,094	0,084	0,163	0,210	0,048	0,155	0,206	0,039	0,222	0,181
946 MHz 10m_8	0,132	0,084	0,087	0,159	0,118	0,065	0,136	0,095	0,053	0,210	0,213
946 MHz 21m_1	0,103	0,053	0,019	0,124	0,118	0,067	0,044	0,121	0,016	0,073	0,098
946 MHz 21m_2	0,113	0,054	0,010	0,119	0,086	0,105	0,015	0,030	0,066	0,022	0,022
946 MHz 21m_3	0,301	0,087	0,242	0,113	0,045	0,369	0,488	0,238	0,433	0,093	0,074
946 MHz 21m_4	0,113	0,025	0,033	0,062	0,114	0,019	0,096	0,105	0,034	0,072	0,078

Table 4- 2: Simulation results of all scenarios and all dosimeters at GSM frequency of 946 MHz and 1 W transmitted power. All results are given in [V/m]. The E-fields in the exposimeter volume and the fields in the whole body volume are squared averaged.

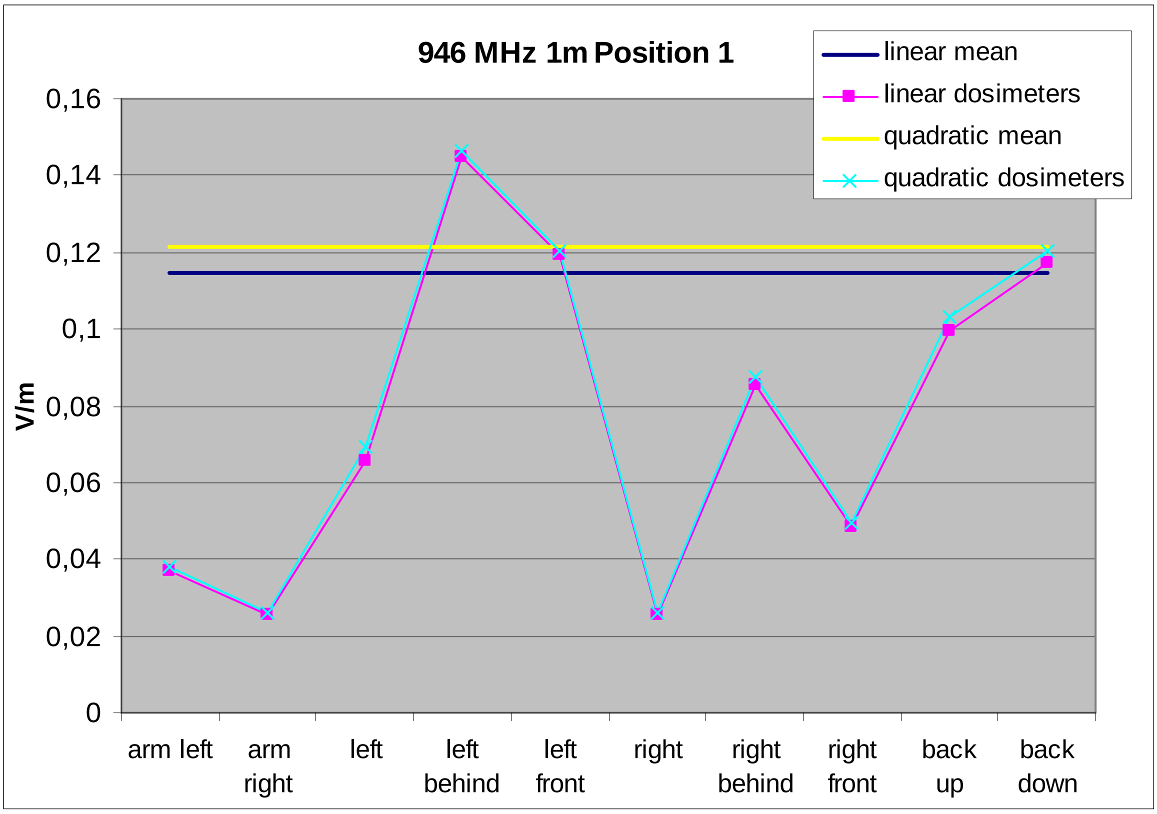

Figure 4- 12: Results of scenario 1m_1 at 946 MHz (1 W transmitted power) with linear and quadratic mean. All exposimeter positions and the averaged E-field over the whole body volume (without phantom) are shown. In this position the antenna is left behind of the model, so the exposimeter positions on the left side have higher values compared to the right side.

Linear averaged	arm left	arm right	left	left behind	left front	right	right behind	right front	back up	back down
	normalized	normalized	normalized	normalized	normalized	normalized	normalized	normalized	normalized	normalized
946 MHz 1m_1	0,32	0,22	0,57	1,26	1,04	0,22	0,75	0,42	0,87	1,02
946 MHz 1m_2	0,82	0,22	1,33	1,13	1,11	0,18	0,48	0,36	0,55	0,61
946 MHz 1m_3	0,57	0,41	1,26	0,89	1,13	0,85	0,60	0,47	0,35	0,24
946 MHz 1m_4	1,22	0,90	1,18	0,68	1,70	0,81	0,63	1,56	0,58	0,36
946 MHz 1m_5	0,31	1,03	0,36	0,88	0,62	1,29	0,99	1,31	0,62	0,53
946 MHz 1m_6	0,82	0,22	1,33	1,13	1,11	0,18	0,48	0,36	0,55	0,61
946 MHz 1m_7	0,63	0,56	1,02	1,27	0,27	0,89	1,23	0,22	1,43	1,32
946 MHz 1m_8	0,70	0,58	1,01	0,72	0,50	1,03	0,94	0,40	1,49	1,66
946 MHz 1m_9	0,88	0,26	1,13	1,10	0,65	0,44	1,06	0,12	0,95	1,13
946 MHz 10m_1	0,56	0,16	0,70	1,13	1,23	0,16	0,69	0,53	0,70	0,88
946 MHz 10m_2	0,95	0,13	1,29	1,05	1,02	0,16	0,43	0,34	0,63	0,58
946 MHz 10m_3	0,98	0,47	1,55	0,95	1,56	0,60	0,61	0,94	0,57	0,38
946 MHz 10m_4	1,04	0,75	0,88	0,66	1,32	1,17	0,68	1,34	0,36	0,30
946 MHz 10m_5	0,49	0,86	0,65	0,76	0,98	0,67	0,83	1,25	0,46	0,37
946 MHz 10m_6	0,34	0,43	0,42	1,17	0,97	0,79	1,19	0,60	1,39	1,24
946 MHz 10m_7	0,56	0,50	0,98	1,28	0,29	0,94	1,27	0,23	1,34	1,10
946 MHz 10m_8	0,66	0,69	1,28	0,91	0,52	1,09	0,74	0,42	1,66	1,70
946 MHz 21m_1	0,54	0,19	1,29	1,23	0,67	0,45	1,24	0,17	0,73	1,00
946 MHz 21m_2	0,51	0,09	1,13	0,79	1,00	0,14	0,28	0,62	0,20	0,20
946 MHz 21m_3	0,28	0,79	0,36	0,14	1,22	1,63	0,77	1,44	0,31	0,25
946 MHz 21m_4	0,24	0,30	0,58	1,08	0,18	0,91	1,00	0,31	0,68	0,74
Linear average of all positions	0,64	0,47	0,97	0,96	0,91	0,70	0,80	0,64	0,78	0,77

Table 4- 3: Exposimeter results normalised to the whole body E-field linearly averaged at 946 MHz.

Quadratic averaged	arm left	arm right	left	left behind	left front	right	right behind	right front	back up	back down
	normalized	normalized	normalized	normalized	normalized	normalized	normalized	normalized	normalized	normalized
946 MHz 1m_1	0,31	0,22	0,57	1,21	0,99	0,21	0,72	0,41	0,85	0,99
946 MHz 1m_2	0,82	0,23	1,33	1,14	1,11	0,18	0,50	0,37	0,58	0,63
946 MHz 1m_3	0,56	0,41	1,22	0,87	1,10	0,82	0,61	0,47	0,34	0,25
946 MHz 1m_4	1,14	0,84	1,11	0,63	1,57	0,78	0,61	1,45	0,54	0,35
946 MHz 1m_5	0,30	0,96	0,37	0,83	0,58	1,20	0,94	1,23	0,61	0,53
946 MHz 1m_6	0,82	0,23	1,33	1,14	1,11	0,18	0,50	0,37	0,58	0,63
946 MHz 1m_7	0,63	0,57	1,03	1,27	0,28	0,90	1,23	0,22	1,44	1,32
946 MHz 1m_8	0,68	0,55	0,96	0,71	0,48	0,98	0,92	0,38	1,43	1,59
946 MHz 1m_9	0,89	0,27	1,14	1,11	0,66	0,45	1,08	0,12	0,96	1,15
946 MHz 10m_1	0,56	0,16	0,72	1,08	1,17	0,17	0,67	0,51	0,68	0,86
946 MHz 10m_2	0,96	0,14	1,29	1,06	1,03	0,16	0,45	0,35	0,66	0,60
946 MHz 10m_3	0,94	0,45	1,47	0,92	1,50	0,57	0,60	0,93	0,55	0,37
946 MHz 10m_4	0,96	0,70	0,83	0,63	1,23	1,08	0,63	1,25	0,36	0,31
946 MHz 10m_5	0,46	0,80	0,64	0,71	0,91	0,65	0,79	1,16	0,44	0,37
946 MHz 10m_6	0,36	0,42	0,43	1,12	0,92	0,77	1,13	0,58	1,34	1,17
946 MHz 10m_7	0,57	0,51	0,99	1,28	0,29	0,94	1,26	0,24	1,36	1,11
946 MHz 10m_8	0,63	0,66	1,21	0,90	0,50	1,03	0,72	0,40	1,59	1,62
946 MHz 21m_1	0,51	0,18	1,21	1,16	0,65	0,43	1,18	0,16	0,71	0,96
946 MHz 21m_2	0,48	0,09	1,05	0,75	0,93	0,13	0,26	0,58	0,19	0,19
946 MHz 21m_3	0,29	0,80	0,38	0,15	1,23	1,62	0,79	1,44	0,31	0,25
946 MHz 21m_4	0,22	0,29	0,55	1,01	0,16	0,85	0,93	0,30	0,64	0,69
Linear average of all positions	0,62	0,45	0,94	0,94	0,88	0,67	0,79	0,61	0,77	0,76

Table 4- 4: Exposimeter results normalised to the whole body E-field quadratic averaged at 946 MHz.

Dosimeter results of	Averaged	Minimum	Maximum
all values	0,76	0,09	1,70
arms	0,55	0,09	1,22
hips	0,83	0,12	1,70
back	0,78	0,20	1,70
left side	0,87	0,14	1,70
right side	0,65	0,09	1,63

Table 4- 5: Averaged, minimum and maximum exposimeter results obtained at all examined positions separated in respect of different positions on the body at 946 MHz normalised to the linear averaged whole body E-field.

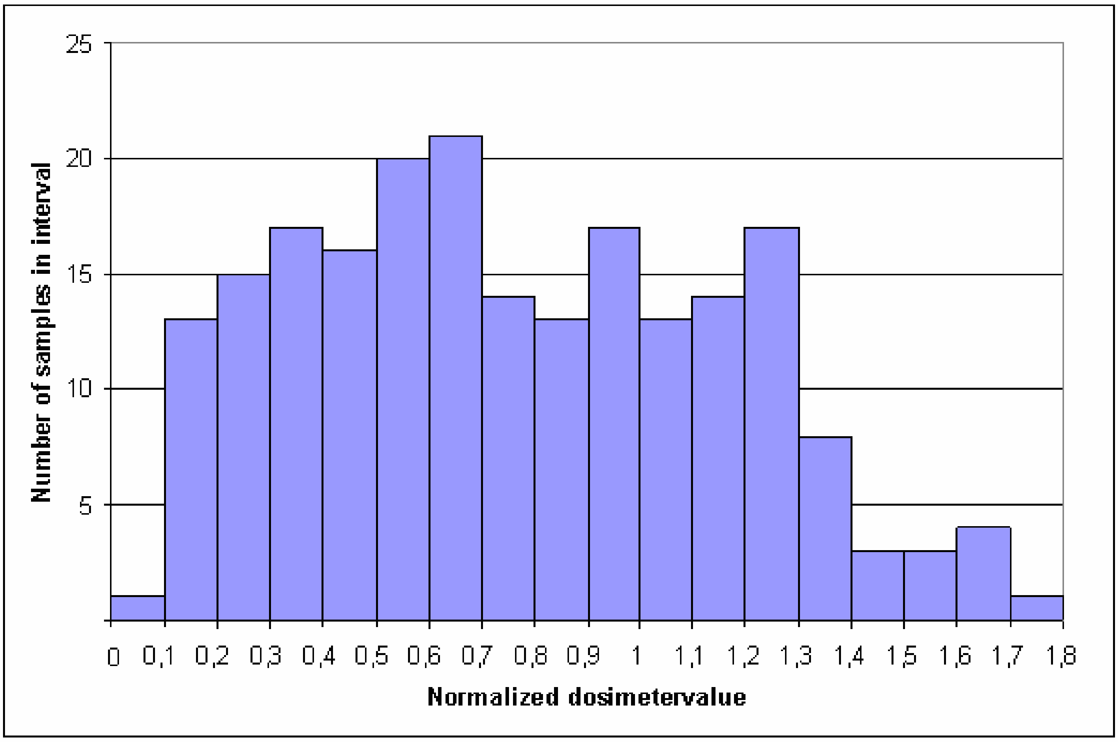

Figure 4- 13: Number of normalised exposimeter results at 946 MHz separated in interval steps of 0.1 for 210 exposimeter positions

4.2.2. Results for 100 MHz (VHF)

Dosimeter results of	Averaged	Minimum	Maximum
all values	0,9980	0,3034	2,8634
arms	1,6799	0,5765	2,8634
hips	0,7661	0,3034	1,8667
back	1,0117	0,4340	1,6130
left side	1,0154	0,3067	2,8634
right side	0,9736	0,3034	2,5987

Table 4- 6: Averaged, minimum and maximum exposimeter results separated in respect of different positions on the body at 100 MHz normalised to the linear averaged whole body E-field.

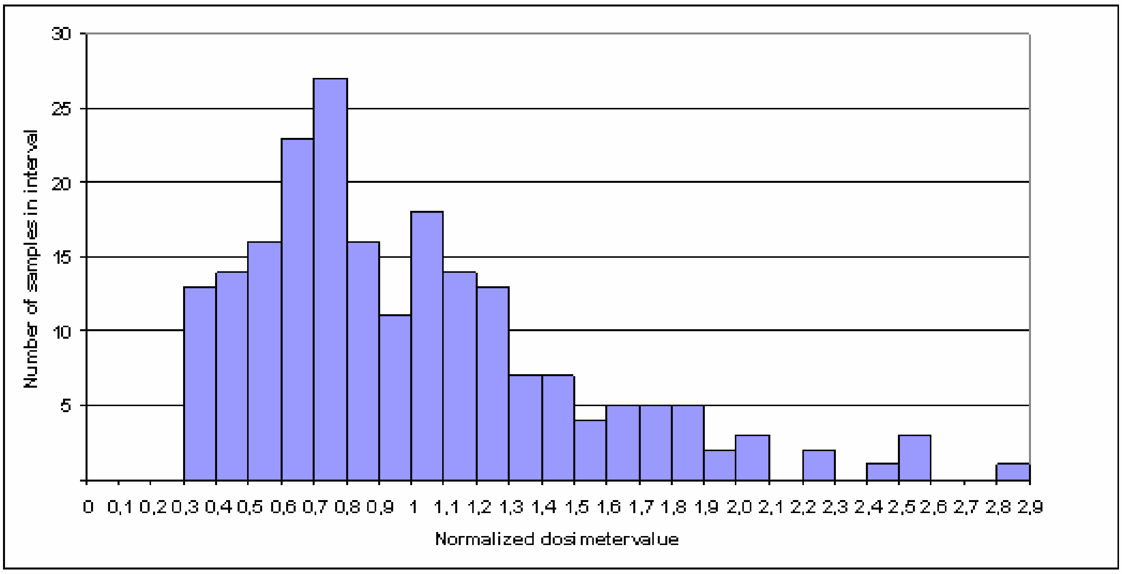

Figure 4- 14: Number of normalised exposimeter results at 100 MHz separated in interval steps of 0.1 for 210 exposimeter positions.

4.2.3. Results for 2140 MHz (UMTS)

Dosimeter results of	Averaged	Minimum	Maximum
all values	0,8719	0,0704	1,8438
arms	0,7803	0,1314	1,8438
hips	0,8797	0,0704	1,5231
back	0,9400	0,1525	1,6734
left side	0,9370	0,0947	1,8438
right side	0,7728	0,0704	1,5057

Table 4- 7: Averaged, minimum and maximum exposimeter results separated in respect of different positions on the body at 2140 MHz normalised to the linear averaged whole body E-field.

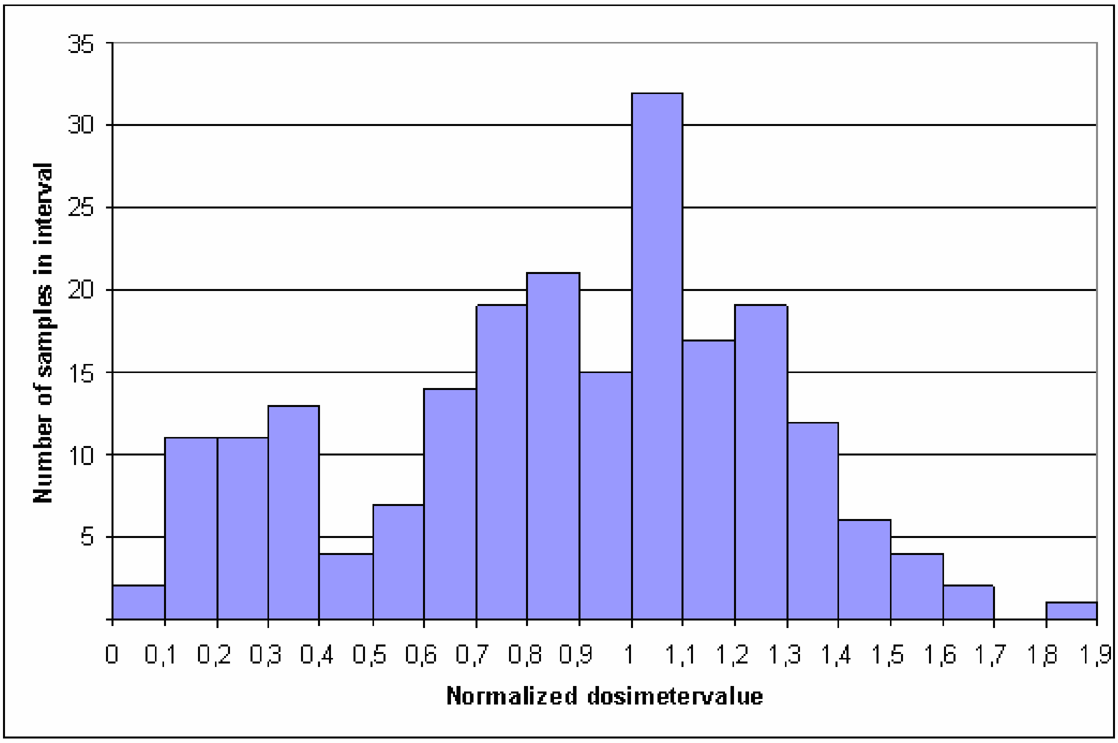

Figure 4- 15: Number of normalised exposimeter results at 2140 MHz separated in interval steps of 0.1 for 210 exposimeter positions.

4.2.4. Results for 2450 MHz (WLAN)

Dosimeter results of	Averaged	Minimum	Maximum
all values	0,6388	0,0800	2,0523
arms	0,6910	0,1876	2,0523
hips	0,7101	0,1220	1,5971
back	0,3728	0,0800	1,4523
left side	0,6852	0,1220	2,0523
right side	0,7255	0,1876	1,8394

Table 4- 8: Averaged, minimum and maximum exposimeter results separated in respect of different positions on the body at 2450 MHz normalised to the linear averaged whole body E-field.

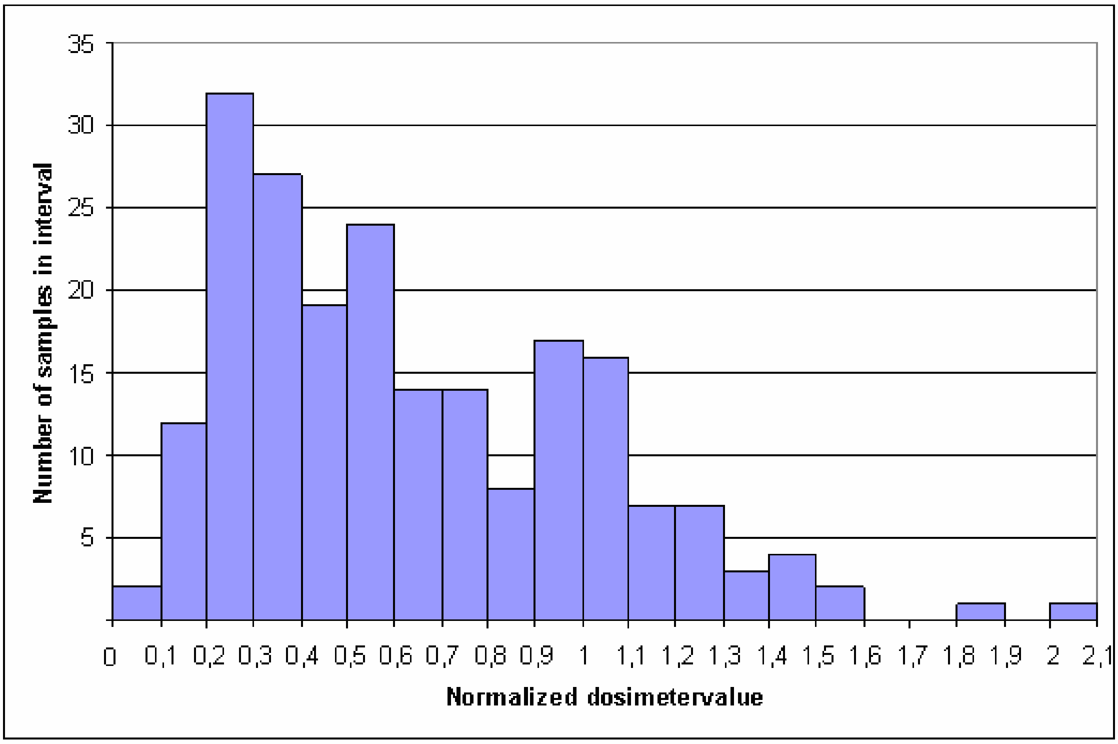

Figure 4- 16: Number of normalised exposimeter results at 2450 MHz separated in interval steps of 0.1 for 210 exposimeter positions.

4.2.5. Discussion of simulation results

	100 MHz	946 MHz	2140 MHz	2450 MHz
Mean value	0,998	0,764	0,872	0,639
Median	0,855	0,704	0,913	0,544
Standarddeviation	0,501	0,398	0,383	0,382
5 % Quantile	0,380	0,177	0,169	0,190
10 % Quantile	0,443	0,238	0,291	0,222
25 % Quantile	0,646	0,433	0,644	0,309
50 % Quantile	0,855	0,704	0,913	0,544
75 % Quantile	1,251	1,076	1,140	0,940
90 % Quantile	1,739	1,289	1,332	1,167
95 % Quantile	1,940	1,412	1,439	1,309
% < 1	57,14	70,00	55,71	80,48

Table 4- 9: Normalised results of all frequencies with mean values, median values, standard deviation, quantile values and percent of values und 1.

The normalised simulation results show that the majority of the results are below 1 and the 50% quantiles are less than 1, too. However, except for the indoor WLAN scenario investigated at 2450 MHz, the 75 % quantiles are above 1. Therefore for most of the exposimeter positions the exposure by the electric field is underestimated, this could be compensated by a frequency depended correction factor of the exposimeters.
The results of the exposimeter readings depend on the path of the electromagnetic wave from the transmitter to the exposimeter. Exposimeter positions with Line of sight (LOS) most time have higher values than positions with Non Line of sight (NLOS). Furthermore exposimeter positions with LOS give most time an exposimeter result with similar values compared to the whole-body averaged values, because the field at the exposimeter position is mainly generated by the LOS-path as well as the whole body field value, which is calculated without body model. So the normalised values of exposimeters with LOS are most times around 1. This indicates at least one maximum around 1 for the LOS-positions in the distributions of the normalised exposimeter values.
At 100 MHz, 946 MHz and 2140 MHz the 4-square outdoor scenario is investigated. In this scenario the Wireless Insite results are transferred to SEMCAD. In SEMCAD the human phantom is always orientated in the same direction. This means, that the human phantom is always orientated in the same direction in the 4-Square Scenario, too. In Figure 4- 17 the orientation of the model is shown. The model is “looking” in the direction of the big arrow in all 21 positions. Therefore in most of the positions the model is exposed from the left side and the exposimeters on the left side have in most of the cases LOS conditions. Because of this, the averaged field levels of the left side at 100 MHz, 946 MHz and 2140 MHz are higher than the values obtained on the right side. In the Coffeehouse scenario the model is exposed from different direction and the difference between left and right is marginal.

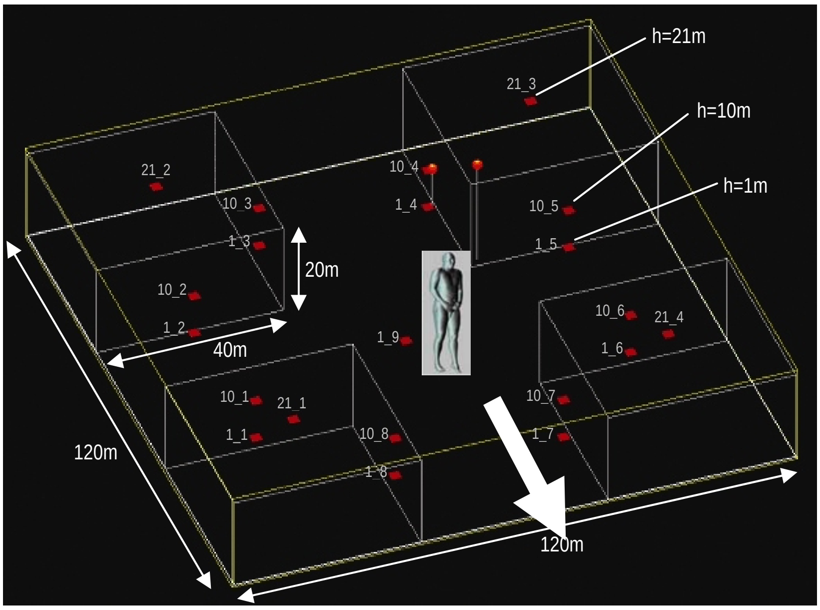

Figure 4- 17: Orientation of the human body model in the 4-Square Scenario.

4.3. Comparison of Numerical Simulation Results with Exposimeter Measurements

The results of the simulation in Chapter 4.2 have to be verified by comparisons with measurements. For the comparison the same scenario has to be investigated for the simulation and the measurement. So the exposimeter scenarios in the anechoic chamber were modelled in SEMCAD at the frequencies of 946 MHz and 2140 MHz. For the simulations the same simulation environment as for the simulations in Chapter 3.1.4 was applied. In this environment the human body model described in chapter 4 is positioned with the exposimeter sensors shown in Figure 4- 18. The values of the exposimeter sensors were treated as described in chapter 4.1.

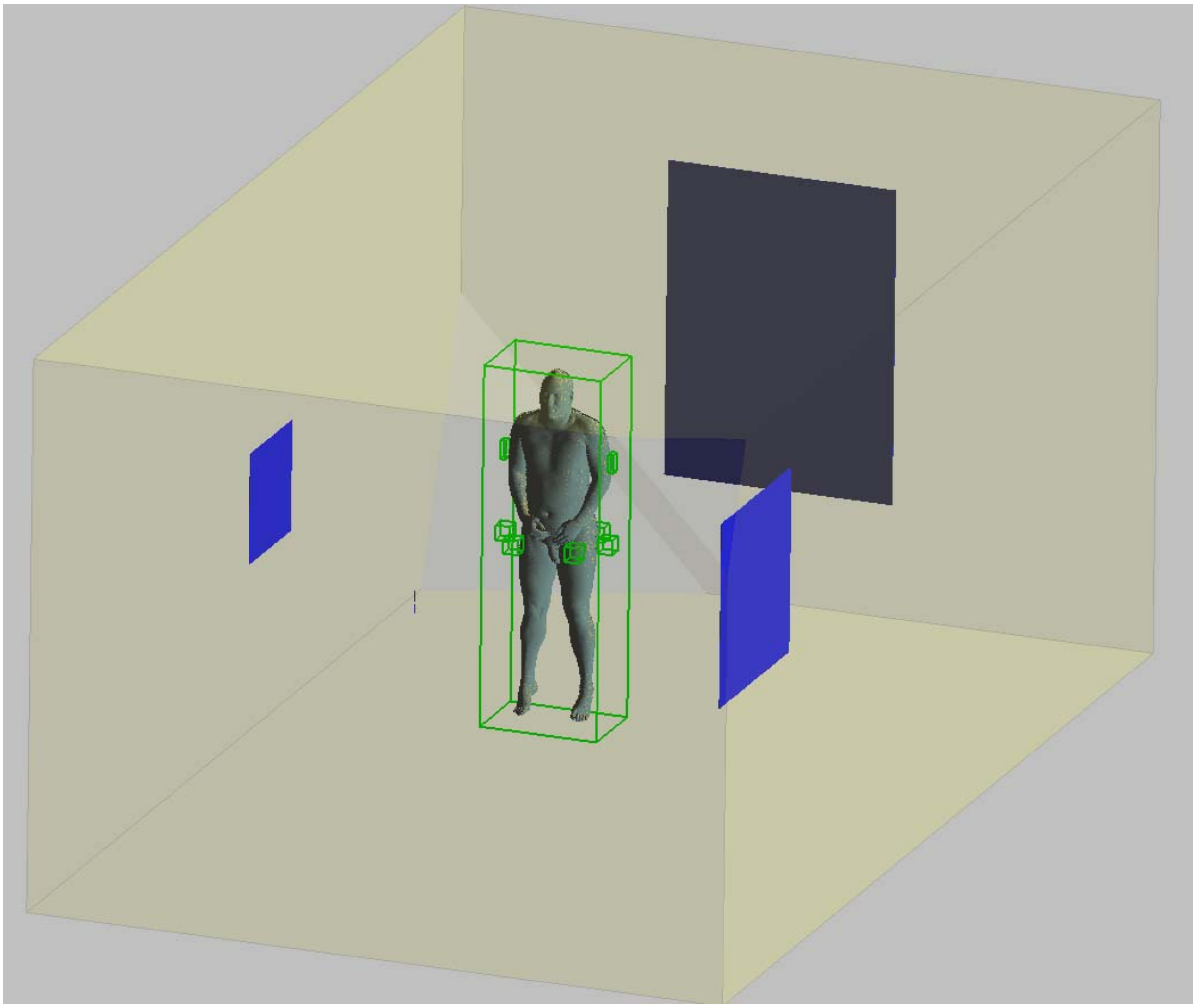

Figure 4- 18 : Simulation of anechoic chamber with human body model with exposimeter positions at 946 MHz. Excitation with dipole antenna.

Conformal to the measurements the results of the simulation are normalised to a radiated power of 1W. Because of the long calculation times of these extensive simulations (120h per simulation) symmetry of the human body was stipulated to reduce the number of simulations. In each simulation two exposimeter positions of hips and upper arm were simulated. The exposimeter on the hip was on the left side of the body, so at the 0°-position for the hip exposimeter (position shown in Figure 4-18) the 0°-position was on the left side of the body and at the same time on the right side of the body the 180°-position was simulated. So for the exposimeter positions from 180° to 330° the body is orientated in the opposite direction. This approach was also used for the upper arm exposimeter positions. For the back position this approach was not applied, so for this positions only the exposimeter results for 0° to 150° are shown in the diagrams.
In the following comparison of measurements and simulations, both results are modified by correction factors. In simulating the antenna model and the model of the chamber, one has to take into account have that they do not have completely the same properties compared to the real scenario. This can be seen in the difference between the measured and simulated 6P-values, where only the simulation model of the antenna has an impact on the simulation results. To eliminate this difference the simulation results are scaled to the 6P-measurement results of each scenario. This means, that the simulation result was multiplied with the ratio meas 6P/sim 6P. The factors of normalisation for the different scenarios are shown in Figure 4- 10.

	946 MHz without reflector	946 MHz with reflector	2140 MHz without reflector
Measurement 6P	2,93	3,65	1,37
Simulation 6P	3,28	2,92	2,09
Factor of normalisation for exposimeter simulation	0,89	1,25	0,65

Table 4- 10: Factor of normalisation of the simulation results to the measurement 6P for the different scenarios

Investigations of exposimeter measurements in the “Qualifex-project” of the National Research Programme NRP57 of the Swiss National Science Foundation (www.nfp57.ch) delivered calibration factors for the Antennessa exposimeter using not CW, but real mobile communication signals. These calibration factors were applied on the exposimeter-measurement results of hips and back, because there the Antennessa-exposimeter was applied. There was no calibration factor for the Maschek-exposimeter available, so the Maschek exposimeter results were not changed. The calibration factors for the two applied frequencies are shown in Figure 4- 11.

	946 MHz	2140 MHz
Calibration factor for exposimeter measurements	0,83	2,3

Table 4- 11: Calibration factor for the exposimeter-measurements at the applied frequencies taken from the investigations within QUALIFEX.

In the following diagrams the exposimeter results are shown over the angle of rotation. In this diagrams 0° always means the body is orientated to the antenna, independent from the exposimeter position (in difference to previous diagrams in this report). The angle of rotation, where the exposimeter is turned away from the antenna is different at the different exposimeter positions. So the back position has approximately at 0° a minimum, the hip position at 90° and the upper arm position at 270°.

Simulations at 2140 MHz with reflector could not be done, because of too long simulations times and to much RAM requirement for this dimension of the scenario at this frequency.
For the comparison in the simulation the human body model from the "Visible human project" was applied. So the simulation results were compared to the exposimeter measurements with person B, because person B showed the best agreement in height and weight with the body model in simulation.

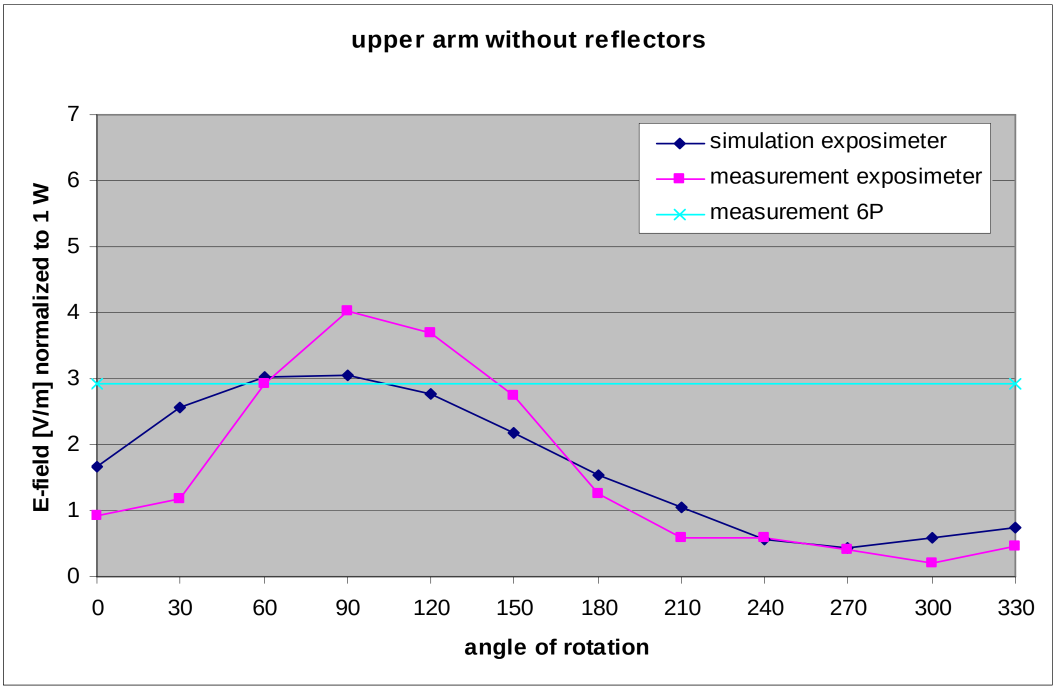

Figure 4- 19: Comparison of exposimeter results of simulation and measurement over the angle of rotation at upper arm position without reflectors for 946 MHz

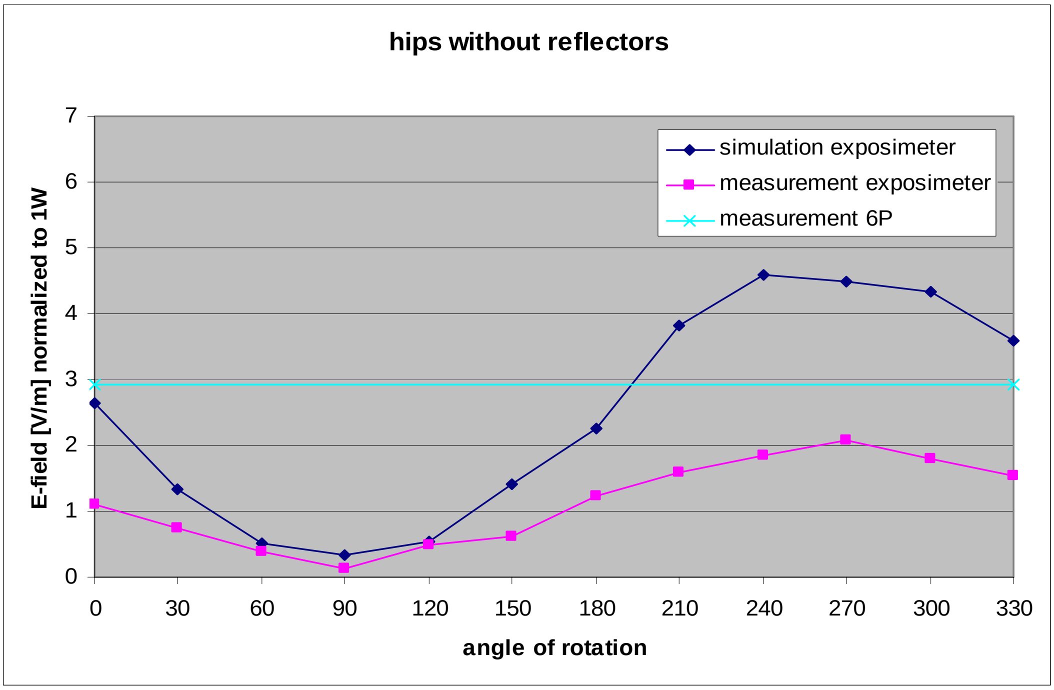

Figure 4- 20: Comparison of exposimeter results of simulation and measurement over the angle of rotation at hip position without reflectors for 946 MHz

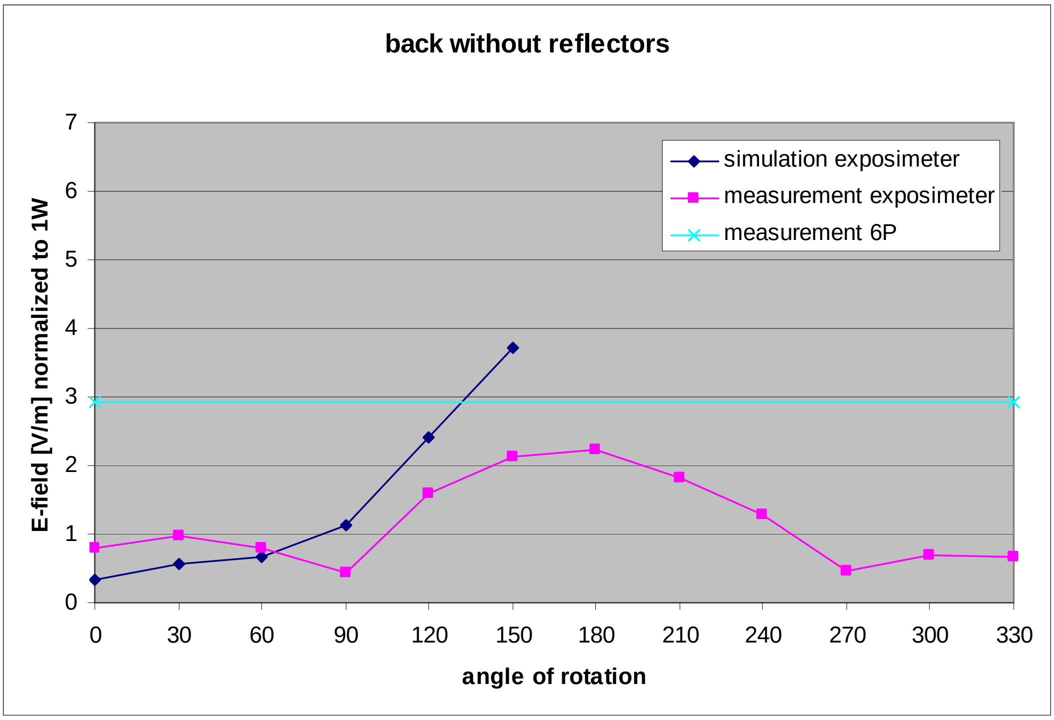

Figure 4- 21: Comparison of exposimeter results of simulation and measurement over the angle of rotation at back position without reflectors for 946 MHz

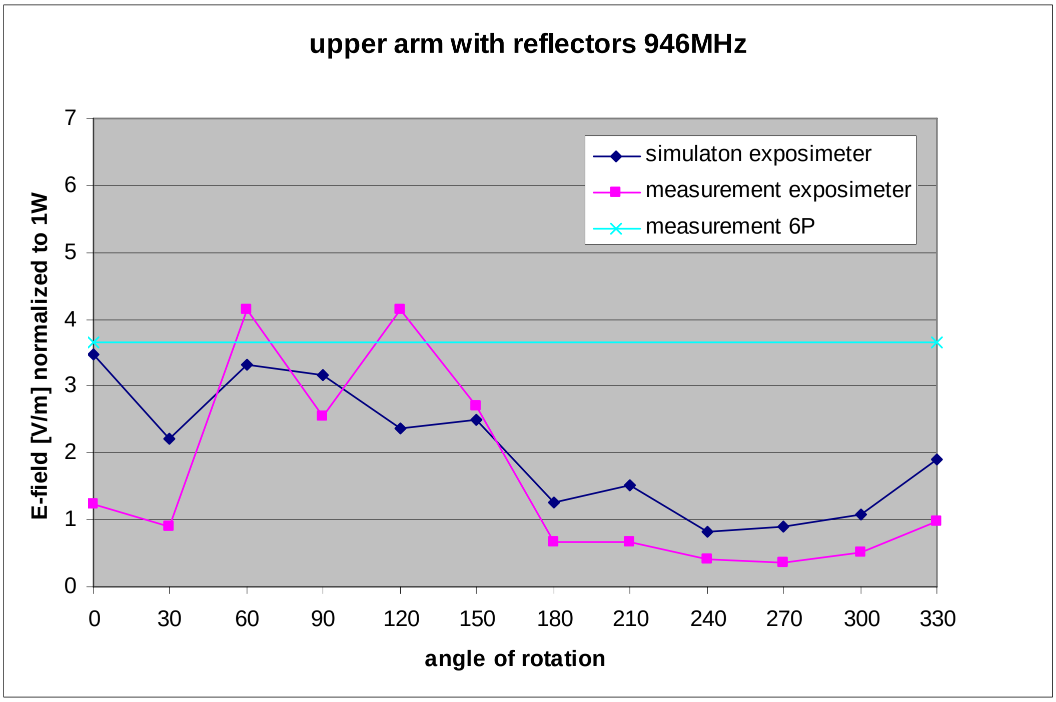

Figure 4- 22: Comparison of exposimeter results of simulation and measurement over the angle of rotation at upper arm position with reflectors for 946 MHz

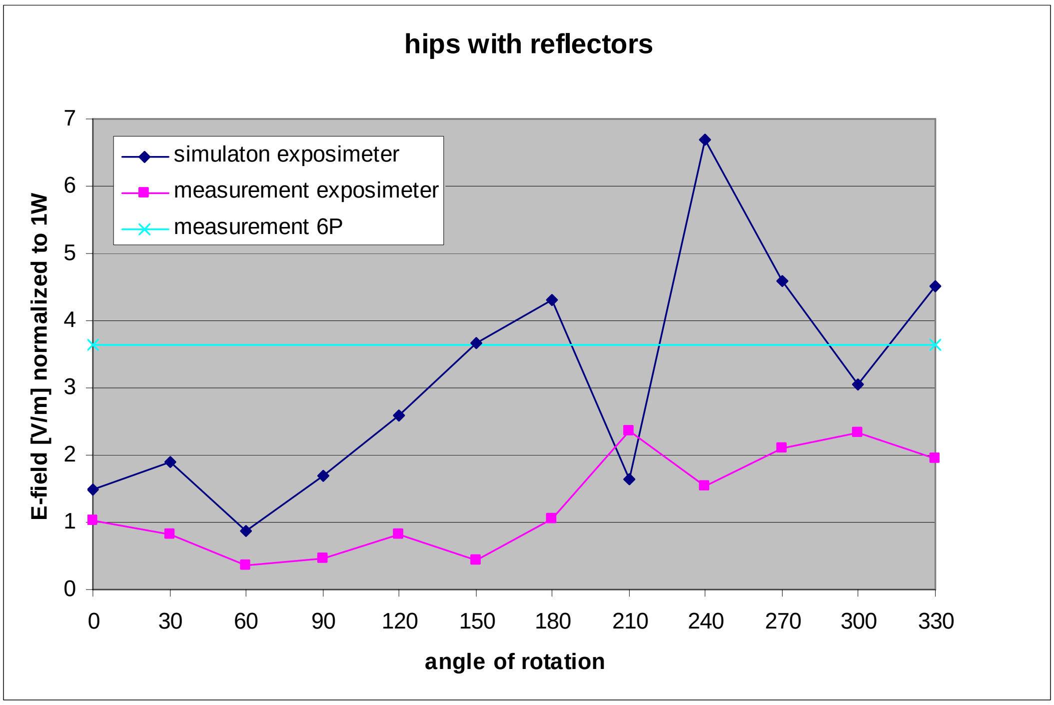

Figure 4- 23: Comparison of exposimeter results of simulation and measurement over the angle of rotation at hip position with reflectors for 946 MHz

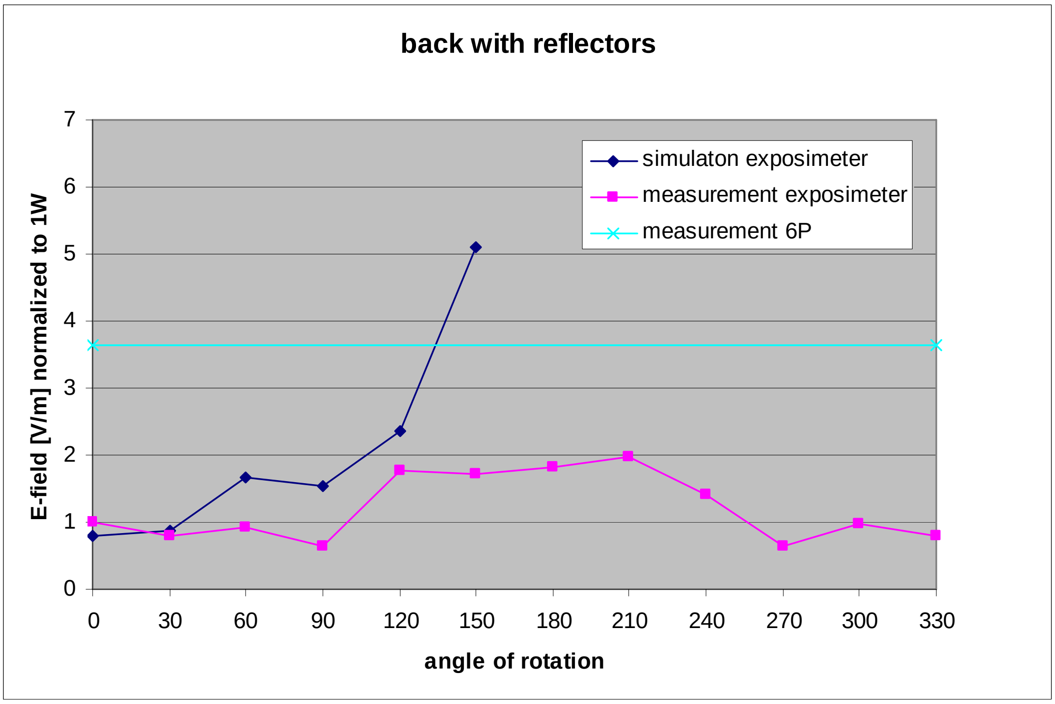

Figure 4- 24: Comparison of exposimeter results of simulation and measurement over the angle of rotation at back position with reflectors for 946 MHz

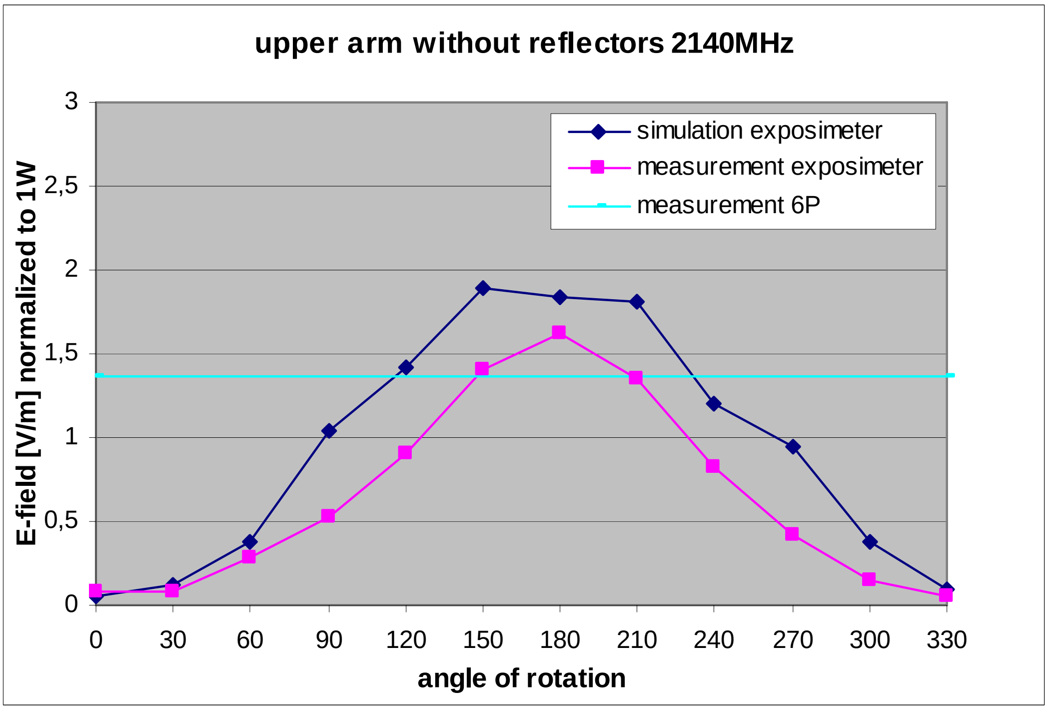

Figure 4- 25: Comparison of exposimeter results of simulation and measurement over the angle of rotation at upper arm position without reflectors for 2140 MHz

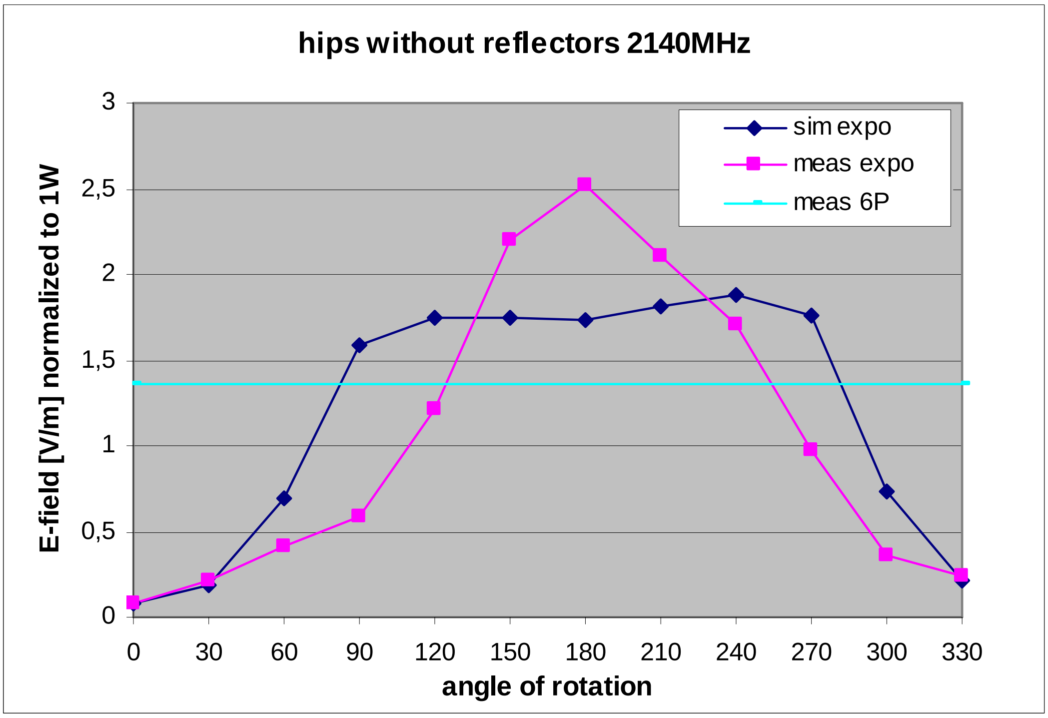

Figure 4- 26: Comparison of exposimeter results of simulation and measurement over the angle of rotation at hip position without reflectors for 2140 MHz

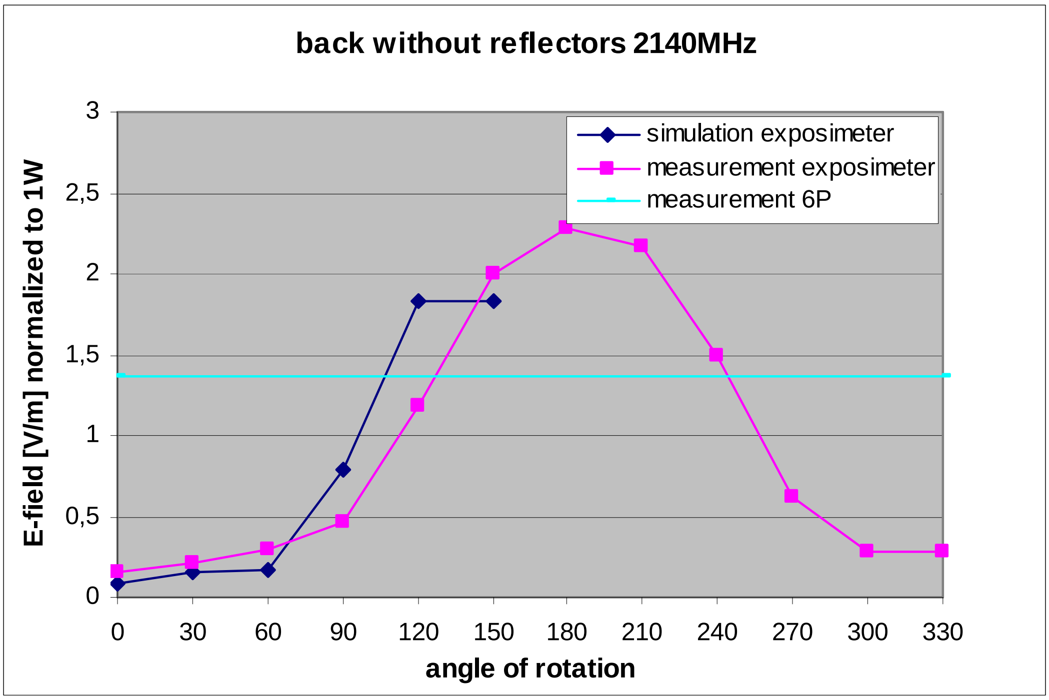

Figure 4- 27: Comparison of exposimeter results of simulation and measurement over the angle of rotation at back position without reflectors for 2140MHz

The results of the exposimeter measurement and simulation show widely conformance, in most cases the relation between simulations and measurements is below a factor of 2. The differences for the comparison with the reflectors are higher, because of the uncertainty arising from the positioning of the reflectors. Small differences in the position of the reflectors can move the examined position to a maximum or a minimum of the standing wave. Furthermore differences of measurement and simulation are mainly caused by the differences of the human body model in simulation and person B and the differences in measuring the E-fields. In the simulation the E-field in the exposimeter volume was averaged over the volume of the antenna, while in reality the exposimeter antenna measures the field.
The results show that the simulation of the exposimeter averaging of the E-field of the exposimeter antenna volume shows good agreement with exposimeter measurements and can be applied in further simulations for evaluating exposimeter results.

5. Discussion and Conclusions

Exposure assessment in epidemiological studies is a crucial topic. The selection of an adequate assessment tool is imperative for the quality of the study. In recent studies it turned out that exposimeter are a quite suitable approach to determine individual exposure profiles, however this approach has also some limitations. Apart from the limited dynamic range it is important to take into account that these devices give only an approximation of the exposure. It is therefore necessary to investigate the relation between the field strength measured close to the human body at the location of the exposimeter and the exposure, i.e. the field strength at the location of the human body without the human body being present.

In the recent years it became more and more common to investigate exposure profiles by mean of exposimeters. But the investigations on the correlation between exposimeter reading and the real exposure, i.e. the electromagnetic field at the location of the human body, were very limited. Knafl and colleagues used phantoms of the human body to investigate the impact of the human body on exposimeter readings. They found an underestimation of the exposimeters both in the UMTS and GSM bands.

In the frame of this project two different scenarios were investigated by numerical means using the visible human model as phantom. For FM, GSM and UMTS an urban outdoor scenario was examined having the transmitting antenna mounted on the roof of one of four buildings of a street crossing. In total 21 positions on the ground, locations of balconies and on roof level were investigated. For GSM the average degree of underestimation by the exposimeter (relation of the averaged field levels at the location of the exposimeter to the field level averaged over the volume of the human body not being present) was 0.76. The lowest ratio was found for the location of the exposimeter on the arms (0.55), the highest one for the hips (0.83). For UMTS the degree of underestimation was lower (0.87). It was again more pronounced for the arms, whereas it was quite weak for the back (0.94).
For FM the situation was different. Taking all examined positions together, the field levels at the location of the exposimeter reflected exposure very good, the ratio was 1. At the arms an overestimation was observed (1.67), at the hips the exposure was somewhat underestimated (0.77).
To investigate the conditions for WLAN a different scenario was examined; it was an indoor scenario with the antenna located below a desk. The scenario corresponds to a coffee shop, in total 7 positions of the phantom were investigated in the virtual coffee shop. In this case the general degree of underestimation was more pronounced, the ratio was 0.64, somewhat higher values were obtained at the hips (0.71), but the degree of underestimation reached 0.37 for the back.

Taken together, the results of the simulations clearly demonstrate that the field levels at the location of the antennas of the exposimeters located nearby the human body tend to underestimate the exposure depending on the investigated scenario and the frequency band. In the frame of this project the degree of underestimation ranged from 0.64 to 1, when all locations of the exposimeter on the body are taken together.

To verify the outcome of the numerical simulations, measurements with exposimeters were performed in an anechoic chamber. In general, two volunteers carried the exposimeters at field levels well below the reference levels of the general public given in the ICNIRP guidelines of 1998, the exposimeter readings were compared to the exposure assessed by frequency selective measurements. The arithmetic mean of several samples measured by the exposimeter was taken to obtain reproducible results. As an example, 55 samples were used to describe the exposure of a person located at an orientation of 0° in a GSM 900 field.

The comparison of the measurement data performed in the different frequency bands clearly demonstrate that the strongest deviation between the measured reference values obtained by the Add3D method and the average of all values obtained with the exposimeter mounted on the volunteers can be seen in the UMTS and WLAN band. For UMTS the average of all exposimeter measurements normalised to the 6 – point averaged field levels is 0.33 (standard deviation 0.27), for WLAN 0.29 (standard deviation 0.24). For FM and GSM the deviation from the reference field levels is considerably lower: 0.69 (standard deviation 0.4) and 0.65 (standard deviation 0.44), respectively. In all cases there is a trend of underestimation by the exposimeter measurements that can be observed. For FM 22 % of all field levels measured with the exposimeter are above the reference value, for GSM 15 %, for UMTS 4 % and for WLAN no values above the reference value were observed. In that context it has to be mentioned that only a limited a number of measurements were performed in the WLAN band, these results are not adequate to draw final conclusions.

An extension of the investigations from 2 to 11 probands was performed at one position in the GSM 900 band. Using the Antennessa exposimeter the underestimation became even more pronounced and ranged from 0.46 to 0.6, depending on the proband and his anatomy and morphology. A correlation with the BMI of -0.28 was found. Looking at all probands together highest exposure was found at an orientation of 180° (relation exposimeter reading to the reference field 0.91, 0° means that the exposimeter is completely shielded by the human body) and lowest at 0° (0.34). Results were similar for the Maschek exposimeter. The underestimation ranged from 0.37 to 0.56, a correlation with the BMI of -0.39 was observed. The lowest exposure was found again at an angle of 0° (0.14), the highest one was observed at 120° (0.91).

When comparing the position of the Antennessa exposimeter on the hip with the position on the back no clear differences were observed. Comparison of the Antennessa exposimeter with the Maschek exposimeter showed some differences: the values obtained by the Maschek device tended to show a somewhat more pronounced underestimation in the GSM 900 band compared to the French device. The Maschek exposimeter showed an average value of 0.55 (normalised to the reference value, std.dev. 0.44). The Antennessa device on the hip delivered a normalised average of 0.59 (std.dev.0.6), the value on the back was 0.73 (std.dev. 0.67). In contrary, In the UMTS band the Maschek device delivered values closer to the reference. Both devices underestimated the field levels compared to the reference field levels.

To evaluate the exposure estimates delivered by the exposimeters the exposure was assessed by different means. Measurements performed according to methods established in internationals standards were used as primary reference (Add3Dmes). In addition, numerical simulations were performed to investigate the field distribution at the location of the human body with the exposimeter without the person being present. On one hand the simulations were performed according to the methods described in international standard, i.e. averaged over 6 points (Add3sim), on the other hand all electric field values of the grid used in the simulations were averaged over a volume corresponding to that of the human body (Add3DsimWB). These values were compared to the averaged exposimeter readings (Exposimeter). The correlation coefficients between the measured values and the different other exposure assessments are given in Fehler! Verweisquelle konnte nicht gefunden werden..

Correlation	Reference = Add3DMeas							
	ALL	**No WLAN**	**GSM+ UMTS**	**WLAN+ UMTS**	**GSM+ UKW**	**UMTS**	**UKW**	**GSM**
Add3Dmeas-Add3Dsim	0.75	0.75	0.74	0.81	0.76	0.86	0.69	0.74
Add3Dmeas-Add3DsimWP	0.76	0.75	0.79	0.65	0.83	0.64	0.93	0.88
Add3D-Exposimeter	0.42	0.38	0.43	0.32	0.48	0.47	0.69	0.47

Table 5- 1: Correlation between the measured and simulated field strengths without the human body being present and the field strengths measured with exposimeter on the human body

If the field values obtained in all the four investigated are taken together a correlation of 0.75 and 0.76 was found for the relation between measured and simulated field levels. For the small band services GSM and FM this correlation is somewhat higher for all simulated field levels, i.e. 0.88 and 0.93, respectively, but lower for UMTS (0.64). The correlation between the measured reference field levels and the exposimeter reading is in any case considerably lower. If all bands are taken together a correlation of 0.42 was found. These results are well in line with the observation that the exposimeters tend to underestimate exposure. On the other hand good agreement between the simulation and the reference measurements was observed.

In addition, evaluations based on all samples instead of arithmetic means of samples were performed. A major reason for these additional investigations was to obtain more statistical power due to the considerably higher number of samples compared to the number of averaged exposimeter results. As expected, a general trend of underestimation of exposure was also observed in this case for both exposimeters. For GSM the normalised mean value was 0.44, for FM 0.55, for UMTS 0.14 and for WLAN 0.17. If all samples are taken together the degree of underestimation was 0.3. When comparing these results to the values obtained by analysis of the arithmetic means of the samples taken in a specific period, e.g. 30 seconds of exposure of a volunteer being exposed in an orientation of 90°, one can see that the analysis based on samples leads to somewhat lower values. For GSM the analysis of the averages led to an underestimation of 0.65 compared to 0.44 based on sample analysis. For UMTS a similar effect could be observed: sampling analysis led to 0.14 whereas analysis of averages led to 0.33. This indicates that a few considerably higher samples lead often to arithmetic means being relatively high compared to the majority of the samples. In contrast to the first investigations the sampling based averaging was performed using the geometrical mean being less sensible to out layers compared to the arithmetical mean. There are no large differences between mean values and median values; this might be seen as indicator for a rather symmetrical distribution of the samples. As expected, also in this case highest values were found when the exposimeter was between transmitting antenna and human body, i.e. the orientation of 180°. No major differences in the degree of underestimation were observed due to the variables distance to the transmitting antenna, location of the exposimeter on the body, heterogeneity of the field, i.e. use of reflectors and person carrying the exposimeter. Again the degree of underestimation of the Antennessa exposimeter was lower in the GSM 900 band, but this was not the case in the UMTS band. These results do not necessarily mean that an exposure assessment leads with exposimeters leads to an underestimation of the exposure. A multivariable regression model of the Antennessa measurements shows for instance if person I might be exposed dorsal to the incoming field having the exposimeter mounted on the back being exposed in the GSM 900 band at a distance of 3m from the transmitting antenna with reflectors in the room, then the exposimeter would overestimate the field by a factor of 1.43, i.e.143% of the real exposure. However, most combinations of the variables lead to an underestimation of the exposure when using the exposimeter. The model shows that the highest underestimation would occur if person E would be exposed by the UMTS signal frontal to the transmitting antenna having the exposimeter mounted on the hip in a distance of 2.5 m from the antenna without reflectors in the room. In this case only 3.6 % of the real exposure would be assessed by the exposimeter. These two values represent the range of under – and overestimation by the Antennessa exposimeter found in the frame of these investigations. Based on the assumption that distance and angle to the source are randomly varying and on the fact that location on the body and the reflector do not play an important role an underestimation of 0.53 (95 % CI 0.52 to 0.54) can be expected when using the Antennessa exposimeter. For UMTS this factor is 0.11, for WLAN 0.19 and for FM 0.55.

Similar investigations with the Maschek exposimeter lead to an underestimation of 0.44 in the GSM 900 band, 0.17 in the UMTS band and 0.18 in the WLAN band. It has to be taken into account that the investigations in the WLAN are based on a limited number of measurements.

Finally, the association between body measures and EMF exposure was investigated. In case the exposimeter is shielded by the body, body measures have a significant effect on the measurements. At an angle of 0° (shielding by the body) the strongest association was found for the Antennessa device. Each kilogram increase in body weight reduced the EMF measurement by a factor of 0.985. For the mean over all angles there was no significant association with the BMI. For the Maschek device no significant correlations were found.

Taken the results of the simulations and the measurements together it is clear that the exposimeters underestimate exposure. The question arises what calibration factor might be applied. When looking at the data obtained from simulations several aspects need to be considered. First of all CW signals were used for simulations. This means that signal shape specific responses of the exposimeters cannot be observed. It has been shown in the frame of ongoing investigations within the project QUALIFEX in particular in the UMTS and WLAN band that the Antennessa exposimeter can underestimate real life downlink signals up to a factor of 3. These kinds of effects cannot be seen in the frame of these numerical simulations. Moreover, the visible human model was used as phantom. This model with a weight above 100 kg is not representative for the typical population. The probands used for the measurements have more representative anatomical and morphological properties compared to the phantom. In that context it needs to be taken into account that the scenarios investigated in the frame of the simulations are not the same as for the measurements. The simulations were dedicated to investigate typical scenarios; measurements were done in a generic scenario. However, validations have shown that there is a general good agreement between numerical simulations and measurements, in most cases the relation between simulations and measurements is below a factor of 2.

In that context and when using a conservative approach (to avoid underestimation of the exposure) we recommend to use the most conservative correction factors obtained in the frame of this study when taking the impact of the human on the exposimeter reading into account. This implies that for GSM 900 downlink and FM signals a correction factor of 1.9 can be applied. For UMTS downlink signals a correction factor of 9 can be recommended, the data on WLAN are too limited to give recommendations. It has to be considered that the rather large correction factor in the UMTS band is composed from two factors: the first component is the impact of the human body, the second a signal specific calibration factor.

There is high need to extend these types of investigations to other frequencies not covered in the frame of this project, e.g. GSM 1800, broadcasting or DECT. In addition, it would be of relevance to extend the investigations to other morphologies and anatomies, in particular to investigate the reliability of the exposimeters for studies with children. Moreover it would be of importance to examine the conditions in other scenarios, e.g. additional indoor scenarios and look at the impact of large objects in the close vicinity of the exposed persons, e.g. cars or other persons. Finally, there is need to replicate the findings of this study.

5.1. Uncertainty

In the following tables the uncertainty of the measurement and simulation results are listed. This uncertainty evaluation should not be confused with the uncertainty that can be expected when using an exposimeter. The uncertainty given describes the uncertainty of the reference field that is used to validate exposimeter readings. To determine the uncertainty that can be expected when using an exposimeter, the correction factors established in the frame of this report have to be combined with the below described uncertainty of the assessment methodology for the reference field.

Uncertainty parameters of the measurement are given in Table 5- 2. A short description of the different contributions is given below:

E-field measurement with Add3D: These values are well known from previous field measurements with this system, and are specified in Table 5- 3.
Field heterogeneity: The variation of the field distribution in the anechoic chamber taking into account the field decrease with distance from the antenna in the measurement volume
Positioning of exposimeter and proband: The variation of the field distribution in the anechoic chamber in the volume, where the exposimeter can be positioned because of the uncertainty in positioning of the proband and in consequence the dosimeter on the proband
Different probands: Uncertainty because of probands with different morphology and anatomy (e.g. height, weight, sex) evaluated from the measurements with different probands at 900 MHz

Uncertainty parameters	FM	GSM900	UMTS	WLAN
E-field measurement with Add3D (positioning, equipment)	13.7%	10.0%	13.8%	12.0%
Field heterogeneity of anechoic chamber	5.0%	5.0%	5.0%	5.0%
Positioning of exposimeter and proband	7.0%	7.0%	7.0%	7.0%
Different probands	23.7%	23.7%	23.7%	23.7%
Combined Standard Uncertainty (k=1)	**28.7%**	**27.1%**	**28.7%**	**27.9%**
Expanded Standard Uncertainty (k=2)	**57.4%**	**54.3%**	**57.5%**	**55.8%**

Table 5- 2: Uncertainty assessment for exposimeter measurement results in this project

			100 MHz	900 MHz	2100 MHz	2400 MHz	
			u^2	u^2	u^2	u^2	
	Uncertainty source						
1.	Antenna factor, calibration uncertainty		37.22	37.22	37.22	37.22	
	Isotropic uncertainty ADD3D-method		0.00	9.23	98.03	44.36	
	Temperature dependence (antenna, cable)		17.05	17.05	17.05	17.05	
	manual positioning errror, angle orthogonal tripod		0.48	0.48	0.48	0.48	
	cable loss calibration uncertainty		0.34	0.34	0.34	0.34	
	missmatch (standing waves) between antenna and measurement receiver		100.23	4.08	4.09	11.11	
2.	Uncertainty voltage measurement Spectrum Analyzer (SA)		32.34	32.34	32.34	32.34	
	Combined standard uncertainty u_c		13.70	10.037	13.768	11.954	[%]
	k		2	2	2	2	
	Expanded uncertainty U		27.40	20.07	27.54	23.91	[%]
		corresponds to	2.10	1.59	2.11	1.86	[dB]

Table 5- 3: Uncertainty balance for field measurements wit Add3D

In Table 5- 4 the uncertainty for the simulation results are listed. In this uncertainty assessment the variation of the human body model and the variation of the model of the antenna are not included.

	E-field uncertainty near body model [dB]	probability distribution	divisor	ci	E-field standard uncertainty near body model [dB]	[%]
Modelling						
ABC	0.5	rect.	1.732	1	0.30	
deviation from steady state	0.2	rect.	1.732	1	0.12	
discretization (2mm)	0.2	normal (k=1)	1.000	1	0.20	
Evaluation						
Interpolation	0.1	rect.	1.732	1	0.06	
SAR Integration	0.2	rect.	1.732	1	0.12	
Combined Standard Uncertainty (k=1)					**0.39**	9.4%
Expanded Standard Uncertainty (k=2)					**0.75**	18.8%

Table 5- 4: Uncertainty balance for simulations with the visible human body model within SEMCAD

5.2. Recommendations for the exposimeter handling

Based on the results of the investigations of this study several recommendations can be given:

1) Before handing over exposimeters to volunteers the functionality of the device needs to be checked
2) Exposimeters have to be calibrated in regular intervals, it can be recommended to use realistic signals instead of CW signals for the calibration
3) Due to the fact that the human body has considerable impact on the field levels measured by exposimeters it can be recommended to apply correction factors obtained
4) It is crucial to distinguish between periods when the exposimeter is carried on the body and periods when the exposimeter is placed nearby the person using it
5) The recommendations of the manufacturer of the devices have to be taken into account, e.g. the temperature range specified shall be taken into account
6) The batteries shall be fully charged before to start measurements, the internal clock of the exposimeter shall be synchronised with reference clocks
7) In the frame of measurement campaigns the sampling period shall be harmonised
8) The use of mobile phones shall be recorded by the user, a minimum distance between exposimeter and the mobile phone shall be maintained to avoid use of the exposimeter above his upper dynamic range limit
9) The exposimeter should not be brought in close proximity to powerful RF and ELF sources, e.g. MRI, diathermy, plastic welding devices, transformers, RFID – it is at least necessary to record periods of exposure due to such devices and also the type of device to have the possibility to identify out of band coupling
10) The exposimeter shall be always carried at the same position on the body
    It is recommended to carry the exposimeter in a backbag, the belt clip might be used to adequately fix the exposimeter in the backbag in combination with e.g. a tape.
11) During periods of non – movement the exposimeter shall be placed in adequate proximity of the user. Such periods might be sitting on a table, desk in front of the TV etc. Adequate proximity means that the user shall be far enough away to avoid considerable impact of the users body on the exposimeters reading on one hand and close enough to be representative for the user's exposure. A distance of 0.5 to 1 m seems to be adequate.
12) The exposimeter shall be placed at a height that reflects the current location of trunk or head of the user. Adequate positions might be desks in offices or bystand tables next to the bed. When driving in a car the seat of the co-driver might be an adequate location for the exposimeter.

6. Literature

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List of measurement equipment used for the investigations:

Device	Manufacturer	Type	Frequency Range	SN
UKW Measurement Set Up				
Signal Generator	Agilent	E8257D	250 kHz – 20 GHz	E0217
Amplifier 500 W	AR	500W1000M7	100 MHz – 1 GHz	E0712
Dual Power Meter	Agilent	E4419B	-	E0151
Power Head – fwd	Agilent	8481A	10 MHz – 18 GHz	E0154
Power Head – rev	Agilent	8481A	10 MHz – 18 GHz	MY41091414
Biconical Antenna TX	EMCO	3109	20 MHz – 300 MHz	E0520
Directional Coupler	AR	DC 6280	80 MHz – 1GHz	E0816
Attenuator 10 dB	Radiall	R414710	0 – 12.4 GHz	E0789
Cable SG	n.a.	RG 214	0 – 3 GHz	E0865b
Cable AR	n.a.	RG 214	0 – 3 GHz	E0898c
GSM Measurement Set Up				
Signal Generator	R&S	CMU 200	400 MHz – 2,5 GHz	E0149
Amplifier 50 W	AR	50S1G4	800 MHz – 4,2 GHz	E0717
Dual Power Meter	Agilent	E4419B	-	E0151
Power Head – fwd	Agilent	8481A	10 MHz – 18 GHz	E0154
Power Head – rev	Agilent	8481A	10 MHz – 18 GHz	MY41091414
Omnidirectional Antenna TX	Kathrein	738 449	870 MHz – 960 MHz	n.a.
Directional Coupler	AR	DC 7144	800 MHz – 4,2GHz	E0821
Attenuator 6 dB	Rosenberger	53 AS 102-K06	0 – 12.4 GHz	n.a.
Cable SG	Suhner	Sucoflex 106	0 – 18 GHz	E4852
Cable AR	Suhner	Sucoflex 106	0 – 18 GHz	E4851
Cable FWD	n.a.	RG 214	0 – 3 GHz	Nr. 19
Cable REV	n.a.	RG 214	0 – 3 GHz	E0898c
UMTS Measurement Set Up				
Signal Generator	R&S	CMU 200	400 MHz – 2,5 GHz	E0149
Pre-Amplifier 10 mW	Miteq	AFS 3	100 MHz – 6 GHz	E0733
Amplifier 50 W	AR	50S1G4	800 MHz – 4,2 GHz	E0717
Dual Power Meter	Agilent	E4419B	-	E0151
Power Head – fwd	Agilent	8481A	10 MHz – 18 GHz	E0154
Power Head – rev	Agilent	8481A	10 MHz – 18 GHz	MY41091414
Omnidirectional Antenna TX	ARCS	POD 16	1 GHz – 6 GHz	n.a.
Directional Coupler	AR	DC 7144	800 MHz – 4,2GHz	E0821
Attenuator 6 dB	Rosenberger	53 AS 102-K06	0 – 12.4 GHz	n.a.
Cable SG	Suhner	Sucoflex 106	0 – 18 GHz	E4852
Cable AR	Suhner	Sucoflex 106	0 – 18 GHz	E4851
Cable FWD	n.a.	RG 214	0 – 3 GHz	Nr. 19
Cable REV	n.a.	RG 214	0 – 3 GHz	E0898c
WLAN Measurement Set Up				
Access Point	Lancom	L-54g Wireless	2,4 GHz – 2,48 GHz	4000163806000037
Directional Coupler AP	Narda	4013C-20	2 GHz – 4 GHz	E0807
Attenuator 10 dB	Weinschell	33-10-34	0 – 8 GHz	E0757
Amplifier 50 W	AR	50S1G4	800 MHz – 4,2 GHz	E0717
Dual Power Meter	Agilent	E4419B	-	E0151
Power Head – fwd	Agilent	8481A	10 MHz – 18 GHz	E0154
Power Head – rev	Agilent	8481A	10 MHz – 18 GHz	MY41091414
Omnidirectional Antenna TX	ARCS	POD 16	1 GHz – 6 GHz	n.a.
Directional Coupler	AR	DC 7144	800 MHz – 4,2GHz	E0821
Attenuator 6 dB	Rosenberger	53 AS 102-K06	0 – 12.4 GHz	
Cable AP	Suhner	Sucoflex 106	0 – 18 GHz	E4852
Cable AR	Suhner	Sucoflex 106	0 – 18 GHz	E4851
Cable FWD	n.a.	RG 214	0 – 3 GHz	Nr. 19
Cable REV	n.a.	RG 214	0 – 3 GHz	E0898d

Measurement equipment used for the Add3D measurements – receiving equipment for all four frequency bands.

Device	Manufacturer	Type	Frequency Range	SN
Spectrum Analysator	Agilent	E4405B	9 kHz – 13,2 GHz	E0185
Receive Antenna	ARC	PCD 8250	80 MHz – 2,5 GHz	E1607
Cable	n.a.	RG 400	0 – 3 GHz	E4830
Cable	n.a.	RG 214	0 – 3 GHz	Nr. 29

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