INDOOR MEASURMENTS OF THE ELECTRICAL FIELD CLOSE TO MOBILE PHONE BASE STATIONS

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ABSTRACT

Extensive comparisons of simple free space propagation calculations and measured maximum field strength values for indoor situations around base station antennas for mobile communication are presented. The agreement is rather poor. However, in most of the cases these worst case calculations overestimate the measured maximum field. Qualitative and quantitative analysis of the results of simple measuring methods compared to more complex methods, based on extensive measurements under realistic conditions, shows that simple methods overestimate the average field situation considerably. Moreover, the reproducibility of successive measurements is low.

INTRODUCTION

In most countries the limits for the exposure of the general public to electromagnetic fields are based on the ICNIRP recommendations [1]. In several countries the precautionary principle is under discussion or even applied, calling for lower limits than proposed by ICNIRP. In Switzerland, for intensively used locations such as apartments and offices, so-called “installation limit values” - in the frequency range of interest a factor of ten lower than the ICNIRP field strength values – have to be followed [2]. These “installation limit values” are valid for each single transmitter. In current mobile phone networks using the operating parameters defined in the respective standards electrical field strength values of several V/m are produced in the vicinity (up to 100 m). To verify the compliance with the Swiss “installation limits” being in the same order of field strength, conclusive and accurate calculation and measurement methods are needed in order to determine the electric field conditions in a reproducible way.
From a theoretical point of view electromagnetic waves are well described and understood in the framework of electrodynamics. Nevertheless, the precise experimental determination of high frequency electric fields in complex environment is still difficult task. This is mainly due the interaction of three fundamental physical properties of electromagnetic waves or waves in general: reflection, absorption and interference. Under controlled conditions, for instance in an anechoic chamber, reproducible measurements should in principle be possible. In a more complicated environment, however, different measurements can lead to quite different results due to changing conditions. Thus, the physical properties of electromagnetic waves and the requirement of reproducibility are diametrically opposed.
The aim of the here presented work is to address several open questions concerning the determination of the intensity of RF electric fields inside buildings. For this purpose, the electric field distribution in realistic situations near mobile phone base stations was used as a model case. The first part consists in a comparison of simplified calculation methods with simple measurement methods. In a second step we address the question whether and to which extend interference pattern found in highly reflective environments can be represented by measuring methods of various complexity. Finally, different aspects as the variability of the measured field strength, its statistical distribution and the reproducibility of the different measurement methods in a real life environment are discussed.

METHODS AND MATERIALS

Simple Free Space Propagation Model

The complexity of shape and material characteristics encountered in real life environments, especially inside buildings, does not permit the use of sophisticated EMF simulation tools for general use. Therefore, simple free space propagation models disregarding the interference properties of electromagnetic waves and using worst case assumptions for the attenuation characteristics of the EMF have to be used. Such procedures are proposed by the Swiss regulation [3]. From the definition of the power density S and the fact that in far field conditions S equals the square of the electric field strength E divided by the speed of light c and the permeablility μ_0, the so-called plane wave impedance of 377 Ω, one finds after some transformations the simple calculation prescription given below:

$$E = \sqrt{\frac{1.64\, c\mu_0}{4\pi d^2}} \sqrt{\frac{ERP}{\delta\, \gamma}} = \frac{7}{d}\sqrt{\frac{ERP}{\delta\, \gamma}} \quad (1)$$

Where d is the distance to the source, ERP is the Effective Radiated Power. The two factors δ and γ describe the attenuation of the electric field due to the presence of construction materials and due to the characteristic of the radiation pattern, respectively. For the sake of simplicity the attenuation factors are fixed by the calculation prescriptions. So, for the attenuation of materials only three different categories of attenuation are distinguished: 0, 5 and 15 dB. The attenuation due to the radiation pattern of the antenna can be taken into account as specified by the manufacturer. However, if the attenuation exceeds 15 dB the attenuation has to be set to 15 dB. As a consequence, the pattern in forward direction is correctly integrated in the calculation whereas outside the main beam the attenuation is clearly underestimated. The calculated value is thus based on worst case assumptions.

Simplified On Site Measurement Methods

Fundamentally, one can distinguish two different kinds of available methods for high frequency measurements. On one hand isotropic field sensors allow for a simple, non-selective measurement of the electric field strength. One the other hand more complicated, frequency selective measurements are possible by the combination of an antenna with a spectrum analyser or a test receiver. The major drawback of the easy to use broadband probes is that the non-selectivity of this method is in contradiction with the frequency selective Swiss installation limits. For installations in different frequency ranges the limits are different, i.e. 4 V/m for the 900 MHz band, 6 V/m for 1800 MHz band, 5 V/m for combined mobile phone base stations and 3 V/m for broadcasting installations. The use of a frequency selective method is thus compulsory.

For cost effective verification of the calculated value, mostly simplified but frequency selective measurement methods, relying on the determination of a so-called "maximum electric field strength value in a given space", are used [4]. In order to determine the maximum field strength in a given volume, the receive antenna is moved in this volume using a receiver or spectrum analyser with the peak detector in its maximum hold function. The use of the peak detector alone leads already to an overestimation of the relevant RMS signal. Moreover, the peak detector properties are varying with the different type of analysers. The hereby used receive antenna is not specified by the prescription. It simply has to be individually calibrated in the frequency range of interest.

In the case of GSM systems the broadcast channel BCCH is measured, as this channel is independent of the load of the station. Based on the field strength generated by this single channel E_{BCCH} the maximum possible electric field strength E_{max} can be extrapolated as given in (2):

$$E_{max} = \sqrt{\frac{ERP_{max}}{ERP_{BCCH}}} \cdot E_{BCCH} \quad (2)$$

Proceeding in this way we make the assumption that electromagnetic waves of minor difference in frequency react in the same way with the environment.

Spatial Averaging Methods

In order to achieve a better knowledge on the variation of the electric field strengths in real-life environments the above described simplified measurement methods are clearly not sufficient. There is no precise spatial information about the intensity of the field. Moreover, in the complex situations encountered in highly reflective environments, where contributions from all directions build up the total electric field at a given point, a measurement should be isotropic. As no high frequency antenna used in combination with a spectrum analyser has an isotropic characteristic, the solution consists in turning an antenna with an appropriate characteristic successively in three orthogonal room directions. By taking a biconical or a dipole antenna this requirement is approximately fulfilled. The total electric field is then given by the root mean square value of the three contributions. We used a biconical antenna and a system for the easy realisation of three orthogonal room directions, the so-called Add3D method, developed by the Austrian Research Centre Seiberstorf. The measurement points have been taken in a cylindrical volume of 0.5 m radius on three different planes at 0.75, 1.25 and 1.75 m height above ground. In each plane 21 points have been equidistantly distributed like the corners of a chessboard (lattice distance of 22.5cm). A total of 63 measurement points has thus been acquired. For the sake of comparison, in the same volume the maximum field strength has been determined by the maximum search method described above. In all measurements a minimal distance of 50 cm to the next nearest object has been respected.

RESULTS

Comparison of Maximum Search Measurements and Simplified Calculations

Using the above described methods, based on [3, 4], calculated and measured maximum field strength values have been compared for precisely defined locations. In difference to the prescription [4] the measurement uncertainty was not added to the measured value. The comparison is based on a total of 82 measurements performed by different measurement teams. For the purpose of inter-compatibility of the results from various locations with different field strength intensities the calculated value was set as the reference value. The measured value M is then given in % of the value calculated by the prescription given by (1). Fig. 1 shows a histogram of all the collected data compared to the calculated data. The mean value of M is 60% of the calculated value with a standard deviation of 49 (M=(60±49)%). It can be seen that, due to the worst case assumptions for the off-beam attenuation in the prescription, most measured values are lower than the calculated ones. However, in about 20% of the cases M is bigger than the value given by simple free space propagation approximation.

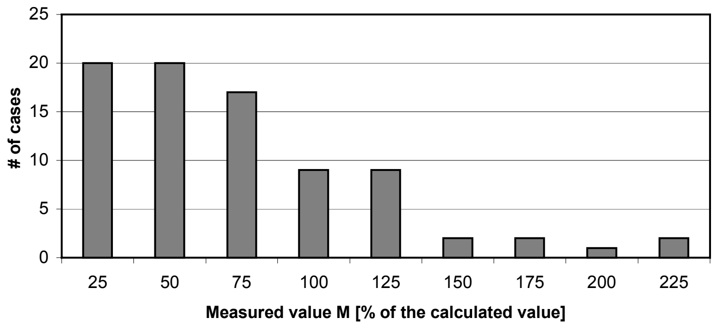

Fig. 1. Values measured with the maximum search method compared to the simple free space approximation.

Variation and Distribution of the Electric Field Strength in Highly Reflective Environments

To address the question of the variability of the electric field strength in several cases more than 21 points have been measured in a plane. To resolve an interference pattern resulting from an 1800 MHz signal in a complex indoor situation, measuring points have been sampled with step widths of 4 cm. Such a measurement is shown in Fig. 2 where a total of 81 measurement points has been acquired. It can be seen that the electric field shows a quite complicated spatial pattern with spatially well defined maxima being present. The intensity distribution is shown on the right hand side of Fig. 2. The distribution – here best fitted with a Weibull distribution – is right skewed. The consideration of the distribution evinces that a value around the spatial average is more probable to be measured than the maximum field intensity as this latter is located at the low-probability end of the distribution. The property of right skewness may albeit be induced by the geometrical distribution of the equidistant measurement points. By using a geometrical distribution as proposed in [6], which simulates the human exposure to EMF, the distribution revealed to be of different shape.

Comparison of Sophisticated Measurements and Simplified Maximum Search Methods

As the measurements should be used for the compliance verification of legal limits, the reproducibility of the different methods is of main interest. The standard deviation out of at least three measurements at one measurement site was averaged for four different locations. For the simplified maximum search method the 2-σ standard deviation was 32% whereas for the spatial averaging method with 63 sample points it was only 22%. Averaging methods show thus not only as theoretically expected but also experimentally the higher reproducibility than the maximum search methods. Moreover, taking the average value as the reference the maximum search methods deliver values that are about 1.5 to 2 times bigger than the average electric field strength.

DISCUSSION

Beside simplicity and speed of use, measurements based on simplified test methods have severe disadvantages. They give no information about the spatial distribution of the electric field in the scanned volume, the average field conditions are overestimated and the results are less reproducible. Moreover, realistic exposure of the human body is not sufficiently described the maximum field strength in a given volume.

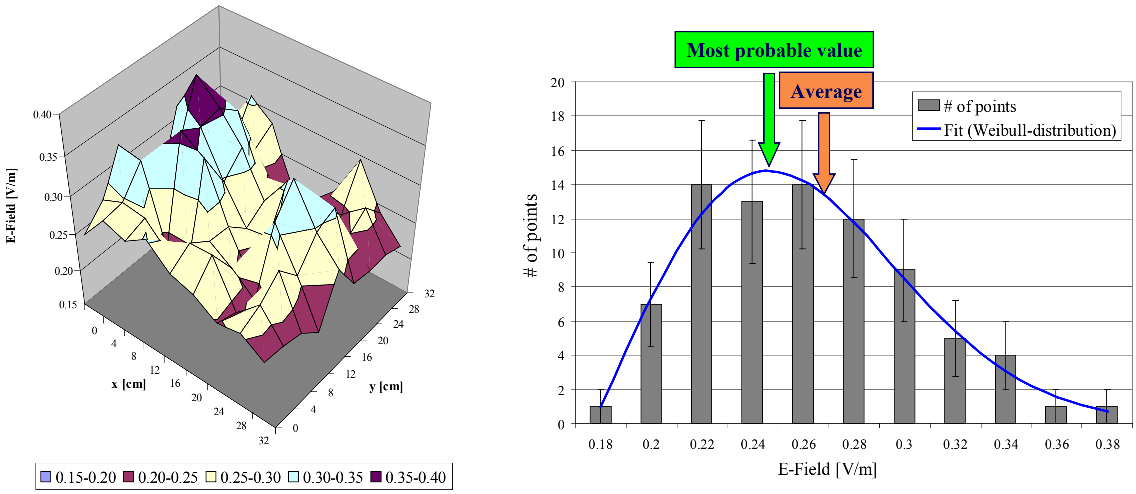

Fig. 2. Electric field strength induced by 6 BCCH frequencies measured in a room below a base station antenna (left hand side) and distribution of the electric field intensity for the n=81 measuring points (right hand side).

There is however also a fundamental problem if the measurements are used to verify the values calculated by using (1). This simple prescription (1) gives the estimation of the average field at a point and not the maximum produced by interference of different contributions in a reflective environment. This can be shown by comparison to more sophisticated calculations as performed in [5]. For two situations the average simulated electric field $E_{Max,\ simulated}$ in a volume was compared to the calculation by (1). As can be seen in table 1, the simple calculation agrees quite well with the average simulated field. Therefore, by using a maximum search method one determines not the accurate observable.

Table 1**:** Comparison between the simulations performed by Bernardi et al. [5] and the values calculated with the free space propagation approximation (1) for two locations differing by their position relative to the base station.

Situation	$E_{Max,\ simulated}$ [V/m]	$E_{Average,\ simulated}$ [V/m]	$E_{equation\ (1)}$ [V/m]
Directly in front of the antenna	8.1	5.5	5.4
below the antenna	1.3	1.1	1.1

CONCLUSION

The agreement of simple maximum search measurements with simplified free space propagation approximations is poor. However, in most of the cases simple calculations (1) using the worst case assumptions described above overestimate the measured maximum field. The electric field conditions in realistic cases near mobile phone antennas show a quite complicated pattern. Compared to the spatial average, the maximum search methods overestimate the field conditions and are less reproducible.

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