BENCHMARKING PERSONAL RADIOFREQUENCY EXPOSIMETERS

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Abstract
The two on the market available personal RF exposimeters (pem) have been tested under laboratory conditions. Even though the two devices use different underlying principles, the measurement values converge under intended use conditions on a test person towards rather similar values. Although the measurement results of the two pems may diverge by an important amount at a given point, on average the relative difference is smaller than the measurement error. Furthermore, the test under intended use conditions revealed that the mean values as obtained with the pems tend to underestimate the free field measurements. By combining the pems with a GPS device the comparison of propagation model calculations and measured data along the measurement path is made possible. The comparison indicates that the empirical COST-Walfisch-Ikegami model tends to underestimate whereas the free space model overestimates the experimental results. Taking into account the observed underestimation of the free field measurements, it can be concluded that for exposure assessment purposes the simple free space model might be a valid approximation. This result has however to be consolidated by further measurements and extended statistical analysis. For the correct assessment of the total exposure some band selectivity problems have yet to be solved, at least for one of the tested devices.

Introduction
In the actual debate about mobile phone masts and possible health effects of electromagnetic radiation, the public asks for epidemiologic studies. The World Health Organisation (WHO) lists the need for improved exposure assessment to be used for epidemiologic studies in first position of its revised Research Agenda on Radio Frequency (RF) fields [1]. Therefore, it is not surprising, that recently two commercial personal RF exposimeters have been developed [2,3]. Although both devices are designed for the purpose of exposure assessment, the underlying concept is fundamentally different: the instrument dsp120 [2] measures the electrical field in an isotropic way, whereas the instrument esm140 [3] uses a dipole antenna as sensor, measuring thus mainly the component of the electric field collinear to the dipole. Also in terms of calibration differences have to be noted: On the one hand, the dsp120 is calibrated in free field conditions, very much like standard free field sensors. On the other hand, the influence of the human body is said to be taken into account for the calibration in the case of the esm140 from the very beginning. Also in terms of band selectivity, filtering characteristics and signal treatments differences have to be accounted for. For these reasons, the measurement results obtained with the two instruments should be different. It was already shown that the correlation between the measurement data was only low [4]. Moreover, problems with band selectivity and out of band sensibility have been reported for both devices [4,5]. Due to this fact, misclassifications cannot be excluded and should be corrected for.
As both pems are worn close to the body a comparison with the ICNIRP reference values [6] for the electrical field is questionable by definition. But also the SAR concept for near field

exposure seems quite useless, as public exposure occurs mainly in the far field. Moreover, the SAR values in such situations would be extremely small. From a fundamental point of view, the question of the dose concept for RF-fields would have to be answered first. Nevertheless, the pems are intended to be used for exposure assessment in the framework of epidemiologic studies in the near future. It is therefore of major importance to know whether the obtained measurement results will compare or not. Differing results would lead to incoherent classification in epidemiologic studies and thus hinder inter comparability as well as pooling of the data.
For all theses reasons, it is outmost important to compare the measurements of the two devices under controlled conditions. We performed measurements using the two instruments in an anechoic chamber as well as under more realistic conditions involving interference patterns. Both devices have been tested in the free field as well as with a body phantom and test person under indented usage conditions. Furthermore, the pems have been combined with data obtained with a GPS device for outdoor measurement under real life conditions. Results of these measurements will be shown and compared to exposure calculations.

Methods

Measurements set up
In both investigated situations, i.e. in the absorber room as well as in the reflecting situation, the identical field generating set up was used. A schematic view is given in Fig. 1.

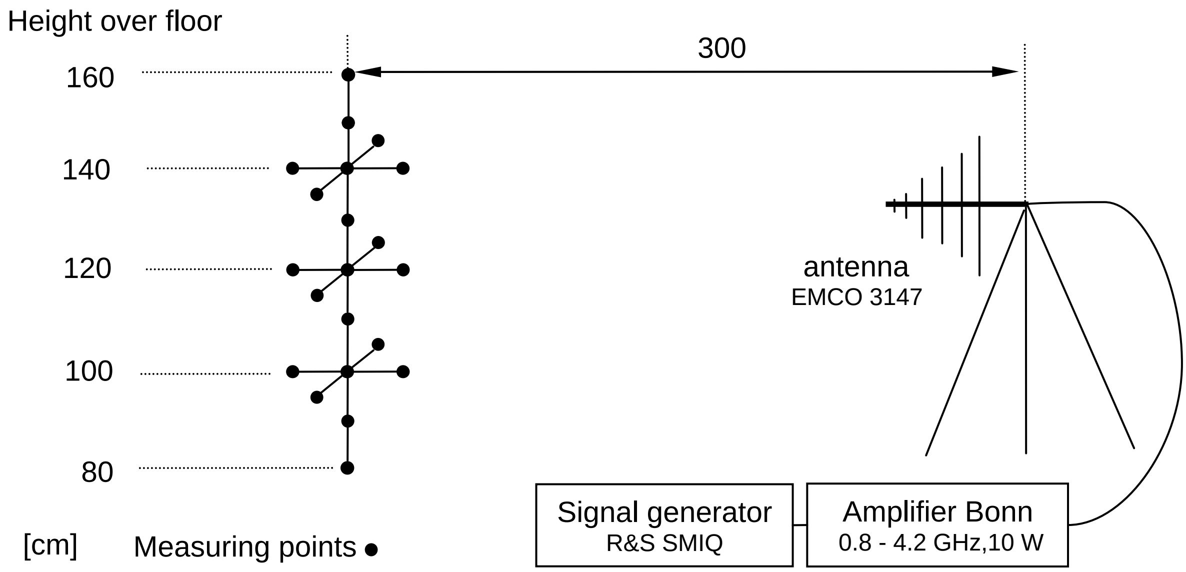

Fig. 1: Schematic view of the test set up, on the left hand side the measurement points used to determine the average field are shown.

The GSM and UMTS downlink signals have been generated using the R&S signal generator SMIQ. For GSM a BCCH channel like signal at 940 MHz was created by filling up all time slots of a GMSK modulated carrier. In the case of UMTS, a W-CDMA signal was modulated with a test model containing 16 channels; the chosen frequency was 2140 MHz. The output signal of the generator was amplified with a 10 W BONN amplifier in order to obtain a field intensity of somewhat more than 2 V/m (see Table 1 for details).
In order to dispose of a homogeneous field, in a first step, the tests have been performed in the semi-anechoic absorber chamber in the laboratories of Swisscom Innovations in Bern. To avoid ground reflections, the floor was laid out with additional absorbers. Therefore, field

conditions should be quite homogenous. This was controlled by free field measurements with the reference broad band probe (emr300 from narda-sts, probe type 18, 100 kHz - 3 GHz). In the reflecting situation - a corridor next to the absorber room - the same set up was realised, with the only exception that no additional absorber material was used. As the two test sites are located in the basements of the building no other RF sources are present. The field conditions in the volume defined by the 21 measuring points are given in Table 1. As expected, in the corridor the standard deviations from the mean value are three times higher than in the anechoic chamber.

Table 1: Free field conditions in the two different test locations

Situation	Absorber room		Reflecting room (corridor)	
Observable	Mean (min, max) [V/m]	Standard deviation [% of mean]	Mean (min, max) [V/m]	Standard deviation [% of mean]
GSM	2.38 (1.98, 2.71)	9	2.38 (1.32, 3.98)	33
UMTS	1.88 (1.55, 2.31)	10	2.34 (1.38, 3.52)	23

Measurements involving a body phantom or a human test person

The intended use condition was simulated by using a simple cylindrical body phantom filled with salt water. Two plastic bottles filled with water have been added to the cylinder in order to simulate the arms of the human being.

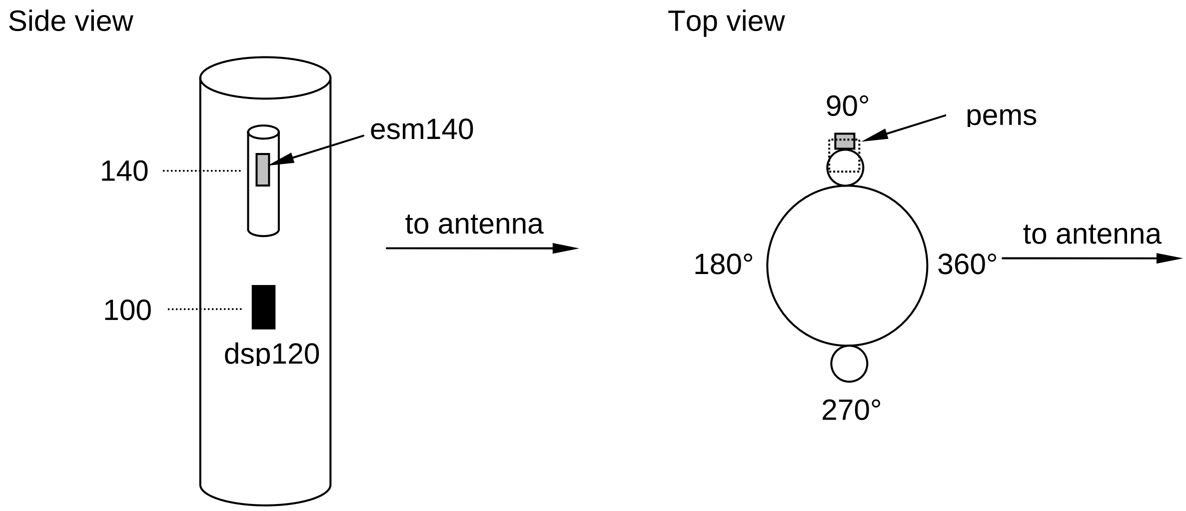

Fig. 2: Left hand side: The body phantom with the pems mounted in their intended use position. Right hand side: Top view of the phantom with the different measuring positions (90° - 360°).

In the final step a human test person was equipped with the devices. The esm140 has been mounted at a height of 140 cm over ground whereas the dsp120 was mounted at the height of the belt (1m over the ground). The body phantom and the person have been positioned such that the pems are located at exactly the same position as was the emr300 probe for the free field measurement. In this way, a one to one comparison of the intended use condition and the free field measurement can be performed.

Results

Comparison of free field measurements

In a first step the measurements have been performed in the anechoic chamber without the body phantom. The point to point comparison between the two pems and the reference probe in this free field condition is illustrated in Fig. 3. One observes that the dsp120 effectively leads to an isotropic measurement. The UTMS field, however, is underestimated by this device. Not astonishing, the esm140 exhibits a strong dependence on the direction of the probe with respect to the incident field. This follows from the directional characteristics of the receiving antenna used in this exposimeter [7]. In addition to this inherent anisotropy (see Fig. 3) an important influence of the polarisation of the incident wave has to be taken into account for the esm140. If the receiving dipole is polarised orthogonal to the incident field the measurement results are only fractions of the real field intensity (15% of the free field measurement). This fact has to be kept in mind, for the assessment of WLAN signals, which are often horizontally polarised.

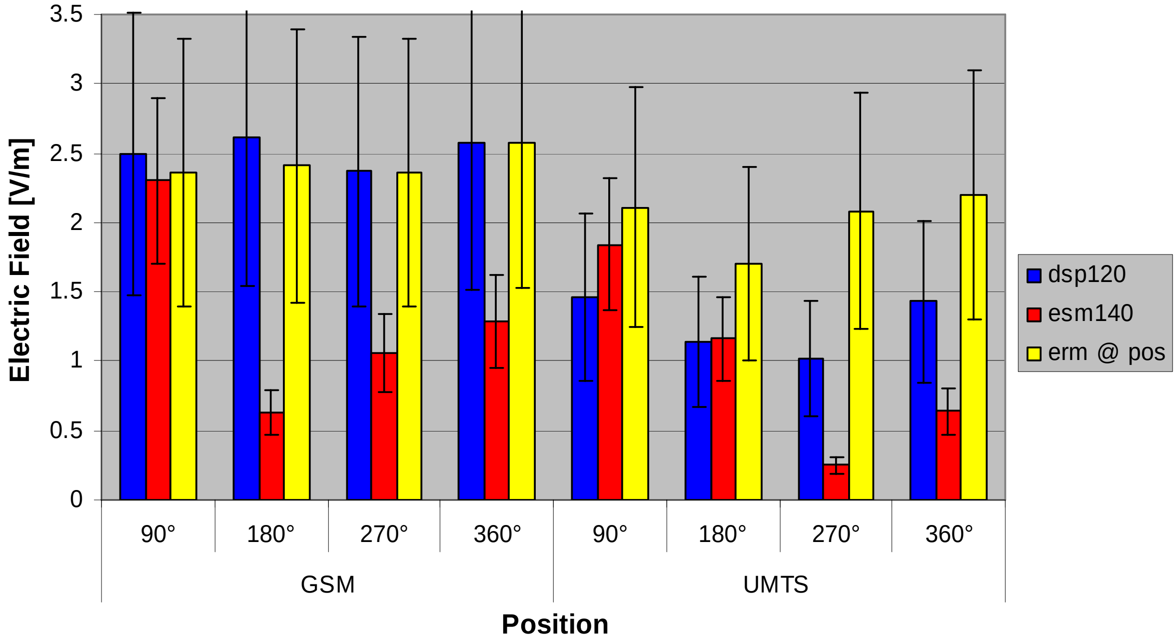

Fig. 3: Comparison of the free field measurement results for the different positions given in Fig.2 (without the body phantom). An error of ±41% (3dB) was adopted for all measurement devices.

Intended use condition: body phantom and human test person

Also in the absorber chamber the devices have been mounted on the body phantom. The results are shown in Fig. 4. It can be observed that the body shields the pems from the incident field. The effect is slightly more important for the esm140 device. For the 360° situation the measured field is – due to reflections at the body phantom - too high. However, on average the measured field is lower than the average of the free field measurement.

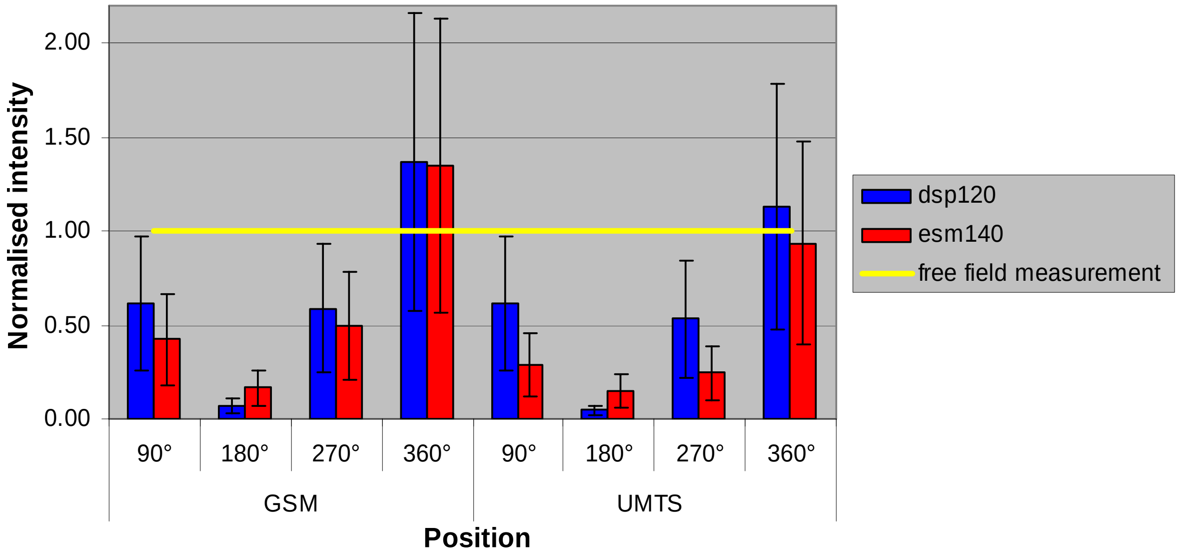

Fig. 4: Comparison of the measurement results in the anechoic chamber for different measuring positions (see Fig. 2) with pems mounted on the body phantom. Shown are the normalised intensities with respect to the free field results (E_{pem}/E_{emr300}) at the same position. An error margin of ±58% (4dB) was adopted for both devices.

The question arises whether and how the picture changes in a situation characterised by inhomogeneous field conditions. Thus, we performed similar experiments in a corridor limited by concrete walls and metallic elements. Moreover, the body phantom was replaced by a human test person. These results are given in Fig. 5.

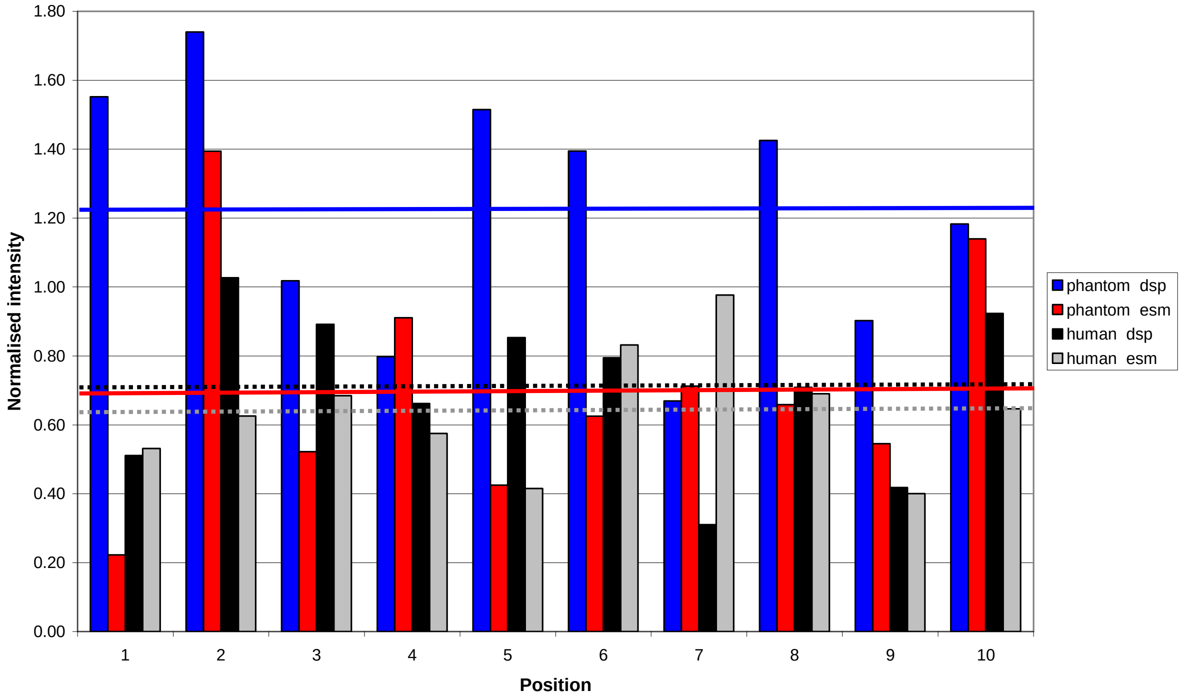

Fig. 5: Comparison of the measurement results in a reflecting situation for different measuring points. The pems have been mounted on the body phantom and a test person. Shown are normalised intensities for GSM. Straight and dotted lines show the mean values over the measurement points for the 4 different cases.

An important difference between the values obtained with the body phantom and the test person is observed. The geometry of the test person as well as the differing dielectric properties obviously may have an important impact on the results. Furthermore, it has to be noted that the differences between the two pems diminish. The mean of the normalised intensity over the positions in the case of the phantom measurements is 1.22 for the dsp120; it diminishes to 0.72 in the test with the real person. The isotropic probe seems to be more influenced by the from the body reflected field. Through its ground plate, the esm140 is less sensitive to body properties and the values change less: from 0.71 (phantom) to 0.64 (human). Compared to the free field measurements the values obtained with both pems are on average too small. Similar results in terms of mean values have been obtained in performing a random walk with the pems in the same volume.

Comparisons measurement – calculations under "real life conditions"

Under realistic usage the comparison of pem and free field measurements would be too costly. It is however possible to perform model calculations. We compared our data of GSM900 mobile phone exposure with the simple free space line of sight model as well as the empirical COST-Walfisch-Ikegami line of sight (CWI-LOS) model. Topography was taken into account with a digital terrain model (spatial resolution of 25 m). In order to be able to compare measurement results and calculated exposure the test person was equipped with a GPS receiver [8]. Over the time stamp the data sets can be combined, so that one obtains for each field value its position in space. The path of measurement results and the model calculations are represented in Fig. 6. As the colour scheme is identical, total agreement of measurement and calculation would mean disappearing of the measurement path. The comparison of the mean values along the path of measurements shows that the CWI-LOS tends to underestimate the experimental data, whereas the free space model overestimates the measurement results. Taking into account the underestimation of the free field intensity by the pem measurement under realistic conditions, the simple free space model might deliver the better results for exposure assessment than the CWI model.

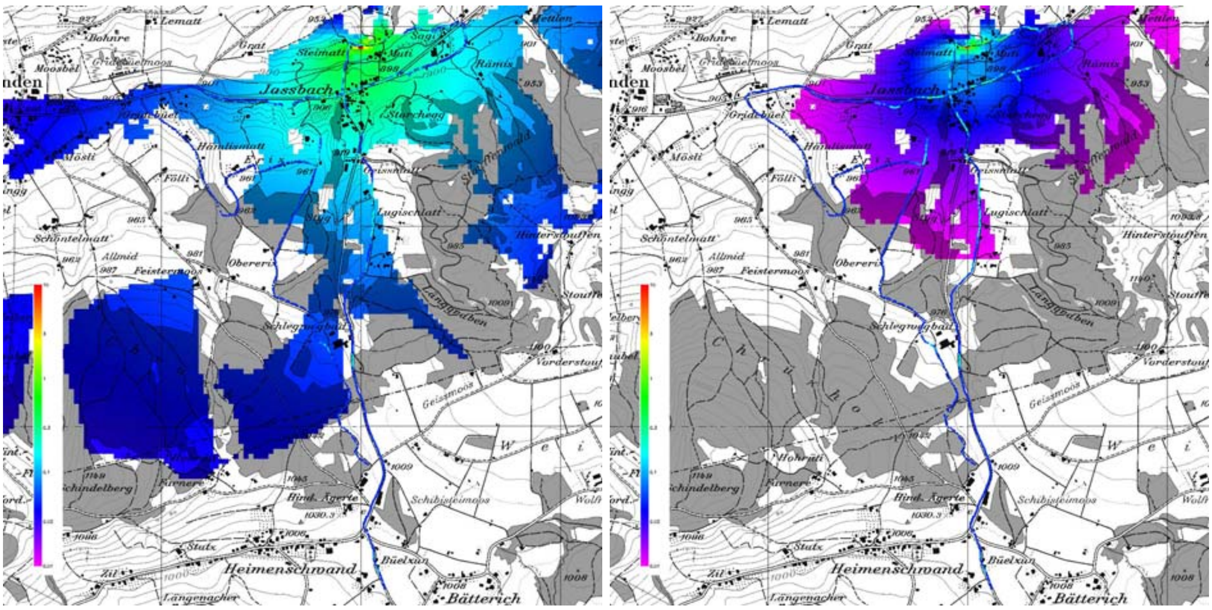

Fig. 6: Comparison of the dsp120 measurement results with the free space LOS model and CWI-LOS model calculations for GSM900, 1.5 m over ground.

During the measurement campaign it appeared that the esm140 has insufficient band selectivity. Out of band influences have been observed in almost all bands, especially the intense uplink signals penetrate in the down link bands, but also UMTS and WLAN are not sufficiently discriminated. In this case the filters should be improved or signals with high correlation be discarded. In the present form, a correct assessment of the total exposure is thus not feasible with the esm140.

Discussion

The tests in the laboratory revealed that even though the exposimeter use different underlying principles the measurement values converge under the intended use conditions on a human test person to rather similar values. On average the relative difference between the two pems is smaller than the measurement error. Moreover, the mean values as obtained with the pems underestimate the free field measurements. However, the actual placement of the pem on the body, the geometrical form and the dielectric properties of the body, the polarisation of the incident field as well as band selectivity of the devices remain strong confounders. In a real life situation a first analysis indicates that the average measured field tends to lie in between the predictions of the CWI-LOS and the free space model. Taking into account the observed underestimation of the free field measurements, it can be concluded that for exposure assessment purposes the simple free space model might be a valid approximation. This conclusion has however to be consolidated by further measurements and extended statistical analysis.

Literature

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