Exposure Modelling for High-Frequency Non-Ionising Radiation: Results of a Pilot Study

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Abstract

We present results of a pilot study modelling the electromagnetic fields produced by fixed transmitters of base stations for mobile communications, broadcast (UHF and DAB radio, television) and paging services. The aim of the study was to explore the possibilities and limits of modelling the actual, time-averaged background electromagnetic field over an extended region, taking into account a 3-dimensional topographical and building model. The comparison of the model results with exploratory measurements gave a remarkably good agreement and allowed to identify the most realistic propagation models.

1. Introduction

Exposure to electromagnetic fields can be assessed either by measurement or by mathematical modelling. Both methods have their strengths and weaknesses. A measurement can determine the effective field strength at a given point at a given moment of time. Measurements are expensive, however, and therefore carried out for individual points only or at best on rather coarse grids. They can hardly resolve the details of the small-scale features which are characteristic of the fields of base stations for mobile communications. Mathematical modelling could in principal be carried out on an arbitrarily fine grid and with arbitrary precision, as the physical laws covering the propagation of electromagnetic waves are well known. In practice, however, this would require an extremely detailed description of the sources and the paths of propagation by reflections, scattering, diffraction and absorption due to the terrain, buildings, and vegetation. The necessary input required for the detailed modelling of an extended region is prohibitively expensive, not to mention the demand on computing power. For this reason, models for extended regions typically use simplifications in their description of the sources, the propagation paths and the obstacles. The results of these simplified models can then in turn be tested against measurements, thereby combining the strengths of both methods. Measurements can be used to test the validity of the computational models, to asses the magnitude of their errors and to refine the model parameters. On the other hand, a computational model can put a measurement point in relation to its environment, it can show how representative it is, and test if there are any "hot spots" that the measurement might have missed.

The aim of the pilot study was to explore the possibilities and limits of modelling the actual, time-averaged high frequency background electromagnetic field over an extended region. Models could be useful for assessing standard limit compliance, but also exposure of large collectives of persons, e.g., for epidemiological studies. The study consisted of a literature survey and evaluation of applicable propagation models which were then programmed as extensions into the NISMap-software which is used by the Basel air quality agency for regulatory purposes (NISMap is a software for 3D field calculation and

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air quality agency for regulatory purposes (NISMap is a software for 3D field calculation and mapping). With these software extensions, maps were calculated for two regions. Finally, two exploratory measurement series were carried out, and the results of model and measurement compared (Bürgi, 2005).

2. Description of the model

The aim was to model the ambient field as realistically as possible, both outdoors and at the places where people live, using semiempirical models including 3D topographic and building information, actual data on antenna and transmitter powers and estimated values for time variations due to network traffic.

For regulatory purposes, typically a free-space propagation model with worst-case assumptions concerning emission power etc. is used. This will, however, overestimate the actual field by a large amount, and more realistic algorithms have to be used. For mobile communications we used both the models of COST-Walfisch-Ikegami (COST-WI, Cichon and Kürner 1999) and of the International Telecommunications Union (ITU-R P.1411, 2003). For broadcast (FM-radio and TV) we used ITU-R P.1456 (2003). All of these models are semi-empirical, and they typically come in both a version for line-of-sight (LOS) and non-line-of-sight (NLOS) conditions. All of these prescriptions have a limited range of applicability concerning frequency and distance. An additional model in the form of a double-power-law, which can be used as a default when non of the other models is applicable, was therefore also used. A comparison of the different propagation models, for frequency $f =$ 900 MHz is shown in Figure 1.

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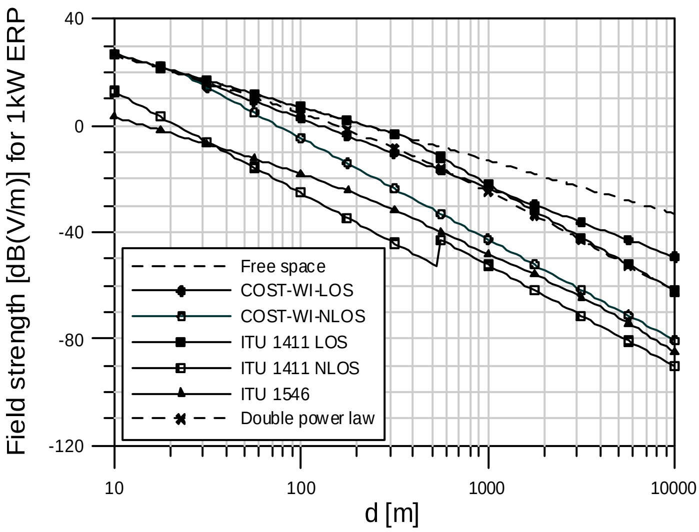

Figure 1: Comparison of the various propagation prediction models for distances between transmitter and receiver in the range 10 m – 10 km and frequency $f =$ 900 MHz. Most of the models are valid only in part of the distance range. Note the large offset between LOS and NLOS models, especially at large distances.

Buildings are important in several respects: They act as obstacles that hinder the propagation of the radiation, but they also define the locations where people may dwell at other elevations than the ground level. In the presence of buildings, the model calculates two propagation paths: A damped path (using average wall and roof damping values) and a diffracted path over the rooftops and terrain. The larger contribution of the two is taken as the result. Diffraction laterally around buildings and reflection from surfaces is not included in our semiempirical propagation models.

The model uses the data on stationary emitters from the NISMap-database of the Basel air quality agency. This database contains data of all transmitters for cellular mobile telephony and paging services for the cantons of Basel and the border regions of adjacent Swiss cantons. It was supplemented by data on the dominant broadcast emitter (the St.-Chrischona tower). No data were available for transmitters across the French and German borders. For the calculation, the effectively used transmitter powers were imported from a database of the Federal Office of Communications. These emitter powers were multiplied with a factor taking into account the diurnal time-variations of the emission (Lehmann et al 2004).

3. Results

The computations were carried out for two model regions: Region A is a suburban region covering several square kilometres (2.75 x 2.3 km^2) centred on the town of Pratteln; region B is an urban region in the centre of the city of Basel, covering roughly half a square kilometre. For the suburban region, only topographical, but no building data were available. The results were calculated for different models with different propagation prescriptions. For this paper, only the results for the model which turned out to be closest to the measurements were included. This is a model using COST-WI for mobile telephony, ITU-R P.1546 for radio and TV broadcast and the double power law for paging services (Figure 2).

Figure 2: Results for model region A (Pratteln). Maps of the electric field strength superimposed on the topographical map for LOS (left) and NLOS-conditions (right). The maps are black-and-white approximations of an originally colour-coded map. Equidistance of contour-lines is 0.1 V/m. Background pixel map PK25 reproduced with permission of swisstopo (BA057134).

As there were no building data available for model region A, the distinction between LOS and NLOS could only be made in a global fashion for the entire model. Fields were calculated at 1.5 m above ground. The topography was taken into account using the 25-m digital terrain model DHM25 of the Federal Office of Topography. The resolution of the calculation grid is 25 m (as for the terrain model). The dominant contribution in model region A is from the radio and TV broadcast tower located approx. 7 km due north. Additional contributions are from base stations for mobile communications and paging. The field strengths in the LOS-case are approximately 3 times higher than in the NLOS-case.

Model region B covers an area of 650 x 650 m^2 in the centre of the old city of Basel (Figure 3). Detailed topographical and building data were available from the 3D-city model of the Basel office of land register and surveying. The calculation was made on a grid with resolution of 5 m. Fields were calculated at the height of 1.5 m outside of buildings and at the uppermost floor plus 1.5 m inside buildings.

Figure 3: Black-and white approximation of the map of the electric field superimposed on the city map for model region B (centre of the old city of Basel). The equidistance of the contour lines is 0.5 V/m. The Rhine river is in the upper right corner. Basel city model used with permission of 7.12.2004, © Office of land register and surveying, Basel.

The radio and TV broadcast tower is some 5 km to the north-east, but its contribution is mostly shielded by a hill along the Rhine-river and the first row of buildings standing thereon. As a consequence, the field contribution of the broadcast station is relatively low, and the field is dominated by the contribution of cellular base stations. The fie ld is strongly influenced by the presence of buildings, both due to the choice of calculation height and the effect of shielding in courtyards and narrow roads.

4. Comparison of model and measurements

Two series of exploratory measurements were carried out for each of the model regions. For model region A, the missing building data turned out to create some difficulties in interpreting the results, as the distinction between LOS and NLOS was not clear. For model region B, the results are shown in Figure 4 (the measurement points are shown as crosses in Figure 3). For GSM 900 and 1800, the agreement between model and measurement is remarkably good. For UMTS, many stations were only just going into operation, the actual UMTS transmitter powers are likely to differ from the values in the database, and the agreement is poor. For radio and TV broadcast, the measurements were dominated by noise, and no conclusions can be drawn. The total field was reproduced to within a factor of 2 for 50% of the points, and to within a factor of 4 for 95% of the points.

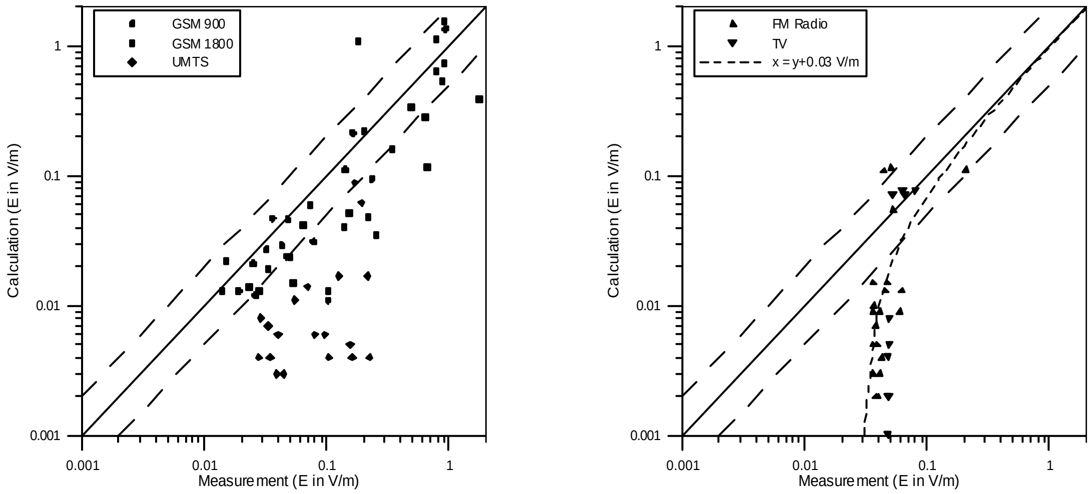

Figure 4: Comparison of model and measurement for model region B (Basel). The main diagonal corresponds to perfect agreement between model and measurement. The short-dashed line in the right frame shows the same, but with an added receiver noise of 30 mV/m (as applicable to the FM radio band).

5. Summary and conclusion

We have derived a methodology to model electromagnetic fields produced by broadcast and mobile communications base stations. The methodology was implemented into a computer model (NISMap) and applied to two model regions. The model results were then compared to results from an exploratory series of measurements. The comparison allowed to identify the more realistic propagation models (and to rule out some others). They confirmed the feasibility of the modelling approach, and the agreement between model and measurement was remarkably good. However, more detailed studies and model validation are still necessary.

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